USING AND UNDERSTANDING

PROBES

by RUDOLF F. GRAF

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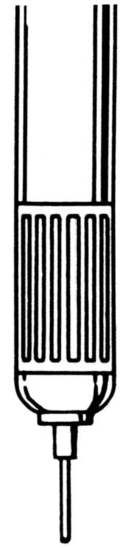

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by RUDOLF F. GRAF

HOWARD W. SAMS & CO., INC.
THE BOBBS-MERRILL COMPANY, INC.
Indianapolis • New York

FIRST EDITION

FIRST PRINTING — MAY, 1960

USING AND UNDERSTANDING PROBES

Library of Congress Catalog Card Number: 60-12077

PREFACE

"For want of a nail . . .
A war was lost."

—Benjamin Franklin

So goes an old saying which points out that even the most unobtrusive item is often more significant than its outward appearance would seem to indicate. This is true of probes as well. Because they are attached to other, more complex and expensive instruments, probes are often regarded distainfully, or even ignored altogether. Their low cost, compared with the cost of the accompanying equipment, belies the inestimable value of these "Cinderellas" of electronics.

The science of measurement might very well be called the backbone of all other sciences. If this is true (and who would dare refute it?), then probes are the fingers. Like the sensitive fingers of the brain surgeon, these "little giants" play a vital role . . . not one secondary to that of the measuring instrument, but on an equal par. For the most expensive measuring instrument—whether a VTVM, an oscilloscope, or other—is for the moment but a useless pile of glass and metal if the probe falls down on its job.

This book could easily be called an encyclopedia of probes. At least it is encyclopedic in content, if not in format. Nevertheless, it is written for the informed layman as well as the bench-hardened technician. Although electronic probes are highlighted, other, lesser-known probes used in industry, agriculture, and medicine are also explained.

The probes in this book were designed to overcome the limitations of the instruments with which they are used, or to extend the usefulness of the instrument to a degree not otherwise possible. Hand-in-hand, the probe and instrument observe, test, explore, and measure many phenomena.

If I have succeeded in bringing to light the many facets of the probe, I have fulfilled my aim—to write a reference book that will painlessly guide the service technician through the labyrinthic subject of probes.

My appreciation and indebtedness are due those who graciously supplied much of the illustrative material in this book. Also, a word of appreciation to my wife, Bettina, who unselfishly gave much of her time and sacrificed many days of companionship to help make this book possible. Finally, this book is dedicated to my son and daughter, Jeffrey and Debbie.

RUDOLF F. GRAF

March, 1960

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Chapter 1

DIRECT AND ISOLATION PROBES

IF we wish to measure or observe a signal, we must be concerned with not only the frequency of the signal, but also its voltage and impedance levels. Voltages encountered may vary considerably. For example, in television receivers, only a few microvolts may appear at the input of the tuner, but up to 20,000 volts may be applied to the picture tube.

Voltages can be AC, DC, or a combination of both. AC voltages may consist of simple sine waves of various frequencies, or a complex wave combining harmonically related sine waves. AC signals may also have a DC potential. This DC may be essentially "clean," or it may have a certain amount of ripple. There are also pulsating DC voltages, like the ones at the output of a rectifier.

When the voltage is measured or observed at some point in a circuit —whether with a meter, an oscilloscope, or a tracer—the impedance at that point is important. This fact is often overlooked by even the more experienced technicians.

Resistive circuit loading becomes a problem when the test equipment has a low input impedance. However, such loading can be minimized by the use of high-impedance measuring instruments. Another point that should be considered is the effect of stray fields on scope and meter indications. The instruments themselves cannot differentiate between desired and undesired signals. They must therefore be shielded from extraneous electromagnetic and electrostatic fields which could introduce noise, hum, or other interference. Enclosing test equipment in a metal case helps shield against such stray fields. For maximum shielding, however, the leads from the test equipment must also be shielded.

In sensitive circuits, unshielded test leads sometimes produce rather puzzling effects. They may also act as antennas and radiate signals from one part of the circuit to the other. In this way, cross coupling or feedback occurs between sections normally isolated from each other. Oscillations may then occur, resulting in erroneous readings.

Shielding the test leads does indeed exclude interference. Unfortunately, it adds something else—shunt capacitance. At the higher frequencies, shunt capacitance lowers the input impedance of the instrument, thereby adding to the loading of the circuit under test. Thus, although gaining the desired shielding, we do so at the expense of undesirable shunt capacitance.

TEST LEADS

The simplest probe (if it can be called a probe) is the test leads in Fig. 1-1. Essentially, such leads are an extension of the input circuit in the test instrument. Rarely are test leads alone fully satisfactory, except for low-impedance, high-level measurements in relatively low-frequency circuits. They are quite good for

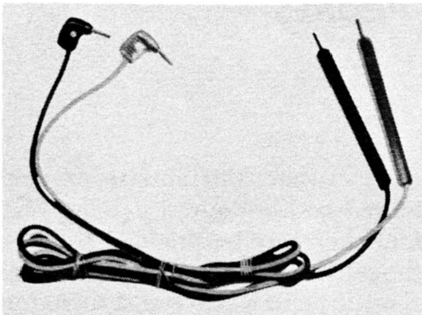


Fig. 1-1. Test leads. (Courtesy of General Cement Mfg. Co.)

such simple measurements as DC resistance. In RF, IF, video, or high-fidelity audio tests, however, test leads can introduce erroneous indications.

DIRECT PROBES

The shielded direct probe (sometimes called a "straight-through" probe) is simply a shielded cable terminated in a test prod. Fig. 1-2 shows its internal construction. It is generally used with signal tracers, vacuum-tube voltmeters, and oscilloscopes, adding an over-all capacitance of approximately 100 mmf to their input circuits. The frequency range over which a direct probe can be used depends on (1) the complexity of the signal to be observed, and (2) the impedance of the circuit to be measured. Actually, the maximum frequency range of a direct probe depends on the impedance of the circuit being tested. If circuit impedance is low, all low-frequency voltages (even those with complex waveforms) can be measured. However, as circuit impedance increases, the shunting effect of the probe becomes more pronounced. Hence, the direct probe is not suitable for frequencies above several hundred cycles in some cases; in other cases, it is satisfactory for frequencies of several thousand cycles.

The direct probe is not absolutely accurate for measuring and observing complex waveforms, particularly those containing high-frequency pulses. Loading by the cable capacitance modifies the waveshape too much.

However, there are places where this probe is most useful—for example, to check ripple in power supplies and plate-supply circuits, and to signal-trace and observe audio, transistor, and other low-impedance circuits. The additional shunt capacitance placed across the circuit under test is usually between 50 and 150 mmf, depending on the length of the cable and its capacitance per foot.

When a direct shielded probe is used, maximum sensitivity from the test instrument can be obtained because the probe contains no attenuating elements. To help prevent pickup of unwanted signals when a direct connection is required, a shielded probe, rather than unshielded test leads, should be used.

The importance of choosing a fully shielded direct probe is illus-

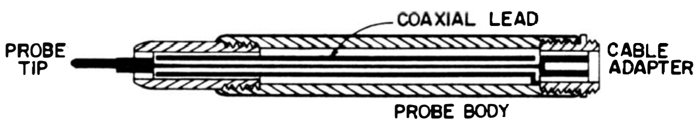


Fig. 1-2. Internal construction of a shielded direct probe. (Courtesy of Precision Apparatus Co., Inc.)

trated in Fig. 1-3. The waveform in Fig. 1-3A was obtained by using ordinary test leads; in Fig. 1-3B, a shielded direct probe was used. The signal displayed is the same, except that the waveform in Fig. 1-3A is very jittery because of hum picked up by the open leads.

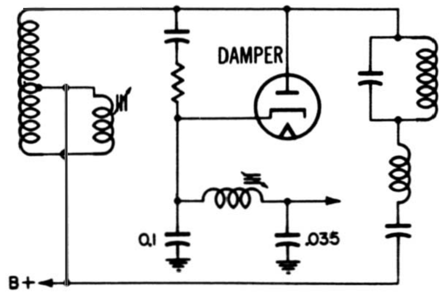
(A) Waveform obtained when unshielded test leads are used.

(B) Waveform obtained when a shielded direct probe is used.

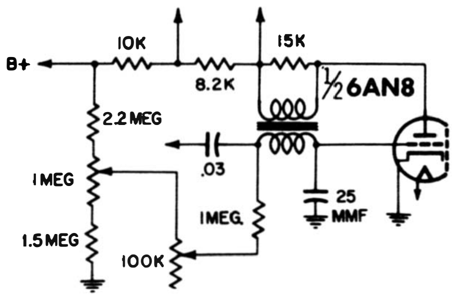
Fig. 1-3. The effect of a shielded direct probe on a waveform.

In order not to excessively load or otherwise disturb the circuit under test, the probe should have an input impedance at least ten times higher than the source impedance. Some examples of where and where not to use a direct probe are shown in Fig. 1-4.

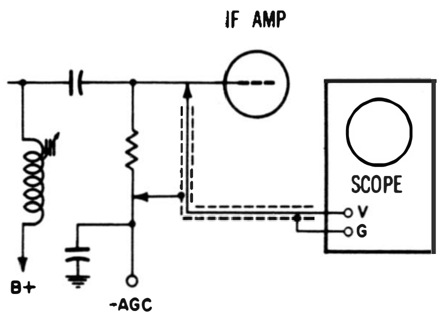
The impedance of the circuit under test must not be so sensitive that it would be detuned or otherwise disturbed by a shunt capacitance of 100 mmf or so from the probe. Fig. 1-4A shows a horizontal-damper circuit. A direct probe *can* be readily used at the damper-tube cathode, where the capacitance is at least 0.1 mfd. On the other hand, suppose we applied a direct probe at, say, the grid of the vertical blocking oscillator in Fig. 1-4B. Because of the lower capacitance to ground (only 25 mmf), the added 100 mmf from the probe would drastically alter the circuit performance, or even disable the circuit. When we are trying to



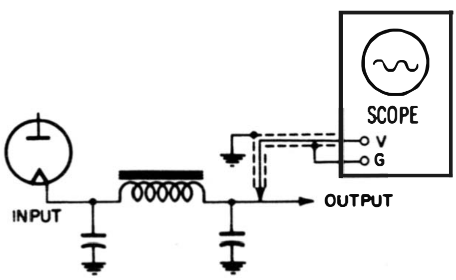
(A) Can be used at the damper cathode.



(B) Cannot be used at grid of vertical-blocking oscillator.



(C) Cannot be used at IF stage.



(D) Can be used at power supply.

Fig. 1-4. Examples of circuits where a direct probe can or cannot be used.

decide whether to use a direct probe, it is not so much the operating frequency that is important; rather, it is the capacitance and impedance levels. To further explain this statement, let's use the illustrations just discussed as examples. The frequency of the voltage at the damper cathode in Fig. 1-4A was 15,750 cps, yet it was only 60 cps at the grid of the vertical blocking oscillator in Fig. 1-4B. The direct probe could not be used at the blocking-oscillator grid, simply because of the high circuit impedance. The mere fact that a direct probe could measure a signal with a frequency of 15,750 cps at the damper cathode would indicate that impedance—not frequency—was the determining factor here.

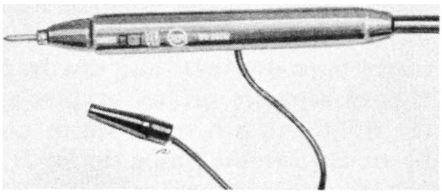
Aside from its loading effect, a direct probe alone does not attenuate the voltages applied to it. In other words, the same amount of voltage applied at the tip of the probe will be applied to the input terminal of the test instrument. For this reason, a direct probe used with an oscilloscope must never contact any points exceeding the maximum voltage that can be safely applied to the scope input. Therefore, to measure voltages beyond the capability of the measuring instrument, we must use a low-capacitance or high-voltage probe (both types will be discussed later), or a simple voltage divider made up of two or more resistors.

Because of its severe capacitance shunting effect, a direct probe should not be applied directly to the output circuit of a video detector. Doing so will not only seriously reduce the apparent bandwidth of the circuit, but may also cause parasitic oscillation. Only a low-capacitance probe is suitable here. Use of an isolation probe or simply an isolation resistor is sometimes suggested at the video-detector output. However, such a resistive-type isolation probe exhibits a low-pass filtering action, which will be discussed later in this chapter.

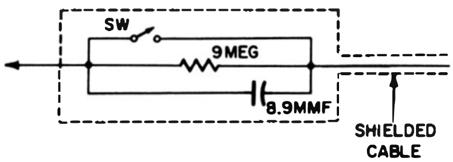
A direct probe used with an oscilloscope is *not* suitable for checking the TV IF amplifier because the frequencies encountered are beyond the capable response of the oscilloscope. A demodulator probe would be required here. However, if you do use a direct probe at the grid of an IF amplifier (as shown in Fig. 1-4C), you will probably get a weak or greatly disturbed response because of regeneration at some frequency within the receiver IF band. This regeneration will overload the IF stage, causing the IF tube to be overdriven. The resulting waveshape will be distored, and not at all indicative of the true circuit performance.

A direct probe is suitable for observing and tracing hum or ripple in a power supply. (See Fig. 1-4D.) The small shunt capacitance of the probe does not affect the extremely high shunt capacitance in the power-supply circuit. The biggest advantage of the direct probe is that it lets us use the full sensitivity of the oscilloscope to measure the rather low ripple voltages in most well-filtered power-supply circuits. (Remember that 600 volts DC is the maximum that can be applied to the vertical-input terminals of most oscilloscopes. Never exceed this level!) On the other hand, trying to measure the ripple voltage of a TV high-voltage supply with a direct probe would be disastrous. Even though the ripple may be relatively low, the high DC potential (in the thousands of volts) is far beyond the capabilities of the oscilloscope (unless the proper attenuating probe is used).

An interesting combination is the direct–low-capacitance probe, in Fig. 1-5, using a resistor and a capacitor in parallel. This combination, together with the compensating capacitance in the oscilloscope, forms a low-capacitance probe. Also note that the isolation resistor has a value of 9 megohms. This higher-than-usual value gives a 10-to-1 attenuation when the probe is used with any of the oscilloscopes for which it is designed. Consequently, when the combination is used as a low-capacitance probe, the input signal must be sufficient to compensate for this loss. When the switch is closed, this probe becomes simply a direct shielded probe.



(A) The probe.



(B) Probe circuit.

Fig. 1-5. A combination direct–low-capacitance probe. (Courtesy of Radio Corporation of America.)

It is sometimes desirable to observe current waveforms in deflection circuits. This can be done by connecting a 1-ohm resistor in series with the circuit. When a direct probe is placed across this resistor, the oscilloscope will indicate the exact waveshape of the current through the resistor. The shunting effect of the direct probe on this 1-ohm resistor is negligible.

ISOLATION PROBES

There are two types of isolation probes — one for oscilloscopes and another for vacuum-tube voltmeters. Both probes have the same circuit, except that the VTVM probe uses an isolation resistor with a value of 1 megohm or higher, whereas the oscilloscope probe uses one between 10K and 50K ohms. For this reason, the probes are not interchangeable. The time constant of the isolation resistor and distributed capacitance is very important.

Fig. 1-6 shows an isolating probe for a DC vacuum-tube voltmeter. These probes usually contain a 1-megohm resistor near the tip. The term *isolation* describes the function of the resistor—to isolate the test instrument so it will not interact

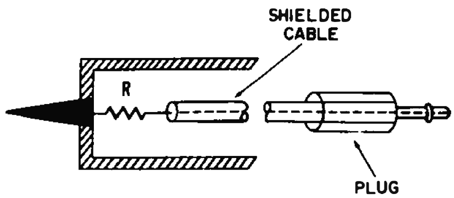


Fig. 1-6. Internal construction of an isolation probe for a DC VTVM.

with the circuit under test. The isolation resistor also reduces the effects of hand capacitance and shielded lead capacitance. Otherwise, loading due to the shunting capacitance of the shielded lead, plus the input capacitance of the VTVM, would produce erroneous readings in sensitive circuits.

The isolation resistor and the distributed capacitance across it not only isolates the VTVM from the circuit under test, but also keeps out the high-frequency AC component. This resistor is usually part of the voltage-divider network in the VTVM input circuit; as such, its value is extremely important to the accuracy and calibration of the meter.

When a VTVM DC probe contains an isolation resistor, the effective input capacitance of the DC probe is usually reduced to approximately 1 mmf. The isolation resistor also prevents the shielded cable from acting as a resonant stub and thus causing erroneous readings at frequencies where the cable measures an integral or fractional part of a wavelength. If there were no isolation resistor, the input capacitance would be around 100 mmf. DC voltages in RF- and IF-amplifier circuits, as well as in local oscillators, would be most difficult, and frequently impossible, to measure.

Sometimes it is desirable to change the resistor in the probe to one of a higher value, or to add an isolation resistor in order to improve the isolation and lower the shunting impedance. We do this by adding another resistor externally. By making this resistor equal to the total input resistance of the VTVM (the resistance of the voltage divider plus the original isolation resistor), we will double the input impedance. Meanwhile, we will also cut the full-scale sensitivity in half. For example, if the voltage-divider resistance in the VTVM is 10 megohms and the isolation resistor in the probe is 1 megohm, and we add an additional 11-megohm resistor in series, we will now have a 22-megohm input impedance—double that of the original value. However, all readings must now be multiplied by 2. For example, what used to be a 10-volt full-scale reading is now 20 volts. Thus, if we read 8 volts with the range-selector switch at the 10-volt position, we actually have 16 volts at the test point.

We can go one step further; we can triple (or even quadruple) the input impedance of a VTVM if we wish to measure voltages in extremely sensitive circuits (in very low-current, high-impedance, high-voltage circuits, for example). If we quadruple the input impedance, we must multiply by 4 any voltage readings obtained. Thus, in the previous example where the meter had an 11-megohm input impedance, we can put 33 megohms in series with the probe, giving a total input impedance of 44 megohms. However, if we again read 8 volts on the 10-volt scale, we would actually be measuring 32 volts. If the readings are too low, we switch to the next lower voltage range.

Vacuum-tube voltmeters have for many years required separate probes for DC and for AC voltage and resistance measurements. This is necessary because of the isolation resistor in a DC probe. Some manufacturers have overcome the disadvantage of separate probes by placing the resistor in a housing which can be attached to the probe tip for DC voltage measurements, or by installing a switch in the probe handle. This switch inserts the isolation resistor in the circuit for DC measurements, but takes it out for other readings. Such a switch should be relatively simple to operate. Yet, it must be compact, so the probe can be handled easily.

An isolation resistor used in conjunction with the oscilloscope will help facilitate waveform observance at the video-detector load. In this way the IF response curve can be seen when a sweep signal is being applied. The isolation resistor serves a dual purpose: (1) As an RF filter, it prevents any IF signal which might have passed through the detector circuit from reaching the oscilloscope and being radiated back into the receiver. (2) Together with the capacitance of the cable and oscilloscope input, the isolation resistor forms an integrating network which bypasses and greatly attenuates any signal above several kilocycles. This results in a sharper marker pip on the IF response curve. Since this curve consists of relatively low-frequency components, its shape will not be altered by the use of this probe. Any 15,750-cycle interference will be greatly reduced, or even eliminated, by the filtering action which occurs with the probe above several kilocycles (unless the interfering signal is excessively strong).

Sometimes an unshielded isolation probe is used with an oscilloscope. However, such a probe tends to pick up horizontal sync-pulse radiation and power-supply hum when not connected to the circuit under test. These extraneous signals will disappear, however, when the probe *is* connected to the circuit. Any undesired signals observed during the test are therefore usually from the circuit itself. Although an unshielded isolation probe can be used with a scope for testing in some circuits, a good shielded isolation probe is still hard to beat.

If direct-connection test leads or probes are used at critical circuit points (at the converter grid of a TV front-end, for example), a feedback loop may tend to be established between the receiver, oscilloscope amplifier, and power line. This loop may produce undesired oscillation. An isolation resistor inserted into the circuit, however, will suppress this tendency by isolating the test circuit from the oscilloscope. Fig. 1-7 shows the effect of such a resistive isolating probe on the marker pip. Fig. 1-7A shows the marker indication when the probe is not used; Fig. 1-7B, when it is. The time constant (formed by the isolating resistor and the capacitance of the shielded cable and oscilloscope) of this filter must be such that marker displacement is not introduced on even the steepest portion of the response curve. Such displacement could be caused by an excessively

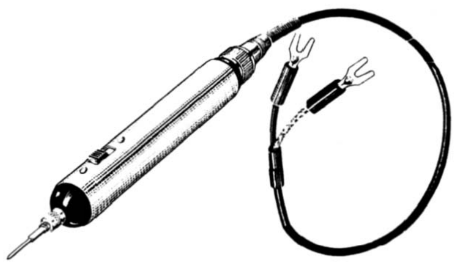
(A) Without probe.

(B) With probe.

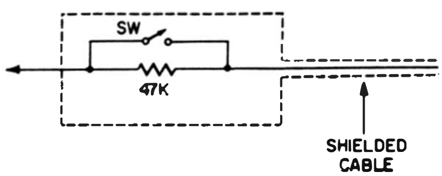
Fig. 1-7. The effect of a resistive isolation probe on the sharpness of the marker pip.

large time delay in the filter. Thus, the values of the isolation resistor and filter capacitor (if a separate unit is added) should be chosen to give a relatively short time-constant.

Careful observation of the beat-frequency marker signal on a response curve will show that the high-frequency components are at either end of the marker. At zero beat and nearby, the frequencies are very low. Therefore, a simple RC filter will more or less suppress the higher frequencies (depending on the value of the resistor and ca-



(A) The probe.



(B) Probe circuit.

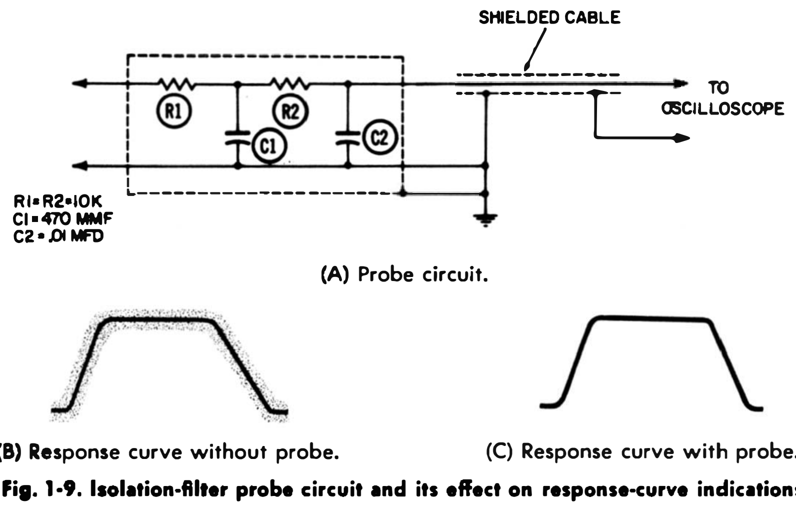
Fig. 1-8. A combination direct-isolation probe for use with an oscilloscope. (Courtesy of Scala Radio Co.)

pacitor) without affecting the low-frequency component or zero beat.

A combination direct and isolation probe to be used with an oscilloscope is shown in Fig. 1-8. This probe is designed to minimize circuit loading and pickup from stray fields near the chassis. Careful shielding tends to prevent false indications caused by stray voltages. The input cable is designed to add the least possible capacitance to the oscilloscope input circuit in order to reduce the shunting effect of the probe. When the switch is closed, we have a direct probe; when open, we have an isolation probe with a 47,000-ohm resistor between the oscilloscope input and the circuit under test.

If we connect an oscilloscope directly across the load resistor of a video-detector output circuit, the scope may operate as a resonant stub unless resistive isolation is used. Stub action is reflected—via the interelectrode capacitance of the video detector— into the last IF stage. Such a disturbance will not only detune the last IF transformer, but may also result in uncontrollable oscillation of the IF amplifier.

Besides providing a low-pass filter action, the isolation resistor also raises the input impedance of an oscilloscope. For example, if we have a total capacitance of 150 mmf (by total we mean the shunt capacitance of the shielded cable plus the input capacitance of the oscilloscope), the reactance at 500 kc is 2,000 ohms. Therefore, if we take a measurement in a 500-kc circuit, we would be shunting it with 2,000 ohms. At higher frequencies, this shunting effect would be even more pronounced. Now, if we use an isolation resistor of anywhere between 10K and 50K ohms, we have automatically minimized the shunting effect to at least the value of the isolation resistance. This reduction in the shunting effect is sometimes of the utmost importance—for example, when excessively high-frequency signals are causing a fuzzy alignment curve. If the isolation resistor alone is not a good enough filter, we can build a low-pass filter which acts like the isolation resistor and the distributed cable capacitance, only more so. Sometimes a .001- up to a .01-mfd capacitor across the vertical-input terminals of the scope will do the job. However, a more elaborate isolation filter like the one in Fig. 1-9 is often preferred. Fig. 1-9A illustrates its cir-



(A) Probe circuit.

(B) Response curve without probe.

(C) Response curve with probe.

Fig. 1-9. Isolation-filter probe circuit and its effect on response-curve indications.

cuit; Fig. 1-9B, the response curve when the filter is not used; and Fig. 1-9C, the response curve when the filter is used. With a sweep frequency of only 60 or 120 cycles, a good scope response up to only 10 kc or so is sufficient for proper response or reproduction of the sweep-generated response curve of a tuned circuit or amplifier.

The compelte isolation-filter network in Fig. 1-9A should be made into a probe and connected to the oscilloscope through a shielded cable. Resistor R1 is the isolation resistor; and C1, C2 and R2 form a pi-type low-pass filter.

For ease in making measurements with a VTVM or VOM, a polarity-reversing probe is unique. Transistors, for example, usually require a front-to-back resistance ratio check. A polarity-reversing probe used with an ohmmeter will greatly speed up this type of check by eliminating the need to reverse the test leads. Instead, the switch on the probe automatically reverses the polarity of the test leads.

Chapter 2

HIGH-VOLTAGE PROBES

BROADLY speaking, there are two types of high-voltage probes. One of these, used with DC VTVM's or VOM's, is of the resistive type: a multiplier resistor in the probe and the input resistance of the instrument form a voltage divider. The other one, used with an oscilloscope or AC VTVM, is the capacitive type: a small capacitor with a very high-voltage rating is used within the probe, while the input capacitance of the instrument and the cable capacitance form another capacitor. The voltage division which occurs is inversely proportional to these two capacitances. We will discuss the resistive type of high-voltage probe first.

RESISTIVE HIGH-VOLTAGE PROBES

The highest voltage range of most VTVM's and multimeters is usually too low for measuring the very high DC potentials in some sections of television receivers and other electronic equipment.

DC voltage ranges usually are no higher than 1,000 volts in VTVM's, and around 1,200 to 1,500 volts in multimeters. However, many multimeters have built into them an input series resistor, making possible DC measurements of around 5,000 volts. Nevertheless, the voltage range of these instruments must be extended even further before high-voltage circuits can be measured. Fortunately, this can be done with a high-voltage probe.

A multiplier resistor, built into the insulated handle of the probe, is connected in series with the internal resistance of the meter. The resistor thus acts as one leg of a voltage divider. Its value is determined by the highest voltage to be measured.

A typical high-voltage multiplier resistor is about 5⁄16 inches in diameter and 5½ inches long, will withstand up to approximately 30,000 volts, and is rated at 5 watts. Longer or thicker units have somewhat higher ratings. For higher than 30,000 volts, resistors can be connected in series within the probe. The resistors are unusually long to minimize the chance of voltage breakdown between the ends. The resistance itself consists of a high-stability carbon coating applied on a strong moisture-resistant steatite rod. Hence, the detrimental effects of temperature and high humidity on the resistance characteristics are held to a minimum. The coating is wound spirally around the rod. Thus, a very long *effective* resistor is provided in a small space. This method also permits use of a relatively low specific resistance coating,

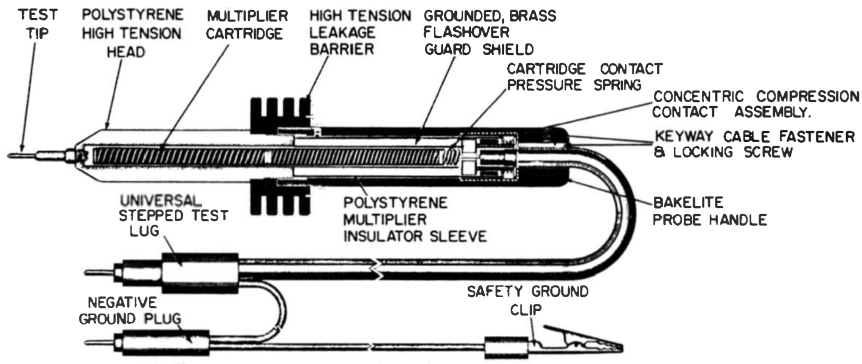


Fig. 2-1. Internal construction of a high-voltage probe.

producing stable resistors with extremely high resistances (up to one million megohms). The relatively low voltage gradient between turns makes a breakdown unlikely, unless the voltage rating is greatly exceeded. The internal construction of a high-voltage probe is shown in Fig. 2-1.

Shielding the multiplier resistor against stray pickup is not practical because this would materially reduce the safety factor gained by using a long resistor and a probe.

Permanent connection to the ends of the resistance element or elements is made by means of a silver contact coating. Another coating of special electrical varnish protects the outside of the resistor. This protective coating must not be punctured because the resistance coating underneath could also be damaged. No solder connections are required between the resistor and external elements, since connection to the resistor is generally made by means of compression springs.

Multiplier resistors are usually chosen to extend the range of a meter by some easily applied multiplying factor—such as 5, 10, 25, 30, or 100.

Let us refer to the input circuit of a typical VOM like the one in Fig. 2-2. As we switch from range to range, the input resistance between the positive and the negative terminal varies in direct proportion to the full-scale voltage range at which the meter is set. On the 2.5-volt range, for example, we have 50,000 ohms between the positive and negative terminals (the 48K re-

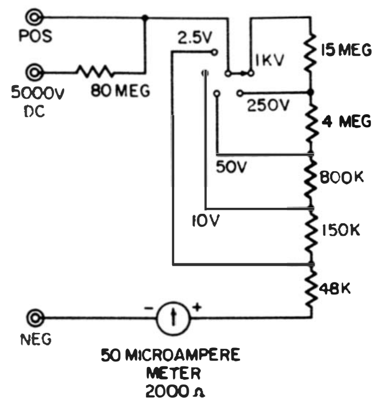


Fig. 2-2. Simplified DC input circuit of a typical VOM.

sistor plus the 2,000-ohm meter resistance); on the 10-volt range, we have 200,000 ohms; on the 50-volt range, 1,000,000 ohms; on the 250-volt range, 5 megohms; on the 1,000-volt range, 20 megohms; and on the 5,000-volt range, 100 megohms.

On the other hand, the input resistance of the VTVM in Fig. 2-3 remains constant, no matter where the voltage-range selector switch is set. This input resistance is the 5 megohms in the isolation probe plus 20 megohms, or 25 megohms, plus

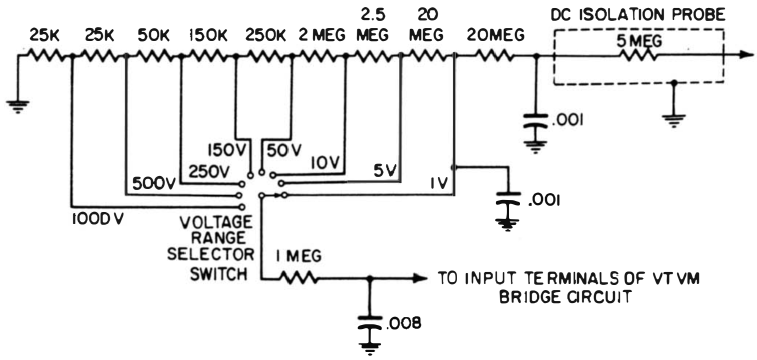


Fig. 2-3. Simplified input circuit of a typical VTVM.

the sum of all the voltage-divider resistors, which adds up to another 25 megohms. Thus, we have a total input resistance of 50 megohms.

How, if at all, does this difference in the meter input circuit affect the selection of a high-voltage probe? Let us first consider the multimeter. We said before that the high-voltage multiplier resistor in the probe is part of a voltage divider. In order for it to act as such, we must also know the sensitivity of the meter in ohms per volt (20,000 for the multimeter in Fig. 2-2). The ohms-per-volt rating of any multimeter is determined by the current required for full-scale deflection. Here, we use a meter with a full-scale sensitivity of 50 microamperes.

By using Ohm's law, we can easily determine the current-limiting resistance required per volt for full-scale reading. Let us say we want to measure 1 volt:

$$R = \frac{E}{I}$$

$$= \frac{1}{0.00005}$$

$$= \frac{100{,}000}{5}$$

$$= 20{,}000 \text{ ohms.}$$

This 20,000 ohms is the constant resistance required for each volt to be measured. For 5 volts we need 5 × 20,000, or 100,000 ohms; for 100 volts, 100 × 20,000, or 2 megohms; for 1,000 volts . . . 20 megohms; and for 5,000 volts . . . 100 megohms.

To increase the voltage range to 25,000 volts full scale by means of a high-voltage probe, we use the 5,000-volt range of the meter, and employ the multiplier resistance of the high-voltage probe to drop the other 20,000 volts. Let us figure what resistance we need. Since we must drop 20,000 volts across the multiplier resistor in the probe, and we need a resistance of 20,000 ohms for each volt we want to measure, we simply multiply 20,000 (volts) by 20,000 (ohms/volt) to come up with 400 million ohms (400 megohms).

Setting up a formula for calculating the value of the multiplier resistor for a particular HV full-scale range is no problem. All we have to know is the resistance at the meter terminals on the voltage range we want to use. Since the multiplier resistor is in series with the meter resistance, the voltage drops will be proportional to the respective resistances. This gives us the following formula:

$$\frac{E_{ext}}{R_{ext}} = \frac{E_{int}}{R_{int}}$$

or,

$$\frac{R_{int}}{R_{ext}} = \frac{E_{int}}{E_{ext}}$$

where,

E_{ext} is the voltage drop across the multiplier resistor,

E_{int} is the full-scale voltage reading of the meter,

R_{ext} is the resistance of the high-voltage multiplier resistor,

R_{int} is the resistance between the meter terminals for "E_{int}" full-scale voltage readings.

The new full-scale reading is $E_{ext} + E_{int}$.

The HV probe now extends the meter range to 25,000 volts. To read the meter properly, we use the 5,000-volt DC scale and multiply the reading by 5. For example, if the meter reads 4,000 volts, we are actually measuring 20,000 volts.

A particular value of multiplier resistor is suitable for only one range of the VOM. Notice that the internal resistance between the positive and negative terminals of the multimeter in Fig. 2-2 changes with each voltage range setting. Therefore, a different value of multiplier resistance must be computed for other voltage ranges, using the formula just discussed.

Table 2-1 shows the values of multiplier resistors needed to extend the voltage range of multimeters with sensitivities of 20,000 ohms per volt. Normally it is impractical to extend

Table 2-1

Resistors required for extending the voltage range of non-electronic voltmeters (20,000 ohms/volt).

Manufacturer	Model No.	VOM Range Setting(s)- DC Volts	Range(s) VOM extended to- DC Volts	Scale Factor	Multiplier Resistor Megohms
EICO	555, 565	5000	25,000	5	400
		1000	25,000	25	480
		1000	30,000	30	580
		500	25,000	50	490
EMC	104	3000	30,000	10	540
Hickok	450	5000	25,000	5	400
		1000	25,000	25	480
		1000	30,000	30	580
Precision	85, 858-P, 654-P, 10-54-P, 120	6000	30,000	5	480
RCA	WV-38A	250	25,000	100	495
Simpson	221, 260	5000	25,000	5	400
		1000	25,000	25	480
		1000	30,000	30	580
		500	25,000	50	490
	262	4000	20,000	5	320
Triplett	625 NA	500	50,000	100	991
	630, 630A	6000	30,000	5	480
Weston	785	1000	25,000	25	480
		1000	30,000	30	580
		500	25,000	50	490

the high-voltage range of VOM's with lower sensitivities, because the power dissipated in the multiplier resistor would be far beyond what could be tolerated. A simple calculation will show what happens when we extend the range of a 20,000 ohms-per-volt VOM to 25,000 volts, using the 5,000-volt range as before —and then if we try to do the same for a VOM with a sensitivity of only 1,000 ohms per volt.

We previously calculated that we need a 400-megohm resistor for our 20,000 ohms-per-volt VOM. From Ohm's law—$W = E^2 \div R$—we find the following:

$$W = \frac{(20{,}000)^2}{400{,}000{,}000}$$

$$= \frac{400{,}000{,}000}{400{,}000{,}000}$$

$$= 1 \text{ watt.}$$

At a full-scale reading of 25,000 volts, the multiplier resistor dissipates 1 watt. This value makes it quite practical for us to use the 5-watt spiral-deposited high-voltage multiplier resistor available for the purpose.

Now let us see what happens if we try to extend the 5,000-volt range of a 1,000-ohms-per-volt meter to 25,000 volts. Again using the formula, we find that the multiplier resistor is 20 megohms, and that the power it dissipates for a full-scale reading of 25,000 volts is 20 watts. Such a power value becomes very impractical, of course, not only from a heat dissipation point of view, but also for another important reason. There are few electronic high-voltage circuits from which so much power can be drawn without either causing the circuit to become inoperative, or else to be so loaded down that any readings would be meaningless.

High-voltage probes are used most frequently for measuring the voltages in high-voltage power supplies of television receivers. The voltage regulation of these circuits, however, is inherently poor. That is, if more current is drawn from the supply than it is designed to deliver, the voltage will drop sharply. Moreover, in such a circuit the loading effect of the probe becomes more pronounced with lower-sensitivity meters. This fact must be considered when voltage measurements are made in television high-voltage circuits.

Present-day picture tubes draw a beam current of approximately 75 to 100 microamperes when the set is adjusted for *normal* brightness. Suppose we use the 20,000-ohms-per-volt meter to measure voltages of, say, 15,000 volts in the high-voltage supply of a television receiver. If we use the probe we designed for a 25,000-volt range, we will apply across this voltage under test a total resistance of 500 megohms. The current drawn by 500 megohms from a 15,000-volt source is:

$$I = \frac{E}{R}$$

$$= \frac{15{,}000}{500{,}000{,}000}$$

$$= \frac{15}{500{,}000}$$

$$= 0.00003 \text{ amperes, or } 30 \text{ microamperes.}$$

Television high-voltage power supplies are generally designed to deliver only a limited amount of current at a particular value of high voltage. This current may be very close to the maximum beam current needed when the set is adjusted for maximum brightness. Any further load upon the supply will cause a drop in voltage. An average picture tube, for example, will draw around

300 microamperes of beam current at the *maximum* brightness setting. If the brightness control is adjusted for maximum and the high-voltage power supply is designed to deliver only 300 microamperes maximum, placing our 20,000 ohms-per-volt meter across the supply would add 30 microamperes, giving a total load of 330. This additional load can cause the high voltage to drop, giving a reading that would seem below normal. On the other hand, had we used a 1,000-ohms-per-volt meter and designed a high-voltage probe for it, we would have overloaded the high-voltage supply so much that the resultant reading would have been meaningless. This situation can be remedied by reducing the load on the high-voltage supply when the voltage is measured. If the brightness is reduced from maximum to normal, the required beam current will likewise be reduced (from approximately 300 to 100 microamperes).

Now the additional 30-microampere load placed on the high-voltage supply by the 20,000 ohms-per-volt meter is negligible, allowing an accurate voltage measurement. The load on the high-voltage supply can be even further reduced by disconnecting the high-voltage lead from the picture-tube anode. Fig. 2-4 shows the output capabilities of a typical television high-voltage power supply.

In a properly operating set, the loading effect of a meter can be observed by noting the brightness with and without the probe, and observing any appreciable difference. If the brightness changes, then the loading from the prove varied the output of the high-voltage supply noticeably.

It is possible to use the same HV probe on several voltage ranges of the VTVM, because the internal resistance of the instrument remains constant on all ranges. When figuring the value of a high-voltage multiplier resistor for a VTVM, however, do not forget that an isolation resistor of anywhere from 1 to 20 megohms is usually placed within the DC probe. (This resistor is removed in changing from the isolation to the

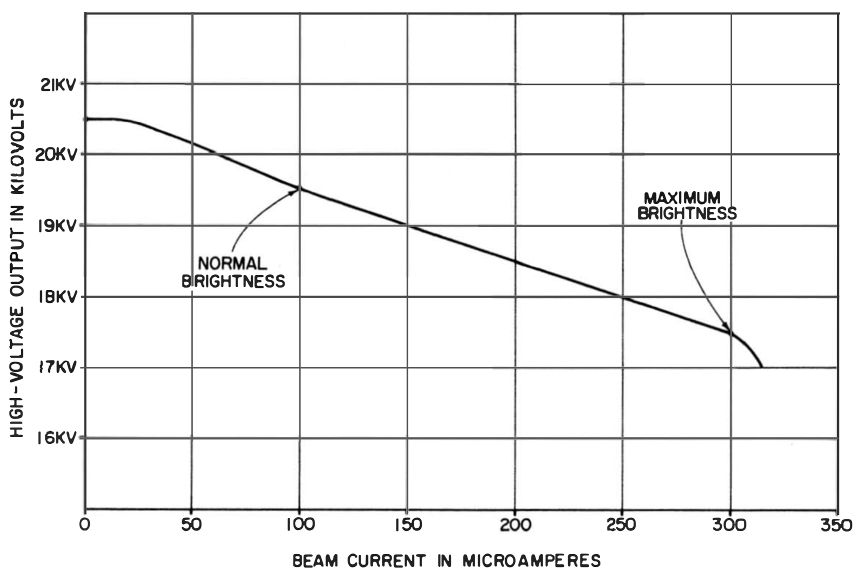


Fig. 2-4. Output voltage versus load current of a typical TV high-voltage supply.

high-voltage probe.) Therefore, the DC input resistance of the VTVM (normally in megohms) is reduced by the amount of resistance in the isolation probe.

The value of the multiplier resistor is determined, as before, by the required new full-scale range and the input resistance of the meter. Here, however, the formula must also take into account the isolation resistor. Thus, we get:

$$R_p = R_{in} (M-1) + R_{iso}$$

where,

R_p is the value of the high-voltage multiplier resistor,

R_{in} is the input resistance of the VTVM (the value given in the manufacturer's specifications, including the isolation resistor),

R_{iso} is the value of the isolation resistor in the DC probe supplied with the meter,

M is the desired multiplying factor for HV measurements (any easily applied factor, such as 5, 10, 25, 30, or 100).

Let us now use this formula to find the proper value of multiplier resistor required to extend the range of the VTVM in Fig. 2-3 to 25,000 volts. The 1,000-volt scale would give us a multiplying factor of 25. Thus:

$$R_{in} = 50 \text{ megohms,}$$
$$R_{iso} = 5 \text{ megohms,}$$
$$M = 25.$$

If megohms are used for all resistances, the value of the multiplier resistor will also be in megohms. Therefore:

$$\begin{aligned} R_p &= R_{in} (M-1) + R_{iso} \\ &= 50 (25-1) + 5 \\ &= 50 (24) + 5 \\ &= 1{,}200 + 5 \\ &= 1{,}205 \text{ megohms.} \end{aligned}$$

If you want to calculate the multiplying factor for a probe with a resistor, the formula becomes:

$$M = \frac{R_p + R_{in} - R_{iso}}{R_{in}}$$

Table 2-2

Resistors required for extending the voltage range of vacuum-tube voltmeters.

Manufacturer	Model No.	VTVM Range Setting(s)- DC Volts	Range(s) VTVM extended to- DC Volts	Scale Factor	Multiplier Resistor Megohms
EICO	214, 221	1000	30,000	30	740
	232, 249	500& 150	50,000& 15,000	100	1090
EMC	106	1000	30,000	30	480
Hickok	215	300	30,000	100	1046
Jackson	709	1000	30,000	30	320
		1000& 100	100,000 & 10,000	100	1090
Precision	EV-10	6000	30,000	100	1320
	EV-20	1200	30,000	100	1320
RCA	WV-77A	300&60	30,000& 6,000	100	1090
	WV-87A,97A	500 & 150	50,000& 15,000	100	1090
Simpson	303	300	30,000	100	991
Sylvania	221 Z	1000	30,000	30	494
Triplett	650	500& 100	50,000& 10,000	100	1090

Thus, if we had a meter with an input resistance of 11 megohms (with a 1-megohm isolation resistor), and a probe with a multiplier resistor of 1,090 megohms, the multiplying factor would be:

$$M = \frac{1{,}090 + 11 - 1}{11}$$

$$= \frac{1{,}100}{11}$$

$$= 100.$$

The multiplying factor of a probe applies to *every range* of a VTVM because the input resistance always remains constant and no current is drawn from the voltage-divider network to actuate the meter movement.

Table 2-2 shows the values of multiplier resistors required for some of the commercial VTVM's. Many manufacturers produce different models of VTVM's which, as the table shows, sometimes require different probe resistances. The value depends on the total resistance of the multiplier string, so always check to be sure.

We sometimes must use a high-voltage probe with a VTVM to measure in other than very high-voltage circuits. With a high-voltage probe, we can realize extremely high input impedances. That is, the circuit loading by the VTVM will be very low. For example, if we use the VTVM in Fig. 2-3, we will have an input impedance of 50 megohms. For a measurement on the 100-volt range, we have a sensitivity of 50 megohms divided by 100, or 500,000 ohms per volt—which is quite high. However, we may at some time need a meter with a much higher input impedance, in order to measure, say, 100 volts or so. If our high-voltage probe has a 455-megohm multiplier resistor, a multiplying factor of 10 will be introduced in every reading. Therefore, we can now get a full-scale reading of 100 volts on the 10-volt range. Note, however, that the meter now presents to the circuit under test not 50 megohms as before, but an input resistance of 500 megohms.

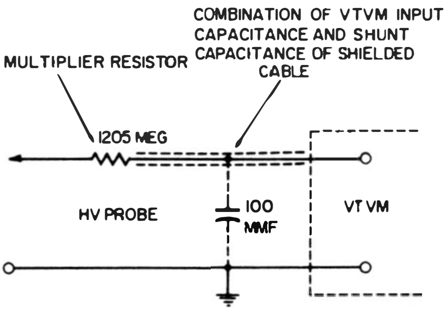
This technique of increasing the input impedance of a VTVM will prove very helpful when the voltage in the grid circuit of a TV vertical blocking-oscillator circuit is measured. Grid resistors here may range from 10 megohms up, and DC voltage levels are generally below 100 volts.

It is sometimes necessary to measure DC voltage of a few hundred volts in circuits where very large high-voltage pulses are present (for example, at the plate cap of the horizontal-output tube in a TV receiver). Many service manuals have a note reading "Do not measure." at that point. Here is why:

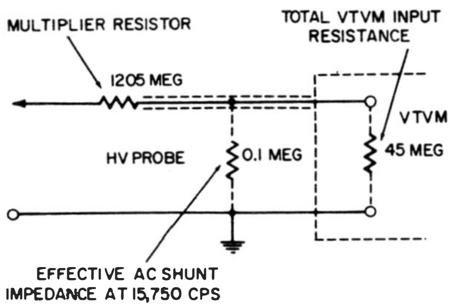
At the plate cap we find both AC and DC. The DC is the normal B+ voltage of about 350 volts, but the AC component consists of 15,750-cps pulses with a peak value of around 6,000 volts. Because their frequency is high and their duration short, the meter needle cannot follow these pulses. Hence, they are not read on the meter. They do, however, cause a current to flow in the meter multiplier resistors. As a result, the resistors will overheat, and are likely to open or permanently change in value.

In spite of this problem, we can still measure the DC plate voltage of the horizontal-output tube, provided we use a resistive HV type of probe. Here, the probe and the input capacitance of the meter (plus the capacitance of the shielded cable, if used) act as a low-pass filter. To explain this, let us use the VTVM input circuit in Fig. 2-3 and the 1,205-megohm HV multiplier probe.

This probe gives us a multiplying factor of 25. We could use the 50-volt range, giving us 1,250 volts full scale. However, too much mental calculation would be required. On the other hand, the 10-volt range is too low, giving us a full-scale reading of only 250 volts. We would therefore set our meter to the 100-volt range, since we expect to read in the neighborhood of 300 volts. This gives us a full-scale reading of 2,500 volts. Now we can read our B+. But what about the effect of the pulses?



(A) Effective shunt capacitance for the DC measurement.



(B) Equivalent circuit of probe for 15,750-cps pulses.

Fig. 2-5. Effect on the shunt capacitance of an HV probe when a DC voltage containing AC pulses at 15,750 cps is measured.

The VTVM has a certain input capacitance—normally around 15 to 25 mmf. If the HV probe uses a shielded cable, it, too, will have a shunt capacitance of anywhere from 50 to 100 mmf. Adding these capacitances, we get about 100 mmf of total shunt capacitance, as shown in Fig. 2-5A. At 15,750 cps, the reactance of 100 mmf is about 100,000 ohms, or 0.1 megohm. This makes the circuit effectively like that of Fig. 2-5B at this frequency. This 0.1-megohm reactance is in parallel with the total meter input resistance of 45 megohms. However, the effective AC shunt impedance will still be 0.1 megohm because the effect of the 45 megohms in parallel will be of no consequence.

This impedance, together with the probe multiplier resistor, forms a voltage divider for the high-frequency pulses. The attenuation ratio is therefore 1,205 to 0.1, or approximately 12,000 to 1. If the pulses have a peak amplitude of 6,000 volts, only 6,000 ÷ 12,000, or about half a volt, will appear at the meter. This, of course, will not harm it.

Even if the HV lead is not shielded, we can still use the HV probe for this measurement. If we take an average VTVM input capacitance of 20 mmf, the shunt impedance will be about 0.5 megohm. This will give a pulse attenuation of 1,200-to-0.5, or 2,400-to-1. With 6,000-volt pulses, this would give 6,000 ÷ 2,400, or only 2.5 volts at the meter—still a safe value.

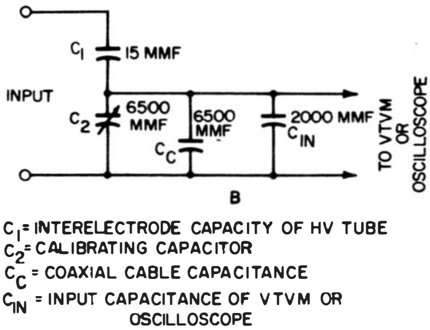
The high-voltage probes are usually terminated by a phone jack, an *Amphenol* connector, or pin jacks. Since the wire from the probe to the instrument is usually not shielded, only one connection to the meter is required. The common connection from the meter is generally made directly by one of the test leads supplied with the instrument.

CAPACITIVE-DIVIDER HIGH-VOLTAGE PROBES

So far, we have talked about measuring DC high voltages only. There are times, however, when we will want to measure or observe high-voltage pulses, such as those in the horizontal-sweep system of a television receiver. These high-voltage pulses, you will remember, were purposely bypassed when the resistive high-voltage probe in the previous application was used. They can be measured or observed, however, with a capacitive-divider type of high-voltage probe.

Capacitive-divider high-voltage probes are employed with oscilloscopes to check waveforms, and with VTVM's to measure high AC voltages. These probes are not frequency compensated. Their attenuation factor is determined by the ratio of the oscilloscope or VTVM input impedance plus cable capacitance to the high-voltage capacitor in the probe.

(A) Physical appearance.



(B) Basic probe circuit.

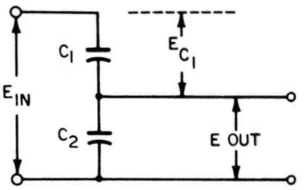
Fig. 2-6. A capacitive-divider high-voltage probe. (Courtesy of the Hewlett-Packard Company.)

Since there is no resistive element within the probe, its operation at low frequencies is not too satisfactory. It does, however, operate most efficiently at the higher frequencies found in TV horizontal-sweep circuits. The lower-frequency pulses in the vertical-sweep section are generally handled more effectively by the 10:1 low-capacitance probe, since the amplitude of these signals is not high enough that a HV probe is required.

Fig. 2-6A shows a capacitive-divider probe which safely measures as high as 25,000 volts. The frequency range over which this probe can be used extends from 25 cycles to 20 megacycles. As the frequency increases, the voltage rating of the probe is reduced in order to limit the amount of RF current flowing through the high-voltage capacitor. A fixed safety gap prevents damage to the probe, should we accidentally apply a voltage higher than the probe is rated for. Breakdown will occur if the applied voltage exceeds about 28,000 volts. Fig. 2-6B shows the basic circuit for this type of capacitive-divider high-voltage probe.

The probe in Fig. 2-6 is intended primarily for laboratory application, but is included here to show its construction. It has a voltage-division ratio of 1,000:1. The maximum voltage rating at 60 cycles is 25,000 volts; at 100 kilocycles, 22,000 volts; at 1 megacycle, 20,000 volts; at 10 megacycles, 15,000 volts; and at 20 megacycles, only 7,000 volts. Fig. 2-6A shows a 15-mmf high-voltage vacuum capacitor, which is encased in a glass envelope. One terminal of this capacitor, C1 in Fig. 2-6B, is connected to the high-voltage point, and the other, to the meter or oscilloscope input.

The operation of this type of probe is based on the fact that a voltage applied to capacitors in series will divide between them in inverse proportion to their respective capacitances. If the capacitance of C2 in Fig. 2-7 is 99 times that of C1, 1/100th of the applied voltage will appear across C2 and 99/100ths across C1. This is true because the reactance of C2 is 99 times lower than that of C1. Most of the voltage will appear across the high reactance, of course.



$E_{IN} = E_{C_1} + E_{OUT}$

ALSO $C_1 E_{C_1} = C_2 E_{OUT}$

SO THAT $\frac{E_{C_1}}{E_{OUT}} = \frac{C_2}{C_1} = M$ M = ATTENUATION FACTOR

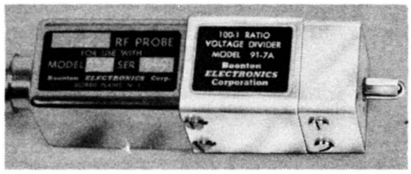
THEREFORE $C_2 = MC_1$

Fig. 2-7. Basic capacitive-divider HV probe circuit, showing how voltage division is accomplished.

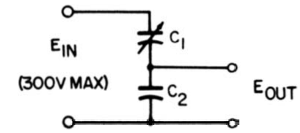
As with the resistive high-voltage probe, the element in the probe has the most high-frequency voltage developed across it; only a relatively small amount is developed across the input circuit of the instrument. If we measure 10,000 volts with a 100:1 probe, we will find 9,900 volts across the high-voltage capacitor of the probe, and only 100 volts across the input circuit of the oscilloscope.

The ideal probe would have an infinite resistance and an infinitesimal shunt capacitance. In this way, the probe would not affect the circuit under test at all. (The total capacitance of capacitors in series is less than the smallest capacitance.) In order to realize a very small shunt capacitance, we must make Cl in Fig. 2-7 as small as possible and still maintain a 99:1 ratio between C1 and the sum of the cable, input, and calibrating capacitances.

Fig. 2-8 shows a capacitive-divider probe for use with a high-impedance probe over a range extending from 500 kc to 600 mc. An exact 100-to-1 division ratio can be obtained by adjusting variable capacitor C1. A very sophisticated solution has been



(A) The probe.



(B) Probe circuit.

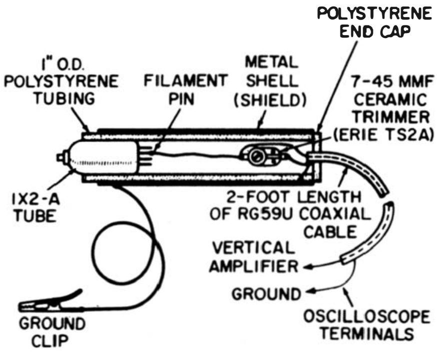
Fig. 2-8. A capacitive-divider HV probe used with a high-impedance probe. (Courtesy of Boonton Electronics Corp.)

found to the problem of obtaining a low-capacitance and high-voltage "capacitor." This is to use a high-voltage rectifier tube—but as a capacitor, not as a rectifier. These tubes have a very high-voltage rating. However, the capacitance between the filament and the plate cap is very small – usually around 1 mmf.

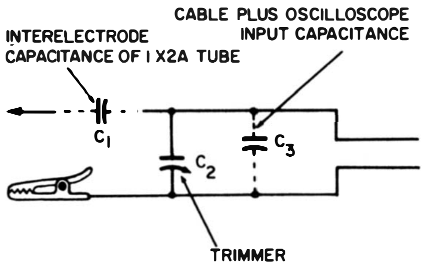
Fig. 2-9A shows the details for constructing a typical capacitive-divider high-voltage probe. The equivalent circuit is shown in Fig. 2-9B.

The high-voltage input capacitor of this probe consists of the plate-to-filament interelectrode capacitance of a 1X2-A high-voltage rectifier tube rated at 18,000 volts maximum. This tube is used as a rather inexpensive high-voltage capacitor with a value of approximately 1 mmf. The interelectrode capacitance of the tube is connected in series with the sum of the input capacitance of the oscilloscope, the capacitance of the cable, and the calibrating trimmer capacitor. By proper adjustment of trimmer C2, accurate 100-to-1 attenuation can be obtained.

The tube is cemented into the end of a length of polystyrene tubing, and its plate top cap used as the high-voltage test prod. A lead is connected from one of the filament pins to C2 (7-45 mmf ceramic trimmer). This capacitor is mounted inside the polystyrene tube. A hole is provided in the wall of the tube so a trimmer-adjusting screwdriver can be inserted.



(A) Construction details.



(B) Equivalent circuit.

Fig. 2-9. Assembling a capacitive-divider HV probe.

This trimmer permits the total output capacitance (the sum of the trimmer, cable, and oscilloscope input capacitances) to be adjusted to 99 mmf. The voltage-reduction ratio through the probe will then be 100-to-1 (assuming the interelectrode tube capacitance is 1 mmf). If the tube capacitance is a little more or less than 1 mmf, the trimmer can be adjusted to compensate for this accordingly. The calibrating trimmer need not be a HV type, since only 1/100th of the test voltage will be across it. At 20 kilovolts, for example, this will be only 200 volts.

The input impedance of such a probe is approximately 10 megohms, with a plate-to-filament capacitance of 1 mmf. At 15,750 cps, the impedance is reduced to about 1 megohm, which normally is still much higher than the impedance of the circuit under test. If we use the high-voltage probe with an oscilloscope calibrated for a sensitivity of 10 volts peak-to-peak per square, the probe now converts the oscilloscope sensitivity to 1,000 volts peak-to-peak per square. Thus, a peak-to-peak waveform of 5,000 volts will cover five squares.

Most present-day oscilloscopes have a maximum vertical-deflection sensitivity of 0.02 volts rms/inch. This corresponds to $0.02 \times 2 \times 1.414 =$ 0.05656 volt peak-to-peak. Thus, to get a 1-inch deflection on the scope with a 100:1 probe, we must have a peak-to-peak input signal of 100×0.05656, or 5.656 volts. This is about the practical low-voltage limit for a 100:1 probe. A 50:1 probe is satisfactory where the shunt capacitance of a 10:1 probe is too high and a 100:1 probe does not deliver sufficient signal.

A relatively simple high-voltage divider can also be made from two lengths of RG59/U coaxial cable, as shown in Fig. 2-10. Remove all the outer braid from the shorter coax, and approximately 3½ inches from the longer one. Then overlap the two pieces of coax three inches, and tape them together with plastic electrical tape. Connect a 100-mmf, 500-volt capacitor between the inner and outer conductors of the longer coax in order to obtain the proper attenuation ratio. This capacitance-divider probe gives a stepdown ratio of approximately 100-to-1. If you want a more accurate attenuation ratio, use a fixed capacitor of about 80 mmf shunted by a small trimmer.

How to Calibrate Capacitive-Divider HV Probes

Most of today's oscilloscopes are equipped with a decimal step attenuator. By connecting the vertical-input terminals of the oscilloscope *directly* to a low-impedance pulse source (such as the cathode of the horizontal driver tube, the bottom of the primary winding of the horizontal-output transformer, or the cathode of the damper tube) you can check the calibration factor of the probe. First, turn the coarse attenuator of the oscilloscope to the X100 position, and observe the amount of vertical deflection obtained on the oscilloscope screen. Adjust the vernier attenuator of the scope to any convenient position. Now, connect the 100:1 capacitance voltage-divider probe and advance the coarse attenuator to the X1 position. This will make the oscilloscope 100 times more sensitive. Apply exactly the same signal source as before and do *not* move the fine attenuator. Adjust the trimmer capacitor to obtain the same amount of vertical deflection as before. The probe is now properly calibrated, and is adjusted to exactly 100:1 attenuation.

After the probe has been calibrated, it is easy to compute the exact value of the peak-to-peak voltage under test, by simply multiplying the oscilloscope calibration factor by 100 (adding two zeros). Such actual measurements can be made only if the probe is used with oscilloscopes that have step attenuators, preferably calibrated in multiples of 10. The cable supplied with the probe must be kept in use. If another cable is substituted, the probe must be recalibrated.

Uses for the Capacitive-Divider HV Probe

Some of the less expensive oscilloscopes do not have a compensated input system. The input capacitance of such oscilloscopes will thus vary as the vertical-attenuator setting is varied. Therefore, the calibration factor of the probe at various attenuator settings will also be changed somewhat, and waveform distortion is likely to be encountered at lower settings because of frequency discrimination and phase shift within the attenuator itself. These factors must be considered when this probe is used with an oscilloscope having

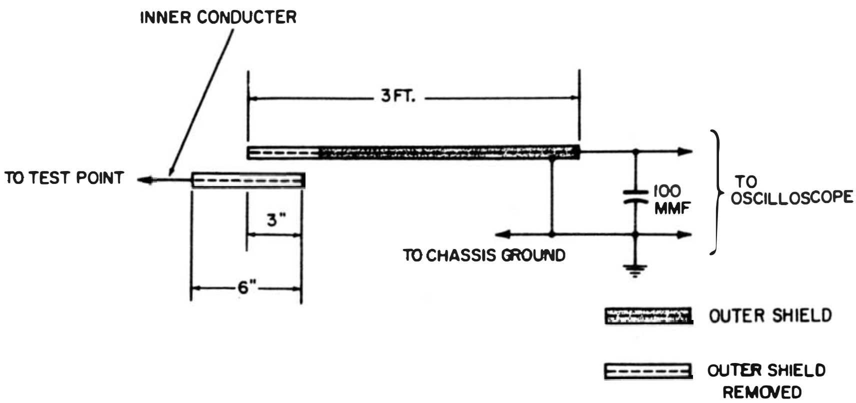


Fig. 2-10. A simple capacitive-divider HV probe can be made from two lengths of coaxial cable.

