VOL. 8 NO. 6 JUNE, 1962

MARCONI INSTRUMENTATION

A Technical Information Bulletin
Issued Quarterly by
Marconi Instruments Limited, St. Albans, England

IN THIS ISSUE

ELECTRONIC INSTRUMENTS FOR TELECOMMUNICATIONS AND INDUSTRY

VOL. 8 NO. 6

JUNE, 1962

MARCONI INSTRUMENTATION

issued with

the compliments of

MARCONI INSTRUMENTS LIMITED

ST. ALBANS

ENGLAND

EDITORS

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Applications

DO YOU KNOW that a pH meter makes an excellent bridge detector? Or how to use an electronic counter for measuring a cowboy's quickness on the draw? Or how to measure the dielectric loss of boiling oil? You may not, of course, want to do any of these things since they represent some of the more unusual applications of our instruments. Your requirement is probably for applications of a more conventional nature, and it is these that naturally have a very large influence on instrument design.

Instruments, by their very nature, must play the role of servant to other electronic equipment and, like all good servants, must not only serve their master's immediate requirements but anticipate his future ones. Since the requirements of the electronics industry are subject to continual change, extension and stringency, the instrument manufacturer must be continually on his toes. As the Red Queen said to Alice, 'It takes all the running you can do to keep in the same place.' This state of affairs is seen in three ways: (*a*) new designs to meet new requirements of the electronics industry, (*b*) new developments in standard designs to match changing patterns of applications or tightening demands of performance, (*c*) introduction of alternative versions of standard designs to cater for specialized requirements. The instruments dealt with in this issue of *Instrumentation* all belong to category (*b*) or (*c*); our system of type numbering indicates which belongs to which. A letter after the basic type number denotes a new version superseding the previous one—for example TF 704C succeeds TF 704B; and a stroke number denotes a special version available as an alternative to the standard one—TF 1060/2 is an alternative to TF 1060.

Transmitter and Receiver Output Test Set Type TF 1065A illustrates a new version introduced to cover a wider range of applications than its predecessor. The original TF 1065 was a multi-purpose instrument for measurements on v.h.f. f.m. transmitters and receivers. It could measure r.f. power, a.f. power, f.m. deviation and d.c. voltage and current. Its successor, with the added facility of measuring amplitude modulation depth, is therefore applicable to a.m. as well as f.m. systems.

U.H.F. Signal Generator TF 1060/2 is a good example of an alternative version for a special application. Tests on secondary surveillance radar equipment by the Ministry of Aviation created the requirement for a u.h.f. signal with high-quality pulse modulation. This special version of the standard TF 1060 generator was created for this application but the TF 1060 is retained for general-purpose use since it is superior in certain other respects to the TF 1060/2.

Special applications for standard instruments are covered from time to time in this journal by Application Notes such as the one on p. 128 which shows how the very high input impedance of a pH meter can be put to good use as a null detector. The picture on the next page was taken during a laboratory experiment in timing; this is in preparation for a television programme in which our TF 1417 Counter is being used to find out just how quick a screen cowboy is on the draw. The Counter is started by the cowboy lifting his finger from a button-switch and stopped by the pulse from the microphone caused by the sound of the shot.

Another aspect of our attempt to please all of the people all of the time manifests itself in our large range of accessories which, like Alice, just keep on growing. A glance at the catalogue shows a formidable list—from r.f. cables to instrument trolleys, from amplifiers to fuse units—all available to increase the versatility of our instruments.

Work on a problem in the Marconi Instruments applications laboratory. Preparations are being made for a television programme in which a TF 1417 Counter is being used to find out how quick a cowboy is on the draw. A pulse from the microphone stops the counter when the gun is fired.

Broadly these can be classified into two types, those which are essential to the efficient operation of the instrument and as such are part of that instrument, and those which are termed 'optional', and are supplied only if required.

Our philosophy in offering, whenever possible, optional as opposed to compulsory accessories is not only to provide a basic instrument at the lowest possible price, consistent with performance, but also to offer additional facilities which may be required to extend the usefulness of an instrument for certain applications. Ideas for these additions come from many sources—frequently they are devices which our own engineers know from experience will serve a useful, if limited function; sometimes they are suggested by the commercial staff, or the customer himself, and if thought to have a reasonable appeal are manufactured for sale.

In effect, it is often a means of creating a new version of an instrument without modification of an existing design. In this issue we have two articles dealing with companion instruments which are rich in the number of accessories available, namely the V.H.F. Signal Generator TF 1064B series and the Transmitter and Receiver Output Test Set TF 1065A. With these it is possible, for example, to select by order from a wide range of crystals to determine the oscillator frequency, and various matching and attenuator pads are also available together with suitable leads to assist measurement.

The importance of applications research has led to the setting up recently of an Applications Engineering Laboratory under the control of our Technical Services Manager. When fully operational, this new department will have two main functions—investigating new uses for our instruments and influencing the specification and design of future ones. In connection with its work on new uses the Applications Engineering department will issue applications reports which will be published in this journal. The effect of the influence on new designs will of course not be evident so quickly, but in the long run it will undoubtedly ensure that our instruments are always designed with the user in mind.

J. R. H.

621.396.615.14

MARCONI INSTRUMENTS

U.H.F. Signal Generator . . . . . TYPE TF 1060/2

by J. W. MACFARLANE,
B.Sc. (Hons.),
Graduate I.E.E.

This modified version of the well-known TF 1060 U.H.F. Signal Generator has been designed to provide better performance under external pulse modulation operation than was obtainable with the standard model. Rise times of less than 0·1 μsec can be obtained. Operation of the two instruments using the c.w. or internal a.m. facility is identical.

THIS INSTRUMENT was initially designed to operate in conjunction with the Ministry of Aviation's Test Set 506, TF 1349, a Differential Pulsed Attenuator for secondary surveillance radar. This application required pulses of shorter duration and of better shape than could be obtained using the standard U.H.F. Signal Generator TF 1060.

Fig. 1 shows the circuit arrangement of the modulator and r.f. oscillator of the standard TF 1060 as set for external pulse modulation operation. The modulator valve is connected in series with the oscillator between earth and the negative h.t. line, and its grid is connected to a more negative bias supply so that it is normally cut off. This prevents current flowing in the oscillator valve which thus cannot oscillate.

The application of a positive going pulse to the grid of the modulator allows current to flow in the modulator and hence in the oscillator which is then able to operate. The minimum input pulse amplitude for satisfactory operation is 30 V and, at this level, slight limiting action is obtained at the grid of the modulator valve. As the input amplitude is increased beyond this level, so does the degree of limiting increase, and the duration of the current pulse through the oscillator follows closely that of the limited part of the modulation waveform. The start of the output pulse is thus delayed on that of the input pulse by an amount which depends on the rise time of the input pulse and on that of the waveform at the oscillator cathode.

In spite of this delay the r.f. pulse width measured at the half amplitude points was found to be greater than that of an applied pulse. This was due to the high Q of the r.f. cavity which maintained oscillation after the oscillator valve current had ceased. The minimum r.f. pulse width which could be produced satisfactorily was 1 μsec.

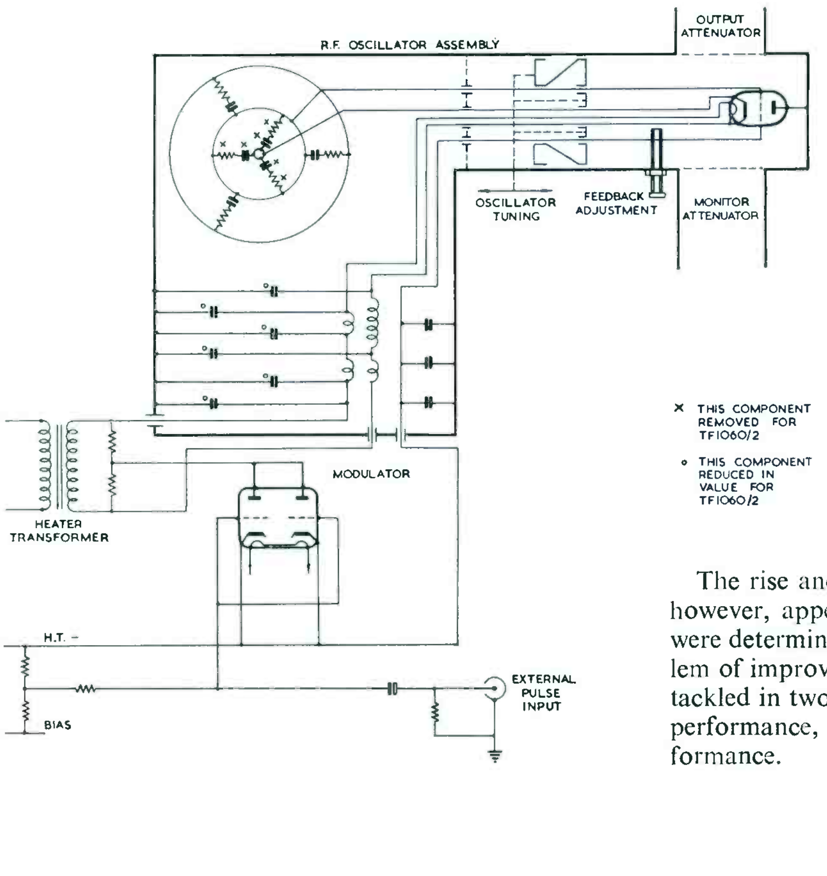


Fig. 1
Circuit of TF 1060 oscillator and modulator for external pulse modulation

The rise and decay times of the video pulses did not, however, appear to affect those of the r.f. pulse which were determined by the Q of the r.f. circuits, so the problem of improving the instrument's performance could be tackled in two separate stages, one to improve the video performance, and the second to improve the r.f. performance.

Video improvements

To improve the video performance, it was necessary to reduce the rise times of the input pulse and of that at the cathode of the oscillator valve. The former is obviously dependent on the source from which the pulse is obtained, but is also affected by the input capacitance of the Signal Generator. This was measured to be of the order of 300 pF.

In order to handle the oscillator current, a fairly large modulator valve must be used, with a correspondingly large input capacitance which would be very difficult to reduce, making the problem one of reducing stray capacitance to earth. By careful wiring and positioning of components this was reduced to 22 pF.

The situation at the cathode of the oscillator was considerably more complicated. The oscillator valve has one side of the heater connected to the cathode. The heater supply has thus to be run from a transformer whose secondary is at the d.c. potential of the oscillator cathode. To prevent r.f. leakage along the heater leads, each lead incorporates, within the metal work of the r.f. assembly, a two-stage LC filter which acts as a small delay line to a video pulse. In addition, an RC network is used to terminate the end of the grid-cathode coaxial line behind the plunger to prevent back cavity resonance. All of these contributed to the capacitance at the cathode of the oscillator.

It was found that though the terminating network was good design practice, it could be removed without any serious effects. The capacitors in the two r.f. filters were decreased in value from 100 pF to 10 pF. Any increase in stray radiation produced by this change was noticeable only at the very lowest levels of r.f. output. As in the case of the input circuit, a few components were repositioned, and point-to-point wiring was used instead of high capacitance cable-formed leads.

R.F. improvements

To improve the r.f. pulse shape, it was necessary to reduce the Q of the anode-grid coaxial cavity. To do this some lossy material had to be placed in the cavity at a low impedance, i.e. high current point. A small piece of ferrite fixed to the face of the plunger had the desired result, giving a rise time of better than 0·1 μsec, and a fall time of about 0·15 μsec. During the rise time, i.e. the leading edge of the pulse, the oscillator valve is conducting, so its anode impedance acts as damping on the cavity. During the fall time or rear edge of the pulse, the oscillator valve is cut off and the damping due to its anode impedance is removed, giving the cavity a higher Q and hence making the fall time longer than the rise time.

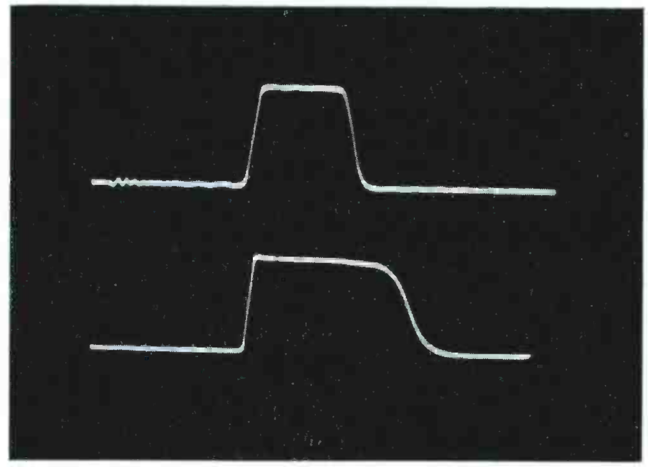


Fig. 2. Improved pulse shape: top, TF 1060/2; and bottom, TF 1060

The rise time of the r.f. pulse depended to some extent on the amount of feedback to the oscillator cathode cavity. Increasing the feedback improved the rise time, but there was a limit imposed by the maximum oscillator cathode current rating. As the mean cathode current was negligible under pulse conditions, this was only important on c.w. and a.m. operation.

