GED-968

How to Make Measurements in FM TRANSMITTERS

GENERAL ELECTRIC

MEASUREMENTS IN FM TRANSMITTERS

by

H. P. THOMAS

RADIO TRANSMITTER ENGINEERING DEPARTMENT

GENERAL ELECTRIC COMPANY

Schenectady, N. Y.

Reprinted from May and July, 1941 issues of Electronics

MEASUREMENTS in F-M TRANSMITTERS—I

Since the F.C.C. requirements for commercial broadcasting by frequency modulation are considerably more rigid than for amplitude modulation, more precise measurement techniques are in order. Mr. Thomas outlines the methods of measuring frequency deviation and audio quality in this first installment

H. P. THOMAS

General Electric Company, Schenectady

THE system of wide-band frequency modulation as it is being used for broadcast service is capable of providing highly faithful transmission of speech and music. This is due largely to the great noise reduction of the system and the lack of any high-frequency limitations imposed by adjacent channels such as prevails in the standard wave broadcast band. To maintain a high standard of fidelity in this new field of broadcast transmission, the F.C.C. has set up standards of good engineering practice requiring performance considerably superior to that in the standard broadcast band, and the commercial equipment manufacturers are guaranteeing performance which should exceed the required standards under most conditions. Examples of the requirements and typical performance figures are shown in the accompanying table.

Many people will contend that such high standards of quality are unnecessary, but under the proper conditions some observers can detect distortion as low as 2 or 3 per cent, and certainly noise levels of —60 decibels are detectable, even if not objectionable under normal conditions. It therefore seems probable that these requirements will not be reduced in severity, but may possibly be tightened further in the future.

As a result of the high performance standards required, it is necessary to make measurements with a considerable degree of refinement.

Frequency-Modulated Signal

$$(1)\quad e=\sin(\omega t+m\sin\mu t)$$

ω = angular velocity of carrier
μ = angular velocity of modulation
m = deviation ratio = $\frac{\Delta\omega}{\omega}$

By expansion

$$(2)\quad e=\sin\omega t\Big[J_0(m)+2\sum_{n=2,4,6\cdots}J_n(m)\cos n\mu t\Big]+\cos\omega t\Big[2\sum_{n=1,3,5\cdots}J_n(m)\sin n\mu t\Big]$$

$$(3)\quad e=J_0(m)\sin\omega t+J_1(m)[\sin(\omega+\mu)t-\sin(\omega-\mu)t]+J_2(m)[\sin(\omega+2\mu)t+\sin(\omega-2\mu)t]+J_3(m)[\sin(\omega+3\mu)t-\sin(\omega-3\mu)t]+\cdots$$

$$J_0(m)=0 \text{ for } m=2.4048,\ 5.5201,\ 8.6537,\ 11.7915$$

Fig. 1—The fundamental frequency modulation equation and its expansion to show the sidebands. The Bessel function of zero order (carrier voltage) may be made to vanish at certain deviation ratios, thus providing easily-found check points in measuring the deviation

Most of the measurements made on f-m systems are the same or similar to those used with amplitude modulation since both systems are designed to perform the same function, that is, to reproduce audible sounds. However, due to the difference in the method of transmission, we need a slightly different technique in some cases, and new definitions and references in others.

In amplitude modulation one of the basic reference levels is 100 per cent modulation, which represents the maximum modulation capability of a transmitter. With frequency modulation there is no such limitation. Of course the frequency deviation corresponds very closely to per cent modulation in the a-m case, but there is no definite upper limit. With any particular receiver the amount of frequency swing is limited by the linear range of the slope circuit which converts the frequency modulation into amplitude modulation for detection; but this limit is an entirely arbitrary one, and can be varied within almost any desired limits. The choice of a suitable upper limit to the frequency swing is based on the channel width which it is permissible to use without seriously limiting the number of channels and the noise level which can be tolerated, since the noise level decreases as the frequency deviation ratio is increased.

Fortunately, this matter has been crystalized since the F.C.C. began

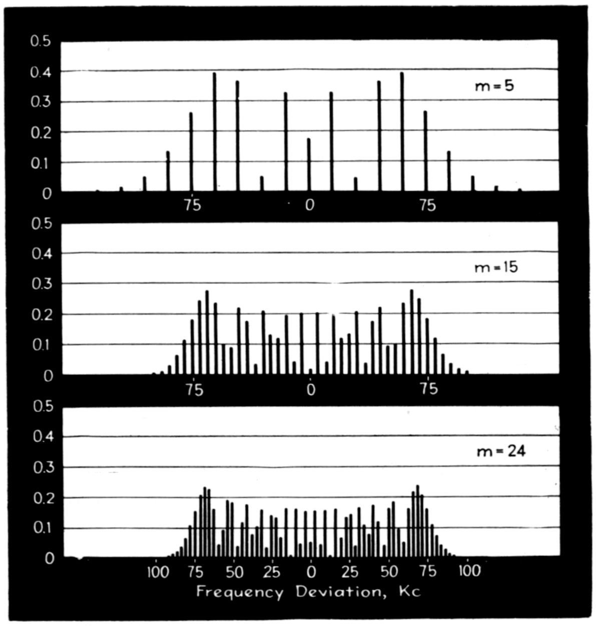

Fig. 2—Typical sideband magnitudes for different deviation ratios, computed for a maximum range of plus or minus 75 kilocycles

assigning licenses on the basis of 200 kilocycle channel separation and has therefore specified ±75 kilocycle as 100 per cent modulation in its standards of good engineering practice. This is sufficient frequency swing to obtain good noise reduction, while leaving some margin as a guard band to prevent adjacent channel interference.

