Audio Frequency-Response Measurements In Broadcasting

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Describing the proper technique of testing broadcast audio apparatus.

AMONG the important characteristics by which performance of broadcast equipment is judged is the frequency response of the equipment. This characteristic is important to the broadcast engineer and to the designer of broadcast equipment for two reasons—first, prudent operation demands the best possible fidelity, consistent with other considerations, and second, the Federal Communications Commission has established, in its Standards of Good Engineering Practice, minimum frequency-response requirements[1,2,3] with which the equipment must comply. While there exists some controversy as to the desirability of a "wide-range" system, we choose to take no part in these discussions. Rather, some considerations bearing directly upon the engineer's job of determining the frequency-response characteristics of the electronic portions of his equipment will be presented.

Frequency Response

A question might arise as to the necessity for accuracy in such measurements. While the FCC standards allow for a reasonable variation in response with frequency over the required ranges, there are nevertheless the response characteristics of many individual pieces of equipment included in the over-all composite curve of a station, from microphone to transmitter output. To comply with present requirements, measurements must be carefully made in determining the performance of each unit. These tests become somewhat critical at the high-frequency extreme (i. e., 15 kc) of the required range of audio response for FM stations and for the sound channels of television stations.

It is well that there should be agreement upon what is meant by the term "frequency-response characteristic." This is the "response" (gain, amplification or transmission) of a system or unit, versus frequency. We may indicate a loss or attenuation as a negative gain, with obvious correctness. There are a number of ways in which gain can be defined.[4] In this article, we shall take the "response" as the *transmission insertion gain*[5,6] (or amplification, etc.) which is defined as

$$\text{gain (db)} = 10 \log_{10} \frac{P_0}{P_0'}$$

Here, P_0 is the output power of the equipment under test, when driven by the specified generator and when connected to its specified load (generally a resistive load, in broadcast audio facilities). Likewise, P_0' is the power assumed to be delivered to the same load by the same generator when it is connected to the load through a hypothetical ideal transformer of the most favorable ratio.

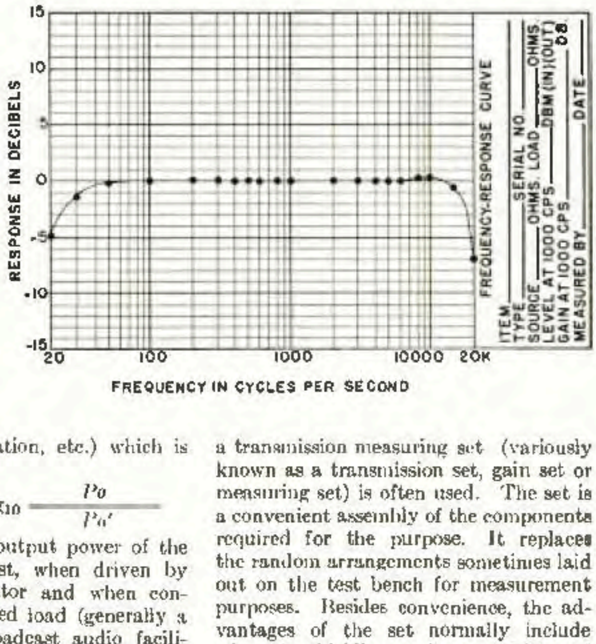

Fig. 1. Sample frequency-response curve, showing method of plotting curve.

The characteristic is generally obtained by point measurements, although curve-tracing devices have been developed for such purposes. In U. S. broadcasting practice, the response curve shows the response in decibels as ordinates, versus frequency in cycles as abscissae. The response obtained at 1000 cycles is often used as a reference point. Linear decibel and logarithmic frequency scales are used. See *Fig. 1*.

Transmission Measuring Sets.