The improved pulse shape is illustrated in Fig. 2, showing comparative results before and after modification. This improvement enabled shorter pulses to be

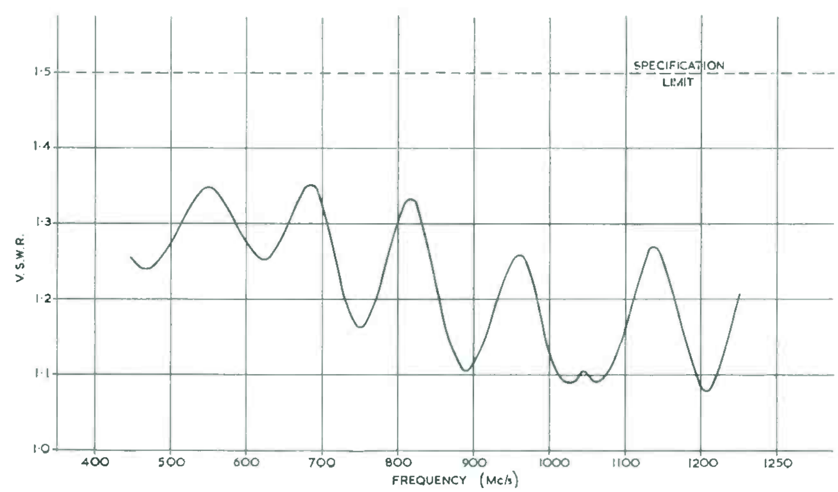


Fig. 3
Typical output v.s.w.r. for TF 1060/2 and improved TF 1060

U.H.F. Signal Generator, Type TF 1060/2

obtained than previously and satisfactory operation is now possible down to a width of 0·3 μsec.

Inevitably, the lower Q of the anode cavity decreased the maximum r.f. frequency at which the oscillator would operate. The restriction was, however, small—to 1200 Mc/s as compared with 1250 Mc/s for the standard model TF 1060.

In addition to the foregoing it was also desired to improve the output v.s.w.r. This is largely determined by the configuration of the termination at the piston attenuator which comprised a simple loop, part of which was formed by a 50 Ω resistor. To achieve a good v.s.w.r., the termination must be resistive, so capacitance had to be added across the loop to tune out its inductance by adjustment during calibration. The Q of this arrangement was very low, giving good results over the entire frequency range of the instrument, and permitting the v.s.w.r. specification to be improved from 1·8: 1 to 1·5: 1, while the actual figure is much better than this over a great part of the frequency range as illustrated in Fig. 3.

Improvements to Standard TF 1060

The means used to improve the pulse input circuitry and output v.s.w.r. for the TF 1060/2 had no ill effects on any other feature of the instrument. These modifications are now incorporated in the standard model TF 1060, making it possible to improve its specification to equal that of the TF 1060/2 for c.w. or internal a.m. operation.

CORRECTION

The author of the article *H.F. Spectrum Analyser* which appeared in Vol. 8, No. 4, December 1961, is grateful to a reader of the Post Office Engineering Department, W.O. Branch, who pointed out an error occurring at the end of the last paragraph on page 94. The last two sentences should read: 'A test to prove ringing is not present is to *decrease* the sweep width and if ringing is present the amplitude of the signal will increase. If ringing is present then the sweep width should be *decreased* or the speed decreased.'

This follows from the formula

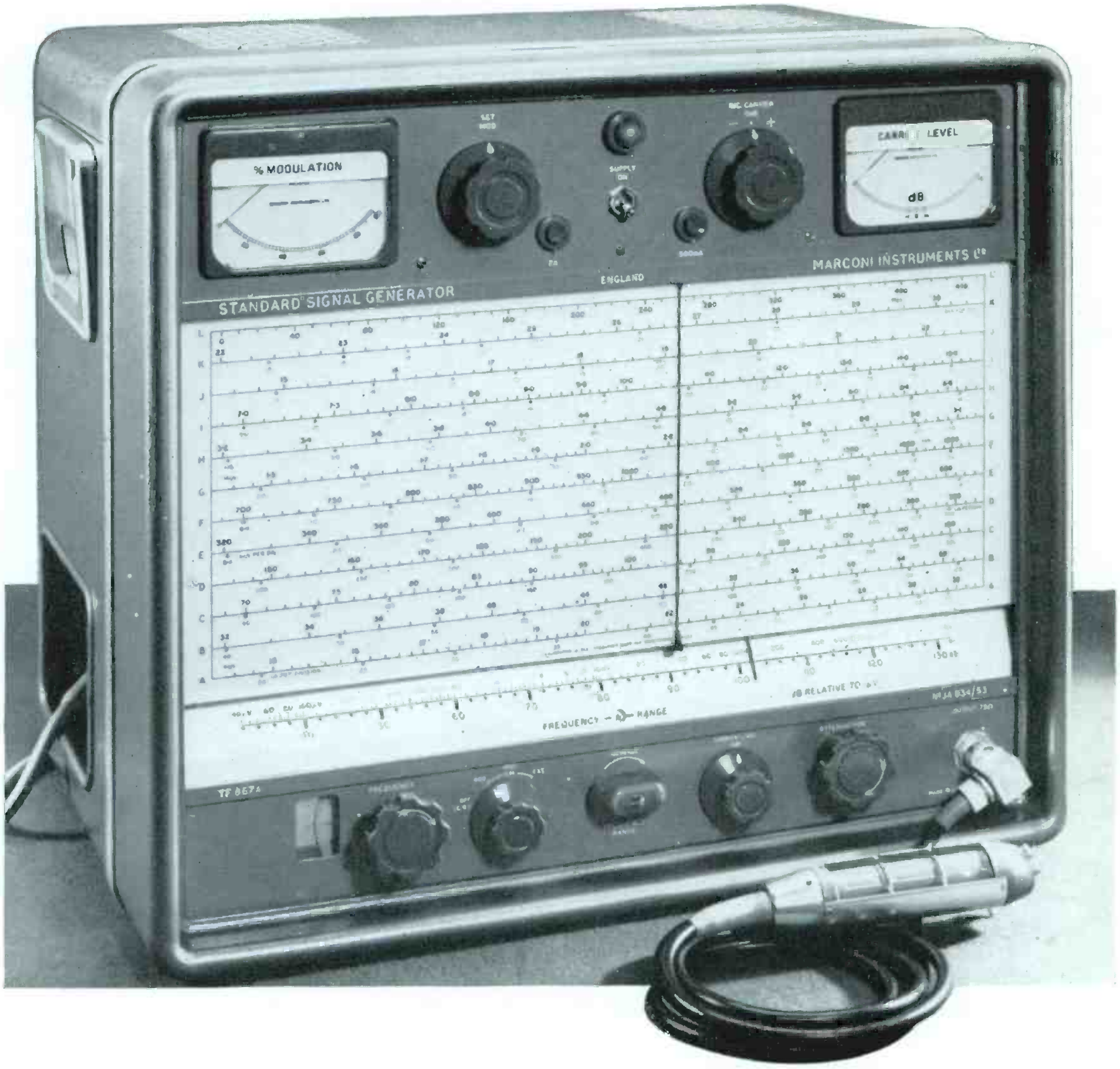
$$F = w/tB^2$$

where F is the sweep bandwidth factor, which is a measure of distortion,
w is the sweep width in cycles per second,
t is the sweep time in seconds,
and B is the bandwidth of the system in cycles per second.

As B is fixed for a particular circuit, F can be decreased by decreasing w or increasing t, which is inversely proportional to speed.

J. H. D.

MARCONI INSTRUMENTS



The precision amplitude-modulated m.f./h.f. signal generator, TF 867, has been superseded by a new model, TF 867A. This new version includes a fully stabilized h.t. supply, and has additional screening to improve r.f. leakage at the lower carrier frequencies. The original features—high output, good discrimination and high quality a.m. up to 100% depth—have been retained.

621.396.615.12

Standard Signal Generator . . . *TYPE TF 867A*

by J. M. PARKYN

AS FREQUENTLY STATED in catalogues and specifications, it is the policy of Marconi Instruments to subject instruments to a process of continuous development to ensure a product which is up to date and equal to the ever more stringent requirements of the electronics industry. Readers of *Instrumentation* will be familiar with the frequent articles describing improved versions of established instruments which supersede the basic form and also special alternative versions which are available in addition to the basic type to meet special requirements. The present article describes an improved instrument to supersede the well-established precision m.f./h.f. amplitude modulated signal generator TF 867.

When TF 867 was originally designed the attitude towards circuit complication was such that it was not, as is now the case, considered automatically essential to incorporate a regulated power unit in all electronic measuring instruments. Not that the consideration of good frequency and amplitude stability on poor mains was ignored, in fact there is a degree of cancellation of mains variation effects on carrier frequency due to the opposed action of the different valve supplies within the instrument. Automatic level control, in all models of TF 867, although primarily intended to offer the great advantage of constant carrier level whilst changing the frequency setting incorporates a lamp bridge reference circuit to keep the carrier level constant with fluctuating mains supplies. However, to reduce to an absolute minimum small carrier frequency shifts which could be measured at the highest carrier frequencies when the instrument was operated on badly fluctuating mains, a fully stabilized h.t. supply using the now common series stabilizer circuit has been fitted in TF 867A. The overall power consumption of the signal generator has not been significantly changed because the loss in the series regulator circuit, both in h.t. and extra heater power, has been offset by the use of high efficiency silicon junction h.t. rectifiers in place of the original valve rectifier.

One of the many popular features of TF 867 has always been the high output level and this feature now often leads to its being used to feed a loop to create a known field for testing receivers fitted with ferrite aerials. (A high output e.m.f. is usually required so that a large value of series resistor can be used to swamp the launching loop reactance to maintain a loop current independent of frequency.) Improved receiver design has shown that the screening of the high level circuits of TF 867 is not always fully adequate at the lower carrier frequencies in spite of the fact that the coil turrets are of an inverted form with the coils inside so that the turrets provide a screening action. A further screen is fitted over the turrets and the mild steel outer case could be expected to give a further reduction in the external stray field. However, TF 867A has been fitted with additional mild steel screens surrounding the individual coils to reduce further the leakage at the lower carrier frequencies, particularly in the long and medium wavebands.

In addition to the two improvements mentioned, TF 867A retains the many other features for which the original model has been noted. Among these features may be included the exceptionally large clear main tuning scale which together with the built-in crystal calibrator ensures good absolute accuracy and discrimination. But the most significant feature of the original design is the very low modulation distortion, which is specified as being less than 3% at 80% depth to cater for the worst conditions but is at most frequencies much better than this and maintains an excellent waveform up to a full 100% depth. Also associated with the modulation performance is the accurate monitoring system and the very low spurious f.m. on a.m. maintained by the use of an intermediate buffer between the master oscillator and tuned output stage.

Below is reproduced the abridged specification of TF 867A which supersedes the original Standard Signal Generator TF 867.

ABRIDGED SPECIFICATION

Frequency

RANGE: 15 kc/s to 30 Mc/s in eleven bands.

CRYSTAL CHECK: At 1 Mc/s intervals.

SCALE DISCRIMINATION: Approx. 1 part in 10^4 of total scale length.

Output

VOLTAGE: 0·4 μV to 4 V e.m.f.

IMPEDANCE: 75 Ω from 4 μV to 4 V ; 13 Ω from 0·4 μV to 0·4 V.

Modulation

INTERNAL SINEWAVE: 400 and 1,000 c/s.

DEPTH: 0 to 100%, variable and monitored.

ENVELOPE DISTORTION: Less than 3% at 80% modulation.

SPURIOUS F.M.: Less than 200 c/s deviation at 30% a.m.

R.F. leakage

Negligible; permits full use of lowest output.

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MARCONI INSTRUMENTS APPLICATION NOTE

A pH METER AS A BRIDGE DETECTOR

by B. A. MURPHY

A calibration engineer uses the TF 1093 pH meter as a bridge detector in measuring the resistance of a d.c. multiplier for the TF 1041C valve voltmeter

ONE LIMITATION of using Wheatstone Bridge methods for the measurement of a wide range of resistance values is the detector. The D'Arsonval or moving coil galvanometer, the usual detector, is a current operated device and as such its sensitivity varies considerably depending on the ratio of the bridge arms. It varies for two main reasons:

(1) When the bridge arms have a large value, the current through them is small. Therefore the out of balance current is extremely small.

(2) When the arms have small values, the galvanometer is fed from a low impedance source, which damps its movement.

There are various ways of overcoming these difficulties, the most common method being the d.c. chopper system. This system is a great improvement over the galvanometer, but at high resistance values the system falls down owing to the difficulty of amplifying very low currents. It is also necessary to construct amplifiers and other circuitry. An alternative form of detector would be a very high impedance voltmeter. Providing the current drawn is very small the voltmeter could be used as a voltage detector over a very large range of resistance up to $5 \times 10^9\ \Omega$ and higher.

A pH meter, for example Marconi TF 889/1M or TF 1093, which basically are very high impedance voltmeters, could be used as such a detector. The current drawn by the TF 889/1M is less than 5×10^{-10}A and the TF 1093 less than 1×10^{-12}A. To illustrate this, three examples of their use as detectors are given below; each deals with a particular problem which occurred in the production departments of Marconi Instruments.