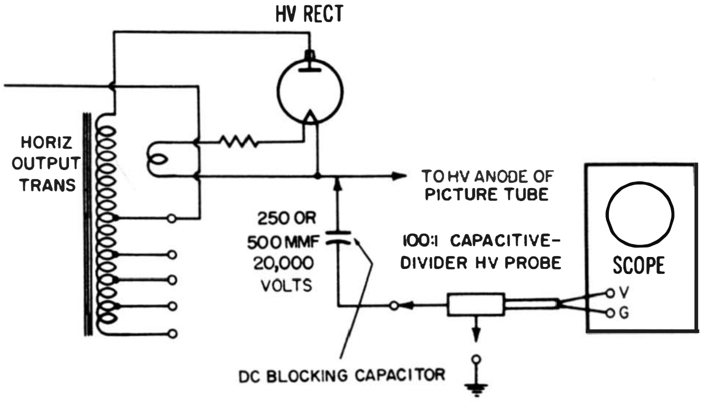


Fig. 2-11. Connections for checking the waveform and peak-to-peak voltage in a TV high-voltage supply when a capacitive-divider HV probe is used.

an uncompensated vertical-input circuit.

The capacitive-divider HV probe can also be used for measuring the peak-to-peak ripple voltage in the output circuits of a TV high-voltage supply, provided a suitably rated high-voltage filter capacitor is connected in series with the probe to block the DC voltage component. (See Fig. 2-11.)

Oscilloscopes are generally designed for input voltages up to 600 volts. Distortion will take place if this maximum voltage is exceeded by even a small amount. Moreover, if exceeded greatly, it will damage the oscilloscope input circuit *unless* a suitable attenuating probe is used. For example, when a 6,000-volt peak signal is applied to the 100:1 capacitive-divider HV probe, the oscilloscope receives only 1/100th of this voltage, or 60 volts. This is certainly well within the capabilities of the oscilloscope input circuit.

The capacitive-divider HV probe is suitable not only for quantity, but also for quality, measurements. The probe enables the waveshapes of the signal at various test points in the television receiver to be compared with those in the service data.

Because considerable capacitance is shunted across the scope terminals, the resistive components of the scope input impedance can be neglected at high frequencies. Therefore, such a probe does not require compensation at the frequencies encountered in the average horizontal oscillator-driven TV power supplies.

We must realize, however, that since the probe is not frequency compensated, it is not suitable for low-frequency circuits (such as 60-cycle vertical-sweep circuits) because the reactance of the oscilloscope input capacitance at 60 cps would greatly exceed the resistive component of the oscilloscope input impedance. This, however, need not be of concern because the 10:1 low-capacitance probe will adequately accommodate the operating voltages encountered in vertical-sweep circuits.

The 100:1 capacitive-divider probe not only loads the circuits less than the 10:1 low-capacitance probe does, but also delivers only one-tenth as much signal. The shunt capacitance is approximately 2 mmf for the capacitance-divider probe, and 8 mmf for the low-capacitance probe. Fig 2-12 shows their shunting effect.

Peak-to-peak voltage readings in television receivers should fall within approximately twenty per cent of the reading given in the service manual for the particular set under test. For example, a 5,000-volt peak-to-peak signal should measure between 4,000 to 6,000 volts peak-to-peak in order to be within the normal tolerances expected in commer-

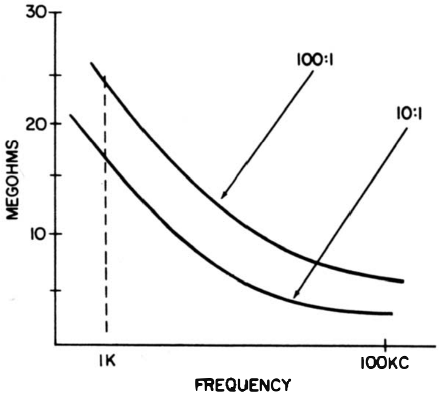
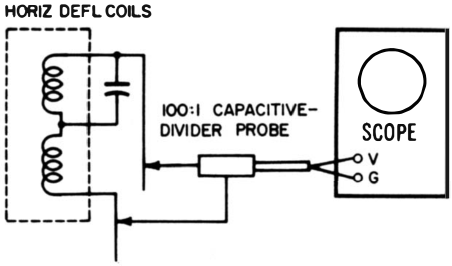


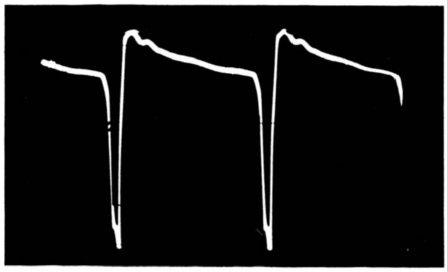
Fig. 2-12. Shunting impedance of a typical 100:1 capacitive-divider HV probe and a 10:1 low-capacitance probe.

cial television receivers. Remember that the voltage readings in service manuals are generally based on a line voltage of 117 volts. Any variation must be taken into account because it will affect the high voltages in the horizontal-deflection circuits.

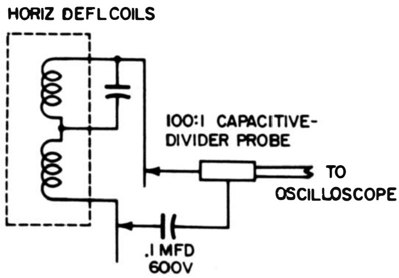
Fig. 2-13A shows a 100:1 capacitance-divider probe applied across the horizontal-deflection coils. The resultant waveform, shown in Fig. 2-13B, is almost always indicative of the actual waveform across the horizontal-deflection coils. Sometimes, however, there is sufficient impedance between the "low" side of the deflection coils and ground to produce a distorted waveform. If so, the actual waveform across the coils can be obtained by placing a 0.1-mfd capacitor in series with the ground lead of the probe, as shown in Fig. 3-13C. The capacitance (0.1 mfd here)



(A) Direct connection.



(B) Waveform across coils.



(C) Capacitor in series with ground lead of probe.

Fig. 2-13. Checking the waveform across the horizontal-deflection coils with a 100:1 capacitive-divider probe.

must be high enough that the AC impedance is negligible. It is not recommended, for safety's sake, that the scope ground be connected to the "low" end of the deflection coil because the scope case will then be at B+ potential, and any contact between it and the receiver chassis will result in a nasty jolt.

SAFETY FIRST

It is interesting to note that sometimes as much as 95 per cent of the high voltage under test is dropped within the probe. For example, when 20,000 volts are measured, 19,000 volts may be dropped by the multiplier resistor in the probe, and only 1,000 volts within the VTVM. Therefore, the probe must be constructed of a good insulating material, in order to provide maximum protection for its user.

Most present-day high-voltage probes are equipped with a safety flange (sometimes referred to as a flash guard or barrier) consisting of one or more discs about two-thirds of the way up the probe. These discs prevent the operator's fingers from slipping too close to the high-voltage source. They also greatly reduce the possibility of corona or arcing.

Some Safety Precautions

The high-voltage power supplies of TV receivers can be dangerous. For this reason, television receivers are equipped with an AC interlock that disconnects the power line from the set when the rear cover is removed. It is possible, however, for a charge to remain in the receiver even after the power line has been disconnected. Most color television receivers have a safety device which automatically grounds the high-voltage supply when the back is removed. Fig. 2-14 shows a color TV interlock "cheater" that enables the set to be operated even with the back removed. In addition to preventing the high-voltage supply from being disabled, the "cheater" also accommodates a high-voltage probe so voltage measurements can be made. Be extremely cautious when checking equipment that does not use pulse-operated or RF power supplies (such as the higher current, high-voltage supplies in industrial equipment).

Always observe the following safety precautions when working with all types of high-voltage equipment:

1. Before starting, make sure you know the location of all high-voltage points in the equipment under test.
2. If the floors are not wooden, keep some dry one-inch planks handy for use as a platform. A hard rubber mat is even better.
3. Hands, shoes, bench, and floor must be completely dry.
4. Work with one hand only, and keep the other one in your pocket. Make sure no part of your body contacts any point that might be a ground. When working near water or steam pipes, radiators, and grounded electrical conduits or switches, set up some sort of barrier to protect you from touching them accidentally.
5. Always hold the probe so the disc barriers are closer than your hand to any high-voltage point. Do not extend your fingers over the disc barriers. Keep your hand closed around the probe handle, and away from all high-voltage points. High voltage may discharge from point-to-point or point-to-air (corona).

Fig. 2-14. A color TV interlock "cheater" permits HV measurements with the back removed. (Courtesy of Walsco Electronics Manufacturing Co.)

6. Measure the high voltage at the second-anode terminal of a cathode-ray tube. Most TV receivers have a current-limiting resistor which restricts the power at this terminal.
7. Never depend on the insulation of a high-voltage wire for protection.
8. When you are working on defective equipment, it is wise to remember that high voltages may show up in unexpected places. If a bleeder is open, a capacitor may remain highly charged, even after the equipment has been turned off. If the current-limiting resistor is shorted, the second-anode terminal of the cathode-ray tube will be a low-resistance, high-power source.
9. If the cathode-ray tube in the equipment under test has two coatings (which are used as a capacitor), keep in mind that these coatings discharge slowly.
10. Do not use a screwdriver to discharge filter capacitors. A grounded chain or wire at the end of a long *Bakelite* rod is recommended instead.
11. For continued safety, always keep the inside and outside of the probe absolutely free from dirt, grease, or moisture. Before using the probe, disassemble it to release the cable and multiplier resistors. (The multiplier resistor is fragile. Do not drop it on a hard surface or otherwise mar its surface.) Wipe the resistor and the outside of the probe with a soft, dry cloth to remove any moisture and dirt. The interior of the probe can be dried with a narrow bottle brush. One suggestion for storing and carrying the high-voltage probe is to keep the multiplier resistor in a toothbrush case lined with a soft, dry cloth. The disassembled probe can be stored in a small carrying bag.

For absolutely safe high-voltage measurements, the following sequence is suggested:

1. Turn off the equipment to make sure there will be no high voltage at the measurement point.
2. Connect the high-voltage probe to the meter to be used, and set the meter to the required scale.
3. Connect a ground lead between the equipment under test and the meter.
4. Attach the probe to the high-voltage point *while the equipment is still turned off*.
5. Turn the equipment on and read the meter; then turn the equipment off.
6. Be sure the high voltage has been dissipated before removing the probe.
7. Before checking a transformerless television receiver with an AC-powered VTVM, be sure the meter case or negative terminal is at the same potential as the TV receiver B—. The meter ground, if connected to the TV receiver, could be the "other side" of the power line. If so, a short circuit will take place. For this reason, it is advisable to use an isolation transformer with the VTVM when this type of receiver is checked. No isolation transformer is needed with a VOM or a battery-operated VTVM, however.

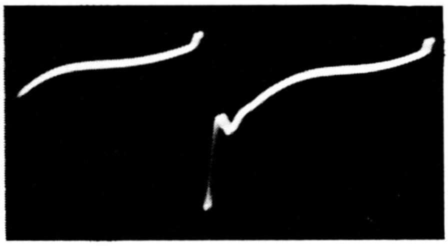
Chapter 3

LOW-CAPACITANCE PROBES

MOST oscilloscopes, VTVM's, signal tracers, distortion analyzers, and frequency meters or counters have a comparatively high input resistance. They also have a certain amount of shunt capacitance, which will not be detrimental when used for measuring in low-impedance circuits. However, severe distortion may occur in high-impedance, high-frequency circuits, such as sync and video-amplifier circuits. Even a slight degree of loading may produce erroneous indications. With a low-capacitance probe (also known as a high-impedance or attenuation probe), the sync pulses can be followed from the take-off point to the horizontal and vertical oscillators without disturbing the synchronization of the receiver. This probe is also useful for signal-tracing and checking the signal levels through various stages of video amplifiers, because it does not contribute excessive shunt capacitance across the peaking coils to disturb the operation of the circuit. Signal levels can be observed at both the grid and the plate circuits without upsetting the circuit operation.

The low-capacitance (low-C) probe is also useful for checking the waveforms in horizontal-AFC circuits. Proper waveshapes at the various test points are usually given on TV schematics and in service manuals. Since a low-C probe will not load the circuit, the scope indication will be a truer representation of conditions within the circuit. The signal observed may now be compared with the one shown in the service literature.

(A) Waveform without the probe.



(B) Waveform with the probe.

Fig. 3-1. Effect of a low-capacitance probe on waveform indications.

The grid-leak resistor in the vertical-blocking oscillator may have a value as high as 10 megohms, and the waveform at the grid will be sharply spiked. Therefore, any high-frequency content in this waveform could easily be lost if a direct scope connection were made at the grid. However, if a 10:1 low-C probe were used, the capacitance across the circuit under test would be reduced to about one-tenth the value it would be if a direct connection were made. The resultant waveform displayed on the scope will therefore be more accurate, since the circuit loading is greatly reduced. Waveform distortion may occur at the grid of *some* vertical oscillators, even with a 10:1 probe. If so, a 100:1 low-C probe must be used. Fig. 3-1 shows the effect of a low-C probe on a waveform indication.

The shunt capacitance in the vertical-input circuit of an average oscilloscope is approximately 30 to 50 mmf. To this we can add, on the average, another 25 to 50 mmf arising from the use of the test leads. Thus, when we place our test prod at some point within a circuit in order to observe the waveform, we are automatically shunting this point with a capacitance of 55 to 100 mmf. This will have no noticeable effect in some circuits, but in others—particularly where the waveforms under observation contain relatively high frequencies, such as square sync pulses — the additional capacitance will alter the shape of the waveform appreciably. Not only will the waveshape become distorted, but the peak amplitude of the signal will also be reduced. Furthermore, the additional capacitance of the connecting leads, or an instrument having relatively high input capacitance, will detune resonant or tuned high-frequency circuits like the ones in television IF stages.

The input resistance of test instruments is usually high. It may consist of the grid resistance of a tube, or the sum total resistance of a VTVM input-circuit voltage divider, plus the resistance of the isolation resistor. This resistor, as its name implies, isolates the instrument from the circuit under test. That is all well and good if we need just resistive isolation and if the signals are essentialy sinusoidal. If we want to observe signals on an oscilloscope, we may use a small capacitor for isolation, instead of a resistor. That, too, will reduce the input capacitance of the instrument; however, we do not have a known attenuation factor. Let's see what happens if a resistor or capacitor is used alone. We will soon realize that neither will do the job that both can accomplish together.

If, when checking waveforms with a scope, we use an isolation resistor alone in the probe, it and the distributed and input capacitance of the oscilloscope will form a low-pass filter, thereby causing integration to take place. This, of course, results in a rather large attenuation of *higher* frequencies and, therefore, subsequent rounding off of all sharp wavefronts. On the other hand, a series capacitor alone, used to reduce the input capacitance and loading effect, would have to be a small one. The impedance of this capacitor will be quite high, however, compared with the input resistance of the oscilloscope. Therefore, this combination—the series capacitor and input resistance — will form a differentiating network (high-pass filter), resulting in attenuation of the *lower* frequencies. If we now combine a series resistor and a capacitor of the proper value to get not only low shunt capacitance, but also frequency compensation *and* a known attenuation ratio, we will have accomplished what we set out to do. Fig. 3-2 illustrates the basic circuit for such a probe, in which a low-value, semi-variable capacitor and a shunt resistor are encased in a special housing. The reduction in shunt capacitance takes place because the added capacitor (approximately 5-15 mmf) is actually placed in series with the 80 to 100 mmf from the connecting cable and the vertical-amplifier input circuit. This added capacitance reduces the effective over-all capacitance to a little less than the 5- to 15-mmf—certainly a marked improvement over the 80 mmf or so present before the probe was added. There is, however, one disadvantage to this arrangement: the voltage actually reaching the vertical amplifier of the scope is

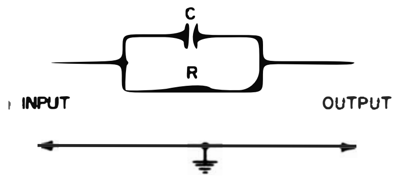


Fig. 3-2. Basic circuit of a low-capacitance probe.

reduced in the same proportion as the input capacitance. Thus, if the total input capacitance is decreased by one-tenth, so is the signal voltage reaching the scope. In television service work, the low-C probe is usually used for observing waveforms in circuits which have sufficient voltage to offset this loss, such as the video-amplifier, sweep, and sync stages.

Let us look at a simplified diagram (Fig. 3-3) in order to understand the operation of a low-capacitance probe. Since the probe is always used with a shielded lead, the capacitance of the shielded cable (C_C in Fig. 3-3A) and the input capacitance of the instrument are added together. This total capacitance (which we will call C_I) is shunted by the input resistance (R_I) of the instrument. The resistor in the probe is called R_P, and the probe capacitance, C_P.

The signal under test is applied between terminals A and B. The equivalent circuit in Fig. 3-3B shows we now have a voltage divider consisting of two resistors shunted by two capacitors.

The low frequencies divide across R_P and R_I in *direct proportion* to their resistance, and the high frequencies divide across C_P and C_I in

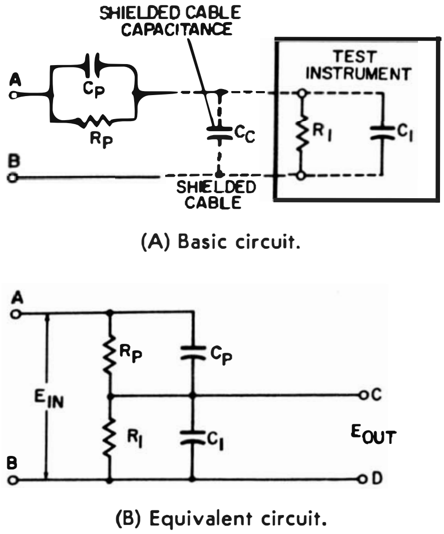


Fig. 3-3. Operation of the low-capacitance probe.

inverse proportion to their capacitance or in *direct proportion* to their capacitive reactance. The voltage division is constant from DC up into the RF range. The attenuation factor is very easily calculated, as we will soon see. Essentially, the probe increases the input impedance of the test instrument and, at the same time, attenuates the input signal. The attenuation factor can generally be compensated for by simply adjusting the vertical-gain control of an oscilloscope for greater deflection, provided the signal under test is of sufficient amplitude. We have, however, gained the advantage of reducing or eliminating waveshape distortion, which would normally occur if there were no low-C probe.

In order for the probe to be properly compensated for at all frequencies, the following relationship must hold true:

$$C_P R_P = C_I R_I$$

where,

C_P is the probe capacitance,
R_P is the probe resistance,
C_I is the input capacitance (cable plus oscilloscope),
R_I is the input resistance of the oscilloscope.

The amount of attenuation experienced from using the low-C probe is given by the following formula:

$$A = \frac{R_P + R_I}{R_I}$$

$$A = \frac{X_{C_P} + X_{C_I}}{X_{C_I}} = \frac{C_P + C_I}{C_P}$$

Now suppose we have an oscilloscope with an input resistance of 500,000 ohms and an input capacitance of 25 mmf. Using a two-foot coaxial cable with a capacitance of 10 mmf per foot between the probe and the oscilloscope will add 20 more mmf. Therefore, the effective input capacitance of the scope will now be 45 mmf. Let us see what the values of R_P and C_P would have to be to provide an attenuation factor of 10-to-1.

$$R_I = 500K$$

$$C_I = 45 \text{ mmf}$$

$$\text{since } A = \frac{R_P + R_I}{R_I}$$

$$\text{then } R_P = R_I (A - 1)$$

therefore,

$$R_P = 500{,}000\ (10 - 1)$$

$$= 500{,}000 \times 9$$

$$= 4.5 \text{ megohms}$$

We need a probe resistor of 4.5 megohms for an attenuation factor of 10-to-1. Now, what will C_P have to be?

$$\text{since } A = \frac{C_P + C_I}{C_P}$$

$$\text{then } C_P = \frac{C_I}{(A - 1)}$$

therefore,

$$C = \frac{0.000045 \text{ mfd}}{10\text{-}1}$$

$$= \frac{0.000045 \text{ mfd}}{9}$$

$$= 5 \text{ mmf}$$

Thus, we need 5 mmf for the probe capacitor. What must we do to make this probe practical to construct? A 4.5-megohm resistor is quite easy to obtain. However, as far as the capacitor is concerned, there are several problems. First of all, the input capacitance of the oscilloscope may vary by 20% or more from the manufacturer's specifications. Moreover, the cable capacitance may also vary by the same percentage. We also have to take into account a little distributed capacitance here and there. So, from a practical point of view, a small adjustable ceramic or mica trimmer capacitor between 3 to 30 mmf can be used. Its exact value is not important since it will be adjusted anyway. However, its lowest value must always be lower than the calculated probe capacitance; and its adjustment range is expected to compensate for other distributed capacitances in the circuit.

Not only does the low-C probe raise the input capacitance and reduce the input signal by the same attenuation factor, but it also attenuates any DC component in the circuit under test. In doing so, it reduces the DC voltage stress across the series blocking capacitor in the input circuit of AC oscilloscopes (some of which have either AC or DC inputs). In a DC scope or at the DC input setting on an AC-DC oscilloscope, this blocking capacitor is not in the circuit, of course.

Frequency compensation of a low-C probe is best accomplished with a square-wave generator. The trimmer in the probe is adjusted for best square-wave reproduction at 20 and 20,000 cps. Several adjustments should be made by alternately switching back and forth between 20 and 20,000 cps. Usually, a satisfactory compromise adjustment can be made after a few tries. If a square-wave generator is not available, an audio sine-wave generator will do. Adjust the probe trimmer for a sine wave of equal amplitude (or a compromise) at 20 and 20,000 cps. Repeat the adjustment several times as before.

A *properly* operating television receiver can also be used in adjusting the low-C probe. Apply the probe at the grid or cathode of the picture tube (depending on which elements are fed from the video-output stages), and observe the composite video signal on the oscilloscope. Then adjust the capacitor in the probe until the equalizing and vertical-sync pulses have the same peak amplitude, and observe the horizontal-sync pulses for proper shape (set the oscilloscope sweep rate at 15,750 cycles). The trimmer capacitor in the probe can again be slightly adjusted, if necessary, so the horizontal-sync pulses will have the least rounding and tilt.

In many instances the frequency response of a particular oscilloscope is so narrow that the higher frequencies are attenuated. Thus, when a composite video signal is viewed (the higher frequencies in this instance), the horizontal-sync (15,750 cps) and equalizing pulses (31,500 cps) are not amplified as greatly as the low-frequency vertical pulses (60 cps). Never forget that the frequency characteristic of the scope presentation can be only as good as the response of the scope before the probe was added.

A low-C probe should not be used when the full sensitivity rather than the wide-band response of an oscilloscope is required—for example, in tracing and locating hum. Instead, a direct probe made of ordinary shielded cable is preferred.

Fig. 3-4 shows the proper way to check the response of a video amplifier with a low-C probe. If we want to observe the video signal at the picture tube, it is advisable to disconnect the picture tube so the circuit will not be disturbed by the

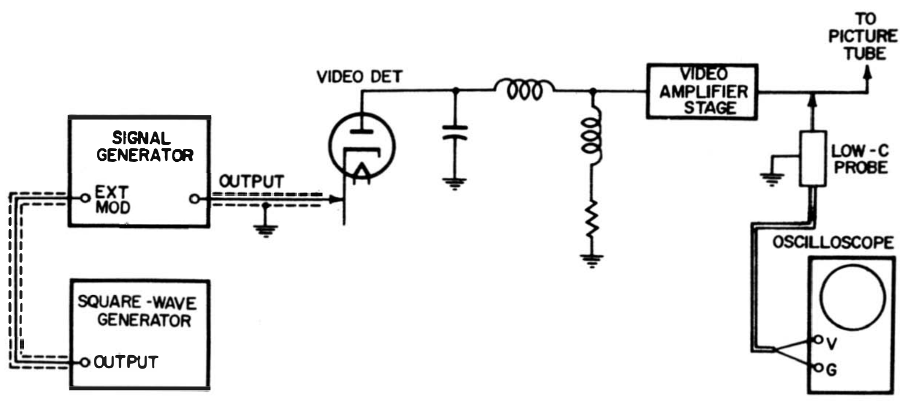


Fig. 3-4. Test setup for checking the response of a video amplifier with a low-C probe.

slight capacitance added by the probe. By unplugging the picture-tube socket, we have actually substituted the input capacitance of the probe for that of the picture tube.

Insufficient vertical-amplifier bandwidth in oscilloscopes with no peaking coils can be improved by adding a small damped peaking coil in the probe, as shown in Fig. 3-5. The value of the coil will fall somewhere between 150 and 300 microhenrys — depending on the distributed capacitance in the probe, cable, and scope. Several values of inductance should be on hand; the proper one is determined experimentally. Damping resistor R_2 in Fig. 3-5 reduces the Q of the coil to provide a broader peak and thus an essentially flat over-all frequency response. Its exact value can be anywhere from 5,000 to 10,000 ohms.

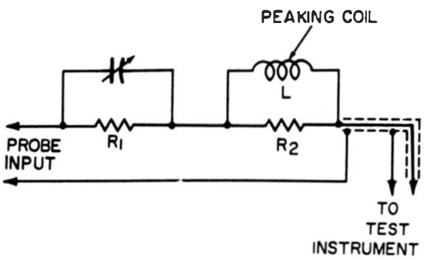
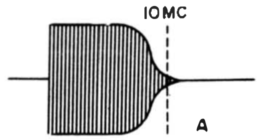
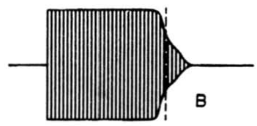


Fig. 3-5. A low-C probe with peaking coil added to help compensate for insufficient vertical-amplifier bandwidth in some oscilloscopes.

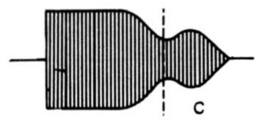
In order to determine the best value for L, apply the output from a video sweep generator to the probe, and observe the undemodulated response curve on the oscilloscope. Fig. 3-6 shows the effect of the peaking coil on the response curve. Try several values of L for best response, and adjust the trimmer capacitor in the probe for the flattest output. Use the smallest possible inductance consistent with a good response curve. Of course, the output of the video sweep generator must be flat. (This can be quickly checked with a demodulator probe.) It is therefore desirable to use a cable with the lowest possible shunt capacitance, because the cable itself adds a substantial amount. The lower the instrument and cable capacitances, the smaller the compensating capacitor can be, with a consequent reduction in the shunting capacitance of the probe.



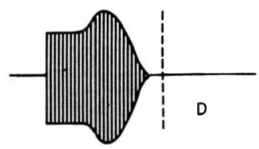
(A) Without peaking coil.



(B) With proper peaking-coil inductance.



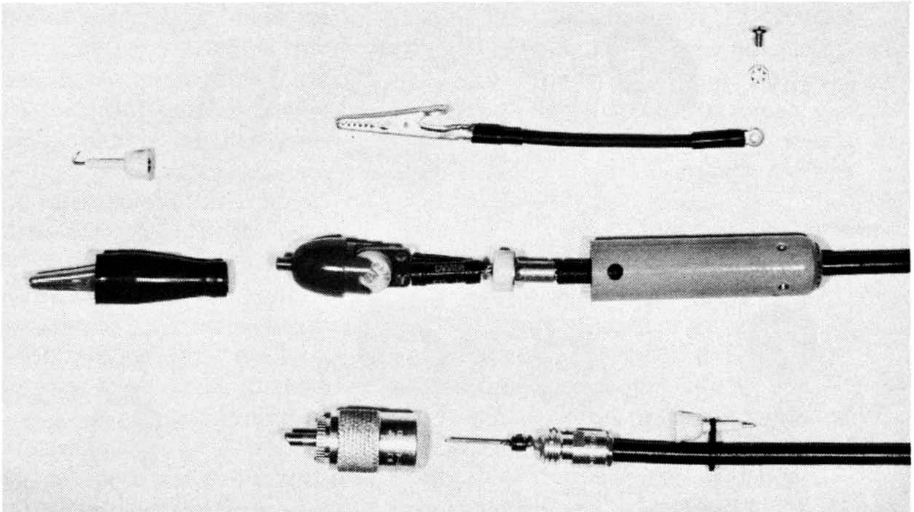
(C) Inductance of peaking coil too low.



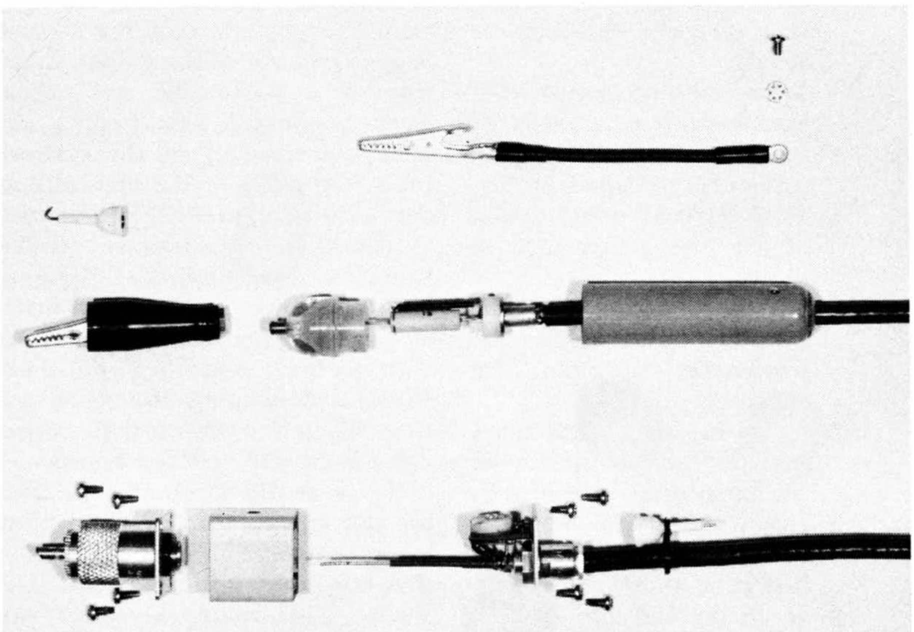
(D) Inductance of peaking coil too high.

Fig. 3-6. Effect of peaking-coil inductance on the response curve.

A set of five low-capacitance probes is made by Tektronix, Inc. The attenuation ratios available are 5:1, 10:1, 20:1, 50:1, and 100:1. Fig. 3-7A shows the construction of the probe and connector for the 5:1, 10:1, and 20:1 probes. Although the part values differ for each ratio, the construction is the same. Fig. 3-7B shows the construction of the 50:1 and 100:1 probes and connectors. Notice that the calibrating capacitors for the 50:1 and 100:1 probes are in a



(A) The 5:1, 10:1, and 20:1 assembly.



(B) The 50:1 and 100:1 assembly.

Fig. 3-7. Internal construction of a commercial low-capacitance probe. (Courtesy of Tektronix, Inc.)

terminal box at the opposite end of the probe cable.

HOW TO MAKE YOUR OWN LOW-CAPACITANCE PROBE

Fig. 3-8 shows the details for constructing a probe.

Parts Required

1 tube socket.
1 ceramic trimmer capacitor (7-45 mmf).
2 tube shields.
1 resistor (100K ±10%, ½W).
1 resistor (1 meg ±10%, ½W).

5 ft. of RG/59 coax cable.
1 finishing nail (1¼ in. long).
1 rubber grommet (should fix coax snugly).
1 wire (8 inches long).
1 alligator clip.

Construction Procedure

1. Bend the tube-socket wiring lugs back until they touch the socket mounting ring.
2. Wire the 1-meg resistor across the capacitor lugs, and insert one end into the tube-socket center shield. Solder in place.
3. Wire the 100K resistor from the other end of the 1-meg resistor to one of the tube-socket lugs at the loop, as shown.
4. Wire the coax center conductor to the junction of the 1-meg and 100K resistors and the capacitor lug.
5. Wire the coax shield to one of the tube socket lugs, as shown.
6. Slip the tube shield over the assembly, and solder to the tube-socket mounting ring, as shown.
7. Insert the rubber grommet into the hole at the top of the remaining tube shield.
8. Insert the shield over the coax cable, and solder to the first tube shield, as shown.
9. Insert the nail into the center shield of the tube socket, and solder.
10. Drill a hole in the shield, opposite the adjustment screw of the ceramic trimmer capacitor.
11. Cement the grommet to the tube shield. Let dry overnight.
12. Solder the 8-inch wire to the tube shield. Connect the alligator clip to the other end, to serve as a ground lead connection.

The input resistance of an oscilloscope can be easily measured in the following manner. First be sure any DC blocking capacitor in the input circuit (Fig. 3-9A) is either shorted or switched out of the circuit. Then connect a low-voltage AC signal (such as the 6.3 volts from a filament transformer) to the vertical-input terminals of the oscilloscope, and adjust the vertical-gain control to obtain nearly full-screen deflection or an even number of divisions. Now disconnect one lead and insert a 3- to 5-meg potentiometer in series with the lead, as shown in Fig. 3-9B. Without disturbing the scope setting, adjust the pot until the signal deflects exactly half the number of divisions it did originally. Remove the pot and measure with an ohmmeter that portion of the resistance that was inserted in the circuit (Fig. 3-9C). The value measured will

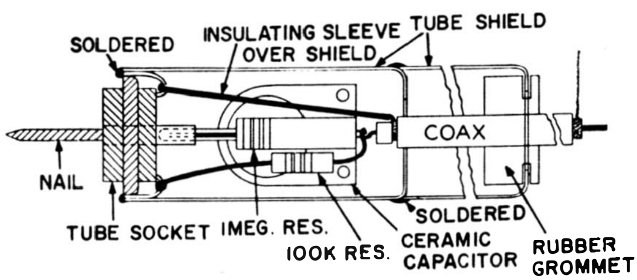
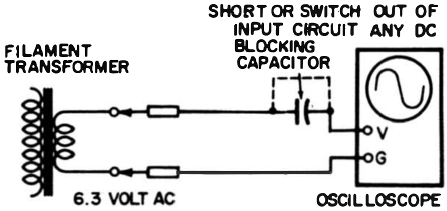
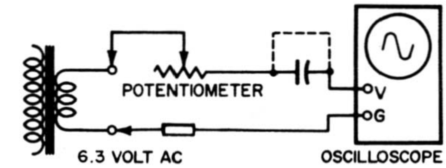


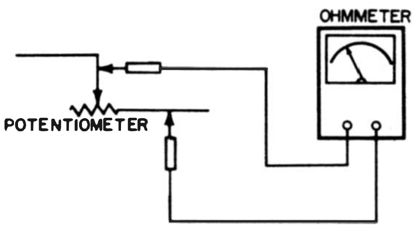
Fig. 3-8. Constructing a low-capacitance probe. (Courtesy of Philco Corp.)



(A) Short DC blocking capacitor (if used) and connect signal source to scope.



(B) Place potentiometer in series with scope vertical-input lead.

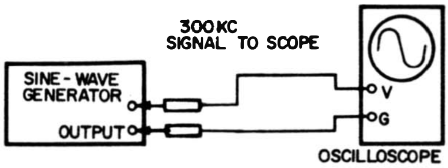


(C) Measure resistance across potentiometer.

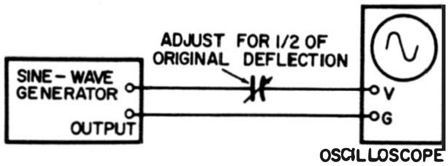
Fig. 3-9. Measuring the input resistance of an oscilloscope.

equal the input resistance of the scope.

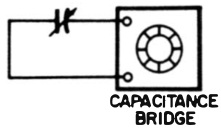
In order to measure the input capacitance of the oscilloscope, we proceed as follows: First, set the scope vertical attenuation to the position at which we wish to measure the capacitance. Apply a 300-kc AC signal (Fig. 3-10A), and note the deflection. Now disconnect one scope lead and add a small adjustable capacitor (around 100 mmf or so) in series with the lead, as shown in Fig. 3-10B. Try various values, or a trimmer in parallel with a fixed capacitor. The value giving exactly one-half the deflection, when the signal was directly connected to the input circuit, is equal to the input capacitance of the scope. Determine the amount of capacitance with a



(A) Apply a 300-kc sine wave to vertical input of oscilloscope.



(B) Place an adjustable capacitor in series with scope vertical-input lead.



(C) Measure capacitance with a bridge.

Fig. 3-10. Measuring the input capacitance of an oscilloscope.

capacitance bridge (Fig. 3-10C). Be sure the level of the signal stays constant during this test.

Probe attenuation can be checked by applying a 1,000-cps sine wave to the vertical-input terminals, and adjusting the scope deflection to a convenient number of divisions as close to full-scale deflection as possible. Now connect the probe to the scope terminals, and apply the same 1,000-cps signal voltage to the probe. This time the deflection will cover a much smaller number of divisions. Divide this number into the one previously obtained. The result is the probe attenuation factor. For example, if there were 40 divisions of vertical deflection without the probe and now, with the probe, only 4 divisions, the probe attenuates 40 divided by 4, or a factor of 10. Frequency compensation must be made, of course, as outlined before.

To review briefly, there are three distinct advantages of a low-capacitance probe.

1. The input impedance is kept high.
2. The input impedance is known and can therefore be reckoned with because it does not depend on the lead or proximity to ground.
3. Pickup of extraneous signal is reduced to a minimum because a shielded lead is used.

CATHODE-FOLLOWER PROBES

Cathode-follower probes provide another means of offsetting the loading effect of an instrument on high-impedance circuits. A cathode follower is a high-impedance input–low-impedance output device which exhibits excellent frequency response.

In order for high-frequency waveforms in high-impedance circuits to be measured or observed with any degree of success, the input impedance of that measuring device must be considerably higher than that of the circuit point being measured.

All measuring instruments affect, even if only to a small degree, the circuit to which they are connected. This disturbance becomes more noticeable in high-impedance circuits. The ideal measuring device would require absolutely no energy from the circuit under test. In order to approach this ideal condition, we endeavor to make the input impedance of the instrument as high as possible—which, of course, would require the shunting resistance to be high and the shunt capacitance quite low.

One of the problems in measuring voltages with a high-impedance voltmeter or oscilloscope in high-impedance audio and video circuits is the effect of test-lead capacitance. Shielded test leads are usually necessary to prevent hum pickup, but their shunt capacitance may seriously load the circuit under test—even as high as 100 mmf or more. At 15 kc, this represents a reactive loading of about 100,000 ohms—a very appreciable amount, even across a one-half megohm circuit.

An average oscilloscope, together with its shielded cable, offers a circuit load of about 2 megohms shunted by around 125 mmf. An RC-type low-C probe can be constructed by the methods outlined earlier in this chapter. However, for proper compensation we must take into account the position of the vertical-gain control.

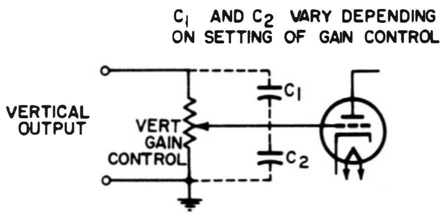


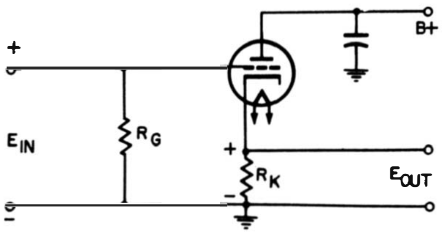
Fig. 3-11. High-impedance uncompensated gain-control circuit used in some oscilloscopes.

Some of the more inexpensive oscilloscopes have uncompensated vertical-input circuits like the one in Fig. 3-11, in which the input capacitance varies with each setting of the vertical-gain control. Thus, it is not practical to use a low-C probe at any but the one setting for which it has been calibrated. On the other hand, a cathode-follower type low-C probe overcomes this problem and, in addition to its other advantages, is the only practical probe that can be used with an oscilloscope having an uncompensated vertical-gain control.

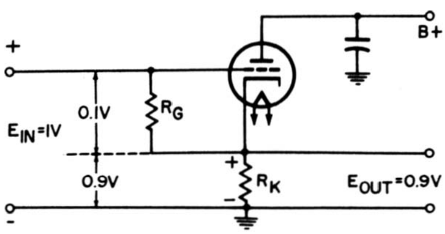
A cathode follower resembles an RC-coupled amplifier, except that the output is taken from the cathode instead of the plate circuit. The basic circuit of a cathode follower is shown in Fig. 3-12A. Notice that the grid resistor (R_g) goes directly to ground.

When a signal is applied, the plate current changes in step with the control-grid–to–cathode voltage. Since the plate and cathode currents are the same, the cathode current also changes when the plate current changes, reproducing the input signal across the unbypassed cathode resistor (R_k). The output signal, which is taken from across R_k, has the same phase as the applied signal.

Since the cathode return is also part of the grid-cathode circuit, the output voltage across the unbypassed



(A) Grid resistor connected to ground.



(B) Grid resistor connected to cathode.

Fig. 3-12. Basic cathode-follower circuit.

resistor (R_k) is opposed by part of the input voltage. As a result, negative feedback and degeneration are introduced. The voltage developed across R_k can never be equal to (or greater than) the applied voltage. Thus, the cathode follower has a gain of less than unity. We have a high input impedance at the input of the circuit, but a low impedance at the output. No voltage gain is derived, although the circuit does have a large power gain.

Fig. 3-12B shows a slight modification of the cathode-follower circuit. The input resistor (R_g) is now returned to the cathode. This connection makes it possible for a higher value of cathode resistor to be used and, consequently, a signal of greater amplitude to be applied.

To understand how a cathode follower works, assume we have an input signal of one volt applied between the grid and ground (the input terminals of the probe). The output voltage is taken across cathode resistor R_k. Because grid resistor R_g is connected to the cathode and not to ground, it is in series with the cathode resistor. Consequently, we have a current amplifier with a voltage gain of somewhat less than 1. For ease of understanding and for the sake of illustration, let us assume the voltage gain is 0.9. Therefore, with an input signal of 1 volt, we will get an output signal of 0.9 volt.

If we apply a 1-volt signal of such polarity that the grid is positive, the cathode current through R_k will immediately increase, making the cathode more positive with respect to ground. Thus, as the grid goes positive, so does the cathode. The cathode voltage changes in phase with the input voltage. The voltage across cathode resistor R_k will approach the input voltage. As we said before, for ease of understanding we shall assume a gain of 0.9 for the circuit. Thus, only 0.1 volt remains across the grid resistor, which therefore looks 10 times as large as it actually is. For example, with a 10-megohm grid resistor, the input resistance of the probe will be 10 times as much, or 100 megohms.

The input resistance of circuit B is equal to $R_g \div 1\text{-}A$, where A is the gain of the circuit. If the gain is 0.95 and R_g is still 10 megohms, R_{in} will be 200 megohms.

With good design, the gain of a cathode follower can be made as high as 0.98—which, of course, would greatly increase the input resistance. Theoretically, if the gain could be made exactly 1—in other words, if the output signal (the one across R_k) would be exactly equal to the input signal—the input resistance would be infinite.

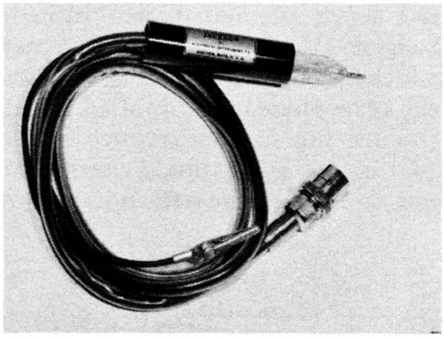
In the circuit in Fig. 3-12A, the input resistance is equal to the value of the grid resistor. Because of the large amount of inverse feedback, the output impedance is only a few hundred ohms. So, we can feed our output signal to an oscilloscope or VTVM through a shielded lead, without running into pickup problems or undue attenuation of high-frequency signals.

A cathode-follower probe is also suitable for use with an AC VTVM. However, the gain of the probe, being somewhat less than 1, must be taken into account when voltage readings are made.

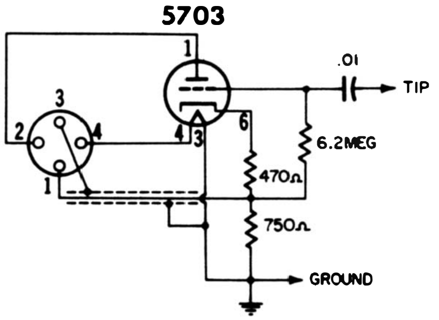
Another very favorable advantage of a cathode follower is that the capacitance between the grid and cathode circuits is also decreased by a factor of 1 minus A. Thus, for a gain of 0.9 we are left with only one-tenth the grid-to-cathode capacitance. The only other capacitance left is grid-to-plate, which accounts for about half the total input capacitance.

Sometimes it is advisable to use a cathode-follower probe ahead of a demodulator probe if circuit impedances are so high the demodulator probe alone would present greater loading than can be tolerated. The cathode-follower probe can thus "pick off" the signal and convert it to a low-impedance level without too much loss—at which time the demodulator probe takes over.

Now, for some practical circuits. Some oscilloscope and VTVM manufacturers have provided for a cathode-follower type of low-C probe, in which the required supply voltages are furnished by the test equipment being used. The Jackson Model LC 2-1P probe in Fig. 3-13, is designed for an oscilloscope equipped with a connector to provide the necessary



(A) The probe.



(B) Probe circuit.

Fig. 3-13. Jackson LC-2-1P cathode-follower probe. (Courtesy of Jackson Electrical Instrument Co.)

filament and plate voltages. This connector also carries the cathode-follower output signal to the vertical-input circuit of the oscilloscope.

A .01-mfd blocking capacitor in the grid circuit allows AC measurements to be made in circuits where both AC and DC are present. The maximum signal voltage that can be applied to this probe is 25 volts peak-to-peak, and the maximum DC level at which measurements can be made is 500 volts. The input impedance of the probe is 6.2 megohms, shunted by 8 mmf. A 5703 submini-

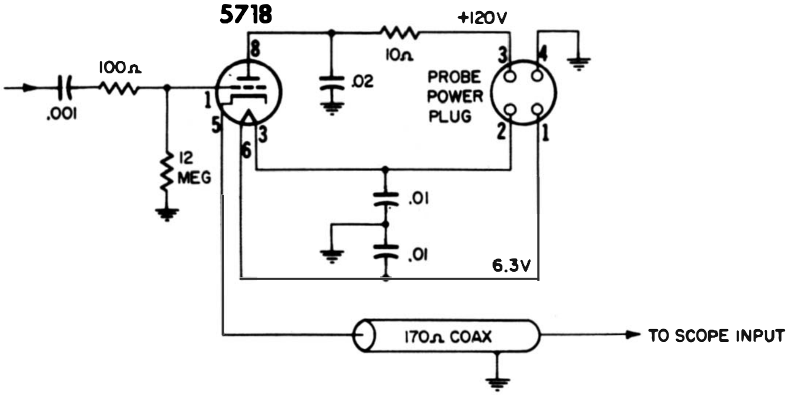


Fig. 3-14. Schematic of the Tektronix P170-CF cathode-follower probe.

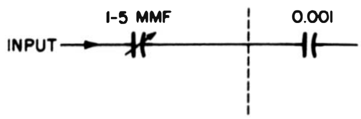
ature tube is used in the cathode-follower circuit, and the probe has an attenuation ratio of 2 to 1 – lower than the ratios of the RC-type low-C probes discussed previously.

Another cathode-follower probe is the Tektronix P170-CF shown schematically in Fig. 3-14. The three attenuator circuits used with it are shown in Fig. 3-15. This probe, when used without attenuators, also has an attenuation factor of 2-to-1. It is designed for a maximum signal input of no more than ±2 volts peak for undistorted output. Available are variable attenuator heads that screw onto the head of the probe (Fig. 3-16) and are adjustable by means of a screwdriver adjustment in the nose.

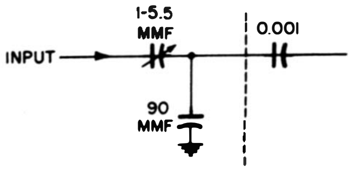
A maximum signal of ±6 volts may be applied at a minimum setting of the first attenuator (Fig. 3-15A). For an attenuation ratio of 20 or over, the input signal may be increased to ±20 volts with the second attenuators (Fig. 3-15B). If we use the third attenuator (Fig. 3-15C), which gives a minimum attenuation of 200, a maximum input signal of ±200 volts may be applied.

This probe is used with a Type 517 oscilloscope, which has provisions for supplying the plate and filament voltages required for proper operation of the 5718 tube in the probe.

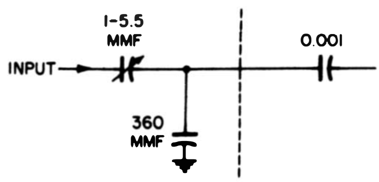
Note that there is no cathode resistor in the probe. The cathode follower depends on the termination of



(A) Attenuator 1.



(B) Attenuator 2.



(C) Attenuator 3.

Fig. 3-15. Attenuators used with the cathode-follower probe in Fig. 3-14.

the coaxial cable to complete its cathode circuit to ground. When the probe is used with the Type 517 oscilloscope, the cathode resistor of the tube is the 170-ohm input termination of the preamplifier grid line

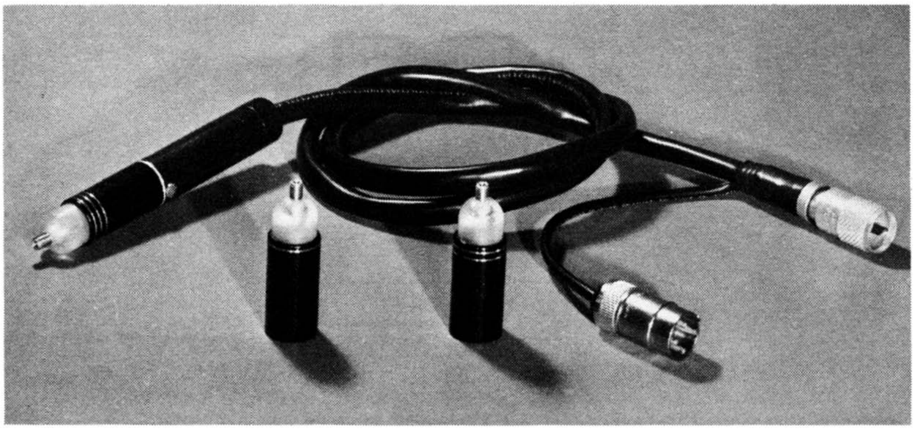


Fig. 3-16. The P170-CF cathode-follower probe and the various attenuators. (Courtesy of Tektronix, Inc.)

in the scope. With any other oscilloscope, however, a suitable 170-ohm termination resistor must be connected across the vertical-input terminals of the scope. For proper matching, the output signal from the cathode follower is fed through

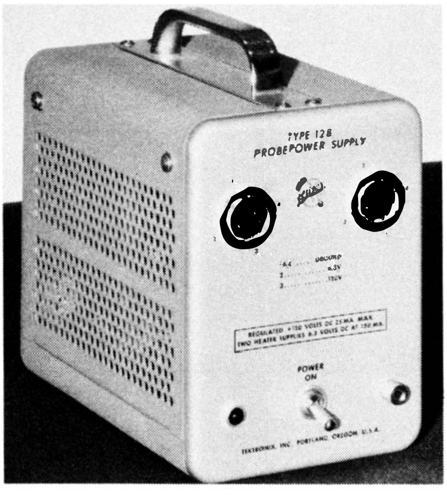


Fig. 3-17. A probe power supply. (Courtesy of Tektronix, Inc.)

the coaxial cable, the characteristic impedance of which is also 170 ohms. If the instrument has no plate and filament voltages, a source of low-ripple 120-volt B+ and 6.3-volt filament voltage (150 milliampere; preferably DC) must be made available. A power supply suitable for operating two of these probes is shown in Fig. 3-17.

A mathematical analysis would show that a cathode follower with a capacitive load in a cathode circuit exhibits a negative-resistance component (conductance) at certain frequencies. For example, the probe circuit in Fig. 3-14 exhibits conductance between approximately 2.5 to 12 megacycles, its greatest value being somewhere between 7 and 8 megacycles. Therefore, in an inductive or tuned circuit that resonates between 2.5 and 12 megacycles, we may experience an apparent increase in the Q of the circuit. If the circuit losses are sufficiently low, the application of the probe may cause oscillations, similar to the way a Colpitts oscillator operates. Such difficulties can generally be overcome by inserting an isolation resistor of several thousand ohms at the probe tip.

Always remember, when using a cathode-follower probe, that the output-signal level will contain a DC component of several volts. Therefore, if there is no DC blocking capacitor, one must be inserted in the input circuit of the oscilloscope. When an AC-DC scope is employed, the switch should be in the AC position.

If no cathode-follower probe is at hand, one can be very easily constructed for checking equipment when a filament and plate voltage source is readily available. This might happen while we are servicing a television receiver and want to make observations on an oscilloscope, but have neither a low-C nor a cathode-follower probe handy. Fig. 3-18 shows the circuit of a cathode-follower probe that can be easily assembled because it contains only a few parts.

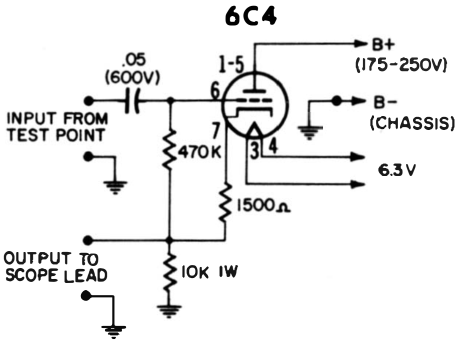


Fig. 3-18. An easily constructed cathode-follower probe.

The filament and plate voltages for this probe are taken from the receiver with which it is used. Signals up to 75 volts peak-to-peak can be applied to this cathode follower. Higher ones should be attenuated before they are applied to the probe, or else they can be directly applied to the vertical-input terminals of the oscilloscope.

Chapter 4

RECTIFIER PROBES

RECTIFIER probes are added to voltmeters to enable the measurement of RF, IF, and video frequencies. Normally they increase the input resistance and decrease the input capacitance of the meter.

VTVM's are essentially DC indicating devices. The most common is the two-tube bridge type (shown schematically in Fig. 4-1), in which a potential unbalance due to application of a voltage to one of the grids causes a difference of potential between the two cathodes. This, in turn, sends a current through the meter.

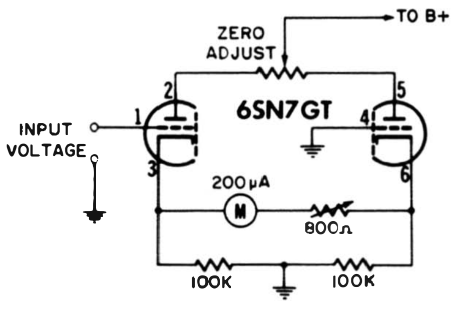
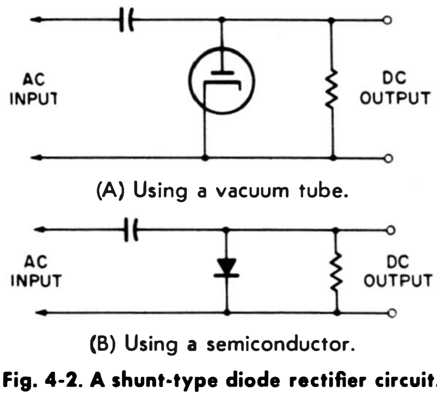


Fig. 4-1. Basic circuit of a vacuum-tube voltmeter.

The DC scales of the meter are linear, but a linear AC scale would also be desirable. Therefore, a linear rectifier is needed, the DC output of which is directly proportional to the applied AC voltage.

A vacuum-tube or semiconductor diode in the probe furnishes this rectification. Although both types of diodes serve the same purpose, each has its advantages and drawbacks. The waveform, frequency, and amplitude of the voltage being measured determine the selection.

If we are interested in measuring the peak value of a signal, the VTVM must have a half-wave peak-indicating rectifier preceding its voltage-divider input circuit. The scale of the VTVM is then calibrated to read peak AC voltage.



(B) Using a semiconductor.

Fig. 4-2. A shunt-type diode rectifier circuit.

The rectifier circuit itself may be built into the VTVM, or contained within the probe . . . the operating principle is the same. If the circuit is in the meter, the frequency response is limited to no more than a few megacycles at best. Beyond that, accuracy will drop sharply because of the shunt capacitance from the cable connected to the meter. The most common rectifier circuit, the shunt type in Fig. 4-2, uses either a vacuum-tube (Fig. 4-2A) or semiconductor (Fig. 4-2B) diode.

Some VTVM's contain rectifier circuits which indicate peak-to-peak voltages of all waveforms—including sine waves as well as complex waves and pulses. Peak-to-peak reading VTVM's are particularly useful in the servicing of television receivers because, in addition to the correct waveshape, the service manuals indicate the peak-to-peak voltage values throughout the receiver. Peak-to-peak indicating VTVM's usually have an additional scale showing the rms values of sine-wave signals.

Peak-to-peak indications are obtained by means of a voltage-doubler rectifier circuit which, like the half-

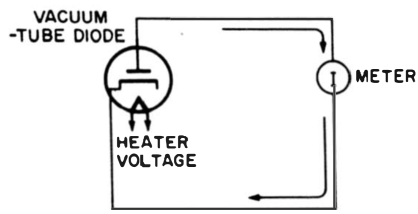


Fig. 4-3. A small current will flow in a diode circuit with only heater voltage applied.

wave rectifier, is built into the instrument or probe. Here again we may use two semiconductor rectifiers or a twin-diode vacuum tube—usually a small high-frequency diode designed for reasonably high voltages, with low plate-to-cathode capacitance.

Some instruments or their probes permit either peak or peak-to-peak indications to be selected by simply flipping a switch.

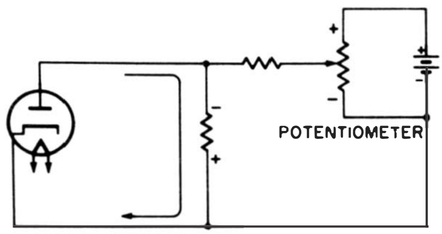
Fig. 4-3 shows a diode with only heater voltage applied. If a meter is inserted in the plate circuit, a small current will flow from cathode to plate, even though no plate voltage is applied.

This current occurs when some of the electrons which leave the heated cathode manage to reach the plate, even though no positive voltage is present there to attract them. Admittedly, the current is indeed small. Nonetheless, if there were a resistor in the plate-to-cathode circuit, a voltage drop would be developed across it.

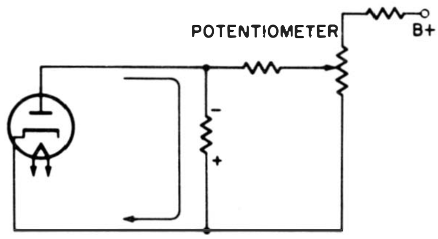
Even if the current is only 25 microamperes, a 20,000-ohm resistor in the plate circuit will produce a voltage drop of one-half volt. This means the plate will now be one-half volt negative with respect to the cathode. Therefore, we would first have to apply one-half volt to the probe—in order to overcome this opposing voltage—before we could get any output indication from the signal under test. Of course, the sensitivity of the probe will then be reduced, particularly at low voltages. We will also get a one-half volt indication on our VTVM, even though there is no applied voltage. This voltage (called contact potential) can be nullified, however, by a bucking (canceling) voltage equal in magnitude but opposite in polarity.

The contact potential of a vacuum-tube diode can be nullified in several ways. The one usually employed in a vacuum-tube voltmeter is to connect one or more dry cells and a potentiometer to the tube in such a manner that we can adjust the pot to deliver a voltage of equal size but opposite polarity to the one developed by the diode. This is shown in Fig. 4-4A. If we want to get away from the problem of replacing dry cells, we can get the same results by tapping a bleeder resistor in the power supply. In Fig. 4-4B, a potentiometer is connected through a voltage-divider resistor to

B+. A small positive voltage (with respect to ground) is developed across the potentiometer, the arm of which is connected to the diode plate through an isolation resistor. By proper adjustment of the potentiometer, we can apply a bucking potential which opposes the contact potential developed by the tube. As long as the diode is operating properly, the potentiometer should need no further adjustment.



(A) By using a battery.



(B) By tapping B+.

Fig. 4-4. Two ways of obtaining a bucking potential.

A third way of neutralizing the contact potential of the diode is to add another diode—either the second half of a twin diode, or a separate tube within the instrument—and use the contact potential of this diode to counteract that of the first. This is explained later in the chapter.

VACUUM-TUBE AND SEMICONDUCTOR DIODES

Although it does have the advantage of being able to handle higher voltages than the semiconductor diode, the vacuum-tube diode requires a filament voltage and a means of compensating for the contact potential it develops. On the other hand, the semiconductor diode not only requires no filament voltage, but also is smaller. Its voltage-handling capabilities are usually limited, but its output may be fed directly to the DC voltmeter—no balancing (bucking) potential is needed.

The plate-voltage — plate-current characteristics of a typical diode tube are shown in Fig. 4-5. Except at the two extremes of the curve, the plate current varies proportionally with the plate voltage. At the

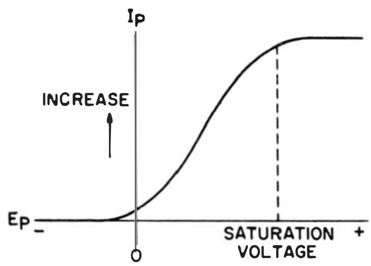


Fig. 4-5. Typical plate-voltage and -current characteristics of a vacuum-tube diode.

top of the curve, the characteristic of a diode is such that any further increase in plate voltage will not proportionally increase the plate current. This point is the saturation voltage of the tube.

It is most desirable for the plate current of the vacuum tube to vary in step with the plate voltage. In this way, when a vacuum tube is used as a rectifier, its output over most of the characteristic curve will be directly proportional to the applied AC signal.

We can avoid the saturation region by limiting the maximum applied voltage to the tube. However, linear output still cannot be obtained at the lower end of the curve when small input voltages are introduced. For this reason, the 1-, 3-,

Table 4-1

Comparison of vacuum-tube and germanium diode characteristics.

