Part 1

THE TRANSISTOR—A NEW FRIEND FOR THE BROADCASTER *

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INTRODUCTION

Broadcast engineers who make no attempt to become acquainted with transistors will very rapidly find themselves unable to participate in some of the liveliest technical conversations in the industry. The transistor, scarcely more than ten years old, has been refined and developed to the point where it is a fast-rising contender for many of the circuit functions required in broadcast equipment, both audio and video. It is not such a miraculous device that it will make tube-type equipment obsolete overnight, but it offers enough advantages that we can confidently predict a steady trend toward transistorization in all categories of broadcast equipment. Reputable manufacturers and wise broadcasters will be careful to see, however, that transistorized equipment fully measures up to broadcast requirements before it is offered for sale or pressed into service. The novelty value which helps to sell transistorized consumer products is useless to the broadcaster, who must demand reliability in all equipment involved in the handling of his highly perishable prodnct—broadcast time.

The purpose of this part is to introduce the broadcast engineer to the transistor in such a way as to initiate a lasting friendship between the two. The material is intended, of course, only for those broadcast engineers who have not yet had the opportunity to become acquainted with transistors through education or actual experience with them. The authors feel qualified to make an appropriate introduction, because we have had the privilege of getting to know both broadcasters and transistors through our professional activities extending over several years. We appreciate that broadcasters are not professional physicists, so we shall avoid the conventional approach

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which attempts to describe transistor behavior in terms of "holes," electron flow, energy levels, and other aspects of semiconductor theory. We shall assume that transistor designers have done their job well, so the transistor can be introduced to the broadcaster as just another basic component, like the resistor, capacitor, inductor, or diode, that can be called upon to do specific jobs in electronic circuits. We shall present a brief summary of the "personality traits" of transistors and a description of their typical behavior. We shall explain how they can be put to work in a few typical circuits and shall conclude with a few observations on handling precautions that will help to keep transistors and broadcasters on friendly terms with each other.

ADVANTAGES

The major advantages of transistors in comparison with hot-cathode tubes have been so widely publicized that only a brief summary is required here. The small size of transistors, coupled with their very low power-input requirements, makes possible substantial reductions in the size and weight of electronic equipment. These advantages will be appreciated by broadcasters not only for portable field equipment but also in cases where new facilities must be added to broadcast plants without increasing the floor space in control rooms. The reduced heat dissipation not only will add to operator comfort in crowded locations and reduce the power bill for technical equipment but will also increase the life expectancy of nearly all circuit components (which always age less rapidly at reduced temperatures). The transistor itself enjoys a much longer life expectancy than its vacuum-tube cousin, provided it does not meet an untimely death from overexposure to unfavorable conditions. There is considerable evidence that many transistor types have a life expectancy of the order of 70,000 hr (about 8 years) of continuous service if used under conservative conditions. This long life contributes, of course, to greater reliability in transistorized equipment. The absence of heated cathodes reduces substantially the warm-up time required for transistorized circuitry. Still another trait that is winning friends for the transistor is its versatility. It can be constructed in a variety of forms, many of which will do jobs that could never be done reasonably with tubes. Two transistors can be made as "mirror images" of each other for use in balanced or symmetrical circuits, for example, and it is even possible to make a transistor which behaves exactly the same whether it is hooked up "backward" or "forward."

PRESENT LIMITATIONS

These obviously friendly remarks about transistors should not lull the reader into the false assumption that transistors are paragons of virtue. They have their faults and limitations, and broadcasters would do well to become acquainted with these less favorable attributes of transistors right from the beginning so as to make proper allowances for them. Fortunately, many of the limitations of transistors are not of major concern to equipment *users*, provided the equipment *designers* understood them and took them into account.

At the present state of the art, transistors are definitely limited in either frequency response or power-handling capability. Types have been developed which handle substantial amounts of *power* for such applications as series regulators in power supplies, but these types are generally useful only for frequencies below a few thousand cycles per second. At the other end of the scale, types can be obtained which operate up to hundreds of megacycles, but their power-handling capabilities must be measured in milliwatts or microwatts. This problem is a basic one, resulting from the fact that the transistor action actually occurs in a tiny active region within a pellet of semiconducting material. Because of the submicroscopic spacing between the "elements" of a transistor, its input and output capacitances tend to be quite high unless the active area is kept very small. When the active elements of a transistor are made large enough to handle appreciable amounts of power and are thermally coupled to heat-dissipating structures, the capacitances become so great that operation at high frequencies becomes impossible.

A transistor may be regarded superficially as a sophisticated type of nonlinear impedance, implying that it does not follow Ohm's law when voltages or currents are applied to its terminals. It should not be surprising, therefore, that inherent nonlinearity must be counted as one of its limitations in many circuit configurations. An ingenious circuit designer can get around this problem in a variety of ways, but nonlinearity prevents the use in high-quality broadcast equipment of many simple circuits that look like obvious approaches to the transistor novice.

The relatively low impedance characteristics of most transistors may be either good or bad, depending upon the application. Broadcast engineers who have been "brought up" on tube circuits will probably find it difficult to break away from the habit of ignoring input impedances. A tube normally has an input impedance of several megohms, which can safely be ignored when shunted across the load impedance of the preceding stage. A transistor, however, has an input impedance that may vary from a very few ohms up to perhaps 100,000 ohms, depending upon the transistor type and the circuit configuration. In almost all cases, the transistor draws significant current from the preceding stage, so its input impedance must be taken into account when analyzing or designing circuits.

Two transistor traits of great significance to broadcasters are temperature sensitivity and rapid response to conditions of overstress. Transistor performance characteristics definitely vary with temperature, although a competent circuit designer should be able to provide stable performance over a reasonable operating range. There is a temperature threshold, however, above which transistors cannot be operated without suffering irreversible damage. For most germanium transistors, this critical temperature is about 85°C at the active region. When due allowance is made for normal temperature rises within the transistor cases and within confined equipment spaces, we find that about 55°C (131°F) is about the practical upper limit of ambient temperature for transistorized equipment using germanium devices. Silicon transistors will operate at substantially higher temperatures but are considerably more expensive and are limited in some other performance characteristics. Until the temperature problem is overcome, broadcasters would do well to mount transistorized equipment in relatively cool locations.

The transistor cannot compete with its cousin the tube when it comes to tolerating occasional abuse "beyond the call of duty." While a tube is quite vulnerable with respect to its mechanical structure, it is surprisingly tolerant with respect to severe overrating conditions aplied to its internal elements on a momentary or accidental basis. An accidental short of a grid circuit to +B may cause a tube to glow red very quickly, but it can be restored to its normal condition if the overstress is not continued too long. Not so with the transistor. If it is pushed well beyond its ratings in any respect even momentarily, it just quits in less time than a human hand could possibly take corrective action. Usually there is no flash, no red glow, no puff of smoke, not even a little "pop"—the transistor just dies, in silent protest against the intolerable conditions imposed upon it. Broadcasters need not fear transistors for this reason but should use appropriate caution when poking around in "hot" transistor circuits.

THE TRANSISTOR AS A RELATIVE OF THE DIODE

The transistor is a very close relative of the familiar semiconductor or "crystal" diode. A diode is formed at the junction between two electrically dissimilar materials when they have the property of conducting freely in one direction but not the other. In most practical diodes, the basic material is usually highly refined germanium, but minute quantities of impurities are added to control its electrical properties. Germanium which has been "doped" properly to serve as the anode of diode junction is called "*p*-type" germanium, and germanium doped to function properly as a cathode is called "*n*-type" (*p* and *n* stand for ***positive*** and ***negative,*** respectively). When the *p* side of a junction diode is connected to the positive terminal of a battery, the diode conducts freely and behaves like a relatively low impedance (commonly about 50 ohms). When the battery is connected in the reverse direction, however, the current flow is impeded, and the device appears to have an impedance of the order of 100,000 ohms or more.

A junction transistor consists, in essence, of two diode junctions in series, with the same very thin piece of *n*-type material shared by both diode junctions. The three elements of the transistor are connected to separate leads and are labeled *emitter, base,* and *collector,* as shown. In a few transistor types of symmetrical design, the emitter and collector have identical properties and can be freely interchanged, but in most transistors the collector junction has a larger area than the emitter junction, leading to differences in electrical characteristics.

In the majority of practical transistor circuits, the emitter junction is biased in the forward direction (i.e., in the direction of easy current flow) while the collector junction is biased in the reverse direction. If the transistor really behaved like two independent diodes in series, the operating currents would appear as shown in Fig. 1-4. The current through the reverse-biased collector would be very small compared with the emitter current, and the base current would be almost equal to the emitter current. Actually, the situation is almost the reverse (see Fig. 1-5). The forward-biased emitter draws current freely from its bias supply, but instead of flowing down through the base, the great majority of this current flows straight through to the collector (where its flow is aided by the added "push" of the collector supply battery). In a typical transistor, only about 2 per cent of the emitter current will appear in the base lead. This apparently strange behavior is the very key to transistor action. As noted earlier, it is vitally important that the emitter and collector junctions are very close to each other (on a microscopic scale) and that they share the same base material. While a complete description of the action which takes place in a transistor is beyond the scope of this material, the matter can be covered superficially by the statement that the current-flowing activity in the emitter junction so alters the characteristic of the immediately adjacent collector junction that it is able to pass the emitter current rather freely. Of great significance is the fact that a deliberate change in either the emitter current or the base current will cause the same *percentage* change in the collector current. Considerable gain is made possible by the fact that a change in the relatively small base current can control the much larger collector current.

The foregoing figures indicate that a transistor, in its simplest form, may be thought of as a "sandwich" of *n*-type "meat" and *p*-type "bread." When constructed in this manner, it is called a *p-n-p* transistor. However, perfectly good transistors can be constructed by reversing the "bread" and the "meat," as shown in Fig. 1-6.

This arrangement is known as an *n-p-n* transistor. The major difference between the two types lies in the fact that the various voltages applied to a *p-n-p* transistor must be reversed for an *n-p-n* transistor.

In schematic diagrams, *n-p-n* and *p-n-p* transistors are identified by the contrasting symbols shown in Fig. 1-7. In both cases, the element symbolized by the arrowhead is the emitter, and the direction of the arrowhead indicates the direction of easy current flow.