In obtaining the frequency-response characteristic of a piece of equipment, a transmission measuring set (variously known as a transmission set, gain set or measuring set) is often used. The set is a convenient assembly of the components required for the purpose. It replaces the random arrangements sometimes laid out on the test bench for measurement purposes. Besides convenience, the advantages of the set normally include adequate shielding and repeatability of results. Many engineers have made use of the circuits about to be described without applying the name "transmission measuring set" to their equipment.

The set is divided into two sections, the transmission (or input or sending) section, and the load (or output or receiving) section. These sections may be assembled as one unit, or, for program-line measurements, constructed separately. The purposes of the transmission

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[1] Federal Communications Commission, "Standards of Good Engineering Practice Concerning Standard Broadcast Stations," Effective August 1, 1939, Revised to June 1, 1944, U. S. Government Printing Office, Washington 25, D. C., 65¢; pages 52 and 61.

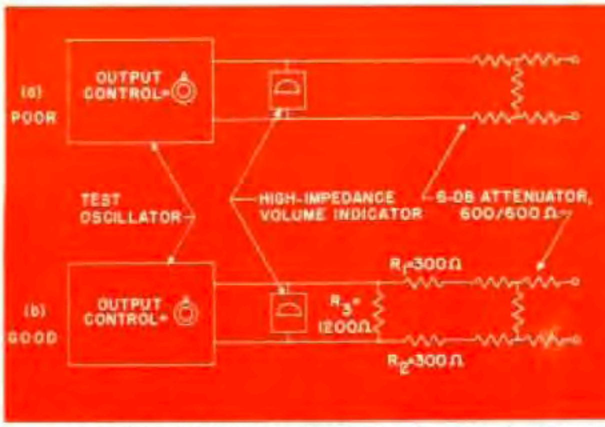
[2] Federal Communications Commission, "Standards of Good Engineering Practice Concerning FM Broadcast Stations," effective September 20, 1945, Revised to January 20, 1946, U. S. Government Printing Office, Washington 25, D. C., 10¢; pages 14 and 21-22.

[3] Federal Communications Commission, "Standards of Good Engineering Practice Concerning Television Broadcast Stations," December 19, 1945, U. S. Government Printing Office, Washington 25, D. C., 10¢; page 14.

[4] S. J. Haefner, "Amplifier-Gain Formulas and Measurements," *Proc. I. R. E.*, Vol. 34, No. 7, pages 500-505; July, 1946.

[5] Research Council of Academy of Motion Picture Arts and Sciences, "Motion Picture Sound Engineering," D. Van Nostrand Co., New York, N. Y., 1938, pages 226-227.

[6] See Reference 4, page 505.



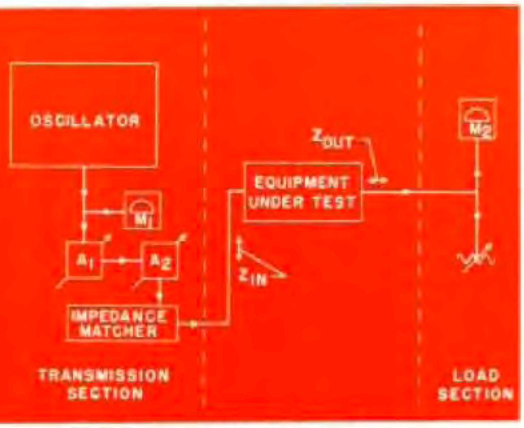


Fig. 2 (left). (a) Isolating volume indicator from tested equipment by use of a pad, and (b), with addition of series resistors. Fig 3 (right). Basic transmission measuring set.

section of the set are (1) to provide audio-frequency signal voltages of known and adjustable frequency, (2) to adjust the amplitude of these signals to accurately-determined values, and (3) to provide the desired internal source impedance.

The load section is intended to provide the desired load impedance for the equipment being tested. A volume indicator or other suitable instrument for determining levels, is provided. Its frequency characteristic over the audio range should conform to that of the indicator of the transmission section.

