Telephone Lines in Broadcasting

Part I—Frequency response measurement and equalization of program lines

By LEIGH L. KIMBALL*

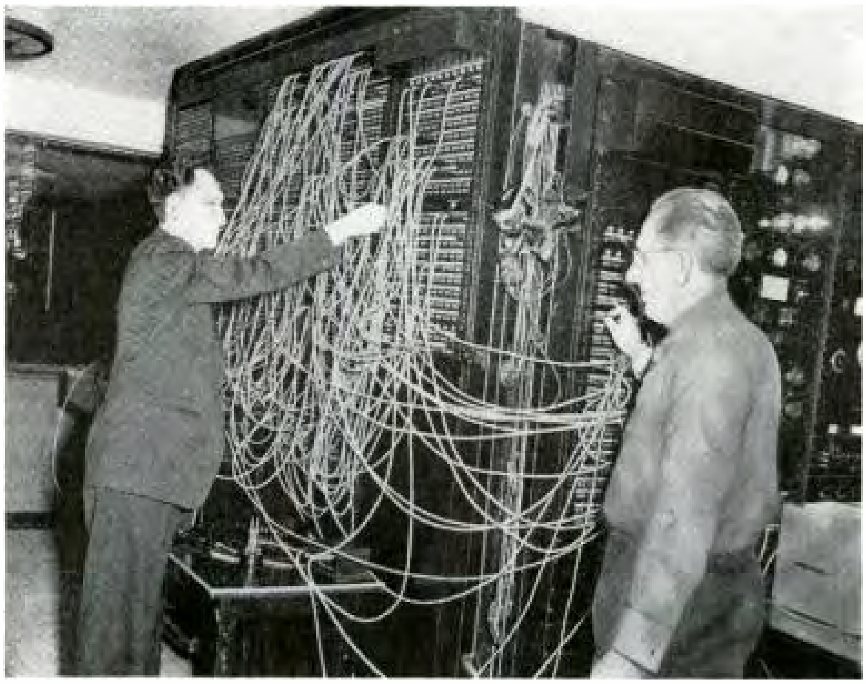
THE telephone line is still the major link between the broadcast studio, the remote pickup point, and the transmitter located outside the city. Relay transmitters and portable recorders despite all their recent developments are still a long way from supplanting the telephone line because of the latter's simplicity, relatively low cost, and ready availability from the various telephone systems throughout the country. Today, telephone lines go to almost every point of interest—networking even small communities in amazing detail—so that it is usually no problem for the telephone companies to supply wire facilities to broadcast stations quickly, efficiently, reliably, and inexpensively, with a minimum amount of bother to the broadcaster. But the problems confronting the broadcast engineer are what to expect from his lines in the way of performance and how to use telephone facilities most efficiently.

Telephone lines have two main uses in broadcasting: program transmission from remote pickup point to studio, from studio to transmitter, and from studio to the long-lines exchange for network operations; and program-coordination communication by means of the program pair itself or by means of a private line (PL) direct to the remote point, intended primarily for telephone communication. Long-distance intercity facilities should not be left out of a list of major uses, but in most cases the only part of such circuits over which the broadcast engineer has any direct control is the local loop to the long-lines exchange. Therefore, this article will concern itself strictly with the relatively short telephone lines referred to as *local loops*.

The most important technical characteristics of a telephone line are frequency response, loss, and noise.

Frequency-response measurement

At audio frequencies telephone lines are mainly capacitive, which, along with copper and insulation losses, reduces their efficiency at higher frequencies. There are several methods of compensating for or equalizing the high-frequency drop; one of these is to add series inductance at intervals along the line. The telephone companies make wide use of this series loading, both in intracity voice circuits and intercity long lines. But that procedure is usually too complicated for radio circuits which may be used for relatively short periods of time. The more common practice is to supply the line without loading and use equalizing equipment at the terminations.


Courtesy National Broadcasting Co.

Election-night state of NBC's patch board shows importance of telephone lines to broadcasting.

Frequency response of nonloaded lines is determined mainly by line length and the gauge of the wires used. The heavier the gauge, the better the high-frequency response. As line length increases, it becomes more difficult to transmit high frequencies. The response may be calculated in advance; but, since the total line may include several different wire gauges, it is usually much simpler to measure it. The measurement is a problem in itself.