THE TRANSISTOR AS A RELATIVE OF THE VACUUM TUBE

The transistor, being an amplifying device, bears a resemblance to the vacuum tube in that the three "elements" of a transistor correspond (approximately) to the three elements of a vacuum tube. Equivalent functions are performed, for example, by the vacuum-tube cathode and the transistor emitter. The same may be said for the base and the grid and the collector and the plate, respectively. These equivalences can be used to produce the equivalent symbols shown in Fig. 1-8.

One should not infer, however, that these equivalences are anything but approximate. For example, consider the difference between a grid and a base. A grid, in normal negative-biased operation, draws no current. The total cathode current flows in the plate circuit as indicated in Fig. 1-9. It was stated above, however, that the emitter current in a transistor divides between the collector and the base, so that the base has an appreciable current flowing in it as shown in Fig. 1-10. Since the current that flows (for a given voltage) is an indication of the impedance of a circuit, the fact that the base draws current while a grid does not leads to the conclusion that the impedance seen looking into a base would be very much smaller

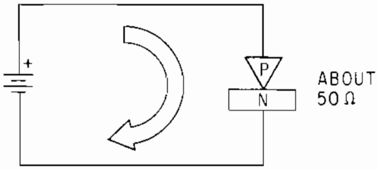

Fig. 1-1. Simple conducting diode circuit with p and n appropriately connected to a battery.

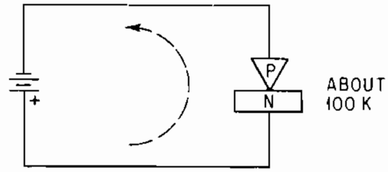

Fig. 1-2. Reverse connected transistor exhibiting high impedance to the current flow.

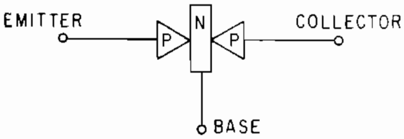

Fig. 1-3. A junction transistor.

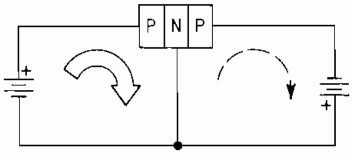

Fig. 1-4

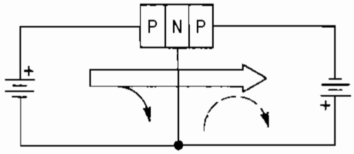

Fig. 1-5

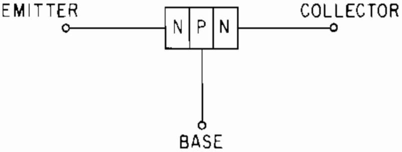

Fig. 1-6

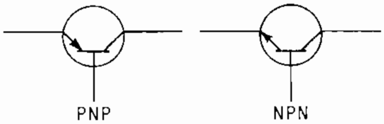

Fig. 1-7

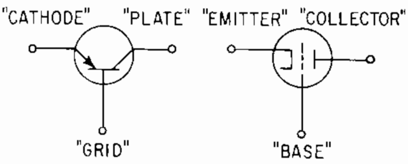

Fig. 1-8. Equivalent symbols for transistor and three-element vacuum tube.

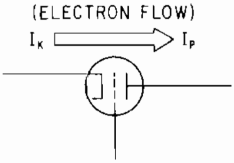

Fig. 1-9. Electron flow in vacuum tube.

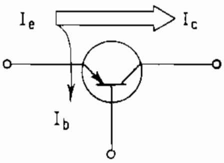

Fig. 1-10

than the impedance seen looking into a grid. The conclusion is correct: a typical vacuum tube, it is well known, has a grid impedance of several megohms, while a typical transistor may have a base impedance of less than 2,000 ohms.

Definitions of Alpha (α) and Beta (β)

Two transistor parameters that have an importance in transistor circuits comparable to the importance of transconductance (g_m) and amplification factor (μ) in tube circuits are those designated *alpha* and *beta*.

Alpha is the ratio of the collector current to the emitter current and is typically of the order of 0.98 for small transistors at low frequencies. Alpha is always less than unity and indicates the current-gain capabilities of the transistor when operated as a common-base amplifier. (The common-base circuit configuration will be described presently.)

Beta is the ratio of the collector current to the base current and is related to alpha by the expression, $\beta = \alpha/(1 - \alpha)$. For a typical small transistor with $\alpha = 0.98$, $\beta = 0.98/0.02$, or 49. Beta indicates, in a general way, the current-gain capabilities of a transistor in the common-emitter configuration to be described presently.

Unless indicated otherwise, α and β describe the behavior of a transistor for small signal-current swings at low frequency around the no-signal operating point; values for α and β determined by d-c measurements alone may differ somewhat from the a-c or signal values. Both α and β tend to decrease with frequency. The alpha and beta cutoff frequencies commonly listed in transistor specification sheets represent the frequencies at which α and β, respectively, decrease to 70.7 per cent of their low-frequency values. In general, β decreases much more rapidly with frequency than does α.

The Three Basic Circuit Configurations

As in the case of tubes, transistors can be used in a wide variety of circuits, designed to function as amplifiers, oscillators, clippers, modulators, regulators, dividers, and other specialized devices. There are, however, three basic circuit configurations which are encountered very frequently and which should be mastered by the transistor

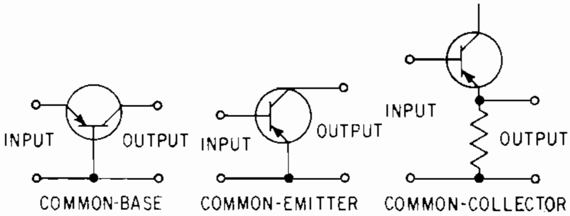

Fig. 1-11

novice as a prerequisite for understanding the more complex configurations. Within the limited scope of this part, we can examine the three basic configurations only in the relatively simple forms in which they are found in straightforward amplifier service.

The three basic circuit configurations are usually designated common-base, common-emitter, and common-collector and are symbolized in simplified form in Fig. 1-11. These three basic configurations are superficially equivalent to the vacuum-tube configurations commonly known as grounded-grid, ground-cathode, and cathode-follower, respectively.

Transistors are similar to tubes in that certain power-supply voltages (or currents) must be applied to establish reasonable operating conditions before the devices can handle signal voltages or currents in a useful fashion. As noted earlier, the great majority of practical transistor circuits involves a *forward* bias (in the direction of easy current flow) in the emitter junction and a *reverse* bias in the collector junction. The voltages required for transistor circuits are relatively low compared with those employed for tubes. In many transistorized devices, the highest voltage encountered is only about 20 volts. The fact that transistors require no special supplies or wiring for heaters is a definite advantage which helps to keep transistor circuits simple and compact.

Instead of describing each basic circuit configuration in detail before going on to the next, we shall discuss in parallel the major aspects of all three types, so that their differences will be more readily apparent. We shall begin by considering typical input and output impedances. Then we shall continue by describing practical bias arrangements and conclude this section of the part by examining typical behavior for a-c signals. For the sake of simplicity, we shall consider only *p-n-p* transistors and shall confine our attention to low-frequency behavior. For the practical illustrations, we shall assume the use of a single transistor type with reasonably typical values of α, β, input impedance, and output impedance. We shall also assume that the same α and β values hold for both d-c and a-c conditions.

Typical Input and Output Impedance

The broadcaster who is only mildly interested in the principles of semiconductor physics which account for transistor behavior will often find it helpful to think of transistors in terms of the equivalent impedances represented by the input and output circuits, just as he has found it helpful to think of diodes as equivalent to either very low or relatively high resistances, depending upon whether the diode is forward-

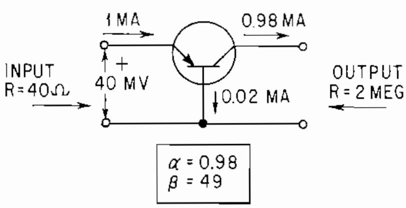

FIG. 1-12

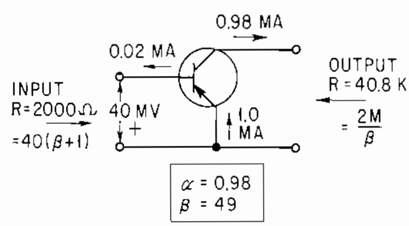

FIG. 1-13

biased or reverse-biased. For the present discussion, we shall assume that practical bias arrangements have been provided to keep the emitter junction in a freely conducting condition and the collector junction in a reverse-biased condition.

Typical input and output impedances are easiest to visualize in the case of common-base circuits, where the forward-biased emitter appears as the equivalent of about 40 ohms (in a typical case) and the reverse-biased collector appears as about 2 megohms as shown in Fig. 1-12. The voltages and currents shown represent small *changes* superimposed on the steady-state bias conditions. The very high output impedance implies that the operating currents are quite independent of the collector voltage. Even a wide change in collector voltage would cause very little change in the collector current. A voltage change of only 40 mv on the emitter, however, would cause a 1-ma change in the emitter current, leading in turn to current changes of 0.98 and 0.02 ma in the collector and base, respectively.

If the very same transistor is operated in a common-emitter circuit, however, the input and output impedances are substantially altered, as shown in Fig. 1-13.

In this case, as before, a 40-mv change in the base-to-emitter voltage results in current changes of 1.0, 0.98, and 0.02 ma in the emitter, collector, and base, respectively, but the resistance looking into the base is $E/I = 40/0.02 = 2{,}000$ ohms. Note that this is exactly $(\beta + 1)$ times greater than the resistance looking into the emitter, by virtue of the fact that the emitter current is $(\beta + 1)$ times greater than the base current. The output impedance is reduced by a factor of β relative to the output impedance of the same transistor in a common-base configuration. This reduction occurs by virtue of the fact that the very small reverse-bias current that flows as a result of the collector supply voltage (normally negligible when superimposed on the much larger current flowing into the collector as a result of the forward bias in the emitter-to-base junction) is also drawn through the emitter-to-base junction, resulting in its amplification by a factor of β. Hence, a given voltage change on the collector of a common-emitter stage will cause a collector current change β times as great as in the case of a common-base circuit.