The first measurement problem is, then, to measure the frequency deviation of an f-m signal. In order to see how this may be done, let us examine the equation for an f-m wave (Fig. 1). Equation 1 represents a carrier having an angular velocity $\omega = (2\pi f)$ being frequency or phase modulated $\pm \Delta\omega$ at an angular velocity μ. By mathematical expansion, we can convert this equation into the form shown in Eqs. 2 and 3, which represents the same wave in the form of a carrier and side bands. This transformation of the equations is similar to what we do with amplitude modulation when we consider a wave of varying amplitude as a carrier and side bands. However, in the f-m case there are an infinite number of side bands, all spaced from the carrier by multiples of the modulating frequency, the amplitude of each one being given by the Bessel functions $J_1(m)$, $J_2(m)$, and so on, m being the deviation ratio. We will also notice that the carrier amplitude is not constant, but depends on the value of the zero-order J_0 Bessel function.

Those not familiar with Bessel functions do not get a very clear idea of the magnitudes of the various components of the f-m wave. Some calculated examples to illustrate a few particular cases are shown in Fig. 2. The value of m has been changed by varying the modulating frequency and maintaining the frequency deviation constant. This corresponds to the case of an f-m transmitter operating with a swing of ±75 kilocycles and varying the frequency of the audio input. It will be noticed that as μ decreases m increases and more side band terms appear, becoming spaced closer together. In all cases there is very little energy far outside the limits of the frequency swing. Now suppose that we want to accurately measure a frequency deviation of ±75 kilocycles. By referring to Eq. 3 we see that the carrier amplitude is given by the function $J_0\ (m)$ and by examining the tables we find that this is zero for various particular values of m. Thus by using a modulating frequency of 13,586 cycles and a sharply tuned receiver (for instance one having a crystal filter) and watching the amplitude of the carrier as recorded on a signal strength or a-v-c meter while we increase the amplitude of the modulating voltage impressed on the transmitter, we will notice that the carrier strength will reach a minimum at a level corresponding to 32.66 kilocycles swing, where $m = 2.4048$, and a second minimum at a level corresponding to 75 kilocycles swing, where $m = 5.5201$.

This gives us quite an accurate measure of the deviation of a transmitter at the higher modulating frequencies, but is not applicable to the lower frequencies since the side bands will then be so close together that it will be impossible to separate them from the carrier with the receiver, and also it will be necessary to count up to very large numbers of carrier null points for normal frequency deviations since m becomes very large.

A method of measuring frequency swing at low modulating frequencies follows from an examination of the diagrams in Fig. 2, which indicates that as the deviation ratio is increased, we are approaching the limiting case of a nearly uniform distribution of energy out to the edge of the frequency swing and zero beyond this point. Thus by using the highly selective receiver again and tuning across the frequency band occupied by the transmitter while it is modulated with a tone of say 50 cycles per second, there will be a fairly steady signal received within the limits of the transmitter deviation and very little signal beyond the limits of this region.

We have found that slightly more

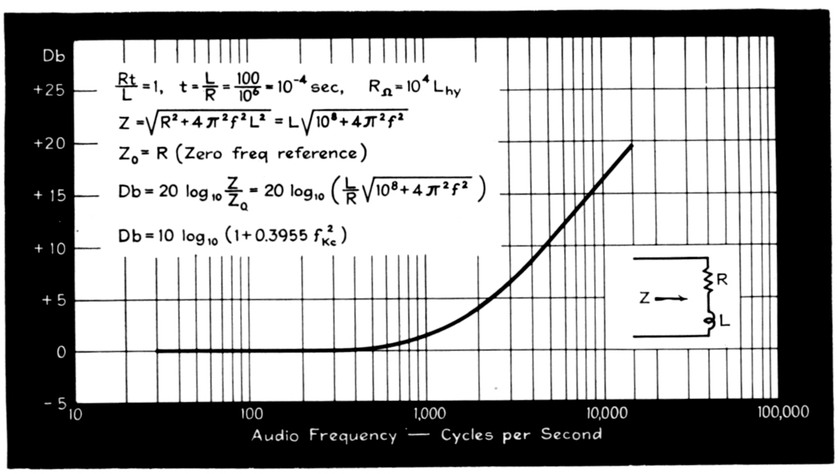

Fig. 3—The pre-emphasis curve specified as standard for commercial f-m transmissions (impedance characteristic of series inductance-resistance circuit, having a time constant of 100 microseconds)

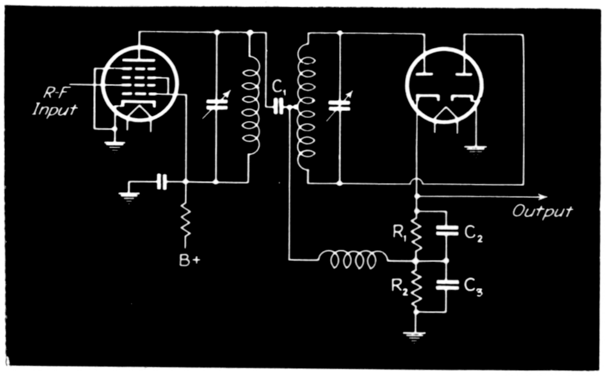

Fig. 4—Typical discriminator (frequency-modulation detector) circuit. This circuit is used in deviation monitors as well as in receivers

accurate results can be obtained by using a heterodyne oscillator in the receiver during this measurement and noting when the transmitter signal sweeps down to zero beat with the receiver oscillator at the end of the frequency deviation cycle. We have checked this method against the carrier null method by reading the output from a linear slope circuit and detector caused by a transmitter which has had the deviation adjusted by each of these methods and found an extremely close agreement.