(1) This problem concerned the resistance measurement of the D.C. Multiplier TM 5033A which is used with the Valve Voltmeter type TF 1041C. The resistance

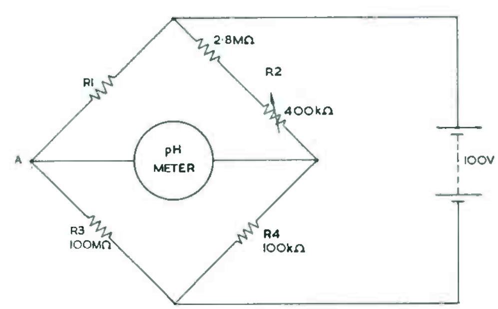


Fig. 1. Measuring 3000 MΩ multiplier

to be measured was a nominal 3000 MΩ, and it was required to know its exact value within ±2%. Fig. 1 shows the bridge that was used; R1 is the resistor under test, and R2 is a series combination of a 2·8 MΩ fixed resistor and a 400 kΩ variable resistor. Thus, when the variable resistor is set to its mid point, R1/R3 = R2/R4 which is the condition of balance for a Wheatstone Bridge. The 400 kΩ variable resistor was calibrated directly in megohms, giving a range of about ±7 %, thus allowing the multiplier TM 5033A to be measured exactly.

If R1 should, say, be 1 % low, i.e. 2970 MΩ, then the voltage at A would rise by about 33 mV. Now the discrimination of the TF 1093 pH Meter when used as a millivoltmeter is 2 mV. It is therefore theoretically possible to detect changes of resistance of less than 0·06 %. Similarly the discrimination of the TF 889/1M pH Meter is 2·9 mV, giving a discrimination of resistance of about 0·09 %.

When R1 is 1 % away from nominal, the pH meter will measure an out of balance voltage of 33 mV, assuming that the ratio R2/R4 is correct. The input resistance of the TF 1093 is $10^{12}\Omega$. Therefore the current drawn will be $33\times10^{-3}/10^{12} = 33\times10^{-15}$A. The current through R1 and R3 $= 100/(3{\cdot}100\times10^{9}) = 32{\cdot}25\times10^{-9}$A. Thus it can be seen that the detector will not load the bridge. The TF 889/1M would under these conditions draw a current of $1{\cdot}5\times10^{-13}$A which, though higher than that drawn by the TF 1093, is still small enough to ignore. Although, theoretically, it is possible to detect changes of 0·06 % and 0·09 % there are some limitations due to leakage current. The mechanical layout and the quality of the insulation used in the construction of the bridge then become very important.

(2) The problem in this case was to adjust the range resistors of a Valve Voltmeter TF 958 to within 0·25 %. These resistors ranged in value from 5·34 kΩ to 825 kΩ. The resistors are a series combination of a high stability

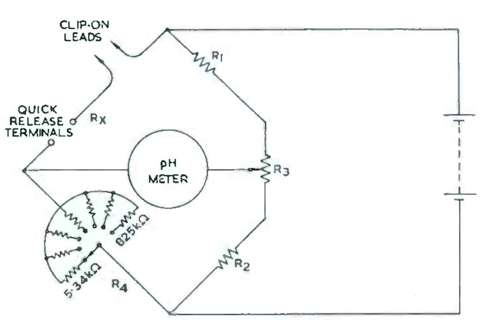


Fig. 2. Selecting valve voltmeter range resistors

resistor of tolerance +0 %, −1 % and a resistor which is selected during test. The bridge shown in Fig. 2 was constructed. R1 = R2, and R3 was calibrated directly in percentage to read a maximum of ±0·25 %, zero being at its mid point. The high stability resistor, which was already wired into the valve voltmeter, was connected to the bridge by means of a pair of clip-on leads. The series padding resistor was then held in a pair of quick release terminals. R4 was switched such that the ratio RX/R4 was constant at 1. It was then a very quick and simple matter of trying various resistors until the correct one was selected.

By using a pH Meter as the detector very good discrimination was achieved and it also remained substantially constant over the wide range of resistance that was measured. This bridge simplified the selection problem to such an extent that it was possible to have the selection performed in the Assembly department and thus save expensive time of the calibration engineer.

(3) This third problem arose with adjustment of the attenuators in the balanced inputs of the Television Measuring Oscilloscope TF 1277. The problem was to adjust the paired attenuator sections to within 1 % of each other. Fig. 3 shows how the attenuator sections appear in the instrument. A jig was constructed so that by using

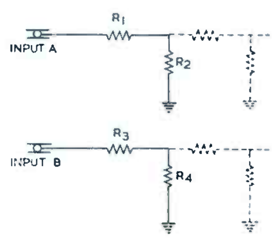


Fig. 3. Oscilloscope input attenuator sections

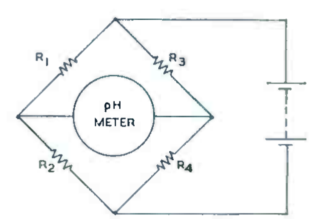


Fig. 4. Rearranged to form a bridge

clip-on leads it was possible to arrange the paired sections as shown in Fig. 4. It was then a simple matter of trying different resistors in place of R4 until the bridge balanced.

It was found that the usual bridge detectors were inadequate for this job and it was only possible to use this method by using a pH Meter as the detector. By doing so it was found that seven hours were saved on the calibration of the complete instrument.

These three examples show that by making use of the very high impedance of a pH Meter it is possible to greatly increase the sensitivity and range of a normal Wheatstone Bridge, and by the construction of special jigs, which all contain cheap and easily obtainable components, it is possible to solve many resistance measurement problems that would normally take considerable time and also be very tedious.

During the past fifteen years the mailing list of *Marconi Instrumentation* has increased to 35,000 copies and it is probable that the bulletin is now being incorrectly addressed to some readers. If this is so in your case it would be appreciated if you will kindly inform your nearest Marconi Instruments Area Office or Agent.

MARCONI INSTRUMENTS

621.396.662

A New 600 ohm Attenuator for the TF 1073A Series

by G. D. WATTS,
Graduate I.E.E.

The TF 1073A/4 is a new 600 Ω step attenuator for use in audio, video and m.f. measurements. It has a frequency range of d.c. to 5 Mc/s and provides up to 100 dB of attenuation in 1 dB steps. This instrument is an addition to the well-known TF 1073A series of r.f. attenuators; the basic design of all instruments in this series is described together with their applications.

THE FIRST ATTENUATOR to be designed in this series was the TF 1073, a 100 dB Step Attenuator of 75 Ω characteristic impedance; later a companion model, the TF 1073/1, was introduced to operate at 50 Ω. In both these instruments the 100 dB of attenuation was provided in 1 dB steps by means of two sections, a coarse and a fine, and the design enabled them to be employed over the frequency range of d.c. to 100 Mc/s with an accuracy of ±0·5 dB.

These two models have been superseded by the 75 Ω R.F. Attenuator TF 1073A and the 50 Ω R.F. Attenuator TF 1073A/1 in which the fine and coarse sections have been accommodated in a modern styled case equipped with BNC sockets.

Alternative versions of these models are available with individually switched input and output terminating resistors equal in value to the characteristic impedance, and these are known as the 75 Ω R.F. Attenuator TF 1073A/2S and the 50 Ω R.F. Attenuator TF 1073A/3S.

To this well-established list of Attenuators a new model of 600 Ω characteristic impedance has been added. Unlike most 600 Ω attenuators its performance extends beyond the usual audio and l.f. bands to cover the m.f. and video region. The total cumulative error of all the steps does not exceed 1 dB at 1 Mc/s and 2 dB at 5 Mc/s: Fig. 1 shows a typical curve of attenuation accuracy against frequency at 100 dB attenuation.

Design of the TF 1073A Series Attenuators

All the attenuators in the TF 1073A series have the same basic design, described in detail in an earlier issue of *Instrumentation*,[1] and which has been evolved in the following manner.

In order to provide a range of attenuation from zero to 100 dB the simple ladder attenuator construction cannot be employed directly, as a means has to be found for providing a direct connection between input and

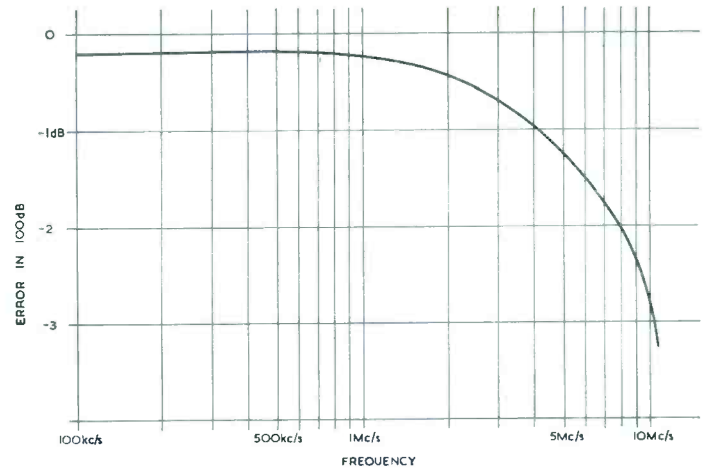


Fig. 1.
Variation of attenuation accuracy with frequency

output sockets with no shunt path to earth when all the attenuation is switched out. This problem has been overcome by inserting a pad or pads of the required attenuation, or a direct connection between the input and output socket by means of switching as shown in Fig. 2.

The required attenuation is provided by the coarse and fine sections operating in cascade. The coarse section has an attenuation range of 80 dB in 20 dB steps, and the fine section an attenuation range of 20 dB in 1 dB steps, giving a total of 100 dB. The coarse section is made up of four separate unbalanced π networks of 20 dB each, which may be switched additively to give 20, 40, 60 or 80 dB of attenuation, each 20 dB pad is separated by an electrostatic screen. The fine section comprises 20 different separate networks with only one network in circuit for each switch position. The 1 dB and 2 dB pads are unbalanced T networks and the remaining 18 pads are unbalanced π networks.

The series elements of the fine attenuator pass through holes in an earthed screen to minimize the direct capacitance across the series arm and the earthy ends of the shunt elements are connected to the same screen. Short lengths of coaxial cable join the sockets and attenuator sections together. By employing this careful layout, well screening each pad and providing overall double-screening throughout the instrument, capacitive leakage and coupling currents have been kept to a minimum.

Applications

The 75 Ω R.F. Attenuators TF 1073A and TF 1073A/2S and the 50 Ω R.F. Attenuators TF 1073A/1 and

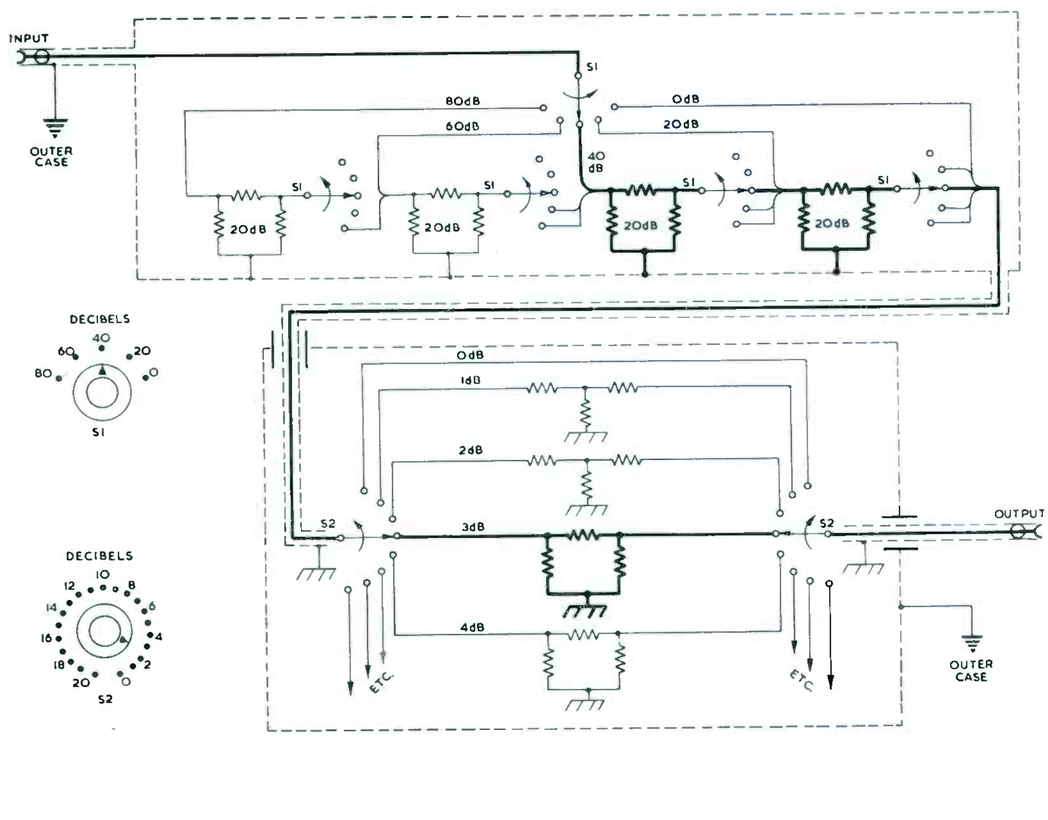


Fig. 2
Functional diagram of Attenuator, Type TF 1073 series

TF 1073A/3S may be employed as instruments in their own right, or in conjunction with other test equipment for many applications over a frequency range from d.c. to v.h.f. They may be used to produce accurate changes in signal level at audio and r.f. frequencies, for measuring amplifier gain, transmission loss of networks, frequency response of filters, and for making power level tests on transmitters.