When the same transistor is used in a common-collector circuit (often called an *emitter follower* because of its similarity to the cathode follower), the input and output impedances are both significantly influenced by the value of the load resistor. Let us consider the case where the load resistor has the reasonably typical value of 2,000 ohms (see Fig. 1-14). The collector, in this case, must be connected to a

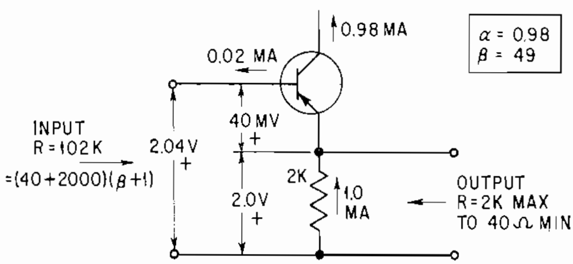

FIG. 1-14

source of suitable supply voltage but does not directly influence the circuit behavior. As in the two previous cases, it still requires a 40-mv change in the base-to-emitter voltage to cause current changes of 1.0, 0.98, and 0.02 ma in the emitter, collector, and base, respectively. Because of the inherent feedback resulting from the presence of emitter resistor, however, the *input* voltage must be changed by 2.04 volts to realize a 40-mv change in the base-to-emitter voltage. By Ohm's law, the input resistance is $E/I = 2{,}040/0.02 = 102{,}000$ ohms. Note that this is $(\beta + 1)$ times greater than the sum of the load resistance and common-base emitter resistance of the transistor itself. If the external resistance in the base circuit is very high, the output impedance of the emitter follower is nominally equivalent to the load resistance. If, however, the base is driven from a very low-impedance source, the IK load resistance is shunted, as far as the output is concerned, by the emitter-to-base resistance of the transistor itself, and thus the output impedance may fall to slightly less than 40 ohms.

Practical Bias Arrangements

Let us now consider the problem of providing practical biasing arrangements to achieve reasonable d-c operating conditions. For the sake of consistency in our practical illustrations, let us assume that we are to handle fluctuating *emitter* currents on the order of 1 ma peak-to-peak. To achieve reasonable linearity, we must arrange conditions so that the direct emitter current at the zero-signal operating point is of the order of 2 ma. We must also see that the collector always remains at least a few volts negative relative to the base to assure a proper reverse-bias condition. Let us assume that we have stabilized sources at +20 and −20 volts available. (These are reasonably typical values for transistorized circuits.)

The simplest bias arrangements for common-base circuits are quite straightforward, consisting of the collector load resistor plus an emitter bias resistor as shown in Fig. 1-15. Since the emitter input resistance of only 40 ohms is negligible in series with the 10K bias resistor, the emitter bias current is determined by dividing the bias supply voltage (20) by the resistance (10K), giving 2 ma. If the transistor has a d-c α of 0.98, the collector current is 1.96 ma and the collector voltage is equal to the supply voltage (−20) less the drop across the load resistor (9.8 volts), giving −10.2 volts. The actual value of the load resistor is normally determined more by considerations of gain or bandwidth than by bias considerations.

Unfortunately, the simplest type of bias arrangement for the common-emitter configuration is a very poor one for practical amplifier circuits, but it is worth reviewing as an illustration of several aspects of transistor behavior. This simple, though impractical, bias arrangement requires only two resistors and a single voltage source as shown in Fig. 1-16. Since the 2,000-ohm imput resistance looking into the base of the transistor is negligible in series with the 500K bias resistor, the nominal bias current is determined by dividing the supply voltage (−20 volts) by the bias resistance (500K), giving 0.04 ma in the direction indicated. The collector current is β times as great, or 1.96 ma, and the collector voltage is determined by subtracting the drop across the load resistor from the supply voltage.

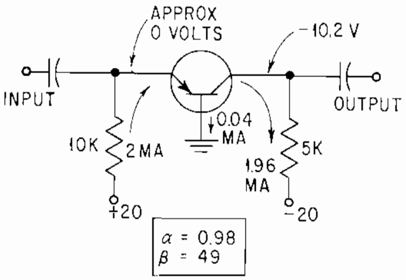

Fig. 1-15

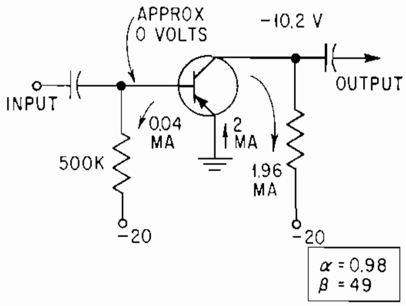

Fig. 1-16

The two major deficiencies of this simple but impractical bias arrangement are: (1) It is unduly sensitive to variations in the β of the transistor, and (2) its operating point tends to vary excessively with temperature. When the α of a transistor falls from 0.98 to 0.97 (causing only a slight variation in the performance characteristics of a common-base circuit), the β falls from $^{98}/_{2} = 49$ to $^{97}/_{3} = 32.3$, a change of almost 35 per cent! This change would seriously affect both the d-c operating point and the a-c gain of the simple common-emitter circuit in Fig. 1-16. The temperature sensitivity of the circuit results from the fact that substantially all the reverse-bias current (i.e., the current that flows through the collector diode even when the emitter is open) must pass through the emitter-to-base junction, where it becomes subject to the current-amplifying action of the transistor. This current varies exponentially with temperature and may become large enough to cause a significant shift in the d-c operating point.

The usual approach to the stabilization of a common-emitter circuit to avoid these problems involves (1) lowering the external impedance of the base circuit and (2) raising the external impedance (at least for direct current) in the emitter circuit. It is interesting to note that these actions make the circuit behave more nearly like the common-base circuit described earlier, which is a very stable circuit. A practical arrangement is shown in Fig. 1-17. Because of the 2,000-ohm emitter resistance, the d-c resistance looking into the base of the transistor is 102,000 ohms, just as in the case of Fig. 1-14. This high resistance is negligible when shunted across 2,000 ohms, so the current in the voltage divider in the base circuit is nominally equivalent to the supply voltage (−20) divided by the total resistance (10K), or 2 ma. The voltage on the base is therefore approximately −4 volts. Because the voltage drop across the forward-biased emitter-to-base junction is negligible, the voltage at the emitter must also be about −4 volts, implying that 2 ma must be flowing through the 2K emitter resistor. If the α and β of the transistor are 0.98 and 49, respectively, the collector and base currents must be 1.96 and 0.04 ma, respectively. The collector voltage is determined by subtracting the drop across the load resistor from the supply voltage.

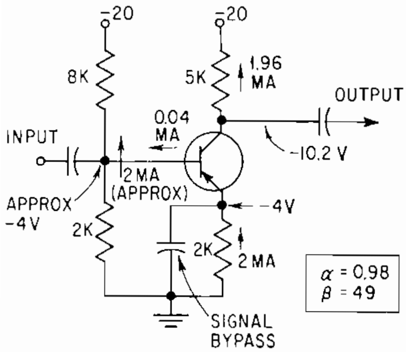

Fig. 1-17

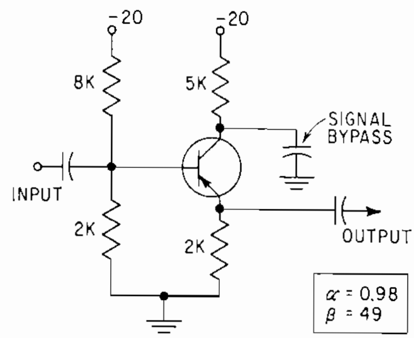

Fig. 1-18

For a rigorous analysis, the small 0.04-ma base current should be taken into account in the determination of the actual voltage on the base, but since it is only 2 per cent of the nominal current in the bias network, it can safely be ignored for a practical, approximate analysis.

This practical version of a common-emitter circuit provides less current gain than its simpler counterpart and also has a lower input impedance because of the shunting effect of the bias network in the base circuit. These handicaps are outweighed, however, by the greatly reduced temperature sensitivity and decreased dependence on β. Reasonable current gains can still be achieved (as will be shown later) provided the emitter resistor is bypassed to avoid the inverse feedback that would otherwise result.

A practical version of a common-collector circuit (or emitter follower) can be obtained by using exactly the same circuit constants shown in Fig. 1-17, except that the bypass capacitor should be moved to the collector circuit and the output taken from the emitter (see Fig. 1-18). If the same transistor type is used, the d-c operating conditions are exactly the same as in the preceding example and the analysis need not be repeated. The only function of the bypassed resistor in the collector circuit is to reduce the collector dissipation by decreasing the effective supply voltage. In many practical circuits, the collector resistance and its associated bypass capacitor would not be needed. Because a reasonable degree of stabilization is provided by the load resistor in the emitter circuit, the impedance of the bias network in the base circuit could safely be increased in many practical applications where a higher input impedance is required, but this action would tend to make the circuit increasingly sensitive to temperature.

LOW-FREQUENCY PERFORMANCE OF TYPICAL PRACTICAL CIRCUITS

In considering the performance of a practical transistor circuit for low-frequency a-c signals, it is necessary to take into account the source impedance of the preceding stage, because the input impedances of transistor circuits are generally so low that their loading effects on the preceding stages cannot be ignored (as in the case of tubes). Keeping this factor in mind, let us examine the low-frequency performance characteristics of the practical circuits previously described.

The *current gain* of a common-base amplifier is always less than unity, because some of the input signal current is always lost in the base, but the voltage gain may be quite appreciable if the load resistance is much larger than the input resistance of the circuit, as in Fig. 1-19. This figure illustrates the basic performance characteristics of common-base amplifiers, which can be summarized as follows: (1) low input impedance, nominally equal to the input impedance of the transistor alone; (2) relatively high output impedance, nominally equal to the load resistance; (3) no polarity inversion; (4) current gain only slightly less than unity; and (5) the possibility of considerable voltage gain, approximately equal to the ratio of the output impedance to the input impedance. It is interesting to note, however, that it does no good to cascade two or more common-base amplifiers if voltage gain is the objective—the voltage gain in each stage is effectively canceled by the loading effect of the following stage unless an impedance-matching transformer is used.