Vacuum-Tube Diodes	Germanium Crystal Diodes
Develops contact potential which must be compensated for.	Develops no contact potential.
Emission affected by line voltage.	No such problem.
High-frequency response limited by transit time.	High-frequency response better than for tube.
Maximum input voltage is usually 200 to 500 volts.	Maximum input voltage of most crystal probes is 28 volts peak.
Momentary overload usually doesn't cause permanent damage.	Voltage overload usually destructive.
Is stable over wide temperature range.	Affected by changes in temperature.
Tubes can be easily replaced. Usually no selection, only changing required.	Diodes may have to match meter scale and instrument calibration.
Response becomes very nonlinear below one volt due to curvature of characteristic curve.	More linear response than tube at low voltage levels.

and sometimes the 5-volt ranges are nonlinear on a VTVM containing a vacuum-tube rectifier.

The vacuum-tube diode in a probe should have the lowest possible plate-to-cathode capacitance and the highest possible input resistance, in order to offer a high input impedance to the circuit under test. Special diodes are available which have all the desirable characteristics for use in high-frequency probes. The chart in Table 4-1 compares the characteristics of vacuum-tube and semiconductor diodes.

Semiconductor diodes are very small compared to vacuum tubes. For this reason, the elements do not have much capacitance and series inductance. So, we gain the advantage of a very good frequency response. There are a few commercial probes which, by using the frequency-response characteristic to the utmost, permit measurements in the kilomegacycle range.

Fig. 4-6 shows some vacuum-tube and semiconductor diode symbols and how to identify their polarities.

When an AC voltage is applied across a semiconductor diode, current will flow during one half of each cycle. During the other half the semiconductor diode will present a much higher resistance. This is its *inverse resistance*. The ratio between these two resistances should be at least 1,000:1. In most vacuum tubes, the inverse resistance of around two to ten megohms is so high, compared to the shunt resistance across the circuit, that we can ignore it. In a semiconductor diode, however, it may drop as low as several thousand ohms. Since the inverse resistance and the input circuit of the probe are essentially in parallel, the input impedance of the probe may be seri-

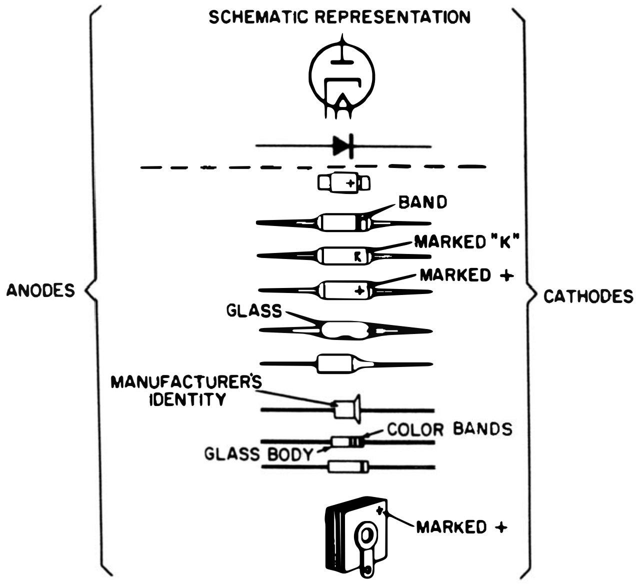


Fig. 4-6. Representations of vacuum-tube, germanium, silicon, and selenium diodes.

ously reduced at low frequencies. (Keep this fact in mind when measuring low-frequency signals with a probe containing a semiconductor diode!)

The characteristic curve of a 1N34 diode (Fig. 4-7) is similar to that of

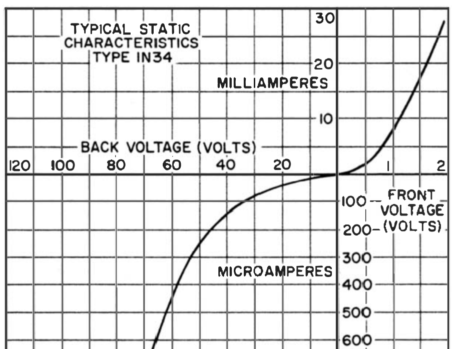


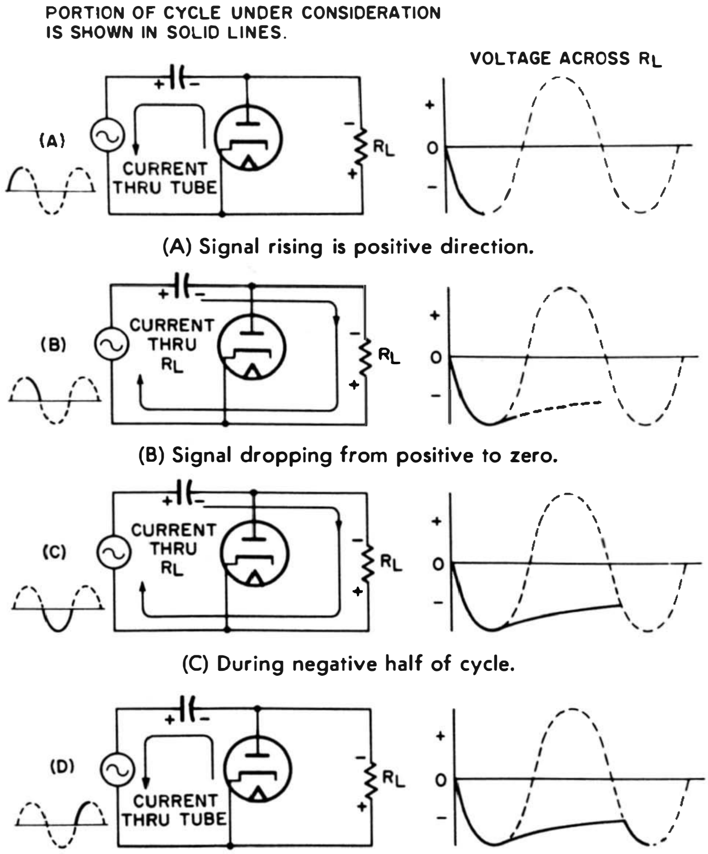
Fig. 4-7. Static characteristics of the 1N34 germanium diode. (Courtesy of Sylvania Electric Products, Inc.)

a vacuum tube at the lower portion, becoming essentially a square-law curve below one volt. Unlike the vacuum tube, however, the semiconductor diode has zero current at zero volts. The reason is that we do not have the contact-potential problem we had with the vacuum tube, since there are no electrons being propelled by thermionic emission.

PEAK-READING, SHUNT-TYPE RECTIFIERS USING VACUUM TUBES

A rectifying probe raises the high-frequency range of the meter being used. The probe functions as an RF detector to provide a rectified output voltage proportional to the peak value of the voltage detected. First, let us discuss the circuit of the peak-indicating, shunt-type rectifier emplaying a vacuum-tube diode. Its DC output is equal to the peak value of either (but not both) half cycles of the applied AC input voltage.

Fig. 4-8 shows the simple circuit for a shunt diode rectifier. It has an AC input voltage (which, for simplicity, we will assume to be a sine wave) and a load resistor, R_L, across which we get our output voltage.



(A) Signal rising is positive direction.

(B) Signal dropping from positive to zero.

(C) During negative half of cycle.

(D) Signal going from zero to positive peak.

Fig. 4-8. Operation of a shunt-type rectifier.

R_L may be split up into two resistors and the output taken across only one of them. For ease of explanation, we will use only one resistor now.

When the input voltage first swings in a positive direction (Fig. 4-8A), the plate of the diode also becomes positive with respect to the cathode. The tube then conducts and thereby acts as a low resistance in parallel with R_L. During the first half of the positive cycle, the increasing positive plate voltage attracts electrons through the tube, to the side of the capacitor connected to the plate. The capacitor is thus charged to the peak value of the applied voltage; the polarity of this voltage is such that the side connected to the plate is negative with respect to the side connected to the input signal. As the voltage drops from its peak value during the second portion of the positive cycle (Fig. 4-8B), the tube does not conduct because its plate is negative with respect to its cathode. Now the tube acts as a high resistance across the circuit, so the capacitor begins to discharge through R_L.

The resistance of R_L, although relatively high, is still lower than that of the tube when not conducting. So the discharge will take place rather slowly and will follow the shape of the standard discharge curve of a capacitor. The time constant of this circuit is made so long that, even at low frequencies (and here, the lower frequency limit is determined partly by the size of the capacitor), very little of the capacitor charge will leak off through the resistor before the current flows through the tube, again recharging the capacitor.

As the input signal passes through zero and into the negative half cycle (Fig. 4-8C), the capacitor will continue to discharge through the resistor. There can be no further conduction through the diode because its plate is still negative with respect to its cathode. The input signal again goes through zero and in the positive direction (Fig. 4-8D). When the input voltage exceeds the level to which the capacitor has discharged through the load resistor, the plate becomes more positive than the cathode and the tube conducts, again charging the capacitor to the peak value.

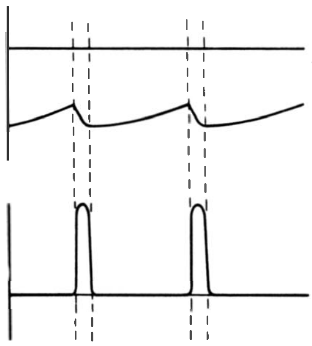


Fig. 4-9. Current pulses through diode after several cycles of input signal have passed.

After the first cycle, the circuit will asume a steady-state condition. The only current will consist of pulses—each lasting only a tiny fraction of a cycle—through the diode during positive peaks of the input signal, as shown in Fig. 4-9. The plate resistance is infinite while the tube is not conducting. This infinite resistance, plus the fact that the load resistor is usually many megohms, is the reason for the extremely high input impedance of the circuit. Any or all of the capacitor charge that leaks off through the load resistor while the tube is not conducting is applied to the VTVM. The voltage drop across R_L is directly proportional to the charge on the capacitor. Therefore, the DC voltage output is a direct indication of the peak value of one-half cycle of the applied AC voltage.

In addition to functioning as a charging capacitor for the rectifier circuit, the input capacitor also blocks any DC, to prevent it from reaching the diode. Therefore, measurements can be made at the plates and grids of vacuum tubes, where a DC voltage also accompanies the AC signal.

Because of the way the diode is connected in Fig. 4-8, the meter indication will be proportional to the positive peak voltage of any signal applied. The diode will conduct during the positive half cycle only; there will be no conduction during the negative half cycle, regardless of any excursion in that direction. If we ground the plate and connect the cathode to the capacitor, we will get an indication during the negative peak value of the input voltage only. The tube operates exactly as before, except now it conducts during only the negative peak of the input signal. Of course, the plate is still made positive (with respect to the cathode) before the tube conducts.

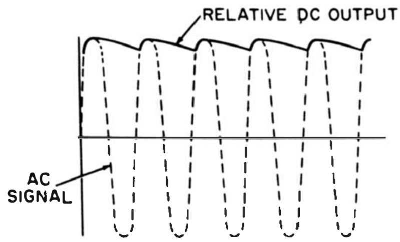
When the rectifier is in a separate probe connected to the VTVM with a shielded cable, the shield or ground will be positive with respect to the VTVM input terminal if this tube is connected as shown in Fig. 4-8. If we reverse the tube—that is, ground the plate and connect the cathode to the capacitor—the shield will be negative with respect to the input terminal. In a zero-center

VTVM, the needle will swing to the left or right, depending on the polarity of the probe output voltage. On most VTVM's, however, the zero is on the left side of the dial. By setting the polarity switch on the front panel, we can make the needle read upward, regardless of whether a positive or negative voltage is applied.

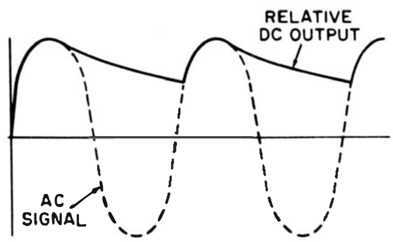
From Fig. 4-9, we can see that the capacitor charges through the tube during only a very short portion of the input-voltage cycle. During the remainder of the cycle (which is many times longer), the capacitor discharges through the resistor. The rather low average current through the vacuum tube results in a very high input impedance for the probe. By maintaining a low shunt capacitance and limiting the current through the tube to a small portion of the cycle, we present a high impedance to the circuit under test. This, of course, means less loading than if there were a large distributed capacitance and a more continuous current through the diode.

During each cycle of the input voltage, the capacitor is quickly charged, but only partially discharged. Therefore, the time constant of the input capacitor and the load resistor must be made as long as practical, so the capacitor will discharge as little as possible between peaks of the input voltage. In this way, the DC level can be maintained equal to the peak input voltage.

In Fig. 4-10 we see that with a given time constant, the output voltage depends on the frequency of the input signal. The time constant must therefore be chosen so the shunt capacitance is kept low for the higher frequencies. Yet the time constant must be long enough that low-frequency voltages can also be measured satisfactorily. It is obvious that the value chosen for the capacitor must be a compromise. Usually it is such that the time constant of the RC network is approximately 100 times the reciprocal of



(A) High-frequency signal.



(B) Low-frequency signal.

Fig. 4-10. Effect of the input-signal frequency on the rectifier output.

the lowest frequency we wish to measure. This is given by the following equations:

$$T = \frac{1}{f}$$

where,

T is the time for one cycle of the input signal,

f is the frequency of the signal in cycles per second.

The time constant of an RC circuit equals R times C (where R is the resistance in megohms and C is the capacitance in microfarads); RC must equal 100T. Therefore, by substitution:

$$RC = 100 \times \frac{1}{f}$$

$$fRC = 100$$

$$C = \frac{100}{fR}$$

If the value of the capacitor is too small, or if the frequency to be measured is lower than the one chosen for our capacitor value, the meter indication will be low because the capacitor will lose too much charge between peaks of the input voltage. Therefore, the average voltage across R_L will be lower than the peak input voltage.

Let us cbnsider the relationship between time constant RC and the charge remaining in a capacitor at various times during discharge. This relationship is shown by Fig. 4-11, where the charge is plotted vertically and time (t) horizontally. Notice that the *X* axis is divided into RC units, not seconds—that is, 0.1RC, 0.2RC, 1RC, and so on. Although the co-ordinate for any value of *t* can be found by formula, we will not give it here, but may quote values obtained by its use.

The formula enables us to find the charge remaining on the capacitor after one cycle of discharge. This can be done for *any* RC product or *any* signal frequency. For example, suppose we choose a specific signal frequency and design a probe to meet the requirement of RC=100T. How closely will the output voltage match the input voltage? Rearranging the formula, we get T = RC ÷ 100. The corresponding value for *t* in Fig. 4-11 would be RC ÷ 100, or .01RC, except for one fact: *t* in Fig. 4-11 represents the discharge time entirely; *T*, the duration of one complete input cycle, is therefore half charge and half discharge time. For this reason, we must use the formula, t = .005RC. This value is too small to be read on the curve of Fig. 4-11, but if substituted in our absentee formula yields .9952—the charge remaining at the end of the cycle. In other words, the charge on the capacitor has dropped less than ½ of 1%. Thus, the formula RC = 100T gives us a negligible loss. In fact, a figure of RC = 10T might sometimes be acceptable. The latter would give a loss of not quite 5%.

Let us see what value of RC would be necessary for a probe designed to pass 60 cps—first for RC = 100T, and then for RC = 10T.

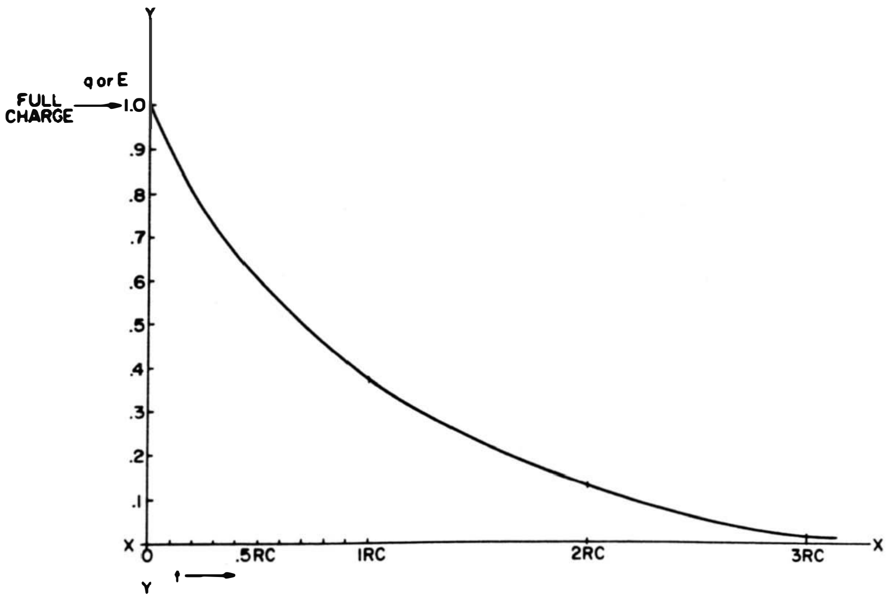


Fig. 4-11. Discharge curve for an RC circuit.

(1) At 60 cps, T = 1 ÷ 60 and RC = 100 ÷ 60.

If we choose 10 megohms for R, then C must be approximately 0.17 mfd. If R is 20 megohms, then C can be half as large, or .085 mfd.

(2) RC = 10T and T = 1 ÷ 60; therefore, RC = 10 ÷ 60.

If R is 10 megohms, C will be .016 mfd; and if R is 20 megohms, C will be .0085 mfd.

Frequencies lower than 60 cps would result in a greater loss, which becomes smaller at higher frequencies. Therefore, the probe is good for all frequencies above 60 cps (up to the point where distributed circuit capacitance begins to take effect). For lower frequencies, however, we must accept more loss.

Besides the characteristics of a probe at higher frequencies, we must be concerned with those of the material in the probe, plus skin effect and the transit time of the tube. To keep the dielectric losses as low as possible, those portions of a tube carrying RF energy are usually protected by polystyrene or other good RF insulation. Skin effect (where the higher-frequency currents travel close to the surface of a conductor instead of through it) can be greatly reduced by making the RF-carrying circuit—in other words, the probe tip and the capacitor leading to the diode—as short as possible. Transit-time difficulties can be lessened, up to several hundred megacycles, by using the tiny ultra-high-frequency diode tubes designed for this purpose.

One of the more important requirements for a high-frequency probe is that it exhibit the lowest possible shunt capacitance. Why this is true can be understood from the fact that at 100 megacycles, for example, the reactance of a 10-mmf capacitance is only 160 ohms. The probe itself not only must have a low input capacitance, but also must not introduce additional stray capacitance when connected to the equipment under test.

So far we have dealt with sine waves only. But if the input voltage contains harmonics, our meter indication may differ (sometimes even greatly) from the rms value. The amount will depend on the percentage of harmonics and their phase relationship to the fundamental frequency. Fig. 4-12A shows the result-

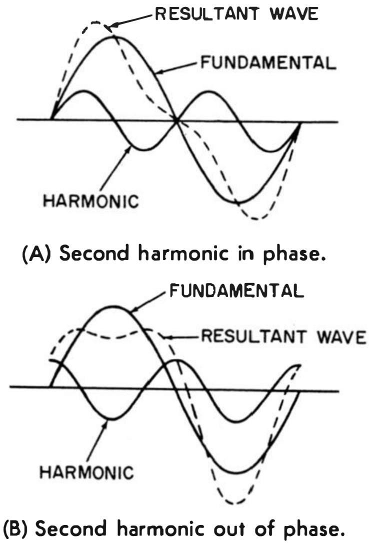


Fig. 4-12. Effect of the second-harmonic phase on the fundamental waveform.

Table 4-2

Measurement errors from harmonic or other spurious voltages.

% Harmonic	True Rms Value	Peak Meter Indication
0	100	100
10% 2nd.	100.5	90 to 110
20% 2nd.	102	80 to 120
50% 2nd.	112	75 to 150
10% 3rd.	100.5	90 to 110
20% 3rd.	102	88 to 120
50% 3rd.	112	108 to 150

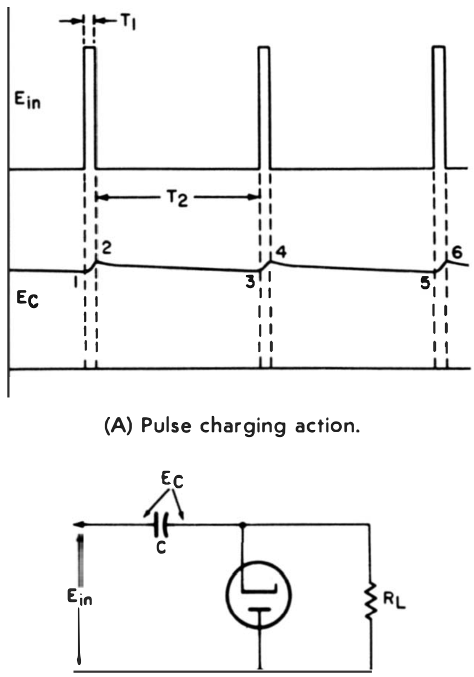
ant waveform when an in-phase second harmonic is combined with the fundamental; Fig. 4-12B, when the second harmonic is out of phase. Table 4-2 is an example of the erroneous readings obtained when voltages containing harmonics are applied to an rms-calibrated VTVM. These errors will crop up, regardless of whether the meter is calibrated for peak or for rms voltages.

A peak-reading voltmeter will also give erroneous readings if used to measure an unsymmetrical waveform. Moreover, if a 180-degree phase shift exists (such as at the grid and plate of a tube), two different peaks will be measured—the positive or negative one at the grid, and a peak of the opposite polarity at the plate. One way of circumventing this problem is to measure peaks of the same polarity at both the grid and plate. This we do by using the polarity-reversal switch on the voltmeter as we check from grid to plate. However, we must also take the electrical characteristics of the signal source into account, so we can be sure such a reversal will not be detrimental.

Transit Time

The frequency of the voltage under test increases until the time (transit time)· the electrons take to travel from the filament or cathode to the plate of a diode becomes a noticeable—and often an appreciable—portion of a cycle of the applied input voltage. From here on, the tube characteristics change radically: The electron flow between elements is no longer instantaneous; nor does it follow exactly the changes in plate-to-cathode voltage. Because the tube is unable to respond faithfully to the changes in amplitude of the input signal, an error is introduced in the output voltage. This error becomes larger as the frequency of the applied signal increases. The plate resistance and the plate-to-cathode capacitance of the tube also change. This is the reason tubes with a short transit time, high self-resonant frequency, and the lowest possible cathode-to-plate interelement capacitance have been designed.

In the input diode of the VTVM, the amount of error due to the transit-time effect depends on the magnitude and frequency of the applied voltage and on the characteristics of the tube—the latter involving the shape, size, and spacing of the electrodes.



(A) Pulse charging action.

(B) Rectifier circuit.

Fig. 4-13. Output-voltage and pulse-width repetition-rate relationship of the rectifier.

Pulse Response

Let's examine the pulse in Fig. 4-13A. Its width, T_1, is small compared with the repetition rate, T_2. The tube, which conducts only when pulses are present, will thus charge the capacitor connected across the load resistor. Our meter will read the voltage developed across R_L in Fig. 4-13B. The voltage across the capacitor (Fig. 4-13A) has a chance to build up between the very short time interval *1* and *2* only, but has a relatively long time to discharge. The slope of the curve between *2* and *3* will be determined by the time constant of the capacitor and load resistor. If the ratio between time intervals T_2 and T_1 is small, the capacitor will then have no difficulty charging to the peak value of the applied voltage. On the other hand, if the ratio is high, we will run into a problem. Assume T_2 is 999 microseconds and T_1 is 1 microsecond. During this 1 microsecond, the tube must therefore pass the total current drawn by the load during the entire 1,000 microseconds from pulse to pulse. So the instantaneous current drawn from the source is 1,000 times the current required by the measuring circuit. Moreover, because of transit-time difficulties, the slope from point *1* to *2* may not be steep enough to fully charge the capacitor to the peak applied voltage. Therefore, the capacitor charge at point *3* will also be reduced. As a result, the reading will be below the actual peak value.

When servicing a TV receiver or other complex electronic equipment, we encounter many nonsymmetrical and nonsinusoidal voltages like the ones in Fig. 4-14. As you can see, the pulses are narrow and widely spaced—in other words, they have a low repetition rate. Before we can obtain an accurate indication of their peak or peak-to-peak values, we must remember that a relatively constant charge must be maintained on the capacitor between input-voltage peaks. If these peaks are short and very widely spaced, the charge on the capacitor may not be replenished fast enough for an accurate peak-to-peak reading. The curve in Fig. 4-15 shows the pulse-response capability of a typical VTVM, based on a source impedance of 50 ohms or less. If the source impedance is higher, the measurement error will increase proportionally.

The pulse-response capability of a peak or peak-to-peak measuring circuit is determined by the time constant of a resistor and capacitor. Therefore, we can measure pulses with a low repetition rate and a narrow pulse width by increasing the value of either the capacitor or the load resistor. The load resistor used to develop the output across the grid circuit of the bridge-type VTVM should be as large as possible without causing grid current to flow. The capacitor should also be as large as possible—up to a certain point. Beyond this point the shunt capacitance will be unbearable.

Because of the difficulties encountered when a VTVM is used to

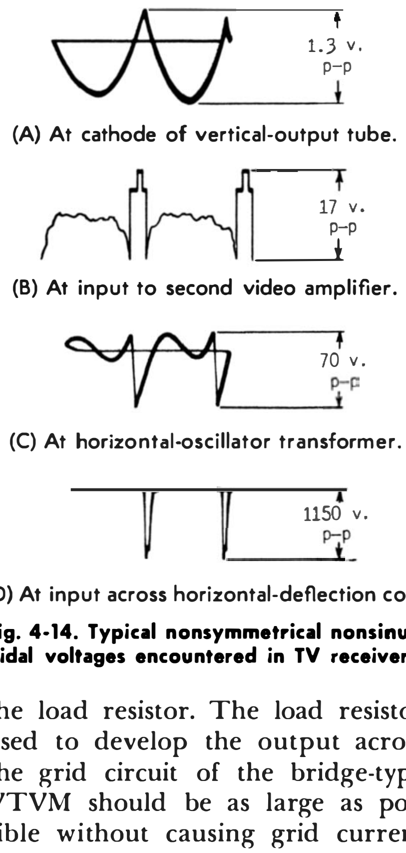


Fig. 4-14. Typical nonsymmetrical nonsinusoidal voltages encountered in TV receivers.

measure the peak-to-peak value of a complex wave, an oscilloscope is often preferred for more accurate measurements.

Fig. 4-16A shows the Precision Apparatus RF-10A peak-indicating probe. It employs a diode-connected subminiature triode, as shown by the schematic in Fig. 4-16B. The graph in Fig. 4-16C compares the meter readings with the actual peak voltage under test. Meter readings become inaccurate below three volts, and even more so below one volt. If precise voltage levels are important, they can be interpolated from the graph. Below 200 cycles, a low-frequency correction factor must also be applied, as shown in Fig. 4-16B. The probe indication is proportional to the positive peak value of the applied AC voltage.

Another interesting probe is shown disassembled in Fig. 4-17A, and schematically in Fig. 4-17B. The instrument to which the probe is attached operates as a peak voltmeter calibrated to read rms values of sine waves. At high frequencies, the meter normally reads high because of resonance in the input circuit. However, the transit-time effect of the acorn diode rectifier tube in the probe causes the meter to read low. At low voltages, the transit time and resonance effects tend to cancel each other. At higher voltages, however, the measuring errors are due almost entirely to resonance.

The curve in Fig. 4-18 shows the frequency correction required for various voltage ranges. At low frequencies, the equivalent input-circuit impedance of the probe is 25 megohms; but losses due to a shunt capacitance of about 3.1 mmf (with the probe cap and plug removed; 4.3 mmf if they are included) reduce the 25 megohms at high frequencies.

When the rotating metal cover of the probe in Fig. 4-17A is closed, the probe is completely shielded except for the small insulated area. A metal cap permits various fittings and screws to be attached to the end of the probe. A phenolic cover, held by a nut fastened to a cable strain release, insulates the probe body be-

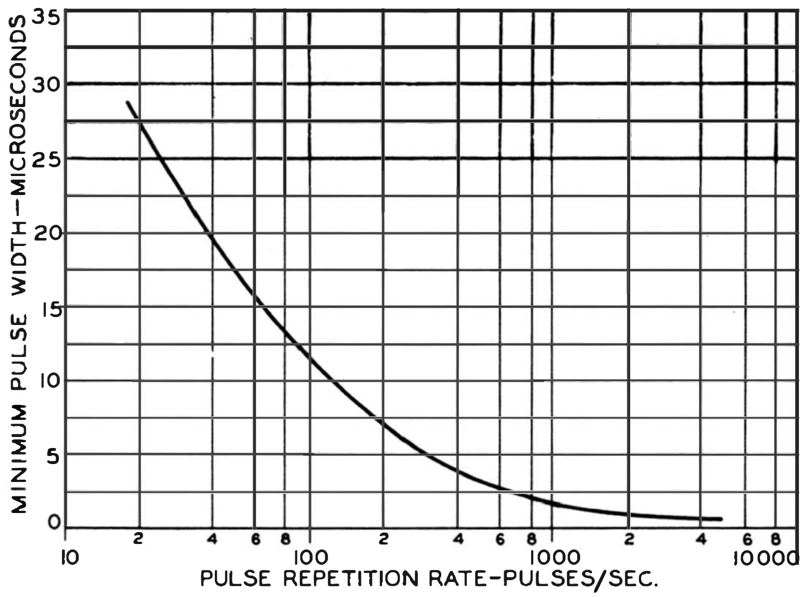
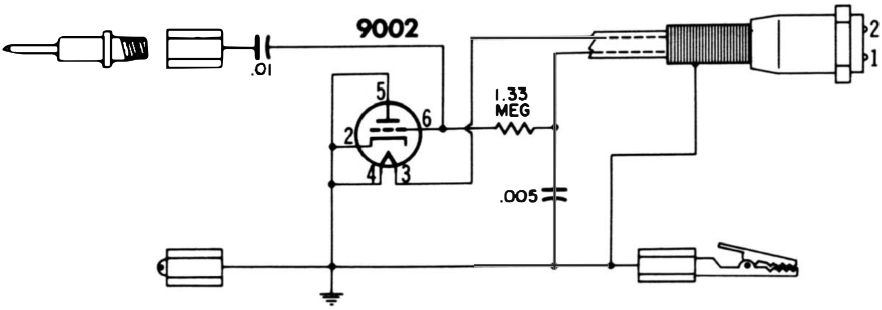
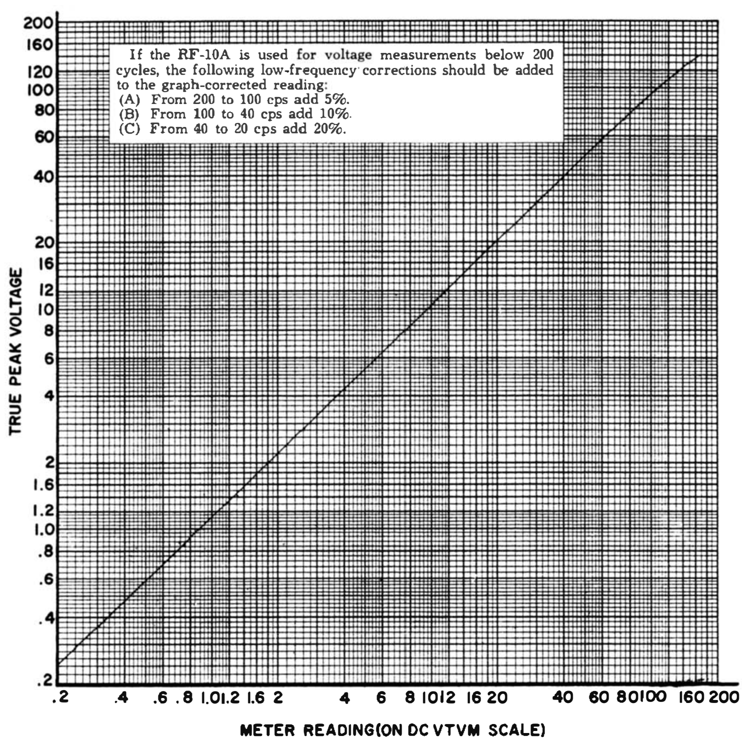


Fig. 4-15. Pulse-response capabilities of a typical VTVM. (Courtesy of Radio Corporation of America)

(A) Probe.



(B) Probe circuit.

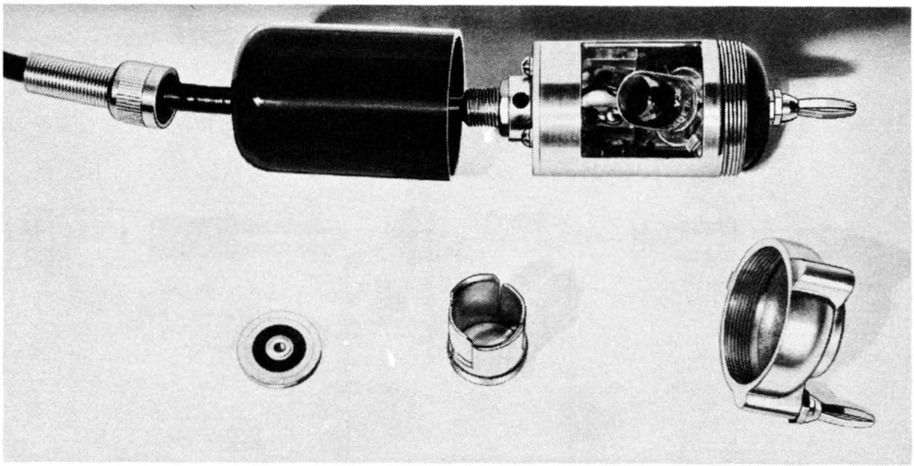


(C) Voltage- and frequency-correction chart.

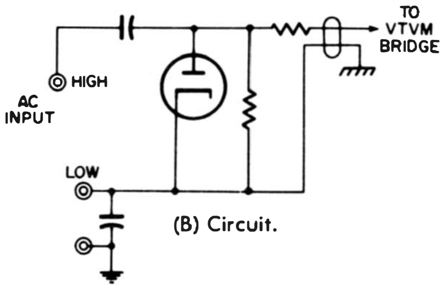
Fig. 4-16. Model RF-10A peak-indicating probe. (Courtesy of Precision Apparatus Co., Inc.)

hind the cap. For high-frequency measurements, where the minimum inductance is desirable, a cap can be fastened to a flat ground plate and an axial hole provided for the center terminal.

At low frequencies, the response of this probe drops off because of



(A) Construction.



(B) Circuit.

Fig. 4-17. A commercial high-frequency peak-indicating probe. (Courtesy of General Radio Company.)

the increasing reactance of the input circuit (but not more than 2 per cent at 20 cycles).

A high-frequency multiplier attachment is available which increases the voltage rating of this probe 10 times.

Fig. 4-19 is a cutaway view of a high frequency probe using a special diode. This tube, which has a

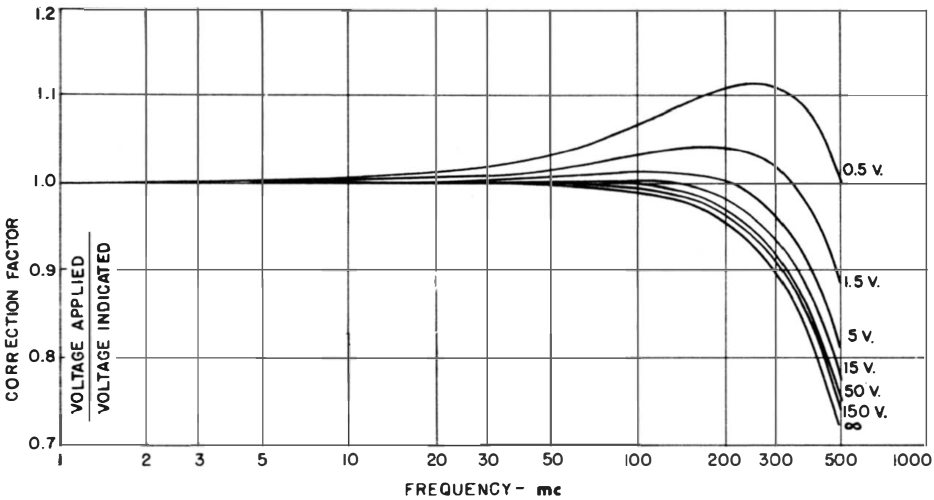


Fig. 4-18. Frequency-correction curve for the probe in Fig. 4-17. (Courtesy of General Radio Company.)

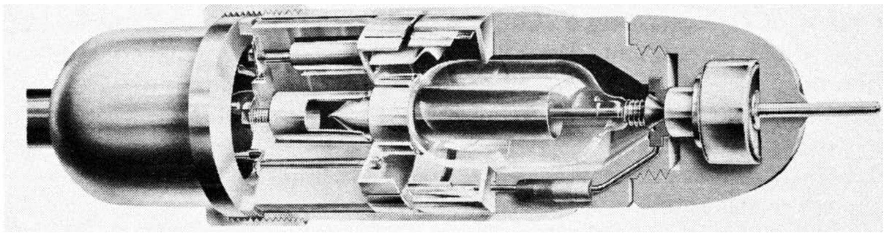


Fig. 4-19. Internal view of the Hewlett-Packard high-frequency probe used with the Model 410-B VTVM. (Courtesy of Hewlett-Packard Co.)

self-resonant frequency of around 1,250 mc, places approximately 1.5 mmf across the circuit under test. At low frequencies the probe has an input impedance of 10 megohms shunted by 1.5 mmf. Its frequency response is flat within ±1 db from 20 cycles to 700 megacycles. The lower part of this probe is completely enclosed within a grounding shell to aid in establishing a reliable high-frequency ground connection. The Hewlett-Packard probe in Fig. 4-19 is used with the Model 410B VTVM.

As a result of design considerations, the probe has a resonant frequency of approximately 1,500 megacycles. The DC output of the probe *versus* the frequency of the input signal is shown in Fig. 4-20. Nete that there are three characteristic curves at the high-frequency end—one each for the 1-, 3-, and 10-volt ranges. At these high frequencies, the response of the probe is affected by (1) the transit time, which depends not only on the frequency, but also on the magnitude of the applied voltage; and (2) the self-resonant frequency of the probe, which is independent from the voltage under test. The effect of the transit time is shown by a dip in the 1-volt curve in the vicinity of 500 mc. The rise beyond 500 mc can be attributed to the fact that the probe becomes resonant and thereby overshadows the transit-time effect. The input resistance and shunt capacitive reactance of the probe in Fig. 4-19 is shown in Fig. 4-21. At frequencies up to 100 mc, the input

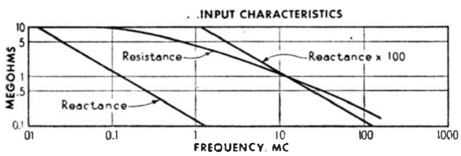


Fig. 4-21. Input characteristics of the probe in Fig. 4-19. (Courtesy of Hewlett-Packard Company.)

resistance is greater than 10 megohms, decreasing at higher frequencies because of dielectric and tube losses and the high-frequency effect of the resistor. The shunt-capacitance component is approximately 1.5 mmf, and the reactance curve varies accordingly.

In a voltmeter probe using a vacuum-tube diode, one of the prob-

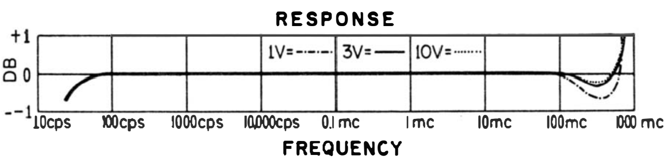
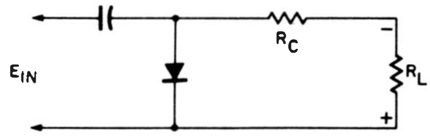
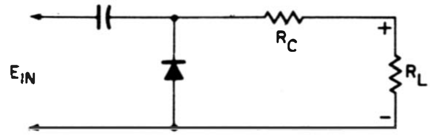


Fig. 4-20. Frequency response of the probe in Fig. 4-19. (Courtesy of Hewlett-Packard Co.)

lems in achieving good stability is the effect of changes in line voltage on the characteristics of the tube. When no plate voltage is applied to the tube, we will still get some contact potential. This contact potential, which transfers a small amount of energy to the anode, is directly related to the filament voltage. Hence, changes in the filament voltage will vary the amount of contact potential. Even though relatively small, this change may nonetheless prove



(A) Responds to negative peaks only.



(B) Responds to positive peaks only.

Fig. 4-22. Shunt-type peak-reading rectifier probes using germanium diodes.

to be annoying when measurements are made at low voltage levels. If the contact potential of another diode is used to counterbalance that of the active tube (as explained previously), the line-voltage changes will affect both tubes at the same time and in the same direction. Therefore, the change in contact potential will not be as detrimental to the accuracy of the measurement.

A ballast element, sometimes used in the more expensive instruments, regulates the filament voltage supplied to the rectifying diode. In this way, a more constant voltage can be maintained over a rather wide variation in line voltages.

PEAK-READING, SHUNT-TYPE RECTIFIERS USING SEMICONDUCTOR DIODES

The circuit of a semiconductor diode probe (Fig. 4-22) is similar to the one employing a vacuum tube mentioned before, in which the peak value of the input voltage is developed across the input capacitor. The same time-constant relationship also holds true for the semiconductor diode—except for one slight difference. When we calculate our time constant, we must remember that the back resistance of a semiconductor diode is not infinite. For this reason, and because the diode is in parallel with the load resistor, some of the capacitor charge leaks off through the diode. We would therefore need a somewhat larger capacitor in order to minimize errors at low frequencies.

When the diode is connected as shown in Fig. 4-22A, the output of the probe is negative; so the VTVM must be set for negative DC volts. If we reverse the diode (as shown in Fig. 4-22B), the output will be

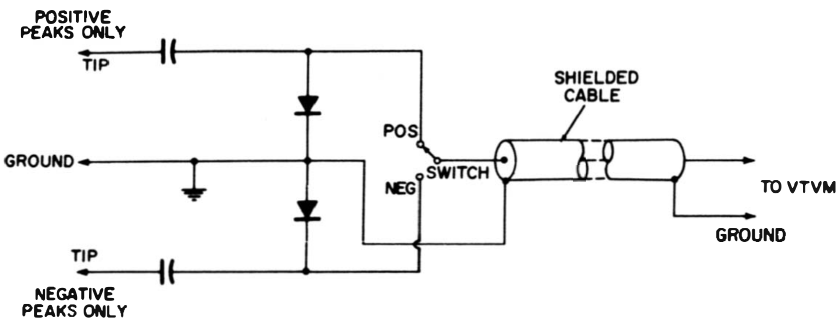


Fig. 4-23. A peak-indicating probe which will read either the positive or the negative peak, depending on the switch setting.

positive, and now the meter must be set for positive DC volts.

The two probes in Fig. 4-22 can be combined, giving one which, by means of an SPST switch, can measure either the positive or negative peak of a signal. Its circuit is shown in Fig. 4-23. In order to be completely symmetrical, this probe should be made with two individual tips and identical circuitry, except that the cathode of one diode and the anode of the other are grounded. This gives a choice of positive or negative peak indication, allowing us to measure the positive or negative half cycle of an unsymmetrical signal.

The signal-handling capability of a probe can be increased by connecting two or more rectifiers in series, as shown in Fig. 4-24. Not only is the voltage-handling capability of the probe increased, but also the input impedance, because

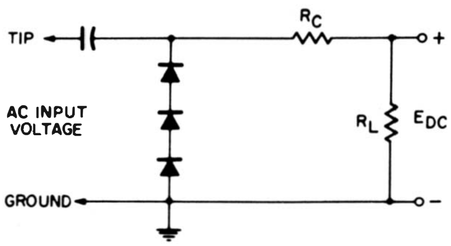


Fig. 4-24. Using more than one diode in series to increase the input impedance and voltage-handling capability of a probe.

the back resistances and shunt capacitances of the diodes are now in series. With two diodes, the voltage-handling capability and shunt resistance are doubled, and the shunt capacitance is one-half. With three diodes . . . tripled and one-third—and so on for each additional diode.

The applied AC voltage must never exceed the voltage rating of the semiconductor diode; nor should the DC component exceed the voltage rating of the blocking capacitor. The highest operating frequency of a probe is determined not only by its self-resonant frequency, but also by the spacing of its components and leads. The input impedance of a well-designed shunt-type peak indicating probe is usually over 250,000 ohms, up to 1 megacycle; and over 5,000 ohms, up to 250 megacycles.

It is possible to increase its RF voltage-handling capabilities by shunting the probe with a capacitor to form a capacitive divider with the

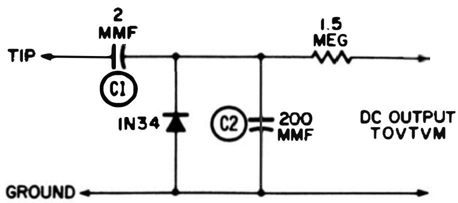


Fig. 4-25. Capacitive-divider method of increasing the voltage-handling capability of a probe.

input charging capacitor. The circuit (Fig. 4-25) has a 100:1 voltage division. This is suitable for measuring up to 2,500 volts, because the voltage across the semiconductor will not exceed 25 volts—still a safe value for our diode.

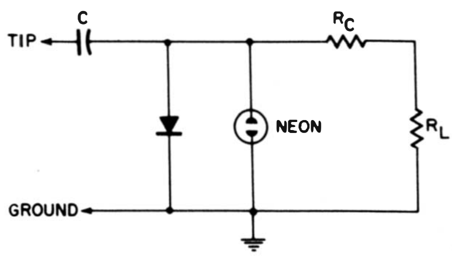


Fig. 4-26. Using a neon bulb to protect the diode against damage from voltage overloads.

To prevent a voltage overload from burning out the diode, it can be shunted with a neon bulb, as shown in Fig. 4-26. The bulb will light during an overload and thereby keep the voltage down to a safe level until the overload has been removed. The ionization level of the bulb should be lower than the maximum rated voltage of the diode.

Fig. 4-27 shows the schematic of a high-frequency probe designed for a VTVM having an input resistance of 10 megohms. The frequency response of this shunt-type, peak-indicating probe is flat within ±10%, from 20 kc to 100 mc; and the indication is proportional to the *positive* peak of the applied voltage.

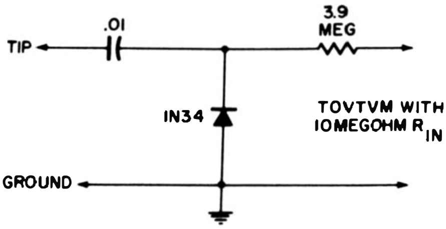
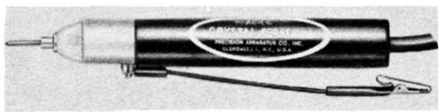


Fig. 4-27. A high-frequency peak-indicating probe for use with a VTVM having a 10-megohm input resistance.

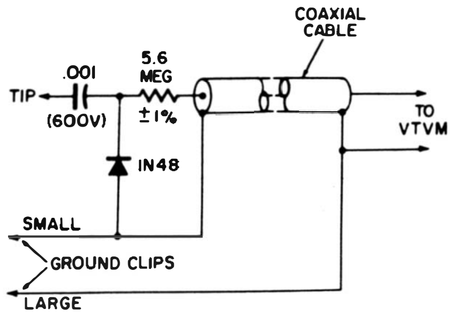
The crystal diode-detector probe in Fig. 4-28 is slipped over the regular DC isolation probe of the RCA Model WV-98A VTVM, for which it was designed. Obviously, no additional lead is required to the meter. The probe extends the frequency range of the VTVM to 250 megacycles. It can be used in circuits where the DC voltages do not exceed 250 volts and the AC voltages are not more than 20 volts rms or 28 volts peak.

Fig. 4-28. This crystal diode-detector probe is slipped over the regular DC isolation probe for which it was designed. (Courtesy of Radio Corporation of America.)

Fig. 4-29 shows another interesting probe. The 5.6-megohm series resistor is chosen to give rms indications on the VTVM for a sinusoidal input voltage. Designed for a frequency range of 50 kc to 250 mc, the probe is accurate within ±10%. On the 3-volt range, a correction chart (Fig. 4-30) must be applied. The probe has a shunt capacitance of approximately 3 mmf when the small ground clip is attached. A second ground clip, from the connector can be used for measuring frequencies below 200 kc. The equivalent shunt resistance is approximately 200,000 ohms at 50



(A) The probe.



(B) Probe circuit.

Fig. 4-29. A typical commercial peak-indicating probe. (Courtesy of Precision Apparatus Co., Inc.)

kc, decreasing as the frequency increases. A compensated X10 multiplier (Fig. 4-31) can be used to extend the usable AC voltage range to 300 volts rms. The probe tip must be unscrewed, replaced with the multiplier head, and the tip screwed into the other end of the multiplier. Do not forget that all scale readings taken with the X10 multiplier head must be multiplied by 10 before the actual voltages can be read. The X10 multiplier head also lowers the input shunt capacitance and raises the equivalent shunt resistance.

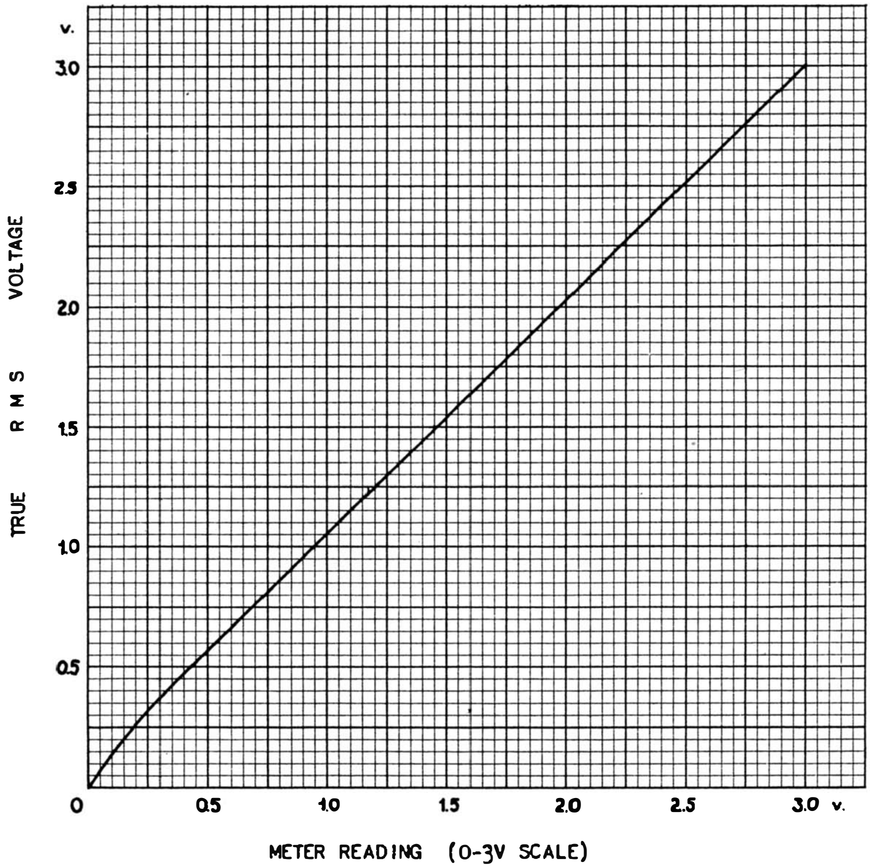


Fig. 4-30. Correction chart for the three-volt range of a VTVM when the probe in Fig. 4-29 is used. (Courtesy of Precision Apparatus Co.)

PEAK-READING, SERIES-TYPE RECTIFIERS

Fig. 4-32 shows about the simplest version of a peak indicating probe—a semiconductor diode connected in series with the center conductor of a shielded cable. The capacitance of the cable, acting as the charging capacitor, charges to the positive or negative peak value of the applied voltage (depending on the way the diode is connected).

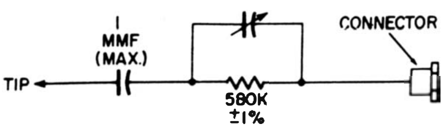


Fig. 4-31. A × 10 multiplier for the probe in Fig. 4-29.

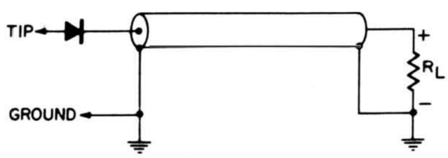


Fig. 4-32. Basic circuit of a peak-reading, series-type rectifier probe.

Even though very simple to make, this probe has its faults. At certain frequencies, the shielded cable may act as a resonant stub. The way to circumvent this difficulty is to insert a charging capacitor and a resistor, and then let the cable capacitance act as an additional capacitor to smooth out the peaks. (This is shown in Fig. 4-33.) The resistor can also act as a calibrating resistor so that either peak or rms readings can be obtained with the VTVM. If the diode is connected as shown in Figs. 4-32 and 4-33, the output voltage will be positive and there will be a positive voltage on the center conductor of the cable going to the VTVM. If the diode is reversed, the center conductor will of course have a negative DC voltage.

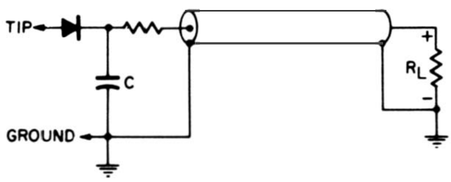


Fig. 4-33. Adding a charging capacitor and a resistor to the basic circuit will improve its performance.

No blocking capacitor is shown because these probes are suitable only for low-level AC measurements where no (or a very low) DC component is present. If there is a DC component and its direction and magnitude are such that it cuts off the diode or overrides the signal, we may get no indication at all. Moreover, if the signal is larger than the reverse bias voltage, our indication will be considerably lower than the actual AC voltage. The reason is that the DC voltage biases the semiconductor diode into the nonconducting region, so this bias voltage is exceeded only during the extreme peaks of the AC signal. (See Fig. 4-34.)

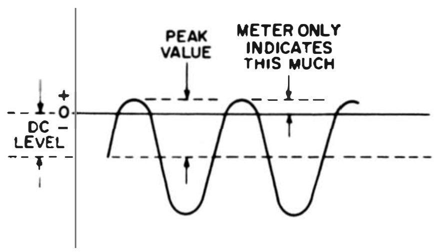


Fig. 4-34. Measuring error introduced when AC is measured in a circuit that also contains DC and no DC blocking capacitor is used.

There is, however, an advantage to this arrangement—we have about the least shunt capacitance we could possibly hope for with a rectifying probe. Here is why. The approximately 1 mmf shunt capacitance of the semiconductor diode is in series with the considerably greater shunt capacitance of the cable (or charging capacitor, if used). Since the sum of two capacitances in series is always less than the smaller of the two, the equivalent capacitance of the diode and the cable capacitance is less than 1 mmf. To that, however, must be added the distributed capacitances from the operator's hand, the shielded cable, and the proximity of the probe to the ground or return of the circuit being measured. Nevertheless, the shunt capacitance is lower than with most any other rectifier probe.

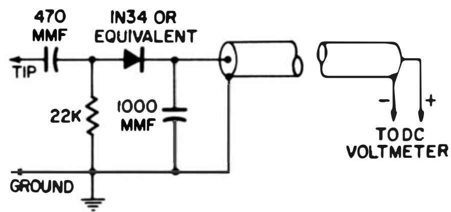


Fig. 4-35. A rectifier probe suitable for a VOM with a sensitivity of 5,000 ohms per volt or higher.

A semiconductor-diode probe can also be used with a VOM to extend the AC frequency response of the meter beyond that of the built-in rectifier. Such a probe circuit is shown in Fig. 4-35. The meter should have a sensitivity of at least 5,000 ohms per volt—and preferably higher. The output terminals of the probe are connected to the DC voltage terminals of the voltmeter. Since the input resistance of the meter is rather low (only 15,000 ohms on the 3-volt range of a 5,000 ohms-per-volt meter), the rather high load the probe places on the circuit will tend to alter the RF voltage being measured (unless we are measuring voltages in low-impedance circuits). For this reason, any indication—although theoretically that of the peak voltage under test—will be only of voltage present, rather than an actual measure. This is due to the circuit loading effect of the probe. With low-impedance circuits, however, we can actually calibrate the probe with a known voltage and thereby get meaningful measurements.

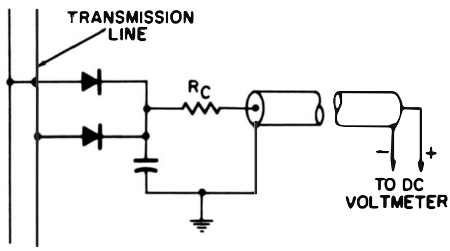


Fig. 4-36. A probe suitable for measuring in a balanced circuit.

If we want to measure in a balanced-to-ground circuit (in a twin-lead transmission line, for example), we can add another diode, as shown in Fig. 4-36. We now have a double-ended probe we can apply directly across the transmission line to measure, with the least shunt capacitance, the voltages on the line. The diodes are connected in the same direction because, at any point across the line, the polarity of the voltage alternates at the operating frequency. As a result, first one diode will conduct, and then the other. The charging capacitor thus receives two pulses—one each time a diode conducts. As before, resistor R_C isolates the probe from the circuit; it can also be used as a calibrating resistor.

PEAK-TO-PEAK RECTIFIERS USING VACUUM TUBES

So far, we have measured only positive or negative peak voltages, depending on how the diode was connected. However, at times we may also need to measure peak-to-peak voltages of complex waveforms with a VTVM, even though we ordinarily can observe them on an oscilloscope. Offhand, one might be inclined to think that the peak-to-peak value of any voltage can be found by merely multiplying the rms meter reading by 1.414 and then by 2. This is true only if we measure a sine wave. Fig. 4-37 shows the relationship between rms and peak values of a sine wave and several nonsinusoidal waveshapes. This relationship becomes even more complex for waveshapes in, say, TV circuits.

Another thought is that we could take two readings—in other words, measure the upper (positive) portion of the wave and then—by using the polarity-reversal switch on the meter—the negative half, and add the two readings. Although seemingly an elegant solution, this is not practical for the following reason. The side of the VTVM connected to the low-potential point of the circuit under test is grounded. If the polarity of the probe is reversed, the ground of the VTVM will then be connected to the high side of the circuit. As a result, the circuit will be disabled completely, or else so loaded down that the waveshape will be greatly distorted. Obviously then, we need a meter that will measure peak-to-peak voltages irrespective of the waveshape. We also need two rectifier circuits—one to measure the positive and the other the negative half cycle—plus some means of combining the two in order to obtain a DC output

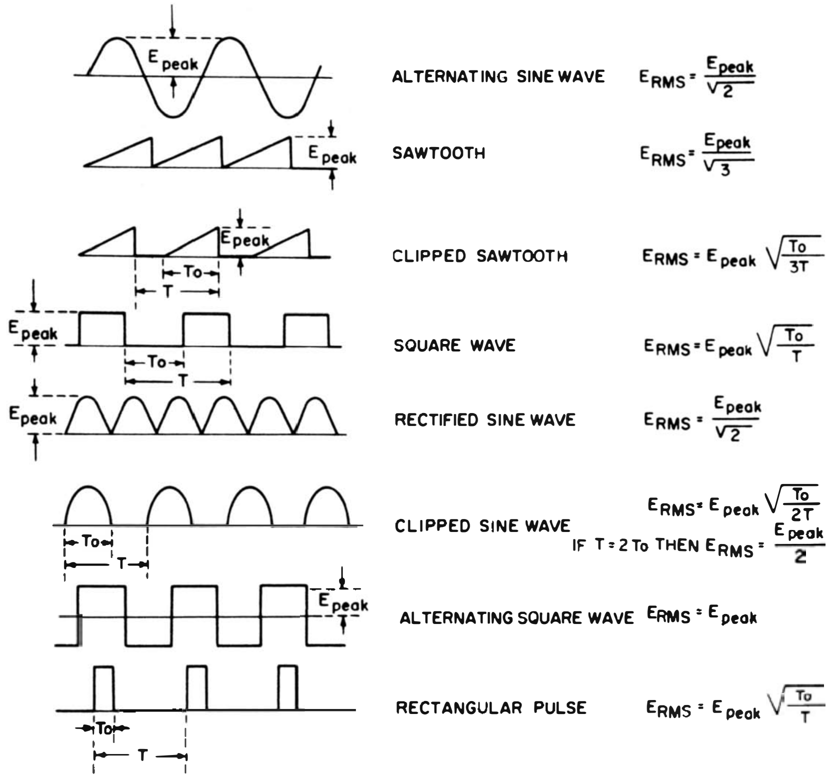


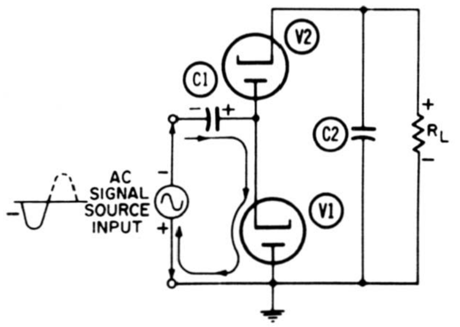
Fig. 4-37. Relationship between the peak and rms values of various waveforms.

equal to the measured peak-to-peak voltage.

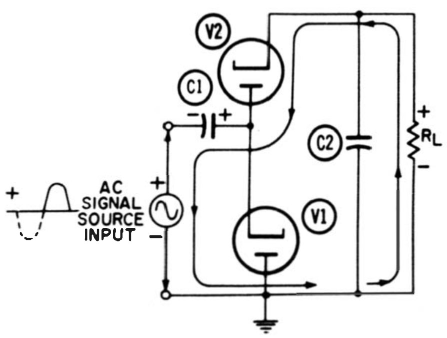
One way of accomplishing our goal is with the half-wave voltage doubler in Fig. 4-38. Note the *two* capacitors and *two* diodes (compared with the *one* capacitor and *one* diode for the half-wave rectifier). As before, either vacuum tubes (usually a twin diode) or semiconductor diodes will do. A cascade-type, half-wave, voltage-doubler circuit is usually preferred because of its advantage of having a common ground.

Now let us see how this circuit works. We will start by tracing the circuit in Fig. 4-38A while the negative half cycle of a sine wave is being applied. As we approach the negative peak value, V1 will conduct and charge capacitor C1 to the peak negative half cycle of the input voltage. V2, the other diode, does not conduct at this time, because its plate is negative with respect to its cathode. The charge on C1 is now equal to the peak negative half cycle of the input voltage and has the polarity indicated. During the second half cycle (Fig. 4-38B)—or the positive excursion—the input voltage, now in series with the previous voltage across C1, goes in such a direction that V1 no longer conducts. Instead, V2 does; and the current through it and R_L develops across R_L a voltage with the polarity shown. This voltage will be maximum when the positive peak of the second half of the input cycle is maximum.

