ENGINEERING DEPARTMENT

General Radio Company

CAMBRIDGE, MASSACHUSETTS

Reprint No. A-52 1950

Reprinted from FM-TV May 1950

Checking Frequency and Deviation

BY

FRANK D. LEWIS

PRINTED IN U.S.A.

CHECKING FREQUENCY & DEVIATION

EXPLAINING HOW TO MAKE FAST, ACCURATE CHECKS OF CENTER-FREQUENCY AND MODULATION SWING ON MOBILE FM TRANSMITTERS—*By* FRANK D. LEWIS*

TO insure compliance with FCC regulations concerning mobile FM transmitters, measurement and adjustment of both center frequency and frequency swing under modulation must be made at frequent intervals. In particular, center frequency must be held within $\pm 0.005\%$ for transmitters operating above 50 mc. and within 0.01% for lower frequencies, and the modulation system must be so adjusted that frequency swing cannot exceed 15 kc.[1]

Methods of center-frequency measurement employ techniques similar to those used for AM, but the measurement of deviation calls for techniques not so commonly used in other branches of radio maintenance. Both types of measurement, however, can be made with the General Radio 1110-A interpolating frequency standard[2] and the 720-A heterodyne frequency meter.[3]

Center-Frequency Measurement:

It is generally agreed that frequency-measuring equipment should be at least twice as stable as the equipment being measured. Therefore, measuring equipment should contribute errors of ± 0.0025 or less. Accuracy of this order is provided in the 1110-A interpolating frequency standard in the frequency range concerned. Since operation of the interpolating frequency standard depends on the production of many harmonics of an accurately-known reference frequency, some means must be provided for identification of the actual transmitter carrier frequency, and for detection of the beat notes produced during the measuring process. The 720-A heterodyne frequency meter serves this purpose.

The heterodyne frequency meter consists of a calibrated oscillator operating in the range from 100 to 200 mc., a detector, and an amplifier for use with headphones in detecting beats. The oscillator is tuned to zero-beat with the carrier to be measured, and the main and vernier dial scales are read to determine the frequency. The zero-beat point is determined by listening with headphones, or by watching the beat-indicating meter on the panel. When servicing FM mobile equipment, it is sometimes necessary to use a harmonic of the transmitter under test to obtain a zero beat. If any doubt exists as to the approximate operating frequency of the transmitter, it should be removed at the start of the measuring procedure by the use of a wavemeter.

Precision measurement of the transmitter frequency is accomplished by tuning a harmonic of the interpolating frequency standard to zero-beat with the transmitter carrier and the heterodyne frequency meter, and listening as before with headphones plugged into the frequency meter. With reasonable care, the overall accuracy of this precision frequency check will be $\pm 0.0025\%$ or better. Accuracy can be increased still further by comparing the frequency of the interpolating frequency standard with standard-frequency transmissions from WWV.

Measurement in the 152- to 162-mc. band is simple, since the dial of the heterodyne frequency meter covers this range directly. Frequencies of transmitters operating in frequency bands below the directly-calibrated range can be measured by using harmonics of the transmitter. Even though the harmonic output of the transmitter may be relatively low, measurement is still possible since the crystal rectifier used in the mixer of the frequency meter will generate the required harmonics. Mobile equipment in the 30- to 50-mc. and 72- to 76-mc. bands can, therefore, be checked without additional equipment.

Deviation Measurements:

Measurements of modulation deviation can be made using the heterodyne frequency meter, an audio oscillator with a calibrated frequency scale, and a volume indicator or audio voltmeter to check the level of the modulating voltage at the microphone input. This measurement depends on certain fundamental phenomena involved in frequency-modulated waves. Since these phenomena may not be familiar to all, they will be reviewed here briefly.

A frequency-modulated signal, in the absence of any applied modulation, consists of a carrier wave with no side bands provided no amplitude modulation is present. Under such conditions, the modulation index of the wave is zero. The modulation index is defined as the ratio of the frequency deviation of the carrier to the audio modulating frequency. Expressed mathematically,

$$M = \frac{\Delta f}{f m}, \text{ where}$$

M = modulation index
Δf = modulation swing in cycles
fm = audio modulation frequency in cycles.