These methods cannot be used for monitoring a program since they require the application of a steady tone modulation in order to take readings. However, both methods are suitable for calibrating some indicating device which can be used as a modulation indicator. All that is needed for this purpose is a linear slope circuit and detector, or in other words an f-m detector. However, in order to make the output amplitude correspond directly to frequency deviation, some provision must be made to maintain a constant input. This may be done by using a good limiter or by reading the input voltage with a meter and adjusting to the same level for all readings. This circuit will deliver an audio output voltage having a magnitude directly proportional to the frequency deviation of the signal.

The audio voltage can be utilized in a number of ways: it could be applied directly to a cathode-ray oscilloscope for instance. But it is probably more convenient to apply it to a peak reading vacuum tube voltmeter to read peak modulation swing in the same way as is customarily done in reading peak modulation in a-m broadcast transmitters.

The audio voltage may also be used for operation of an amplifier and loudspeaker for aural monitoring. However it must be remembered that de-emphasis must be used in this case in order to reproduce the sounds correctly as the transmitter is pre-emphasized according to the curve shown in Fig. 3. To make the monitor more convenient to adjust for operation on various carrier frequencies and to standardize the design of the slope circuit, it is advantageous to employ a converter and have the slope circuit and detector operate at the intermediate frequency. In other words, we use a simplified receiver.

Figure 4 shows the circuit of a discriminator and Fig. 5 shows the characteristics of a discriminator of this type. If this characteristic can be made sufficiently linear over the required frequency range, the circuit can be employed to measure all the audio characteristics.

The only fundamentally sound method known to the writer for measuring linearity is to measure the output voltage with a d-c instrument and vary the applied frequency by accurately known steps. The frequency steps can be determined with very good accuracy by synchronizing the applied frequency oscillator with harmonics of a 10-kilocycle crystal oscillator. This is a somewhat difficult measurement to make as all the conditions must be maintained very accurately during the time necessary to read a fairly large number of points. For example, the voltage from the oscillator delivering the input signal must not vary during the measurements, or if a limiter tube is used to maintain constant input, the voltages on the limiter must not change enough to affect its output. To obtain sufficient accuracy in measuring the output voltage will probably require the use of a potentiometer. For preliminary adjustments(, it is advisable to use a sweep oscillator and oscillograph in the method commonly used for receiver alignment. The accuracy of this method depends on the linearity of the sweep circuits and the linearity of the deflection of the oscillograph, so it cannot be depended upon too much for accurate results.

Carrier Noise Level

Suppose we wish to measure the carrier noise level of a transmitter. First of all we must set the modulation level of the transmitter at ±75 kilocycles, or 100 per cent modulation, by one of the methods described earlier in this article. This gives a certain audio voltage level out of the modulation monitor corresponding to 100 per cent modulation, that is, this sets the decibel reference level. All audio input to the transmitter is then removed and the noise level output read by means of a suitable tube voltmeter. The ratio of noise voltage to 100 per cent modulation signal level is the carrier noise level, assuming no noise is introduced by the measuring equipment. How closely this condition is met can be determined by taking a measure-

Fig. 5 — Discriminator characteristic of the circuit shown in Fig. 4. The slope must be very accurately linear over the range of 200 kc for accurate monitor work

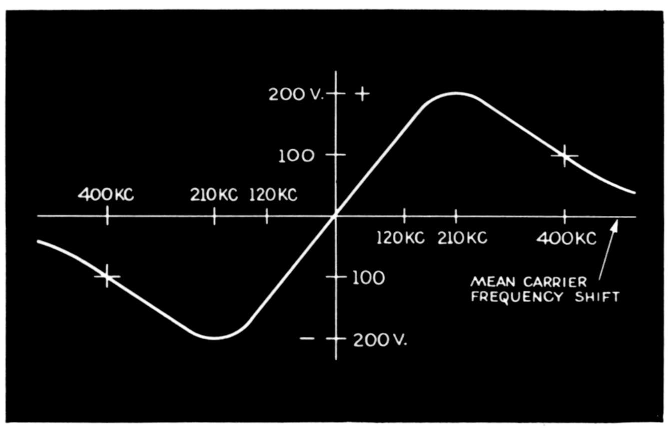

Fig. 6—Square-wave generator which has come into use in testing the waveform reproducing capabilities of an f-m system. Transient wavefront should be reproduced accurately when the full range of audibility is employed

ment of the noise, read when a signal is fed to the monitor from a good crystal oscillator, which will have practically zero frequency modulation. During this measurement, as in fact for almost all the audio measurements, de-emphasis should be used, since this is the condition under which the normal receiver operates. A convenient instrument for this type of measurement is a noise and distortion meter which consists of a vacuum-tube voltmeter calibrated in decibels and equipped with attenuators for reading large changes in level.

Distortion

For measuring harmonic distortion, we can measure the audio output of the modulation monitor by means of a noise and distortion meter, which balances out the fundamental and leaves the distortion terms to be read on a tube voltmeter, indicating total r-m-s voltage; or we can use a wave analyzer, which is a very selective filter for selecting any single frequency, and measure the fundamental and each of the harmonics separately. The wave analyzer gives a little more information by separating the various harmonics. This may be useful in analyzing the source of distortion, but is a little slower than the distortion meter and requires some calculation to determine the total distortion. Care should be taken to use a source of audio frequency having very low harmonic content if distortion readings as low as 2 per cent or less are to be made.