Transmission Section

If we should attempt to excite the input circuit of a device under test directly from the output of the usual audio-frequency oscillator, we encounter some difficulties. First, many broadcast devices operate at very low input levels. For testing under operating conditions, the oscillator output control would be a very crude means of setting levels accurately when in a nearly "off" position. Also, a sensitive instrument would be needed to indicate these levels directly. At low levels, the noise in the oscillator output stages might mask the signal if the output control were situated at a low-level point in the oscillator amplifier, as is often the case.

Finally, the input impedance of many devices to be tested varies greatly over the audio spectrum. Because of the internal impedance of the oscillator, this variation would cause the voltage applied to the input of the tested equipment to vary. Hence, difficulty is encountered in maintaining a constant reference reading on the input volume indicator. Of course, we could always reset the oscillator output control, thus maintaining a constant reference level at all frequencies. This adjustment of oscillator output is an artificial condition, however, because the source which *normally* feeds the equipment being tested will, in practice, not adjust its amplitude at different frequencies to compensate for the variation in input impedance. This continual adjustment of oscillator output would give the oscillator the equivalent a source having zero output impedance (a constant-voltage generator). Obviously, we should not provide a source whose internal impedance is zero, but one whose impedance is in accordance with that specified for the equipment being tested.

Fig. 4. Hewlett-Packard 206-A Audio Signal Generator, equipped with volume indicator and attenuators. This instrument can replace the input section of the transmission set for 50, 150 and 600 ohm circuits. A resistor and vacuum-tube voltmeter can serve as the output section.

As the first approach to the source-impedance problem, as applied to measurements, assume a device to be tested requiring a fairly high input level at a resistive, balanced impedance of 600 ohms. The test oscillator is intended to work into a 600-ohm load.

If we first insert a 6-db isolating attenuator between the volume indicator M and the tested equipment (see *Fig. 2a*), we will effect some improvement over the direct connection to the oscillator. But the impedance variation of the tested device will still reflect somewhat upon the instrument reading. The result is a resistive source impedance, having a magnitude in the neighborhood of 350 ohms, which, while representing an improvement over the zero-impedance source, is yet hardly satisfactory.

Going now to *Fig. 2b*, resistors R_1 and R_2, each of 300 ohms, are inserted in series with the input of the pad. These introduce an additional 6 db loss, but since the oscillator remains an effective short-circuit when looking back to its terminals (as long as the volume-indicator reading is kept constant) the pad is now matched on its input side by R_1 and R_2. Likewise, we have our desired 600-ohm resistive source. The 1200-ohm resistor across the oscillator terminals completes the 600-ohm oscillator loading system, in conjunction with the added resistors in the circuit to the pad. The desired circuit constants are now realized.

If the isolating pad is increased to 20 db or more, the effective impedance seen by the input circuit of the device being tested will vary by only a comparatively few per cent. Since attenuation of 20 db or more will often be required to reduce the oscillator signal to the operating input level, the additional series resistors

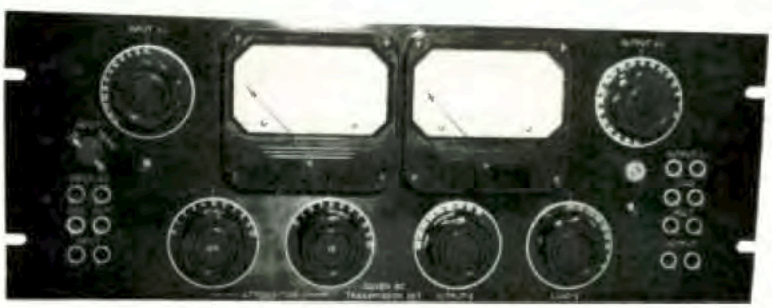


Fig. 5. Daven 6C Transmission Measuring Set.

R_1 and R_2 *may* not be required. The foregoing example, however, illustrates the importance of adequate isolation between the input circuit of the tested device and the volume indicator. The circuits, as shown, apply only to the balanced-to-ground case. Other arrangements are required if one side of the circuit is to be grounded.