When a pure sine wave is used as the audio modulation, the amplitude of the

*Engineer, General Radio Company, 275 Massachusetts Ave., Cambridge 34, Mass.

[1]Effective July 1, 1950.

[2]J. K. Clapp, "The Interpolating Frequency Standard," *General Radio Experimenter*, Volume XXIII, No. 7, December 1948.

[3]Eduard Karplus, "A Heterodyne Frequency Meter for 10 to 3,000 Megacycles," *General Radio Experimenter*, Volume XX, Nos. 2 & 3, July and August, 1945.

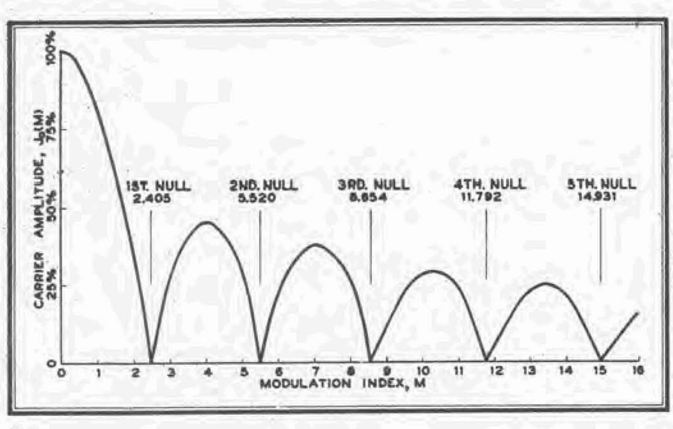


Fig. 1. Center-carrier amplitude varies as modulation index increases.

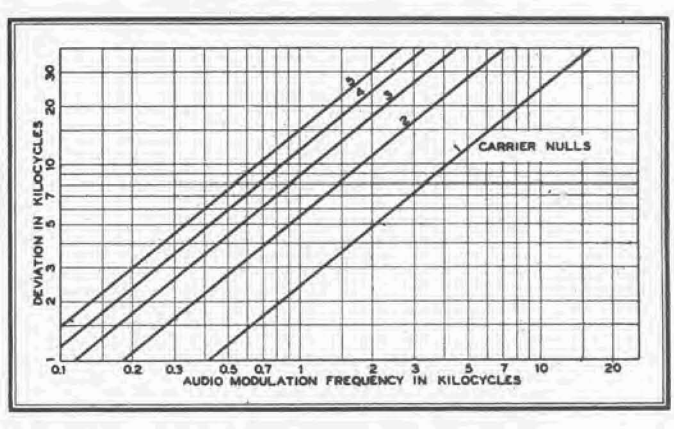


Fig. 2. Null points increase with modulation frequency

NOTE: The terms "frequency deviation" and "frequency swing" are used interchangeably in this article.

center-frequency carrier will vary, depending on both the amplitude and frequency of the audio modulating voltage. The mathematical expression for this variation is:

$$E = J_0(M), \text{ where}$$

E = amplitude of center-carrier
M = modulation index
$J_0(M)$ = Bessel function of the first kind, zeroth order, of the modulation index as argument.

In Fig. 1, the magnitude[4] of the Bessel function is plotted. It will be seen that the magnitude of this function, which represents the center-frequency carrier amplitude, goes to zero when the modulation index, M, is 2.405, 5.520, 8.654, 11.792, 14.931, and certain higher values. For measurement purposes it is permissible to consider the given values and to neglect the higher null points.

Interpreted in terms of physical phenomena, the equation and graph show that as the sine-wave audio modulating voltage of fixed frequency is increased, the center-frequency carrier amplitude will change in accordance with the variation of the Bessel function, going periodically through null points. This change in the carrier amplitude is sometimes difficult to measure, since it can be obscured by sidebands produced in the modulation process. However, if interest is confined solely to detection of the points where the carrier component disappears, the problem is easily handled. The null points can be detected by listening for the disappearance of the beat note which is produced by beating an external oscillator against the carrier. A chart of carrier nulls as a function of modulation frequency and swing is given in Fig. 2.