Audio Frequency Response

Frequency characteristics can be measured easily with a modulation monitor and some form of tube voltmeter, reading audio output from the monitor against audio input to the transmitter over the entire audio band. In all of these measurements, care should be taken to make certain no r-f voltage is introduced to the measuring equipment. It is often desirable to put an r-f choke at the input of the measuring equipment, but it is necessary to be sure that it is not so large as to affect the audio-frequency response. Shielded leads can be used if care is taken to make certain that they do not have so much capacity that they affect the audio characteristics. It should also be mentioned that to assure a good audio-frequency characteristic from the modulation monitor, the r-f bypass condensers should not be too large. Calculation of impedances will tell whether they

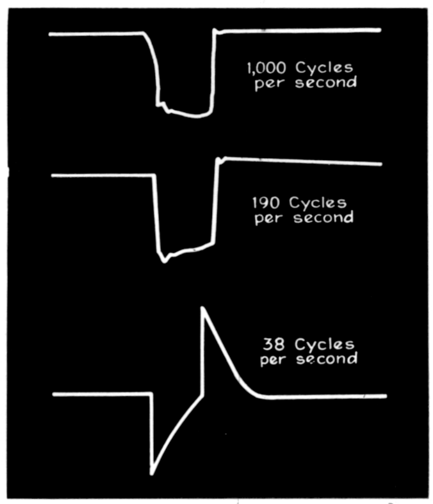

Fig. 7—Square waves traced from an oscilloscope connected to a developmental receiver. The pulse width in this case is 15 per cent of the total square wave period

have any appreciable shunting effect on the load resistors at the highest audio frequency. It should be noted that in a discriminator the capacity coupling the primary and secondary coils is also shunting half the audio load, hence should be made fairly small.

Cross Modulation

Most of the measuring equipment available will not permit harmonic measurements at frequencies above about 15 or 20 kilocycles. Harmonics at frequencies higher than this are not audible so it might seem that it

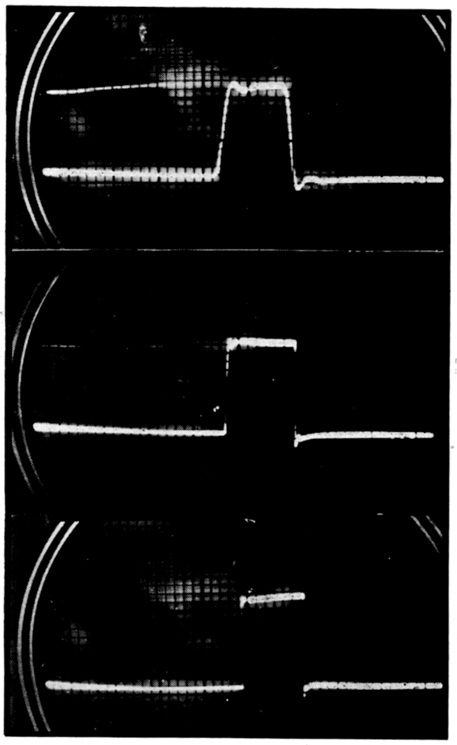

Fig. 8—Square waves reproduced after passage through an f-m transmitter and discriminator receiver. Frequencies from top to bottom are 1000, 190, and 38 cycles per second

F.C.C. Performance Requirements and Typical Commercial Transmitter Characteristics

Freq. characteristic	±2 db 50-15000	±1 db 30-16000
Distortion	2% rms ±75 kc	1.5% ±75, 2% ±100 kc
Noise level	Better than 60 db	70 db
Mean carrier stability	±2 kc	Under 2 kc, usually ½ to 1 kc

would be useless to make distortion measurements at modulating frequencies above about 7 kilocycles. However, a non-linear characteristic at the higher audio frequencies will cause cross modulation which will be audible. Special measuring equipment can be used to measure the super-audible harmonics, but the same result can be obtained by actually modulating with two tones simultaneously and measuring the cross modulation terms. This is a more direct and fundamental method since it actually measures what we hear. Also there is some difference in the results in the case where pre-emphasis is used, as is standard in f-m transmission. The difference is that harmonics of the higher audio frequencies are de-emphasized in the receiver whereas the difference term resulting from cross modulation is actually increased in amplitude in comparison with the fundamental tones, since it comes at a lower frequency. Cross modulation terms result from curvature of an amplitude characteristic in exactly the same way as harmonic distortion terms. For example, a second harmonic is the result of a square law term in the power series expression for the amplitude characteristic. If two modulating frequencies each half the size of the single frequency used previously are applied simultaneously, the same square law term will give sum and difference terms each half as large as the second harmonic term found previously. So if we add all the cross modulation terms as an r-m-s sum and express them in per cent of 100 per cent modulation, they should have an amplitude about 0.7 of the distortion terms obtained with a single modulating frequency. In making cross modulation measurements care should be taken not to have the two audio oscillators too tightly coupled to each other or cross modulation may take place in the output stages of the oscillators. This can be checked by a measurement taken directly at the input terminals of the transmitter. Of course, for these measurements it is necessary to use a wave analyzer.

One characteristic of a transmission system which usually is not considered is the phase characteristic or time delay error. In the past this has been considered unimportant. However, phase errors can seriously distort transient wave fronts, so it would seem that for true high fidelity reproduction it might be important to keep such errors small. A simple method for checking frequency characteristic and phase characteristic simultaneously is to apply a square wave to the input of the system and observe the shape of the wave which appears at the output by means of a cathode-ray oscillograph. A square wave is rich in harmonics, and if any of these components is changed in amplitude or phase, as compared with the others, the output wave will show distortion. Figure 6 shows a unit which will generate square waves having a repetition rate anywhere from 1.5 to 250,000 cycles per second, and two widths, one about 10 per cent and the other 50 per cent of a full cycle. These are adjustable over a small range. Figure 8 is a photograph of the cathode-ray screen when 16 per cent pulses having fundamental frequencies of 38, 190, 1000 cycles per second were passed through a f-m transmitter and a modulation monitor. It will be noted that at 1000 cycles per second we can observe a definite slope to the sides of the wave, indicating a limitation of the frequency band being passed, although this limitation is at a frequency in the order of 20 kilocycles or more. There is also a slight oscillation at the beginning and end of the pulse. That is due to the pre-emphasis circuit, which consist of series *L* and *R*, resonating with the shunt circuit and tube capacity. The resonance is fairly heavily damped, and is at a frequency of about 20 or 25 kilocycles, so is outside the audible region. Figure 7 is a tracing made from the cathode-ray oscillograph when the same pulses have passed though the f-m transmitter and also a developmental f-m receiver. These show a fairly large phase error at low frequencies as well as some other irregularities in the characteristic at higher frequencies. Figure 9 shows how the phase shift of an *R-C* network can be analyzed in terms of the square wave response.