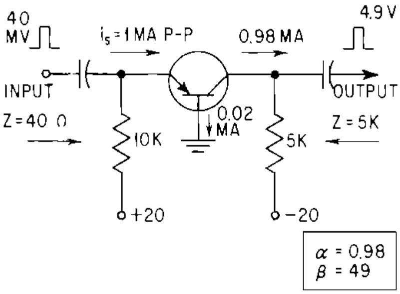

FIG. 1-19

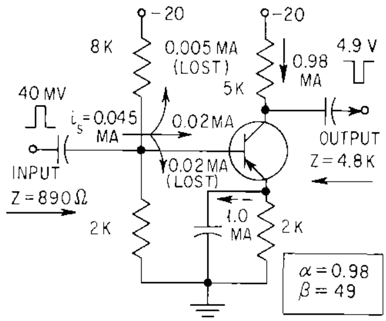

FIG. 1-20

The performance characteristics of a practical common-emitter circuit are illustrated in Fig. 1-20. In summary form, the key features of this circuit are (1) a current gain of about 22, which is less than the β of the transistor primarily because of the loading effect of the base bias network; (2) a voltage gain of about 122, assuming that the output is not loaded down appreciably by the following stage; (3) a reversal in the polarity of the signal; (4) an input impedance appreciably higher than that of a common-base amplifier but considerably lower than the 2,000-ohm input impedance of the transistor alone because of the loading effect of the base bias network; (5) an output impedance that is slightly less than value of the load resistor because of the shunting effect of the output impedance of the transistor itself. The shunting impedance is somewhat higher than the 40,000 ohms indicated in Fig. 1-13, because not all the reverse-bias current that is involved in the determination of the output impedance of the transistor is drawn through the emitter-to-base junction in this practical circuit—some of it is drawn directly from the base bias network. The output impedance of the transistor alone turns out to be the order of 200,000 ohms in this case, which is intermediate between the 2 megohms expected of a common-base circuit and the 40 kilohms expected of a common-emitter circuit with very high impedance in the base lead. It should be noted that the analysis performed here is only approximate, based on several simplifying assumptions, but the characteristics indicated should hold within about 5 per cent.

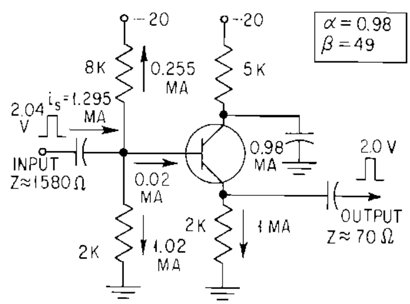

FIG. 1-21

The common-emitter configuration finds wide applications where either current gain or voltage gain is required. In general, it provides more gain than the common-base configuration, but its frequency response for a given transistor type is more severely limited.

As shown in Fig. 1-21, the common-collector circuit behaves very much like a conventional cathode follower. The important characteristics of this circuit are (1) a voltage gain only slightly less than unity, (2) a current gain slightly less than unity (This is not necessarily typical of emitter followers, but results from the use of relatively low bias resistors. Note that the current gain of the transistor itself is +1, a value which could be approached in the complete circuit by the use of very high bias resistors, at some sacrifice in temperature stability), (3) no polarity inversion, (4) a moderately high input impedance, and (5) a relatively low output impedance, consisting of the output impedance of the transistor shunted by the load resistor. The impedance characteristics of this circuit could be changed substantially by altering the bias network. For example, if the two resistors in the base circuit were increased 10 times to 80K and 20K, the input impedance would become about 13,800 ohms, the output impedance would go up to about 305 ohms, and the current gain would go up appreciably.

HANDLING HINTS AND PRECAUTIONS

We hope that we have succeeded thus far in introducing the transistor as a potential friend and ally of the broadcaster. As in the case of any good friend, the transistor has a right to be treated with a reasonable degree of consideration and respect. The rules of etiquette when dealing with transistors are really quite simple and should not interfere with the smooth workiug of the broadcaster-transistor team.

The most important rule to remember is that the transistor is a tiny little fellow with little capacity to absorb heat. He does his best work when kept cool and commits suicide in protest when his junction temperature is raised above a safe limit. He appreciates the delicate touch of a pencil-type soldering iron, applied only sparingly to his leads. A big 200-watt bruiser can make him very unhappy, even if it is only held near his case. It's a good idea to use a transformer-type soldering iron, because many 110-volt types pass enough leakage current through their tips to damage a small transistor.

There are many potential hazards in the servicing of electronic equipment that can cause a transistor to fail, usually from a momentary thermal overstress. In the case of equipment employing socket-mounted transistors, it is important to remember that, unlike tubes, transistors can easily be inserted in their sockets the wrong way, possibly resulting in the application of excessive voltages. A few minutes spent in gaining familiarity with transistor basing arrangements and socket connections will pay big dividends in avoiding frustrating accidents. It is wise to adopt the general rule that power should always be removed before inserting or removing a transistor from its socket. A brand-new transistor may lay down its life in vain if it is expected to absorb a charging surge for a capacitor or if its bias is suddenly altered by the removal of a circuit mate in an adjacent socket. If the broadcaster finds it absolutely necessary to poke around in a "hot" transistor circuit, he would do well to use well-insulated test prods and miniature test leads. As noted earlier, a transistor gives no visible or audible warning when it has become the victim of an accidental short circuit—it just doesn't feel like working any more.

One of the attractive features of transistors is the ease with which they can be tested, at least superficially, with an ordinary ohmmeter. It is important, however, that only the $R \times 10$ or higher scale be used. The $R \times 1$ scale on most ohmmeters can deliver enough power through the test leads to destroy a small transistor. Resistance measurements between emitter-base and collector-base pairs should both show a very low resistance in one direction and a relatively high resistance in the other; that is, the test should indicate that there is an active diode between either of these pairs. The direction of easy current flow (low resistance) depends upon whether the transistor is of the *p-n-p* or *n-p-n* type. Resistance measurements between the emitter and collector leads should always indicate a high resistance in both directions. If a transistor passes all these ohmmeter tests, chances are very good that it is an operable unit.

The authors hope that those broadcasters who have first become acquainted with transistors through this part will enjoy a long and happy association with them.

Further information can be obtained from An Introduction to Junction Transistors by R. N. Hurst, appearing in the October, 1958, issue of *Broadcast News*. We wish to acknowledge the generous and constructive assistance of Mr. Arch C. Luther, Jr., in the preparation of this material.

Part 2

SUBSIDIARY MULTIPLEX SERVICE FOR FM BROADCAST STATIONS

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FM MULTIPLEXING †

A unique form of broadcasting is now in use that enables the FM broadcaster to enhance his income. By a process known as multiplexing, additional program channels are transmitted on the same carrier that serves the general public. By specific authorization of the Commission, these "closed-circuit" channels can be used for such purposes as transmitting background music or commercials to stores. The purpose of this portion of the part is to describe the technical processes and equipment required to make possible this method of broadcasting.

General System

In order to multiplex, a high-pitch or supersonic tone is transmitted along with the regular program heard by the public. In other words, a high-pitch tone far beyond the range of the human ear is generated and sent into the transmitter. The pitch, or frequency, of this tone will be between 20,000 and 75,000 cps as compared with the regular main-channel audio that lies between 50 and 15,000 cps. This supersonic tone, in turn, is "modulated" with the desired audio and at the receiving end is filtered from the main-channel audio and in turn "detected." Thus, special receivers will hear the information transmitted on the so-called "subcarrier" and the general public will be unaware of its existence.

The high-pitch tone called the subcarrier is in turn modulated with program information by a frequency-modulation method. We now have an FM-on-FM system where a frequency-modulated supersonic tone is in turn frequency-modulating the signal transmitted by the station along with the regular program material heard on the regular FM receiver.

* No longer employed in this capacity.
† By Dwight Harkins.

Since AM broadcast transmitters and bandwidth allocated would not permit the transmission of these supersonic tones, multiplexing is available to broadcasters in the FM band from 88 to 108 Mc.[1] Each station is allocated sufficient bandwidth to permit transmission of the complex signals generated without causing interference.

At the present development of the art, two supersonic tones or subcarriers are being transmitted in addition to the regular audio below 15 kc. This allows a single transmitter to broadcast three separate programs at the same time. The Federal Communications Commission will grant authorization for a Subsidiary Communication Authorization permitting the FM broadcaster to use these multiplex channels for such purposes as storecasting, functional music, and similar closed-circuit uses where the listener must subscribe to the service. The function of the station as a broadcast service to the public is not changed.

Although FM is well known to be capable of broadcasting audio frequencies up to 15,000 cps with low distortion and noise, the system must now faithfully transmit and receive up to 75,000 cps in order to permit successful multiplexing.

In both the transmitting system and at the receiver certain techniques must be used to prevent intermodulation taking place. The first type of intermodulation or cross modulation is that caused by the regular program audio modulating the transmitter in the range of 30 to 15,000 cps. This undesired intermodulation shows up as cross talk of the main-channel program breaking through into the subcarriers. This occurs both in the transmitting end and at the receiver.

The second type of intermodulation is that caused by noise pulses. The FM method of transmission has been long considered noise- and static-free through the use of limiters in the receiver. For normal FM broadcast reception this has been adequate. When a noise pulse actually phase-modulates the supersonic subcarrier, however, this noise cannot be removed by amplitude limiting or any other known method of reception technique. If the multiplex channels are to be received as well as the main channel, all parts of the system must be designed to prevent intermodulation or phase modulation by noise pulses. When this has been accomplished, reception of the subcarriers can be realized throughout the same coverage area served by the regular FM broadcast service.

Figure 2-1 shows a block diagram of the transmitting and receiving process. The equipment needs for an over-all system consist of an exciter, a subcarrier generator, a station multiplex monitor, and the receiver. Each of these will be described in detail. Before the individual sections of the over-all multiplex system are described, the problem of cross talk, intermodulation, or cross modulation that is common to all parts of the system will first be discussed.

Causes of Cross Talk

To understand better the cross-talk problem and its cure, an examination of basic FM theory must be made. As the transmitted carrier is modulated, the energy is divided up into additional carriers known as sidebands. In comparing FM with AM, it can be shown that the AM carrier develops an upper and lower sideband of energy directly related to the audio frequency being transmitted. The total power being transmitted varies directly with the modulation and is not constant. One hundred per cent modulation in the case of AM is considered that point where the audio wave has caused the AM carrier to go to zero instantaneously on one half the cycle and to twice carrier amplitude on the other half of the audio cycle. Modulation beyond the 100 per cent point causes severe distortion, since the carrier voltage is doubled on the upward swing of AM and the radiated power is the square of this or four times. The energy of the additional power radiated by the AM transmitter is to be found in the sidebands generated from the audio introduced into the modulation system. With a sine-wave audio signal modulating an AM transmitter 100 per cent, the average power output will be found to be 1½ times that of the unmodulated carrier.

The pair of sidebands above and below center carrier in the AM case are found to be 180° out of phase with each other.

[1] 88 to 92 Mc allocated to educational stations.