The voltage across V2 is therefore equal to the sum of the peak negative and positive half cycles. So the voltage being developed across C2 and R_L is equal to the peak-to-peak applied voltage. As before, C2, now fully charged, will slowly discharge through the load resistor, at a rate determined by the time constant of C2 and R_L. If this time constant is made long enough, the capacitor will stay at essentialy the peak-to-peak voltage during the entire cycle. The important thing, insofar as accuracy of measurement is concerned, is the interval between the time C2 charges to its peak value, until the next peak arrives.



(A) During negative half of cycle.



(B) During positive half of cycle.

Fig. 4-38. Operation of a half-wave, cascade-type, voltage-doubler circuit.

Fig. 4-39 shows the circuit of a symmetrical voltage-doubler, peak-to-peak probe. To better understand its operation, let's start at the instant input terminal 1 is positive with respect to input terminal 2. This will make the plate of V1 positive and that of V2 negative with respect to their cathodes. V1 will therefore conduct, and current will flow from its cathode to its plate and through resistor R1. This current (I_1) will develop across R1 a DC voltage with the polarity indicated. During the second half of the cycle, input terminal 2 will be positive with respect to input terminal 1, making the plate of V2 positive

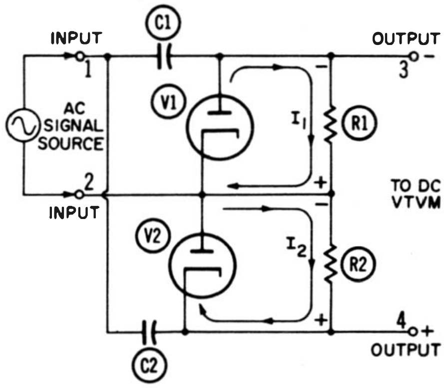
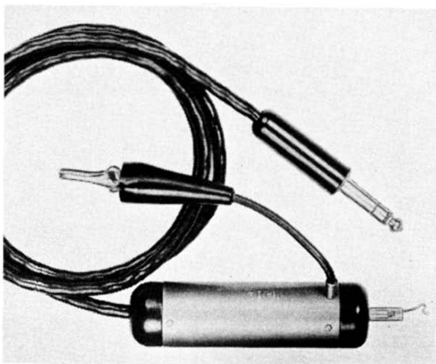


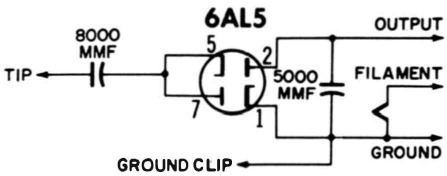
Fig. 4-39. A symmetrical voltage-doubler circuit.

with respect to its cathode. V2 will now conduct, causing a current (I_2) to flow through R2. As a result of this current, a voltage with the polarity shown will be developed across R2. Note that the voltages developed across R1 and R2 during alternate half cycles are now in series. The voltage across terminals 3 and 4 will be equal to the sum of the voltages developed across R1 and R2. By thus adding, in series, the peak positive and negative half cycles of the applied voltage, we get a DC output equal to the peak-to-peak input signal. C1 and C2, connected in series, are actually in parallel with R1 and R2. The charge on these capacitors is therefore equal to the sum of the voltages across R1 and R2. The latter is the output voltage across terminals 3 and 4; it is such that terminal 3 is negative with respect to terminal 4. With this type of peak-to-peak rectifier arrangement, there are no terminals common to the input and output circuits. Therefore, the low-potential end (terminal 4) of the VTVM must never be connected to the low-potential point (terminal 2) of the input signal. Otherwise, V2 will be shorted out of the circuit. Even though not detrimental to the circuit, such a short definitely affects the output. Instead of a peak-to-peak indicating meter, we will end up with simply a peak-indicating probe like the one discussed previously.

Fig. 4-40 shows a commercial half-wave, voltage-doubler probe using a vacuum tube. This probe has a voltage range of up to 150 volts rms; a flat frequency response within ±5%,



(A) Probe.



(B) Probe circuit.

Fig. 4-40. A cascade-type voltage-doubler probe using a vacuum tube. (Courtesy of Simpson Electric Co.)

from 50 cycles to 100 megacycles; and an input capacitance of 10 mmf. The vacuum tube receives its power, through a three-circuit plug, from the voltmeter to which it is connected. One terminal is ground, the other is the filament, and the third is the output voltage from the probe to the DC indicating circuit of the VTVM. A short ground clip, supplied with the probe, keeps all connections for RF as short as possible.

PEAK-TO-PEAK RECTIFIER PROBES USING SEMICONDUCTOR DIODES

Circuitwise, a peak-to-peak probe using semiconductor diodes is much like the voltage-doubler probe using a vacuum tube. The advantages of the former are that it is smaller (and thus easier to handle) and there is no contact-potential problem. As with any probe using semiconductor diodes, however, its signal voltage-handling capability is less than for one with a vacuum tube.

The lower input impedance of a peak-to-peak probe (compared to that of a peak-indicating one) must be taken into account when measurements are made. The same pulse-handling limitations apply for this probe as for one with a vacuum-tube diode.

A peak-to-peak probe can be modified to make it a combination peak- and peak-to-peak–indicating

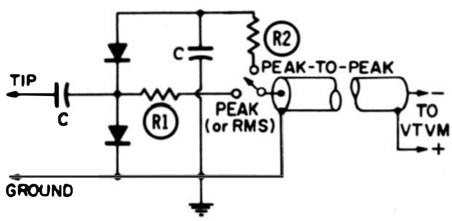


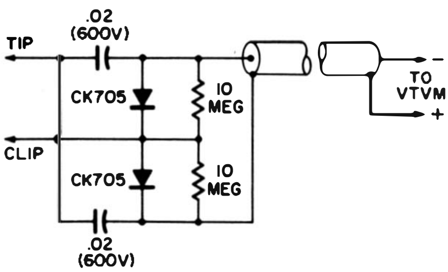
Fig. 4-41. Circuit of a combination peak and peak-to-peak probe using semiconductor diodes.

probe. This is shown in Fig. 4-41. By making R2 and the isolation resistor (used with the DC probe) equal in value, we can use the DC scale of the VTVM to get the exact peak-to-peak value of the voltage under test. The value of R1 must be such that our indication will be

70.7% of the positive peak applied voltage. We can increase the voltage-handling capabilities by connecting diodes in series, as we did for peak-indicating probes.

Fig. 4-42 shows a symmetrical voltage-doubler, peak-to-peak probe using semiconductor diodes. Its negative DC output voltage is equal to the peak-to-peak value of any waveform—complex or sine. The maximum AC input signal may be 80 volts peak-to-peak, and the DC potential must not exceed 600 volts

(A) Probe.



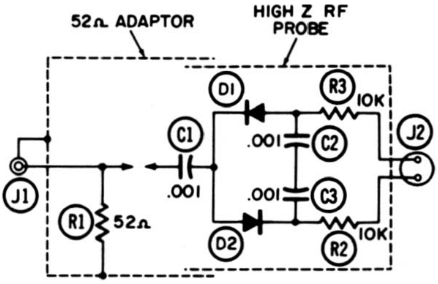
(B) Probe circuit.

Fig. 4-42. A typical symmetrical voltage-doubler, peak-to-peak probe using semiconductor diodes. (Courtesy of Electronic Instrument Co., Inc.)

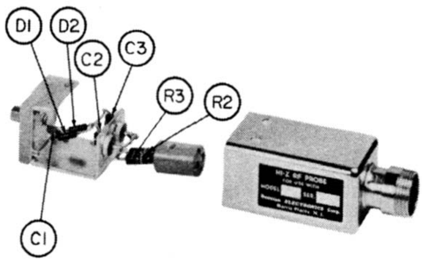
(the rating of the .02-mfd blocking capacitor).

There is no common connection betwen the meter ground and the ground lead of the probe. For this reason, the ground connection must be made at the probe, not at the meter. Otherwise, half of the circuit will be shorted.

Fig. 4-43A shows the circuit of a full-wave, semiconductor diode-detector probe suitable for operation at RF voltages of 1 millivolt to 3 volts, over a frequency range of 500 kilocycles to 600 megacycles. Below approximately 0.1 volt, the output voltage is close to the rms



(A) Circuit.



(B) Construction.

Fig. 4-43. A commercial full-wave, semiconductor-diode detector probe. (Courtesy of Boonton Electronics Corp.)

value; but it changes to the peak output at higher voltages because of the characteristics of the diodes. The shunt capacitance is approximately 2 mmf above 1 volt, and about twice as high at 0.1 volt or less. The shunt resistance also varies, depending on the size and frequency of the applied voltage. The construction of this probe is shown in Fig. 4-43B. A 52-ohm coaxial adapter with a low VSWR up to 600 megacycles can be slipped over the high-impedance probe and screwed into place, making a good ground connection between the two. The adapter circuit, together with the probe, is shown in Fig. 4-43A.

Voltage Multipliers

When the voltages are very low, the probe in Fig. 4-44 will come in handy. Actually two peak-to-peak probes in series, it will quadruple the RF or AF input voltage. That is, the DC output will be four times

1.414, or 5.656, times the rms voltage applied to the probe. Thus, a signal of only 0.88 volt rms will give *full-scale* deflection on the 5-volt DC scale of a VTVM. It is advisable that the diodes have equal forward and reverse resistances. To assure proper quadrupler action, check the probe against a known voltage source. Depending on the diodes, the output may not always be exactly 5.656 times the input voltage. Some correction may therefore be required. As before, the applied AC signal must not exceed 80 volts peak-to-peak. Note from the schematic that the probe and meter grounds must not be connected. Otherwise, half of the probe will be shorted.

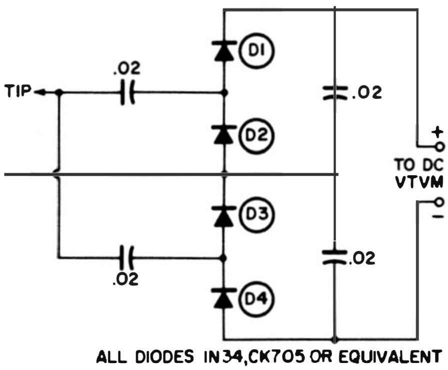


Fig. 4-44. A voltage-quadrupler circuit.

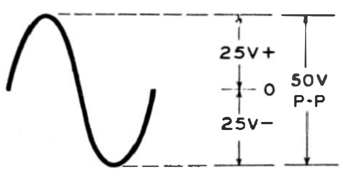
Rectifier Probe Selection and Use

Two important considerations in the selection of a probe are the range of frequencies to be measured and the type of voltage to be applied. Even though more suitable than vacuum-tube types at higher frequencies (there are some exceptions, however!), semiconductor probes have a more limited voltage-measuring range. When the voltage under test is expected to exceed the limitations of the semiconductor diode, a vacuum-tube or multiplier probe is the only answer. In addition, the probe must have facilities for making a good ground connection close to the circuit under test.

Before taking any measurements, we must of course have an idea of what kind of signal we have and what indication we want. If we have a sine wave, a peak-indicating meter will give us peak or rms readings. On the other hand, if we have a nonsinusoidal wave, only peak-to-peak readings would indicate what we have. The voltage level being measured must never be higher than the maximum rating of the semiconductor diode, or several hundred volts for a vacuum-tube diode (except high-voltage rectifiers).

Let us see what we get into if we measure a nonsinusoidal wave on a meter that indicates rms values. For one thing, in a complex wave the positive and negative peaks usually have different values. This is clearly shown by the two signals in Fig. 4-45. Notice that both have a 50-volt peak-to-peak value. However, the nonsinusoidal wave in Fig. 4-45A goes 20 volts in the positive and 30 in the negative direction, whereas the sine wave in Fig. 4-45B goes 25 volts on either side of zero. For the nonsinusoidal wave, a VTVM will indicate only about 14 volts on

(A) For a nonsinusoidal waveform.



(B) For a sine wave.

Fig. 4-45. The relationship between peak and peak-to-peak values of waveforms.

its rms scale because it gives a reading during the positive portion only.

If we try to calculate the peak value by multiplying the 14 volts by 2.828, we will obtain a peak-to-peak value of 39.6 volts—a 20 per cent error, since we started out with 50 volts peak-to-peak. A calculation based on one-half of the sine wave, however, would give a true indication, since both halves are the same.

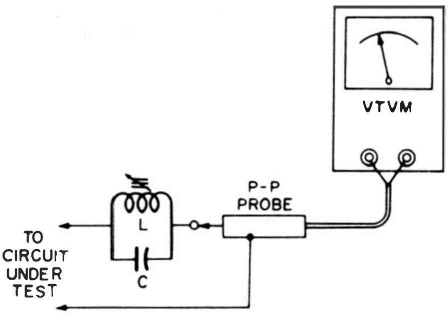
When comparing readings obtained with a peak and peak-to-peak probe, remember that the peak-to-peak indication will not always be double the peak reading. It may be more or less, depending on the type of waveform measured. If one peak of a nonsinusoidal waveform we measure is *lower* than the other one, the peak-to-peak will be *more* than twice the peak reading. Conversely, if *higher*, the one reading will be *less* than twice the other.

We sometimes are interested in measuring the peak-to-peak voltage of vertical- or horizontal-sync pulses at a point in the circuit where they appear together. To do this, we use a peak-to-peak probe, but connect a parallel- or series-resonant tuned circuit ahead of it to select and measure only the signal we want. The *parallel*-resonant circuit in Fig. 4-46A passes the vertical-sync pulses, but rejects the horizontal ones. The *series*-resonant circuit in Fig. 4-46B does just the opposite—it passes the horizontal-sync pulses while rejecting the vertical ones.

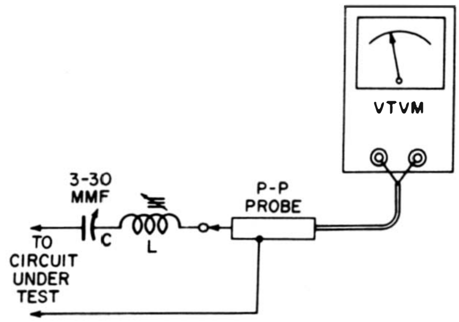
Peak-indicating probes, and peak-to-peak probes using semiconductor diodes, should not be used in sync or sweep circuits because the high voltages (above its maximum rating) could ruin the diode.

When servicing television receivers (where complex waves are common), it is advisable to first consult the manufacturer's service literature in order to know what voltage levels to expect at the various test points. (The voltages in IF and RF circuits are normally too low to harm the probe.)

Several precautions must be observed when the probe is used at



(A) Circuit for rejecting the horizontal-sync pulses.



(B) Circuit for rejecting the vertical-sync pulses.

Fig. 4-46. Using a resonant circuit ahead of the probe to reject unwanted sync pulses.

high frequencies. It (and its housing, if grounded) must be grounded as close to the measurement point as possible. The long ground lead from the meter is not satisfactory because of the inductance and capacitance it adds. The higher the frequency, the smaller the inductance and capacitance; therefore, the more sensitive the circuit to additional inductance and capacitance.

Even moving a wire will change the frequency considerably—a mere quarter of an inch in a 200-megacycle circuit will have a greater effect than moving the same wire several inches in a low-frequency circuit.

In high-frequency circuits, the probe may become resonant (the capacitive and inductive reactances will be equal). This manifests itself as an increase in the meter reading, beginning at approximately one-half the self-resonant frequency. The error becomes larger until resonance is reached, at which time the meter may read two or three times the actual voltage. Past resonance, the reading error decreases, becoming equal to and then lower than the actual voltage as the frequency rises.

Voltmeters with built-in rectifiers have a limited high-frequency range, because the large shunt capacitance of the shielded lead through which the signal is applied greatly attenuates the high frequencies. This is one advantage of having the probe at the end of the cable, rather than in the meter. The meter also loads the circuit under test because of shunting by the cable. Locating the rectifier in the probe rather than in the instrument not only lessens the attenuation of the signal as it enters the meter or scope, but also lessens the loading effect of the meter on the circuit.

The success of a rectifier probe depends on its construction and on the components used. If low-inductance capacitors, good-quality resistors, a good insulating material for mounting the components, and shortest possible wiring and leads are used, and if designed to have minimum stray capacitance, the probe will be quite practical for very high frequencies. Many such well-designed probes are available, either as accessories or supplied with the instrument.

Chapter 5

DEMODULATOR PROBES

THE usefulness of the present-day oscilloscope is undisputed. Its value as a research tool and service instrument is further enhanced by several types of demodulator probes which permit the oscilloscope to be used at frequencies it would otherwise not be suitable for—such as those in television IF, RF, and video stages, which are too high to be observed directly on an oscilloscope.

Television stations transmit a composite TV video signal consisting of an amplitude-modulated RF carrier, together with blanking and sync pulses. These carrier frequencies are close to 900 megacycles if we go as far as Channel 83 in the ultra-high frequency band. Although the vertical-amplifier sensitivity of oscilloscopes is quite high, their limited frequency response causes us difficulty. Direct observation of signals above several megacycles becomes unreliable, and often impossible, with a general-purpose oscilloscope. Wide-band oscilloscopes, with a frequency response extending to perhaps five megacycles or more, are not only more expensive; but their deflection sensitvity also is usually less than that of a high-gain, relatively narrow-band oscilloscope. The latter somewhat limits their suitability for observation in low-level circuits.

When we talk about the sensitivity and frequency response of an oscilloscope, we will concern ourselves with the vertical amplifier only. With many oscilloscopes, the signal we wish to observe can be connected directly to the vertical-deflection plates. Thus, we circumvent the frequency-limiting characteristics of the vertical amplifier; but, in doing so, we sacrifice the deflection sensitivity gained by using the amplifier. Therefore, this method of operating is suitable only for signals whose amplitudes are such that we get satisfactory deflection directly, without the need for additional amplification.

Because the vertical-amplifier circuits of oscilloscopes do not respond to the high frequencies in the IF and RF circuits of radio and television receivers, and since we are interested in the modulation envelope only, we can use a demodulator probe to demodulate our signal and thus get the desired indication on the oscilloscope.

The performance requirements for a demodulator probe are more stringent than for a rectifier probe. The main difference between a demodulator and a rectifier probe is that the former rectifies and removes the carrier frequency before passing the modulation envelope of the RF signal on to the vertical amplifier of the oscilloscope. The rectifier probe, on the other hand, rectifies and filters both the carrier and the modulation component, giving an output proportional to the peak value of the carrier signal (whether modulated or not). Accordingly, the filter characteristics of an oscilloscope demodulator probe are determined by the service applications it is designed to meet.

The peak value of our modulated signal varies at the modulation rate. We must therefore design our probe so its output voltage will rise and fall with the envelope of the RF signal. In other words, in video circuits our probe must completely rectify and filter video frequencies from 100 kc to 4.5 mc, and must also pass a 60-cycle square wave undistorted. For IF signal tracing, the probe should have a relatively high input impedance from 25 up to 45 megacycles. The demodulator probe thus gives a low-frequency vertical-deflection voltage proportional to the instantaneous amplitude of the RF signal. Since the voltage levels at which such signals exist are not too low, we do not need a very sensitive probe. So, we can direct our efforts toward designing a wide-band probe. The gain of the oscilloscope is also on our side. It usually does not take much input signal to get a substantial deflection on a relatively sensitive oscilloscope. Fortunately, the input to the oscilloscope is the demodulated signal; so, we can concentrate on the probe for fidelity and on the oscilloscope for sensitivity.

The input characteristics of the probe also are important. Must the impedance always be high? Or should it sometimes be low? Does the frequency response always have to be wide? Or is a relatively narrow frequency response sometimes sufficient? Such questions enter into the choice of a probe. Any characteristic can be made predominant by proper design. The highest possible fidelity of reproduction is usually achieved at the expense of input impedance. Therefore, a probe which faithfully reproduces signals over a very wide frequency range usually has a low input impedance. Conversely, a high-input impedance probe usually has rather poor frequency characteristics. Demodulator probes are a rather good conpromise.

Some of the more desirable characteristics of a typical demodulator probe include the highest practical input impedance, the greatest possible sensitivity, high fidelity of output, good mechanical construction, and 60-cycle hum rejection. Of course, these qualities cannot all be successfully combined in a practical probe—but at least this is our design goal.

The RF signal we observe will be either frequency- or amplitude-modulated. Nevertheless, we must first demodulate the signal, and then apply the demodulated signal to the vertical amplifier of our oscilloscope.

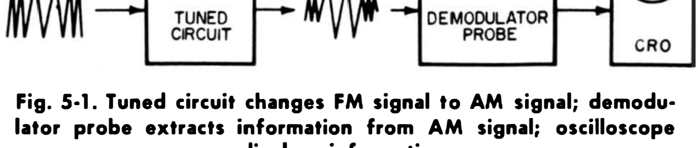


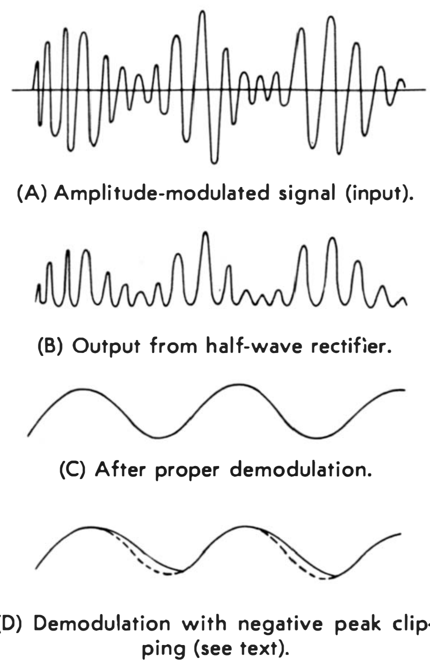
Fig. 5-1. Tuned circuit changes FM signal to AM signal; demodulator probe extracts information from AM signal; oscilloscope displays information.

Let us first consider a frequency-modulated signal, which we can use to test the frequency response of an IF amplifier. Fig. 5-1 shows such a signal applied to a tuned circuit. The output signal from the tuned circuit varies in amplitude, in conformance with the frequency response of the tuned circuit.

A frequency-modulated test signal has a center frequency from which it deviates, usually at a 60- or 120-cycle rate. For example, if the signal has a center frequency of 44 megacycles and a deviation of ±4 megacycles, it will contain all frequencies from 40 to 48 megacycles. The tuned circuit will pass only those frequencies within its passband, and the magnitude of each frequency at its output will be directly proportional to the characteristics of the tuned circuit. The signals here are of such high frequencies they cannot be displayed directly on an oscilloscope, but must first be demodulated. This is accomplished either with a demodulator probe, or by the demodulator in the equipment under test. If we wish to observe the characteristics of successive tuned stages as we progress toward the earlier stages of a receiver, we apply the output of a demodulator probe to our oscilloscope.

We start out by applying a constant-amplitude, frequency-modulated signal to our circuit under test. Then we take the output signal, which now has amplitude characteristics corresponding to the frequency response of the circuit under test, and demodulate it. (This is shown in Fig. 5-1.) We thus come up with a modulation envelope representing the characteristics of the tuned circuit. Now we have a means of observing the characteristics of a circuit that operates at frequencies far beyond the capabilities of an oscilloscope.

At first glance, a demodulator probe looks much like the rectifier probe discussed previously. That is true — the probe circuits *do* look alike. However, the values of the components in the two probe differ. With the rectifier probe, we charge a capacitor to the peak value of the applied signal, and keep it charged to that value. Then we measure this charge with a DC measuring device. A different situation prevails with the demodulator probe. Here, we are interested not so much in the exact amplitude of the signal, but in its shape. The probe must therefore faithfully demodulate an amplitude-modulated signal and present on the oscilloscope an exact reproduction of the modulation envelope. We are now faced with a time-constant problem. Whereas before we wanted a long time constant, now we want a relatively short one, compared with that of the signal under test. Fig. 5-2 shows the action of a half-wave demodulator probe.



(A) Amplitude-modulated signal (input).

(B) Output from half-wave rectifier.

(C) After proper demodulation.

(D) Demodulation with negative peak clipping (see text).

Fig. 5-2. Successive steps involved in demodulating an amplitude-modulated signal.

When a signal is demodulated, either the positive or the negative half of the modulated signal is rectified to provide either the positive- or the negative-modulation envelope. Therefore, from the probe is obtained a unidirectional output signal which changes in step with the modulated signal. If the time constant of the probe is too long, a sharp drop (fall time) cannot be followed because the charge on the capacitor will not have a chance to leak off. This will cause negative-peak clipping. On the other hand, if the time constant is too short, our signal will be ragged or fuzzy; and it will tend to follow the carrier frequency rather than the modulation.

The magnitude of the signal is generally such that semiconductor diodes can be used in place of vacuum tubes. This is an advantage, for semiconductor diodes require no heater voltage; nor is there the hum problem associated with AC filament voltage, to cause troublesome hum modulation on an oscilloscope. In addition, the semiconductor diode makes possible a much smaller (and thus more easily handled) probe than does a vacuum tube.

The front-to-back resistance ratio of the diodes should be as high as possible. In a balanced probe, this ratio (as well as the values of both the front and back resistances) should be matched for both diodes.

The characteristic curve of a germanium diode becomes nonlinear below about 0.5 volt. This causes difficulties at signal levels of 0.5 volt or lower. The curvature, which distorts and magnifies changes in signal voltage, becomes troublesome when we measure voltage ratios. For example, a 5-to-1 change in actual signal level from 0.5 to 0.1 volt may show up as a change of perhaps 6- or 8-to-1 because of the nonlinear characteristics of the diode. Another time this characteristic may become bothersome is in observing the response curve of a tuned circuit. At the extremes of the curve, where there is very little signal, the probe may show that the curve falls off more rapidly than it actually does. This is an important point to consider when measurements are made at low levels.

The response of a probe to complex signals is determined by the relationship of the resistors and capacitors following the rectifier. The RF high-frequency limits are influenced by the circuit preceding the rectifier probe. A high-impedance diode and a short lead will greatly improve the high-frequency characteristics of a demodulator probe, and proper shielding is most important. Available are series- and shunt-type demodulator probes which use series resistors to isolate the oscilloscope and cable shunt capacitances from the probe.

As the frequency increases, the impedance of our demodulator probe becomes very low. Therefore, we must be sure to measure from a low-impedance point if possible, so the low impedance our probe presents at frequencies above 100 megacycles does not disturb the circuit response. At 1 mc, the equivalent input resistance of a typical semiconductor demodulator probe is approximately 25,000 ohms. It drops to about 5,000 ohms at 100 mc, continuing to drop as the frequency rises. The input capacitance of a demodulator probe should be kept as low as possible; the average is somewhere between 3 and 10 mmf.

SHUNT-TYPE DEMODULATOR PROBES

The performance characteristics of the shunt-type demodulator probe are similar to those of the equivalent shunt-type rectifier probe in Chapter 4. The schematics of both probes are similar, except the capacitance and resistance of the shunt-type demodulator probe are smaller in order to provide a shorter time constant. In some demodulator probes, the semiconductors are inserted in a direction which will give a positive-going output voltage. Therefore, the anode of the diode is at ground potential, and the cathode is connected to the input signal whose positive modulation envelope we will then display. If this output is applied to an oscilloscope designed to give an upward deflection when a *positive-going* voltage is applied to its vertical-input circuit (most oscilloscopes are designed this way), maximum output from the probe will result in maximum upward excursion on the response curve. The response curve will then be of a polarity usually considered normal or upright. If the oscilloscope gave an upward deflection for a *negative-going* voltage, the response curve would be inverted.

Although not necessarily incorrect, inverted response curves may be misleading (or inconvenient) if they are to be compared with certain illustrated examples. A reversal of the diode would reinvert the curve, bringing it back to the accepted, normal position. For convenience, both types of probes could be kept on hand—one giving a positive and the other a negative output. The desired polarity of the response curve could then be obtained by using the proper probe.

Fig. 5-3 shows the schematic of a shunt-type demodulator probe. Like the rectifier probe, it has a capacitor which charges to the instantaneous peak value of the modulation envelope. This is a most important requirement; so we try to achieve it as closely as we can. The series resistor here is not used for calibration, but rather to isolate the cable capacitance from the input circuit. Unlike the rectifier probe (which develops a constant DC voltage), this one develops a varying DC voltage. If the RF filtering is not sufficient, the RF pulses may become troublesome if permitted to travel the length of the cable.

A demodulator probe for video-amplifier display must be designed to demodulate a 60-cycle, square-wave modulated RF signal without introducing noticeable distortion. The ability of the probe to do this depends on the resistance and capacitance values within the probe, as well as on the prevailing distributed capacitances. We want these components to be small—yet, if they are too small, they will not do their job. For instance, too small a series resistor will not isolate sufficiently, and too small a shunt resistance (if used) will short out the signal voltage applied to the probe. We must therefore arrive at a compromise. The time constant of the probe is made up of the cable and input capacitances of the probe, as well as any additional shunt filter capacitance, plus the combined resistance of the shunt and series resistors. The probe is less susceptible to hum because fortunately we now want a

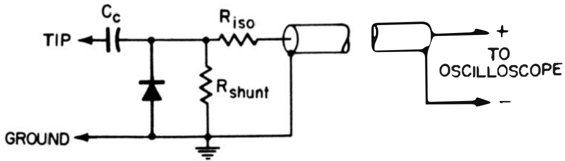


Fig. 5-3. Basic schematic of shunt-type demodulator probe.

small value of charging capacitor (usually not more than a few hundred mmf).

We can improve high-frequency characteristics of our demodulator probe by inserting a small inductance in the cable. The situation here, however, is somewhat more delicate because we have to be concerned with the waveshape of the output signal. Therefore, if we have a high-frequency square wave modulating a high-frequency signal, and want to display the demodulated square wave on our oscilloscope, we can insert a small peaking coil to reduce the rounding of the leading edge. However, we must make sure our inductance does not cause ringing. The coil must therefore be selected very carefully. It may even have to be damped by a shunting resistor. To further reduce the loading effect of a demodulator probe, we can also use an isolation resistor of a few thousand ohms ahead of our blocking capacitor.

Probes are often used to display AC waveforms in the presence of relatively high DC voltages. If so, suitably rated blocking capacitors must be used. The semiconductor diodes must not only have a high front-to-back ratio, but must also accommodate reasonably high AC signal voltages without loss of sensitivity or burn-out.

At the video-amplifier output we may find a rather large signal—in fact, one greater than the voltage-handling capability of our diodes. If so, we can put two or more semiconductor diodes in series to increase our signal voltage-handling capabilities, as we did for the rectifier probe. In low-level circuits, however, the output of our probe may not be sufficiently great to provide a usable deflection on our oscilloscope. So we may have to use additional amplification. This must be a high-quality amplifier which introduces very little, if any, hum at all on its own; its frequency response should be essentially flat from about 20 to at least 500,000 cycles. A resistance-coupled amplifier must therefore have a gain of at least 20—and, if possible, higher.

SERIES DEMODULATOR PROBES

Here again we have a circuit like the one discussed at great length in the chapter on rectifier probes. This is still about the simplest probe we can make—which we do by placing a semiconductor diode in series with our shielded cable, as shown in Fig. 5-4. Between successive peaks of the modulated RF signal, this capacitance discharges somewhat, and then is of course charged again by the following RF pulse. If the cable acts as the capacitor, it will carry a series of pulses at the carrier frequency rate. These pulses may have serious consequences at those frequencies where the cable is a multiple of a quarter wavelength. Depending on the frequency, a condition of resonance or anti-resonance may exist which greatly change the sensitivity of the probe. Furthermore, since this cable capacitance is quite large, we would experience the negative-peak clipping mentioned previously

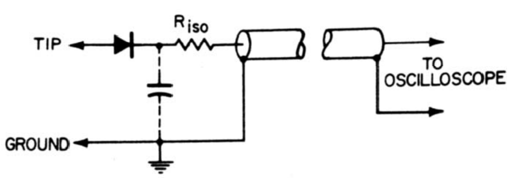


Fig. 5-4. Basic schematic of a series demodulator probe.

—horizontal-sync pulses would be greatly attenuated and severely distorted.

In order to avoid these difficulties, we must remove the cable capacitance from the circuit. We can do this with the rectifier probe by inserting an isolation resistor between the cable input and the demodulator output. The value of this resistor must not be too large. Otherwise, it will seriously distort the waveshape of the demodulated signal, as well as shift the marker position on the steep side of the response curve. The isolation resistor reduces the sensitivity of the probe somewhat. It is therefore best to make the resistor small (or even leave it out if we can) and compensate by other means—such as using a capacitor as a charging capacitor, in lieu of the cable capacitance.

We can rapidly discharge the cable capacitance by shunting it with a resistor, so our oscilloscope can follow the modulation envelope of high frequencies and steep pulses. The back resistance of the semiconductor diode determines the performance of the probe. This is a variable value; in fact, if the diode has a low back resistance, the shunting resistor may not even be needed because the cable capacitance can discharge through the diode.

Also to be considered is the effect of measuring an AC voltage when a DC biasing voltage is present. This bias voltage may even exceed our signal voltage; if it does, we will get no indication at all. If the signal peaks exceed the biasing voltage, we will get an indication only while the diode receives a signal in the conducting direction. This difficulty can occur in a series demodulator probe if a good blocking capacitor is not used and DC is present. (It can also be caused by a leaky oscilloscope input capacitor, even though a good blocking capacitor is used.) Ideally, the blocking capacitor is an open circuit. However, it does have some leakage resistance which, although high, is in series with our rectifier and input circuit. As such, it forms part of a voltage divider across any DC circuit we apply our probe to. It takes only a minute leakage, resulting in a small biasing voltage, to disable our probe. Therefore, if a probe is not working properly, the blocking capacitor should be one of the first items checked.

The DC blocking capacitor in the oscilloscope also becomes important when we use a series demodulator probe. Its leakage resistance is in series with the vertical attenuator. Thus, we do have a DC resistance path (it may be a great many megohms) between the vertical-input terminals. It and the back resistance of the semiconductor diode now form a voltage divider. If the probe is applied to the plate of a vacuum tube (which may be several hundred volts above ground), DC current will flow through the semiconductor diode, the leakage resistance of the capacitor, and the vertical attenuator, causing a certain amount of DC voltage to appear across our diode. This is undesirable because (1) the current, if sufficiently high, will damage the diode, and (2) the voltage drop across the diode may bias the diode into an operating region where its full sensitivity will not be realized.

Because these circuits are powered from a rectifier, hum voltages may be present. Although not noticeable on the picture tube of a television receiver, these hum voltages would be displayed, along with the signal under test, on our oscilloscopes. This is so because up to now we have had no means of 60- or 120-cycle rejection. We can correct this by adding a small capacitor in series with our semiconductor diode. That is the first job of this capacitor. The second one is based on the fact that, being small (usually mica or ceramic), its insulation resistance is almost infinite. We therefore will not have the DC current and diode biasing problems we would have without this capacitor. Of course, the problem is aggravated if our oscilloscope has no blocking capacitor. We could add a resistance, of a few megohms at most, from the input terminals to ground. However, large—and probably destructive — currents would develop through the diodes if we measured at the plate of vacuum tubes without using any DC blocking capacitors.

The input capacitance of the probe may be sufficiently high to detune the circuit under test. This effect not only is detrimental in some circuits, but may also cause regeneration. This difficulty is overcome by connecting a probe with a low input impedance across the stage *following* the one we are observing. The intervening stage, which acts as a sort of buffer, may also be tuned; but the low impedance of the probe will effectively swamp the tuned response of the circuit and thus prevent regeneration. Because it is now a low-impedance probe, its output is much lower than if it were a high-impedance one. We can usually take care of that by advancing the gain control on the oscilloscope. Although some output is lost, we have prevented our circuit from breaking into oscillation, which would make any observation impossible.

The probe in Fig. 5-5 is of conventional design, with a blocking capacitor, a series rectifier, and a network to filter out any RF impulses. The blocking capacitor should be as close to the rectifier as possible; its other end, designated the tip, should be short so it can be brought out directly to the point under measurement. The blocking and charging capacitors if of a good quality, should allay our worries that the leakage resistance of the oscilloscope input capacitor will harm our rectifier. (This type of low-impedance probe is often shown in the service manuals for television receivers.) If a low-impedance probe is not available, we can still use a high-impedance demodulator probe for meauring in a tuned circuit. This we do by adding a swamping network consisting of a DC blocking capacitor, plus a resistor of several hundred ohms, in series across our tuned circuit. The leads between the probe tip and the ground lead must be very short for both components.

It is of prime importance that the detuning effect of the probe be reduced. One way is to apply the output from a cathode-follower probe to the demodulator probe. Being a low-capacitance device, the cathode-follower probe is designed to do nothing more than pick off a signal with the least disturbance to the circuit. Its output can then be directly connected to the demodulator probe and, in turn, fed to the oscilloscope through a shielded cable. With signals of up to several mega-

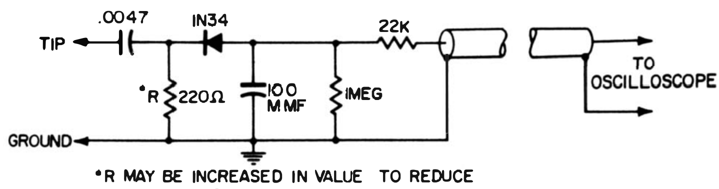


Fig. 5-5. Series demodulator probe (low impedance).

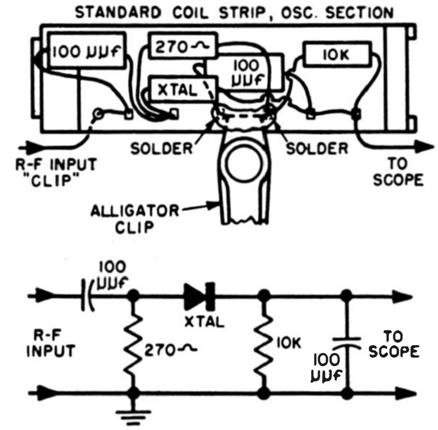


Fig. 5-6. Series demodulator probe suitable for alignment of overcoupled video-IF stages.

cycles, a demodulator probe is often unnecessary if the vertical-amplifier response of the oscilloscope is wide enough to accommodate them. We simply pick off our modulated signal with the cathode-follower probe, applying its output directly to the vertical-input circuit of the oscilloscope. This is a good arrangement for us to keep in mind when observing video-amplifier or sync circuits.

The series-demodulator probe in Fig. 5-5 is used most frequently for television receiver servicing, where it is moved from stage to stage during alignment or signal tracing. Since it is a demodulator (detector) probe and travels from stage to stage, it is often referred to as a "traveling detector." Fig. 5-6 shows the circuit and construction information of another simple probe suitable for alignment in video-IF stages. This probe is designed to give the proper loading for correct adjustment of overcoupled IF stages.

Fig. 5-7 shows the circuit of a series demodulator probe available in kit form; Fig. 5-8, a semiconductor-diode detector probe recommended by a TV manufacturer for aligning his television receiver. A high-impedance demodulator probe is shown in Fig. 5-9.

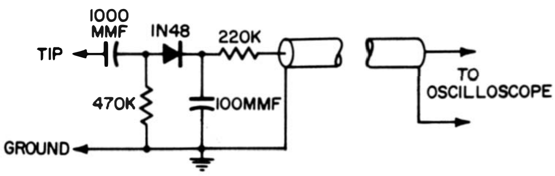


Fig. 5-7. Series demodulator probe available in kit form (Eico Model PSD).

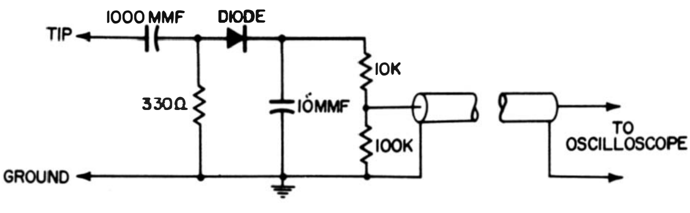


Fig. 5-8. Probe recommended for TV receiver alignment.

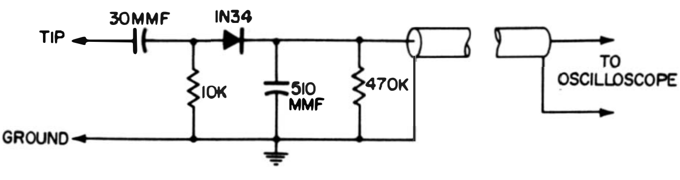


Fig. 5-9. High-impedance series demodulator probe.

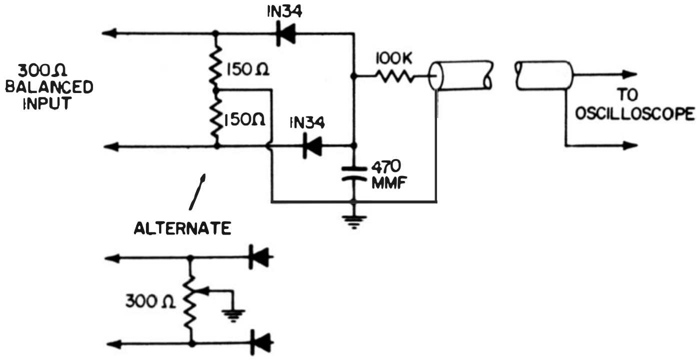


Fig. 5-10. Balanced demodulator probe having 300-ohm input.

BALANCED DEMODULATOR PROBES

A balanced demodulator probe will often be useful, just as the rectifier probe has been, for observations in such balanced circuits as a twin-lead transmission line or the input of television receivers, boosters, or converters. The probe in Fig. 5-10 has a balanced 300-ohm input and a single-ended, or unbalanced, output. Two rectifiers, connected in the same direction, are employed. This arrangement is satisfactory without a DC blocking capacitor because there is usually no DC voltage where balanced measurements are made. The charging capacitor receives alternate pulses from either diode. When one diode is conducting at its maximum, the other has a signal in the opposite direction, also of maximum magnitude. These polarities alternate at the frequency of the signal under measurement. The output signal from the probe is the modulation envelope of the amplitude-modulated signal under test. The ground lead from our probe should be kept as short as possible and connected to the nearest ground. If a balanced demodulator probe is not available and measurements under balanced conditions are desired, we can use two identical demodulator probes in parallel, and also connect their outputs in parallel to our oscilloscope. This method is shown in Fig. 5-11. Be sure the diodes in both probes are connected in the same direction.

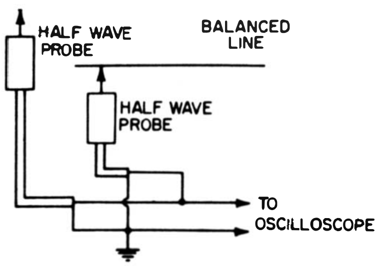


Fig. 5-11. Two identical half-wave probes used to make measurements on a balanced line.

A balanced high-impedance probe is diagramed in Fig. 5-12.

If we use only one unbalanced probe to measure on a balanced

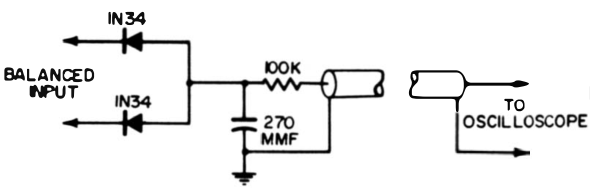


Fig. 5-12. Balanced high-impedance probe.

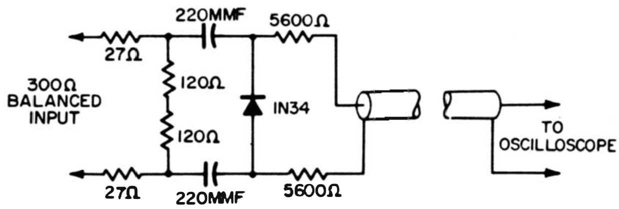


Fig. 5-13. Balanced 300-ohm probe using only one semiconductor diode.

line, we will upset the balance and thus get an erroneous indication. It is therefore advisable, when making measurements in a balanced circuit, to construct a balanced probe, or else use two probes as outlined in the previous paragraph. Fig. 5-13 shows the schematic of another balanced probe which uses only one diode, but still offers a balanced input of 300 ohms and an unbalanced output to our oscilloscope. This probe can be constructed on terminal strips. It does not have to be shielded because the low-valued resistors make it relatively insensitive to extraneous pickup.

PEAK-TO-PEAK OR VOLTAGE-DOUBLER DEMODULATOR PROBES

We can get a more sensitive probe by making a voltage-doubler or peak-to-peak reading probe. The probe is referred to as one or the other, depending on the type of signal measured. With a symmetrical wave, we will have a voltage-doubler action; but with an unsymmetrical wave, the output voltage will equal the peak-to-peak value of that waveform. The operating principles of the voltage-multiplier circuit are identical to those discussed in Chapter 4, except the time constant is much shorter. A typical voltage-doubler demodulator probe is shown in Fig. 5-14. With a symmetrical signal, a voltage-doubler probe will produce, on our oscilloscope, twice the deflection a half-wave probe would. Such a voltage-doubler probe is therefore useful at low signal levels. However, because it has a lower input impedance than the half-wave probe, it is suitable only for measurements where impedance levels are relatively low. This characteristic may turn out to be the limiting factor in some applications. The frequency response of this probe is also not as good as that of a half-wave probe.

The input capacitor and output charging capacitors are again made rather small in order to make the probe relatively insensitive to 60- or 120-cycle hum. The signal-handling capabilities of our probe are once more limited by the voltage rating of the diode. The DC level at which measurements are made should not exceed the voltage rating of the probe input capacitor. AC voltages in excess of 50 volts peak will tend to produce pattern distortion, whereas inputs in excess of 60 volts peak can impair the sensitivity of the semiconductor diodes, or even burn them out completely. Because of the 60-cycle rejection capabilities of our probe, we can make tests for RF in filament, AGC, and B+ cir-

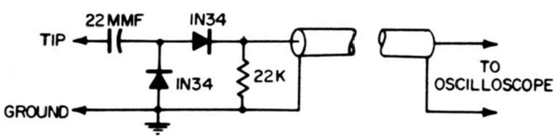


Fig. 5-14. A voltage-doubler demodulator probe.

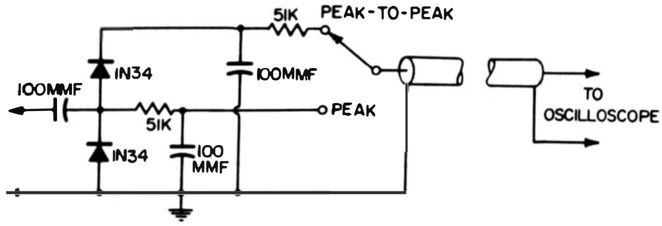


Fig. 5-15. Combination peak and peak-to-peak reading demodulator probe.

cuits, and thus check to see whether or not the filtering, bypass, and decoupling capacitors are doing their jobs.

Because of the similarity of design between demodulating and meter rectifier probes, we are also faced with corresponding problems. Just like a rectifier probe, the peak-to-peak probe may provide more or less than twice the output of a half-wave probe. The reason, of course, is that again the signals may not always be symmetrical in their positive and negative excursions. Hence, if we measure the larger excursion with our half-wave probe, the peak-to-peak probe will give us less than twice the output of the half-wave probe. Conversely, if we measure the smaller excursion of the modulated signal, the voltage-doubler probe will then give us more than twice the reading of the half-wave probe.

In order to check the half-wave and voltage-doubler probes against each other, obtain a symmetrical signal, preferably one you can control (from a signal generator, for example). First, observe this signal on an oscilloscope, to see whether both halves of the modulation envelope are equal. Then take measurements with both probes to see whether the voltage-doubler probe gives exactly twice the output of the half-wave probe.

A peak-to-peak indicating circuit can be modified to give only peak voltage readings. This is done by means of a switch, which eliminates one diode and capacitor from the circuit. An example of this type of circuit is shown in Fig. 5-15. When the switch is in the "peak" position, only one diode is in use. In the

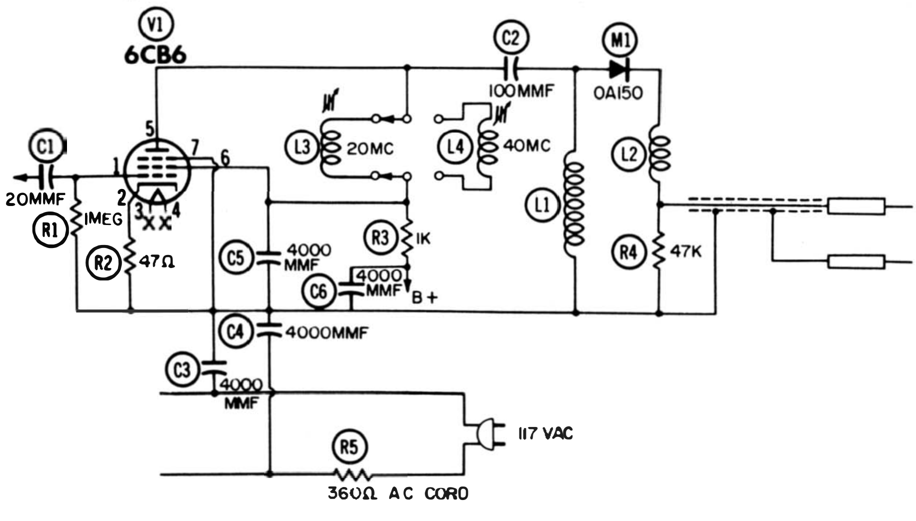


Fig. 5-16. Tuned high-gain RF demodulator probe (Doss D-200).

"peak-to-peak" position, both diodes are active.

Fig. 5-16 shows the schematic of a tuned high-gain RF demodulator probe containing a calibrated, adjustable amplifier tunable over the 20- and 40-megacycle IF bands. This probe is useful for demodulation, alignment, and signal tracing in IF stages of television receivers. It amplifies the composite video signal before demodulation to thus yield a larger output signal than a demodulator probe does without amplification.

DEMODULATOR PROBE SELECTION AND USE

The RF and IF frequencies in television receivers are too high to be displayed directly on an oscilloscope. Before these signals can be observed, they must be demodulated so a modulation envelope can be obtained. In other words, a demodulator probe extracts the signal from the RF carrier. This signal will have a DC component and, on a DC oscilloscope, will be displayed vertically by an amount equal to the DC component. On an AC oscilloscope, the signal will be centered about the zero axis.

The demodulator probe adds a certain amount of capacitance. This we must take into account when measuring the stage gain and characteristic of tuned circuits, because the output voltage of our probe may not be the same as the actual voltage at the point of measurement (depending in which direction our probe detunes the circuit). Sometimes the probe may supply the necessary additional capacitance to properly tune our circuit; then we would get a better indication than without the probe. On the other hand, if our probe detunes the circuit, the indication would be lower than normal. The circuit may also break into oscillation when the probe is applied, in which event any indication would be completely meaningless.

Demodulator probes should be shielded so they will not pick up voltages, other than those at the point under observation. If a probe is simply held near a field-producing element (such as the horizontal-output transformer of a television receiver), there will of course be an indication, which should disappear as soon as the probe is connected to the point under test. To check the shielding of our probe connect a small resistor of perhaps 10,000 ohms between the tip and ground. With the resistor connected in this manner, move the probe around the television chassis. If the probe is properly shielded, there will be no indication on the oscilloscope.

Briefly comparing the characteristics of series, shunt, and voltage-doubler probes, we will find that the series-demodulator probe is somewhat more sensitive, but does not attenuate hum as much as the shunt-type demodulator probe does. Furthermore, the series-type probe, although more sensitive, causes more distortion – which becomes objectionable if faithful reproduction of the demodulation envelope is important. The shunt-type demodulator probe is less sensitive, but provides a somewhat greater rejection of hum and higher fidelity of demodulation. The voltage-doubler probe has a higher sensitivity, but its frequency response is more limited.

The ambitious person who wants to build his own probe will do well to pay close attention to the following. The probe should be carefully shielded. If a balanced probe, it must be balanced both mechanically and electrically. Connections within the probe should be short, and components must be suitable for high frequencies. The resistors should be small, noninductive carbon or carbon-film; and capacitors must be disc ceramic or small mica. Furthermore, two or more diodes used together, especially in a balanced arrangement, should have matching forward and back resistances.

A tuned circuit can be used with a demodulator probe—either a coil with a capacitor across it, or one resonating with its own distributed capacitance. The tuned circuit is connected between the tip and the ground connection of the probe, and is then placed near the circuit whose waveform we wish to observe. The resonant circuit of the probe should be tuned to the same frequency as the circuit under test. The advantage of such an arrangement is that the coupling to the tuned circuit can be made quite loose. Thus, the circuit under test will not be loaded and thus disturbed as much as it would if a direct connection were made with a demodulator probe. For this purpose, we can use an IF coil if we wish to make observations in the IF circuit, or a video-peaking coil in a video circuit. Minimum additional capacitance is almost always desirable because the distributed capacitance of a probe will add enough to assure resonance at the desired frequency.

Sometimes we may wish to pick up a signal by placing a floating shield over the tube and connecting our demodulator probe to it. We will indeed pick up a signal—plus extraneous signals which may be picked up from the horizontal- and vertical-sweep circuits. In many instances, the interfering signals will override the one under test. To overcome this difficulty, it is best to disable the sweep circuits.

In RF measurements, keep the ground lead very short, and make the ground connection as close as possible to the ground return of the point where the signal is taken off. This fact cannot be over emphasized. More often than not, beginners mistakenly use just any point as a ground, and then simply move the probe clip around. More than anything else, the ground connection may, at frequencies above 100 megacycles, determine the correctness of our response curve.

The length and position of the ground lead are also important. The ground return lead is part of the RF carrying circuit and, as such, the demodulator circuit. In a probe used for meaurements up to the video range, the position of the ground clip may not be overly critical. On the other hand, with TV carrier frequencies, it must be short and direct. If the ground return is too far from the probe, deceiving displays will be obtained because of ground current loops in the chassis. A simple DC ground connection, made to an arbitrary point somewhere on the chassis, is not always satisfactory.

Because of its loading effect, the demodulator probe should always be applied to low-impedance points. If we have no such point and do not want to swamp the circuit, we can insert a resistor of several ohms in the cathode circuit of a tube. The resistor will often develop across it sufficient signal to give a usable display on our oscilloscope, and yet not load the circuit if picked up by the demodulator probe. The blocking capacitor, of course, will eliminate any DC voltage developed from this connection.

A detailed treatise on the use of demodulator probes in servicing television receivers is beyond the scope of this book. We will therefore touch only on some of the highlights, to whet the reader's interest.

The response of a video amplifier can be checked in two ways. Both require that a swept video signal be applied at the video-amplifier input. The output signal can be applied directly to the vertical-input circuit of a wide-band oscilloscope, or it can be demodulated with a demodulator probe and its output displayed on an oscilloscope. When we observe the swept output signal directly without a probe, the display looks somewhat like Fig. 5-17. We run into a little problem there because the response of our oscilloscope must be essentially flat up to at least 4.5 megacycles.

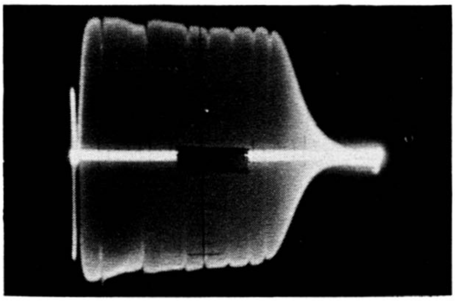


Fig. 5-17. Video-amplifier output, showing response to a video-frequency sweep signal.

A much simpler way to display the video-amplifier characteristics on our oscilloscope is to use a demodulator probe. What we do is apply the video-amplifier output to the demodulator probe, and then observe the modulation envelope on our oscilloscope. However, our oscilloscope must definitely be able to display a 60-cycle square wave with no distortion, because the sweep generator usually operates at a 60-cycle sweep rate. If the video-amplifier characteristics were ideal, amplification would be equal for frequencies up to 4.5 megacycles. As a result, the response curve would increase sharply at the low-frequency end, stay flat all the way up to the highest frequency, and then drop off sharply. This, of course, is a square wave; and since each sweep is completed in one-sixtieth of a second, a 60-cycle square wave is thus displayed. When a demodulator probe is used, the picture-tube socket should be removed from the picture tube and the probe inserted at the point where the video signal is obtained, because video circuits are critical as far as shunt capacitance is concerned. What we have done is remove the effective capacitance of the picture tube and substitute an equal amount of capacitance presented by our demodulator probe. The swept signal, if used directly, should be connected to the oscilloscope through a low-capacitance probe. We apply this signal to the video-amplifier input, and apply the output from our demodulator probe to the vertical-input circuit of the oscilloscope. A marker signal should also be applied so the frequency characteristics of the video amplifier can be determined. The value of the series filter resistor in the demodulator probe now becomes of great importance. The time constant of the resistor and the filter capacitance of the probe must be long enough to give the probe a good response for a signal as low as 60-cycle square wave. In this way, the display near zero frequency will be correct, not fuzzy, because of the inability of the probe to respond to those low frequencies.

Video amplifiers can also be tested with square waves at several frequencies. The demodulator probe is not used. Instead, we apply the output from our video amplifier through a low-capacitance probe, to the vertical-input circuit of a wide-band oscilloscope.

Sweep generators used for RF and IF alignment also operate at a sweep frequency of 60 cycles. As we can see from Fig. 5-18, a response curve also approximates a square wave. For an undistorted display, our oscilloscope and demodulator probe must not distort a 60-cycle square wave. A flat-top response curve obviously would be a square wave.

Our probe must be able to display a 60-cycle square-wave modulation envelope; and it can be so designed, depending on how rapidly we can charge and discharge the

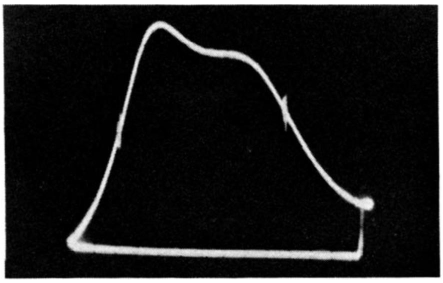


Fig. 5-18. Typical response curve of a tuned circuit.

capacitance in the circuit. This, in turn, depends on the magnitude of that capacitance. The smaller it is and the lower the resistance we discharge into, the faster this charge and discharge can occur. However, as we increase our square-wave modulation frequency, we experience difficulties with phase shift and attenuation. The latter show up as rounded corners of the demodulated square wave, becoming more severe as the modulation frequency increases. It is therefore easy to see that a probe, unless designed to do so, will not faithfully display horizontal-sync pulses. One way of alleviating this situation is to reduce the effectiveness of our low-pass filter network by eliminating the series resistor which isolates the cable capacitance from the probe. This may clear up the difficulty somewhat. However, it will cause difficulties as our carrier frequency increases, because of the effect of the RF pulses on the cable (as outlined previously). We must therefore arrive at some compromise value of resistor which will isolate sufficiently, yet not affect the fidelity of demodulation too greatly. Too large an isolating resistor will also shift the marker pip on the steep side of a response curve because of the time delay in the RC network.

We can test our probe by using the output from a 60-cycle square-wave generator to modulate a RF signal, and then apply the modulated RF signal to our demodulator. The output of the probe should again be a 60-cycle square wave, and the fidelity of the square wave will be a direct indication of the demodulation capabilities of our probe.

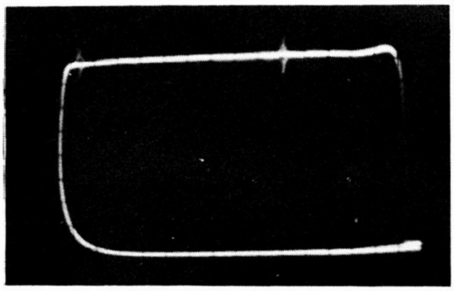
Demodulator probes can be used with either AC or DC oscilloscopes. The advantage of a DC scope is that we can obtain a zero-voltage level, which greatly facilitates the measurement of response curves. Demodulator probes sometimes do not have output capacitors and, if used with DC oscilloscopes without a blocking capacitor, will displace the output signal from the center line by an amount proportional to the DC level of the RF carrier. In scopes with blocking capacitors, the waveform will be displayed in the center, as usual.

Demodulator-probe characteristics at low frequencies (in the audio-frequency range) are of interest. With most probes, if we apply an audio signal in various frequencies—starting from perhaps 20 to 30 cycles or so and going up to several hundred thousand cycles—we will experience feed-through over a certain broad frequency range. This will manifest itself as an output voltage equal to the input voltage, without being modified in any way. This feed-through characteristic will drop off at high and at low frequencies for two reasons. (1) At the high-frequency end, the filter characteristics of our RF network will attenuate; and (2) at the low-frequency end, the reactance of the input capacitor will become very high. This behavior, which is normal for demodulator probes, should be remembered.

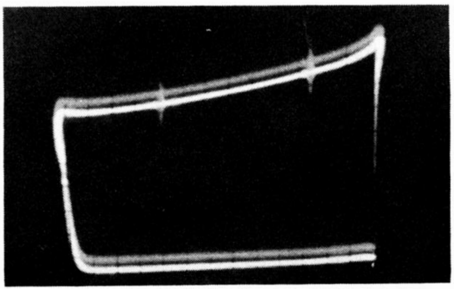
Be extremely careful not to overload the probe and thus damage the semiconductor diode. Never apply the probe to the horizontal- or vertical-deflection circuits because even a momentary contact will immediately burn out the diode.

Semiconductor diodes are rather sensitive to heat. So, if one must be replaced, hold the lead with a pair of pliers, which will serve as a heat sink to conduct the heat from the soldering iron or gun away from the diode. Also, it is advisable, when using a probe in a television receiver, not to lean it against hot vacuum tubes or resistors because enough heat may be conducted through it to ruin the diode.

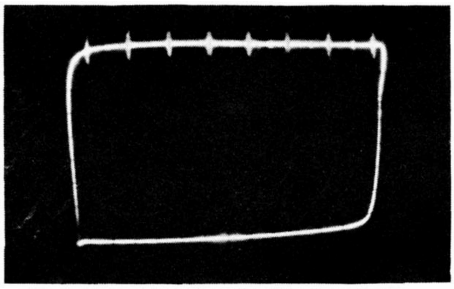
The accuracy and linearity of the output from a sweep generator can be tested with a demodulator probe and oscilloscope, as shown in Fig. 5-19. Connect the demodulator probe to the properly terminated output from the sweep-generator cable, and the output from the demodulator probe to the vertical-input terminals of the oscilloscope. Couple in a marker signal through a small coupling capacitor. (One or more mark-



(A) Generator with flat output. Markers at 41.25 and 47.25 mc.



(B) Output from a second generator. Markers at 41.25 and 47.25 mc. Output is acceptable for all practical purposes.