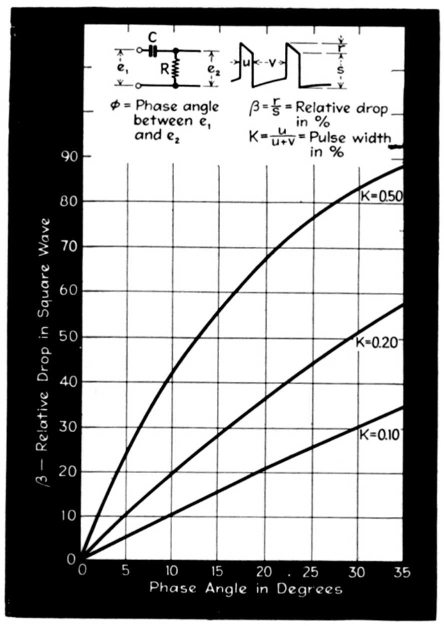

Fig. 9—The relationship between square wave dimensions and phase shift in an *R-C* combination, for various percentage pulse widths

Measurements in F-M Transmitters—II

In the second half of his paper on f-m measurements, Mr. Thomas discusses methods of determining the linearity and degree of modulation, determination of transmitter power, arrangements for measuring the mean carrier frequency, and concludes with practical considerations of the problem of making field strength surveys

By H. P. THOMAS

General Electric Company
Schenectady, N. Y.

IN order to reproduce sounds faithfully the output of the receiver should bear a direct relationship to the input to the transmitter. In other words there should be no compression or expansion of the volume range of the original sounds. Since no expansion system is normally employed in receivers, this means that the transmitter frequency swing should be directly proportional to the audio input. This is easily measured by reading the audio output from a modulation monitor as the audio input to the transmitter is varied in amplitude.

Measurement of the carrier frequency of an f-m transmitter can be done very simply when there is no modulation, using the usual methods employed with a-m transmitters. A satisfactory method is to beat the carrier frequency against that of a crystal oscillator and measure the audio beat frequency. However, with such methods, the frequency can be checked only very occasionally when a transmitter carries a broadcast program. There are two methods by which the carrier frequency can be measured at any time regardless of modulation. One consists of dividing the frequency a sufficient number of times to reduce the frequency deviation to such a small amount that there is a steady carrier which can be measured by the usual methods.

The other method is to impress the f-m signal on a linear-slope circuit such as that used for a modulation monitor. The average direct voltage developed by this circuit is proportional to the mean carrier frequency. When this system is used as a frequency monitor, a crystal oscillator can be provided to check the alignment of the circuit. A complete monitoring system for an f-m transmitter may consist of a discriminator circuit operated from a converter and crystal oscillator, with another crystal oscillator provided for checking the alignment of the circuit. A d-c instrument can be connected to the output of the discriminator and may be calibrated directly in terms of frequency deviation from the assigned carrier frequency. Audio output which can be used directly to operate any type of modulation indicator is also available, and through a de-emphasis circuit to operate an audio amplifier and loudspeaker. Good amplitude limiting should be provided in such an instrument in order to make the readings independent of any normal variation of applied signal level, and also to prevent any small amount of amplitude modulation of the signal from affecting the instrument.

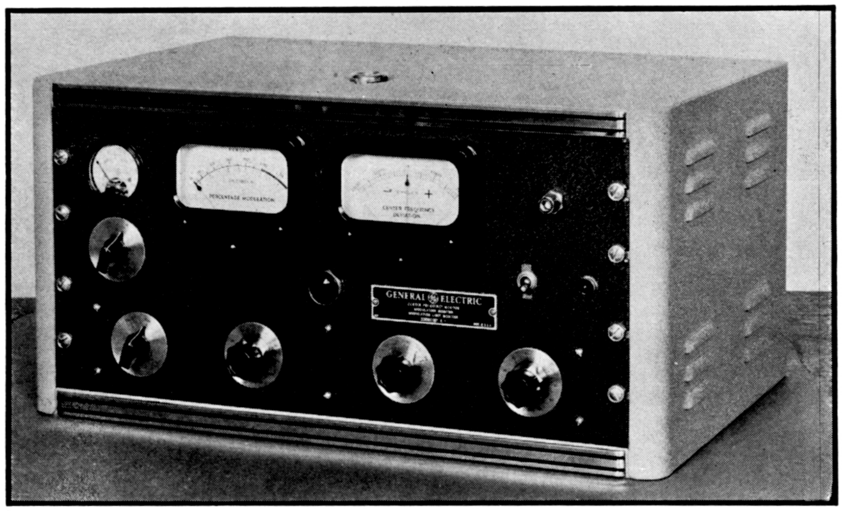

Fig. 1—Monitor for frequency-modulation radio station. This unit measures the center-frequency deviation with or without modulation as well as the percentage modulation. It contains a modulation limiter flasher, high fidelity audio frequency output, and temperature controlled piezoelectric crystal

An f-m transmitter should radiate a signal of constant amplitude at all times, but in practice it is difficult to prevent some unwanted amplitude modulation. A small amount of amplitude modulation will not injure the operation of the system if there is a sufficiently good limiter in the receiver. However, if a receiver is located in a fairly weak signal area, it probably will not give more than 15 to 20 db of limiting action, and to be on the safe side we should not