In the FM case, radically different conditions exist. *First,* as the audio modulates the carrier by causing it to shift in frequency, the total power radiated is unchanged. *Second,* the carrier power is divided into many sidebands above and below unmodulated carrier in frequency. *Third,* the energy in the sidebands represents a portion of the center carrier power. *Four,* the individual upper and lower sidebands created are 90° out of phase with each other. *Five,* under certain conditions the total carrier power is divided up among the sidebands and the carrier is absent. *Six,* the position and amplitudes of the sidebands is a direct relation between modulation freqnency and amount of carrier shift in frequency. This is known as the modulation

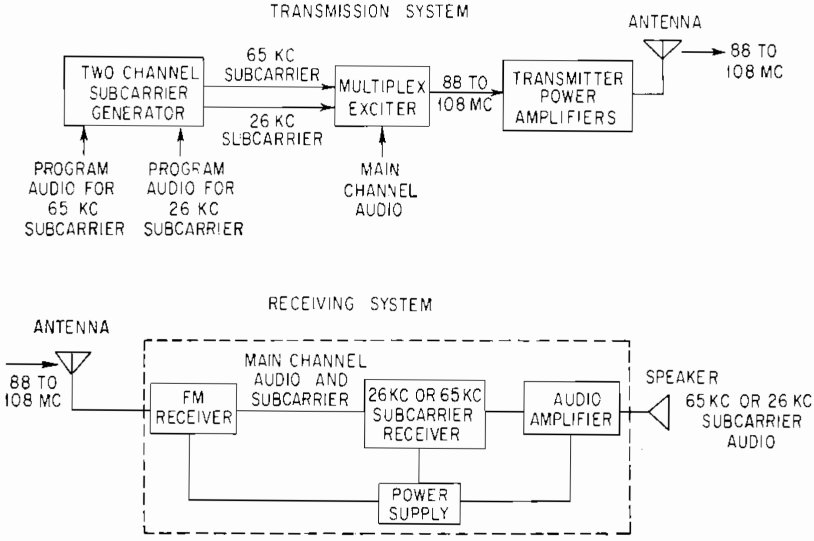

FIG. 2-1. Block diagram of transmitting and receiving process.

index and is determined by dividing the amount of carrier deviation by the modulating frequency. *Seven,* the point of 100 per cent modulation is established in the FM system by system standards rather than limitation of the process. For example, 75-kc deviation is considered 100 per cent for the FM broadcast band, while 25-kc deviation is considered 100 per cent for the TV aural transmission. FM microwave units will deviate several megacycles with ease.

It is seen at this point that the FM signal is much more complex than the AM wave. For example, a 1,000-cycle tone modulating the FM rig 100 per cent would produce several hundred sidebands above and several hundred below the center carrier. The streugth of each sideband can be computed mathematically and easily tuned in and measured individually with the proper equipment. Those sidebands that fall more than 75 kc above and below center carrier are usually considered insignificant for undistorted reception of the audio signals between 30 and 15,000 cps in the case of the FM broadcast transmitter.

Since we are now dealing with a complex signal occupying quite a bit of space above and below carrier, we must reckon with the bandwidth of the system in order to allow all the desired components to reach the point of detection.

For example, in the AM case, a bandwidth in the system of 10 kc would accommodate the upper and lower sidebands from a 5,000-cps audio signal modulating the transmitter 100 per cent. In the FM case, a bandwidth of 150 kc would be called for to accommodate the upper and lower sidebands created by the same modulation. Even with a bandwidth of 150 kc there would be a small percentage of the generated sidebands that did not get through.

The term "bandwidth" is used to describe the ability of a tuned circuit, transformer, antenna, or any device used in the transmitting and receiving system to pass a certain "band" of frequencies instead of just one single frequency. For example, a circuit that permits equal passage of frequencies from 1,000 to 1,100 kc and rejects all others would be said to have a bandwidth of 100 kc. For many years, the FM receivers sold to the public have been built with IF bandwidths of 200 to 300 kc to ensure high-fidelity reception of the FM signal. Prior to multiplexing, the highest audio frequency desired to be passed was 15,000 cps. Prior to multiplexing, the measuring stick for successful FM broadcasting consisted of low harmonic distortion, low residual noise, and flat frequency response in the audio range. Measurements of intermodulation distortion were never taken or required by the Commission. As a matter of fact, the intermodulation distortion between low and high audio frequencies was low enough that it was not considered a factor of performance. The intermodulation between a tone of 1,000 cps and one of 25,000 cps, however, was a horse of another color and was found to be on the order of 5 to 10 per cent at the receiver. This was especially discouraging to multiplexing, as the intermodulation showed up in the supersonic tone as a phase-modulated component of the lower audio tone.

The causes of cross talk can be generalized by referring to the basic FM theory outlined. It was pointed out that the FM signal consisted of many sidebands which are found to be 90° out of phase when any pair above and below the carrier center is compared. It can now be stated that any part of the transmitting or receiving system that either restricts the passage of the sidebands or alters the phase relationship of the sidebands will cause cross talk. The observed result in either case is the same. With either narrow bandwidth or phase distortion the FM carrier develops an amplitude-modulation component. Its amplitude varies with modulation. The existence of a combination AM and FM signal is easily ascertained with relatively simple measuring equipment. The limiting action of Class C stages of the transmitter coupled with the receiver limiter tend to "whitewash" the apparent AM component, but even though limited out, a remaining phase intermodulation makes multiplexing unsuccessful.

This last statement is best understood by recalling the early days of AM broadcasting when it was found that frequency modulation was an unwanted byproduct of amplitude modulation. It is to be remembered that one of the original methods of obtaining phase modulation consisted of first creating an amplitude-modulated wave, then clipping out the AM components or balancing them out and proceeding to use the residual phase shifts produced as the basis for multiplying into an FM signal.

If the audio modulating the FM transmitter produces an AM component anywhere in the system from start to finish, the result is cross talk into the subcarriers. With this basic fact established, the individual components of the system will be described with pointers showing how the pitfalls of multiplexing are avoided.

The Exciter

All existing FM transmitters have one function in common. All of them produce the modulation at a relatively low frequency and then by means of multipliers arrive at the transmitting frequency in the 88- to 108-Mc region. By process of multiplication, the amount of deviation is increased directly by the factor of these stages. In the transmitters using reactance-tube modulators the multiplication is on the order of 11 to 16 times, while in the transmitters using phase modulation, or "indirect FM," the multiplication is from 400 to 1,000 times in various units.

Early in the experiments toward multiplexing, it was discovered that the simple process of introducing the supersonic subcarrier along with the regular audio was impractical owing to the bandwidth restrictions of the lower frequency multiplier stages. It was found that a secondary modulation stage higher in the multiplication stages would be best for subcarrier injection and that a low-distortion and low-noise-modulation system must be used for the main channel.

Meeting all requirements for the main channel was the system known as the Serrasoid, developed by J. R. Day (*Electronics*, October, 1948). The Serrasoid has proved itself to be reliable, with extremely low distortion and noise along with excellent linearity of frequency response. It also enables direct crystal control of the center frequency of the station. As incorporated in the multiplex exciter, the output of the Serrasoid is multiplied 972 times to make possible the necessary deviation of plus or minus 75 kc at the output frequency.

Figure 2-2 illustrates the schematic of the Serrasoid section. *V*1 is a crystal oscillator functioning in the 100-kc range and chosen so that its frequency multiplied by 972 arrives at the assigned frequency of the station in the FM band. The oscillations of the crystal are converted into positive pulses by *V*2. These pulses are applied to *V*3, both halves of which make up a nonoscillatory sawtooth generator and bootstrap cathode follower, timed to allow a linear sawtooth wave to be developed upon the application of each input pulse.

The linear sawtooth waves thus generated at a recurring rate of approximately 100 kc are applied to the grid of *V*4, and the cathode resistor adjusted to a point where the grid bias created by plate current is such that conduction occurs wheu the sawtooth applied is about 50 per cent of its way up. Upon conduction, the balance of the sawtooth wave is clipped, and at the very instant the tube conducts, a negative pulse is observed on its plate. This is the most important event of the process, for it is by this means that the linear sawtooth can be utilized to produce a phase-modulated or frequency-modulated transmission.

If the cathode bias resistor on the left half of *V*4 is varied, it is easily shown on an oscilloscope that the negative pulse formed on the plate at time of tube conduction will vary its position either sooner or later in reference to the starting of the sawtooth. In other words, a conduction point lower or higher on the slope of the sawtooth causes the plate pulse to be formed in time position either sooner or later. If, instead of varying the conduction point by adjustment of the cathode potentiometer, an audio voltage was applied at this point, the plate pulses would be positioned by the audio voltage superimposed upon the cathode. At this time a system of pulse-position modulation has been developed or, to put it another way, the plate pulses are phase-modulated by the audio voltage determining the instantaneous conduction point of the tube.

The amount of phase shift possible with this circuit is on the order of plus or minus 150°. In actual application, only 90° of plus or minus 1½ radians is used as the basis for producing 100 per cent modulation at the output frequency after being multiplied 972 times. Since all systems of phase modulation deviate 6 db/octave more as the audio frequency is increased, it is apparent that the greatest excursions of the sawtooth clipping will occur at 50 cycles and that the familiar "predistortion" network must be applied to the audio signal in order to realize flat response required for frequency modulation. In addition to this, preemphasis must be inserted to allow the final product to meet the Commission's Standards for FM stations.

The two audio tubes and associated circuits not only provide a distortion- and noise-free audio signal for the cathode of the sawtooth modulator tube but also include the corrections in the response curve that are necessary.

Figure 2-3 shows waveforms resulting in the pulse-forming and modulation process just described. The phase-modulated negative pulses are inverted to positive-going pulses by the other triode section of *V*4. These positive pulses are applied to the grid of the first of a string of multipliers. In the first plate load, the resonant circuit converts the pulse into a frequency-modulated sine wave. After a series of multipliers being doublers and triplers a total factor of 972 yields a carrier in the FM band with a deviation capability considerably in excess of plus or minus 75 kc.

Probably the only deficiency of this system of modulation is that the fundamental crystal frequency is so low that it produces a component in the early multiplier stages that rides through to the final of the transmitter. For example, a station operating on 97.2 Mc would have a master crystal of 100 kc. This 100-kc component appears at the 300-kc stage and thereafter just as an unwanted subcarrier. In order to attenuate this unwanted 100-kc component better than 70 db, the arrangement of Fig. 2-4 was used at the first multiplier stages.