In general, it is best to test a line with the amplifiers that will be used for program purposes. The input level to the sending amplifier should be held constant as frequency is varied. A typical arrangement is shown in Fig. 1. The receiving amplifier may simply be connected to the line and adjusted for a convenient reading on a standard volume indicator (VI) in its output circuit. A dummy load R_L equal to the amplifier's output impedance (usually 600 ohms) should be provided, as the VI is a high-impedance device (7,500 ohms for the NAB standard VU meter) and will not load the amplifier correctly.

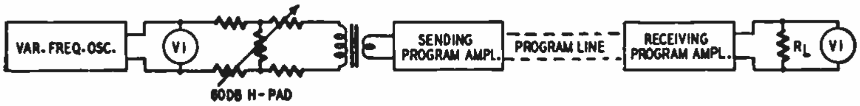


Fig. 1—Setup for measuring frequency response of phone line. VI's are volume indicators.

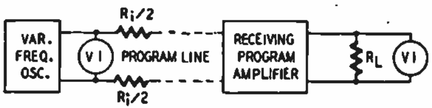


Fig. 2—Simpler response measurement hookup.

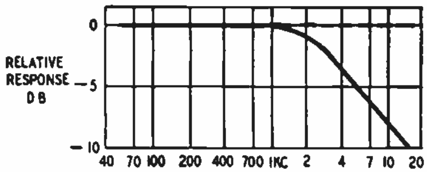


Fig. 3—Correct and incorrect measurements.

If the arrangement in Fig. 1 is too bulky for portable work, another arrangement requiring only an oscillator (shown in Fig. 2) is equally good if the internal impedance of the sending amplifier is known. In the diagram R_i is the internal impedance of the sending amplifier normally used at the line input.

This is the arrangement agreed upon by the major networks and the A. T. & T. When only an oscillator is available for line frequency-response measurement, it should be adhered to strictly. Putting the voltmeter or VI (used to see that oscillator output is held con-

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stant) directly across the line terminals at the sending end can result in serious errors, since the test generator's effective internal impedance becomes zero rather than simulating that of the amplifier to be used for transmitting programs. An indication of the possible error is shown in Fig. 3 for an actual case on a short loop. The solid curve shows the line to be actually very poor when used with a 600-ohm amplifier, although, when measured incorrectly (dashed line) it looks very good.

The reason for the series resistors is that an audio amplifier is actually a constant-voltage generator with an *internal resistance* of R_i, as shown in Fig. 4. The constant voltage E can be considered as the microphone output voltage (amplified by a constant factor) which, of course, is independent of conditions in the output circuit. Therefore, when E is constant, the amplifier output voltage E_o depends only on the internal resistance of the generator, and on the load impedance at any frequency. This is true of an amplifier, and the condition is duplicated, for all practical purposes, by the arrangement in Fig. 2 where R_i is split into two parts for the sake of line balance. The internal voltage of the generator is held constant manually, by adjusting the gain control at each frequency for constant reading on the VI across the output.

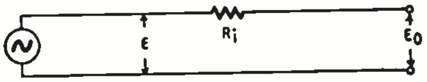

Fig. 4—Audio amplifier output, equivalent.

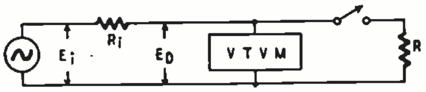

Fig. 5—Internal impedance measurement rig.

Internal impedance

The internal impedance of a commercial broadcast amplifier may or may not be equal to its rated output impedance. For instance, the 600-ohm output of a popular line amplifier was found to have 65 ohms internal impedance due to inverse feedback over the last two stages. This is desirable, as the low internal impedance helps to equalize the line. But if line frequency-response measurements are to be made in accordance with Fig. 2, the true internal impedance of the program amplifier should be known. Measuring it is simple.

Referring to Fig. 5:

$$E_o = E_i \frac{R}{R+R_i}, \text{ and}$$

$$R_i = \frac{R(E_i - E_o)}{E_o}.$$

E_i is measured by the a.c. v.t.v.m. when R is disconnected from the circuit and an audio tone is applied to the input of the amplifier; E_o is the a.c. voltage across the output terminals when R is connected; and R is a resistance comparable to R_i. R must be small enough to give a substantial difference between E_i and E_o, yet large enough not to cause distortion in the output stage of the amplifier. A workable value usually is 600 ohms.

The procedure is valid only if the output impedance of the amplifier is constant and resistive over the audio range. This is usually true of a high-quality broadcast amplifier; but, if there is any doubt, R_i can be measured at several frequencies. If there is appreciable variation in R_i, the line must be equalized and tested in accordance with Fig. 1.