(C) Space between markers is 1.5 mc. Equal spacing indicates linear output from generator.

Fig. 5-20. Oscilloscope displays of sweep-generator characteristics. (Courtesy of General Electric Co.)

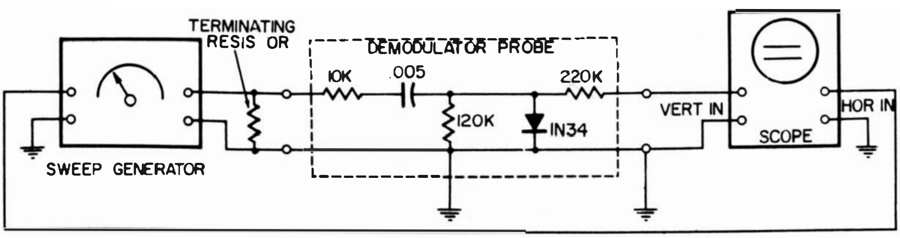


Fig. 5-19. Equipment setup for testing flatness and linearity of sweep-generator output.

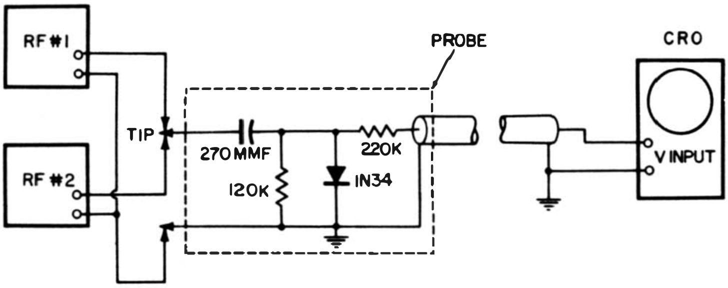


Fig. 5-21. How to compare the frequency of one RF signal with another.

ers can be used.) Fig. 5-20A shows the output from a sweep generator with markers at 41.25 and 47.25 megacycles. The output from this generator is of constant amplitude over this particular band. Fig. 5-20B shows the output from another generator, with a slight variation in output amplitude. The tilt in the curve is due to the variation in amplitude along the swept band. This error is not too great and is acceptable for all practical purposes. We can check the sweep linearity by injecting a series of markers and noting the separation between them. If the markers are equally spaced, the linearity is good over the swept band. See Fig. 5-20C for a scope display showing properly spaced markers. Sixty-cycle horizontal deflection is required, either from within the oscilloscope or from the sweep generator.

A demodualtor probe can also be used to check the frequency of one RF signal against another, as shown in Fig. 5-21. The RF signals from the two sources are fed to the input circuit (one end of the 270-mmf capacitor), and the output signal from the demodulator is fed to the vertical-input terminals of the oscilloscope. Then the frequency of one of the signals is varied. As we approach and go through the same frequency as the other signal, we will observe a zero-beat pattern on the oscilloscope screen.

In order to check the characteristic impedance of a line, we connect one end to a sweep generator with the appropriate center frequency. At the other end we connect a balanced probe, as shown in Fig. 5-22. The load resistor should be equal to the characteristic impedance of the probe; so, we use two 150-ohm resistors in series to give us the required 300 ohms. The center con-

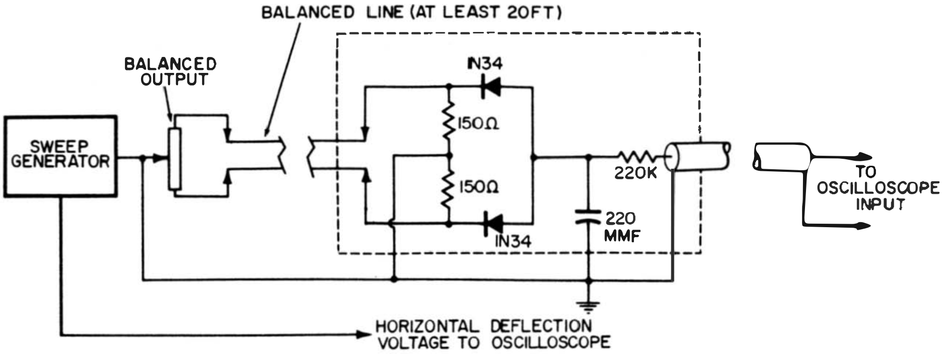


Fig. 5-22. How to check the characteristic impedance of a balanced line.

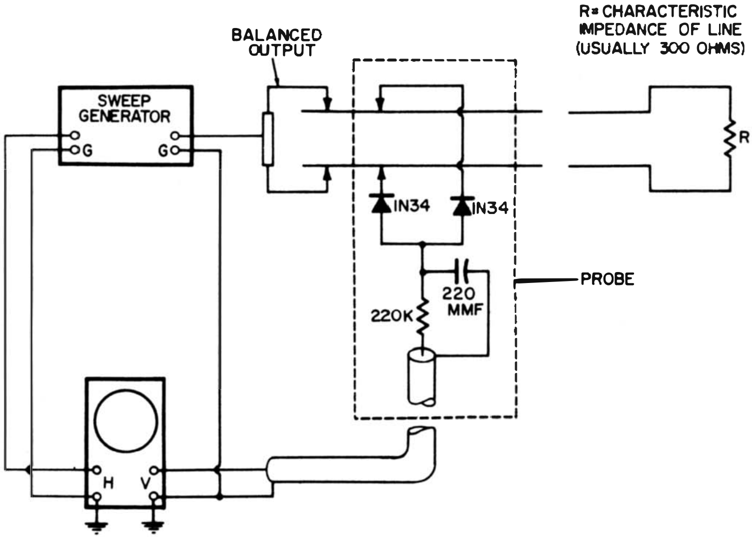


Fig. 5-23. Another way to check the characteristic impedance of a balanced line. (Generator and oscilloscope on the same side of line.)

nection between the cable and resistors is grounded to provide a DC return for the probe.

If the characteristic impedance of the line is equal to 300 ohms, the display on our oscilloscope will be a straight line. If other than 300 ohms, the display will be curved, the amount being directly proportional to the degree of mismatch. At least twenty feet of transmission line must be used in order for a satisfactory indication to be displayed on the oscilloscope. If the line is shorter, the standing waves may not be strong enough to develop a satisfactory indication.

It is inconvenient to run horizontal-deflection voltages from the sweep generator to the oscilloscope if the two instruments must be separated by twenty or more feet. If so, the setup in Fig. 5-23 may be more desirable. Here, the oscilloscope and sweep generator are next to each other, and the probe is connected to the same end of the line to which we apply the output from our sweep generator. The other end of the transmission line must be terminated by a load resistor equal to the characteristic impedance of the line. Here, however, the resistor need not be center-tapped because no ground return is required. The

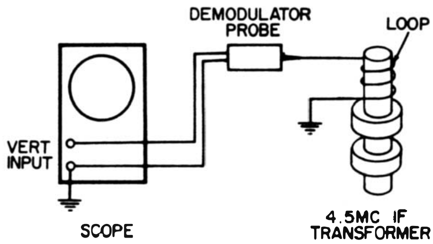
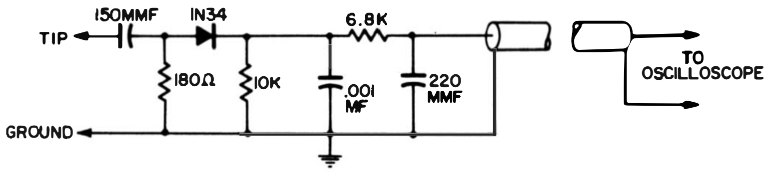


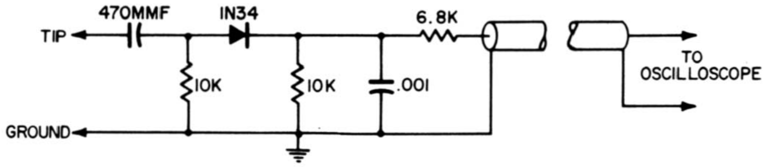
Fig. 5-24. How to check the 60-cycle sync-buzz voltage in a reciever.

terminating resistors in either setup must be noninductive carbon types.

We can apply a voltage-doubler probe directly to the 4.5-megacycle sound circuit in order to measure the percentage of downward modulation due to 60-cycle buzz voltage. For this measurement, we will require a DC oscilloscope. A pickup loop like the one in Fig. 5-24 can be used to check for sync buzz in IF and video amplifiers.



(A) Low impedance.



(B) High impedance.

Fig. 5-25. Demodulator circuits.

Voltage-doubler probes can also be used for making tests in the chroma bandpass amplifier and other video-frequency circuits of color television receivers. The probe should be applied across a low-impedance point, such as the color-intensity control, in order that the probe shunt capacitance will disturb the circuit as little as possible. It should not be connected across the filter coils because shunt capacitance will change the bypass characteristics of the circuit.

In order not to present a noticeable load to the circuit under test, the probe should have an impedance at least ten times as high as the impedance at the circuit point under consideration. For certain alignment procedures, the oscilloscope must be connected to the output of the video-IF stages—preferably through a low-impedance detector like the one in Fig. 5-25A. On the other hand, a high-impedance detector is more desirable for aligning chroma and sound-IF amplifier stages. One such detector is shown in Fig. 5-25B.

The low-frequency limit of the demodulating capability of a demodulator probe can be checked as shown in Fig. 5-26. The output from a video-frequency sweep generator is fed through a marker box to the demodulator probe, the output of which is connected to the input terminals of an oscilloscope. An absorption-type marker is preferred because it does not give confusing beats. As the lower frequency limit of the probe is approached, the probe output falls off and shows evidence of incomplete rectification and filtering. The lower frequency limit can be determined by adjusting the marker to this point.

The peak-to-peak reading with a VTVM rectifier probe will give an indication of the peak-to-peak value of the signal, but will ignore anything between the peaks. Let us look for the moment at the waveshape in Fig. 5-27. The smaller sig-

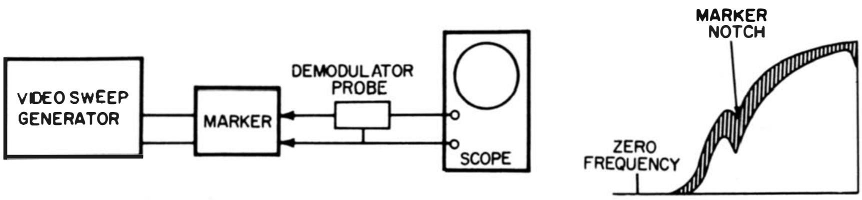


Fig. 5-26. How to check the frequency-demodulation limit of a probe.

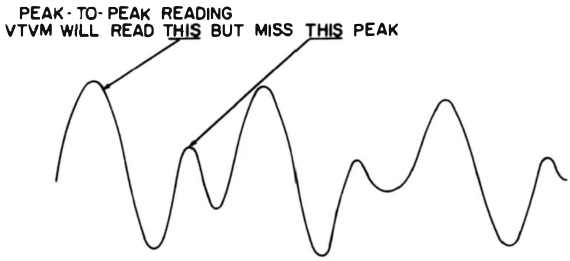


Fig. 5-27. Waveshape having two different values of peak voltage.

nal between the peaks might just as well not be there, as far as the vacuum-tube voltmeter is concerned. Its presence or absence will not be indicated on the meter. On the oscilloscope, however, it is clearly shown.

A demodulator probe can be converted to a peak-to-peak or peak-reading rectifying probe by adding a relatively large capacitor across its output circuit. This is shown in Fig. 5-28. The capacitor can be added externally and the voltage across it applied to the input terminal of the vacuum-tube voltmeter. The DC voltage indication will then be proportional to the peak value of the voltage under test.

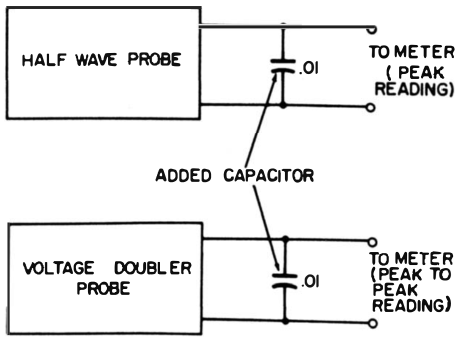


Fig. 5-28. Converting demodulator probes for use with meters.

Chapter 6

SIGNAL-TRACER AND -INJECTOR PROBES

SIGNAL tracing and substitution offer two valuable methods for servicing electronic equipment. They are often quicker than voltage and resistance measurements or parts substitution, although not always more advantageous. Which method to use depends on the complexity of the circuit and the degree of difficulty we experience. Signal tracing or injection are normally employed when the circuit, although not completely inoperative, is malfunctioning to such a degree that the difficulty cannot easily be found with the classic measuring methods.

Even though voltages and resistances may be of the correct value, or within the limits specified in the applicable service literature, the circuit still may exhibit the wrong waveshape, or its frequency may not be correct. Some circuits may develop difficulties only when a signal is applied to them. A signal-injector probe duplicates this condition by substituting a signal.

SIGNAL TRACER PROBES

A signal tracer is one of the simplest yet most effective instruments for rapid and accurate troubleshooting of electronic circuits. Its biggest advantage is that it permits the circuit to be checked under dynamic operating conditions. The technique of signal tracing is relatively easy and straightforward. A test signal, or one from a transmitting station, is applied to the circuit. Then the signal tracer is moved progressively *from the input to the output* of the equipment under test. At the same time, the test signal is checked to see if it is present, and if so, whether it has been amplified or reduced (or perhaps distorted). An inoperative or maladjusted stage can thus be quickly localized, and then other static measurements made, to further localize within that stage the defective component or components. The most popular tracer is the easy-to-operate untuned type, which has no controls except perhaps one for volume.

The probe required for a particular signal-tracing job depends on the type of signal, which in turn depends on the circuit under observation and whether the equipment under test can supply its own signal. (Before we can trace a signal, we must obviously have one to begin with!) The frequency and nature of the signal to be measured are also important. What kind of signal is it—AF, low or high RF, modulated, pulse, or what?

A TV station signal is usually traced with a semiconductor demodulator probe. The probe output is applied to the vertical-input circuit of an oscilloscope. If the television signal is weak, the display on the oscilloscope may be too small to be of any value. The thing to do here is substitute another signal for the one from the television station, or else use a probe which amplifies the signal before applying it to the oscilloscope.

A signal-tracer probe (as well as its output cable) must be shielded so it will not pick up extraneous signals or hash from stray fields and thus mask out our signal.

Our choice of a demodulator probe is also governed by the output desired. Do we want maximum output? Or will we be satisfied with a good match and the least loading? In a demodulator probe, sensitivity must be sacrificed for fidelity. For signal-tracing purposes, however, we are ordinarily more than willing to do the opposite—particularly in low-level stages like those in the RF, mixer, and first-IF stages of a television receiver. For this reason, semiconductor probes intended for signal tracing usually compromise between providing the highest possible output while maintaining reasonable fidelity, so they will be suitable for observing video-amplifier output signals and the waveshapes in TV sweep and sync circuits.

The classic approach to signal tracing involves simply moving the probe from stage to stage, starting at the front and moving toward the output of higher-gain stages, while noting the increase in signal at each successive stage. Initially, it is advisable to go from plate to plate, rather than from grid to plate or plate to grid, because the impedances are usually lower in the plate than in the grid circuits. Thus, the test probe does not affect the plate circuits as severely as it does the grid circuits. The ratio between the signal at the output of a stage to the one at the output of the preceding stage is the gain of the stage being measured.

A sweep signal can also be traced through the IF-amplifier stages. However, the resultant pattern does not usually represent the true response of the stage or stages under test. The reason is that the loading effect of the probe alters the response characteristics of the circuit. This loading effect can be reduced considerably by using a low-capacitance or cathode-follower probe ahead of the signal-tracer probe, or by making the plate load of the last tube nonresonant. The latter is done by shunting (swamping) the load with a resistor of a few hundred ohms.

Some signal-tracer probes are so sensitive that, when held close to a tube pin or on top of an insulated wire carrying a signal, they will pick up enough signal by capacitive coupling to give a suitable indication. This type of signal pickup gives less circuit loading than some others.

The main purpose in signal tracing is not to show the exact waveform or faithfully reproduce the signals at a particular point of a circuit. Rather, it is to show the presence or absence, or the strength or weakness, of a signal at that point.

Signal tracing from stage to stage by means of an oscilloscope affords a rapid and convenient method of locating a defective circuit. Many circuits (such as sweep circuits) generate their own waveforms; therefore, no external signal is needed. On the other hand, audio and video amplifiers and sync circuits do require an external signal, from either a broadcasting station or an audio generator or oscillator.

Aside from showing the approximate gain in each stage, a signal tracer will also meet the challenge of a dead receiver in which all voltages seem normal. Starting at the

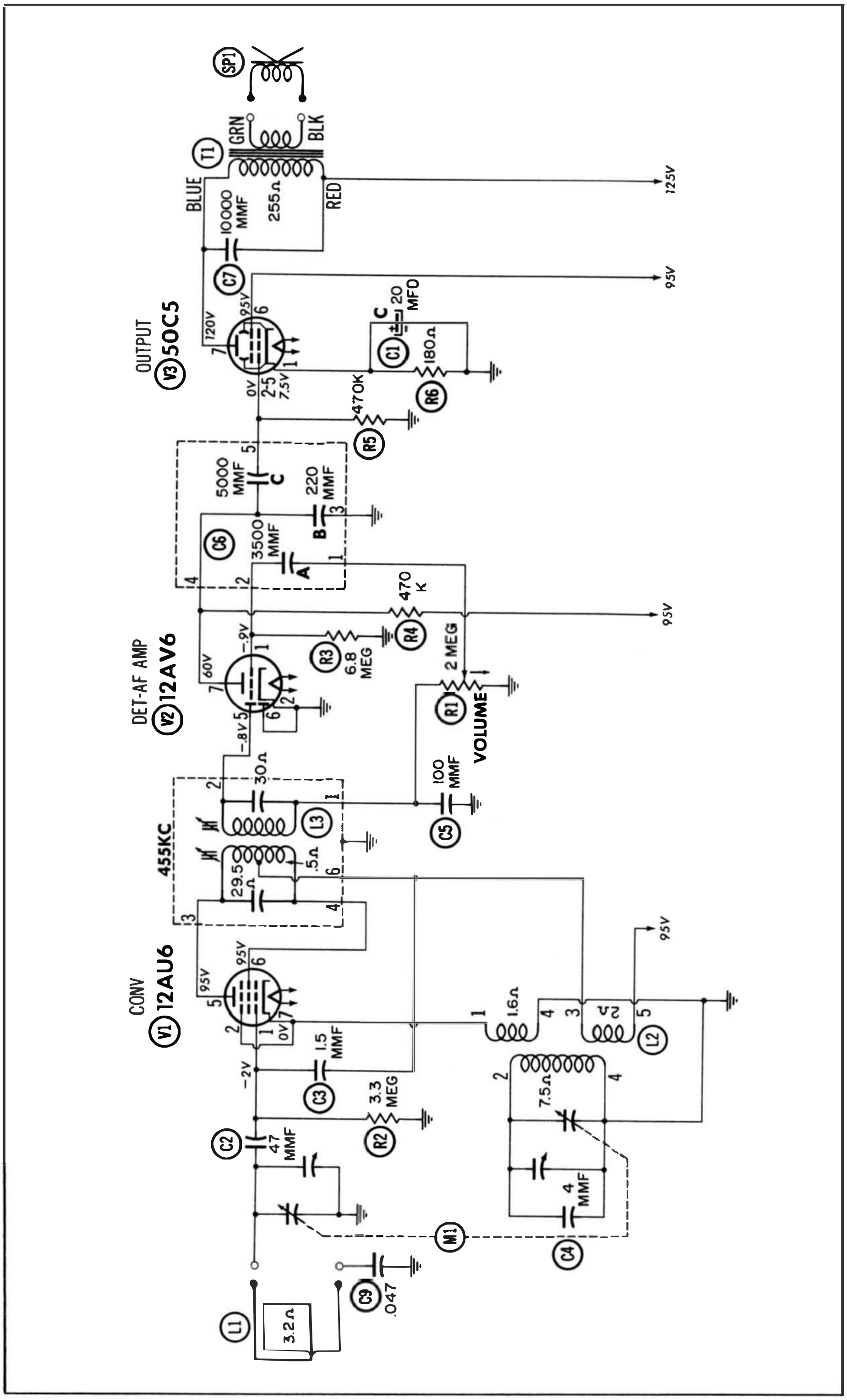


Fig. 6-1. Schematic of a typical superheterodyne receiver.

antenna, we work from plate to grid to plate, etc., until we reach the point where we completely lose the signal. The trouble is between this point and the one where the signal was last encountered.

A signal-tracer probe will help us locate an intermittent. As we trace the signal, we tap the chassis or tube gently (preferably with the eraser end of a pencil) until we find the intermittent.

A signal tracer will also tell us whether or not there is a signal. For example, in the schematic of Fig. 6-1 we see a 20-mfd capacitor in the cathode circuit of the AF power-output stage. This capacitor should bypass any audio signal in the cathode circuit. But suppose, when we apply the probe at the cathode, we do find an audio signal there? This would be a good and quick indication that the capacitor is open or weak. Otherwise, no audio signal could develop across the cathode resistor. Hence, the signal-tracer probe is a quick and simple device for indicating the condition of bypass capacitors.

As we go toward the output of an audio amplifier, we will notice a substantial increase in the signal. However, going from the primary to the secondary of the output transformer, we will observe just the opposite. Because we are moving from a high-impedance, high-voltage primary to a low-impedance, high-power secondary, we will obviously get a reduction in voltage. After all, a signal tracer indicates only voltage —not audio power.

A demodulator probe and an oscilloscope can be used to trace a modulated RF signal—from the antenna, all the way through the detector stages—at frequencies of up to several hundred megacycles. Tune the receiver to some frequency within its range, and feed a fixed signal (from a signal generator) into the antenna terminals. (The signal from a transmitting station may be used, but one from a signal generator is preferred because it is steady and can be kept under control at all times.)

An attempt to evaluate gain may sometimes lead to confusion because the capacitive loading effect of the probe may detune the circuit. For example, in Fig. 6-2 the tracer probe (connected to an oscilloscope) is shown checking either side of the coupling capacitor, between the RF

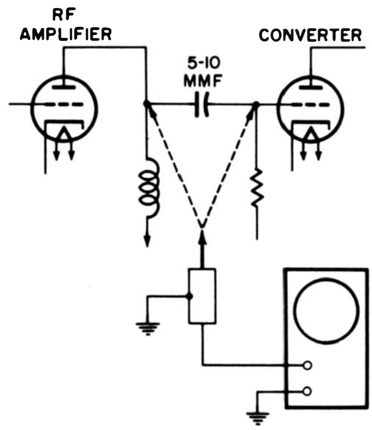


Fig. 6-2. Signal tracing in an RF-converter stage.

amplifier and converter stages. (This capacitor usually has a value of between 5 and 10 mmf.) At the plate of the RF amplifier we may get a deflection of, say, ten units on our oscilloscope. However, at the grid of the converter stage, we may get a deflection of only six or seven units. This is rather confusing, to say the least.

There is nothing wrong with the circuit—it is just the additional capacitance of the signal-tracer probe that is giving us trouble. The probe input capacitance is somewhere around 10 mmf. When applied at the grid of the converter tube, this additional capacitance forms a voltage divider with the coupling capacitor. The full voltage at the plate of the converter is now divided between the coupling capacitor and the input capacitance of the detector probe. We read on the scope only the voltage across the detector probe. Therefore, this voltage will be lower than the one that would normally reach the grid of the converter tube if there were no additional shunt capacitance from the signal-tracer probe. To understand the use of a signal tracer, look at the schematic in Fig. 6-1, and note the various test points. Assume this receiver has been suffering from low volume and we want to find out why. Since it is operating, let us turn it on and tune in a local station. The volume control should be turned down so the speaker output will not interfere with the output from the signal tracer. Clip the ground lead of the probe to the B— or ground point of the receiver. If the receiver is tuned to a strong station, we should be able to pick up the signal right at the antenna and tuning capacitor. That would be the grid (pin 1) of the pentagrid converter. Then we move to the plate, which is pin 5, and then to the detector plate, which is pin 5 of the second-detector–first audio-amplifier tube.

Up to this point the probe switch was in the RF position. But after the signal is detected, it becomes an audio signal, and we no longer need the demodulation properties of the probe. So we switch to AF. Now we have the simple type of capacitive audio tracer probe discussed later. Some signal tracers do not combine the RF and AF functions in a single probe, but use a separate one for each. If we were using such a tracer, we would merely lay down the RF probe, take up the AF probe, and continue tracing. Starting at the detector stage, we now trace our signal through the various audio circuits to the output stage, output transformer, and speaker. A loss of signal in any stage would quickly and easily indicate a faulty circuit.

As we trace the signal, we get an indication of the gain of each stage by the increase in signal. (It is advisable to make this test on an operative receiver first, so you can gain experience in using a signal tracer.) When applied to the tuned circuits, the probe has a slight detuning effect. It should then be advanced to the following test point. If the test signal there is good, it is reasonable to assume the preceding stage is functioning properly. The same test procedure applies to the RF and IF stages of FM and television circuits, except the probe output is usually displayed on an oscilloscope. A semiconductor demodulator probe is used for checking all the way from the front-end or antenna terminal to the picture-tube input. We can go rather rapidly from the front-end — through the mixer and IF stages to the video-detector, -amplifier and -output stages—right up to the cathode-ray tube. In this way, we can trace the signal through the receiver and note where and how losses or disturbances occur. (A more detailed discussion of these servicing techniques is beyond the scope of this book.)

Fig. 6-3 shows a semiconductor-diode signal tracer which requires no external power supply and provides audio output as well as a meter indication. This instrument can be used for troubleshooting the RF, detector, oscillator, IF, and audio stages of the receiver, as well as in audio amplifiers. A 1N54 high-efficiency germanium crystal diode improves the performance. The .01-mfd RF bypass capacitor at the input protects the diode, headphones, and meter from any DC voltage in the circuit under test, but passes audio and RF signals. The 200,000-ohm gain control in the meter circuit allows the meter movement to be adjusted for a suitable deflection. The stronger the signal, the more the resistance inserted into the circuit, and vice versa. Either the meter or the earphones can be plugged into the jack, depending on whether a visible or aural indication is desired. Note that the signal must be a modulated RF or an audio one before an aural indication can be obtained. However, an indication will be obtained whether the RF signal is modulated or not, because the meter responds to the DC level of the rectified RF signal.

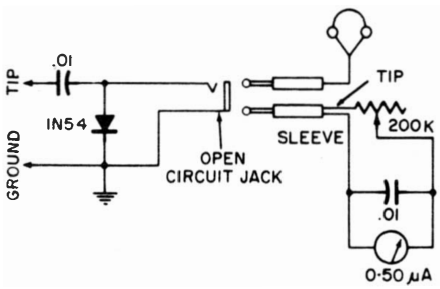


Fig. 6-3. AF-RF signal-tracer probe giving both visual and aural indication.

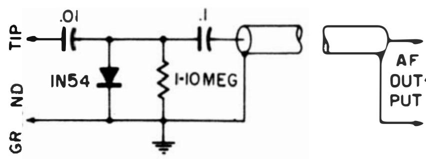


Fig. 6-4. AF-RF signal-tracer probe for use with headphones or AF amplifier. RF signals must be modulated.

Another simple signal-tracing probe is shown in Fig. 6-4. It also is an RF-AF type of probe, except that the DC component of the RF signal is blocked by the 0.1-mfd capacitor. The audio component can then be applied to headphones or to an amplifier or scope. The probe should be shielded to prevent pickup of extraneous signals. When used with headphones, this setup is known as a radio stethoscope.

An interesting RF-IF (video-frequency) signal-tracer probe is the RCA Type WG-302A. Its schematic is shown in Fig. 6-5. This is a slip-on probe used with the WG-300B direct–low-capacitance probe. The circuit of the WG-300B was shown in Fig. 1-5. The signal-tracer probe in Fig. 6-5 contains a semiconductor diode and an RF filter housed in a plastic case. When using it with the WG-300B, set the switch on the latter to the Direct position. The time constant of the rectifier circuit is such that when the slip-on probe is used in high-frequency circuits, the low-frequency modulation is separated from the amplitude-modulated RF carrier and fed to the oscilloscope input through the direct probe. The waveform is centered vertically on the zero axis of the screen when an

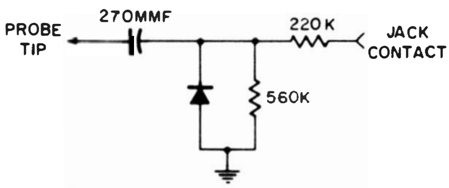


Fig. 6-5. Schematic of RCA WG-302A signal-tracing probe.

AC RC-coupled oscilloscope is used. On a direct-coupled oscilloscope, the waveform is displayed vertically, the distance being proportional to the DC voltage resulting from rectification of the RF carrier.

When this signal-tracing probe is used with an oscilloscope, and a sweep generator is employed to sweep the picture or sound-IF amplifier of a television receiver, it is possible to observe the response curves of tuners and of picture and sound-IF and video amplifiers, plus the over-all response curves in all high-frequency sections of the television receiver, without upsetting the performance of the high-frequency stages.

The low (3-mmf) input capacitance permits the probe to be used in such critical circuits without seriously detuning the amplifiers. Because its capacitance is lower than that of the kinescope grid circuit, the probe can also be connected to the video-amplifier output without affecting the circuit.

The probe extends the range of an oscilloscope to 50 mc—enough to cover the IF and video-frequency sections of television receivers. A three-inch ground lead, connected between the probe and the low side of the circuit under test, will extend the usable range to 250 mc for signal tracing in tuners. To add the ground lead, remove the nylon screw in the body of the case; then install the ground lead here, except use a metal screw and insulate the screw head.

The WG-302A RF-IF-VF signal-tracing probe is an indicating device rather than a voltage-measuring instrument. For voltage measurements, the probe and oscilloscope should be calibrated against a known voltage.

Another interesting probe suitable for signal-tracing in AF, IF, and RF signal receivers is shown in Fig. 6-6. All components are readily available, and their values are not critical. The complete probe can be enclosed in a small plastic box, and should be shielded if possible. The 100,000-ohm resistor is the load at audio frequencies, where the reactance of the 5-millihenry choke is negligible. At radio frequencies, however, this reactance increases until it becomes the load. The resistor is then bypassed by the .0022-mfd capacitor. The detector is a 1N34 germanium (or other readily available) diode. The probe output can be fed to a pair of high-impedance phones or to an audio amplifier or oscilloscope. Connect the ground clip to the ground side or chassis of the receiver, and apply the probe at the antenna first, to pick up the RF signal. If there is a signal there, move back into the receiver, to the grid of the RF amplifier and its plate, to the grid of the converter and its plate, to the grid of the IF amplifier and its plate, and the grid of the AF power amplifier and its plate, until the speaker terminals are reached. If the receiver is dead, the signal will disappear somewhere along the line. Further signal tracing to intermediary points, coupled with voltage and resistance analysis, will reveal the source of trouble.

This probe can be used in a similar manner for signal tracing in a television receiver. Start at the stage where the signal is initiated, and work through the various stages of amplification and modification, up to the point where the signal is displayed or used. Somewhere along

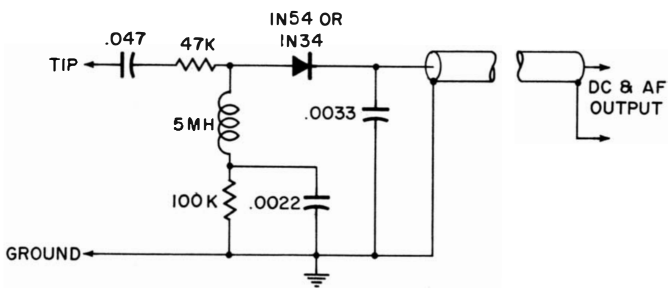


Fig. 6-6. AF-IF-RF signal-tracing probe.

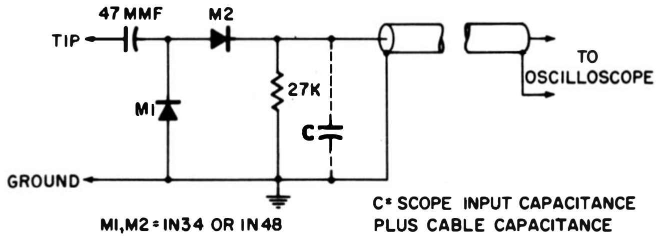


Fig. 6-7. High-frequency signal-tracer probe — Voltage-doubler type.

the line, the stage where the difficulties occur will be found. The 0.047-mfd DC blocking capacitor is rated at 600 volts. This is the lowest voltage rating the capacitor should have. If the probe is to be used in audio and television signal tracing, a 1,000-volt capacitor would be much safer—particularly in television sets, where the boost voltages in the plate supply of some deflection circuits are as high as 600 volts.

The high-frequency, voltage-doubler probe in Fig. 6-7 is designed for signal tracing in TV, video, and IF circuits. The semiconductor diodes are so connected that positive-going sync pulses are provided to the input circuit of the oscilloscope.

The low internal capacitance of the series diode (D2), being effectively in series with the cable and scope capacitances, isolates the latter from the input circuit. Hence, the input capacitance is kept low, without the need for a series isolating resistor.

The input signal capacitor of only 10 mmf further reduces the input capacitance to an absolute minimum. For this reason, the probe has excellent 60- and 120-cycle rejection, and can therefore be used to trace RF interference in B+ and filament circuits. A signal here would constitute an undesirable voltage, which could be cross-coupled between circuits and thereby cause the receiver to operate improperly. The amplitude of the output signal is about twice that of an individual diode probe.

Sometimes a signal-tracer probe does not deliver sufficient signal for a readable deflection on a VTVM or oscilloscope. If not, a single-transistor amplifier stage inside the probe will add sufficient gain to permit RF measurements directly at the TV

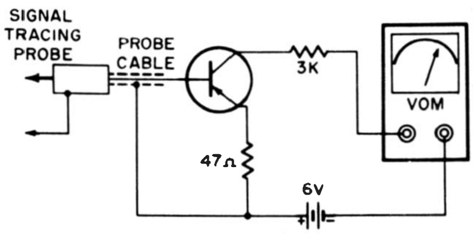


Fig. 6-8. Transistor amplifier for signal-tracing probe.

tuner. Figs. 6-8 and 6-9 show these circuits. There may be a slight deflection in the meter circuit even with no signal applied, due to leakage within the transistor. Select the transistor that gives the least initial meter deflection. The one in this circuit is a PNP. If an NPN transistor is used, the battery voltage and probe cable terminals must be reversed.

Fig. 6-9 shows the demodulator-tracer-amplifier all in one. The unit, together with its battery, should be encased in a plastic tube and connected to the oscilloscope through a shielded cable. The output may also be connected to a pair of headphones. The biggest advantage of the battery-operated signal tracer is

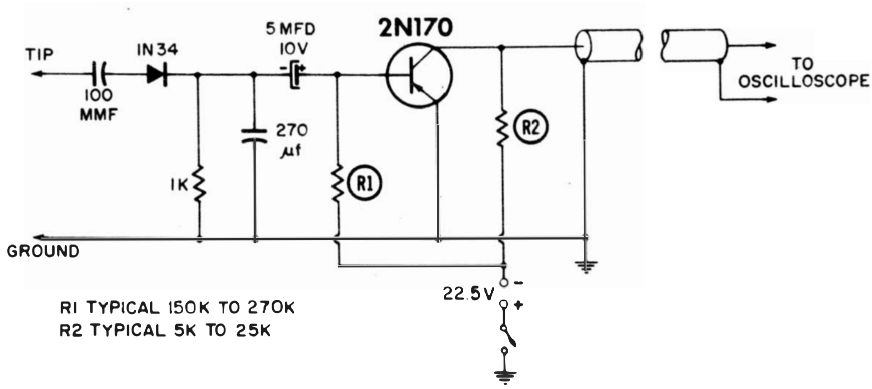


Fig. 6-9. Single-transistor demodulator signal-tracer probe.

that no transformer and no isolation from the line are required. Both amplifiers have a gain of around 10.

Just about the simplest signal tracer imaginable is an AF signal tracer consisting of a pair of high-impedance earphones connected to a blocking capacitor encased in a probe. The capacitor prevents the DC points from short-circuiting through the earphones. We simply listen to the audio signal at various test points in the amplifier, and then judge its quality and volume by ear. Such a probe (Fig. 6-10) consists simply of a 0.1-mfd blocking capacitor

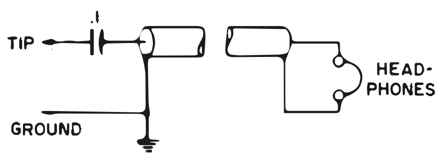


Fig. 6-10. AF signal-tracer probe.

mounted near the tip of a probe. Probe housings are available, making it a simple matter to insert the capacitor into a probe and solder it to the tip. If the probe is plastic, it should be shielded to isolate the circuit under test from hum pickup and body capacitance. This is done by lining the inside of the probe with metal foil. The shield must be connected to the braid of the flexible coaxial cable coming from the earphones.

This elementary signal tracer is used frequently for making rapid analyses in audio circuits. However, it also has some disadvantages. It tends to load the circuit because of the relatively low impedance (2,000 ohms) of the earphones and the negligible reactance of the capacitor at audio frequencies. Furthermore, the human ear is insensitive to any small changes in volume, or even to relatively large amounts of distortion. Nor is there any provision for adjusting the volume. So, as we approach the high-level output stages of an amplifier, the signal grows louder and louder in the earphones, until it becomes quite uncomfortable to the listener. Crystal earphones, the impedance of which is close to 100,000 ohms in the audio range, will not load the circuits under test as much as the high-resistance magnetic earphones.

The somewhat more advanced version in Fig. 6-11 has a volume control and earphone jack, usually mounted in a small metal box. Crystal earphones are used to minimize circuit loading. If desired, the output signal can be fed to an oscilloscope or AC VTVM, or to an amplifier that has its output connected to a speaker or meter.

For the sake of operating simplicity, most signal tracers have no tuned input circuits. Instead, the output from a simple demodulator probe is fed into one or more audio-amplifier stages. Although adequate for most work, such a tracer sometimes is not sensitive or selective enough. Amplifiers can be used after the probe; but because of broadband response of the probe, plus the fact that there is no frequency selectivity, the amount of gain is rather limited. A tuned signal tracer overcomes some

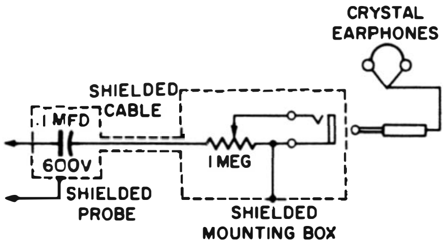


Fig. 6-11. AF signal-tracer probe with volume control.

of these disadvantages. It is many times more sensitive (and somewhat more complex) than an untuned tracer. With it we can narrow our response down to the frequency or band of frequencies we are interested in, and thus exclude all other signals. Such a tracer must be resonated at the frequencies being measured. The tuned circuit need not be in the probe. (For this reason the probe, which sometimes contains a vacuum tube, can be made rather compact.) The output from the probe is fed into the instrument, which contains several tuned circuits. Here, it is demodulated and then fed into a conventional audio amplifier.

A tunable signal tracer is appropriately called a channel analyzer. It can be distinguished from the simpler tracers discussed so far by the fact that it is tuned to the frequency (RF or IF) at which the measurements are made. Any possibility of a spurious indication from signals, other than those we are in-

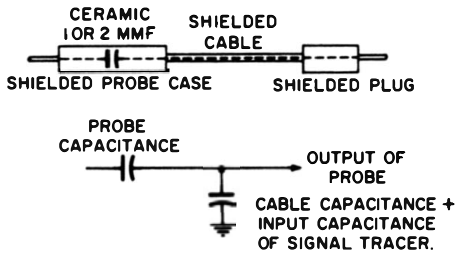


Fig. 6-12. Capacitance-type signal-tracer probe and equivalent circuit.

terested in, is thus eliminated. Because this signal is often taken across tuned circuits, the capacitive loading effect of the probe must be small enough not to detune the circuit under test. Such a probe, together with its equivalent circuit, is shown in Fig. 6-12. The input or coupling capacitor is a 1- or 2-mmf miniature ceramic mounted as close as possible to the tip and inside a shielded test probe. This arrangement is much like the one discussed in the chapter on capacitance-divider type high-voltage probes, except the input capacitor is not a high-voltage type because the probe is not designed

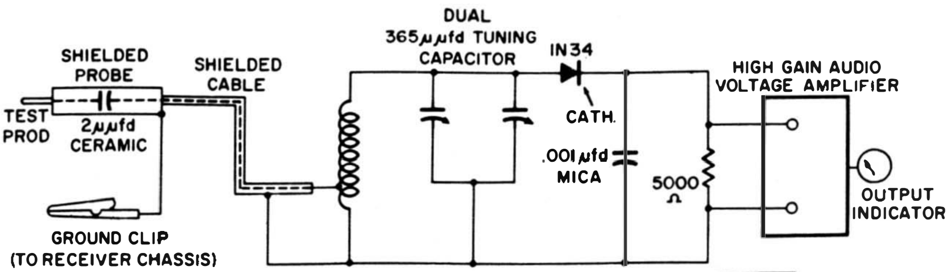


Fig. 6-13. Tuned signal tracer (Courtesy of Sylvania Electric Products, Inc.)

for high-voltage circuits. However, the shunt capacitance from the input circuit of the signal tracer, as well as the capacitance of the shielded cable used with the probe, must once again be taken into account.

Fig. 6-13 shows a simple but quite useful tuned signal tracer. Plug-in coils of different values can be constructed to make this tracer tunable from 400 kilocycles to 30 megacycles in four ranges. The input stage consists of a single tuned circuit and a 1N34 germanium diode detector. This is essentially a crystal receiver. A 2-mmf capacitor, encased in a shielded probe and connected through a shielded cable, connects the probe to the tuned circuit under test.

This one is like the shielded test probe discussed before. Proper impedance match is obtained by connecting the probe to a tap on the coil. The detector output is fed to a high-gain audio amplifier terminated by an output meter or other indicator — or if required, by a speaker. If ultimate sensitivity is not required, a pair of earphones can be substituted for the 5,000-ohm resistor and high-gain audio amplifier. Because the signal tracer is tuned, its sensitivity will be greater than if it were not.

Tuning is accomplished by two parallel-connected 365-mmf variable capacitors. The tuning range includes all the IF, RF, and oscillator frequencies ordinarily encountered in broadcast and short-wave receivers. The coil can be a simply-wound plug-in type to simplify range changing. If desired, a rotary selector switch can be added for greater convenience in changing from band to band. A dial and knob should be connected to the tuning capacitor, and a calibrated dial constructed. The dial can be graduated in kilocycles and megacycles by feeding a modulated signal at integral frequencies from a signal generator to the tracer. In addition to acting as a tunable signal tracer, the instrument can also be used for checking RF oscillators and signal generators, transmitters, and carrier-controlled equipment.

We know that tuned signal-tracing probes select only the signal desired and exclude all undesired ones. Thus, before we can trace a buzz pulse through a video- or video-IF amplifier, we must exclude the video signal.

Any of the untuned signal-tracer probes discussed can be equipped with a tuned head to make the probe suitable for tracing buzz pulses in intercarrier television receivers. Fig. 6-14 gives specifications for two probe heads. One is tuned to 4.5 megacycles; the other can be tuned to the IF-amplifier frequency of television receivers. The inductance in Fig. 6-14A is one of the video-peaking coils in the television receiver.

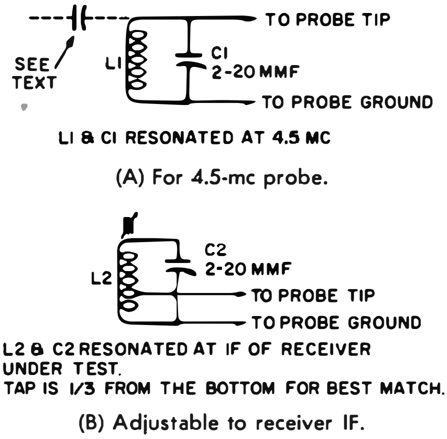


Fig. 6-14. Tuned heads for signal-tracer probes.

The coil (L1), together with a small trimmer capacitor, should be made to resonate at 4.5 megacycles so it will respond to the 4.5-mc audio IF signal, but not to the video signal. The probe coil is held near the peaking coils in the video amplifier. Energy is thus picked up by inductive coupling. The demodulated output signal from the probe can be observed on an oscilloscope or listened to through headphones or an audio amplifier.

The circuit in Fig. 6-14B shows a coil and capacitor resonated to the IF-amplifier frequency. They are also coupled inductively to the IF coil of the receiver, and the output observed in the same way. Both coils pick up the desired signal, but eliminate all video information (which would completely mask the buzz waveform).

Sometimes it is impractical to use inductive coupling because the coils are shielded or the receiver is so crowded the probe cannot be brought close enough to pick up sufficient signal. Instead, capacitive coupling (through a 1- or 2-mmf capacitor) can be used between the probe and the "hot" end of the coil being tested.

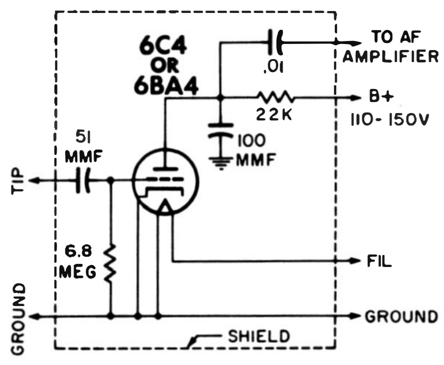


Fig. 6-15. Signal-tracing probe using grid-leak detection.

Fig. 6-15 shows a very sensitive RF signal-tracing probe. This grid-leak detector probe not only detects a very weak signal but—unlike semiconductor or other vacuum-tube types—amplifies it, too. The resistor and capacitor in the grid circuit form the grid leak and thus provide demodulation. Such a probe is useful for signal tracing in the front-ends of radio and television receivers, where the RF signal voltage is usually in the microvolt range. The probe is so sensitive it can pick up a signal at the antenna of a receiver. In fact, it will give an indication when held in the hand or applied to a short wire! The grid-leak detector operates as a combination diode-detector triode amplifier. In effect, the grid and cathode of the tube act as the plate and cathode of the diode detector. The grid, plate, and cathode then operate as a high-gain triode amplifier.

The values are typical: the input capacitor is usually between 10 and 100 mmf, and the grid-leak resistor, anywhere from 5 to 25 megohms. The capacitor in the plate circuit bypasses any RF signal that may have passed through the tube. If too large, this capacitor will also bypass the audio signals we are interested in. It should therefore be no more than 100 mmf or so. The plate resistor is the load, across which is developed the output signal representing the demodulation envelope of any amplitude-modulated signal. This output is then applied to an audio amplifier. Both demodulation and amplification are supplied. The probe is so sensitive it is easily overloaded. Therefore, it is suitable for relatively low signals only. High fidelity also is not one of its advantages. Filament and plate voltages are required; they are usually supplied by the amplifier.

Because of this sensitvity, the grid-leak detector is ideal for tracking down the source of hum, which is sometimes rather difficult to do. We can locate hum by tracing the signal at each grid and plate, moving toward the output stage until we reach the point where the hum increases markedly. Here is the villian! It may be a defective tube, an open

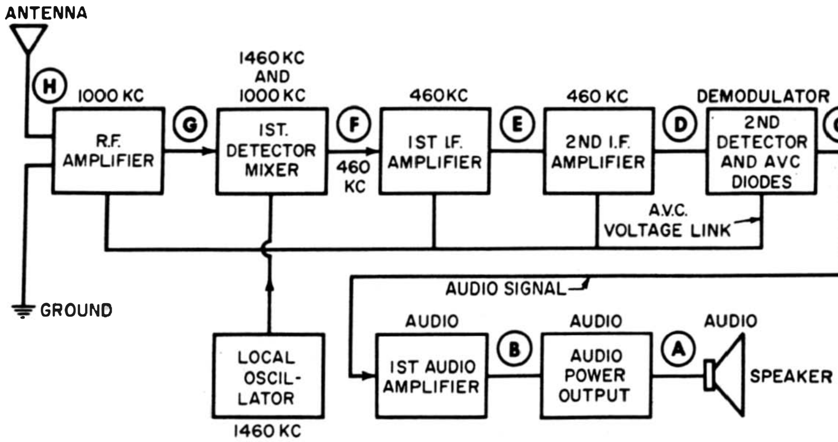


Fig. 6-16. Block diagram of a typical superheterodyne receiver.

bypass capacitor, or any other hum-producing element.

The probe can also be used for checking screen and cathode bypass capacitors. If we find a signal at a screen or bypassed cathode, we know immediately that the bypass capacitor is either open or too low in value.

SIGNAL-INJECTOR PROBES

Unlike the signal tracer, the signal-injector probe works from the output to the input. For example, in a superheterodyne receiver we inject a signal at the output stage; then we work back toward the power amplifier, the first amplifier, the second detector, the IF amplifier, the mixer, and the RF amplifier, until we reach the antenna. (*A*, *B*, *C*, etc., in Fig. 6-16.)

A signal-injector probe furnishes its own signal; thus, it does not have to depend on an external one. Some sort of output indicator is needed, such as a speaker, amplifier, or radio. As long as the circuit is operating, we will hear the output as we move the probe toward the front. But the moment we pass the dead stage, the output will be lost completely (or will drop if the stage is defective but not dead).

Most signal-injector probes are considered noise generators. They are usually vacuum-tube or transistor multivibrators, or blocking oscillators, operating at a fundamental frequency of around two to ten kilocycles. The output signal is a rather rough square wave which is rich in harmonics. Thus, it can be applied to both audio and RF circuits of up to several megacycles. Adjustments or a change of probes is not needed. The very broadband signal is therefore suitable for all types of circuits.

Fig. 6-17 shows the schematic of an easily constructed injector probe. A miniature 12AX7 dual-triode is used in the multivibrator circuit, which operates at approximately 10,000 cps. The available signal is coupled to the probe tip through a .0022-mfd capacitor. A four-conductor cable (it does not have to be shielded) should be used to connect the power source to the probe.

Fig. 6-18 shows a signal-injector probe using two transistors, also in a multivibrator circuit. This probe and the one just discussed can be put together very easily. The vacuum-tube probe requires an outside voltage source and must therefore be connected to a filament and plate supply. The transistor probe can be

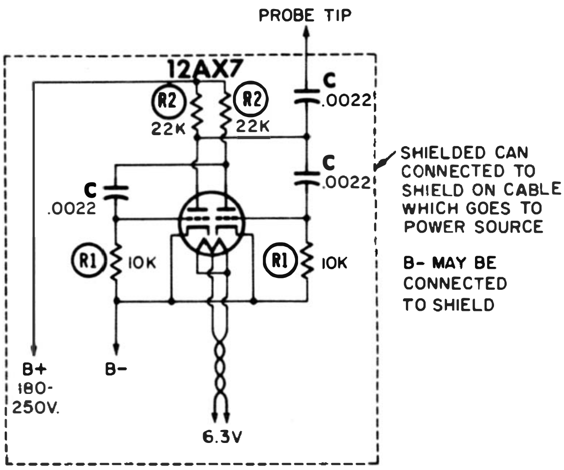


Fig. 6-17. Schematic of a signal-injector probe using a 12AX7 tube.

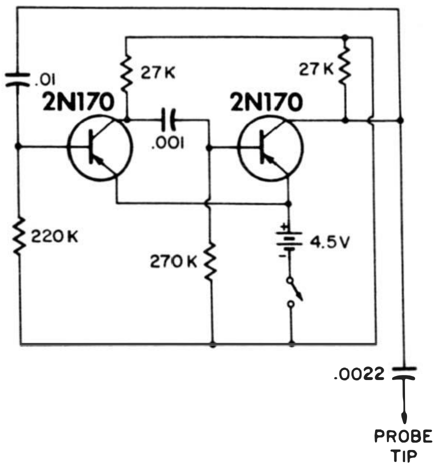


Fig. 6-18. Transistorized signal-injector probe.

made completely self-contained. For this reason, it has the tremendous advantage of being portable—it can be applied anywhere and at any time, because no interconnecting wires are needed.

An interesting signal-injector probe called the "Mosquito" because the signal sounds like a mosquito in flight—is shown in Fig. 6-19. Fully transistorized and powered by a single penlight cell, it houses a transistor oscillator operating at about two kilocycles. Its waveform is square with a sharp spike—very rich in harmonics extending to the IF and RF ranges. This probe is turned on by simply sliding the pocket clip forward. The signal can be heard in the speaker or observed on an oscilloscope.

Signal-injector probes can be inductively coupled to all magnetic-sensitive circuits and pickups. No direct connection is needed.

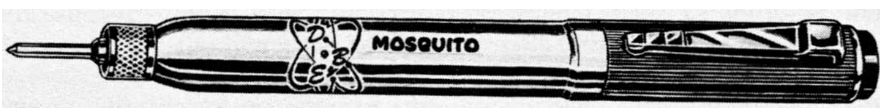


Fig. 6-19. The "Mosquito" transistorized signal-injector probe. (Courtesy of Don Bosco Electronics.)

Chapter 7

SPECIAL-PURPOSE PROBES

INTRODUCTION

This chapter on special-purpose probes has been subdivided into four parts.

The first part is about electronic probes which have a particular application or are of such an unusual nature that they deserve mention in a special section.

The second part is concerned with those probes used most frequently in other than the electronics field. Their unique mechanical design makes them particularly suited for the application to which they are put. Indication still is made by electronic means, however.

The third part deals with those probes and instruments used to indicate radiation.

In the final part of this chapter, the probes used by the medical profession to safeguard our health and well-being are discussed.

Part 1

Unusual and Specialized Probes

CLAMP-ON AND CLIP-ON PROBES

Usually when we want to measure current, we must break into the circuit and insert the meter connection. Not only is this inconvenient; but in some circuits, particularly those containing transistors, the resistance of the moving-coil instrument is often so high (compared with the resistance in the circuit) that it can become intolerable. An ideal current-measuring instrument would have zero series impedance and would therefore present no reactive loading to the circuit under test.

The clip-on DC milliammeter probe in Fig. 7-1, together with the instrument for which it is designed, makes the measurement of direct current in low- and high-impedance circuits very simple and convenient. The DC current range covered extends from about 0.3 milliampere to 1 ampere. The fact that the probe introduces no DC loading is a particularly valuable property when currents are measured in low-impedance transistor circuits, because this can be done without disturbing any operating conditions. The jaws of the probe open for clipping around the conductor, and only a half-inch conductor is necessary for a correct current reading.

The probe senses the strength of the magnetic field produced by the current under observation. This

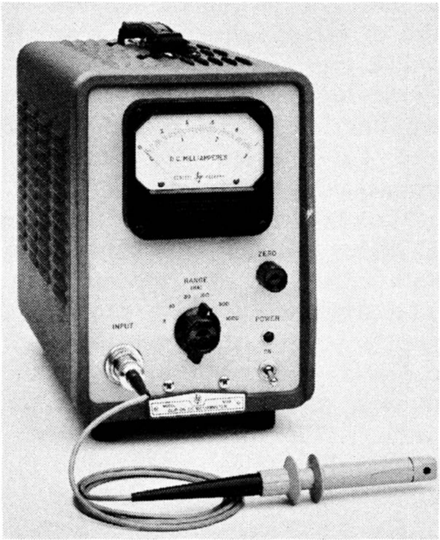


Fig. 7-1. Clip-on probe used for direct-current measurements. (Courtesy of Hewlett-Packard Co.)

sensing requires no energy from the field; therefore, the probe introduces no resistance into the circuit being measured—a most desirable situation. Since it is a direct-current probe, the direction of the current can be determined because the probe is marked with an arrow which shows the current direction for an upscale reading. The probe itself contains a magnetic amplifier which provides an AC output signal proportional to the magnetizing force produced by the direct current being measured. This AC output signal is somewhere around .01 volt peak at a frequency of 40 kilocycles. It is amplified in the meter and then applied to a phase-sensitive detector, the output of which feeds the indicating meter.

Fig. 7-2 shows the probe with a conductor looped through it several times. This is done to increase the

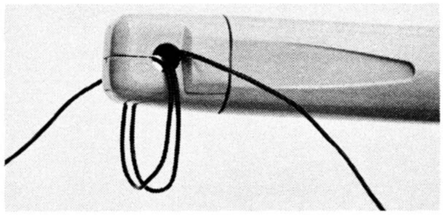


Fig. 7-2. Clip-on probe showing method of increasing pickup sensitivity. (Courtesy of Hewlett-Packard Co.)

effective magnetizing force of the current and thus to make the instrument more sensitive. The readings obtained under these condtions must be divided by the number of loops in the conductor.

Fig. 7-3 shows a similar-looking clip-on probe designed for use with an oscilloscope, together with an appropriate amplifier. It will display current over an amplitude ranging from 1 milliampere to 15 amperes

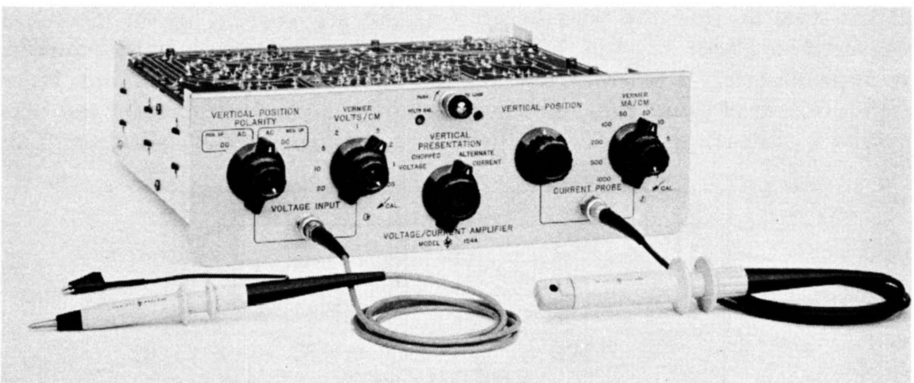


Fig. 7-3. Clip-on probe and amplifier for use with an oscilloscope. (Courtesy of Hewlett-Packard Co.)

peak-to-peak and covering a frequency range from below 50 cycles to 8 megacycles. This probe consists of a wide-range current transformer with a split core which is again clamped over the wire carrying the current we want to observe. The basic schematic of this probe is shown in Fig. 7-4. We see that the current-carrying conductor is, in effect, a single-turn primary for the transformer. The probe output is

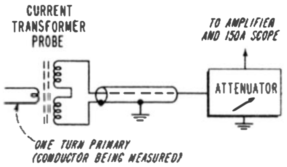


Fig. 7-4. Basic schematic of the clip-on probe in Fig. 7-3. (Courtesy of Hewlett-Packard Co.)

fed to the amplifier, the output of which is connected to the oscilloscope.

The ferrite core used in the probe has magnetic properties which make it suitable over such a wide frequency range. Magnetic (as well as electrostatic) shielding are incorporated to minimize response of the probe to fields other than those of the current being measured. The energy required from the circuit under test is very small—around 10^{-8} watt. The loading reflected into the circuit—that is, into the wire being measured—is about .01 ohm shunted by approximately 1 microhenry. A slight amount of shunt capacitance—around 1 mmf—is also added by the probe. The frequency response of this probe, together with the amplifier, is given in Fig. 7-5. The curve shows the response of the probe and amplifier to be flat within −5 db and +3 db from 30 cycles to 10 megacycles per second.

Direct current up to a half ampere or higher will not have any noticeable effect on any measurement. The sensitivity of this probe can also be increased, as we did with the DC probe, by increasing the number of turns which act as the primary. The increase in sensitivity will be directly proportional to the number of turns.

This probe can be modified somewhat to act as a magnetic search probe and indicate the direction and magnitude of AC magnetic fields. This is done by placing the probe around a single shorted-turn coil. The magnetic fields will induce, in the coil, eddy currents which will in turn be indicated by the probe and displayed on an oscilloscope. We can thus observe the direction and strength of the AC field.

The clamp-on current-measuring probe affords the maximum in flexibility and ease of operation. Fig. 7-6 shows a clamp-on RF current probe. It is used for measuring radio interference in order that the intensity of the RF current in an electrical conductor or group of conductors can be accurately determined. Here again, the conductor under test acts as a one-turn primary winding. The

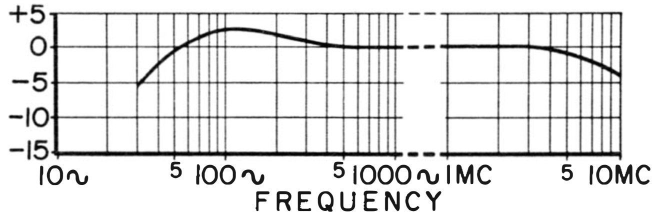


Fig. 7-5. Frequency response of the clip-on probe and amplifier in Fig. 7-3. (Courtesy of Hewlett-Packard Co.)

unique mechanical design of the probe permits it to be used around any insulated cable up to 1¼ inches in diameter. This probe is suitable for use over a frequency range extending from 14 kc to 100 mc and is capable of measurements in circuits where the RF current may be

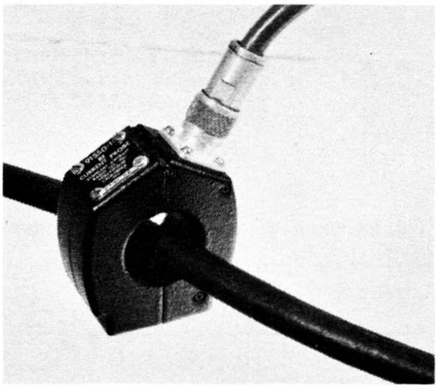


Fig. 7-6. Clamp-on RF current probe. (Courtesy of Stoddart Aircraft Radio Co., Inc.)

as high as 1 ampere. Essentially, this probe is a radio-frequency toroidal transformer designed to deliver voltage through a 50-ohm coaxial cable to any receiver having an input impedance of 50 ohms and covering the frequency range at which we are making our measurements.

A snap-on high-current measuring probe for appliance and electrical testing is shown in Fig. 7-7. It, too,

Fig. 7-7. Snap-on high-current measuring probe for electrical appliance testing. (Courtesy of Pyramid Instrument Corp.)

operates on the transformer principle, where the wire carrying the current acts as one turn on the primary of a current transformer. An accessory, available for use with this probe, extends the current range by a factor of ten. This adapter, called a *Deca-Tran,* is shown in Fig. 7-8, together with the probe. Here again, the sensitivity of the probe can be increased by wrapping two or more turns around the clamp.