Referring to Fig. 2-4, *L*1 through *L*6 are tuned to 300 kc and then stagger-tuned

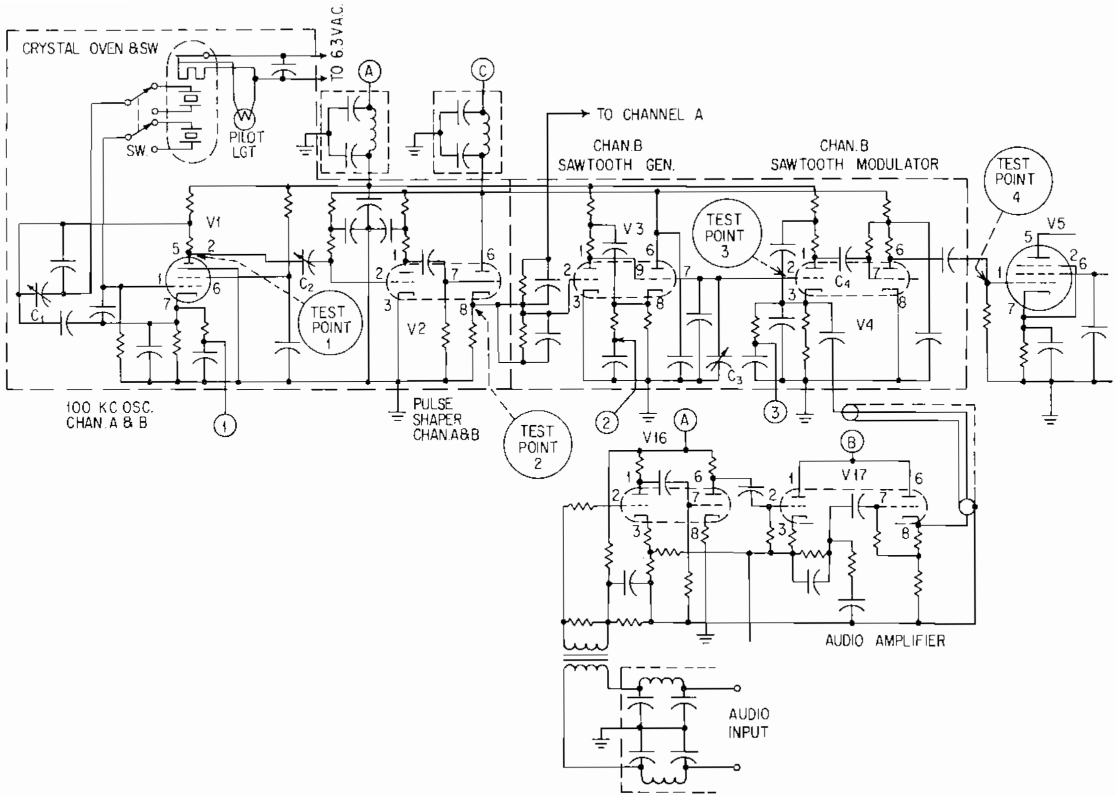

Fig. 2-2. Schematic diagram of Serrasoid modulator.

to produce a 30-kc bandpass. This is necessary in order to allow 15,000-cps audio modulation properly and at the same time to give better than a 70-db rejection of the 100-kc crystal component. This filter network further rejects unwanted noise and hiss products in the regions above 15 kc. If only an excellent FM transmitter were desired, we could let our development stop at this point. However, certain additional precautions must be taken in the multiplication process to make possible multi-

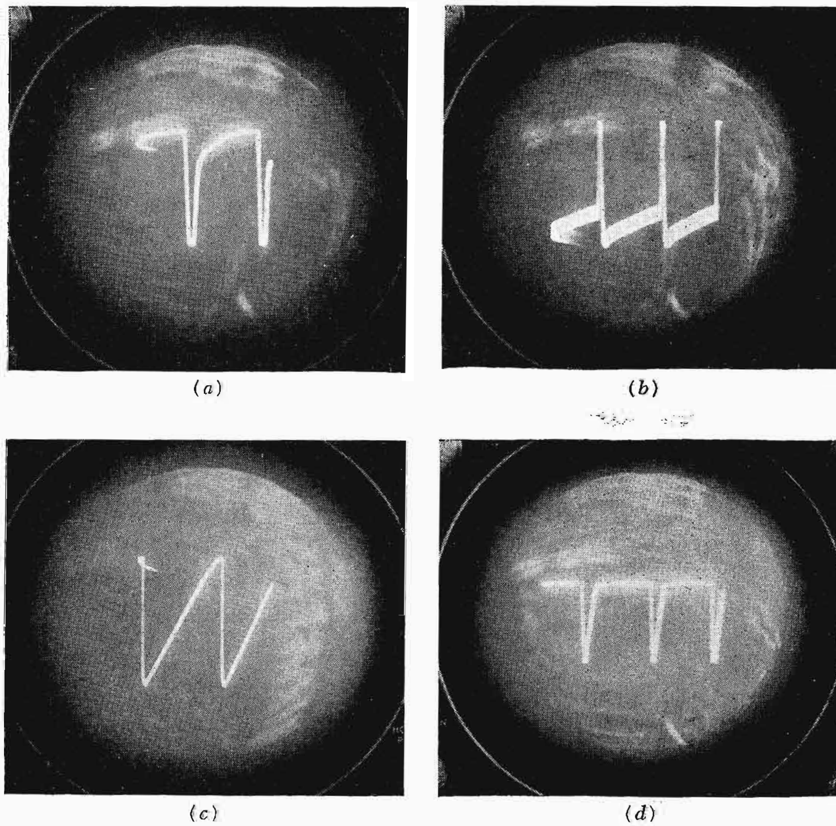

FIG. 2-3. Waveforms resulting from pulse-forming and modulation process. (*a*) At plate of *V*1. (*b*) At pin 2 of *V*3. (*c*) At test point 3 with full bias. (*d*) At test point 3 with cathode bias set for normal operation.

plexing. The circuits normally used for multipliers in FM transmitters have been found to have insufficient bandwidth as well as phase distortions whenever the carrier was modulated. A remedy was found in the use of interstage filters as shown in Fig. 2-5.

It will be seen in Fig. 2-5, that *L*1 and *L*3 make up the parallel-resonant circuit of the plate and grid and are coupled together at a low-impedance point by the series-tuned circuit. The circuit is tuned to have a passband of at least 500 kc.

As outlined earlier, phase distortion produces an AM component which, in turn, causes cross talk. When a signal passes through a stage such as the one under discussion, the circuit is to be measured not only in respect to amplitude vs. frequency but also by phase shift as the frequency changes. In any network or filter, the phase shift is zero at a certain frequency, usually the center frequency of the filter. As the frequency goes above or below center, the phase shift changes but not always in exact ratio to the change in frequency. If, for example, the change in phase as the frequency is shifted higher is at a different rate from the change in phase as the frequency is lowered, we then have a nonlinear phase shift. In this case we want the positive phase shift to occur the same distance away from center frequency as the

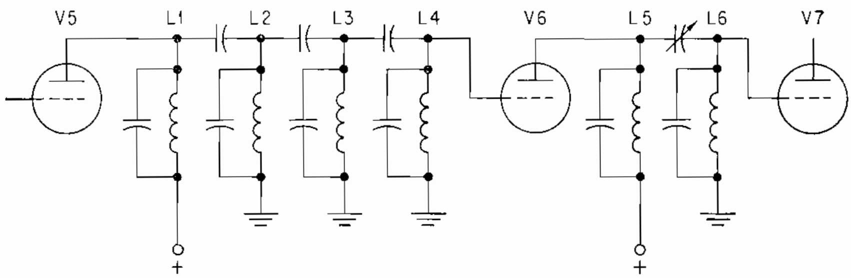

FIG. 2-4. 300-kc attenuation circuits in first-multiplier stages.

negative phase shift occurs on the other side of center frequency. A regularly tuned circuit has a relatively narrow range of linear phase shift.

The phase shift must be linear throughout the range of frequencies occupied by the many sidebands generated by the FM signal. When properly adjusted, no AM component can be detected resulting from the signal going through this multiplier stage. This form of interstage coupling is used in all the multipliers operating below 20 Mc. Above that frequency the desired linearity is obtained with overcoupled coils.

Thus far we have dealt only with obtaining the main-channel modulation and ensuring that it is treated correctly as it is being multiplied to operating frequency. At the 10-Mc level we are now going to add an additional phase modulator and inject the supersonic audio tones known as subcarriers. We desire a device that will phase-shift the carrier already on hand at this frequency and yet not cause any amplitude variation from either the supersonic tones to be added or the audio-modulation components already present from the earlier Serrasoid modulations. Such a device was found with the simple circuit of Fig. 2-6.

In this circuit, variation of the transconductance G_m of the tube has no effect on the magnitude of the output voltage. It will cause the phase of this voltage to vary over a total range of 180° as the transconductance varies from zero to infinity. The device does not have very good linearity because the relationship between the phase shift with change in transconductance and in turn in relation to the modulating voltage is not correlated. By "juggling" the balance of the three nonlinearities, it is easily possible to obtain a relationship between phase shift and the modulation voltages of the subcarriers that is linear over the limited range required. Because of the high frequency of the subcarriers relative to the audio frequencies the amount of phase shift required is in the order of only a few degrees. This tube offers no amplification to the carrier as it passes through to the next multiplier stage. Application of lower audio frequencies below 15,000 cps does not result in enough phase shift to be measured at the transmitter output.

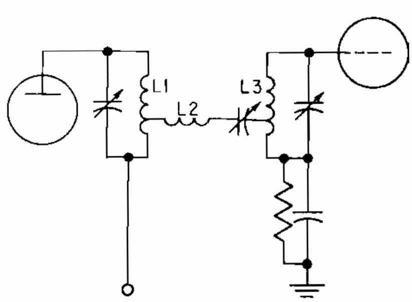

FIG. 2-5. Diagram of interstage filter.

If two subcarriers are injected, they are allowed to deviate the main channel 15 per cent each in accordance with the Commission's regulations.

After the subcarriers are injected, the signal goes through additional doublers and triplers until it reaches output carrier frequency. The exciter then delivers a signal of approximately 15 watts power at carrier frequency.

At this time, over-all measurements should be made, and if all circuits are functioning correctly, the main-channel proof-of-performance figures will be considerably better than the Commission's requirements and the subcarrier will have cross talk lower than 50 db below a reference obtained by 10-kc deviation at the same time that any audio frequency is modulating the main channel 100 per cent (75 kc).