The M.F. 600 Ω Attenuator TF 1073A/4 performs the same functions from d.c. to 5 Mc/s but its impedance makes it particularly suitable for video frequency measurements.

REFERENCE

1. Flanagan, T. P.; Resistance Attenuators. *Marconi Instrumentation*, 4, 215, September 1954.

SPECIFICATION FOR TF 1073A SERIES ATTENUATORS

	TF 1073A/1 and TF 1073A/3S	TF 1073A and TF 1073A/2S	TF 1073A/4
Classification	R.F. Attenuator	R.F. Attenuator	M.F. Attenuator
Characteristic Impedance	50 Ω	75 Ω	600 Ω
Attenuation Range	0–100 dB	0–100 dB	0–100 dB
Attenuator Steps	20×1 dB 4×20 dB	20×1 dB 4×20 dB	20×1 dB 4×20 dB
Frequency Range	d.c.–150 Mc/s	d.c.–150 Mc/s	d.c.–5 Mc/s
Max. Cumulative Error	±0·5 dB at 100 Mc/s	±0·5 dB at 100 Mc/s	±1 dB at 1 Mc/s ±2 dB at 5 Mc/s
Max. Power Input	0·25W	0·25W	0·25W
Connectors	–A/1: 50 Ω BNC –A/3S: 60 Ω PR4D	–A: 75 Ω BNC –A/2S: 60 Ω PR4D	50 Ω BNC

MARCONI INSTRUMENTS

621.396.615.12

V.H.F. Signal Generators *TYPE TF 1064B/5, -/6, -/7 and -/8*

by J. H. DEICHEN, A.M.I.E.E.

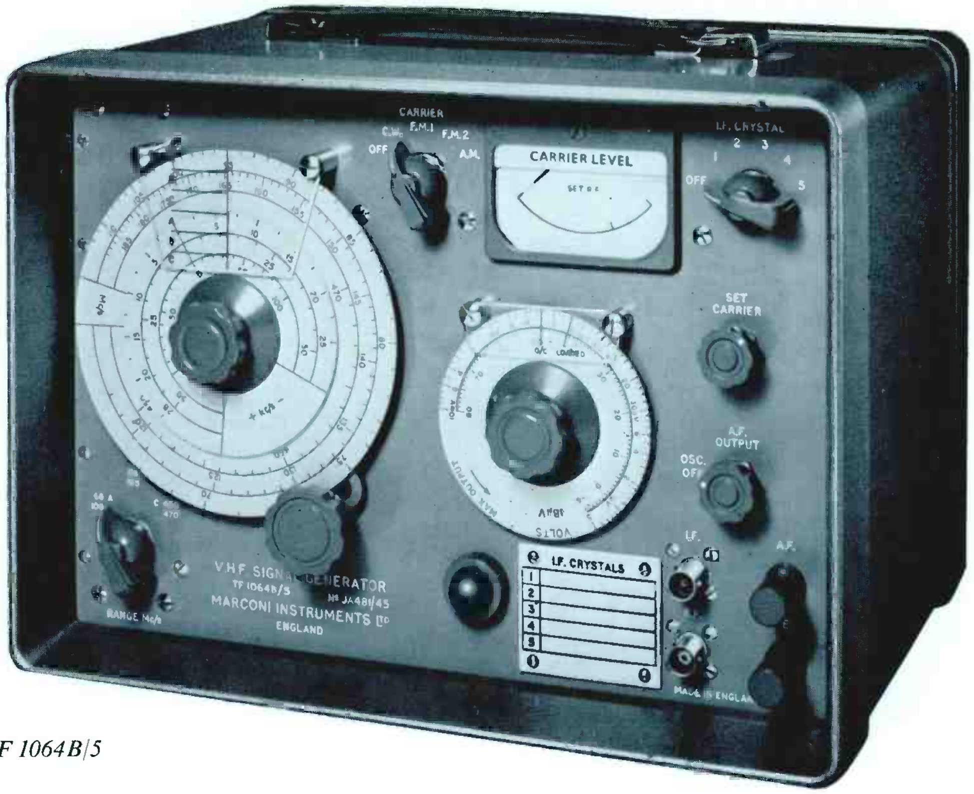
A crystal oscillator circuit designed to handle a wide range of crystal frequencies presents many design problems. These include variation in crystal activities and tolerances and the need to keep crystal voltage within limits. The i.f. oscillator circuit in the TF 1064 series of signal generators was designed with such considerations in mind, and recent refinements to this circuit are employed in the latest series of TF 1064B models.

THE V.H.F. Signal Generators, type TF 1064 series, were discussed in an earlier edition of *Instrumentation*.[1] In that article very little was said about the i.f. oscillator. This article gives additional information regarding the i.f. oscillator circuit and discusses a new arrangement for the oscillator which is now incorporated in the TF 1064B series.

I.F. Oscillator

A crystal oscillator circuit designed for a wide band of crystal frequencies, so that a number of precise frequencies can be obtained by turning a switch presents many difficulties. A consideration of prime importance is that the voltage across the crystal must not exceed the manufacturer's tolerance. This in itself can be a simple matter to control for a single frequency circuit, but when dealing with a wide band in a single circuit the best conditions for one frequency does not necessarily apply for all frequencies in the range. Other problems to consider are crystal activity and frequency tolerance of all the crystals to be used. Therefore before the crystal i.f. circuit was chosen for the TF 1064 series a number of crystal circuits were considered.

The basic circuit finally chosen is shown in Fig. 1. This is a modified Colpitts circuit in which capacitors, C1 and C2, form the tapped capacitance across the crystal, X1. In this circuit over the frequency range of



V.H.F. Signal Generator, Type TF 1064B/5

290 kc/s to 16 Mc/s, using crystals designed for 30 pF circuits, the voltage across the crystal is well below the recommended 15 V limit. On the earlier signal generators the five crystal frequencies are obtained by switching the appropriate crystal only into circuit. The capacitor, C1, is a trimmer and is adjusted so that the circuit as seen by the crystal is precisely 30 pF. Therefore for any crystal used in the circuit the frequency accuracy is very nearly the accuracy of the crystal. The capacitor,

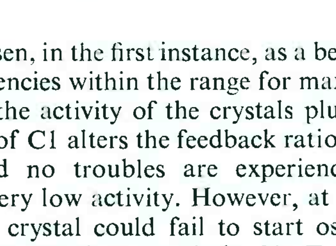


Fig. 1. Basic circuit of i.f. oscillator

C2, was chosen, in the first instance, as a best compromise for all frequencies within the range for maximum output, and to suit the activity of the crystals plus the fact that adjustment of C1 alters the feedback ratio. In the middle of the band no troubles are experienced even with crystals of very low activity. However, at the extremes a low activity crystal could fail to start oscillating when the circuit is tuned to precisely 30 pF. Usually these crystals could be made to work by slightly detuning but at the expense of frequency accuracy. Unfortunately this detuning also causes inaccuracy at all other frequencies. Therefore it is necessary to use high activity crystals at the extreme of the range.

Another characteristic of the circuit shown in Fig. 2 is the low impedance output. This, coupled with the fact that the i.f. signals are usually fed into a high impedance, such as the grid of an amplifier, means that a high level output of at least 200 mV is usually realized even under operating conditions. For those who wish to be able to control the level of the signal an accessory, I.F. Level Control Unit, TM 5570, is available.

The frequency accuracy of a crystal depends on the type of crystal, and the tolerance of the frequency obtainable from manufacturers depends on several factors, including the cut necessary to obtain the wanted frequency. Crystals made at some frequencies cannot realize close tolerances and even the closest tolerance is not always sufficient for very narrow band telecommunication equipment. Better accuracy than that of the crystal tolerance can be obtained with most crystals used in the circuit shown by adjusting C1 to pull the crystal frequency. This, of course, may give a greater inaccuracy for crystals used on the other four positions. Therefore to obtain the highest accuracy on all positions an individual trimmer is required for each. On first inspection of the circuit it would appear to be a simple matter of reducing the values of C1 and C2 and adding a parallel trimmer across each of the crystals. However, difficulties arise using this method due to the low value of C1 which would be necessary to give sufficient cover on all positions. As C1 determines the feedback as well as the frequency there is a limit to its lowest value. In the circuit for the latest TF 1064B series the problem is overcome by switching a trimmer in parallel with a fixed capacitor of low value for each of the five positions, this parallel combination replacing C1. By this method each crystal circuit can be adjusted individually to a predetermined tolerance or to a precise 30 pF, whichever is desired. On the other hand, at the extreme ends of the range the trimmers can be adjusted for better oscillation if the frequency accuracy deterioration can be tolerated; this does not affect the other positions.

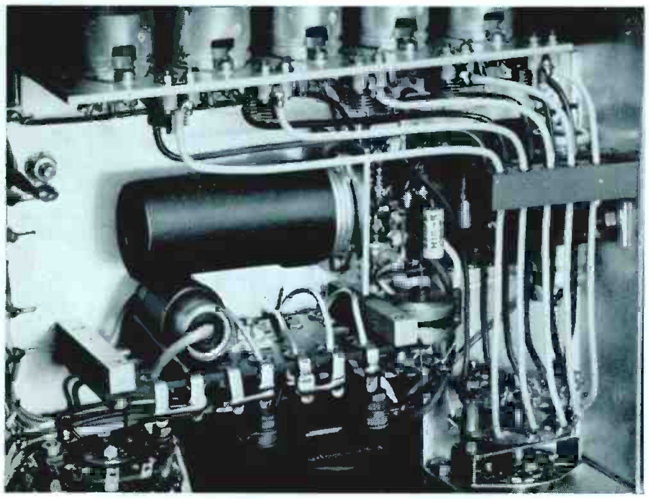


Fig. 2. I.F. oscillator layout avoids high stray capacitance

To make a circuit of this arrangement practical it is necessary to design the layout to give very small stray capacitance, but this is complicated by the need to place the crystal holders, the trimmers and the switch in an accessible position. This has been accomplished by careful wiring and positioning of the components as far as possible from the chassis. A picture of the layout can be seen in Fig. 2. The valve holders and trimmers are accessible from the rear of the instrument and the crystal switch from the front panel. The frequency of the crystal used for each position can be written on a small label attached to the front panel.

The i.f. oscillator valve is one half of a double triode, the other half is used for the a.f. oscillator. As in the earlier models the i.f. oscillator can be amplitude modulated at 1 kc/s, by switching on the a.f. oscillator. The depth of modulation is nominally 30% but depends to a large extent on the activity of the crystal used.

The Latest Models

The V.H.F. Signal Generators, types TF 1064B/5, TF 1064B/6, TF 1064B/7 and TF 1064B/8, are coming into production and are identical, respectively, to the TF 1064B, TF 1064B/2, TF 1064B/3 and TF 1064B/4 except for the i.f. oscillator circuit. As the modification is considered to be minor and does not involve valve changes the new models are given a new stroke number rather than the normal rule of changing the letter designation.

REFERENCE

1. Deichen, J. H.; V.H.F. Signal Generator, Type TF 1064 Series, *Marconi Instrumentation*, **8**, 57 (September 1961).

ABRIDGED SPECIFICATION

R.F. output

FREQUENCY RANGES (Mc/s):

TF 1064B/5	TF 1064B/6
A: 68 to 108	30 to 50
B: 118 to 185	118 to 185
C: 450 to 470	450 to 470

TF 1064B/7	TF 1064B/8
A: 68 to 108	68 to 108
B: 118 to 185	118 to 185
C: 470 to 500	440 to 460

INCREMENTAL FREQUENCY CONTROL:

TF 1064B/5, /7, /8	TF 1064B/6
±25 kc/s on Range A	±25 kc/s on all ranges
±50 kc/s on Range B	
±100 kc/s on Range C	

OUTPUT LEVEL: 0·5 μV to 10 mV source e.m.f., continuously variable. Uncalibrated higher outputs of at least 200 mV.

SOURCE IMPEDANCE: Nominally 50 Ω.

V.S.W.R.: Better than 2·0.

Using 20 dB Pad TM 5573, v.s.w.r. is better than 1·15 on all models.

Modulation R.F. (output)

INTERNAL 1,000 c/s F.M.:

TF 1064B/5, /7, /8:

Fixed deviations, 3·5 and 10 kc/s.

TF 1064B/6:

Fixed deviation, 10 kc/s.

Variable deviation, 0 to 15 kc/s.

EXTERNAL F.M. (TF 1064B/6 only): At the lower modulation frequencies, up to 10 V input across 600 Ω gives 10 kc/s deviation.

SPURIOUS A.M. ON F.M.: Typically, less than 1% modulation depth at maximum deviation.

RESIDUAL F.M.: The f.m. due to hum, noise and microphony is, typically, less than 100 c/s deviation in a quiet location.

INTERNAL 1,000 c/s A.M. (not applicable to TF 1064B/6): Nominally 30% fixed depth.

SPURIOUS F.M. ON A.M.: Typically, less than 100 c/s at levels below 3 mV.

I.F. output

CRYSTAL FREQUENCIES: The i.f. crystal oscillator will function at any frequency between 290 kc/s and 16 Mc/s. Five switch-selected sockets are provided for crystals.