The steps for measuring the modulation swing of an FM transmitter have been outlined. In order to clarify the application of this procedure, consider a typical example of deviation measurement.

The instruments used and their connections are indicated in Fig. 3. The audio oscillator feeds into the microphone input terminals. Any DC supply which may be present for a carbon microphone must be disconnected. An alternative arrangement, indicated on the diagram, makes use of a blocking condenser to isolate the DC from the output control of the audio oscillator or the attenuator. It is possible also to make a connection to the grid of the input audio amplifier, or to the input potentiometer if one is used. This will make practical the use of a smaller blocking condenser or, perhaps, eliminate the need for one at all.

The voltmeter shown at the output of the audio oscillator is unnecessary for the adjustment of the transmitter to a given modulation swing, but it is essential if results are desired in terms of audio input voltage for a given swing. This is required for limiter or compressor circuit calibration, and adjustment of de-emphasis and pre-emphasis circuits.

For convenience in recognizing the carrier null points, it is desirable to select a beat note which will not be confused by the appearance of modulation sidebands. This is made easier if a relatively high modulating frequency is chosen, since the sideband nearest the carrier will be spaced from the carrier by the modulating frequency. A modulating frequency of 2500 cycles will produce the first null at a swing of approximately 6.0 kc., and the second null at a swing of approximately 13.75 kc. This can be seen in Fig. 2. Assume that the transmitter operates in the 152- to 162-mc. band. The heterodyne frequency meter can be tuned to an audible beat with the carrier frequency by referring to the dial calibration of the frequency meter, and the assigned frequency of the transmitter.

The beat note is set to a frequency of approximately 600 cycles. The input audio voltage is increased slowly. When the transmitter swing reaches 6.0 kc., a null will be heard in the beat note. As the modulating voltage is increased further, a second null will be noticed, occurring when the swing reaches 13.75 kc. A convenient way to check these null points is by rocking the audio voltage control slightly to each side of the null point, and noting the disappearance of the beat note in the center of this range. There will be a family of beat notes in the background, which may at first mask the true null. But with experience, the proper beat note can be recognized easily in the presence of the additional beats. Caution is advisable, since it is relatively easy to mistake a null in one of the sideband beats for the desired carrier null. A quick check can be made by removing the audio modulating voltage and noting if the desired beat note is still present.

By choosing several modulation frequencies and measuring the swing for a given input voltage, or the input voltage for a given swing, a calibration curve of modulation deviation vs. input voltage for different audio input frequencies can be plotted, such as those shown in Fig. 5. It is possible also to check the

[4]The sign is neglected, only magnitude being plotted.

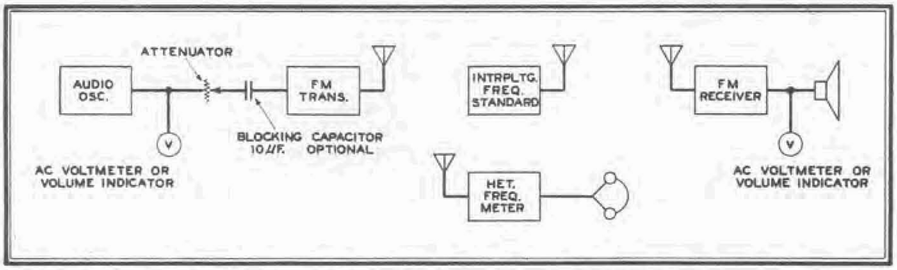
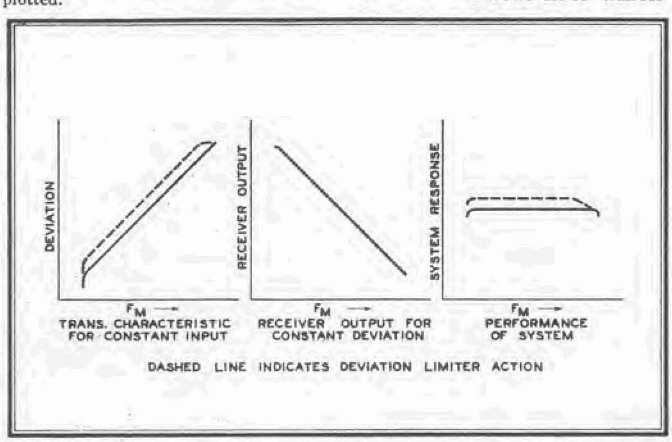