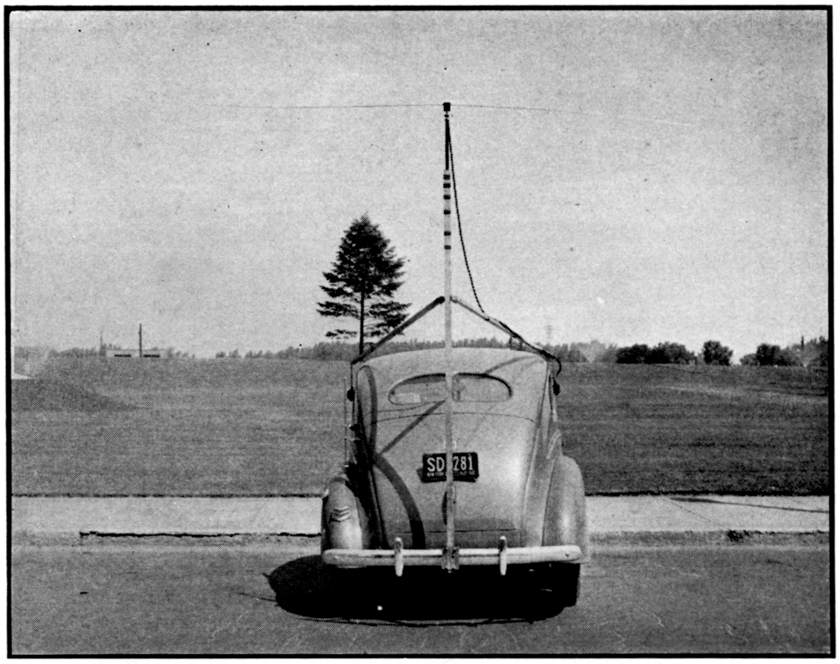

Fig. 2—Automobile equipped with horizontal dipole antenna for field-intensity surveys. This equipment was used in making actual surveys of frequency-modulation station W2XOY

count on more than about 10 db. Now let us consider what effect some amplitude modulation of the transmitter will have on a receiver with an imperfect limiter. First assume that the transmitter is amplitude modulated as well as frequency modulated by the audio signal. Any variations of amplitude which pass through the limiter of the receiver will effectively change the slope of the discriminator curve during the modulation cycle, or in other words will cause distortion. Next consider the effect of a little a-m noise such as might result from ripple voltage variations of the plate supply in the last stage of the transmitter. Even though the limiter in the receiver is not perfect, this noise can be eliminated by a balanced detector such as is commonly used in f-m receivers by tuning so that the signal is exactly at the balance point. However, since the average listener will not tune a receiver very carefully, and since this balance condition does not hold during modulation, noise is present during modulation, although it is balanced out so that the signal is quiet during times of low or zero modulation. Therefore, it seems advisable to set some limit to the amount of amplitude modulation permissible in an f-m transmitter. Measurement of amplitude modulation is done by the usual methods; a linear a-m detector is coupled to the output of the transmitter and a reading of the direct voltage developed across the load is used as a measure of the carrier strength. Any alternating voltage developed in the absence of modulation is classed as noise; any alternating voltage developed due to the modulation results from an amplitude modulated signal. The magnitude of these modulations should be expressed in terms of 100 percent amplitude modulation. In other words if the voltage developed by the carrier is E_o and the r-m-s modulation voltage is E, the modulation factor will be $\sqrt{2E/E_o}$.

Power Measurements

Since f-m transmitters operate at the quite high frequencies of 40 to 50 Mc (and perhaps as high as 300 or 350 Mc for relay transmitters) the accurate determination of the power output presents some problems. Probably the simplest method to use for low-power transmitters, i. e., up to about 1 kw is to use incandescent lamps as a dummy load and arrange a phototube to measure the brightness of the lamp. The lamp can be calibrated by lighting it with ordinary 60-cycle power from a variable voltage source, and measuring the power with a wattmeter. Any differences in impedance or resistance of the filament at the high frequency due to skin effect will not appreciably affect the results since the brightness of the lamp depends only on the actual power in the filament. However, if the filament is not all lit to the same brightness, there may be a considerable error, for the intensity of illumination is not a linear function of power.

An uneven brightness of the two ends of the filament or bright spots are sometimes observed, and have often been ascribed to standing waves on the filament. However, I do not think this is due to the length of the filament, since even at quite high frequencies the actual filament is a fairly small part of a wavelength. I believe that in most cases such effects are caused by large potentials from the lamp to ground which may cause heavy capacity currents to flow in portions of the filament, thus causing irregular heating. Usually, by proper tuning of the load circuit and choosing a lamp of suitable impedance, it is possible to reduce the potentials so that uniform heating is obtained. Of course, in order to be able to observe the filament and thus be sure it is uniformly heated, the lamp should have a clear glass bulb.

There may be some error caused by losses in the glass seal and the lead wires at high frequency which are not present when the lamp is calibrated at low frequency. In order to reduce this type of loss as much as possible it is advisable to remove the base of the lamp. The lead and seal losses are probably not very large, for any large amount of power dissipated at that point would prob-

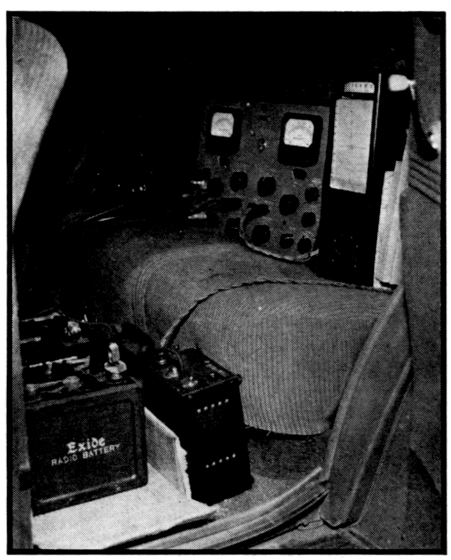

Fig. 3—View of the equipment used in field-intensity surveys of W2XOY. Note the automatic recorder

ably destroy the bulb, and of course losses of this type are in a direction such as to make the power measurements on the conservative side.