The exciter can now be used to drive the power stage of the station's existing transmitter and the signal then radiated from the antenna. It is at this point that some unusual variations in results have been obtained in experience gained from over

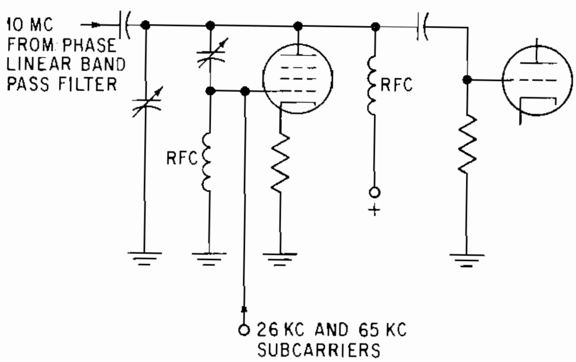

FIG. 2-6. Schematic of circuit to produce carrier phase shift with no amplitude variations.

50 installations around the country. In order to tune the equipment properly, a multiplex station monitor was developed. This device is a linear demodulator, making possible the detection of the entire signal and the further demodulation of the subcarrier. Direct measurements of cross talk are made possible, and transmitter tuning is done to find minimum cross talk. If necessary, the monitor can be coupled into the main transmitter at any point in order to isolate the stage in which the cross talk may be produced. In the transmitters which have been modified thus far, the most critical stages have been tetrodes and their neutralization adjustments. Coupling between stages has also been found critical.

By far the most troublesome part of the transmitting equipment has proved to be the antenna system. If, for any reason, the VSWR is appreciably more than unity, a condition is created making it impossible to get the same signal generated by the exciter on the air. In some cases, the antenna has caused as much as 20-db reduction in the cross-talk readings, making for a subcarrier that is not usable.

Under ideal conditions all the energies contained in the upper sideband maintain an exact phase relationship with the lower sidebands. If the transmitter is loaded into an incorrectly tuned or terminated antenna system, a reactive load exists which offers a different reaction to the upper sidebands from that to the lower, and as a result of phase shifts, the correct relationship between sidebands no longer exists as before. The first obvious result is the development of an AM component in the FM signal. This normally does not degrade the regular FM service but, in connection with multiplexing, causes serious intermodulation of the subcarrier (or cross talk).

Since it is the purpose of this part to outline the processes, it is well that the station engineer who contemplates multiplexing be made aware of the importance of all aspects, especially the transmitter antenna.

In the power stages of the FM station the following items have been found to cause degrading effects:

1. Improper coupling between stages
2. Improper neutralization
3. Regeneration of any type (such as between stages)
4. Old tubes
5. Improperly adjusted harmonic filters
6. Defective transmission lines
7. Improperly tuned antennas
8. Improperly terminated transmission lines

Although the bandwidth linearity problems imposed by multiplex transmission are not so stringent as for television, the same problems exist. If a transmitter and antenna were designed to equal that of a TV system, the problems just discussed would probably be nonexistent.

Bandwidth Occupied

During the development of FM multiplexing, the Commission requested a study of the spectrum occupied by the FM signal. The question arose as to whether or not the addition of subcarriers caused any spurious radiation outside the bandwidth allocated. For purposes of these tests, a panoramic receiver was used together with a frequency meter and a sensitive communication receiver. With a 15,000-cps signal modulating the main carrier 55 per cent together with a subcarrier of 26 and 65 kc modulated 15 per cent each, a measurement of the intensity of each sideband was made. Results of this test as well as with many other modulating frequencies on the main channel proved that multiplexing did not create any undesired effects outside the bandwidth allocated for the station.

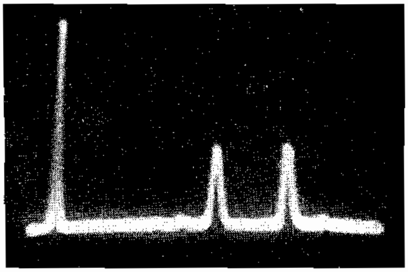

Fig. 2-7. Panoramic presentation of main carrier relative to the first sidebands above 26 and 65 kc.

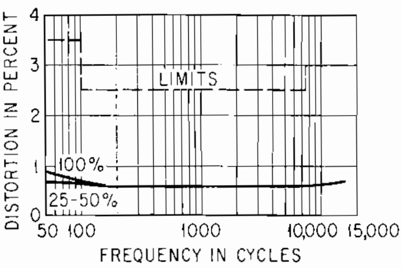

Fig. 2-8. Distortion measurements on main carrier at WMBR-FM.

Figure 2-7 shows the panoramic presentation of the main channel in relation to the first sidebands above 26 and 65 kc. Since the modulation index of the supersonic subcarrier frequencies is so low, only the first pair of sidebands is significant and the second pair is better than 60 db down. No deterioration of the main-channel performance has ever been encountered due to multiplexing. Typical of main-channel results is the chart of Fig. 2-8 from an installation at WMBR, Jacksonville, Fla.

Subcarrier Generator

In addition to the multiplex exciter just described, an additional unit must be used which actually generates the modulated supersonic subcarriers. The subcarrier generator consists of a Serrasoid modulator operating at 100 kc whose output goes through a string of multipliers until it deviates at least plus and minus 10 kc which occurs at about 19.2 Mc. This FM signal at 19.2 Mc is then beat against a fixed crystal oscillating at 19.265 Mc to produce a 65-kc beat note. This beat note is amplified and filtered to become the actual subcarrier injected into the exciter. In the two-channel generator, the use of a second Serrasoid together with a multiplication chain of different frequencies is used to produce a beat note of 26 kc. The generator unit also includes a demodulation unit that acts as a frequency monitor and modulation monitor of the subcarrier.

Receiver

Assuming that all elements of the transmitting system are operating correctly, a receiver must be used that does not distort the correctly generated signal. Unfortunately, the same circuits that are used to provide maximum gain and noise reduction are also guilty of manufacturing conditions that cause intermodulation or cross talk. In the ideal receiver, a signal would be demodulated that accurately reproduces the modulation imposed at the transmitter.

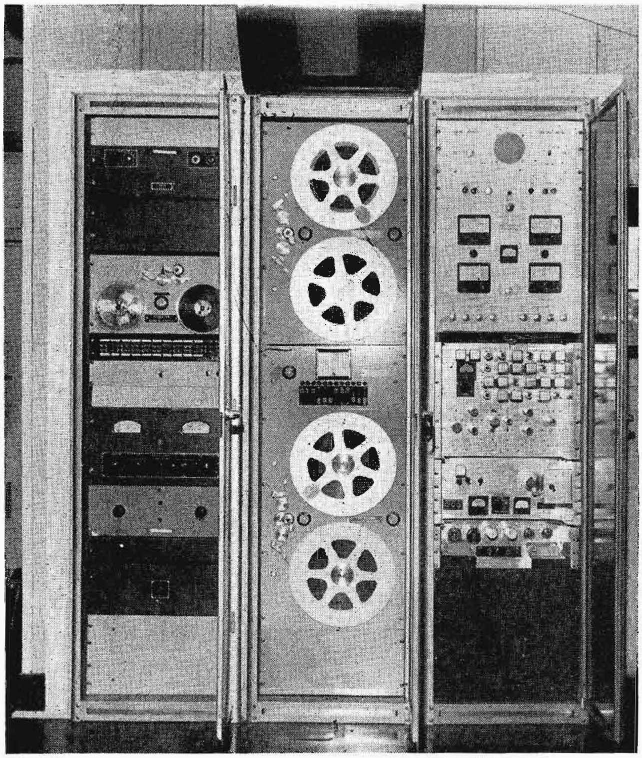

Fig. 2-9. Multiplex installation at WMBR, Jacksonville, Fla. Multiplex monitor, two-channel generator, and exciter are at the right. One subcarrier is programmed with music only, while the other channel is used for transmitting commercials and music to a group of chain-store supermarkets.

The multiplex receiver consists first of a main-channel section comprising a crystal-controlled oscillator used to form the IF, which is, in turn, amplified and detected.

At the main-channel detector, the supersonic subcarrier is filtered out, amplified, limited, and then detected. The "count-down" detector has proved most popular for the last function.

If the receiving antenna is incorrectly oriented or its transmission line mismatched, a condition of cross talk can be easily produced.

Under actual operating conditions in over 50 cities, it has been proved that commercial multiplex operation is possible at any location where main-channel reception is enjoyed. Some stations have subscribers at locations more than 100 miles from the transmitter. Techniques similar to fringe-area TV reception are employed in the reception of the fringe-area multiplex signal with signal boosters and high-gain antennas being used. From the standpoint of service requirements it has been proved that if the installation of the receiver is made correctly, no more service calls are required than for a normal FM receiver.

Development of the multiplex receiver has been the last portion of the step-by-step perfection of multiplexing. During the first few years multiplexing was used by broadcasters, there was not available a linear station multiplex monitor and it was common practice to use a multiplex receiver to seek best transmitter adjustment. This led to misleading conclusions, since it was possible to adjust certain receiver nonlinearities to counterbalance transmitter faults. When the transmitter and receiver nonlinearities were carefully balanced against each other, some remarkable results were obtained. Unfortunately, if a hundred receivers were so aligned by stagger tuning and then a minor adjustment made at the transmitter, all receivers would have to be readjusted for a new point of correct operation.

Along with the development of a phase-linear receiver it was found that correct operation resulted when all circuits at both the transmitter and the receiver were tuned to resonance. All circuits in the phase-linear receiver are tuned only for correct maximum reception of the main channel. Transmitter adjustments are likewise made the same way, with a daily check with the station monitor.

Achievement of the low-intermodulation characteristics of the receiver follow the same principles as in the transmitter and exciter, except when applied to the IF strip and detector itself.

System Requirements

From the installations made throughout the country it has been ascertained that a commercially usable system must have a signal-to-noise ratio on the subcarrier approaching 40 db. This is qualified to mean that a ratio of 40 db exists between the modulation peaks normally received on the subcarrier and the measured residual noise with no modulation. The residual noise then measured is that caused either by main-channel modulations or by other noise generated in the system. If the transmitter and station antenna permit a 50-db signal, this allows a 10-db margin of safety in the receiver. For actual measurement purposes, the main channel is modulated 100 per cent with 1,000 cycles.

The art of broadcast multiplexing has been commercially applied for a relatively short time. Most of the improvements have come from actually field testing at the same time commercial use was being made of the system. A vote of thanks is due the many station engineers who have spent countless nights of testing, obtaining the peculiar behavior patterns of equipment observed during multiplex operation.