FREQUENCY ACCURACY: In general 0·01%, but can be adjusted to better accuracy by associated trimmer.

OUTPUT LEVEL: Greater than 100 mV across a 1 kΩ load.

MODULATION: The crystal oscillator can be amplitude modulated by internal 1,000 c/s source for signal identification.

A.F. output

FREQUENCY: 1,000 c/s.

OUTPUT LEVEL:

TF 1064B/5, /7, /8:

0 to approx. 1·25 V e.m.f. continuously variable.

TF 1064B/6:

0 to approx. 2 V e.m.f. continuously variable.

621.317.382

MARCONI INSTRUMENTS

Transmitter and Receiver Output Test Set
TYPE TF 1065A

by K. PEEL, B.Sc.

This is a development of the TF 1065. The main changes are the addition of amplitude modulation depth monitoring, three extra input impedances for a.f. power measurements and improvements to the f.m. deviation measuring circuit. The article describes the new instrument with emphasis on these changes.

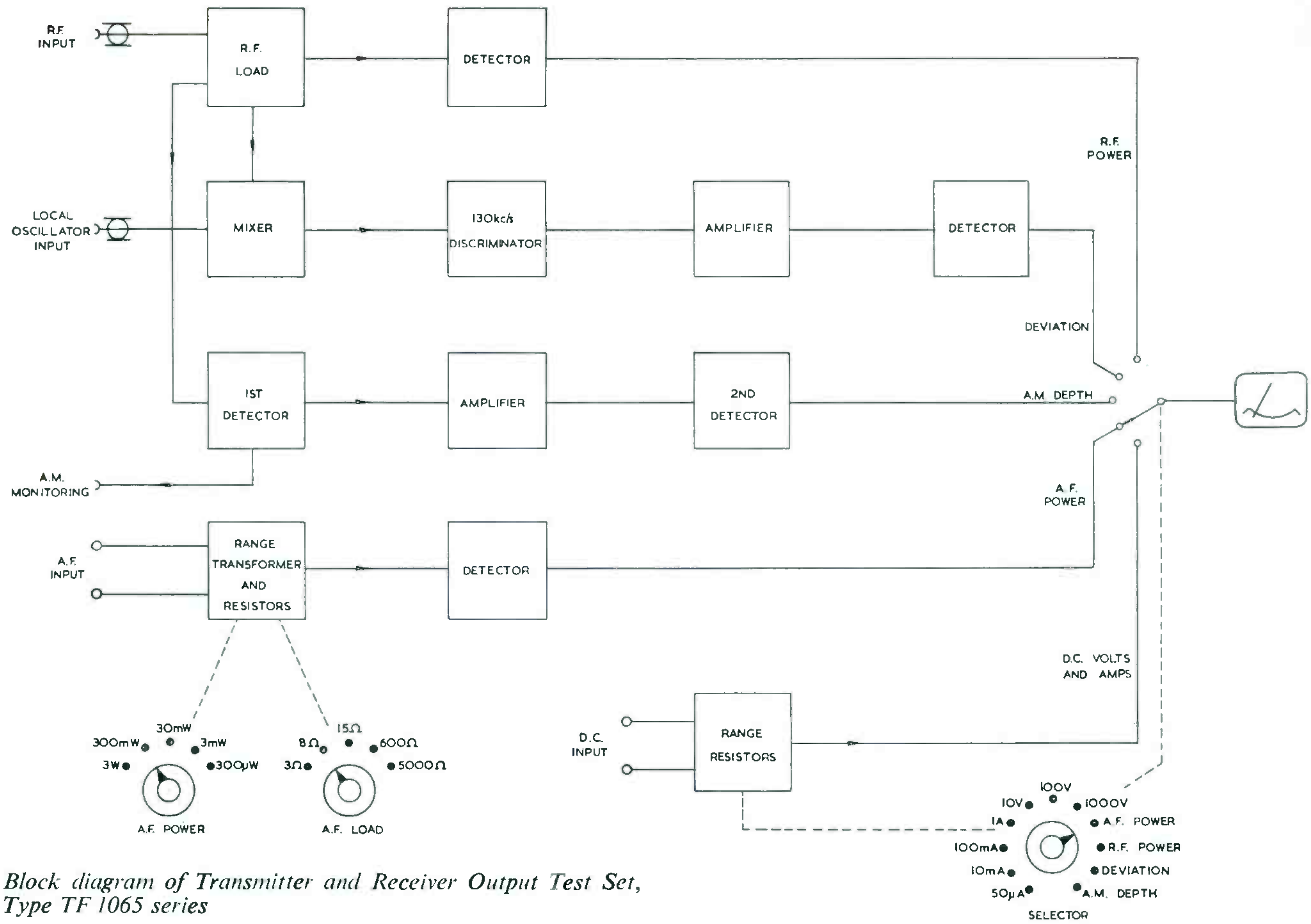
DESIGNED as a portable test unit, the TF 1065 was particularly intended for use in conjunction with the TF 1064 Signal Generator for testing mobile a.m. and f.m. v.h.f. transmitters and receivers in the field. The original model,[1] described in *Marconi Instrumentation* of December 1956, measured r.f. and a.f. power, f.m. deviation, and d.c. voltage and current. TF 1065A is a new model which, in addition, measures a.m. depth.

Amplitude Modulation

An a.m. depth meter circuit has been added for measuring modulation depth up to 80% with a telephone jack provided for aural monitoring of a.m. signals.

A signal of about 1 watt is required at the r.f. input socket. A tap on the r.f. load resistor provides a signal for a crystal detector which gives an output having a d.c. component proportional to the carrier level and an a.c. component proportional to the modulation depth. The d.c. level is used for a SET CARRIER indication. The a.c. component is amplified by about three times using a high-stability transistor circuit and detected by a peak responding detector to give a reading of modulation depth. A small amount of set carrier adjustment (10%) is provided by a potentiometer after the first detector. In practice, the user sets a toggle switch to a SET CARRIER position and adjusts the input and the SET CARRIER control so that the meter indicates at a SET CARRIER mark. The switch is then set to its other position and modulation depth is read on the meter. The scale is marked at 10% modulation intervals up to 80%. A fraction of the envelope signal from the first detector is fed to the telephone jack for aural or visual monitoring.

Transmitter and Receiver Output Test Set, Type TF 1065A



Block diagram of Transmitter and Receiver Output Test Set, Type TF 1065 series

A.F. Power

The audio power ranges are extended to provide three extra values of input impedance. Loads of 3, 8, 15, 600 and 5,000 Ω are now provided with, as before, five power ranges from 300 μW to 3 W full-scale.

The circuit is basically similar to that of the earlier model; that is, the signal is matched to a resistor load by a transformer, and a tap on the secondary feeds a detector which supplies a d.c. signal to the meter, the five power ranges being obtained by switching between five such taps on the secondary. Variation in input impedance is now obtained by switched primary tappings.

F.M. Deviation

Deviation measurement has been made easier by a new circuit which improves gain stability against temperature change and increases sensitivity.

The principle of the circuit remains the same. A signal level of only about 1 W is now required, and a signal generator with an output of about 100 mV. The external generator is needed to provide a local oscillator signal to mix with the signal being measured to give an i.f. of 130 kc/s, and must have good stability and frequency discrimination to make fine tuning possible at high frequencies. The signal is taken from a tap on the r.f. load (the same tap as for a.m. monitoring), mixed with the local oscillator signal, and the resultant applied to a tap on a coil tuned to the i.f. frequency. The output from the coil now goes to a 2-transistor untuned amplifier and thence to a detector which feeds the meter; this differs from the original TF 1065 in which the signal was first detected and the d.c. resultant then amplified. Thus a d.c. amplifier has been replaced by an a.c. amplifier which is much easier to stabilize. The gain of the amplifier is varied by altering its negative feedback to give a set carrier control.

The signal is first applied with no modulation, the signal generator tuned for a maximum on the meter and its output adjusted to give approximately full-scale, the set carrier control being used as a fine adjustment to set the meter to the SET CARRIER mark. Modulation is then applied to the signal. This causes the i.f. signal to go off tune on the modulation peaks and the meter reading decreases. Thus the deviation scale is calibrated in the reverse direction, full-scale corresponding to zero deviation.

R.F. Power and D.C. Ranges

These are unchanged. The r.f. power is dissipated in a 50Ω slab line load, and a crystal detector is fed from a tap on the load to give one range of 25 W full-scale. An alternative model, TF 1065A/1, has a 75 Ω load.

For d.c. measurements the lowest current range is 50 μA; this range is also intended for use with the detector Probe Unit, Type TM 5302 (an optional accessory) for signal tracing.

General

An eleven-position function switch selects the type of measurement to be made. That is a.m. depth, deviation, r.f. power, a.f. power or any of the seven d.c. ranges.

A five-way switch selects the input impedance for a.f. power measurements and another five-way switch selects the power range.

The battery used by the amplifiers in the a.m. and f.m. circuits is a long-life mercury type. It is applied to the appropriate circuit by the function selector and also has a separate on-off switch. The on-off switch also places a short circuit across the meter in the off position.

To reduce the number of controls, the two halves of a twin ganged potentiometer are used for the a.m. and f.m. set carrier controls. Thus a single knob is used for both set carrier operations.

REFERENCE

1. Hammond-Smith, D. F.; Transmitter and Receiver Output Test Set, *Marconi Instrumentation*, 5, 206 (December 1956).

ABRIDGED SPECIFICATION

R.F. power
One range of 25 W full scale.
Frequency: 50 c/s to 500 Mc/s.

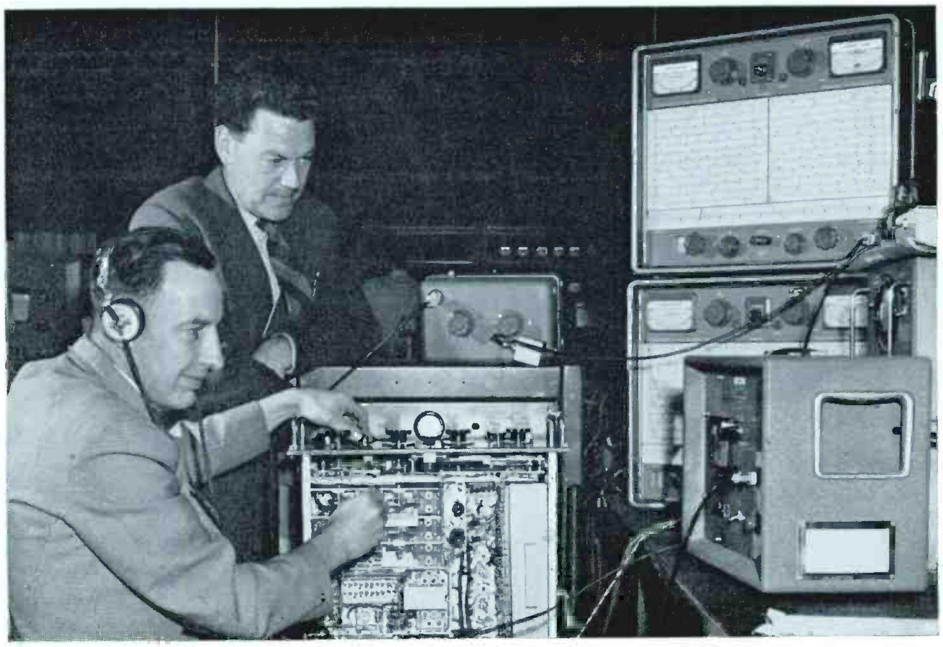
A.M. depth
One range up to 80%.
Carrier frequency: 1 to 500 Mc/s.

Deviation
One range with markings at 5 kc/s, 10 kc/s and 15 kc/s.
Carrier frequency: 10 to 500 Mc/s.

A.F. power
Five ranges of 300 μW, 3 mW, 30 mW, 300 mW and 3 W f.s.d.
Input impedances of 3, 8, 15, 600 and 5,000 Ω.
Indication is flat to within 1 dB from 250 c/s to 10 kc/s. The scale is marked with red dots at 2 dB intervals.

D.C. ranges
Four current ranges of 50 μA, 10 mA, 100 mA and 1 A full scale.
Three voltage ranges of 10, 100 and 1,000 V full scale.

TOOLS OF THE TRADE



In design, development and production there is a Marconi instrument made for the job. Here two TF 867 Signal Generators, a TF 1073 Attenuator and a TF 1106 Noise Generator are being used to test part of the D11 transmitter made at the Basildon factory of Marconi's Wireless Telegraph Co. Ltd.

MARCONI INSTRUMENTS

621.317.372

Dielectric Test Set . . . . TYPE TF 704C

by E. C. CRAWFORD,
Graduate I.E.E.

The TF 704 series of instruments measure permittivity and power factor of dielectrics at r.f. TF 704C is a revised version containing a different voltmeter with a novel method of law calibration which obviates the necessity for a true square law voltmeter characteristic. A note on the measurement of very small dielectric loss beyond the accepted range of Hartshorn and Ward's standard design is also included.

IN THE JOURNAL of the Institution of Electrical Engineers for November 1936, L. Hartshorn and W. H. Ward of the National Physical Laboratory introduced their now well-known Dielectric Test Set, and following the increasing development of radio research at the outbreak of war in 1939 there was a demand for a commercial version of the N.P.L. apparatus. Marconi Instruments set out to develop as compact a version as possible without deviation from the design principles clearly defined in the Journal. It was introduced in 1943, designated Type TF 704, and has been in continuous production ever since with minor improvements. The latest model was TF 704B which has now been superseded by the new version described below.