Fig. 3. Instruments used to check center-frequency and deviation due to modulation



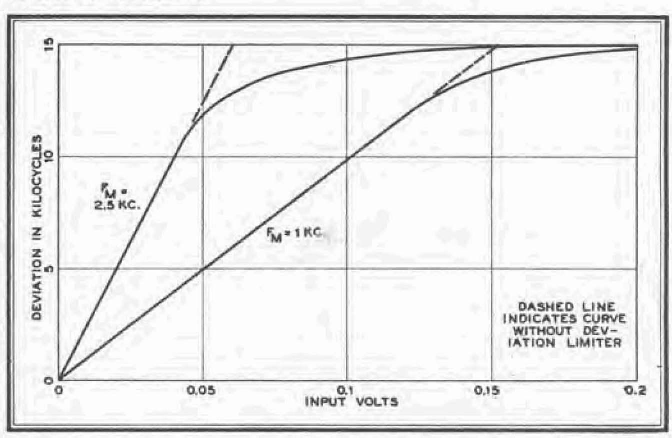


Fig. 4. Performance curves for a mobile system using phase-modulation. Fig. 5. Deviation curves for a typical transmitter

operation of limiters or compressors by this overall measurement, since modulation swing can be observed to see if it flattens off as the audio input voltage is increased.

Since single-frequency sine-wave modulation only can be used to carry out the calibration procedure described above, it is desirable to have some way of converting the results to apply to voice modulation. If the audio voltmeter used is sensitive enough, it can be connected to show the modulating voltage, and the readings noted while talking into the microphone. When this method is used, the previous sine-wave calibration should be carried out with the voltmeter so connected. An alternative arrangement is shown in Fig. 3. A receiver is tuned to the transmitter frequency. The receiver output is fed to a volume indicator, and the readings compared between the calibrated sine-wave audio modulation and the subsequent voice modulation.

The use of the swing-measurement procedure to calibrate the receiver provides a rapid means for checking the operation of modulation limiters or compressors, and for observation of the pre-emphasis and de-emphasis characteristics of the system. Stated another way, the use of the Bessel function method of swing calibration provides points which can be used to calibrate a receiver, employing an output meter as a modulation-measuring device. If the receiver is to be used as a swing or modulation monitor, the de-emphasis circuit should be cut out, or the audio voltmeter connected ahead of the de-emphasis network. The receiver is then suitable for use as a continuous modulation-swing indicator, this indication being subject to an occasional check by the calibration method described. It is then a relatively simple matter to adjust pre-emphasis and de-emphasis for flat overall response, and to check the operation of the modulation limiter.

In order to clarify further the application of this calibration procedure, a hypothetical set of calibration curves are shown, Fig. 5. Many mobile FM systems employ phase-modulated transmitters, which give about 6 db per octave of pre-emphasis unless modified, and complementary de-emphasis in the receiver to provide a flat system response. The characteristics of such a system are shown in Fig. 4. It should be noted that the operation of a modulation limiter restricts the transmission of the high-frequency audio signals before it affects the lower tones. Thus, the dashed curve shows the highs dropping off for a constant input level.