Test leads are usually held against

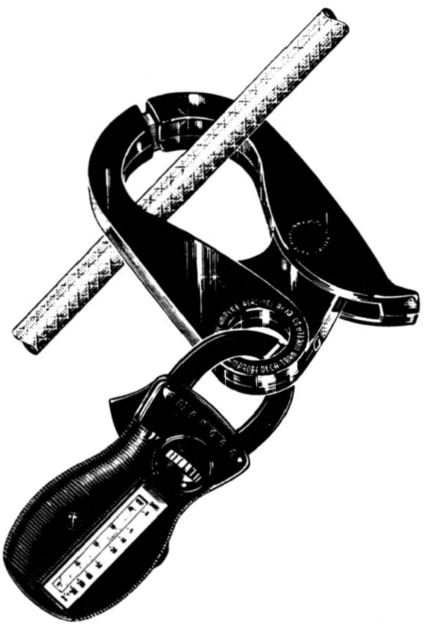


Fig. 7-8. Adapter for extending current range of probe in Fig. 7-7. (Courtesy of Pyramid Instrument Corp.)

the wire, socket terminal, or other point where the measurements are made. There are two types of probes available at present which relieve the user from the necessity of holding the probe. They are clipped (temporarily but securely) to the actual test point. Fig. 7-9 shows a probe which simply hooks over the wire by means of a spring-loaded foot. The probe is placed against the wire and pushed in its direc-

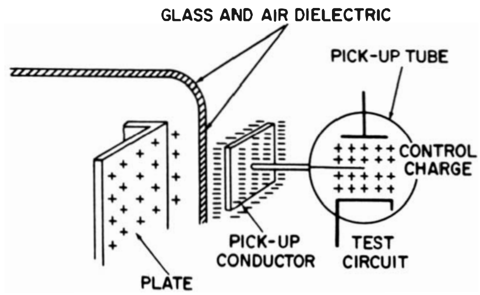
Fig. 7-9. E-Z Hook isolation probe. (Courtesy of E-Z Hook Test Products.)

tion, then slid down and released. Spring pressure firmly holds the probe against the conductor.

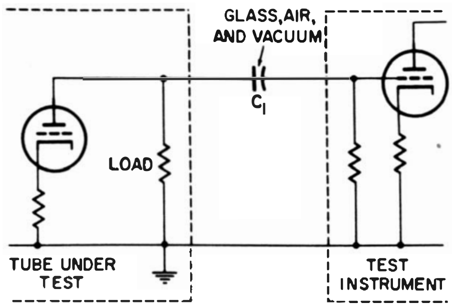
ELECTROSTATIC PICKUP PROBES

Direct connection to electronic circuits is often not desirable or even possible. Some form of coupling, other than direct connection, frequently is much preferred. One method of coupling was just described under "Clip-on and Clamp-on Probes." Here we will deal with a probe, the operation of which is based on the fact that the plate of an electron tube is positively charged. When a conductor is brought near the plate, an electrostatic redistribution of charges will take place, as shown in Fig. 7-10A. We now have an electrostatic pickup device and are thus able to transmit the potential variations appearing at the plate of the tube. To avoid the effect of random charges, we also connect our ground points as shown in Fig. 7-10B. Now the influence of stray charges is eliminated.

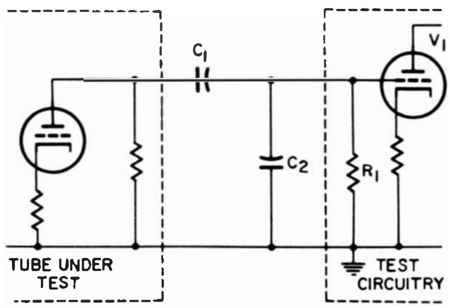
Since most electron tubes are cylindrical, a full or partial ring-type pickup probe is more satisfactory than a flat plate. The pickup probe used consists of an inner conductor, a phenolic dielectric, and an outer shield. When the probe is looped over a tube, a signal is picked up as a result of the capacitance between the inner conductor of the probe and the plate of the tube under test. This signal can then be shown on an oscilloscope. We have also added a little capacitance between the in-



(A) Principle of electrostatic induction.



(B) Capacitive coupling.



(C) Equivalent circuit for capacitive coupling with shield.

Fig. 7-10. Theory of capacitive or electrostatic pickup.

ner conductor and ground (shown as C2 in Fig. 7-10C). This is the capacitance between the inner conductor and grounded outer shield. With pulses or square waves, some allowance must be made for the fact that

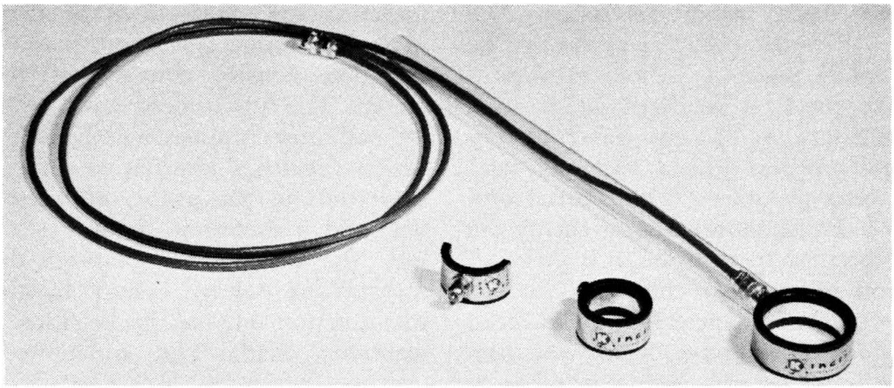


Fig. 7-11. Three forms of electrostatic pickup probes. (Courtesy of Kingston Electronics Corp.)

the coupling circuit now becomes an effective differentiator because of the small capacitance and high resistance values involved in the pickup circuit. Nevertheless, if we are interested in the waveshape only, rather than the precise magnitude, this is an excellent way of rapidly analyzing circuits because there is no necessity to pull tubes, remove a chassis, or make other direct connections. The probe is simply slipped on or brought near the tube, and the signal is immediately displayed. The degree of coupling can be controlled by the placement of the probe on the tube. The instrument covers the full range of TV frequency and in addition, is preset to other often-used fixed frequencies. The frequency range covered extends from 3 to 240 megacycles, and has a possible bandwidth of up to 5 megacycles.

Three different pickup probes are shown in Fig. 7-11. The large probe ring is used with GT-type glass tubes, and the smaller one, for 7-

Fig. 7-12. Induced waveform analyzer. (Courtesy of Winston Electronics, Inc.)

and 9-pin miniature tubes. The third, crescent-shaped probe can be used in place of the others when a fast check is required or if it is necessary to observe waveforms in multipurpose tubes such as twin triodes or others. The desired output can be selected by orienting the crescent-shaped probe so it picks up from one plate or the other.

An instrument called an *induced waveform analyzer,* which also uses an electrostatic pickup probe, is shown in Fig. 7-12. Its output is connected to an oscilloscope for viewing. This instrument can be considered an oscilloscope accessory using an electrostatic pickup probe which makes every glass tube and high-level signal lead a usable test point. We can thus signal-trace and localize defective stages by simply moving the probe from one envelope of a tube to another; there is no need to gain access to the underside of the chassis.

RF- AND MAGNETIC-FIELD MEASURING PROBES

Fields around wires, motors, magnetrons, compasses, transformers, meter magnets, etc., are measured with a *gauss meter*. The gauss is the unit of measurement of magnetic lines of force per unit of area; it represents one magnetic line of force per square centimeter. For example, the flux density of magnets used with magnetrons ranges anywhere from around 1,000 to 6,000 gausses or more. A gauss meter consists of a moving-coil indicator, plus a probe which is used to explore the magnetic field.

The gauss meter in Fig. 7-13 is a transistorized instrument designed to measure, by means of its probe, either AC or DC magnetic fields with flux densities from 10 to 30,000 gausses. Measurements are made by inserting the probe into the magnetic field under study, and reading the flux density directly on the meter. The instrument consists of an oscillator (approximately 3 kc) which furnishes alternating-current excitation to the probe, an amplifier, and a metering circuit. In effect, the instrument measures the unbalanced voltage caused by the introduction of the probe into a magnetic field. The unbalanced

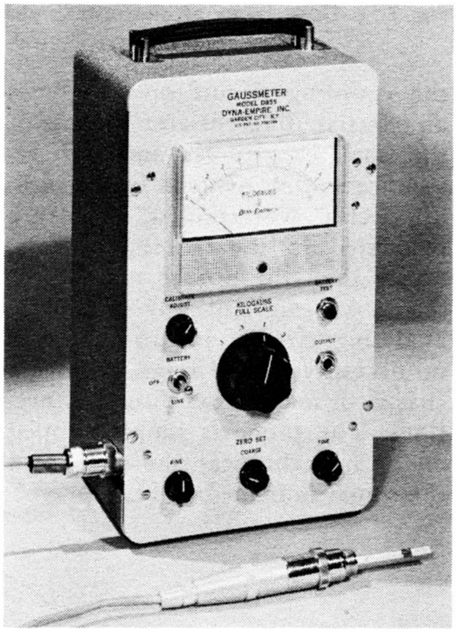


Fig. 7-13. Transistorized gauss meter.
(Courtesy of Dyna-Empire, Inc.)

voltage is amplified and displayed on the meter to show the magnitude of the magnetic field causing the probe unbalance.

The operating principle of this instrument is based on the Hall effect, which is a development of potential difference (Hall voltage) between the two opposite edges (*3* and *4* in Fig. 7-14) of a trip of suitable material of thickness *D* in which an electric current I_1 (the control current) is flowing lengthwise when the strip is perpendicular to the magnetic field (shown as *B*). The frequency of the developed voltage will be identical to that of the control current, and its amplitude will be proportional to the flux density of the magnetic field.

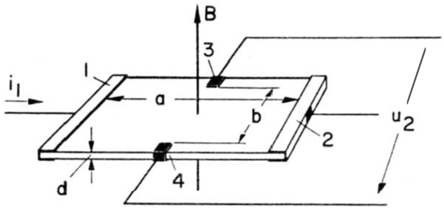


Fig. 7-14. Material exhibiting "Hall voltage" between edges 3 and 4 (see text).

This output voltage usually is passed through a harmonic filter and an attenuator to an amplifier (bridge), and then to an indicating meter. The strip in the probe is a semiconductor. (Indium arsenide has been found to meet all the requirements for this application.) Electrodes 1 and 2 feed the control current, and electrodes 3 and 4 pick off the Hall potential (which is proportional to length "a" and width "b"). This strip, with its metallic conducting electrode leads, is normally 0.1 millimeter or less in thickness. This makes it rather fragile; so any probe using this strip must be handled with appropriate care. The probe tip is only .025 inch thick and .200 inch wide. The active area, which is .070 inch in diameter, is opposite the small round opening near the tip of the probe. Densities of up to 30,000 gausses can be readily measured. The probe is nonmagnetic and thus will not distort the field under observation.

A probe used for locating sources of radio interferences and other RF noises is shown in Fig. 7-15, together with the instrument for which it is designed. The probe is connected by a 25-foot coaxial cable to a sensitive, metered superheterodyne receiver covering a frequency range from 550 kc to 220 mc (which includes

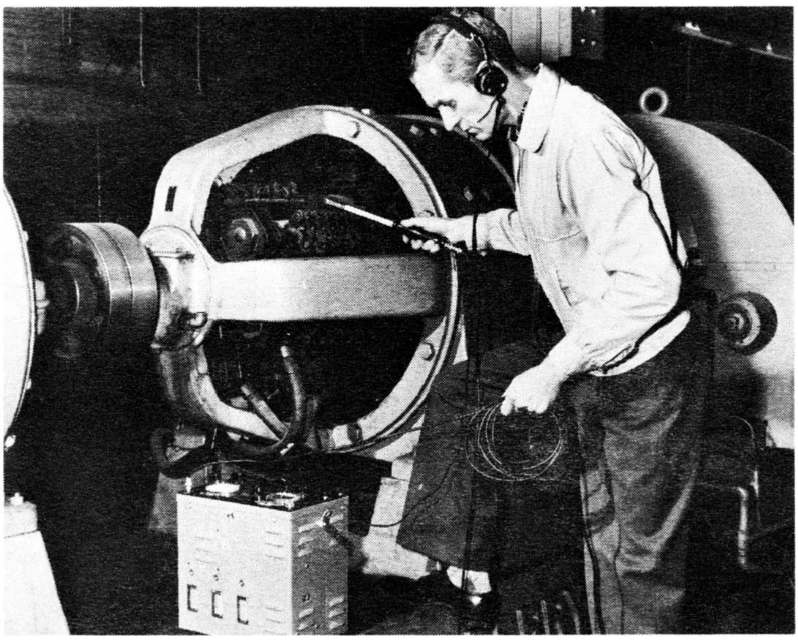


Fig. 7-15. Radio-interference locating probe in use. (Courtesy of Sprague Electric Co.)

Fig. 7-16. Loop exploring and calibration probe. (Courtesy of Ferris Instrument Co.)

the standard broadcast, short-wave, FM, and VHF television bands). This probe permits pinpointing of a source of noise, after its general location has been determined, by means of a loop antenna or a dipole. The probe will locate interference caused by generators, air conditioners, medical equipment, meters, motors, lighting plants, etc.

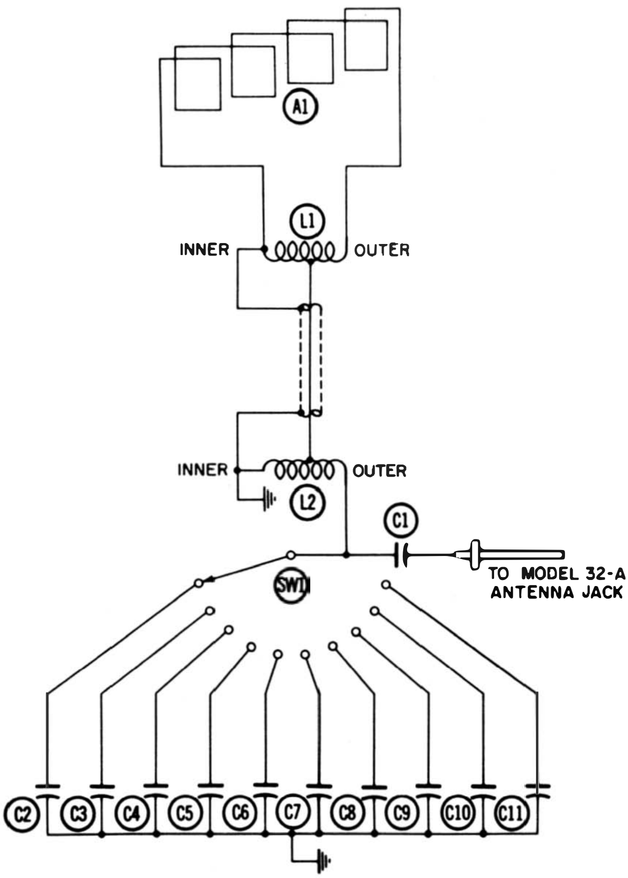


Fig. 7-17 Schematic of the probe and coupling unit in Fig. 7-16. (Courtesy of Ferris Instrument Co.)

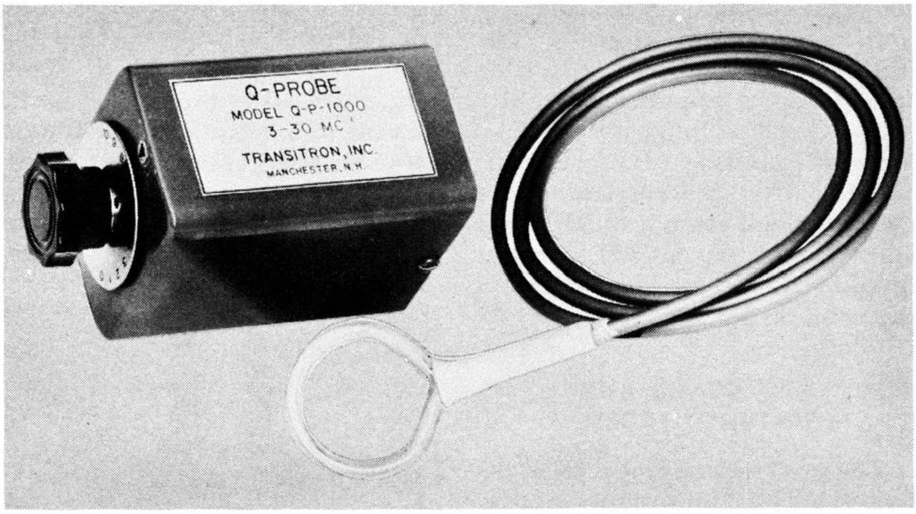


Fig. 7-18. *Q* probe for sampling RF signals. (Courtesy of Transitron, Inc.)

The loop-type exploring probe in Fig. 7-16 is connected to a standard signal generator to provide an overall calibration of the field strength when used with radio-noise and field-strength meters. It can also be used for locating noise sources and investigating induction fields. The probe contains several loops of heavy wire that form a rigid coil. It is broadly tuned by various capacitors, which are coupled into the circuit by means of the switch on its right side. A schematic of the probe, together with the coupling unit containing the switch, is shown in Fig. 7-17.

The *Q* probe in Fig. 7-18 is designed for easy sampling and showing of RF signals on an oscilloscope. It consists of a one-turn pickup loop approximately three-fourths of an inch in diameter. Thus, it can be inserted into tight places, and can be oriented to discriminate between the fields surrounding several coils. The pickup probe, which is connected by a coaxial cable to a shielded enclosure, is in series with the coil of a high-*Q* tuned circuit. The voltage across the whole coil is applied, through a blocking capacitor, directly to the vertical-deflection plates of an oscilloscope. Fig. 7-19

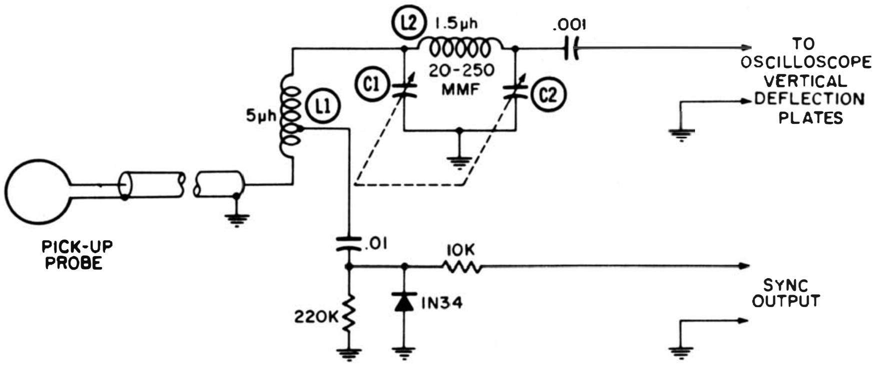


Fig. 7-19. Schematic of *Q* probe in Fig. 7-18.

shows the schematic of the complete unit, together with its probe. The instrument is continuously tunable from three to approximately fifty megacycles. This range is covered by a tuner consisting of L1, L2, C1, and C2. The semiconductor diode detects a small amount of RF signal taken from a tap on L1, and thus supplies a synchronizing signal to the oscilloscope.

BROADBAND AND UNTUNED PROBES

The two types of probes to be described are used for microwave meas-

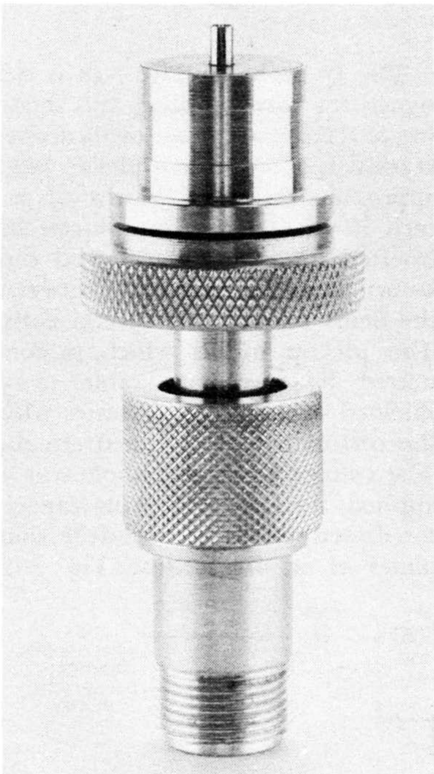


Fig. 7-20. Broad-band probe for sampling RF field in slotted sections of waveguides. (Courtesy of Hewlett-Packard Co.)

urements. The broadband probe in Fig. 7-20 samples the RF field in the slotted section of a waveguide and delivers a signal for connection to a receiver, spectrum analyzer, or other equipment. The probe covers a frequency range from 3,000 to 18,000 megacycles. Its assembly slides in its housing so the depth of penetration into the waveguide can be varied. When voltage standing-wave ratios are measured, the probe should not penetrate any further than neces-

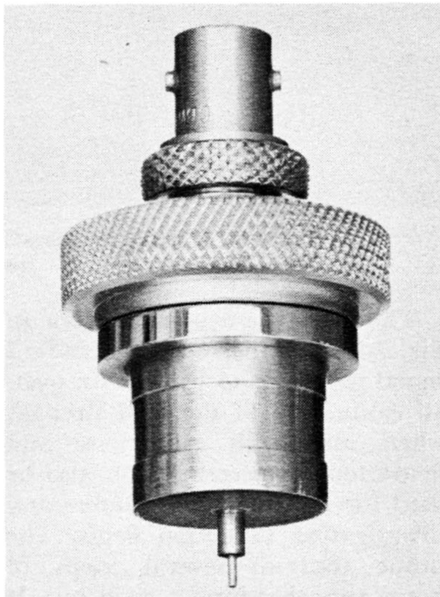


Fig. 7-21. Untuned probe with semiconductor rectifier. Response 4,000 to 18,000 megacycles. (Courtesy of Hewlett-Packard Co.)

sary for the particular measurement. Once the correct position is found, a knurled eccentric ring locks the probe in place. A broadband probe is basically an RF pickup antenna connected to a Type N connector so the field in a waveguide can be sampled. Unlike the untuned probe in Fig. 7-21, this probe has no detector. The semiconductor diode is mounted in a short metal cylinder inside the probe holder, and the center conductor of the semiconductor is extended with a short piece of aluminum which forms the pickup probe. The frequency range covered by this probe runs from 4,000 to

18,000 megacycles. Another untuned probe, operating on the same principle but covering a frequency range from 18,000 to 40,000 megacycles, is shown in Fig. 7-22.

A graph relating the frequency characteristics of the untuned probe to those of tuned detector probes appears in Fig. 7-23. The flat response of this probe is achieved by locating the detector element quite close to the RF pickup antenna and thereby minimizing residual reactance. The detector element itself is a modified 1N26.

Fig. 7-22. Untuned rectifier probe. Response, 18,000 to 40,000 megacycles. (Courtesy of Hewlett-Packard Co.)

GRID-DIP PROBE

A grid-dip oscillator is essentially a calibrated wide-range, low-power RF oscillator used as a frequency-indicating device. It contains a resonance indicator, usually a meter.

The circuit in the instrument oscillates at all times, and there is a continuous flow of grid current indicated on the meter. When the tuned circuit is coupled to an external circuit and the grid-dip meter tuned through the resonant frequency of the latter, power will be absorbed and the grid current of the oscillator will thus decrease. This is the "dip" on our meter, and it indicates that the instrument and the circuit under test are tuned to the same frequency. The tuning dial is calibrated so a frequency reading can immediately be taken. The circuit under test need not have power applied to it; in fact, the only power

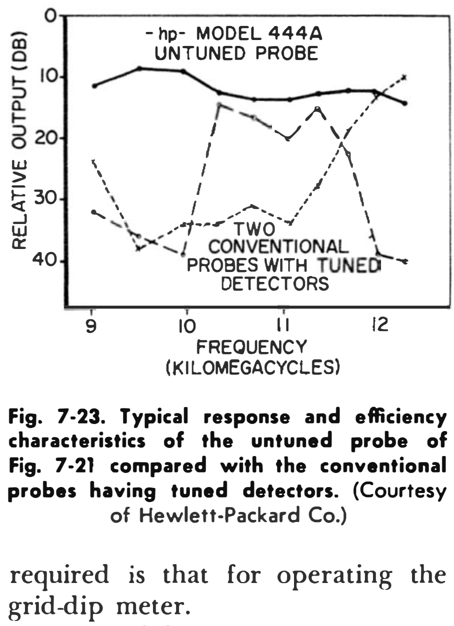


Fig. 7-23. Typical response and efficiency characteristics of the untuned probe of Fig. 7-21 compared with the conventional probes having tuned detectors. (Courtesy of Hewlett-Packard Co.)

required is that for operating the grid-dip meter.

The grid-dip meter in Fig. 7-24, together with its probe, contains a series tuned-resonant circuit capable of efficient operation in the UHF range from 300 to 1,000 megacycles. It can be used as either a grid-dip meter for locating the resonant frequency of passive networks, an absorption-type frequency meter for measuring the frequency of active circuits, or a relative field-strength meter for detecting changes in the signal level of active circuits. Three plug-in coils are provided to permit

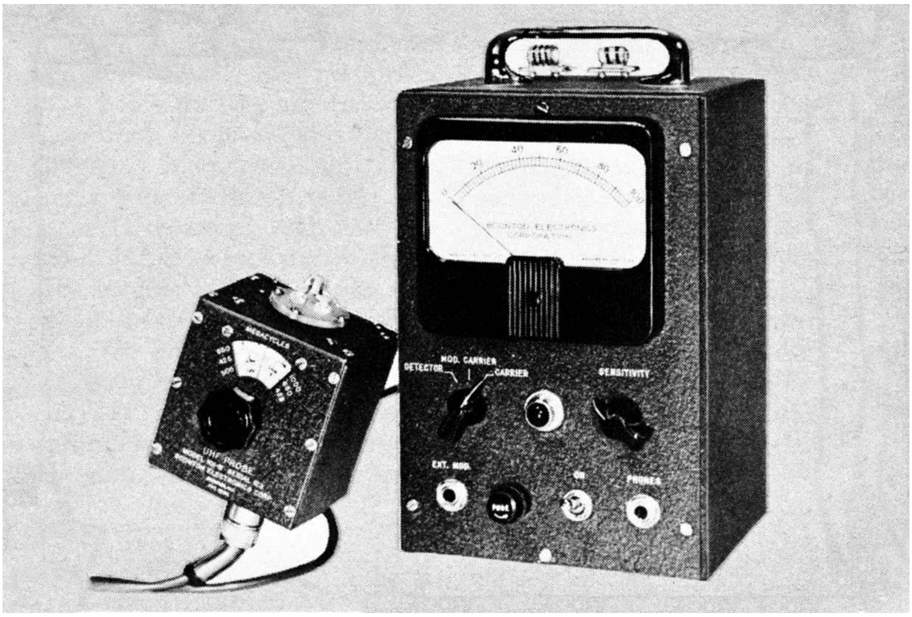


Fig. 7-24. Grid-dip meter with UHF probe in place. (Courtesy of Boonton Electronics Corp.)

switching the band to cover the full range of frequencies. Other grid-dip oscillators, supplied with up to six different coils, cover a frequency range from around 200 kilocycles all the way up to 300 or 400 megacycles, in as many overlapping ranges as required for proper operation.

The grid-dip meter can also be used for checking capacitance and inductance, for testing semiconductors, and for some transmission-line measurements. By loosely coupling grid-dip oscillator to the receiver or other circuit being visually aligned, it is possible to use the meter as a marker generator for sweep alignment. This can be done because the coil in the probe is part of an active resonant circuit and, as such, radiates some signal. The output from the grid-dip oscillator will appear as a marker pip if its frequency falls within the band being swept and indicated on an oscilloscope.

The many other applications possible with this instrument are beyond the scope of this book, but are described in great detail in many technical and semitechnical books.

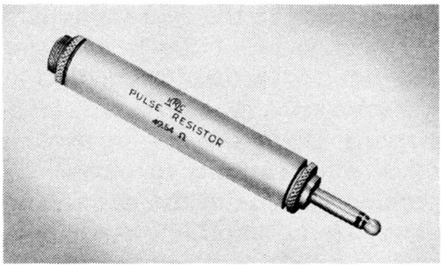
CURRENT PULSE-VIEWING RESISTOR PROBE

For the observation or measurement of the magnitude and rise times of current pulses encountered in magnetrons and other devices, it is necessary to provide a means of applying the pulse as a signal to the vertical-deflecting circuit of a cathode-ray oscilloscope.

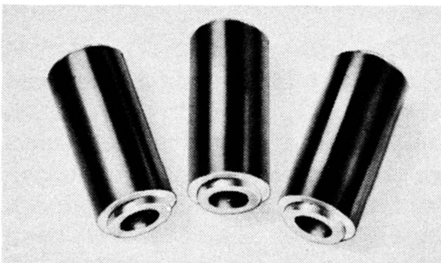
The most convenient method of obtaining this oscilloscopic presentation is to introduce a resistor in series with the circuit; the voltage developed across this resistance by the pulse current is then applied to the deflection plates of the oscilloscope. One of the first requirements of such a resistor is that it have negligible inductive reactance. Ordinary resistors, even the "noninductive" types, have sufficient inductive reactance to cause a spurious spike during fast-rise current pulses.

Special design precautions are therefore necessary.

In the probe in Fig. 7-25A negligible inductance is made inherent in the design by making the probe a two-resistor, three-terminal assembly. This arrangement has an ungrounded lead going completely through the center of the resistor assembly, and the pulse voltage for viewing is taken off at the opposite



(A) Probe.



(B) Resistance elements.

Fig. 7-25. Current-pulse viewing probe and resistance elements. (Courtesy of International Resistance Co.)

end. The inductance within the probe is minimized by arranging two cylindrical resistive elements with nearly equal values in parallel. Resistor elements used in the probe are shown in Fig. 7-25B.

The two resistance elements, R1 and R2, are effectively connected in parallel; and the current flow through the elements is such that the magnetic fields tend to cancel. (See Fig. 7-26.)

Note that in the current pulse-viewing resistor probe, a current of $\frac{I}{2}$ is flowing in the center conductor and resistor R1. In resistor R2, a current of $\frac{I}{2}$ is also flowing, but in the opposite direction from the one in the center conductor.

Since the current in resistor R2 is in a direction opposite from the one in the center conductor, essentially

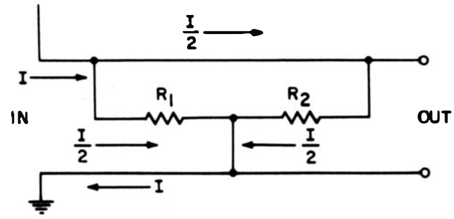


Fig. 7-26. Current flow in the resistance element of the probe in Fig. 7-25.

complete cancellation of the magnetic field takes place across R2. It is across this resistor that the output voltage is developed. This technique greatly minimizes the effect of the magnetic fields. As a result, negligible distortion is encountered in viewing pulses with rise times of .01 to 0.5 microsecond in magnetron oscillators or pulse-generator switch tubes.

ELECTROSTATIC VOLTAGE PROBE

Electrostatic charges are readily acquired on plastics, paper, hydrocarbons, and other poor conductors of electricity. The charges are transferred to these products principally through friction with themselves or with other materials or machinery parts, and once acquired are not easily dissipated. They create many problems in processing, such as attraction of dust, at well as fire and shock hazards to personnel.

The static detecting probe in Fig. 7-27 is a passive body containing a sensitive, well-insulated electrode. It

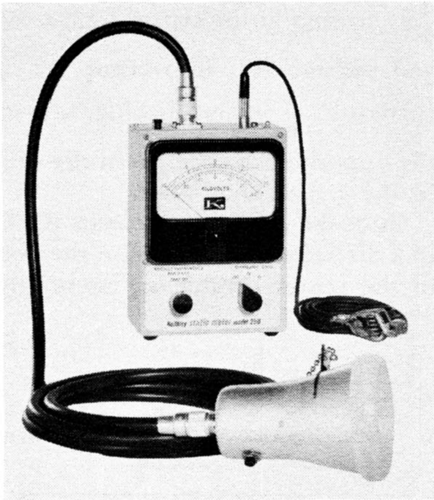


Fig. 7-27. Electrostatic voltage-detecting probe. (Courtesy of Keithley Instruments, Incorporated.)

is connected by a cable to the grid of an electrometer tube in the indicating instrument. When the probe is brought near a charged surface, a voltage is induced on the electrode. This affects the plate current of the electrometer tube and thereby activates the meter, which is calibrated in kilovolts.

In use, the probe is placed three-eighths of an inch from the charged surface. Then the metal slide in the probe is removed, and the meter reading noted. A meter deflection to the left of zero indicates negative electrostatic charges, and a right-hand deflection, positive charges.

HUM FIELD-TRACING PROBE

The probe in Fig. 7-28 is useful for exploring hum fields and checking hum currents in audio, radio, and television equipment. It is connected directly, or through an AC voltage calibrator, to the vertical-amplifier input terminals of an oscilloscope. The oscilloscope gain must be reduced so no or negligible residual hum (due to stray pickup in the room) will be displayed on the screen. When the probe is placed in a hum field, the increase in vertical amplitude will then be proportional to the field strength.

The hum probe can be used for determining the best orientation of transformers, chokes, and leads carrying AC. It can also be used to check hum currents in chassis, by pressing its nose to the chassis and observing the amplitude of the hum pattern on the oscilloscope screen.

CHROMATIC PROBE

The chromatic probe (Fig. 7-29A) is used to mix an unmodulated and a swept RF signal to provide an output signal covering the video-signal requirements of color television receivers. Its schematic is shown in Fig. 7-29B. Three IN56A semiconductor diodes are connected in parallel for most efficient operation. The probe functions quite similar to the mixer in an FM receiver. A frequency-modulated signal (RF from the station) and an unmodulated signal (from the local oscillator) are mixed, and upper and lower sideband signals are thereby generated. In the receiver, the desired sideband is selected and amplified in the IF stages. Meanwhile, the

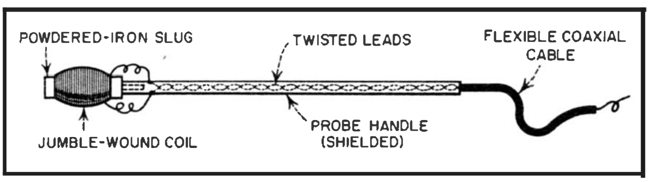
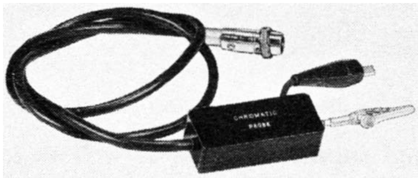
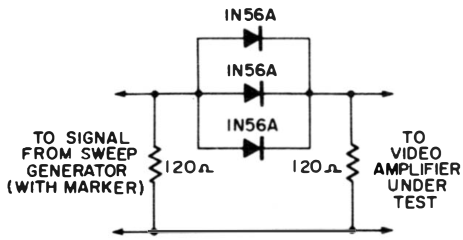


Fig. 7-28. Hum field-tracing probe.

probe mixes an unmodulated signal (from an AM generator) with an FM signal. The signal generators are set so the desired output signal will be the difference frequency and will be swept from approximately 0 to 6 mc. The output signal from



(A) Probe.



(B) Schematic.

Fig. 7-29. Simpson chromatic probe.

the probe is fed to the video amplified under test, the output signal of which may in turn be applied to an oscilloscope through either a demodulator or low-capacity probe. A typical setup is shown in Fig. 7-30. The output signal from the chromatic probe is flat from approximately 8 kc to 4.5 mc. Demodulator probes are usually not practical for use much below 50 kc because they cause distortion at the low-frequency end. The low-capacity probe, on the other hand, will be more suitable since it has no low-frequency limit—the low-frequency response is determined by the oscilloscope only. If a demodulator probe is used, the output will be a response curve; whereas with the low-capacity probe, the scope will indicate the complete modulation envelope, as shown in Fig. 7-30. For best operation, the AM and FM signals should be fundamentals; otherwise, low output and many spurious signals may result.

SPECIAL RADIO AND TV SERVICING PROBES

Fig. 7-31 shows two probes designed especially for radio and television servicing. The high-leak analyzer quickly checks capacitors for leakages or opens. Testing is accomplished by applying a 100-volt DC potential. The capacitor under test is connected between the probe tip and another lead which eminates from the probe. Leakage and charging time are automatically indicated on the neon-bulb indicator in the base of the probe. The probe works

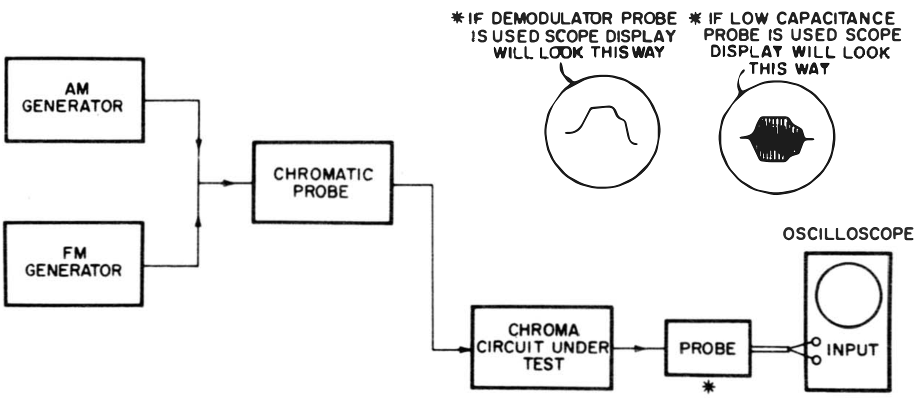


Fig. 7-30. Typical test setup for chromatic probe.

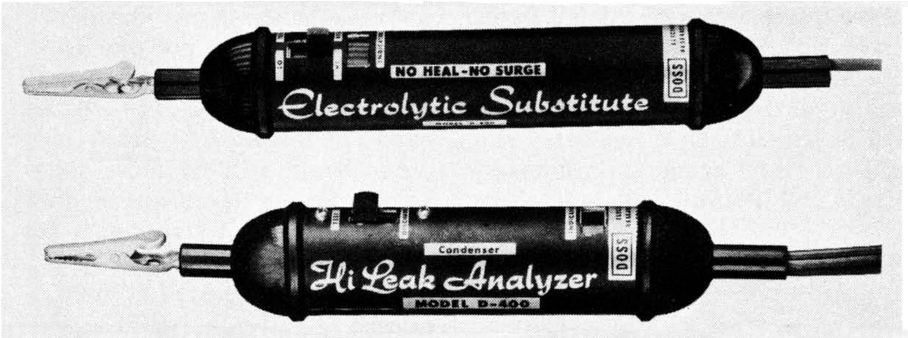


Fig. 7-31. Special radio and TV servicing probes. (Courtesy of Doss Electronic Research.)

on the relaxation-oscillator principle. One short flash of the bulb indicates a good capacitor. Repeated flashes or a steady glow indicates that it is either leaky or shorted. If the bulb does not flash even once, the capacitor is open. The leakage sensitivity is 500 megohms, up to 1 mfd.

The electrolytic substitute probe in Fig. 7-31 is designed for shunt-testing electrolytic capacitors. This is accomplished without the charging surge which often temporarily heals defective electrolytic capacitors and thus nullifies the test. The probe itself contains a controlled-charged network consisting of a resistor in series with an electrolytic capacitor. Electrolytic capacitors are checked by applying the capacitor-resistor network of the probe across the unit to be tested. When the internal capacitor is fully charged, the neon indicator will reach full brilliance. At that point, the resistor can be taken out of the circuit. For all practical purposes, we now have a fully charged capacitor, but without the disturbing charging surge.

PROBE-MASTER

Fig. 7-32 shows the *Probe-Master* combination neon-indicator and signal-tracer probe, which is designed to check for the presence of signal and supply voltages, as well as for testing individual components in electronic equipment. From the schematic of the probe in Fig. 7-33, we see that there actually are three available connecting points—the probe tip and two clip leads, one

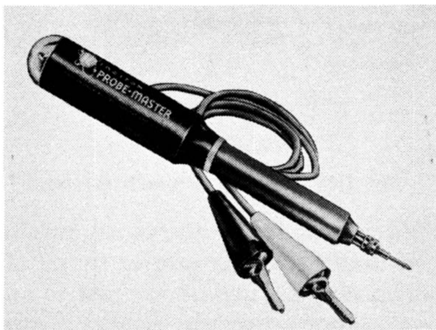


Fig. 7-32. Probe-Master probe. (Courtesy of Kingston Electronic Corp.)

black and one red. The neon-bulb indicator is at the butt end of the probe, where it is easily visible. Using the capacitive network permits bypassing of certain stages within the receiver, and also is useful for

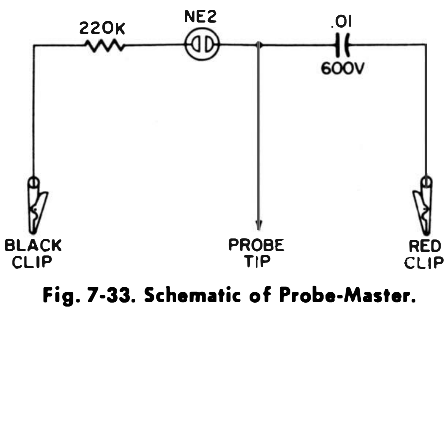


Fig. 7-33. Schematic of Probe-Master.

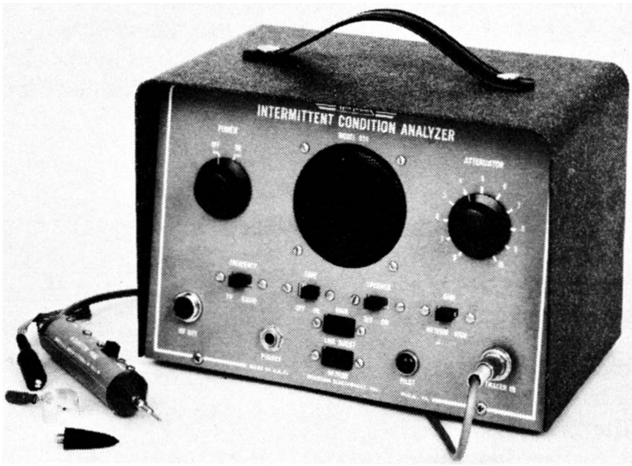


Fig. 7-34. Intermittent-condition analyzer with intermittent probe.
(Courtesy of Winston Electronics, Inc.)

coupling a signal from one stage to another for signal-tracing or -substitution. When the black lead and the probe tip are used, the probe becomes a volatge indicator to show the presence of plate and screen voltages. Because of the neon bulb, the probe can also be used to check for the presence of AC voltages and for tube-filament continuity in a series-connected filament string, as well as to determine the condition of fuses.

INTERMITTENT PROBE

Fig. 7-34 shows an instrument designed specifically for servicing intermittent conditions in electronic equipment. Essentially, it contains an RF signal generator which can be modulated, and a high-gain audio amplifier the input circuit of which is connected to a probe.

The probe itself is broadly tuned for IF and RF tests, and also contains an RC isolation network for audio and video tests. It can be attached directly, or the capacitive pickup discussed earlier can be used. Also available is a rubber tip which allows us to prod without danger of shorts while capacitively picking up a signal around the area we are probing.

PROBESCOPE

The oscilloscope in Fig. 7-35 is unusual because its cathode-ray tube is in the probe. The probe consists of a 1CP1 cathode-ray tube mounted in a mu-metal shield, the face of which is directed toward the user. The other end of the probe contains a tip which is applied directly to the circuit point where we want to make our observations. The in-

Fig. 7-35. Probescope with one-inch cathode-ray tube for probe.

strument contains the usual oscilloscope controls—such as vertical- and horizontal-gain and position, intensity, sync, and sweep. No focus control is provided because the focus is sharp for all settings of the intensity control. The probe is connected to the instrument by a cable.

Part 2
Industrial Probes

TEMPERATURE-SENSING PROBES

The performance of temperature-sensing probes is based on either of two principles—the change of resistance of a wire or semiconductor with temperature, or the thermally-induced voltage of a thermocouple junction.

We will first concern ourselves with resistance-types of temperature-sensing probes, which consist of a length of wire enclosed within a protective sheath. This probe is usually connected as one leg of a Wheatstone bridge. Most wires—such as iron, tungsten, copper, or nickel—have a rather high positive temperature coefficient of resistance (approximately .006, .0045, .004 and .005 ohm-per-ohm-per-degree centigrade, respectively). The resistance of a wire at any temperature is given as:

$$R = R_0 (1 + a \Delta T)$$

where,

- R is the resistance at the final temperature,
- R_0 is the initial resistance at T_0 (usually 25°C.),
- a is the temperature coefficient of the wire,
- ΔT is the number of degrees centigrade above T_0 where R_0 was measured.

For example, if a nickel wire has a resistance of 100 ohms at 25°C., it will have the following resistance at 100°C.

$$R_0 = 100 \text{ ohms}$$
$$\text{and } \Delta T = 100 - 25 = 75°\text{C.};$$

therefore,

$$R = 100\,(1 + .005 \times 75) = 100\,(1 + .375) = 137.5 \text{ ohms.}$$

The resistance change, which can be easily measured in a Wheatstone bridge circuit, is directly proportional to the change in temperature.

Some of the more desirable characteristics of the resistance wire include electrical stability, high resistivity, linear temperature-resistance relationship, relatively high coefficient of resistance, and good mechanical properties.

For accurate indication, the full length of the resistance wire must be influenced by the temperature we are observing. These probes are made broadly in two forms—tip-sensitive and stem-sensitive. The mechanical construction of both types is shown in Fig. 7-36. Copper, nickel, or platinum wires are used most frequently because they exhibit a favorable coefficient of resistance and are also quite reliable. The temperature range over which probes of this nature are useful extends from around −300 degrees to +3,000 degrees Fahrenheit. The ranges of individual probes are of course more limited, usually extending over a few hundred degrees only. Copper is usually used for the low-tempera-

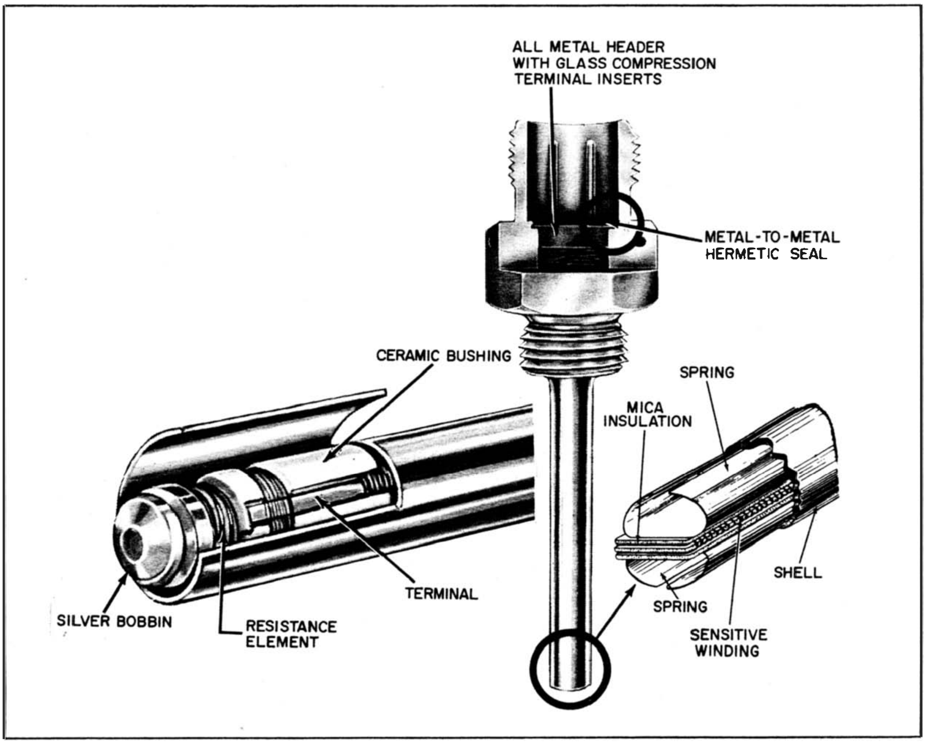


Fig. 7-36. Temperature-sensing probes, showing tip-sensitive and stem-sensitive construction. (Courtesy of Thomas A. Edison Industries.)

ture probes, and nickel and platinum for high temperatures. The typical variation of probe resistance

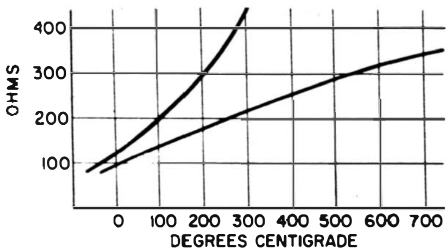


Fig. 7-37. Variation of probe resistance with changing temperature for two different types of wire.

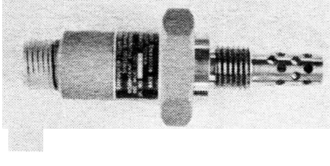


Fig. 7-38. A typical temperature-sensing probe. (Courtesy of Rosemount Engineering Co.)

with changing temperature for two different types of wire is shown in Fig. 7-37.

A probe intended for temperature measurements up to 800°C. is shown in Fig. 7-38. It is intended for such

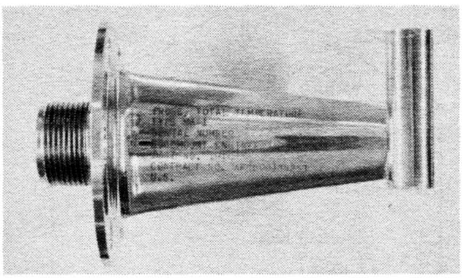


Fig. 7-39. Total-temperature probe. (Courtesy of Rosemount Engineering Co.)

applications as exhaust-gas temperature measurements. Other probes are available for measuring the low temperatures of liquid oxygen and hydrogen.

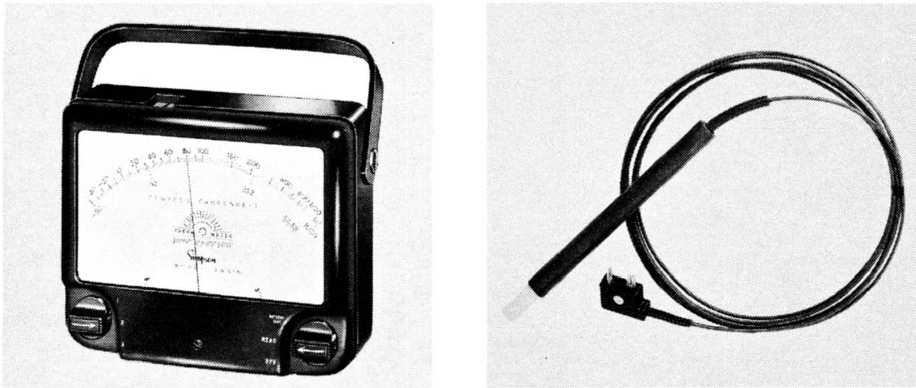


Fig. 7-40. Tip-sensitive thermocouple probe and meter. (Courtesy of Simpson Electric Co.)

We may sometimes be interested in a total temperature measurement. Total temperature is the sum of the static temperature for a compressible fluid, plus the temperature rise due to high speed flow. Such a probe is shown in Fig. 7-39.

A tip-sensitive probe, together with the meter for which it is designed, is shown in Fig. 7-40. This unit gives an indication over a temperature range from −50 degrees to +1,000 degrees Fahrenheit. Two basic instruments are available. One is designed to be used with only one probe, and the other with three probes where the individual probes are selected by the switch on the lower left side of the instrument. The schematic for both probes is shown in Fig. 7-41, and we see that it is a Wheatstone-bridge circuit. Here, the temperature-testing probe is different from the one discussed so far.

The length of the lead from the probe to the indicator becomes important. The lead furnished with each probe is eight feet long and is made up of two wires with *Fiberglas* insulation. The wires are made of two metals—iron and constantan—jointed together and welded at the tip. This is known as the thermocouple or thermojunction. A temperature difference between the two

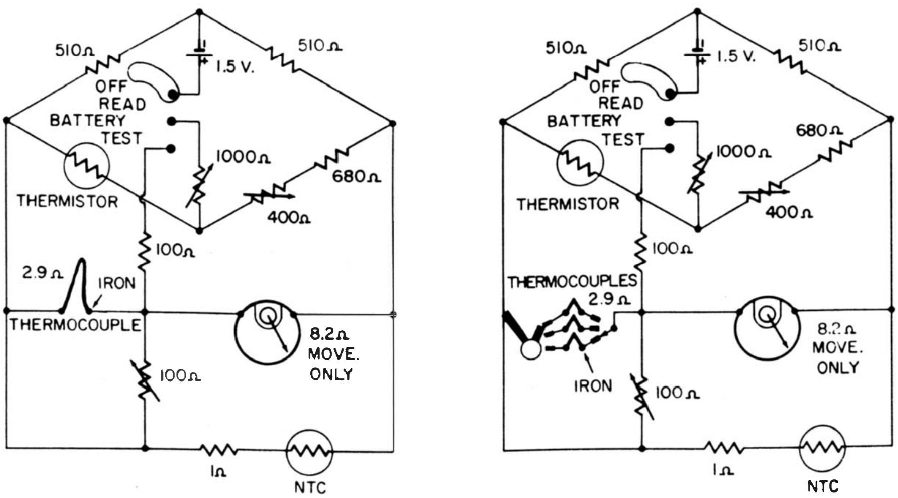


Fig. 7-41. Schematic of probe and meter in Fig. 7-40.

ends of this lead creates a DC voltage difference between the iron and the constantan. When the temperature is higher at the tip than at the plug end of the lead, the voltage at the plug end is positive on the iron wire and negative on the constantan wire. When the two ends are at the same temperature, there is no voltage difference between the wires. When the temperature is lower at the tip than at the plug end, the voltage at the plug is negative on the iron wire and positive on the constantan wire. As the temperature difference increases, the voltage between the wires also increases. This is the voltage applied to the indicating-meter circuit to deflect the pointer and indicate the temperature. The probe tip may be in air or any other gas, in a solid material, or under the surface of a liquid. For best results, be sure to have at least two inches of the probe end in the measured temperature. The probe tip must be held against the surface or exposed in a liquid or gas for about 20 seconds until the meter pointer will come to rest; otherwise, an accurate temperature reading cannot be taken.

Fig. 7-42 shows a temperature-sensing, temperature-indicating instrument using a copper-sensing probe with a resistance of 10 ohms at 25°C. as one leg of a resistance bridge. The unit indicates temperature and also acts as a controlling device to sound an alarm if the temperature under observation exceeds a preset level. Large rotating machine bearings and process temperatures can thus be remotely monitored. Any overload condition would be immediately indicated, and the overheating device automatically shut off. This instrument

Fig. 7-42. Temperature-controlling and -indicating instrument.
(Courtesy of Westinghouse Electric Corp.)

operates over a temperature range of 100° to 400°F. (40° to 200°C.).

Certain semiconductors, known as thermistors, can be made with a comparatively large negative temperature coefficient. They are also employed in temperature-sensing probes because they can detect temperature changes as small as .001°C. if connected in a sensitive Wheatstone bridge circuit. For this reason, they are used for precision temperature measurement or control. Their resistance decreases rapidly as the temperature increases—five per cent per degree centigrade being a typical value. As a result, the resistance-temperature relationship is rather nonlinear. However, it can be made somewhat more linear by the use of series and parallel trimming resistors. Thermistors are available in very high resistance values. This plus their high temperature sensitivity is the reason thermistors provide a high output voltage over a rather wide temperature span.

Thermistor probes are shown in the last part on medical probes.

DISPLACEMENT MEASURING PROBE

Fig. 7-43 shows a cross-sectional view of a probe used for measuring very small displacements. The sche-

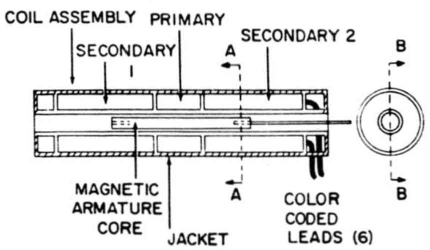


Fig. 7-43. Cross-sectional view of a displacement-measuring probe. (Courtesy of Sanborn Co.)

matic is shown in Fig. 7-44, and characteristic curve of the output, in Fig. 7-45. This probe contains a differential transformer consisting of a tube of nonmagnetic material around which three windings are wrapped. Two of these windings,

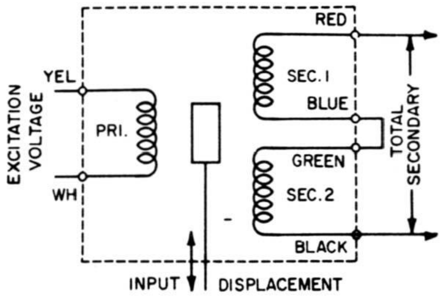


Fig. 7-44. Schematic of the probe in Fig. 7-43. (Courtesy of Sanborn Co.)

connected in series bucking, are at opposite ends of the probe; and the primary is in the middle, between the two secondary windings. An AC excitation voltage (typically 5 volts at 2,500 cps) is applied to this winding. A central core is linked to a nonmagnetic material for mechanical coupling to the surface, or point, the displacement of which we wish to measure with our probe.

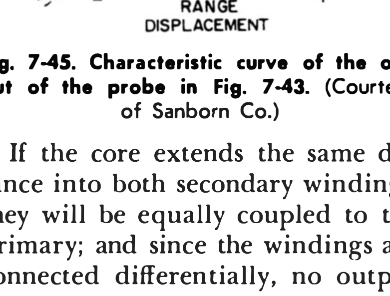


Fig. 7-45. Characteristic curve of the output of the probe in Fig. 7-43. (Courtesy of Sanborn Co.)

If the core extends the same distance into both secondary windings, they will be equally coupled to the primary; and since the windings are connected differentially, no output voltage will be developed. As soon as the core is moved ever so slightly, one of the windings will be more closely coupled than the other and there will be a net output voltage

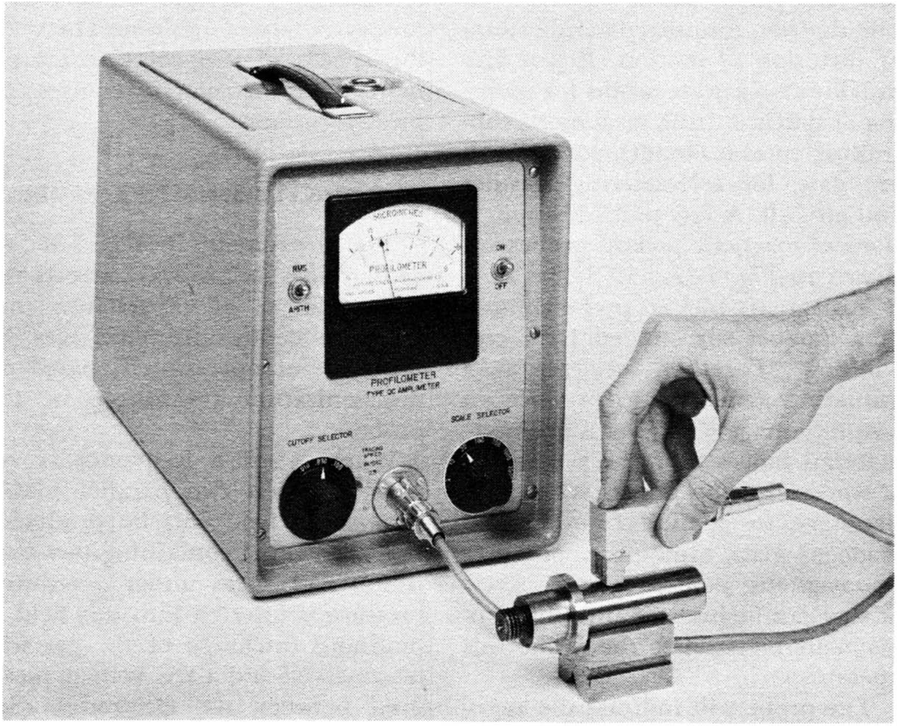


Fig. 7-46. Probe used for determining the "profile" of a smooth surface. (Courtesy of Micrometrical Manufacturing Co.)

which will be the difference between the voltages developed across each of the secondary windings. The magnitude of the output voltage is proportional to the amount of core movement (displacement), and the phase of the output voltage depends on the direction. If the output voltage is passed through a phase-sensitive rectifier, either a positive or negative output voltage will be obtained to indicate the direction of movement, as shown in Fig. 7-45.

Fig. 7-46 shows a probe that has a stylus designed specifically to follow the irregularities of a "smooth" surface. The stylus is mechanically linked to a differential transformer that converts the physical displacement of the stylus into electrical changes, which are then indicated on a meter or recorded on a chart.

The probe provides an electromechanical method for determining the shape, height, and spacing of all sorts of surface irregularities. It shows the profile of practically any machined or finished surface, both internally or externally. Because of the extreme sensitivity of the differential transformer, these probes can indicate surface irregularities as small as a fraction of a microinch. The instrument indicates the surface roughness and height — either the arithmetical or rms (average) value, or in microinches directly on the meter.

PROXIMITY PICKUP PROBE

A proximity pickup probe generates electrical energy from mechanical motion without any need for physical contact. The probe output is proportional to the rate the object moves. A very accurate mechanical-electrical transfer of energy is provided which can be used to indicate motion, torque, rpm, vibration, or direction of motion. It can also provide an accurate means for counting or synchronizing machinery, controlling various circuits, and providing data for telemetering missiles and aircraft. A few possible applications of magnetic pickup probes are shown in Fig. 7-47.

A magnetic pickup probe consists of a magnet surrounded by a coil winding. Together they act as a miniature generator to produce an output voltage whenever a magnetic material moves near the pole piece at the end of the probe. When it is necessary to operate from devices made of glass, aluminum, or other nonmagnetic metals, a steel screw or slug can be inserted into the nonmagnetic material so the probe will operate.

The probe will indicate the angular velocity of a rotating gear or shaft projection. This it does by converting its output signal into a direct current which is proportional to the frequency of the probe output signal. Such an instrument is called a tachometer. A differential tachometer determines the difference (or percentage of difference) between the speeds of two rotating components. This instrument requires two pickup probes.

CAPACITY-SENSITIVE PROBE

The instrument in Fig. 7-48, together with its probes, converts minute changes of capacitance into large analogous output voltages. Its principle of operation is based on the ionization transducer in the probe.