Equalization

Two principal methods of local-loop equalization are commonly employed. They are shown in Fig. 6. Method 1 simply makes use of the transformed input and output impedances of the line amplifiers to provide a heavy (150-ohm) resistive loading to shunt out the effects of line capacitance. This extends the high-frequency response in much the same manner as is sometimes used in audio amplifiers. Method 1 can be used to equalize lines of the following maximum lengths and wire gauges to about 8000 cycles. If 15-kc equalization is desired the lengths should be scaled down.

Wire Gauge	Length (miles)
16	5
19	2.3
22	1.5

The equalizing procedure for method 1 is a simple frequency-response check.

Method 2 makes use of a variable-impedance leg at the receiving end that actually mismatches the line at the low frequencies but has little effect at high frequencies. Correct equalization is obtained when the line loss at high frequencies equals the loss at low frequencies due to reflection from the mismatched termination. This system is used for longer lines than method 1; it will equalize lines up to about 10 miles in length. Method 2 is:

1. Set the parallel resonant circuit (L_e and C_e) to a frequency slightly higher than the maximum desired.
2. With the equalizer in the circuit and R_e at zero resistance, send a tone reference from the test oscillator at the highest frequency desired and note the VI reading at the receiving end.
3. Shift the oscillator to a low frequency (50 or 100 cycles) *maintaining the same output level as before*, and increase the resistance of R_e until the same VI reading is obtained as before.
4. Make a complete frequency run and take care of any touch-up adjustments necessary to get a flat response over the desired range. The maximum variation can usually be held to ±1 db.

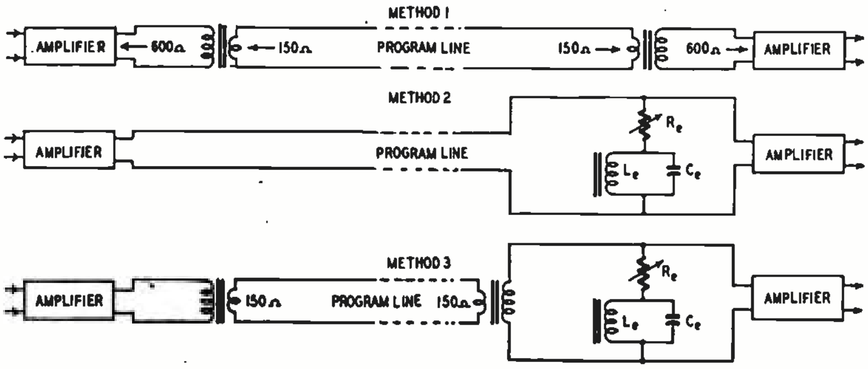

Fig. 6—Several methods of equalizing the frequency response of program telephone lines.

Various combinations of methods 1 and 2 may be used. One of these, method 3 is recommended for especially long lines where good frequency response with low noise level is important.

Two effects which may cause irregular frequency response cannot be removed by these equalization procedures. The first and most serious is a series loading coil in the line. The telephone company may sometimes overlook one of these inductances which they use to equalize voice circuits and unintentionally leave it in the line. The symptoms are unmistakable—no reasonable amount of equalizing work will extend the frequency range much higher than 4 kc. Fig. 7 is a typical response curve.

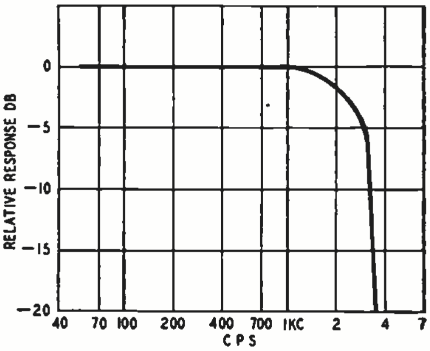

Fig. 7—Effect of loading coils in the line.

The second common cause of irregularity is an impedance discontinuity along the line resulting from the use of different cable gauges in the loop make-up or from branch circuits which are tied on at some point. The principal result is a bumpy response curve. The effects of different cable gauges in the line are usually small. However, the results of branch circuits may be more serious, especially since an unterminated branch is very suceptible to cross-talk interference from adjacent cable pairs.

(The concluding part of this article, which will appear in an early issue, will discuss line loss, noise, correct termination, and maintenance.)