This Test Set is basically an extremely simple instrument; it is the details of the construction which give it the high precision first established at the N.P.L. It is composed of an oscillator with plug-in range coils extending from 50 kc/s to 100 Mc/s and supplied from a stabilized power source. The amplitude of the r.f. output is controllable to fine limits by a coarse and fine arrangement of variable resistors. This oscillator is loosely coupled, via an isolating attenuator to avoid frequency pulling, to an extremely high quality tuned circuit. This has various interchangeable coils and two precision capacitors with micrometer adjustment: the most careful design and manufacture minimizes the possibility of intermittent variation of series resistance loss and residual inductance during the adjustment. In the larger of the two capacitors the sample of dielectric can be inserted so that the loss of the dielectric may be compared with the effective zero loss of air. The Q of the circuit is established by measuring the bandwidth by detuning the smaller capacitor—see appendix. Indication of resonance and of the detuned points was given in the TF 704B and earlier versions by a triode square law anode bend detector driving a mirror galvanometer.

Transition to TF 704C

The requirement for a revised version largely arose because of the increasing difficulty in obtaining supplies of the special decapped triode valve used in the valve voltmeter section. Such a triode was used by Hartshorn and Ward in their original design as the square law anode bend detector which was coupled to the low loss tuned circuit by a small capacitor to prevent h.f. loading effects. It may be that their choice of such a detector was a matter of convenience but it also had at least two significant advantages. First of these is the square law scale expansion where it is needed, and the second is that direct readings in terms of linear deflections of the indicating galvanometer substitute directly into the equation for dielectric loss (tan δ) when working out the result: the instrument is not direct reading for permittivity or dielectric loss but relies upon the insertion of measured values in the appropriate formulae.

The use of such a weakly coupled anode bend detector has always had other practical drawbacks. The most important of these is the exceedingly low sensitivity of the arrangement which results in an unnecessary zero instability relative to the available signal level.

Suppose a triode valve is used which faithfully obeys the three halves power law. The basic formula for the anode current is:

$$Ia = k\left(Eg + \frac{Ea}{\mu}\right)^{\frac{3}{2}}$$

where Ia = anode current
Eg = grid voltage
Ea = anode voltage
μ = amplification factor
and k is a constant which depends upon the valve geometry.

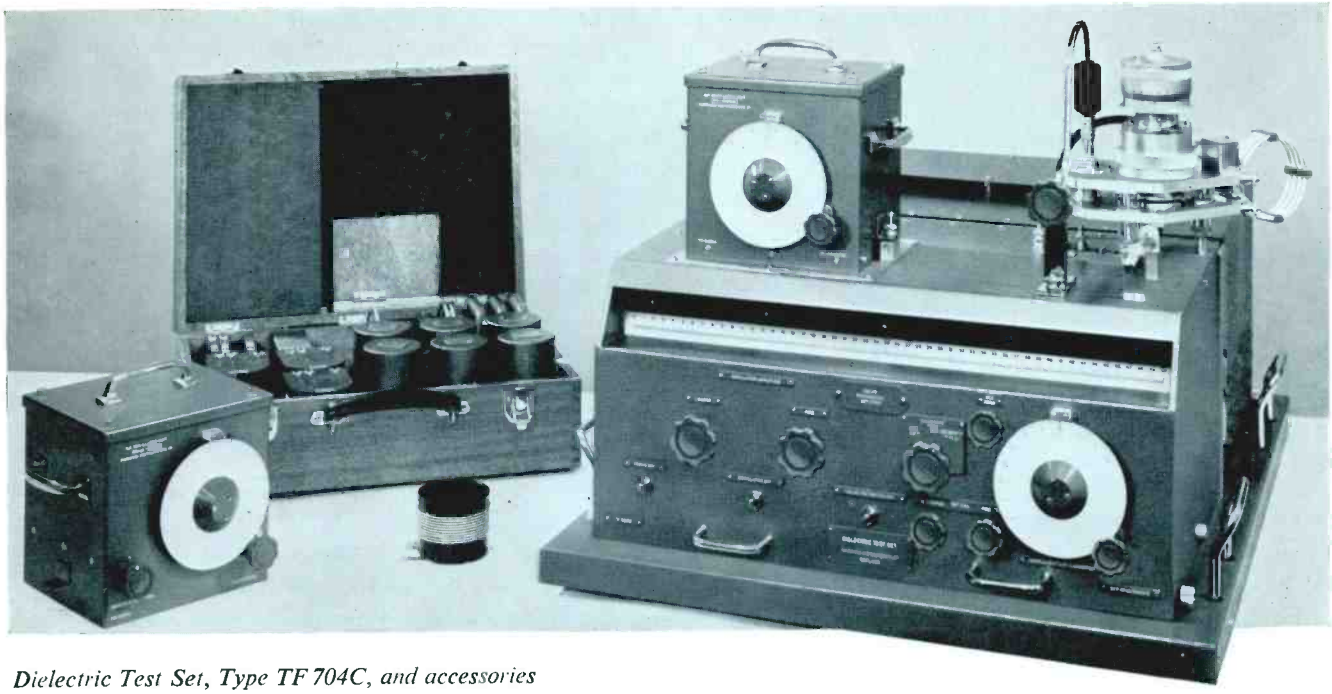
Eg has two components when the signal is applied; these are $-V$ the bias and $E \sin \omega t$ the r.f. to be detected.

Therefore:

$$Ia = k\left(E \sin \omega t + \frac{Ea}{\mu} - V\right)^{\frac{3}{2}}$$

If this is expanded by the binomial theorem a rapidly converging series is obtained which contains r.f. terms involving the fundamental and the harmonics, plus the d.c. terms, one of which is the required square law d.c. output. If for convenience $\frac{Ea}{\mu} - V$ is written as A, the first three d.c. terms of this expansion are:

$$A^{\frac{3}{2}} + \cdot187E^2A^{-\frac{1}{2}} + \cdot0088E^4A^{-\frac{5}{2}}.$$



Dielectric Test Set, Type TF 704C, and accessories

The first term is the standing anode current, the second is the required square law detection component, and the third is an undesirable fourth power component. Higher order terms are insignificant. The ratio of the second to third terms is $21{\cdot}3A^2/E^2$ and this must exceed 100 if there is to be less than 1% deviation from true square law detection. This gives a maximum limit to E of $\cdot 46A$. On substitution of this value of E in the second d.c. term of the expansion this square law term becomes $\cdot 04A^{\frac{3}{2}}$ which shows that anode bend square law detection gives a very small ratio of signal current to standing current. To realize the discrimination necessary for the lowest measurable dielectric loss means that a relative stability of 2 parts in 10,000 for the anode currents of the balanced voltmeter valves is required. As is usual practice, the detector valve's mean current is balanced by an opposing current from a similar valve. This is a very stringent requirement for a valve even with stabilized heater and h.t. supplies.

A further complication arises from other factors. The type of triode which has to be used has a rather low input resistance at the higher frequencies and must therefore be partially isolated from the tuned circuit by a small coupling capacitor. Also, if too much signal is coupled in, the valve is liable to run into grid current which opposes the anode bend detection.

All things considered, it seemed best from the engineering point of view to replace the anode bend valve voltmeter with one of another type, and the obvious choice lay in a diode detector d.c. connected to an ordinary balanced triode d.c. valve voltmeter. By using a high load resistance the required high resistance input conditions are realized and at the same time considerably less anode current stability of the triodes may be tolerated due to the very large increase in detection efficiency. Comparative figures for detection efficiency for the two systems are related by the effective change in grid bias due to r.f. signals of equal amplitude. For the anode bend detectors a typical figure is 100 mV whereas the diode output after filter losses is 2 V; a 20 to 1 improvement. This advantage is not completely gained because of the inevitable vagaries of diode no-signal voltage which count against it, but the overall improvement is impressive. To balance out the residual changes in no-signal voltage from the detector diode, a similar diode is arranged in an opposing fashion to the grid of the other triode of the balanced pair.

Serious consideration was given to using a semiconductor instead of a thermionic diode, coupled to the tuned circuit by a very small capacitor to isolate its comparatively low shunt resistance, but the isolation needed at lower frequencies was too great to make it a practical proposition. With sufficient isolation to keep the input resistance high enough there was almost no signal left to be detected.

Thus the law of the voltmeter now used in the TF 704C is that of an ordinary peak detecting diode operating at levels of 2 V or thereabouts and is therefore approximately linear. Readers who are familiar with the Hartshorn and Ward apparatus or the article in the J.I.E.E. which introduced it, or the British Standard 2607: 1953 may be tempted to cry 'heresy'. But, if you read on, all will be made clear.

Measurements with Linear Voltmeter

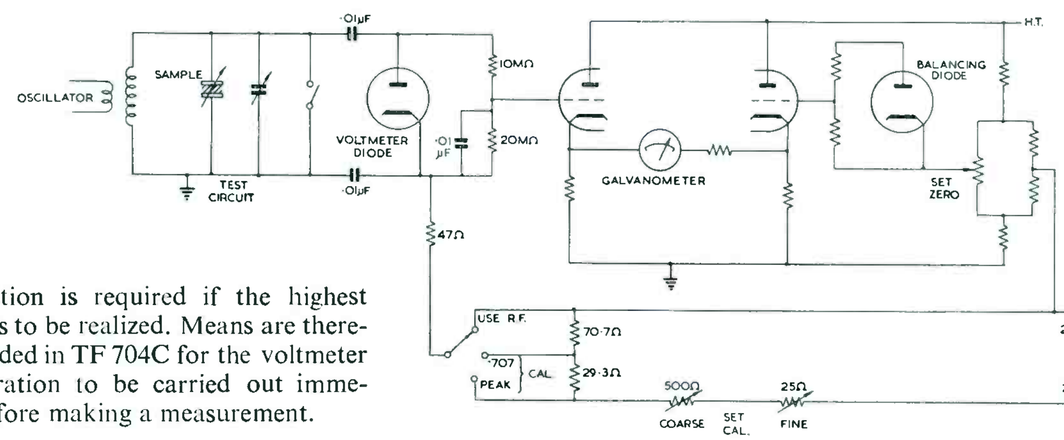
The formula for tan δ that is commonly used is given on page 599 of the J.I.E.E. of November 1936:

$$\tan \delta = \frac{(\Delta Ci - \Delta Co)}{2Cs\,(q-1)^{\frac{1}{2}}}$$

where ΔCi, ΔCo and Cs are capacitor readings defined in the appendix and q equals $\frac{Vr^2}{V^2}$ where Vr is the voltage developed across the tuned circuit at resonance and V is the lower voltage developed when the circuit is subsequently detuned with the smaller capacitor.

The primary voltmeter requirement is thus to give a voltage ratio Vr/V corresponding to the specified conditions. This ratio may *then* be squared so that appropriate substitution can be made in the formula for tan δ. If the valve voltmeter is true square law in that the deflection of the galvanometer is proportional to the square of the r.f. signal then the ratio of two deflection readings is equal to the ratio of Vr^2/V^2 and is thus equal to q. This is one stage of convenience when applying the formula but it is no more *necessary* than expecting the voltmeter deflection to be proportional to $(q-1)^{\frac{1}{2}}$ which would be even more convenient.

Since the actual law or calibration of a peak reading diode detector is only approximately linear, precise determination is required if the highest accuracy is to be realized. Means are therefore provided in TF 704C for the voltmeter law calibration to be carried out immediately before making a measurement.



Functional diagram of valve voltmeter circuit

Determination of Voltmeter Law

The law of a diode voltmeter is unaffected by frequency until transit time effects become significant. Experience gained with the same diode used in another type of voltmeter showed that these effects are unlikely to occur at the signal levels used in TF 704C at frequencies below 150–200 Mc/s. It is therefore practicable to establish the law at the mains frequency of 50 c/s. Referring back once more to the formula for tan δ it will be seen that if $q = 2$ then the expression $(q-1)^{\frac{1}{2}}$ is equal to 1. This corresponds to a voltage ratio of $\sqrt{2}$ to 1. A single calibration ratio of $\sqrt{2}$ to 1 is provided from the 50 c/s l.t. supply which may be varied in absolute amplitude so that any practical part of the scale may be used.

The method of applying the calibration signal is apparent from the diagram. During calibration the tuned circuit is short-circuited to avoid r.f. breakthrough. The resistor network is of 0·1 % accuracy and is proportioned to give exactly $\sqrt{2}$ to 1; the variable resistor controls the current through this network so that any portion of the voltmeter scale may be calibrated. By connecting the calibrating source to the cathode through an isolating r.f. stopper it is possible to avoid interference with the tuned circuit performance, as at the lowest r.f. frequencies for which the apparatus is intended the reactance of the coupling and decoupling capacitors is negligible.

B.S. 2067: 1953, on the determination of Power Factor and Permittivity of insulating materials, is a detailed description of the application of the Hartshorn and Ward Dielectric Test Set. In it, there are frequent references to checking the square law of the valve voltmeter. At the time of the preparation of that B.S. all Test Sets in use had a square law voltmeter and the injunction to frequently test the square law was justifiable. In general, however, it is the capability of the voltmeter to accurately indicate a known voltage ratio which requires to be frequently checked and this is more simply done by the method adopted in TF 704C.