When a radio frequency is applied between two parallel plates, an electric field will be produced. If a glass vessel containing two electrodes and a gas under a reduced pressure is inserted into this field, a luminous discharge of the gas will be observed and a DC voltage measured between the electrodes. (See Fig. 7-49.) The polarity and amplitude of this voltage depends on the position of the tube within the electric field. If it is in the center, there will be zero output. The DC output voltage varies linearly with displacement from the center.

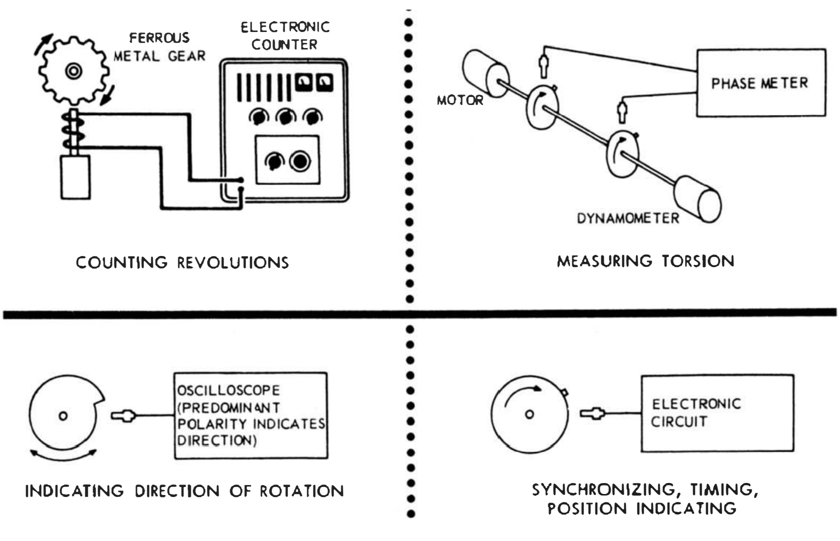


Fig. 7-47. Possible applications for a magnetic proximity pickup probe. (Courtesy of Electro Products Laboratories, Inc.)

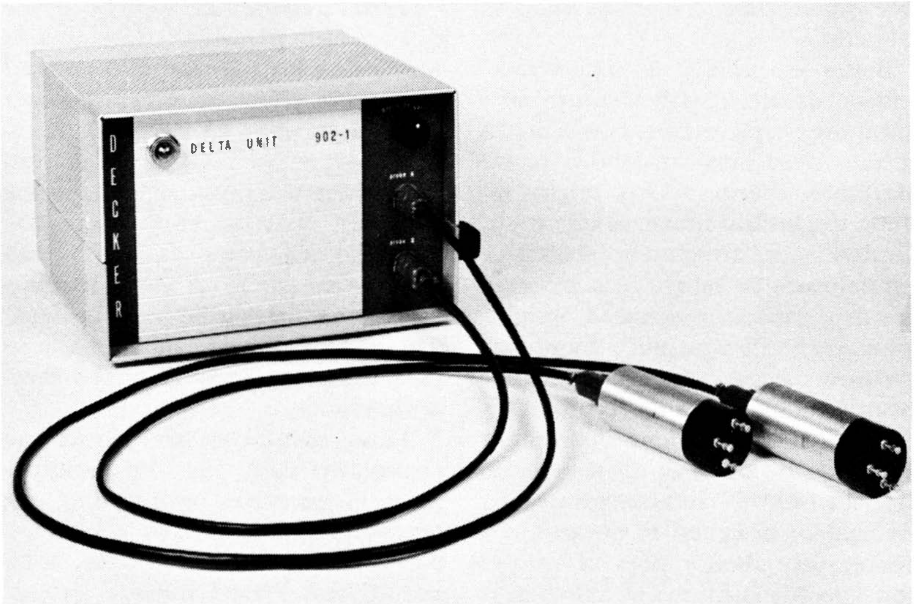


Fig. 7-48. Delta unit using two capacity-sensitive probes. (Courtesy of The Decker Corp.)

The capacity-sensitive probe consists of a glass envelope containing two internal probe electrodes and a noble gas under reduced pressure. This gas is ionized by a stable radio-frequency generator (operating at 250 kilocycles) by externally attached electrodes, so that ions and electrons are produced.

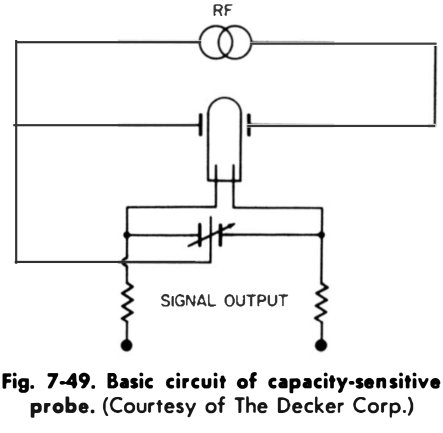


Fig. 7-49. Basic circuit of capacity-sensitive probe. (Courtesy of The Decker Corp.)

A small portion of this high-frequency excitation also appears across the two measuring capacitors, which are connected from the internal transducer electrodes to ground. This AC voltage will vary as the measuring capacitors are varied. When an AC voltage difference exists between the two electrodes, a difference in migration of the electrons in the gas occurs, giving rise between the electrodes to a DC potential difference which is much larger than the AC signal (as much as 30 volts can be obtained without further amplification). Thus, to make a physical measurement, it only becomes necessary to connect an appropriate sensor configuration to the probe so the physical quantity being measured will be converted to a change in capacitance. The probe then converts this capacitance change to an analogous voltage signal. The instrument in Fig. 7-48 will provide sufficient RF voltage to operate two probes. This very sensitive device can measure without any physical contact — and hence, without friction and pressure —static or dynamic conditions. It is so sensitive that there can be an output voltage of up to 5 volts-per-mmf change and it can still indicate capacitance changes as small as .01 mmf.

Being essentially a capacitance-sensing device, it will measure anything the characteristics of which can be translated into capacitance or capacitance change. This might include the measurement of vibration, displacement, roughness, thickness, temperature by means of a bimetallic strip, capacitance, speed, weight, pressure, level, proximity, humidity, pressure, strain—plus many other measurements of this type. This does not mean that one instrument will take the place of all the others described in this chapter, because an instrument designed to do any particular job usually does it in the best possible fashion. Nonetheless, if proper mechanical or electromechanical configurations are employed, this instrument will yield satisfactory results.

PRESSURE-SENSING PROBES

Pressure is a measure of the force or forces acting over a surface. In chemical processing and manufacturing industries, vacuum- and pressure-sensing devices are of great importance. Electronic techniques have now made possible the measurement of presure and vacuum over wider ranges and with greater accuracy than is possible by any other means.

Several different probes are used for measuring pressure, all operating on different principles. The principle of ionization is used in measuring very high vacuums (up to 1 micron). Thermocouples are used for somewhat higher pressures. At still higher pressures (such as 1×10^3 atmospheres), piezoelectric crystals are employed. Here, the change in pressure deforms the crystal, thereby changing its electrical characteristics and thus making it sensitive to pressure changes. The differential-transformer type of probe described under "Displacement Measuring Probes" can also be used where the effect of pressure on a diaphragm must be detected. A capacitive-type pickup probe is suitable where the pressure changes the electrode spacing and hence the electrical capacitance, which can then be measured. A variable-reluctance type of probe can be used where the pressure can be made to vary the characteristics of the magnetic circuit.

Three measuring techniques are commonly used for the measurement of pressures so low they can be considered essentially a vacuum. They are the thermocouple, ionization, and Pirani vacuum gauges. The probes used will now be discussed.

The thermocouple gauge is the simplest of all electrical vacuum gauges. It consists of a probe containing a thermoelectric junction heated by a constant, regulated current. Because of this heating effect, a voltage is developed across the terminals of the junction. This voltage is comparatively large (millivolts) and can therefore be fed directly (through a calibrating potentiometer) to a meter for pressure indication. The temperature of the heated junction will vary according to the amount of heat conducted away from it by the gas within the probe.

Within the range of several millimeters of mercury (atmospheric pressure equals 760 mm of mercury) to somewhat less than one micron, thermal conductivity varies significantly with pressure. The amount of gas within the tube will vary according to the pressure of the system. For this reason, the temperature of the junction—and, therefore, the output of the thermocouple—will indicate the pressure. As it drops, the

Fig. 7-50. Thermocouple gauge with probe, for measurement of pressures from 1 to 1,000 microns. (Courtesy of Consolidated Electrodynamics Corp.)

wire gets hotter and the output of the thermocouple increases.

A thermocouple gauge suitable for measurements of pressures from 1 to 1,000 microns is shown in Fig. 7-50, together with its probe. From the schematic in Fig. 7-51, we see that this instrument can be operated with one or two probes (shown as TC-1 and TC-2).

The operation of ionization gauges is based on the fact that ions will form as a result of collisions between molecules and electrons. Below approximately 1×10^{-3} mm of mercury, this formation of ions varies linearly with pressure. The ionization gauge uses a probe containing a triode, the filament of which is operated at a low temperature so no space charge will be created. The control grid is made positive and the plate negative, because higher sensitivity can thus be achieved.

Electrons passing through the grid will be repelled by the negative plate and returned to the grid. When the probe is exposed to the vacuum, any gas molecules present will be ionized as a result of their collision with electrons and will thereby yield positive ions, which will be drawn to the negative plate. The number of ions thus produced is proportional to the pressure and the applied voltage. If voltages are kept constant, the plate current will be directly proportional to the degree of ionization, and hence, to the pressure.

Because of their sensitivity, ionization gauges can be used over pressure ranges from 1×10^{-3} to 1×10^{-7} mm of mercury.

Fig. 7-52 shows the ionization gauge used in the probe of an instrument designed primarily for measuring pressures in the ultrahigh vacuum region.

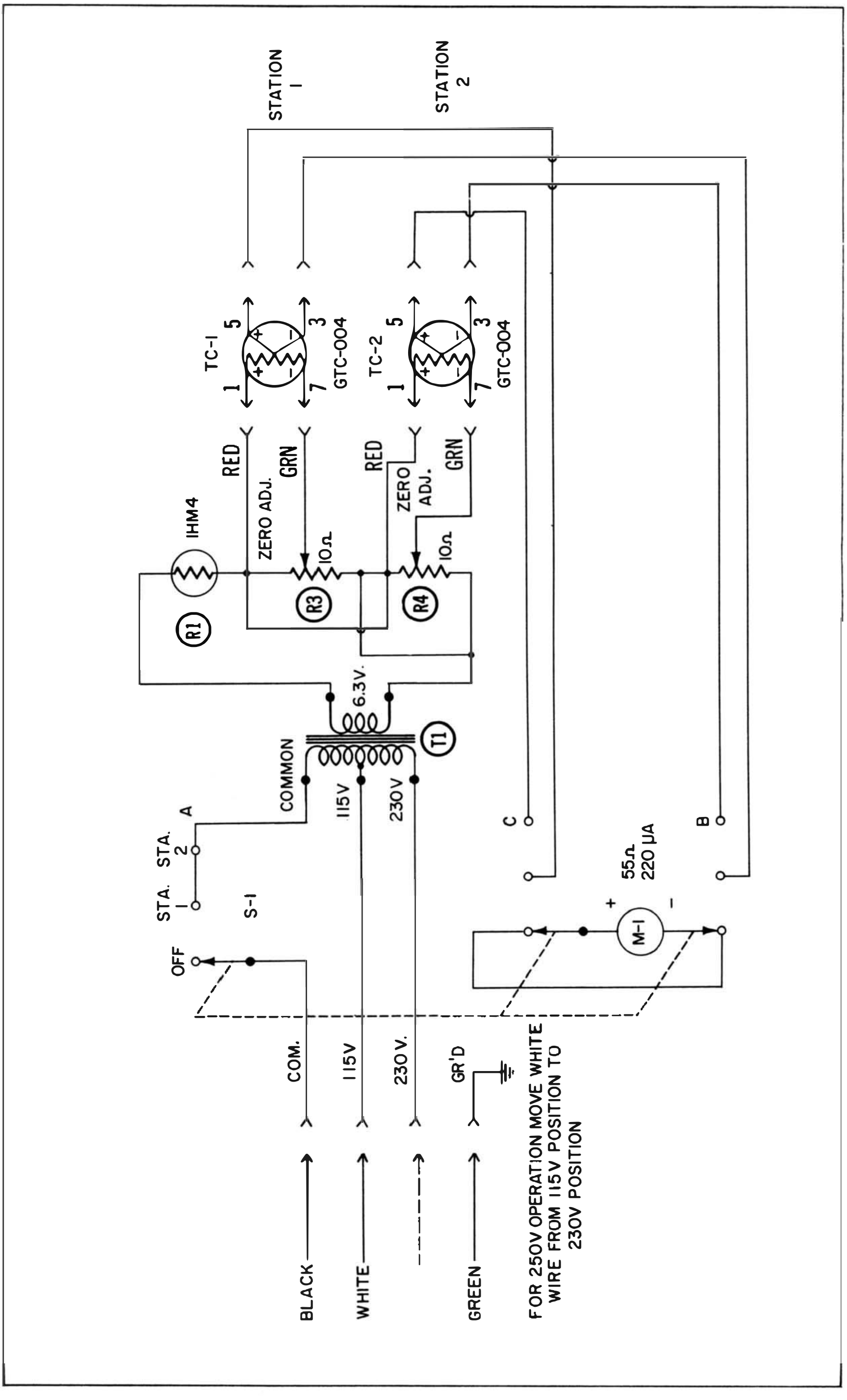


Fig. 7-51. Schematic of thermocouple gauge. (Courtesy of Consolidated Electrodynamics Corporation.)

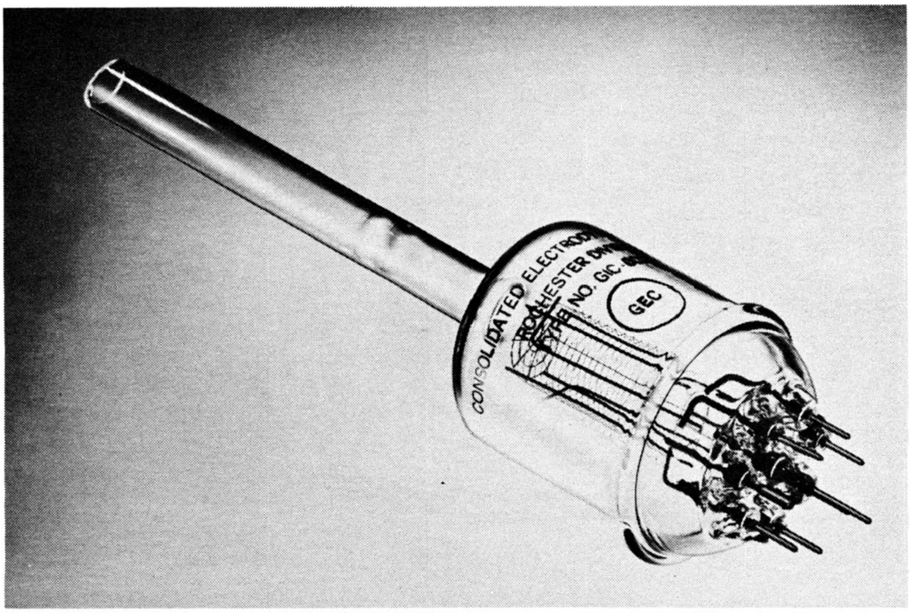


Fig. 7-52. Ionization gauge for measurement of pressures in the ultra-high vacuum region. (Courtesy of Consolidated Electrodynamics Corp.)

The operation of the Pirani, or thermal-conductivity, vacuum gauge is based on the change in the temperature—and therefore, the change in resistance—of a heated filament due to convection. This resistance change is a function of the pressure of the surrounding gas. With decreased pressure, convection cooling becomes less effective; so the temperature of the filament will increase. Resistance is measured in a conventional Wheatstone-bridge circuit, which is made insensitive to ambient temperature changes by use of a similar compensating tube in one arm of the bridge. A sensitive microammeter scaled in pressure units is then used to measure the bridge unbalance caused by the resistance change.

ULTRASONIC THICKNESS-MEASURING PROBE

By ultrasonic means, the thickness of a wide variety of metals, glass, rigid plastics, large vessels, tanks, ship hulls, extrusions, and large sheets or plates can easily be tested nondestructively and from only one side of the material. This is done by determining the resonant frequency of vibration in the thickness direction. This resonant frequency is essentially independent from the other physical dimensions of the material.

Fig. 7-53 shows a transistorized portable ultrasonic thickness tester in use. This is how it works: The output voltage from a self-excited oscillator is applied to the transducer probe, which will then vibrate at the frequency of the applied voltage. (A typical transducer probe is shown in Fig. 7-54.) When the probe is applied to the surface of an object, the ultrasonic vibrations of the probe will be transmitted as a continuous wave into the object and will be reflected from the opposite surface. The oscillator is then tuned to the frequency at which the signal transmitted into the object will be in phase with the previous one that has traveled through and been re-

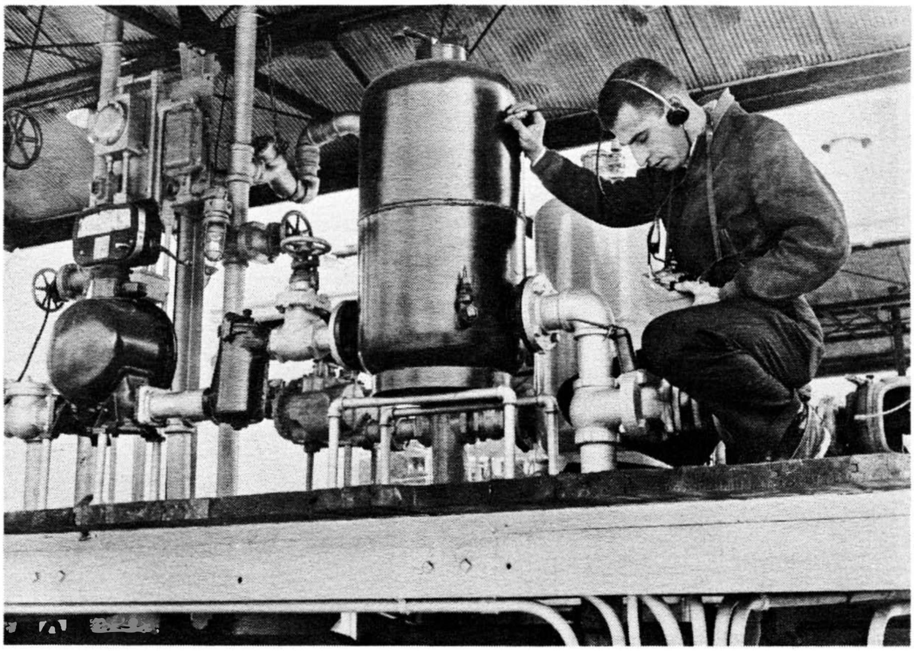


Fig. 7-53. Ultrasonic thickness tester in use. (Courtesy of Branson Instruments, Inc.)

flected from the other surface. This is the resonant frequency of vibration (in the thickness direction) of the object. The minimum, or fundamental, frequency (longest wavelength) at which this condition will occur is proportional to the velocity of the signal in the material under investigation. It is also proportional to twice the thickness of the material because the signal has traveled to one surface and back again because of reflection. Since all materials have internal damping, there is a sharp increase in the energy dissipated in it when the material is vibrated at resonance. (This is the energy furnished by the oscillator.)

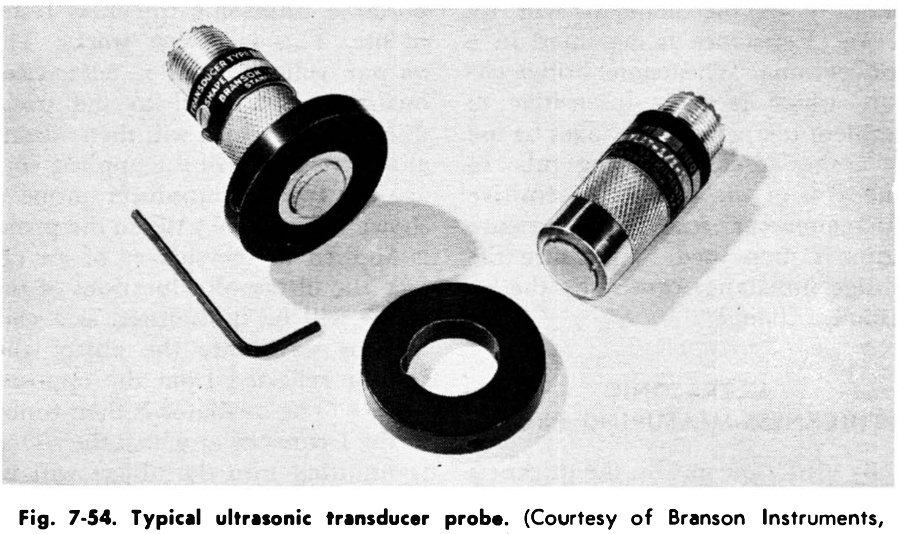


Fig. 7-54. Typical ultrasonic transducer probe. (Courtesy of Branson Instruments, Incorporated.)

The increase will be shown by a meter inserted to indicate the power supplied by the instrument. Therefore, as the resonance point is reached, there will be a sharp increase in the meter reading.

Several peaks will occur at frequencies harmonically related to the one at which this peak would first occur. The other peaks are the result of resonance at various harmonics. It is common practice to measure the frequency difference between two resonant peaks and then use this value to calculate the thickness. This can be done because the difference in frequency between any two adjacent harmonics will equal the fundamental frequency at which the first resonance would occur.

The ultrasonic frequency range from 650 kilocycles to 2 megacycles is most suitable for general-purpose applications. With this frequency range, we can measure the thickness of steel from .060 to 12.0 inches. To measure steel less than .060 inch thick, we must use a higher frequency. For example, a frequency range of two to six megacycles will correspond to thicknesses ranging from .020 to 4.0 inches. At higher frequencies, the roughness of the reflecting surface has a very pronounced effect. Therefore, frequencies much above two megacycles should not be used if the reflecting surface is seriously pitted or otherwise corroded.

The transducers in the probe are either quartz or barium titanate. Their nature is such that, if placed in mechanical contact, they will transmit the vibrations caused by the AC voltage applied to their surfaces. These vibrations are due to the small mechanical deformation resulting from the applied voltage.

Sketches showing the basic construction on three types of transducers are shown in Fig. 7-55. Fig. 7-55A shows a thin quartz-type transducer. It is silvered on both sides for proper electrical contact and its bottom is cemented to a plastic button to protect it against abrasion. Fig. 7-55B shows a quartz crystal transducer protected by an aluminum oxide wear plate; and Fig. 7-55C, a barium titanate transducer with a quartz wear plate.

EDDY-CURRENT PROBE

Eddy-current testing involves the transmission of energy through a

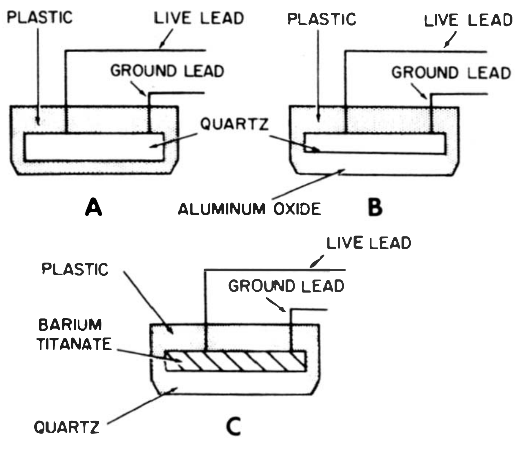


Fig. 7-55. Basic construction of ultrasonic transducer probes.
(Courtesy of Branson Instruments, Inc.)

piece of metal. The action is much like the transmission of heat, X rays, or ultrasonic waves. Whenever a piece of metal is placed in an AC magnetic field, we know that the eddy currents which circulate in closed loops will be set up in the metal. The shape, size, alloy composition, hardness, and purity of the metal, or the presence of porosity or flaws, determine the phase, magnitude, and distribution of these currents. Flaws in the metal divert the currents around them. Eddy currents and their variations set up a magnetic field of their own which can be detected. We can therefore measure several physical characteristics of a metal by placing it in an alternating or pulsating magnetic field and then measuring the resultant field. The depth of penetration of these eddy currents is controlled by the frequency of the AC field. At low frequencies, eddy currents can be set up along the entire volume of a metal bar; but at higher frequencies, we run into the problem of skin effect (discussed earlier) and the eddy currents will be near the surface.

The instrument in Fig. 7-56, together with its probe, makes possible a nondestructive method of measuring the thicknesses of conductive films on conductors, conductive films on nonconductors, and nonconductive films on conductors. The absolute accuracy obtained depends on the accuracy with which the thickness of a standard can be determined. When the correct probe is used, the instrument is capable of distinguishing between film thicknesses differing by only a few per cent of the thickness corresponding to full scale. Furthermore, electrical conductivity can also be checked, and materials can be matched according to their magnetic proper-

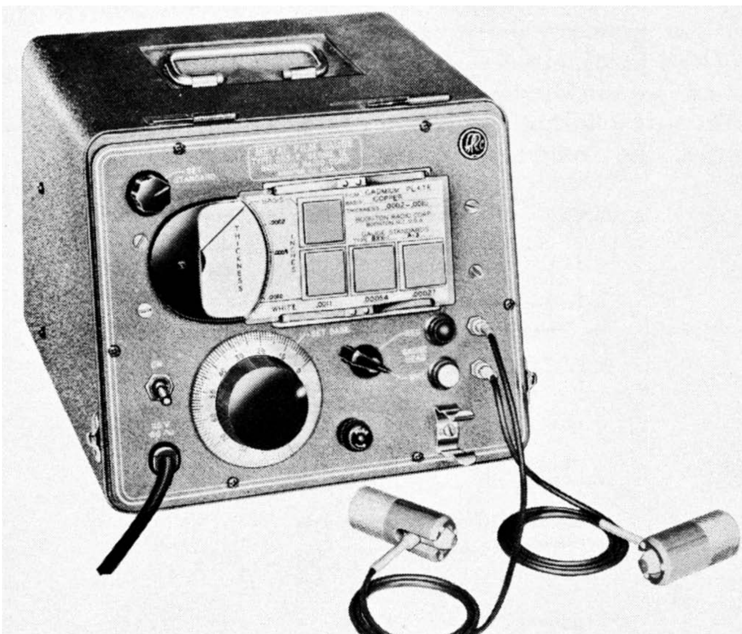


Fig. 7-56. Metal film-thickness gauge with probes. (Courtesy of Boonton Radio Corp.)

ties. All this test requires is that a sample of the material with the desired characteristics be available. We then apply the probe to this material, and set the control to some arbitrary value. To measure such characteristics as the annealing in steel or beryllium, for example, we simply apply the probe to the material under test. If the reading is the same as the one from the sample, the material under test also has the same characteristics.

Eddy currents generate an electromagnetic field, which in turn induces an electromotive force in the exciting coil in the probe. This effect tends to oppose the original current in the coil and thereby change its impedance. This effect is equivalent to introducing an additional "reflected impedance" in the coil. The amount the coil impedance changes depends on a number of factors—such as the electrical and magnetic properties of the conductor, its configuration, the coil-conductor spacing, the geometry of the coil, and the frequency.

If we first consider a flat nonferromagnetic conductor close to the coil and normal to its axis, we find that as the coil is brought close to this conducting plane, its reactance decreases and its effective series resistance increases. The magnitude of these changes depends on the geometry of the coil—especially the reduction in reactance, whereas the increase in series resistance also depends on the continuity of the conductor under test. The combined effect of the reactance and resistance change produces in the probe circuit a change in phase which is a measure of the conductivity of the conductor. If we wish to measure the conductive coating on conductors, the reflected impedance depends on the conductivity of the conductor and the thickness of the coating.

This instrument (Fig. 7-57 shows its functional block diagram) consists of an oscillator circuit. The probe circuit is made resonant at the oscillator frequency with the probe placed on the basis material. Both the probe signal and the reference signal are impressed, after suitable amplification and amplitude limiting, to the grids of a gated-beam phase-detector tube. The indicating meter reads changes in the plate current of this phase-detector tube, which varies in accordance with the phase difference between the probe and reference signals.

Two complete probe assemblies go with each instrument, for use with different thicknesses of films and combinations of materials. The encapsulated gauge-head coil is carried on a lightly spring-loaded plunger which can move up and down in a hand-held probe. The lower end of the probe contains three symmetrically placed bosses; their purpose is to insure that the gauge-coil axis is perpendicular to the specimen under investigation. Each probe covers a thickness range of 5 to 1, and both cover a combined range of 20 to 1 because of somewhat of an overlap. Test frequencies of 500 kilocycles and 8 megacycles have been found to cover the most commonly encountered coating combinations and thicknesses.

The coils used in the probes have a high Q because, in the resistance component of the reflected impedance, the variations which are characteristic of the conductor in the coil field should generally be made as large as possible (in relation to the resistance of the coil), so that good sensitivity can be achieved. Operating the coil in a tuned circuit near resonance will further increase sensitivity.

For measuring the electromagnetic properties of metal parts, the instru-

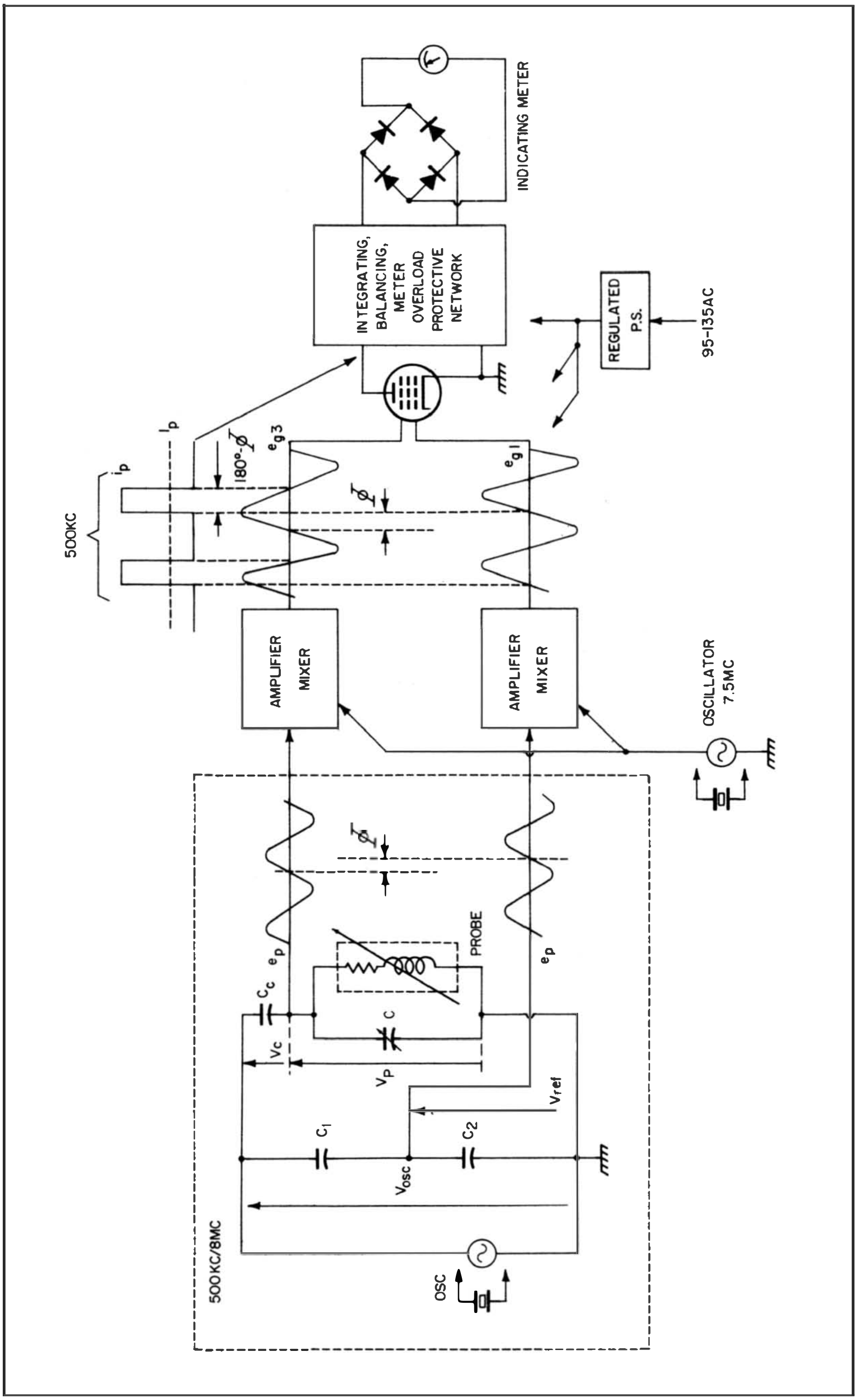


Fig. 7-57. Functional block diagram of metal film-thickness gauge. (Courtesy of Boonton Radio Corp.)

ment in Fig. 7-58 permits sorting of mixed metals according to alloy. It can also be used for detecting the range of heat treatment given to any metal. Measurements are made on any flat surface ⅝ inch in diameter or larger, even when it is rough, dirty, or covered with layers of paint. Measurements are made in about three seconds by touching a hand-held probe to the surface tested. The probe radiates an electromagnetic field which excites eddy currents in the test sample. Instrument response to conductivity and permeability is displayed on a meter. In addition, two alarm lights signal when conditions are above and below preset tolerance levels and, hence, speed the sorting of parts.

The instrument is supplied with plug-in meter scales for different metals and conductivity ranges. As the desired scale is plugged into a six-prong connector on the meter face, several resistors mounted within the scale automatically adjust the range, sensitivity, and lift-off (surface roughness) compensation of the instrument. The only adjustments necessary are occasional calibrations of the low and high ends of the meter scale. This is done by placing the probe on metal specimens supplied by the manufacturer.

These tests are made by means of radio-frequency (262 kc) electro-

Fig. 7-58. Eddy-current instrument for identifying alloys and properties in metals. (Courtesy of Metrol, Inc.)

magnetic waves which are produced at the tip of the hand-held probe. Upon entering the metal part, the waves induce eddy currents in the metal. The strength and distribution of these currents and of their associated electromagnetic field depend on the conductivity and magnetic properties (if any) of the part. The atomic scale conditions which account for the characteristic conductivity and magnetic properties of metal also relate to the strength, hardness, alloy composition, chemical purity, degree of carbonization, and heat-treatment condition of a part. By responding sensitively to changes in conductivity or magnetic properties, this instrument provides a basis for identifying alloys and checking metallurgical and physical properties for uniformity.

Measurements are made by means of test probes, which transmit the electromagentic test signal to the part. Illustrated in Fig. 7-59 are the types of probes available: OD, for inspection of tubing and bar stock from the outside; ID, for inspection of tubing from the inside; area probe; and microprobe, for testing flat stock and miscellaneous shapes offering small, flat areas. Probes are plug-in style for rapid interchange. They make differential and absolute measurements simultaneously, and introduce focused fields for maximum resolution, sensitivity, and analysis possibilities. Faraday shields are used to cut noise pickup. Probe surfaces which slide against the test part are made of self-lubricating and long-wearing *Nylatron-G*.

Each probe contains an exciting and a pickup coil. The eddy currents set up in a magnetic field created by the exciting coil produce a new magnetic field which opposes that original field. The pickup coil measures the sum of the magnetic

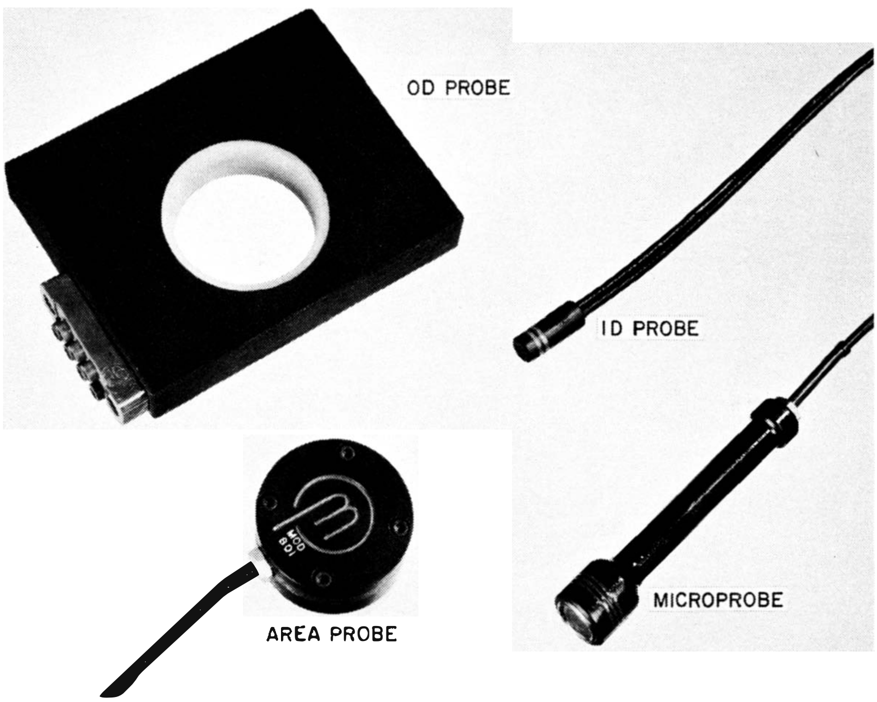


Fig. 7-59. Probes for use with eddy-current instrument of Fig. 7-58. (Courtesy of Metrol, Inc.)

fields set up by the exciting coil and the eddy current. The shape of both coils is determined by the geometry of the metal under measurement. Because both the pickup and the exciting coils are rather close to each other, they will immediately sense any sudden discontinuity (no matter how small) in the common metal area. If it appears suddenly, a rather large difference signal will be produced.

VIBRATION PICKUP PROBE

Undesirable and unnecessary vibrations not only cause noise and discomfort, but also wear and destruction of materials, machinery, and even buildings. Complex vibrations can be measured with the probe in Fig. 7-60. It is used to determine the displacement, velocity, and acceleration of a vibrating body. Once the source of difficulty has been determined, corrective measures can then be taken. Vibration problems due to rotating machinery are particularly common in production plants and power-processing installations. Therefore, the source of difficulty must be determined before any damage becomes irreparable.

The probe contains an inertia-operated semiconductor device which generates a voltage proportional to the acceleration of the vibrating body. It is used with a sound-level meter. The frequency range of the probe extends from 2 to 1,000 cycles per second. The internal construction of the semiconductor element is somewhat similar to the one in Fig. 7-55. With the correct conversion tables and setting of the switch on the control box (which contains an integrating network), acceleration, velocity, and displacement can be measured directly.

THE SMOOTHRATOR

The *Smoothrator* is an electronic testing device which quickly shows the performance qualities of oil-lubricated, instrument-sized, precision ball bearings by revealing their vibrational characteristics. It also indicates the presence of dirt or other contamination as well as any dam-

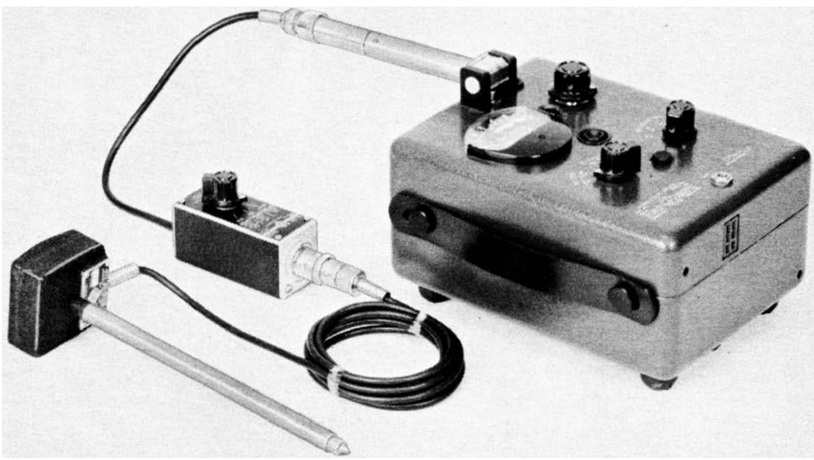


Fig. 7-60. Vibration pickup probe with control box and indicating meter. (Courtesy of General Radio Co.)

age. The unit is equipped with an electromagnetic sensing probe that transforms mechanical vibration from the rotating bearing into electrical signals. After passing through the necessary amplifier and counter stages, the output signals from the probe are then indicated on a dwell-level meter and a counter tube. The dwell-level meter indicates the relatively constant or average signal produced by the normal rolling contact within the bearing, and the counter tube, the transient or peak signals produced by dirt or other foreign matter, or irregularities in balls or raceways. The instrument is shown in use in Fig. 7-61.

The *Smoothrator* must be used in strong fluorescent-lighted areas so the proper stroboscopic effect for indicating the bearing speed can be obtained. The unit is operated by putting the bearing to be tested into an adapter with two concentric rows of holes. The assembly is then placed on the electromagnetic pickup probe. This probe is then equipped with a threaded pickup stud onto which the adapters are screwed to receive the bearings. The adapter is spun by hand. When the inner row of holes reverses its apparent direction (because of the stroboscopic action of the fluorescent light), the bearing is rotating at 600 rpm. A foot switch is released to start the counter test, and the dwell-level meter is now read. When the outer row of holes reverses its apparent direction, the bearing will be rotating at 300 rpm. The counter test is now ended, and the counter tube will give a reading indicative of the quality and cleanliness of the bearing.

FUEL-VAPOR DETECTOR PROBE

Vapor detectors are designed mainly for use on boats, where they

Fig. 7-61. The Smoothrator in use. (Courtesy of the Barden Corp.)

give a warning when the vapor concentration of potentially explosive fumes in the engine compartment exceeds a safe level.

A fuel-vapor detector, together with its probe, is shown in Fig. 7-62. This unit employs a platinum filament which emits infrared rays when gas fumes are present. A silicon solar cell senses the infrared energy given off by the platinum wire. Under normal operating conditions, a small current flows through the platinum filament in the detector probe, causing it to glow faintly. When gasoline fumes are present in the atmosphere surrounding the probe, the filament glow will increase in brilliance and send a signal through the solar cell mounted adjacent to it.

These signals, amplified by a transistor (shown in the schematic in Fig. 7-63), then trigger a flashing red light on the indicator unit to alert the crew long before the gasoline fumes reach dangerous proportions.

The principle of operation of the vapor detector which we have discussed here is illustrated by the block diagram which is shown in Fig. 7-64.

LEAK-DETECTOR PROBE

The operation of the leak detector in Fig. 7-65 is based on an increase of positive ion formation around the heated surface of a platinum element when the halogen content of the air surrounding the filament increases. A cylinder of platinum within the instrument is heated, by means of a heater winding, to approximately 800°C. and then surrounded by another platinum cylinder. The air under test is drawn between these two platinum electrodes by a small vibrator-type pump and is passed around a probe. If the air is clean when a DC voltage is applied between the electrodes, a small positive ion current will flow. A small quantity of halo-

Fig. 7-62. Automatic gas detector. (Courtesy Raytheon Manufacturing Co.)

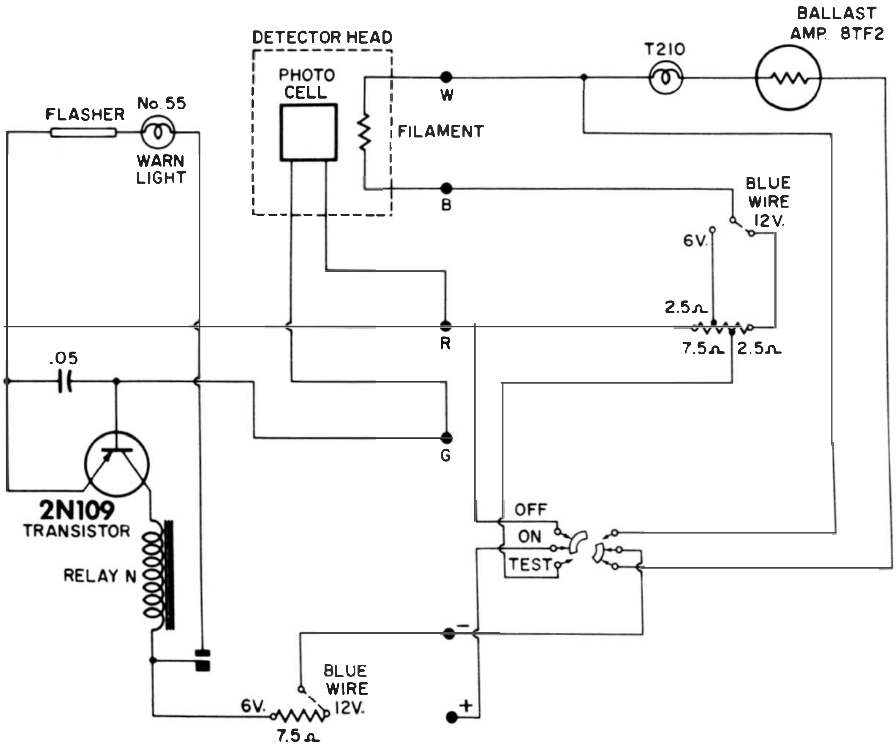


Fig. 7-63. Schematic of automatic gas detector.

gen vapor will, however, increase the ion current.

If the air sample does contain a gas refrigerant, the ion current will increase immediately and cause a lamp in the probe to flash. The circuit in Fig. 7-66 is designed so the lamp will flash for about one second, but only when the concentration of refrigerant in the air under test increases. The lamp remains off at all other times. Very small leaks can be easily detected by this method. The probe (Fig. 7-67) is connected to the instrument by a flexible tube which contains the wires for the lamp, plus a smaller air-supply tube. At the end of the tapered portion of the probe, there is an air filter which removes any

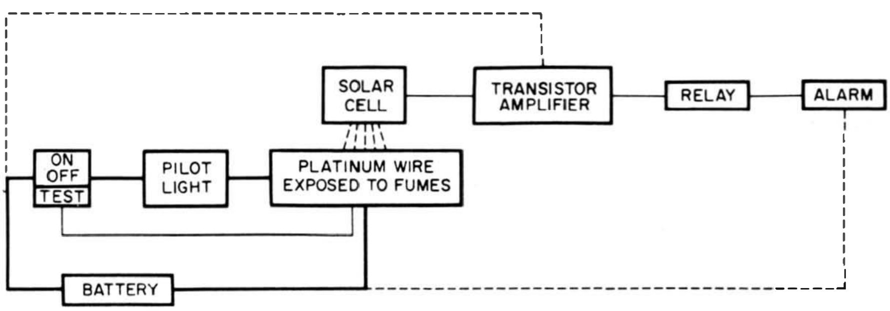


Fig. 7-64. Block diagram of the vapor detector in Fig. 7-62. (Courtesy of Raytheon Manufacturing Co.)

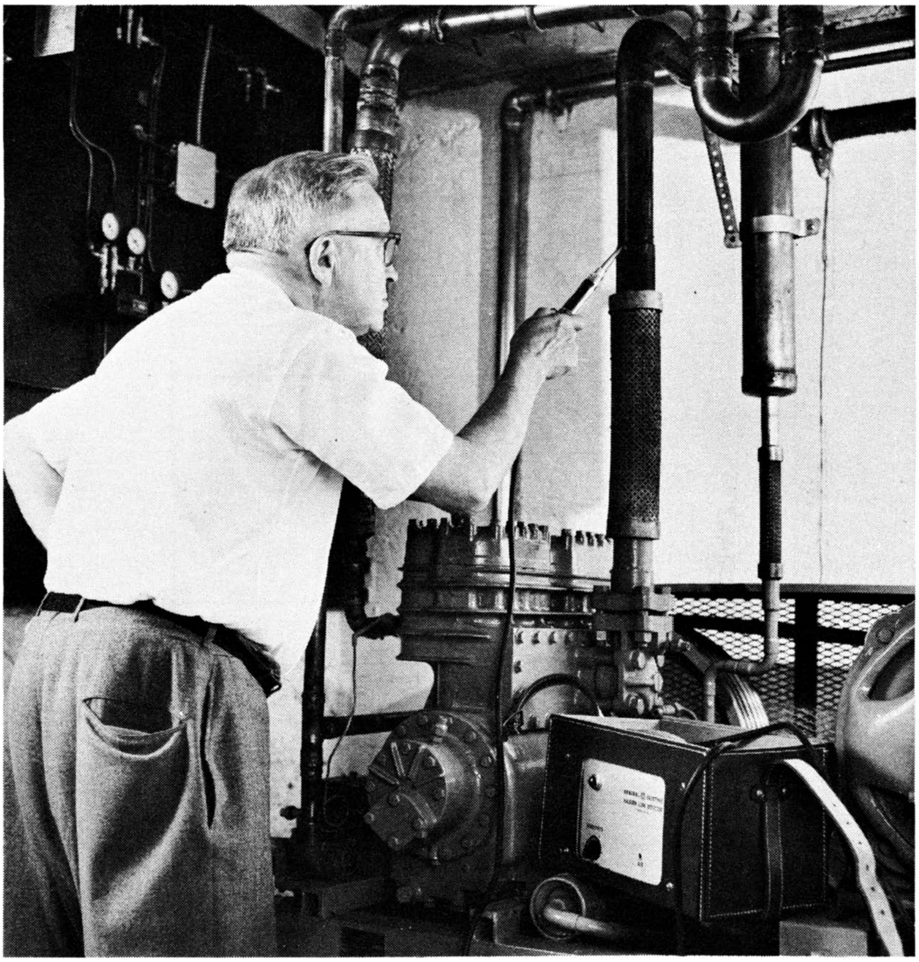


Fig. 7-65. Gas-leak detector in use. (Courtesy of General Electric Co.)

dust or dirt particles from the air to keep them from entering the instrument. The probe is moved along seams, joints, or other areas where a leak may occur. The transparent probe tip will light up when it passes near a leak.

The ion emitter should normally be replaced after about 100 hours of operation. The need for replacement is indicated by a lack of response when the probe is inserted into a halogen reference source. The sensitivity of the instrument can be checked by dipping the probe into halogenated oil and withdrawing it immediately. If the probe does not flash, the ion emitter has lost its sensitivity and must be replaced.

AIR-VELOCITY MEASURING PROBES

Air will flow when a pressure difference exists between two points. The pressure differential actually pushes the air from the high- to the low-pressure point. The speed of the air is called *velocity.* It, in turn, will create *velocity pressure.*

The instrument shown in the phantom view in Fig. 7-68 measures static and total pressure, as well as air velocity. It contains an alumi-

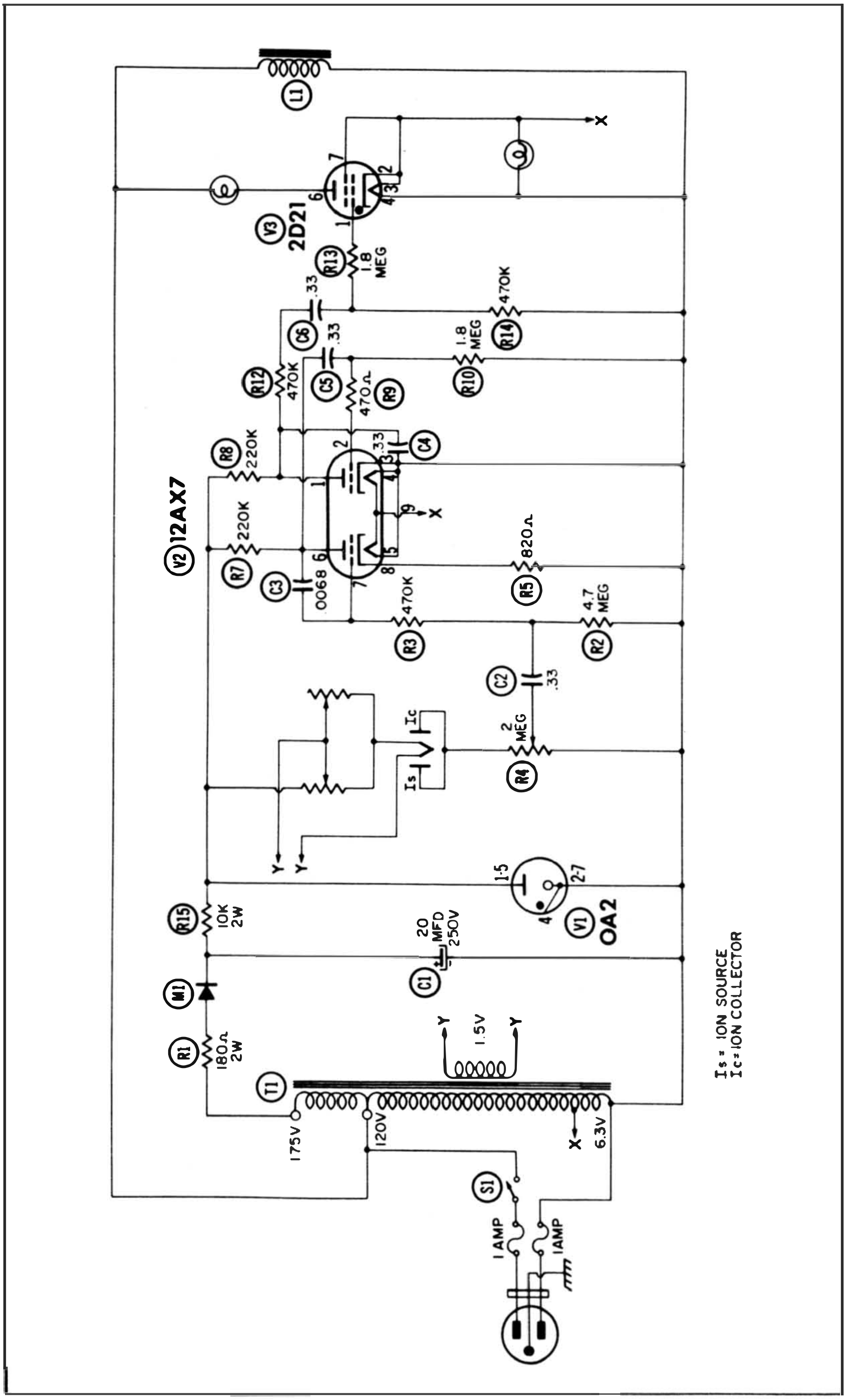


Fig. 7-66. Schematic of gas-leak detector.

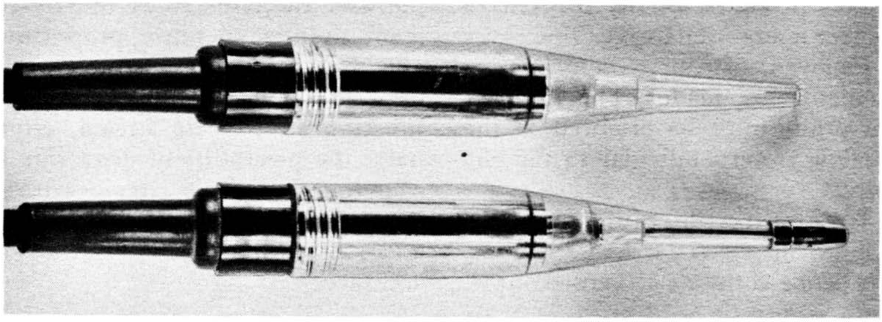


Fig. 7-67. Probe used with gas-leak detector. (Courtesy of General Electric Co.)

num vane located in a calibrated air chamber, which is actually a tunnel going right through the instrument case. Air enters the instrument at the left meter port and leaves on the right side. Flowing through the instrument, the air impinges on a vane, which is deflected against the spring tension holding it. The meter pointer is mechanically linked to this vane; thus, as the vane moves, so does the pointer. The meter scale is calibrated to read velocity in feet per minute. The moving system is loaded by means of

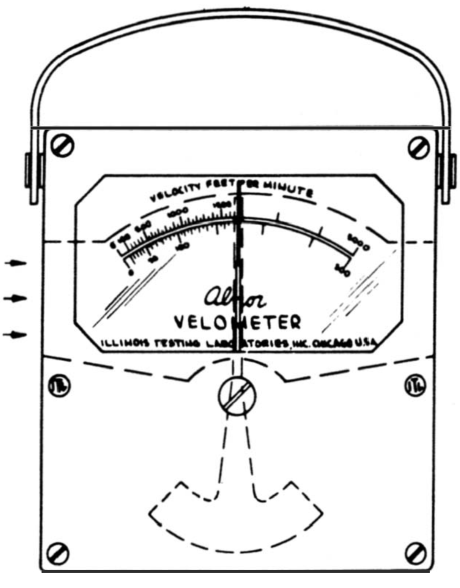


Fig. 7-68. Phantom view of air-velocity meter. (Courtesy of Illinois Testing Laboratories, Inc.)

high-quality phosphor bronze hairsprings and moves in sapphire pivots. Being a balanced moving element, it can be operated in any position. No range switching is required on the instrument; instead, the various ranges are selected by using the proper probe.

Depending on the shape and size of the probe orifice, velocity pressures can be measured in an open space, a room, going into or out of a duct, or within the duct itself. To determine the total volume of air, we multiply the average velocity of the air stream by the area through which it flows.

This instrument, with its various probes, finds its greatest use in heating, air conditioning, and industrial hygienic applications. Fig. 7-69 shows the instrument being used to measure the air velocity in a heating installation.

A thermoanemometer using a heated thermocouple probe for accurate measurements of very low air velocities is shown in Fig. 7-70. This instrument permits measurement of air velocities as low as 10 feet per minute. Whereas the head of the probe used with the previous instrument contained just a calibrated opening, this one contains a delicate assembly of wires which must be exposed directly to the stream of gas or air the speed of which we wish to measure. The tip of this probe is usually covered to protect it against damage. The cover is removed, of course, before measurements are made. The head of the probe must be oriented so the air flow is perpendicular to the element.

The construction of the probe tip is shown in Fig. 7-71. As we can see, this probe contains a thermocouple. Here is how it works: At zero air flow, the fine crossmember reaches its highest temperature (approximately 350° Fahrenheit). A flow of air across this member will cool the thermocouple junction and thus cause its temperature to drop. The drop in temperature changes the millivolt output of the thermocouple and thereby causes the instrument pointer to move proportionally. Having a thermocouple reference junction, as well as the hot junction in the air stream, eliminates the possibility of error due to changing air-stream temperatures. The probe can be used between 20° and 150° Fahrenheit without loss of accuracy.

CORROSION-MEASURING PROBE

Corrosion is produced by the gradual eating (or wearing) away of a substance — usually as a result of some chemical action. A self-contained transistorized corrosion me-

Fig. 7-69. Air-velocity meter in use. (Courtesy of Illinois Testing Laboratories, Inc.)

Fig. 7-70. Thermoanemometer with thermocouple probe. (Courtesy of Illinois Testing Laboratories, Inc.)

ter, together with some of the probes used with the instrument, is shown in Fig. 7-72. This instrument which uses a transistorized Wheatstone-bridge circuit, applies an AC voltage to the probes to eliminate polarization.

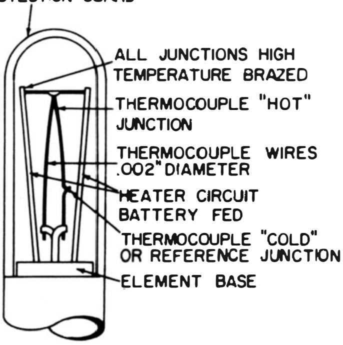


Fig. 7-71. Construction of probe used with thermoanemometer.

The operation of the instrument is based on the fact that the electrical resistance of a piece of metal in the probe increases as corrosion removes some of the metal from its surface. The metering circuit uses this change of resistance to indicate the rate of corrosion. Electrical resistance can be measured very accurately. Therefore, even the smallest amount of corrosion can be detected.

To compensate for temperature changes—which would affect the accuracy of our measurement — a reference specimen (protected against corrosion) is usually placed in the vicinity of the corroding specimen within the probe. Since both the corrosion and the reference specimens experience the same temperature changes, the ratio between the two resistances will depend only upon the amount of corrosion experienced by the exposed specimen. We thus have a quick method for determining the effectiveness of chemical inhibitors in oil-field installations, refineries, pipe lines, natural-gas plants, and other chemical installations. The metal specimen in the probe can be made of whatever metal is of interest.

The measuring circuit, which compares the resistance of the corrosion against the protected specimen in the probe, is usually either a Wheatstone or Kelvin bridge.

The circuit is designed so the ratio of the resistance between the corroding and the noncorroding element is read directly in microinches or mils of material lost. The corrosion rate can then be easily determined. Since we are not measuring the resistance change directly, but rather the ratio of the change between the exposed and the control element, high sensitivity can be achieved.

Special probe elements are made by vacuum-depositing a thin film of the desired material on plastic or glass, and using this as the sensitive exposed material in the probe. The degree of sensitivity is determined by the ratio of length to cross section – the more sensitive probe can detect as little as 0.10 microinch of corrosion.

Retractable probes are available for pressure systems, where the process cannot be interrupted. Instead, the probe must be inserted and removed while the system is in operation.

A functional circuit diagram of the instrument and probe is given in Fig. 7-73. As mentioned before, there are usually two elements in the probe—the exposed and the reference element. As shown here, there is often a third element also, called the check specimen. It is used to verify the resistance of the reference element, to make sure any resistance change is due only to corrosion of the exposed element.

Probes can be constructed in different ways, depending on the avail-

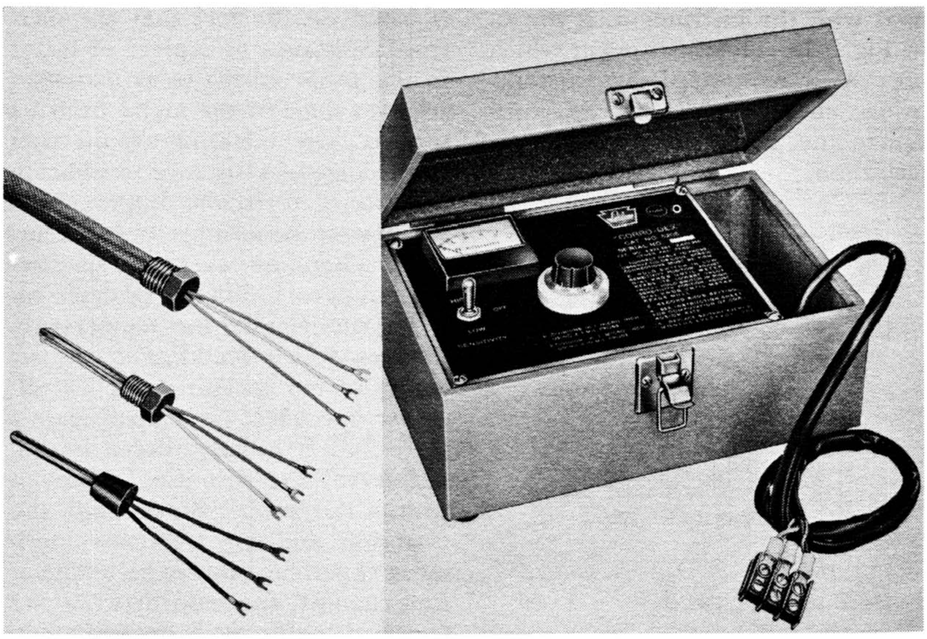


Fig. 7-72. Transistorized corrosion meter and probes. (Courtesy of Labline, Inc.)

able measurement time, as well as on the measuring conditions. They may have a wire element (which will give the longest life) or a strip (which will give the fastest response). Tubing can also be used for a fairly rapid response combined with mechanical ruggedness. The typical useful life of a probe is determined by the thickness of the sensing element. It will vary from 100 hours for a 1-mil element to about six months for a 40-mil element.

pH PROBES

The degree of acidity and alkalinity of a solution is called its pH. This pH value is important in biology, chemistry, food, medicine, sewage, and water treatment, plus many other fields.