Practical Transmission Set

Fig. 3 shows the "block" diagram of a basic transmission measuring set suitable for measuring the loss, gain, or frequency response of most broadcast equipment. The actual components will vary with the particular model. The variable a-f oscillator may be included as a part of the set, or may be connected externally. In some cases, an isolating pad may be inserted between the oscillator output and the point at which the volume indicator M_1 is connected.

Attenuators A_1 and A_2 constitute a decade arrangement, calibrated in decibels. The oscillator noise as well as the signal is attenuated by the decade pads, and a convenient level may be applied to M_1 for measurement. The impedance matcher may be a wide-range matching transformer with tapped windings, in which case an additional fixed isolating attenuator of suitable characteristics and about 20 db loss should be connected between the transformer secondary and the input of any device under test having an appreciable reactance (such as an amplifier with an input transformer). This pad assists in avoiding error at extreme audio frequencies. On the other hand, for measurements on amplifiers, the impedance matcher may be an attenuator, having adjustable output impedance and at least 20 decibels of loss.

The available output impedances of the transmission section should include those commonly encountered at the input of present-day broadcast equipment. Despite the proposed RMA standard of 150-and 600-ohm impedances in broadcast circuits, much equipment in use at the present time has other impedance values. The following values will be recognized: 30, 50, 125, 150, 200, 250, 500 and 600 ohms.

The load section of the transmission measuring set consists of a resistor, and, in parallel with it, an output power-indicating instrument. The resistor is adjustable to values found as loads for broadcast equipment. Besides those input impedances mentioned above, 8 and 15 ohms are encountered as output impedances. The indicator may be coupled to the load by a bridging transformer having a high primary impedance and adjustable turns ratio, in order to maintain a true power indication with different load resistances. Such a transformer may introduce some load errors at the extreme audio frequencies, so the load section may be isolated from the output of the tested equipment by a pad of at least 6 db loss. As previously stated, the indicator should have a frequency characteristic closely similar to that of the instrument in the transmission section.

Certain transmission sets use a single indicating instrument which is switched between the two meter positions shown in *Fig. 3*. A vacuum-tube instrument of very high input impedance may be used, or a suitable resistor may be substituted for the instrument when it is disconnected from either circuit. Typical commercial transmission measuring sets are shown in *Figs. 4* to *6*, inclusive.

Resistive Sources

Except for isolating pads and other resistive networks, most broadcast audio facilities are intended to operate into resistive loads and from resistive sources. Such resistive sources and loads are often provided by isolating or control attenuators or by "differential" networks.[7]

Transmission measuring sets similar to that diagrammed in *Fig. 3* can be used directly for measuring the frequency response of equipment such as:

(1) Amplifiers, in those cases where the source impedance will be an attenuator or other resistive network.

(2) Program lines, with their equalizers and repeating coils, which usually operate into terminating attenuators. At the sending end, the line amplifier is, in actual operation, isolated from the line by a pad of from 6 to 12 db loss; hence, it is proper to test the line from a resistive source.

(3) Filters, when intended to be used with resistive terminations.