A complication can arise during the detailed design and manufacture of the coils for the high Q test circuit, because it is possible for excessive stray oscillator coupling to result in an apparent deviation of the voltmeter from its predetermined law. These possible defects are eliminated during the normal inspection of Marconi Instruments products, but the following alternative method of checking for such deviations may be used.

The circuit is carefully tuned exactly to resonance and the setting of the small micrometer capacitor is noted. A specimen need not be present. The circuit is detuned either side of resonance to give identical deflections of the galvanometer. The plus or minus detuning alterations of the micrometer capacitor from its resonant setting should be identical. If they are equal within the readout limitations of the system, it may be taken that the resonance curve is symmetrical and that there is no significant spurious coupling.

Limitations of the Hartshorn and Ward Method

As outlined in their article, the recommended method has a limiting accuracy of about $\pm 2\%$ and $\pm\cdot00005$ for tan δ due to various uncertainties of mechanical construction, particularly that of the smaller vernier micrometer which cannot normally have a setting tolerance of better than ·004 pF.

But suppose that it is desired to measure *tan* δ of approximately ·00005 at radio frequencies.

The mechanical limitations may be overcome by the use of an alternative method which depends upon the measured change in the peak resonant reading of the voltmeter due to the decrease in the equivalent parallel resistance of the test circuit caused by the insertion of the dielectric sample.

Consider, for example, a test circuit with the following parameters: $Q = 400$, $f = 3$ Mc/s, $Cs = 50$ pF, *tan* δ *of sample* = ·00005 and *additional capacitance* $C = 10$ pF.

The equivalent parallel resistance of the tuned circuit excluding the dielectric loss is given by:

$$Ro = \frac{Q}{\omega(Cs+C)} = \frac{400}{2\pi\times3\times10^{6}\times60\times10^{-12}} = 370\ \text{k}\Omega.$$

The extra parallel resistance due to the dielectric is given by:

$$Rs = \frac{1}{\tan\delta\,.\,\omega\,Cs} = \frac{1}{\cdot00005\times2\pi\times3\times10^{6}\times50\times10^{-12}} = 20\ \text{M}\Omega.$$

The resonant voltage is proportional to the total effective parallel resistance of the tuned circuit and it is evident that in such an example the addition of the dielectric results in a decrease of resonant voltage of

$$\frac{370\times10^{3}\times100}{20\times10^{6}} = 1{\cdot}85\%.$$

So that if the voltmeter at resonance indicated full scale or 50 cm deflection, then with the dielectric added and retuned to resonance it should indicate 1·85% or nearly 1 cm less if the voltmeter is linear. This suggests that provided the required experimental stability is established then *tan* δ may be measured at r.f. to better than ·00005, or even approaching ·00001.

It is vitally necessary, of course, to prove that the arrangement has sufficient overall stability in order to justify the practicability of the scheme. This is done by a series of measurements to establish repeatability.

A detailed description of this modified procedure for *tan* δ of ·0001 or less is as follows:

(1) Insert sample and loading coil and tune oscillator for precise resonance, the galvanometer deflection to be at 1 cm or so below full scale deflection of 50 cm. Note exact value, D_1.

(2) Remove sample with as little disturbance as possible and retune jig capacitor precisely to resonance to give a new deflection, D_2. If over full scale deflection, the procedure will have to be recommenced using a lower value of D_1.

(3) Let $\frac{D_2}{D_2 - D_1} = A$, if using TF 704C, but for square law voltmeters it would be necessary to use the square root of the deflections in this formula.

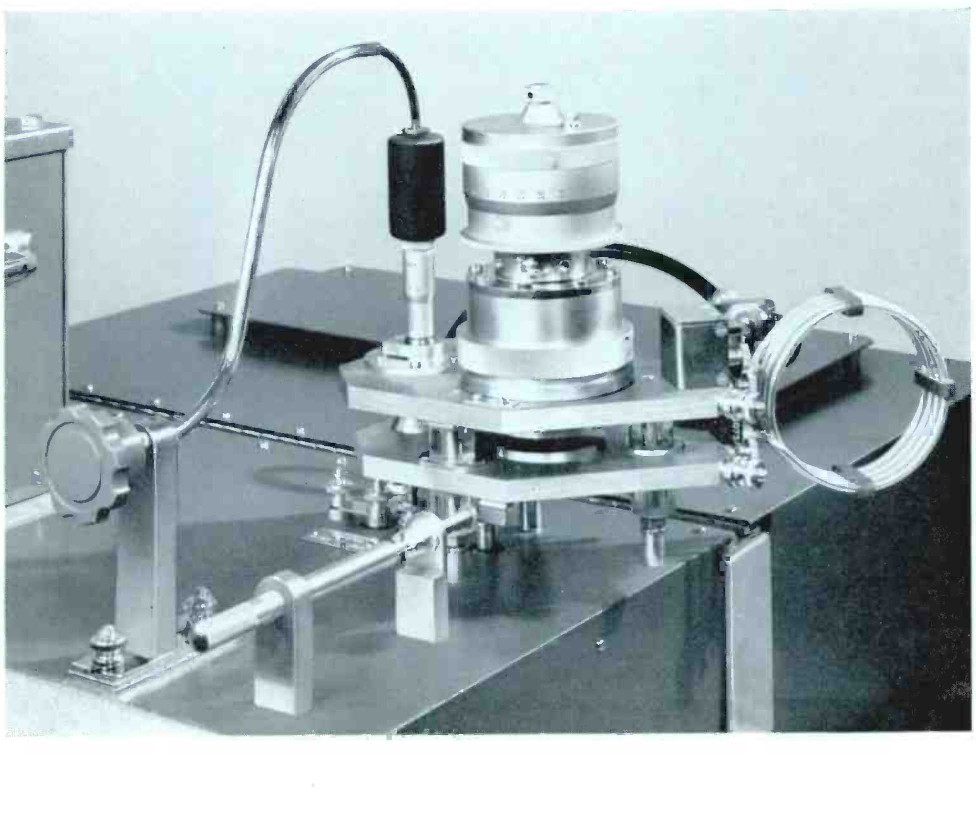
(4) Measure the parallel resistance Ro of the tuned circuit without the sample, by the usual ΔC method of detuning either side of resonance by $\pm\Delta Co/2$, using the vernier capacitor. Then:

$$Ro = \frac{2}{\omega\Delta Co}.$$

(5) Calculate tan δ from the formula:

$$\tan\delta = \frac{1}{\omega\,Cs\,.\,A\,.\,Ro} = \frac{\Delta Co}{2Cs}\,\frac{(D_2 - D_1)}{D_2}$$

On comparing this formula with the usual one, it will be apparent that the difference of two voltmeter readings is substituted for the difference of two capacitor readings.



Solid Dielectric Test Jig, Type TJ 223B. Can be supplied with either N.P.L. or Marconi Instruments calibrations

In our example, however, ΔCo is approximately 0·25 pF but the theoretical difference ($\Delta Ci - \Delta Co$) found by the usual method would be only ·005 pF which approaches the limit of uncertainty due to the mechanical limitations of the system.

An alternative solution might be to reduce the diameter of the stem of the vernier micrometer so that its capacitance range is limited to about 1 pF instead of 10 pF. This would give much improved discrimination but would only be of use for extremely low loss samples.

Measurement of Boiling Oil

It is sometimes necessary to measure the dielectric properties of substances under circumstances which might be injurious to the normal test jig. Extremely hot or corrosive liquids are examples.

To make such measurements a completely separate capacitor must be used which is connected in parallel with the main test circuit by low inductance and resistance leads to avoid error. Such a separate capacitor is perhaps most suitably shaped as a cylinder with a spaced and insulated piston. All the materials used must be capable of withstanding both the high temperatures and the possible corrosive effects of the liquids. A quartz insulator is suitable and rhodium plating may protect the metal.

The cylinder is connected to the earth point in the main instrument, and the insulated piston to the 'live' end of the test coil except that it will be necessary to disconnect this lead during the procedure in order to measure the circuit Q (or ΔCo) without the specimen.

The principles of the method are exactly that of normal dielectric measurements except that:

(1) Cs is found by disconnecting the lead from the piston or inner electrode and observing the *change* in capacitance of the large tuning capacitor necessary to re-establish resonance.

(2) The dielectric constant is found by the change in capacitance when the liquid is introduced into the space between the piston and cylinder. It may be advisable to pre-heat the liquid jig to the same temperature as the sample.

Two forms of such an auxiliary jig for use up to 80°C are available as TJ 228 and TJ 228/1, and further details are contained in another article by Messrs. Hartshorn and Rushton in the *Journal of Scientific Instruments*, **16,** 367 (December 1939).

Appendix

At resonance the parallel impedance of the tuned circuit may be represented by a pure resistance, R. The voltage developed across the tuned circuit is proportional to this resistance which is made up of the combined parallel resistances of the coil, voltmeter, capacitor and the sample dielectric when present. When the circuit is detuned by altering the setting of the vernier capacitor by $\pm\Delta C/2$ the impedance is lowered and the voltage falls.

If the detuning by $\Delta C/2$ lowers the voltage by 3 dB, it follows that the parallel resistance is equal to the change in reactance, that is:

$$R = \frac{2}{\omega \Delta C}.$$

In practice, two values for R must be measured: Ro without dielectric, Ri with it. The parallel resistance Rs of the sample can now be found from:

$$\frac{1}{Ri} - \frac{1}{Ro} = \frac{1}{Rs} = \frac{\omega(\Delta Ci - \Delta Co)}{2}$$

where $\Delta Ci/2$ is the detuning capacitance with the dielectric and

$\Delta Co/2$ is the detuning capacitance without the dielectric.

$$Tan\ \delta = \frac{1}{\omega Cs\,.\,Rs}$$

$$= \frac{(\Delta Ci - \Delta Co)}{2Cs}$$

where Cs = the capacitance formed by the sample in the larger micrometer capacitor.

Summaries of Articles appearing in this issue

RESUME D'ARTICLES PUBLIES DANS LE PRESENT NUMERO

GENERATEUR DE SIGNAL U.H.F. TF 1060/2

Cette modification du génerateur hyperfréquences bien connu TF 1060 a été conçue pour fournir une exécution au régime modulation par impulsions extérieure supérieure à celle obtenue avec le module normal. On peut y obtenir des temps de montée inférieurs à 0,1 µsec.

L'opération des deux appareils est indentique au régime onde entretenue ou modulation en amplitude intérieure. Page 123

GENERATEUR STANDARD TF 867A

Le générateur de précision à modulation en amplitude m.f./h.f. TF 867 a été remplacé par un nouveau modèle, le TF 867A. Cette nouvelle version comprend une alimentation à haute tension entièrement stabilisée et possède du blindage additionel pour améliorer les fuites à haute fréquence aux fréquences inférieures de porteur. Les points originels—niveau de sortie élevé, bonne discrimination et modulation en amplitude de haute qualité avec un taux de modulation jusqu'à 100%—ont été retenus. Page 127

UN pH-METRE UTILISE COMME DETECTEUR DE PONT DE MESURE

Un pH-mètre, consistant essentiellement d'un voltmètre à impédance très élevée est un excellent détecteur pour un pont de Wheatstone pour mesurer la résistance, et possède plusieurs avantages comparé avec le galvanomètre conventionnel et au système d'interrupteur au courant continu. On donne des exemples de l'utilisation de pH-mètres Marconi pour de telles mesures de pont sur des multiplicateurs courant continu, des résistances de gamme de voltmètres et sur des atténuateurs d'oscilloscopes. Page 128

NOUVEL ATTENUATEUR 600-Ohm POUR LA SERIE TF 1073A

L'atténuateur à plots 600 ohms TF 1073A/4 a été conçu pour être utilisé pour des mesures audio-fréquence, vidéo-fréquence, et moyenne-fréquence. La gamme de fréquences ou on peut l'employer est depuis zéro jusqu'à 5 MHz, et l'atténuation donné monte jusqu'à 100 dB par pas de 1 dB. Cet instrument est un accroissement à la série connue TF 1073A des atténuateurs R.F. On decrit le dessein et l'application de tous les instruments de cette série. Page 130

GENERATEURS DE SIGNAL V.H.F. TF 1064B/5, /6, /7 et /8

Un circuit d'oscillateur à cristal conçu pour une large gamme de fréquences de cristal pose plusieurs problèmes. Ceux-ci comprennent les variations des activités des cristaux et des tolérances, et le besoin d'imposer certaines limites sur la tension du cristal. Le circuit de l'oscillateur M.F. de la série TF 1064 de générateurs fut conçu en prenant compte de ces faits, et de récents raffinements sont employés pour ce circuit dans la dernière séries des modeles TF 1064B. Page 132

BANC D'ESSAI POUR EMETTEUR—RECEPTEUR TF 1065A

Cet appareil est un développement du TF 1065. Les différences principales sont l'addition de mesure de taux de modulation en amplitude, trois impédances d'entrée additionelles pour mesure de puissance B.F. et des amélierations au circuit de mesure de déviation de modulation de fréquence. L'exposé décrit le nouvel appareil en s'appuyant sur ces variations. Page 135