For pH measurements a special type of probe like the one in Fig. 7-74 is used. It develops a voltage proportional to the hydrogen-ion concentration in the solution under test. The pH value is defined as follows:

pH = log 1 ÷ hydrogen-ion concentration, molecules per liter.

Any pH number between 0 and 7 indicates an acid solution, the acidity decreasing as the pH number increases. For pH values greater than 7, solutions are alkaline, the alkalinity increasing as the pH number increases. Pure water, which is neither acid nor alkaline, has a pH 7. (See Fig. 7-75.)

The pH scale is not linear with concentration. Rather, a change of one pH unit is equal to a tenfold change in the strength of the acid or base. For example, a pH 5 acid solution is ten times stronger than a pH 6 one. The usual range covered by pH meters is from 0 to 14 pH units, thus covering the whole range from strong acids (0) to strong bases (14).

A basic electrochemical cell consists of two electrodes of different conducting materials immersed in an electrolyte, where the voltage developed between the two electrodes depends on the properties of all three.

We can use two "half-cells" consisting of one electrode of known composition (a calomel electrode is most frequently used) and a pH responsive probe such as glass, hydrogen, or antimony. By immersing them into the solution and measuring the resultant voltage, we can determine whether the solution is acid or alkaline. Polarity must be observed because a neutral solution

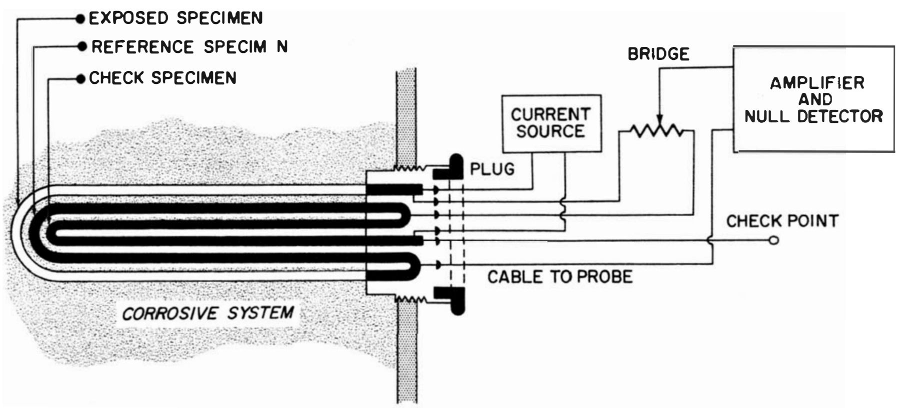


Fig. 7-73. Functional diagram of a corrosion-measuring instrument and probe.

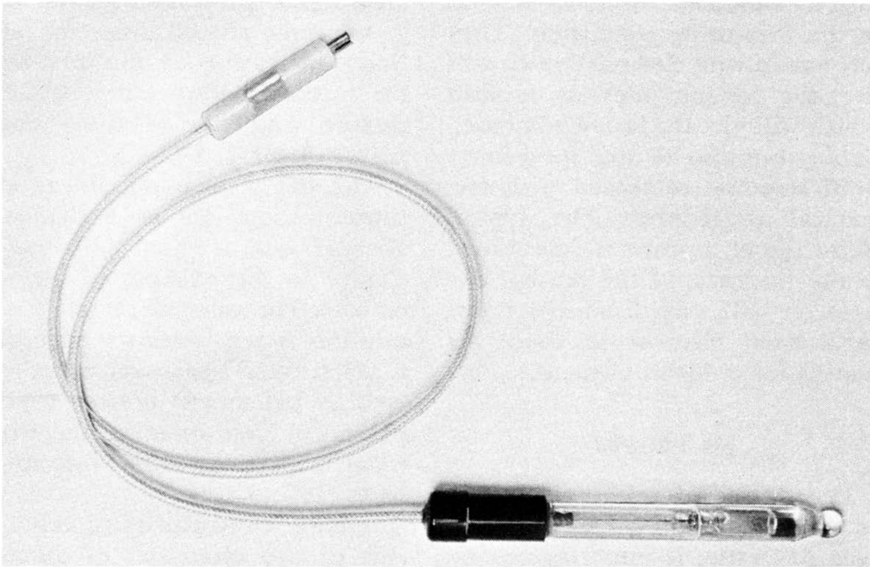


Fig. 7-74. Typical probe used for pH measurements. (Courtesy of Leeds and Northrup Co.)

does not produce zero voltage. The electrolytic disassociation theory assumes the molecules of a solution are separated into electrically negative —(OH) and positive +(H) ions. These ions are charged molecules which tend to combine and form stable molecules. They will do this until an equilibrium stage is reached where the rates of formation and recombination are equal. When this

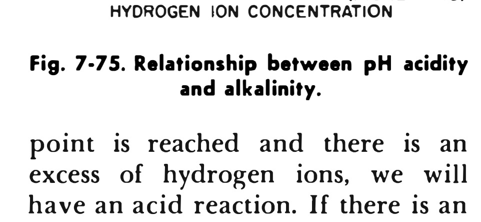


Fig. 7-75. Relationship between pH acidity and alkalinity.

point is reached and there is an excess of hydrogen ions, we will have an acid reaction. If there is an excess of hydroxyl ions, we will have an alkaline reaction. If a balance point is reached, the solution will be electrically neutral.

To determine the hydrogen-ion concentration in an aqueous solution, we usually measure the potential between a hydrogen and a calomel electrode. Instead of the hydrogen electrode, a glass electrode is sometimes used. It consists of a thin-walled glass tube having a certain conductivity (several hundred megohms). The tube contains a solution and a wire for electrical connection. The glass and calomel electrodes are immersed in the solution under test. The voltage developed by this cell is only a few millivolts; so no current can be drawn. The usual way of measuring this small voltage is to use a VTVM having its meter scale directly calibrated in pH.

Another way is with a potentiometer. The typical potentiometric pH measuring instrument consists of a pH-responsive electrode made of glass, a reference electrode made of calomel, and a voltage-measuring device (usually a VTVM) to indi-

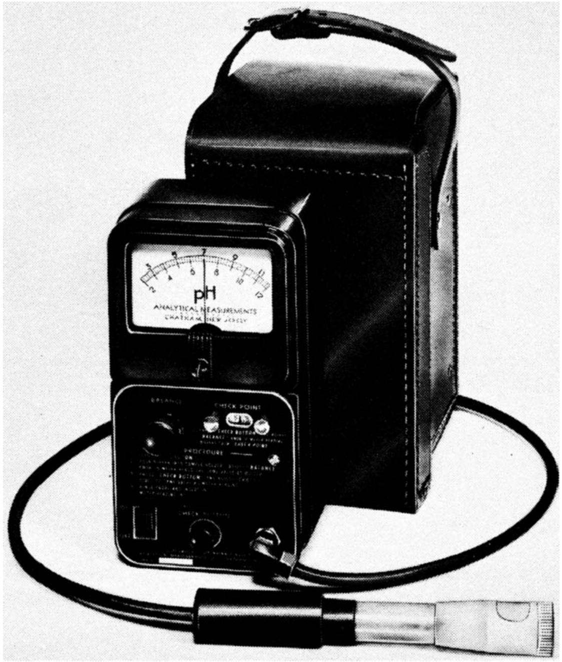


Fig. 7-76. pH meter with combination probe. (Courtesy of Analytical Measurements, Inc.)

cate the potential between the two probes. A glass electrode is used because it is chemically resistant to strong acid solutions. It consists of the glass membrane, the filling solution, and the inner-electrode material.

Often the glass and calomel electrodes are combined. Thus, the combination electrode can take the place of two individual probes. The glass electrode is mounted in a polyethylene tube, and the calomel reference electrode is constructed around it at the upper end. The pH measuring instrument, together with its probe, is shown in Fig. 7-76.

The instrument is initially calibrated by inserting the probe into a buffer solution and adjusting the instrument for a pH reading equal to that of the buffer. The pH value of the buffer solution has been predetermined exactly. It can therefore be used as a standard for calibrating the instrument.

LIQUID-LEVEL MEASURING PROBES

We know that two electrodes separated by an insulating material called a dielectric will form a capacitor.

Such a capacitor can consist of one or more parallel plates, or it can be a concentric rod within a cylinder (somewhat like the center conductor of a coaxial cable). The capacitance of such a combination center conductor and outer cylinder will be determined by the spacing and relative sizes of the conductor and cylinder, and by the dielectric between them. The dielectric constant of air is taken as 1; water, 80; and alcohol and glycols, anywhere from 10 to 30. Let us now fill up the space between the center conductor and the outer cylinder with a material other than air. We can use oil or other liquid fuel (or any other liquid, for that matter). The

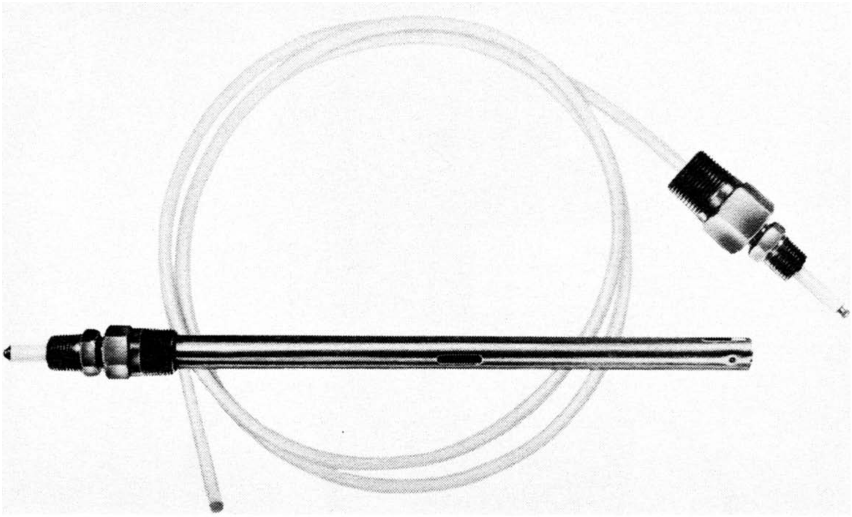


Fig. 7-77. Capacitance type of liquid level-measuring probe.
(Courtesy of Simmonds Aerocessories, Inc., and Robertshaw Fulton Controls Co.)

capacitance will vary, depending directly on the height of the liquid we are dipping our probe into or filling our probe with. A typical capacitance-type liquid-level measuring probe is shown in Fig. 7-77.

In order to measure the varying capacitance resulting from the change in liquid level, we can connect our probe either as one leg of a capacitance bridge or as a frequency-determining capacitor in an

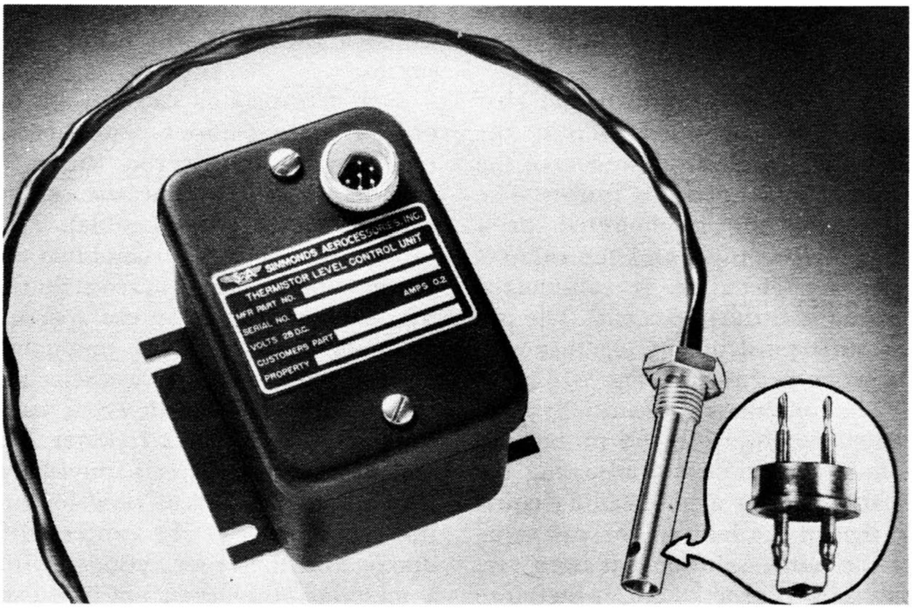


Fig. 7-78. Thermistor type of liquid level-measuring probe.
(Courtesy of Simmonds Aerocessories, Inc.)

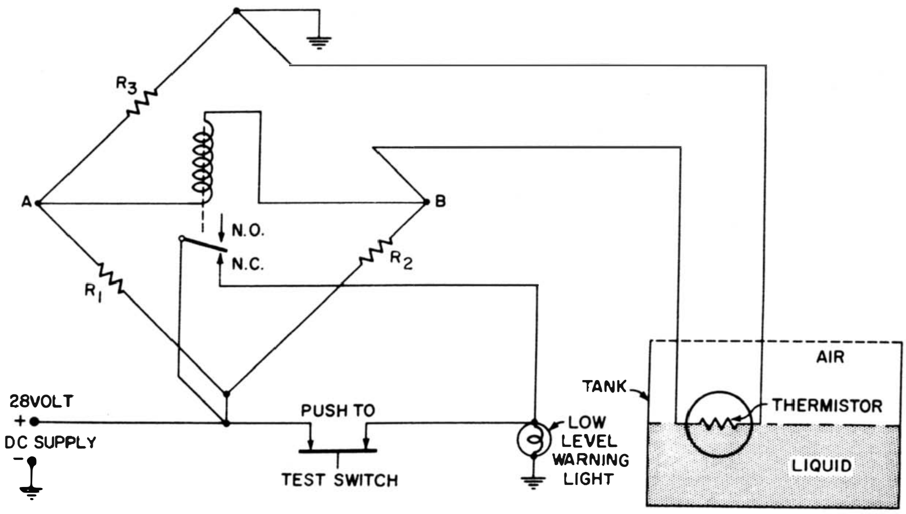


Fig. 7-79. Simplified schematic of the instrument in Fig. 7-78. (Courtesy of Simmonds Aerocessories, Inc.)

oscillator circuit. If used as one leg of a capacitance bridge, the probe is usually operated between 100 kilocycles and 1 megacycle.

The capacitance of these probes is around 10 to 100 mmf. This small capacitance necessitates operating at a frequency higher than perhaps 60 or 400 cycles, because at such frequencies its reactance would be so high that the probe can be easily masked by leakage currents across the insulators.

When the probe is used as the frequency-determining element of the oscillator circuit, the capacitance change due to the liquid level will change the oscillator frequency. This frequency change can then be measured and, with proper conversion, directly related to the change of liquid level.

Another method of determining the liquid level in either aircraft, fuel and oil tanks, missile propellant tanks, etc., is with the thermistor probe in Fig. 7-78. Fig. 7-79 shows a simplified schematic of the resistance-bridge circuit using the thermistor probe for liquid-level sensing.

When surrounded by a liquid, rather than by a gas or vapor, the thermistor in the probe loses heat more readily, and its temperature and electrical resistance are lower than if it is in air. It is this difference in resistance that is used in level detection.

DIELECTRIC-CONSTANT AND DISSIPATION-FACTOR MEASURING PROBES

The analyzer in Fig. 7-80 with two probes (one for liquids and the other for solids) is a bridge-type instrument containing a signal generator, unbalance signal amplifier, two phase discriminators, and two null indicators. The probe (essentially a guarded capacitor) forms one leg of the bridge. A variable-delay network and a variable capacitor form the complementary leg. A functional block diagram of the instrument is shown in Fig. 7-81.

In operation, a dielectric material is placed in the field of the probe. The bridge may be balanced or unbalanced, depending upon the value of the delay and the capacity in the

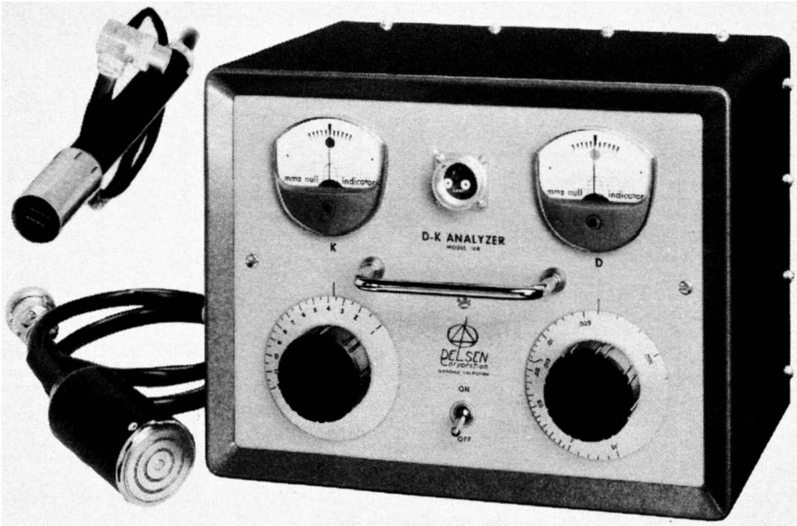


Fig. 7-80. Dielectric constant and disspation-factor analyzer with two probes. (Courtesy of Delsen Corp.)

adjustable leg. An operating frequency of 10 kc has been selected because of the ease of distinguishing material variables at this frequency. If the bridge is not balanced, a signal appears at the input of the amplifier. The signal path is split in the amplifier so the two phase discriminators can be driven. A 90° delay is introduced in the signal supplied to the "K" discriminator. By resolving the unbalance signal into two components—one in phase and the other in quadrature with the reference signal—it is possible to indicate on separate null meters which control we must adjust to obtain bridge balance. The controls are calibrated so we may read the dielectric constant (K) and the dissipation factor (D) of the specimen directly from the dials.

A flat probe is used for analyzing solid materials, and the other corro-

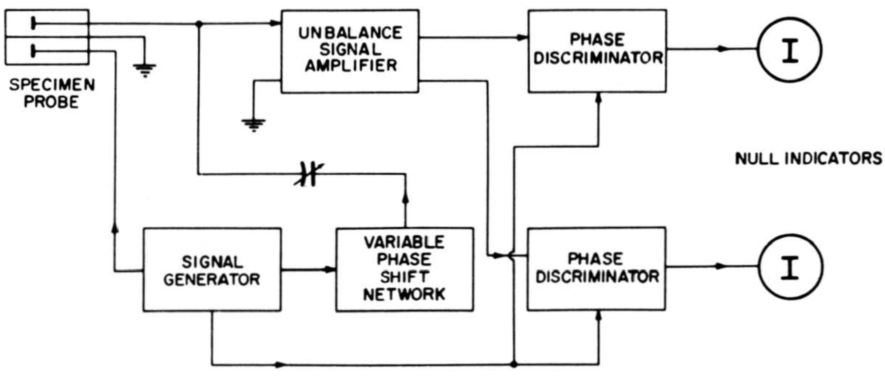


Fig. 7-81. Functional block diagram of instrument in Fig. 7-80.

sion-resistant probe, for measuring the dielectric properties of liquids. The instrument will measure the dielectric constant (K) over a range of 1.0 to 12.0, and the dissipation factor (D) from 0 to 0.15.

The guarded active electrodes of the flat probe are concentric rings which are slightly recessed from the surface of the probe. Therefore, an air gap always exists between the electrodes and the specimen. This type of construction eliminates the difficulties sometimes encountered with contact polarizations.

The liquid probe is a parallel-plate capacitor with an outer cylindrical guard. A window-type guard electrode can be inserted between the capacitor plates in order to multiply the nominal dielectric-constant range by a constant. Guard assemblies with different window sizes are available to cover different dielectric-constant ranges. The active volume of the liquid probe is a cylinder 2½ inches long, with an outside diameter of 1½ inches. A cylindrical handle extends 8 inches behind the active electrode volume.

The probes are suitable for measuring solid and liquid dielectric media, petroleum-base oils, natural and synthetic rubbers, polyesters, polyvinyls, polyurethane, silicone, and epoxy-resin systems.

The instrument can also be used to indicate the thickness of many insulating materials. Because of the probe configurations, the dielectric-constant reading for any given material will depend on the thickness of the material.

Instantaneous measurements can be made from one side of an insulating sheet (such as radomes and nose cones), printed circuits, and other insulating materials. The probe can also be used to scan the surface of the material to disclose any irregularities.

HYGROMETER AND OTHER MOISTURE-DETECTING PROBES

The purpose of most moisture and humidity tests is to obtain, from relatively few measurements, an estimate of the moisture content of a material or the relative humidity of a large area.

The measurement of moisture content is important to manufacturers of cement, gypsum, dehydrated foods, face powders, etc. — who are mainly interested in reducing moisture in their product—and to tobacco processors, horticulturalists, makers of concrete mixes, etc. — who are more concerned with its presence in controlled amounts.

Moisture content is not always uniformly distributed in the sample we want to test. For example, if grain is set on a farm, the effects of rain, sun, and wind will distribute the moisture unevenly. For this reason, several readings should be taken.

Moisture measurements require some sort of sensing probe, which is placed into the area or material. The moisture content can then be measured by connecting the probe as one arm of a Wheatstone-bridge circuit and measuring its resistance change, which will be a function of the moisture content. With proper probes, relatively large changes in resistance can be obtained for comparatively small changes in moisture content.

The moisture meter in Fig. 7-82 measures the moisture content of soil, using a special gypsum probe as its sensing element. Within this probe are embedded two specially-treated, fine-mesh, stainless-steel electrodes. When the probe is buried, it will absorb or give up the moisture from the soil very readily, so its moisture content will follow very closely the moisture content of the surrounding soil. The electrical resistance of the probe will vary with the moisture content. When the soil is wet, its resistance is low; but as it dries, its resistance increases. Therefore, the moisture content of the soil can be obtained by simply measuring the electrical resistance of the probe. The instrument shown is an AC impedance meter using a transistor and a self-contained battery supply. The use of alternating current (usually around 1,000 cps) rather than direct current eliminates errors that would be caused by polarization and electrolysis at high moisture content. Several of these probes are buried at different depths in the soil, the phone tips for connection to the meter being left exposed. Moisture is quickly measured by setting up the instrument and inserting the various probes. The resistance of the probe will vary from several hundred thousand ohms when the soil is dry, to approximately 350 ohms at a moisture reading of 100 per cent.

Other moisture-detecting probes are designed for penetrating bales or bags of material, such as grain and wheat. These probes are available in lengths varying from four to twelve inches.

A hygrometer probe which will sense relative humidity from 30 to 95 per cent is shown in Fig. 7-83, together with the instrument for which it is designed. It is suitable for indicating relative humidity in various sizes and types of enclosures, such as warehouses, animal dens, storage houses, air-conditioning ducts, laboratories, hospital rooms, oxygen tents, etc. The instrument is similar to the moisture meter discussed before, in that it is primarily a sensitive AC resistance measuring device. Current passing through the meter and sensor is

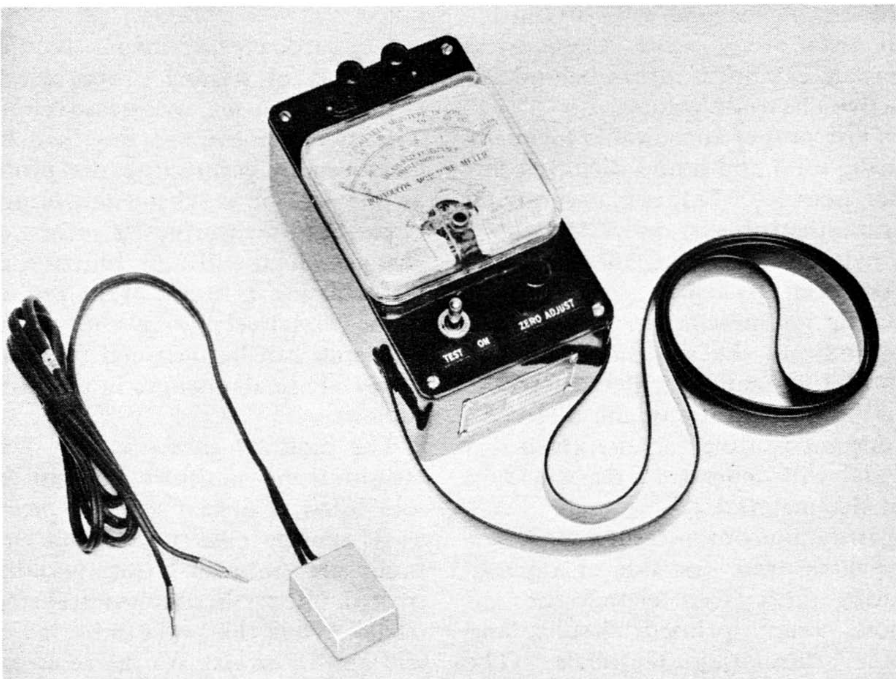


Fig. 7-82. Instrument used for measuring moisture content of soil.
(Courtesy of Industrial Instruments, Inc.)

Fig. 7-83. Hygrometer and probe. (Courtesy of Labline, Inc.)

rectified in a bridge circuit, then applied to the sensitive meter to indicate the relative humidity directly in per cent.

The sensing element is contained in a *Monel* probe 1¼ inches in diameter and 4 inches long. The element consists of a styrene copolymer strip with a platinum printed grid. It is coated with a special hygroscopic material which rapidly releases or absorbs water vapor with changes in humidity. This action, which changes the conductance of the grid, is read directly on the meter as the percentage of relative humidity.

The relative humidity is indicated to an accuracy of $\pm 5\%$. Up to six probes can be connected to an accessory which, by means of a selector switch, selects any one of them. Therefore, the relative humidity of up to six different areas can be checked quickly with six probes and only one meter.

ELECTROLYTIC-CONDUCTIVITY PROBE

Electrolytic-conductivity probes are used for measuring and controlling the concentration of solutions ranging from distilled water to acids or alkalis. Electrolytic conductivity is a measure of the ability of a solution to carry an electric current. It is defined as the reciprocal of the resistance in ohms of one cubic centimeter of the liquid under measurement at a specified temperature. The reciprocal of an ohm is called a *mho*. Therefore, the unit of specific conductance is called the mho per cm (or, for lower conductance, micromho per cm). Pure water at 25° C. has a conductance of about .05 micromho.

Electrolytic conduction differs from conduction in metal. In metal the current is carried by free electrons, whereas in electrolytic solutions it is carried by ions only.

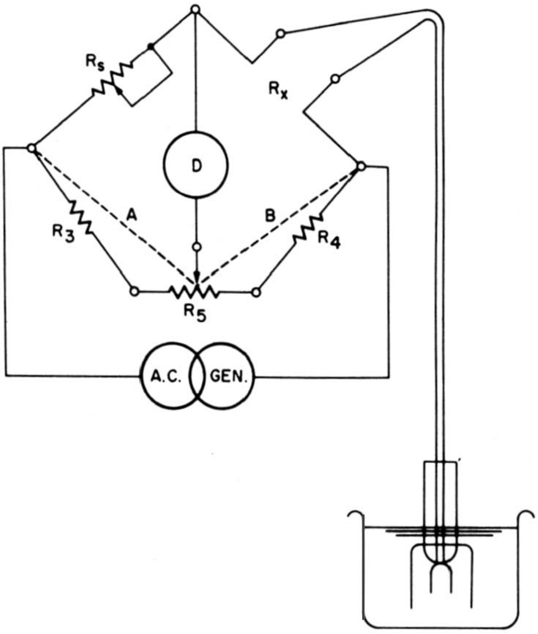


Fig. 7-84. AC Wheatstone bridge used with conductivity probe. (Courtesy of Industrial Instruments, Inc.)

Conductivity measurements require that the resistance be determined by means of an AC bridge, whereas pH measurements require the measurement of a DC potential difference with a potentiometer or high-impedance VTVM. Conductivity is measured by means of an AC Wheatstone bridge, as shown in Fig. 7-84. AC is preferred over DC in order to avoid changes due to polarization in the composition of the solution. For our conductivity tests we require a source of AC, an indicator (*D* in Fig. 7-84), and a conductivity probe immersed in the solution and connected to our instrument. R5 is the calibrated (directly in conductivity) arm of the bridge circuit. The other variable element, R_s, is used to correct for the temperature coefficient of the electrolyte resistance. The typical

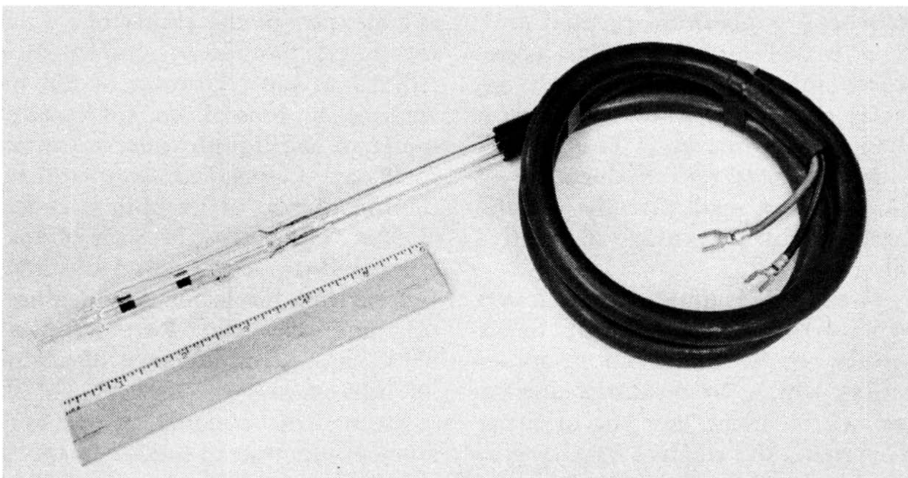


Fig. 7-85. Conductivity probe. (Courtesy of Industrial Instruments, Inc.)

conductivity probe in Fig. 7-85 consists of two metal plates (electrodes) spaced firmly in an insulating chamber which isolates a portion of the liquid under test. This construction makes the measured resistance independent from the volume of the sample and the proximity of conducting surfaces such as metal enclosures or piping. Both electrodes are almost always coated with a spongy black platinum. This platinum deposit reduces the polarizing effect of the current passing between the electrodes by greatly increasing their effective surface area.

The instrument in Fig. 7-86 is a portable, battery-operated, transistorized electrolytic-conductivity recorder, together with its probe. This instrument is used for long-term permanent recordings of conductivity at locations where electric power is not available. Continuous and permanent conductivity readings of up to one week can be made on the ten-inch circular chart. A conductivity probe for insertion in a pipeline is shown in Fig. 7-87. The cell is positioned so the liquid we want to measure goes to the cell from its outer end, to the cross hole near the threaded end. A cross section of the probe, showing the location of the electrodes, is also given in Fig. 7-87.

TRANSISTORIZED OPTICAL TACHOMETER PROBE

The optical tachometer probe is used for precise measurements of velocity, acceleration, vibration, and accentricity, at up to 120,000 rpm. It is used with an oscilloscope and an oscillator, as shown in the functional diagram in Fig. 7-88.

The probe is a completely self-contained instrument. A phototransistor and light source are assembled into a molded rubber head at the end of a gooseneck. The phototransistor and light source are connected

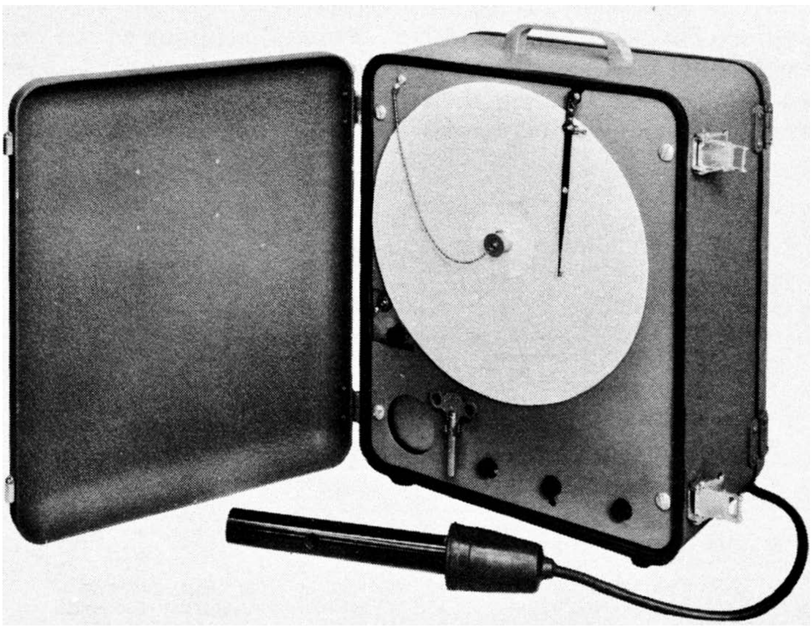


Fig. 7-86. Transistorized portable conductivity recorder. (Courtesy of Industrial Instruments, Inc.)

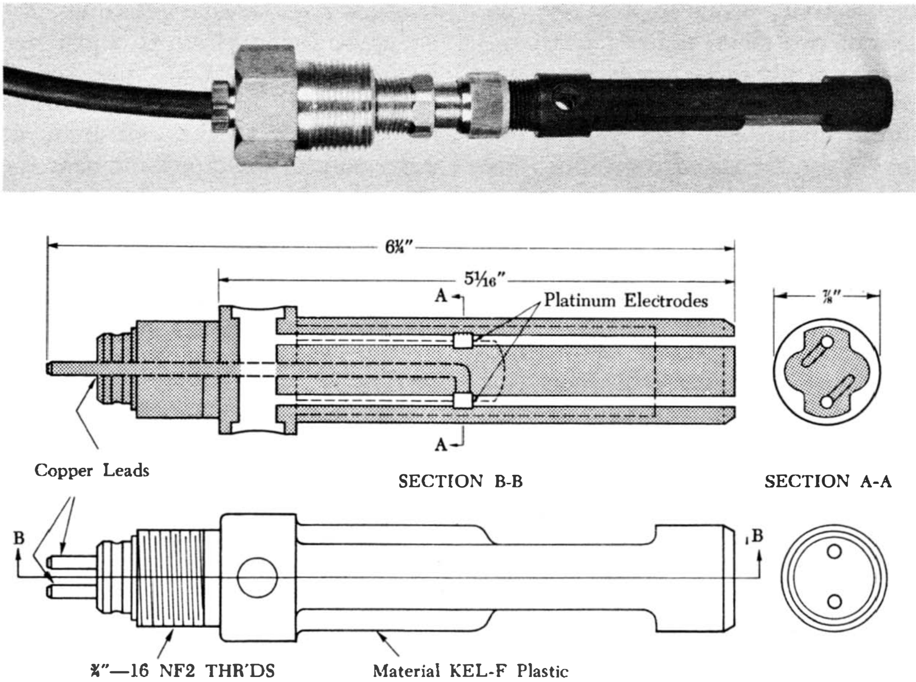


Fig. 7-87. Electrolytic conductivity probe for insertion into a pipeline. (Courtesy of Leeds and Northrup Co.)

to a transistorized amplifier and self-contained battery supply (which are in the probe handle). This unit will accurately sense intricate vibrations of test articles and indicate their relative amplitudes at frequencies from 0 to over 20,000 cycles per second.

Physical coupling to the part under test is not necessary because this is an optical system. Transducers are therefore not required for vibration

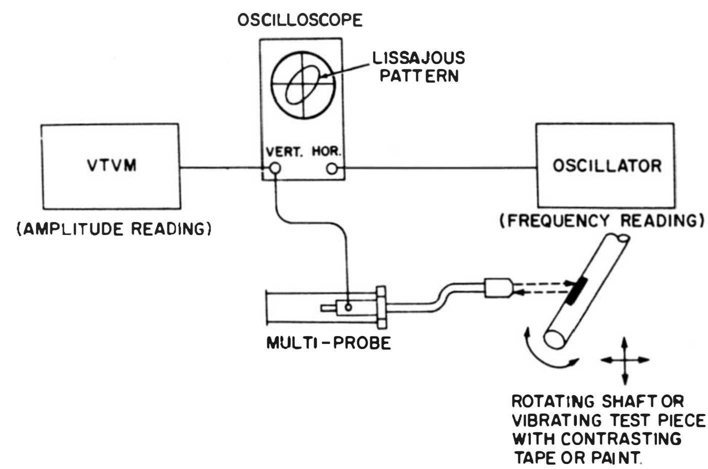


Fig. 7-88. Application of optical tachometer probe. (Courtesy of Optomechanism.)

testing. The multiprobe leads are connected to the vertical input of an oscilloscope and VTVM, and an oscillator is connected to the horizontal input. The VTVM is used for obtaining amplitude readings; it is not needed when a calibrated oscilloscope is available. In use, the probe is pointed at the moving part to be evaluated, and the oscillator frequency adjusted for a stationary Lissajous pattern on the oscilloscope. The frequency of vibration or revolutions per second can then be read directly on the oscillator dial. The relative amplitude of the vibration is read on the VTVM; or it can be computed, based on the calibration of the vertical channel of the oscilloscope. For more accurate low-speed rotation measurements, multiple strips of tape can be added to the shaft to increase the observed frequency. The oscillator frequency reading must then be divided by the proper factor. Complex vibration waveshapes can be observed directly on the oscilloscope—no oscillator is needed. The amplitude of the probe output signal fed to the oscilloscope depends on the contrast of the reflecting surface—for example, black to white. The maximum amplitude of the output signal is approximately three volts.

The probe should be positioned approximately one-half inch from the surface to be measured, although it can be up to six inches away (depending on the contrast) and still yield a useful output signal. The accuracy of this instrument depends only on how accurately the oscillator used to obtain the Lissajous pattern is calibrated.

60-CYCLE STROBOSCOPIC PROBE

Fig. 7-89 shows the circuit and construction of a simple 60-cycle, probe-type stroboscope. Small enough to be carried in one's pocket, this little instrument produces a surprising amount of light, even in a lighted room. It is held like a pencil between the fingers while its flashes are directed at the moving object.

An NE-48, ¼-watt, neon lamp acts as the flasher. The semiconduc-

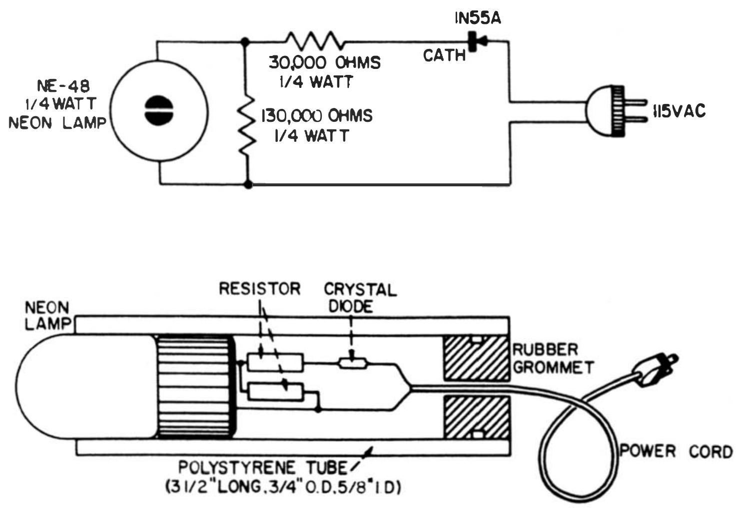


Fig. 7-89. Circuit diagram and construction details of a probe-type stroboscope. (Courtesy of Sylvania Electric Products, Inc.)

tor diode rectifies the line voltage and thereby causes the lamp to flash on and off once during each cycle. The flashes can be used to examine obejcts rotating or vibrating 60 times per second or any whole multiple of this rate. For example, a shaft turning 3,600 times per minute will appear to stand still when illuminated by flashes from the stroboscopic probe. One important application of this simple stroboscope is in the examination of watch movements and electric-clock motors.

Part 3
Radiation Detector Probes

RADIATION—ALPHA, BETA, AND GAMMA RAYS

Radioactivity cannot be seen, heard, nor felt. Moreover, it can be detected only by special instruments, such as Geiger and scintillation counters. Both instruments are used in a similar manner. The major difference between them is in the detecting element, which is usually in the probe. The one in the Geiger counter is a Geiger-Mueller tube filled with a gas; in the scintillation counter it is usually a sodium iodide crystal. The crystal (if sufficiently large) intercepts practically every gamma ray that passes through it, whereas the Geiger tube reacts to less than one per cent of the gamma rays that penetrate it. As a result, the scintillation counter records many times as many rays from the same source as does the Geiger counter.

Alpha particles are positively-charged helium atoms emitted by many radioactive elements such as radium, thorium, uranium, polonium, etc. Beta particles are electrons produced in the disintegration of some of the elements previously listed (except polonium). Gamma rays are similar to X rays, but shorter in wavelength. They are

Fig. 7-90. Radiation detector using Geiger-Mueller tube in its probe. (Courtesy of Victoreen Instrument Co.)

emitted by practically all radioactive elements, radium and thorium being particularly strong emitters. Elements emitting alpha, beta, or gamma rays are called *radioactive* elements.

GEIGER COUNTERS

The instrument in Fig. 7-90 uses a Geiger-Mueller (G-M for short) tube which serves as a sensitive indicator of radioactivity. The probe contains the Geiger tube, which is made of either glass or metal. Actually, its construction and operation are simpler than for most radio and television tubes. It is filled with one or more gasses—such as argon, nitrogen, krypton, or helium — and also contains a thin centrally located wire made usually of tungsten. The wire is charged to about 1,000 volts positive with respect to the surrounding metal cylinder (cathode).

When radioactive emission strikes the probe of the Geiger counter, here is what happens: the alpha particles are stopped by the wall of the tube; the beta particles, because of their greater penetrating power, go through the wall and enter the tube; and the gamma rays, which are still more penetrating, pass through the tube with essentially no ill effects. Some of the gamma rays which enter the tube (about one-half of one per cent) interact with the gas molecules to produce electrons.

Because of the positive charge on the central wire and the negative charge on the outer cylinder, positive ions are attracted to the enclosing envelope, and negative ions are drawn to the positive center-wire electrode. As a result of this movement, a pulse of current takes place each time a ray enters the tube. After ionization, the gas quickly deionizes; and the tube is ready for the next ray. Each pulse develops an output voltage across a high-value resistor placed in series with the positive electrode. This output voltage is usually amplified and then connected to either a visual or an aural indicating device.

A Geiger-Mueller tube is essentially a gas tube to which sufficient DC voltage is applied to bring it almost to the firing point. Only a single ionized particle is needed to start the discharge. The tubes are generally self-quenching—that is, the discharge started by the passage of rays is quickly quenched by the action of the gas in the tube, rather than by external means. In other words, the tube cannot "run away."

The operating potential of Geiger tubes normally is anywhere between 300 and 1,500 volts, 900 volts being the most common.

SCINTILLATION COUNTERS

Scintillation counters are about 500 times more sensitive than Geiger counters. They can detect radioactivity because radiation produces tiny, momentary flashes of light (scintillations) in crystals of certain chemical compounds. A photomultiplier tube then converts these tiny flashes into electrical pulses. A very satisfactory crystal is one made of sodium iodine to which a small amount of thallium has been added so the light output will be in the spectral region, where the photomultiplier tube is most sensitive. Zinc sulfide is another common material for crystals. One surface of the crystal is usually covered with a thin aluminum coating through which the gamma rays pass to strike the crystal. The other surface is coupled optically to a photomultiplier tube which amplifies the effect of the minute flashes of light to produce an output voltage. This voltage is then amplified and fed to an appropriate indicating or counting circuit. Because it operates on the principle of secondary emission, the photomultiplier tube can provide an amplification factor of about 1,000,000.

Compared with the Geiger counter, the scintillation counter detects a much higher proportion (500 times more) of the radioactive emission escaping from a radioactive material. However, it is also more complex. Nevertheless, this greater sensitivity is an overwhelming advantage because it means that much weaker radiations can be detected.

Part 4
Medical Probes

The field of medicine has benefited greatly by the great strides made in electronics. We will discuss some probes used by the medical profession to help safeguard our health and well-being.

GASTROINTESTINAL PROBES

The probe in Fig. 7-91 is used for investigating sounds, temperatures, and pressures within the stomach and intestinal tracts. The probe contains a miniature microphone plus a thermistor, both mounted in the tip of a gastrointestinal catheter. The microphone has a frequency response flat from below 200 to over 3,000 cps. Its output is fed to a high-impedance amplifier and oscilloscope, or to a direct-writing recorder for indication. The bead-type thermistor temperature-sensing device (which is accurate to 0.2°F.) is

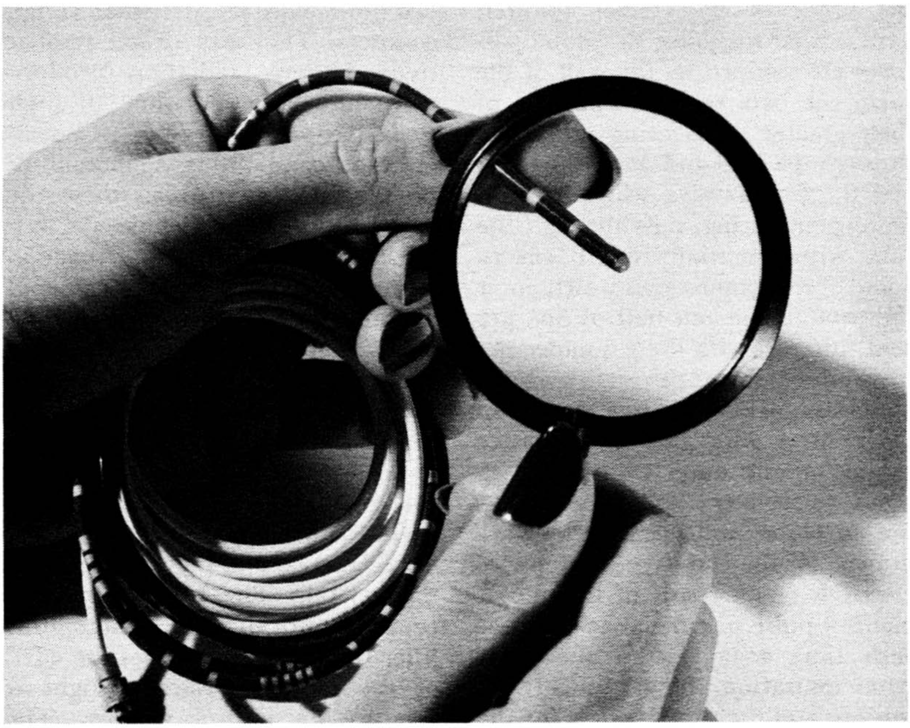


Fig. 7-91. Gastrointestinal probe. (Courtesy of Gulton Industries, Inc.)

connected to a bridge circuit and read-out device (like the one shown with the skin-temperature sensing probe in Fig. 7-92), which is used to measure the temperature of the human body. The thermistor in this probe is of the type discussed under "Temperature Sensing Probes." Measurements take only five seconds and may be made on the skin, or rectally or orally.

INTRACARDIAC PROBES

The intracardiac catheter probe in Fig. 7-93 makes it possible for sounds to be picked up directly from within the heart. This eliminates distortion of the heart beat—due to the body tissue between the heart and the skin—that is experienced with a stethoscope. The probe, which contains a miniature microphone, is connected to the end of a long tube that is introduced into a blood vessel and then directed into any part of the heart. The output from this probe is connected to an oscilloscope for observation. In addition, the tip of the catheter probe can be observed constantly with a fluoroscope.

Fig. 7-94 shows the cross-sectional view of the microphone in the probe. The microphone contains a window diaphragm on which rests a pointer connected to a piezoelectric ceramic element consisting of two thin outer layers of piezoelectric ceramic and a thin inner one of metal. This two-section piezoelectric ceramic element is operated as a "bender." This mode of action is produced by mounting the transducer as a cantilever (fixed at one end, but free to move at the other end where the pointer is fixed). Heart pulsations press against the window diaphragm and thereby move the pointer, which in turn bends the ceramic. This bending expands one side while contracting the other. The two sides are so polarized that the bending causes opposite voltages to be produced on the free sides to which the electrical output leads are connected. The net voltage between these two free sides is fed into a cathode follower and ampli-

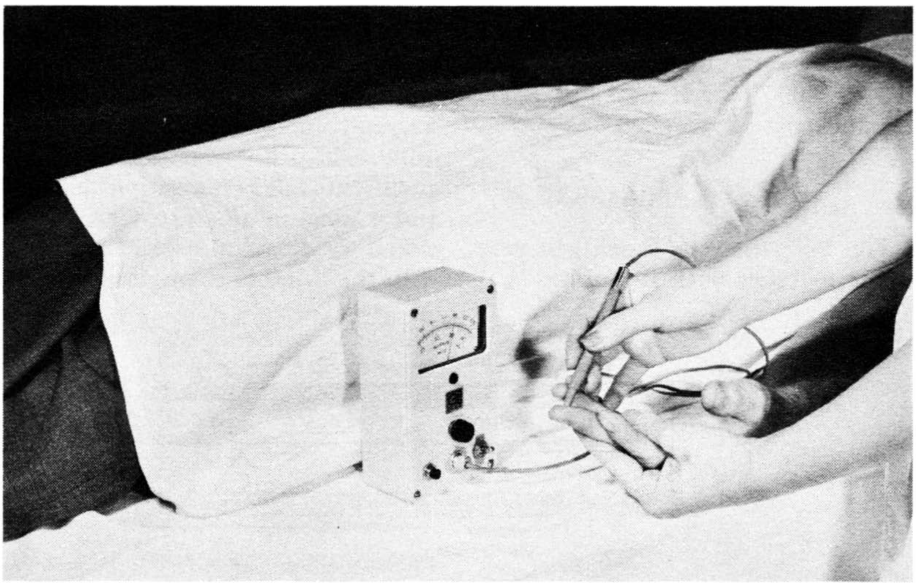


Fig. 7-92. Clinical thermometer in use. (Courtesy of Gulton Industries, Inc.)

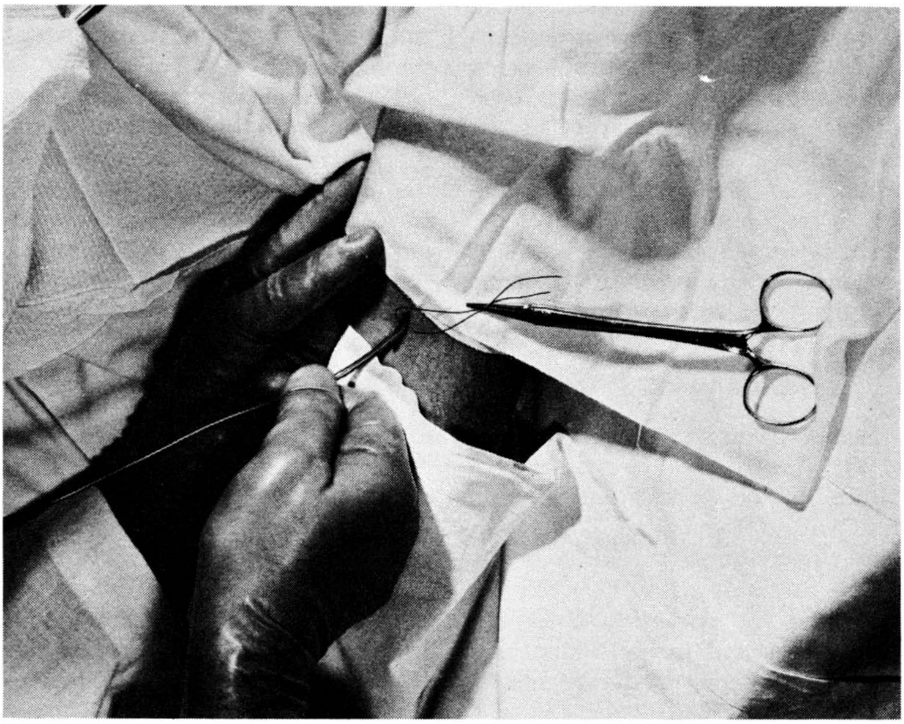


Fig. 7-93. **Insertion of intracardiac catheter probe.** (Courtesy of Gulton Industries, Inc.)

fier for presentation on an oscilloscope or to a direct-writing recorder. Because two sides are used, rather than one, twice the output voltage can be produced. This probe has a frequency response flat from below 200 to 3,000 cps. It peaks at 6,000 cps and cuts off at 8,000.

X-RAY PROBE

Fig. 7-95 shows a Roentgen rate meter together with its probe. It is used to continuously monitor the intensity of an X-ray beam or other radiation by means of a probe placed on the skin, in a body cavity, or in the X-ray beam. A great variety of probes is available, depending on the total dosage, intensity, and energy range to be monitored. The probe assembly consists of an air-equivalent ionization chamber and a vacuum-tube preamplifier enclosed in a stainless-steel housing, with the thimble chamber at the tip

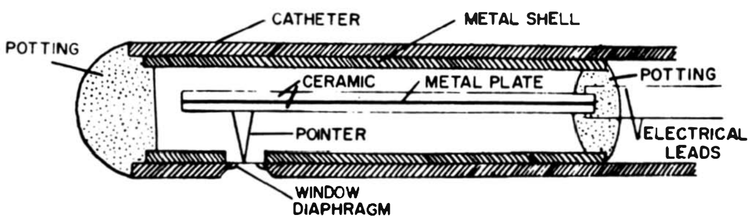


Fig. 7-94. Construction of miniature microphone used in the intracardiac catheter probe. (Courtesy of Gulton Industries, Inc.)

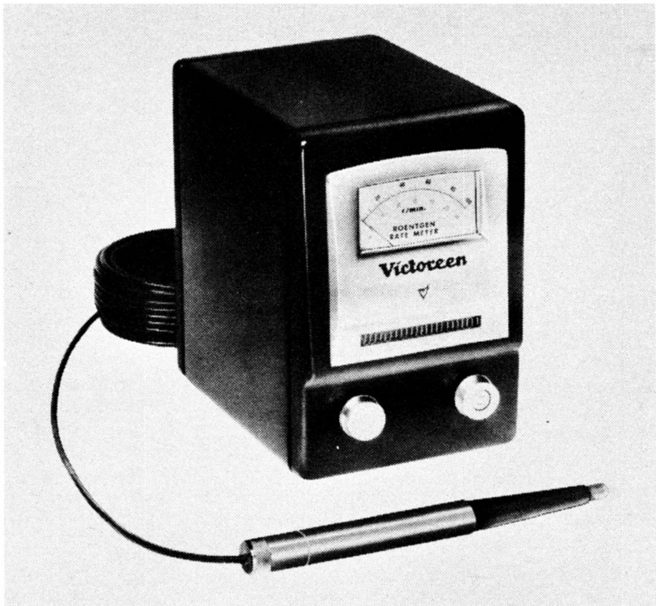


Fig. 7-95. Roentgen rate meter used for monitoring radiation levels. (Courtesy of Victoreen Instrument Co.)

end. The probes are normally connected to the instrument by a 45-foot coaxial cable.

BRAIN AND EYE PROBES

The brain probe in Fig. 7-96 is a small needle-shaped Geiger-Mueller tube designed for locating tumors in the brain region (although it also is useful for locating radioactivity where probing in small, restricted areas is necessary). The entire probe except the beta-ray sensitive tip is shielded against radiation.

The eye probe is similar in design to the brain probe, except that it has a curved tip. This probe is intended for locating tumors in the eye region.

Both probes are about eight inches long. They are sterilized by being soaked in any germicide that is suitable for other surgical instruments.

MAGNETIC STOMACH PROBE

The probe in Fig. 7-97 is connected to a magnetrometer (an instrument that measures the strength, direction, and polarity of very weak magnetic fields). The probe permits gastric notility (stomach action) to be studied. The subject swallows a magnet about the size of a vitamin capsule. The probe then traces its

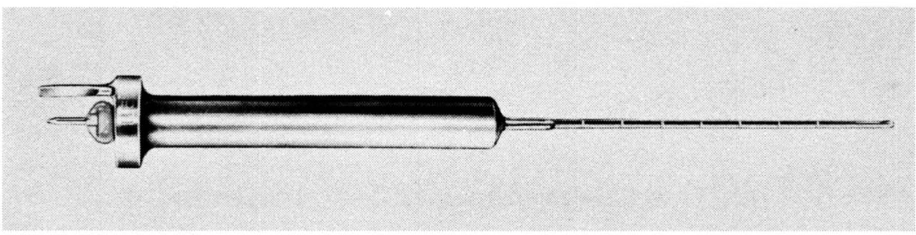


Fig. 7-96. Brain probe containing a special Geiger-Mueller tube. (Courtesy of Tracerlab, Inc.)

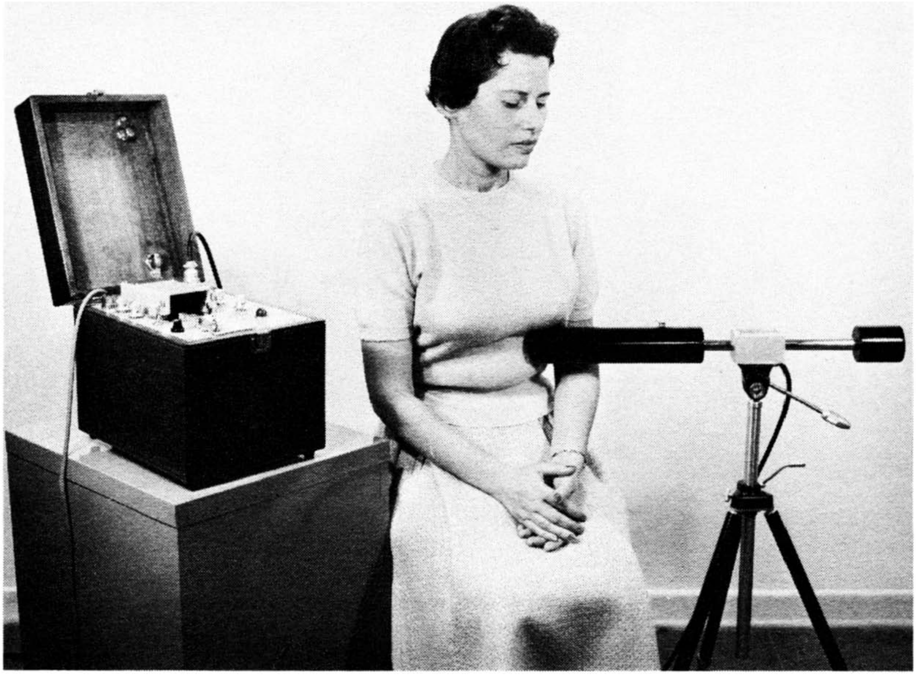


Fig. 7-97. Magnetometer with probe shown in use recording gastric motility. (Courtesy of Irwin Laboratories, Inc.)

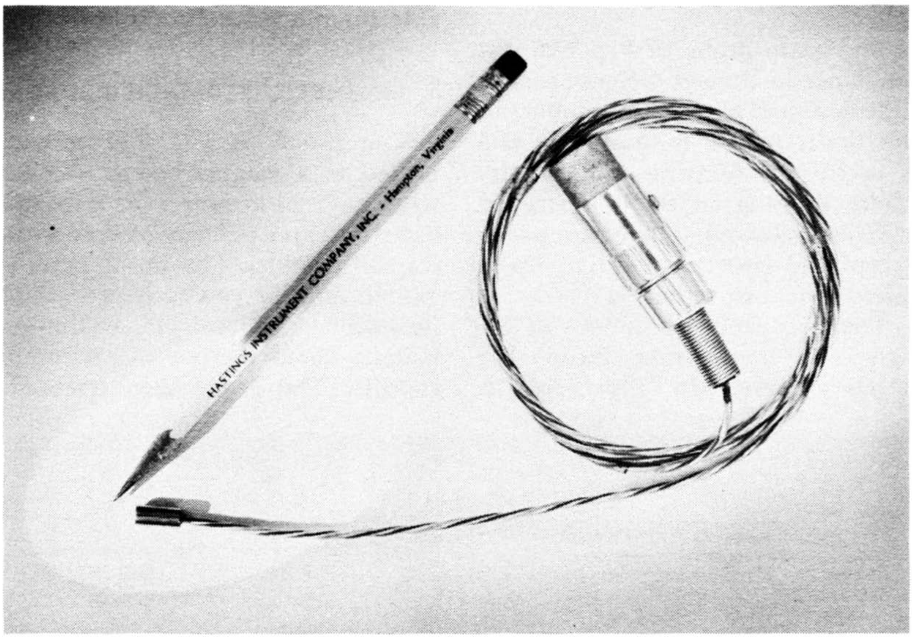


Fig. 7-98. Pulmonary probe used for measuring ventilation in various sections of the lung. (Courtesy of Hastings-Radyst, Inc.)

movements within the various organs. The magnet remains in the stomach for about two hours or more. Field variations can be recorded to show the amplitude of the movement of the magnet, as well as its mode of motion, orientation, and position with respect to the detector probe. In this way, the action of the stomach is thereby indicated.

LUNG PROBES

A patient's lungs can be examined by means of the pulmonary probe in Fig. 7-98. It is inserted into the lungs through a bronchoscope, and the relative amounts of ventilation in various sections of the lung then obtained.

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USING AND UNDERSTANDING

PROBES by Rudolf F. Graf

Probes, along with necessary cables and connectors, serve as the connecting links between your test instruments and the equipment to be analyzed. But there are many different types of probes, and each is limited in its applications. Thus, unless the technician knows which probe to use for each specific job, his test instruments may not provide him with the most accurate information. To make this book as useful as possible, the author has included the design aspects as well as the applications of every type of probe likely to be encountered in any phase of electronics servicing—whether it be in the radio-TV, industrial, or even the medical and agricultural fields. The completeness of his material, along with the numerous illustrations included, make this a volume every electronics serviceman will want to own and use in improving his troubleshooting techniques.

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