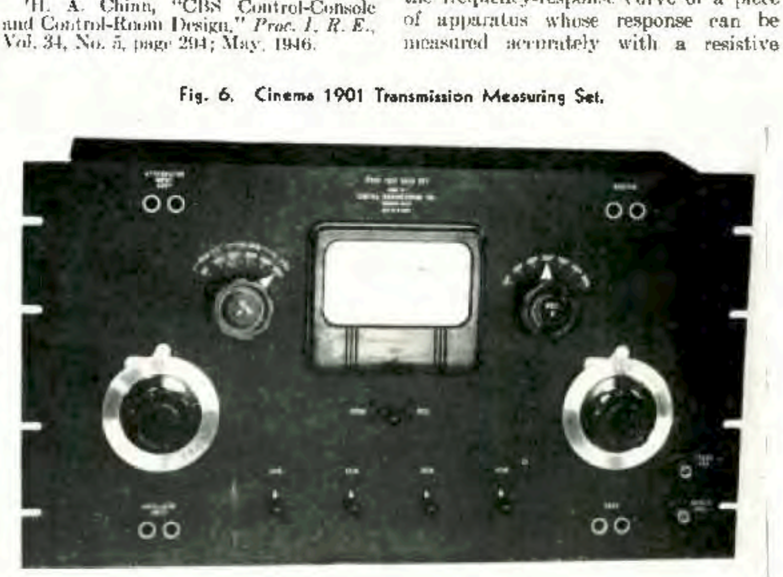
(4) Attenuators.

One may ask: "Why should it be necessary to measure the frequency response of a resistive attenuating pad?" In explanation, both fixed and variable attenuators may have a capacitive "leakage" effect, or, in the case of power-dissipating attenuators using wire-wound resistors, an inductive effect, upon frequency response. This effect will be, of course, most noticeable at the highest audio frequencies. The capacitive leakage effect will often increase transmission. Since many attenuators may be installed in the over-all system, it is well to be able to predict their combined effects. Indeed, errors introduced by possible frequency discrimination of pads in the transmission measuring set itself must be guarded against.

Measurement Technique

Here is the actual procedure to obtain the frequency-response curve of a piece of apparatus whose response can be measured accurately with a resistive

Fig. 6. Cinema 1901 Transmission Measuring Set.



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[7] H. A. Chinn, "CBS Control-Console and Control-Room Design," *Proc. I. R. E.*, Vol. 34, No. 5, page 294; May, 1946.

source and a resistive load. Referring to *Fig. 5*, the load is first connected to the output terminals of the equipment being tested, and adjusted so as to provide the desired loading. The multiplier on the output indicator M_2 is set to the maximum range. Attenuators A_1 and A_2 are set to maximum loss. The audio-frequency oscillator is adjusted to a frequency of 1000 cycles, and the output level is set at a convenient value which is noted on indicator M_1. The impedance matcher is adjusted to simulate the output impedance of the source to be used with the equipment being tested. The attenuators A_1 and A_2 are now adjusted so that their loss (combined with any loss in the impedance matcher) will bring the volume indicated by M_1 down to that normally fed to the tested equipment during operation. (It is well to use a reasonably high level from the oscillator, and thus use sufficient attenuation in A_1 and A_2 to assure adequate isolation of the equipment being investigated from the constant-voltage generator simulated by the oscillator output.)

The transmission section is connected to the input of the equipment being tested, and the multiplier of M_2 is reduced in setting so that a convenient reading is obtained on the scale of M_2. The gain of the equipment at 1000 cycles can now be computed. The gain in decibels of the equipment tested will be equal[5] to its output in dbm minus its input in dbm. The amplitude of the signal fed into the tested unit is, of course, equal to

$$\text{Input} = D_{M1} + S - A_1 - A_2 - C,$$

where D_{M1} = reading of M_1 in dbm.

S = setting in decibels of multiplier attenuator associated with M_1,

A_1 and A_2 are losses in decibels of attenuators A_1 and A_2 respectively, and

C = loss in decibels of impedance matcher.

The output level of the tested equipment is obtained by reading the output meter M_2 and its multiplier. (In some sets, a correction factor may be required for various output impedances.)

In testing most audio facilities, the procedure consists in repeating the response measurements at suitable frequencies, keeping the reading of the input indicator M_1 constant. The resulting deviations of the output indicator M_2 from its 1000-cycle indication are plotted as shown in *Fig. 1*.