BANC D'ESSAI DE DIELECTRIQUES TF 704C

La série d'appareils TF 704 permet la détermination du pouvoir inducteur spécifique et du facteur de puissance des diélectriques à haute fréquence. Le TF 704C est une nouvelle version comprenant un voltmètre différent possédant une nouvelle méthode d'étalonnage qui élimine le besoin d'un étalonnage absolument quadratique. On donne aussi une note sur la mesure de facteurs de puissance extrêmement faibles, au delà de la gamme de la réalisation classique de Hartshorn et Ward. Page 138

ZUSAMMENFASSUNG DER IN DIESER NUMMER ERSCHEINENDEN BEITRÄGE

U.H.F.-LEISTUNGSMESS-SENDER TF 1060/2

Diese abgeänderte Ausführung des bekannten Leistungs-Mess-senders TF 1060 wurde entwickelt, damit bei Fremdmodulationsbetrieb eine bessere Leistungsfähigkeit ermöglicht wurde, als es bei der normalen Ausführung möglich war. Eine Anstiegzeit von 0,1 µsec ist jetzt erreichbar. Die Arbeitsweise der beiden Geräte ist bei Dauerstrichbetrieb und bei eigener Amplitudenmodulation die gleiche geblieben. Seite 123

LEISTUNGS-MESS-SENDER TF 867A

Der Typ TF 867 mit Präzisionsamplitudenmodulation für Mittelwellen und Kurzwellen wurde durch eine neue Ausführung TF 867A überholt. Diese enthält eine vollkommen stabilisierte Anodenspannungsversorgung und ist mit zusätzlicher Abschirmung versehen, um bei niedrigen Trägerfrequenzen die HF-Streustrahlung zu reduzieren. Die früheren Vorzüge—hohe Ausgangsleistung, gute Frequenzeinstellung und Amplitudenmodulation hoher Qualität bis zu 100%—wurden beibehalten. Seite 127

EIN pH-MESSGERÄT ALS BRÜCKENMESSINSTRUMENT

Ein pH-Messgerät, welches in seinen Grundzügen ein Spannungsmesser mit sehr hoher Eingangsimpedanz ist, eignet sich ausgezeichnet als Abgleichinstrument bei Wheatstone-Brücken für Widerstandsmessungen und hat Vorteile gegenüber dem bekannten Drehspulgalvanometer und der Anordnung mit Gleichspannungszerhackern. Es werden Beispiele für die Benutzung der Marconi pH-Messgeräte bei Brückenmessungen von Bereicherweiterungswiderständen für Messinstrumente, Bereichwiderständen für Spannungsmesser und Eichleitungen für Oszillographen angegeben. Seite 128

EIN NEUER 600 OHM DÄMPFUNGSREGLER FÜR DIE GERÄTESERIE TF 1073A

TF 1073A/4 ist die Typenbezeichnung eines neuen 600 Ohm Stufen-Eichteilers für Messungen bei Ton-, Video- und Mittelfrequenzen. Er hat einen Frequenzbereich von 0 bis 5 MHz und kann auf eine Dämpfung bis zu 100 dB in Stufen von 1 dB eingestellt werden. Dies ist eine Erweiterung der bereits gut eingeführten Typenserie TF 1073A von Hochfrequenzeichteilern. Die grundlegende Konstruktion und die Anwendung aller Einheiten dieser Serie werden beschrieben. Seite 130

UKW-MESS-SENDER TF 1064B/5, -/6, -/7 und -/8

Die Entwicklung eines kristallgesteuerten Oszillators für einen grossen Bereich kristallgesteuerter Frequenzen ist mit vielen Problemen verbunden, welche die Änderung des Verhaltens und der Toleranzen des Kristalls und das Verlangen nach begrenzten Kristall-Spannungsschwankungen einschliessen. Der ZF-Oszillator in der Mess-Sender-Serie TF 1064 wurde im Hinblick auf diese Punkte entwickelt. In der neuesten Geräteserie TF 1064B wurden die letzten Verbesserungen an dieser Schaltung angewendet. Seite 132

PRÜFGERÄT FÜR SENDER- UND EMPFÄNGER-AUSGANGSLEISTUNGEN TF 1065A

Dies ist eine Weiterentwicklung des Gerätes TF 1065. Die wichtigsten Änderungen betreffen den Zusatz zur Überwachung des Amplituden-Modulationsgrades, drei zusätzliche Eingangsimpedanzen für Tonfrequenz-Leistungsmessungen und Verbesserungen in der Schaltung zur Messung des Frequenzhubes. In dem Aufsatz wird das neue Gerät mit besonderer Betonung dieser Änderungen beschrieben. Seite 135

VERLUSTFAKTOR-MESSBRÜCKE TF 704C

Mit der Geräteserie TF 704 können die Dielektrizitätskonstanten und der Verlustfaktor von Dielektrika bei Hochfrequenz gemessen werden. Das Gerät TF 704C ist eine verbesserte Ausführung mit einem anderen Spannungsmesser, bei dem eine neuartige Methode zur Kennlinieneichung angewendet wird. Durch diese Methode wird die Bedingung für einen Spannungsmesser mit einer genauen quadratischen Kennlinie überflüssig.

In dem Aufsatz wird ebenfalls die Messung sehr kleiner Verlustfaktoren ausserhalb des üblichen Bereiches der normalen Methode von Hartshorn und Ward beschrieben. Seite 138

SOMMARIO DEGLI ARTICOLI PUBBLICATI IN QUESTO NUMERO

GENERATORE DI SEGNALI UHF TF 1060/2

Questa nuova variante del ben noto generatore di segnali UHF TF 1060 è stata progettata per fornire, in regime di modulazione esterna ad impulsi, un funzionamento migliore di quello ottenibile con il modello standard. Tempi di salita minori di 0,1 µsec possono essere ottenuti ora. Peraltro i due strumenti hanno un funzionamento identico, essendo ambedue previsti per uscita a onda continua o modulata internamente in ampiezza. Pagina 123

GENERATORE DI SEGNALI CAMPIONE TF 867A

Il generatore di precisione di segnali di media ed alta frequenza modulati in ampiezza, TF 867, è stato sostituito da un nuovo modello, il TF 867A. Questo nuovo strumento comprende un'alimentazione di alta tensione perfettamente stabilizzata, ed ha uno schermo addizionale per migliorare la schermatura di radio frequenza alle frequenze portanti più basse. Aspetti del modello originale, quali un'alta potenza di uscita, buona discriminazione e modulazione di ampiezza di alta qualità fino a un coefficiente di modulazione del 100%, sono conservati nel nuovo modello. Pagina 127

UN MISURATORE DEL pH COME RIVELATORE IN CIRCUITI A PONTE

Un misuratore del pH, che è essenzialmente un voltmetro con impedanza altissima, può funzionare come un eccellente rivelatore per un ponte di Wheatstone in misure di resistenza, e offre vantaggi in confronto con il solito sistema facente uso di un galvanometro a bobina mobile e interruzioni periodiche della correnta continua. Vengoni dati esempi dell'uso di misuratori del pH Marconi per misure, con schemi a ponte, su moltiplicatori c.c., resistenze addizionali di voltmetri, e attenuatori per oscilloscopi.

Pagina 128

UN NUOVO ATTENUATORE A 600 OHM PER LA SERIE TF 1073A

Il TF 1073A/4 è un nuovo attenuatore a gradini a 600 Ohm per impiego nelle misure a frequenza audio, video ed a radiofrequenza. La gamma di frequenza su cui può essere utilizzato si estende dalla continua fino a 5 MHz e si può ottenere una attenuazione fino a 100 dB in salti di 1 dB.

Questo strumento si aggiunge alla ben nota serie TF 1073A di attenuatori a radio frequenza; nell'articolo si descrivono il principio di progetto di tutti gli attenuatori di questa serie e le loro possibilità di impiego.

Pagina 130

GENERATORI DI SEGNALI VHF TF 1064B/5, -/6, -/7 e -/8

Un circuito oscillatore a cristallo progrettata per funzionare su di un'ampia gamma di frequenze del cristallo presenta molti problemi di progetto. Questi comprendono le variazoni di attività di mantenere la tensione del cristallo e la necessità di mantenere la tensione del cristallo entro limiti determinati. Il circuito oscillatore di media frequenza nella serie TF 1064 di generatori di segnali è stato progettato avendo presenti queste considerazioni, e perfezionamenti recenti a questo circuito sono stati adottati nella nuova serie di modelli TF 1064B.

Pagani 132

COMPLESSO PER MISURE D'USCITA SU TRASMETTITORE E RICEVITORI TF 1065A

E' una nuova variante del TF 1065. Le modifiche principali consistono nell'aggiunta di un monitore del percento di modulazione di ampiezza, di tre impedanze di ingresso addizionali per misure di potenza ad alta frequenza, e di perfezionamenti al circuito di misura della deviazone in modulazione di frequenza. L'articolo descrive il nuovo strumento ponendo l'accento su queste modifiche.

Pagina 135

COMPLESSO DI PROVA PER DIELETTRICI TF 704C

Gli strumenti della serie TF 704 misurano la permettività e il fattore di potenza di dielettrici a radio frequenza. Il TF 704C è una variante perfezionata comprendente un nuovo voltmetro con un originale metodo di taratura che ovvia alla necessità di una caratteristica del voltmetro esattamente quadratica. L'articolo comprende inoltre una nota sulla misura di fattori di potenza molto bassi, non compresi nell'intervallo di misura del metodo standard di Hartshorn e Ward.

Pagina 138

RESUMENES DE ARTICULOS QUE APARECEN EN ESTE NUMERO

GENERADOR DE SEÑALES EN F.U.A. TF 1060/2

Esta versión del bien conocido generador de señales en U.H.F. tipo TF 1060 ha sido desarrolado con el fin de tener un mejoramiento en el funcionamiento del generador en condiciones de modulación de impulsos externos, sobre lo que se había conseguido con el modelo normal. La subida del impulso que se puede obtener es de menos de 0,1 μseg. La operación de los dos instrumentos usando onda continua o la facilidad de modulación de amplitud interna es idéntica.

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GENERADOR DE SENALES TF 867A

El generador de señales de gran precisión con modulación de amplitud de frecuencias medias y altas tipo TF 867 ha sido reemplazado con el último modelo TF 867A.

Esta nueva versión incluye una alimentación de alta tensión completamente estabilizada y además tiene más protección contra el escape de ondas en las frecuencias menores de la portadora. Las características originales—buena salida, buen discernimiento y alta calidad de la modulación de amplitud hasta el 100%—han sido retenidas.

Página 127

UN MEDIDOR DE pH USADO COMO DETECTOR DE PUENTE

Un medidor de pH que fundamentalmente es un voltímetro de alta impedancia funciona excelentemente como detector para un puente de Wheatstone en medidas de resistencias y tiene varias ventajas sobre el galvanómetro de bobina móvil y sistemas de c.c. de interruptor rotatorio. Se dan ejemplos en el uso de medidores Marconi de pH para medidas de puente de multiplicadores de c.c., resistencias para las bandas de voltímetros y atenuadores de osciloscopios.

Página 128

UN NUEVO ATENUADOR DE 600 OHMIOS PARA LA SERIE TF 1073A

El nuevo atenuador de 600 ohmios TF 1073A/4 es para el uso de mediciones de audio, video y medias frecuencias. Tiene una gama de frecuencias desde c.c. hasta 5 Mc/s y provee hasta 100 dB de atenuación en pasos de 1 dB. Este instrumento es uno más en la bien conocida serie TF 1073A de atenuadores de r.f. Se describe el diseño básico de todos estos instrumentos al mismo tiempo que sus aplicaciones.

Página 130

GENERADOR DE SENALES EN F.M.A. TF 1064B/5, -/6, -/7, y -/8

El circuito de un oscilador de cristal de cuarzo nos presenta con muchos problemas de diseño. Estos problemas incluyen las variaciones en la actividad de los cristales y la necesidad de mantener los voltajes del cristal dentro de sus límites.

El circuito oscilador de f.i. en la serie TF 1064 de generadores de señales ha sido desarrallodo teniendo en cuenta estas consideraciones y se le han hecho varias mejoras a este circuito en la última serie de los modelos TF 1064B.

Página 132

EQUIPO DE PRUEBA DE SALIDA EN TRANSMISORES Y RECEPTORES TF 1065A

Este equipo es un desarrollo del TF 1065. Los cambios principales son: que se la ha añadido la facilidad de medir la intensidad de la modulación de amplitud, tres más impedancias para la medición de potencia en audiofrecuencia y mejoras de los circuitos para medir la desviación en modulación de frecuencia. El artículo describe el equipo nuevo dandole énfasis a estos cambios.

Página 135

EQUIPO DE PRUEBAS DIELECTRICOS TF 704C

Los instrumentos de la serie TF 704 miden la inductividad específica y el factor de potencia de dieléctricos en radiofrecuencias. El TF 704C es una versión nueva que tiene un voltímetro diferente con un método novel de calibración que quita la necesidad de tener una característica verdadera de ley cuadrada para el voltímetro.

Se incluye también una nota sobre la medición de factores de potencia muy pequeños fuera de los márgenes aceptados de los diseños normales de Hartshorn y Ward.

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SIGNAL GENERATORS

NOISE GENERATORS

OSCILLATORS

OSCILLOSCOPES

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Printed in England by
The Campfield Press
St. Albans