At power levels greater than 1 or 2 kw it will be found that lamps of sufficient size to handle the power have so much inductance in the leads that very high voltages are developed across the terminals at high frequency and arcs may occur between the leads or across portions of the filament, so some other method of measurement is required. If we can load the transmitter into an impedance of known value and measure the current, we can calculate the power. A correctly terminated transmission line presents an impedance which is pure resistance at high frequency and has a value equal to its surge impedance. Thus, we can terminate a transmission line with an antenna, measure the voltage along the line by means of a vacuum tube voltmeter and adjust the termination until all the standing waves on the line are eliminated. The line is then terminated in its surge impedance, and we can measure the current into the line and calculate the power from the relation $P=I^2Z_0$. The ammeter used for the current measurement should be accurate at the frequency being used. Many r-f ammeters are not accurate at the higher frequencies, particularly in the large current sizes which will be required for measurements of the higher power.

This method of measurement is not quite as simple as it sounds, since the accurate termination of a transmission line is a laborious procedure. Care should also be taken to be sure that the current measured is that actually entering the line and does not include any capacity current from the meter case to ground or other stray currents. Power can also be computed from the relation $P=E^2/Z_0$ by making voltage measurements with a diode or multi-element tube. This method eliminates troubles of stray capacity. In large transmitters employing water-cooled tubes it is possible to make a fairly accurate determination of the power output by a measurement of the power loss, in the tubes and subtracting that from the total power input including d-c power input in plate plus filament and grid power. The loss is measured by reading the temperature difference between the inlet and outlet water and measuring the rate of flow. The power in kilowatts absorbed by the water is then given by $P=0.263\ T\ q$ where T is the difference in temperature between inlet and outlet water in degrees C., q is the rate of flow of water in gallons per min. The plate tank circuit losses should also be subtracted from the input. If the tank is built so that the cooling water for the tubes also flows through the inductance, as is often done in high-frequency transmitters, this loss will also be included in the measured water loss. Otherwise some estimate of the loss must be made from a measurement of the Q of the circuit and the estimated voltage across it. For Class C operation with efficiencies in the order of 50 to 60 per cent the r-m-s value of the r-f plate voltage can be assumed to be about 50 per cent of the direct component of the plate voltage. Even if this assumption is not very accurate it will not affect the measured power output very seriously since the tank loss will normally be fairly small. The power supplied to the grid of the tube will be the grid driving power, which is given very closely by the product of the peak r-f grid voltage and the d-c component of grid current, minus the power in watts in the bias supply. The r-f grid voltage can be measured, but it is usually sufficiently accurate to estimate, by an examination of the tube characteristics, the peak positive grid swing required to drive the tube to the value of plate current being used. As in the case of the tank loss, this is a fairly small correction, and great accuracy is not necessary.

Another method of measuring power which is suitable for high power levels is to load the transmitter into some form of dissipative load which is water cooled. Then the power delivered to the load can be measured by noting the temperature rise in the water and the rate of flow as described in measuring plate loss in water-cooled tubes. The dissipative load may be a high-loss transmission line made with high resistance conductors or else a poor dielectric.

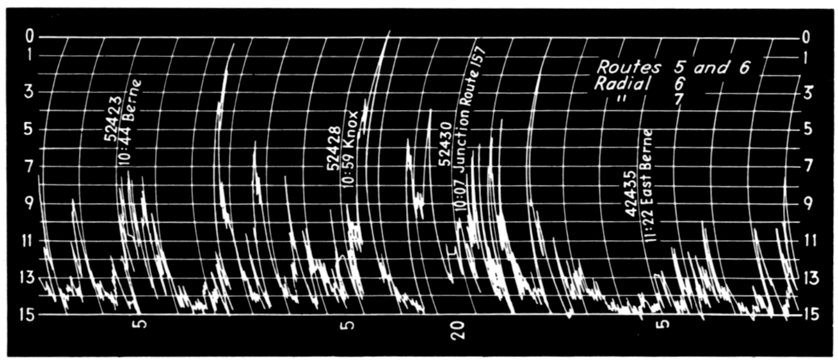

Fig. 4—Section of typical record of field intensity for radio station W2XOY, operated at 2.5 kw. The car routes and radials for which this record applies are shown in the map

F-M Receivers

One of the chief features of an f-m receiver is the limiter. In order to determine how well the limiter is operating, an a-m signal should be applied to the receiver and the amount of amplitude modulation obtained at the output of the limiter measured. A curve can then be plotted showing the amount of limiting as a function of signal input to the receiver. If the receiver selectivity is measured by the methods usually employed for a-m receivers, that is, by determining the amount of signal required at frequencies off resonance to produce standard output, a true picture of how the receiver operates will not be obtained. This is because a strong f-m signal will demodulate a weaker signal and thus reduce the interference ratio to obtain a signal-to-noise ratio of the receiver for a specified output. Another factor which is important in the operation of a receiver is the signal-to-noise ratio obtained at the output. If there is enough signal to suppress the shot noise of the tube, this noise will consist almost entirely of power supply ripple. Part of this ripple may be introduced directly in the audio amplifier, a more serious source of trouble is likely to be the hum introduced in plate or filament voltages by frequency modulation of the oscillator. To measure this hum it is necessary to measure the noise output when the receiver is tuned to a very stable signal source such as a battery operated oscillator or a good crystal oscillator. This measurement is the same as that described for a modulation monitor. Hum introduced by frequency modulation of the oscillator in a receiver is particularly difficult to overcome in very high-frequency receivers such as might be used for relay purposes. This can readily be appreciated when it is realized that to have a noise level of —70 db the oscillator must not vary more than 25 cps. If the oscillator is operating at 300 Mc this represents a precision of about 1 part in 100 million. Other characteristics of a frequency modulated receiver, such as frequency characteristic, distortion, etc. can be measured by the usual methods if an f-m signal generator having sufficiently good characteristics is available.