The method of measurement outlined here is suitable for transmitters operating on frequencies higher or lower than the calibrated range of the heterodyne frequency meter, providing certain precautions are observed. If the transmitter operates on a lower frequency, such as in the 30- to 50-mc. band, it will be necessary to beat a harmonic of the transmitter with the frequency-meter oscillator. The apparent modulation index of the transmitter will be increased in this way. If the fourth harmonic of a 30-mc. signal is used, the apparent modulation index will be four times that of the fundamental frequency of the transmitter. Therefore, the value measured at the harmonic frequency must be divided by four to obtain the actual modulation index of the transmitter. In other words, the frequency swing of the fourth harmonic is four times the swing of the fundamental, and the results must be interpreted accordingly.

Fig. 7. The Type 720-A Heterodyne Frequency Meter.

Under opposite conditions, when a transmitter operates above the frequency-meter range, and a harmonic of the frequency meter beats with the transmitter fundamental, the modulation index observed is that of the actual fundamental frequency of the transmitter. This presents no problem.

The procedures outlined are not new[5]. They have been used for some time in the VHF range, with good results.

Measurements made using this method are accurate enough for routine calibration of modulation swing. Under some unusual circumstances, however, the method is subject to considerable error. In particular, the modulation index observed by the carrier-null method is in error by approximately 2.7 times the third-harmonic distortion contributed by the modulator[6]. The distortion involved is that contributed by the modulator only. The null points are independent of distortion in the audio modulation. Since distortion in a phase modulator is minor for small phase displacements, it is probable that the error in the audio frequency range, over which it is feasible to use the measurement method, will be negligible.

From the outline given, it is apparent that center-frequency and deviation measurements can be made with required accuracy using simple methods and readily available equipment.

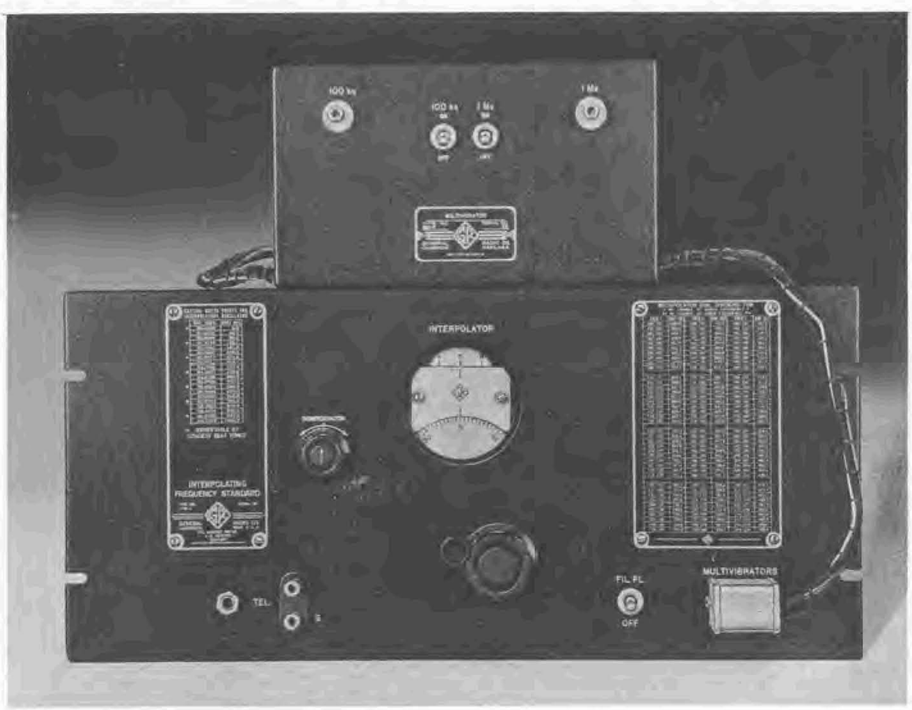


Fig. 6. The Type 1110-A Interpolating Frequency Standard with the Type 1110-P1 Multivibrator.

[5]Murray G. Crosby, "A Method of Measuring Frequency Deviation," *RCA Review*, p. 473, April 1940.

[6]F. L. H. M. Stumpers and W. W. Boelens, "The Determination of Distortion in a Frequency Modulator," *Communication News (Philips)*, August, 1948, p. 107.