Sources of Error

Numerous possible causes of error exist in response measurements, some of which have to do principally with particular equipments and applications. In general, some of the precautions which must be taken in order to avoid misleading frequency-response measurements are:

(1) The measurements should be made with the tested equipment installed and operating as nearly as possible in the manner in which it will be used. This provision applies to power-supply voltages, length and type of input and output leads, and source and load impedances. The same points and sides of circuits should be grounded in the tests as will be grounded in use. The transmission set must be adequately shielded and grounded, not only at the case, but at the output, if the source it simulates will be grounded.

(2) The equipment should be tested at the same approximate power level at which it will be used. This precaution relates especially to low-frequency response. The rise in permeability accompanying an increase in magnetizing force in the cores of transformers operating at low signal levels can result in misleading high values of low-frequency response, if the equipment is tested at an abnormally high power level.[6]

(3) Sufficient attenuation must be used in the input section of the transmission measuring set to assure adequate isolation of the input volume indicator from the input of the tested equipment.

(4) Circuits carrying a-f energy should be well isolated from each other. Thus, the oscillator leads should be isolated by all possible factors, including space, from the input circuit to an amplifier under test, which, in turn, should be similarly well-isolated from the amplifier output circuit. This precaution is worth while in all cases, including those where the leads are twisted and shielded. It is especially important when the circuits concerned carry radically different power levels. It is difficult to duplicate a response curve with different physical equipment set-ups, and the "dress" of the circuits will be found to have an important bearing on this difficulty. The cross-talk between circuits can cause difficulty when the oscillator output is set exceedingly high in order to accommodate excessive attenuation adjustments in the transmission set. Caution should be exercised in the use of long, unshielded patch cords in frequency-response measurements.

(5) Effects of the capacitances of cables and twisted pairs are important. For instance, insertion of unbalanced testing components in rather long shielded pair circuits under certain conditions, may cause an abnormally high response at high frequencies. (This same effect can occur in audio facilities in use.) This effect is shown in *Fig. 7*, where a "Tee" attenuator is connected in a circuit which is floating with respect to ground. The capacitances C to shield, ordinarily expected to cause high-frequency *losses*, may by-pass the higher frequencies around the attenuator to a noticeable extent, thus *increasing* the relative high-frequency response.

Complex Sources

In measuring the frequency response of equipment which is to operate from a source having a reactive component in its internal impedance, the resistive-source measurements described above are not conclusive. For example, if an amplifier output transformer works directly into a reactive filter section, the significant response of the amplifier-filter combination can best be obtained by measurement of the combination rather than by separate measurements with resistive terminations on the amplifier and filter.

Another example is found in measuring the frequency response of a certain microphone preamplifier, when operating from a particular type of microphone. The microphone is very likely to be designed to approach a flat response in output e.m.f. when on open circuit. Its internal impedance may vary with frequency. The preamplifier is designed to have a very high input impedance[7] at most audio frequencies (although its rated *source* impedance may be low). The input impedance may, however, vary appreciably with frequency. The response of the amplifier-microphone combination to the *open-circuit* e.m.f. developed by the microphone may be of interest.

A well-known method of simulating the internal impedance of source of this type is shown in *Fig. 8*. Here, the microphone itself is used to present its own internal impedance to the circuit. The arrangement shown is intended for use where one side of the microphone cir-

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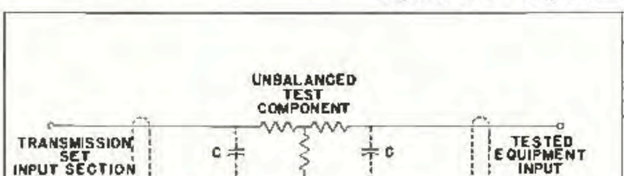
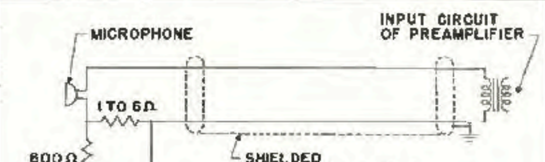
[5] "Dbm" is the single frequency power level in decibels with respect to a reference level of 1 milliwatt.