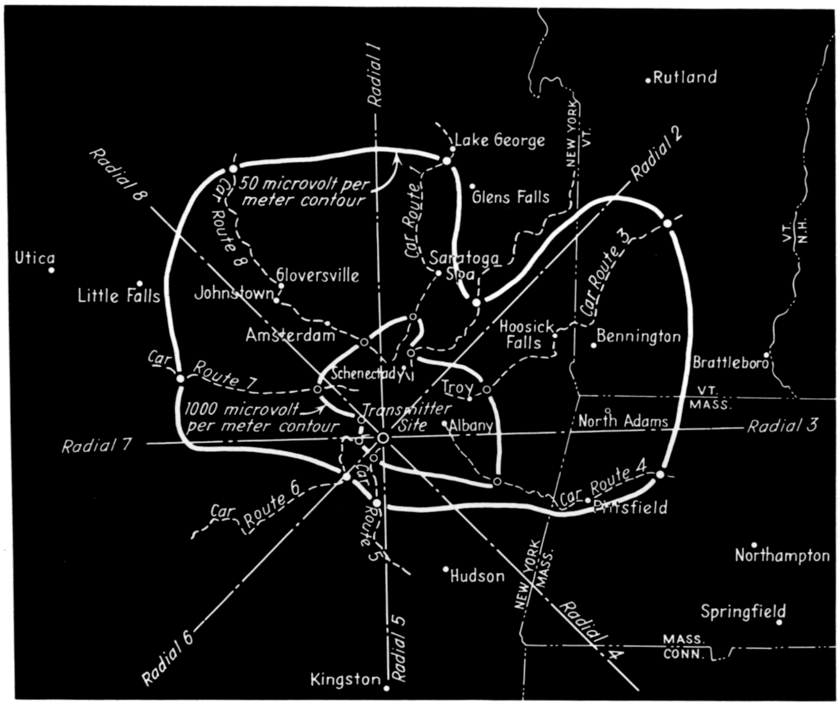

Fig. 5—Measured field intensity contours for radio station W2XOY, operated on 2.5 kw and using a single-bay turnstile antenna. The contours shown here are to be regarded as a preliminary survey rather than as a typical or final example of the operation of W2XOY

Field Intensity

The F.C.C. regulations require that, within one year after an f-m station has begun regular operation, a field survey shall be made to determine the actual boundaries of the service area. Continuous records of the field strength along at least eight radials from the transmitter shall be made. These radials must then be analyzed by dividing them into sectors of not more than 10 percent of the service radius nor more than 5 miles, and the median field determined in each sector. A field strength of 1000 microvolts for urban areas and 50 microvolts for rural areas is considered necessary for satisfactory service. The field survey may have to be extended to the 5 microvolt line in connection with interference problems.

The equipment required for these measurements consists of an antenna, receiver, and recording meter which can be calibrated in terms of field strength. A commercial type of equipment of this sort is available which is calibrated with its own dipole antenna, and has suitable attenuators to cover a wide range of signal strength. It has a power supply for operation from a 6-volt battery which has a voltage regulator so that the readings will be independent of the condition of the battery within fairly large limits. There is only one objection to this apparatus, and that is that the intermediate frequency of the receiver is so sharp that readings cannot be taken while the transmitter is fully modulated. It is possible to use any good f-m receiver for such measurements if a suitable meter can be connected in some way, such as by reading limiter grid current. In this case, the receiver will have to be calibrated. However, the antenna must be calibrated from a known field.

A standard field for this purpose is usually set up by using an oscillator feeding a small loop in which the current can be measured, and calculating the field at a distance. To remove the effect of the ground, the antenna to be measured and the loop can be suspended above ground at a height which is fairly large compared to the separation between them. The antenna is usually mounted above a car at a height of about 10 feet above ground. The effect of the car on the antenna calibration must be determined. This can be done easily by measuring the field from the transmitter with the antenna set up in a level, open space free of reflected signals and then taking another reading at the same spot with the antenna mounted on the car. Readings should be repeated with the car facing in several different directions. Usually the correction factor for the car will be found to be quite small. Readings taken with an antenna height of 10 feet will have to be multiplied by 3 as the field strength desired is based on a 30 foot antenna height.

A map showing the location of the 1000 and 50 microvolt contours of W2XOY operated at a power level of 2.5 kw is shown in Fig. 5. This is only a preliminary survey, and is used merely as an example of the results which will be obtained. It does not show a typical case for several reasons. First of all the transmitter is located on the edge of a high escarpment running roughly northwest to southeast, so there is a large effective height of approximately 1200 feet in the northeast direction, but very litle effective height in the opposite direction. The result can be seen on the map; there is a very much greater range in some directions than in others. In the case of this station, the large signal is in the direction of the desired service area, i.e., Albany, Schenectady, and Troy. Also, at the time these measurements were taken the antenna being used was a single bay turnstile which has a field gain of —3 db compared to a simple vertical dipole, whereas an antenna is now being installed having a gain of +4 db.

GENERAL ELECTRIC

SCHENECTADY, N. Y.

9-41 (5M)
Filing No. 6914

Printed in U.S.A.