[6] See Reference 5, pages 207-208.

Fig. 7 (left). Effect of line-shield capacitances when unbalanced components are used. Fig. 8 (right). Connections for testing the electrical response of a microphone-amplifier combination.





Audio Measurements

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cuit is grounded in practice. It will be noted that the signal is inserted directly at the microphone, to prevent error caused by the by-passing of the higher frequencies around the microphone impedance by the capacitance of the cable.

Filters and Equalizers

Frequency-response measurements on filters and equalizers, and on "pre-emphasized" equipment, involve possible steep slopes on response curves. This is perhaps the single class of frequency-response measurements wherein reasonably low harmonic distortion in the test oscillator output may become important. Even here, however, if the oscillator is a modern one having a fraction of one per cent distortion, the error will be negligible. For large values of oscillator distortion, strong harmonics may occur at frequencies where the response is much greater than at the fundamental, and under these conditions, spuriously high response readings may conceivably occur.

As previously noted, resistive-termination measurements on filters are not precisely indicative of the filter performance when the filter is actually used with complex terminations.

Transmitters

Transmitter audio frequency-response characteristics can be obtained by observing modulation percentage, by means of either an oscilloscope, or the station modulation monitor if the monitor response is sufficiently flat.[10, 11]

The Institute of Radio Engineers has defined[12] the "frequency discrimination" of a transmitter as the comparison of the percentage of modulation of various audio frequencies for constant audio-frequency input. Overloading and overmodulation must be considered as possibilities in this method, in special cases. If overloading or overmodulation occurs as a result of exceeding the modulation legitimately to be expected of the transmitter, a compromise may be made at these points by reducing the input signal and correcting the modulation observations accordingly.

The language of the FCC standards concerning measurements for *type approval* of manufactured transmitters *may* be construed to mean that tests are to be made *at* the specified modulation percentages. In this case, the audio input level variations would be observed at different frequencies while maintaining a constant percentage of modulation. It is probable that results will be found substantially similar, whether measurements are made on a constant-input or on a constant percentage modulation basis, as long as the transmitter response is reasonably flat and no overloading occurs.

RMA Standards

Radio Manufacturers Association (RMA) has recently adopted standards for audio facilities for broadcasting systems. These standards specify, among other interesting items: (1) use of standard impedance values of 150 and 600 ohms in the design of future audio facilities, (2) a standard input signal (for testing) of 2.45 millivolts, r.m.s., in series with 150 ohms, which for system gain calculations corresponds to an input level of -50 dbm, (3) a standard output level of +18 dbm for feeding telephone lines, or of +12 dbm for feeding transmitters, and (4) figures for maximum audio-frequency response deviations permissible for com-

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[10] See Reference 1, page 66.

[11] See Reference 2, page 25.

[12] Institute of Radio Engineers, "Standards on Transmitters and Antennas—Methods of Testing," Institute of Radio Engineers, Inc., New York 21, N. Y., 1938, reprinted 1942, page 4.

pliance with RMA standards. Additional proposed standards, now under consideration, include (1) gain control settings for tests such that the standard input signal results in the standard output signal, and the attenuation as nearly as possible equally divided among all the gain controls in the main transmission path of the tested facility, (2) test oscillator spurious components should not exceed 10%, r.m.s., of the output voltage for frequency-response measurements, and (3) two frequency-response tests are to be made, one at the standard input signal and the second at a level 20 db lower.

Standard measurement methods are, of course, to be recommended because of standard test conditions and the decreased ambiguity in interpretation of results. Emphasis will be placed by the station engineer upon interpretation of, and compliance with, FCC standards and methods of measurement. Future experience will assist the station engineer in formulating the exact methods to be used in assuring compliance with FCC requirements as to frequency response and other equipment characteristics. It is believed that methods and principles which have been presented herein will prove helpful, both for general station measurements, and as a basis for comparing station performance with FCC requirements.