The following is a partial list of the stations at which tests have been conducted: WBBQ, KQXR, KHFM, WCRB, WCPO, WSAI, WHK, KDMC, KDFW, WXFM, KBMS, KWJB, WGCM, KAIM, WMBR, WJDX, WKZO, KCMO, KCMK, KMLA, KGLA, KRKD, KSEL, KCMS, KWFM, WLOL, WMCF, KTYL, WAHR, WWMT, WMC, WBFM, KABC, WHLD, WPEN, WWSW, KGMS, KSL, KITE, KDFC, KCCT, WPIC, KCFM, KTKT, WWDC, WMAL, and WTOP-FM.

PRACTICAL ASPECTS OF MULTIPLEXING *

Introduction

The Rural Radio Network started operations as an FM-only relay operation in June, 1948. The system is shown in Fig. 2-10 with the approximate coverage of each station. Affiliated with the network are six other FM and 21 AM stations.

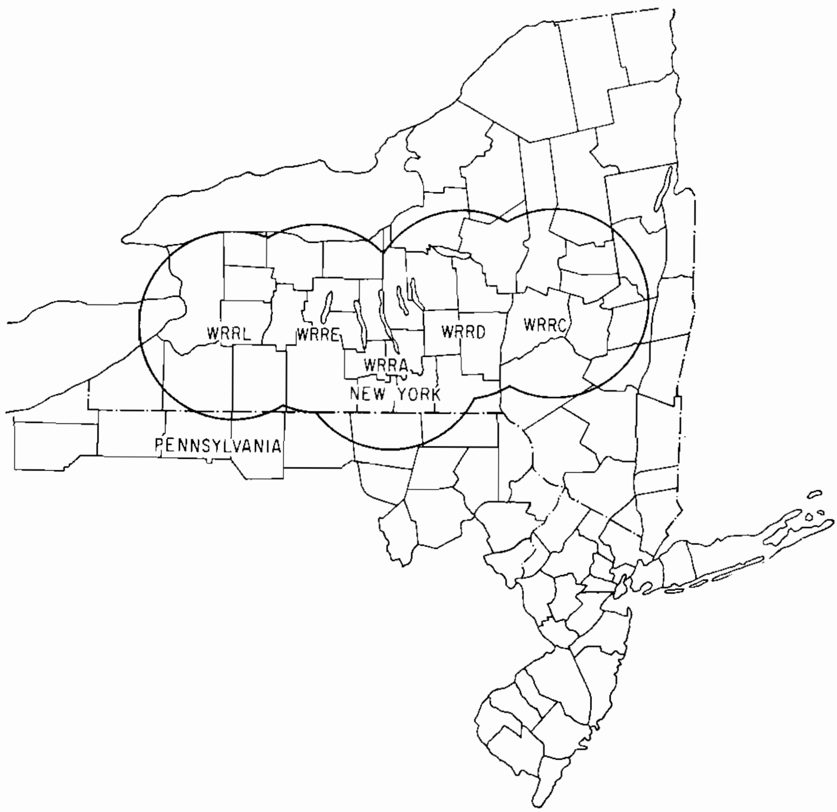

FIG. 2-10. Rural Radio Network, operated by Northeast Radio Corp.

Basic equipment for each station in the network is a General Electric 250-watt exciter, 1,000-watt power amplifier, and an RCA four-bay pylon antenna. Gasoline-motor-driven auxiliary power plants automatically take over when commercial power fails.

Multiplexing was included in the original plans for the network. The first actual use of multiplex was made in 1948 when a constant-amplitude variable-frequency facsimile system was developed. In 1950, we again operated multiplex facsimile, this time relaying from New York City to Ithaca by FM relay through four stations. The same year, we operated radio photo on an experimental basis between Ithaca and Buffalo with a successful series of tests through three stations. Although both were reliable and quality was good, they were not commercially feasible at that time.

* By Donald E. Udey.

Transmitting

The economic aspects of relaying over a five-station FM network already in existence on a relay basis becomes quite apparent when one considers the equipment necessary. Only one complete set of FM multiplex equipment is needed at the point of origin, WRRA. This equipment consists of subchannel generators, the main-channel Serrasoid modulator, and a phase modulator to inject the multiplex signal on the main carrier.

At each relay station, the only equipment necessary is a relay receiver to pick up the subchannel, a phase modulator to reinsert the subchannel on the carrier, and the Serrasoid modulator for the main-channel frequency. Thus, it is unnecessary to have subchannel generators at each of the remote stations. This amounts to a substantial saving on initial purchase, as well as cutting down maintenance and having less equipment to cause trouble.

There are several advantages to this type of operation, the most important probably being that the quality of the subchannel does not deteriorate so much as if the subcarrier program were returned to audio and remodulated on the subcarrier at each station. Preliminary tests have shown no appreciable increase in cross talk with each relay point. The cross talk originates mainly in the transmitter originating the subchannel and in the receivers involved. Relay stations which do not have subchannel generators do not appear to increase cross talk. As an example, we measured 52 db down on cross talk at WRRA and the same measurement at WRRI after the program had gone through WRRE, a total distance of 88 miles. Particular attention must be paid to relay receivers to see that they operate with minimum noise and distortion, as well as minimum cross talk.

We are serving a large territory with comparatively low-powered transmitters. Our signal gets into areas which are far beyond range of telephone-line facilities because of line charges. Many small businesses which cannot afford wire service or on-premise installation of music equipment can be served. Chain-store organizations that would not be interested in a strictly local service are prospective customers because of network operation.

As may be expected, some difficulties were encountered in installation of the multiplex relaying system. These difficulties are of two types: first, interference caused by others; second, interference caused by our own operation.

Some interference was encountered at WRRL from a Canadian television station. This station did not interfere on main channel but did interfere on subchannel. Additional filtering was required to relieve this situation. At WRRD, we encountered interference from a local FM station. This interference was quite serious and required two coaxial high-Q bandpass filters to eliminate it. These were custom-made filters constructed from 1⅝-in. coaxial transmission line. Here again, interference was on our subchannel only, and not on main channel. Commercially available notch-type filters were tried but with only a slight improvement in eliminating unwanted interference.

Remote Control

Several years ago our manual operation was converted to a radio-operated remote-control system, designed and constructed by our own engineering department. WRRA was chosen as the control point because of its central location. The first subchannel was put at 67 kc to get as far away from this remote-control operation as possible. The remote control uses frequencies of 19 through 29 kc with 1,000-cycle separation and a single frequency at 45 kc for control of the four remote stations. Obviously lower frequency subchannels would directly interfere with these control tones. It was found that by keeping control-tone levels low, we were able to operate the 67-kc subchannel without any interference in either direction.

To understand better what is involved with the remote control system, it is briefly described as follows:

Remote-control functions fall into two distinct categories:

1. Those associated with the audio input requirements of the remote-controlled

transmitter, including receiver selection and station breaks, hereafter called "receiver switching"

2. Those associated with the control of the remote station: adjustments, tower-light checking, auxiliary power-plant start and stop, etc., hereafter called "telemetering." These functions must be independent of each other, either being carried on without interfering with the other.

Receiver Switching. A telephone dial controls the pulsing of tones for transmission on the controlling transmitter (WRRA). A series of one to nine pulses of 19 kc operates stepping relays at each of the four controlled stations. These relays step to the same position and control the audio input of the remote transmitters. This permits control of network feed from any remote station or any affiliate that can be picked up on a receiver at the nearest controlled station. Position 10 on the control dial activates a continuous-loop tape playback at each station giving the station break. A 20-kc pulse controlled by a push-button switch resets all stepper relays to the ZERO or OFF position. As an additional insurance against noise or static stepping the relays at remote stations, a pulse of 29 kc is sent just ahead of the 19-kc pulses. The 29-kc pulse opens a "gate" circuit, holding for 5 sec. Only during that time can the 19-kc pulses operate the equipment. Thus, it takes a combination of first the 29-kc "gate" pulse and then 19-kc pulses to operate the stepper relays.

Telemetering. Station control, adjustment, etc., as described in 2 above is performed by a separate frequency for each station. Considering only one remote station, WRRE, Bristol Center, for example, pulses of 22 kc are used to operate stepper relays giving a total of 19 positions at the remote transmitter. Each position is wired to perform a certain function and/or metering.

Reversible motors control five adjustments. They are a-c input to exciter and final, plate tuning of final, antenna loading, and audio input. Clockwise rotation is controlled by a continuous 26-kc frequency, while counterclockwise rotation is controlled by 27 kc. These two frequencies are controlled at WRRA by a key switch. Transmitter on-off-overload reset is also controlled by first dialing into the proper stepper position and then pulsing 27 kc. Reset for the telemetering steppers is 25 kc and is common to all stations.

Return information from each remote station is by 45 kc. Since only one station can be metered at a time, a selector switch at WRRA picks a meter calibrated for the desired remote station. This same switch picks the proper control frequency for that station. Dialing any metering position from 1 to 19 sends out pulses on the chosen frequency, and only the remote station adjusted for that frequency will respond.

At the remote station, the telemetering stepper moves into the dialed position. A sampling voltage from the desired circuit is used to bias a linear amplifier operating at 45 kc. Changing this bias changes the output of the 45-kc signal. The main FM transmitter is modulated with this 45 kc, and receiving equipment at WRRA detects this on a meter calibrated for that station. This meter uses an expanded scale, and it is actually possible to read it more accurately than the meters on the remote transmitter.

Metering of the remote station can be done while mechanical adjustment is made on associated controls. Thus, the final amplifier plate current can be "dipped" while watching the meter reading. Position 1 is meter calibration, used to compare and adjust the remote-station indicating meter at the control point with a constant-voltage source at the remote station. This assures accuracy of readings on each station.

Control frequencies and their functions are as follows:

19 kc, receiver switching
20 kc, receiver switching reset
21 kc, telemetering control WRRL
22 kc, telemetering control WRRE
23 kc, telemetering control WRRD
24 kc, telemetering control WRRC
25 kc, telemetering control reset
26 kc, telemetering control clockwise rotation
27 kc, telemetering control counterclockwise rotation
29 kc, receiver switching "gate"
45 kc, telemetering return from all stations.

Table 2-1. Telemetering and Control Functions Performed

Function	*Meter reading*	*Controls*
Calibrate	Yes	
Exciter a-c volts in	Yes	Raise-lower
Final a-c volts in	Yes	Raise-lower
Auxiliary power plant	Yes	Start-stop
Final plate current	Yes	Raise-lower
Antenna loading	Yes	Raise-lower
Audio input		Raise-lower
RF output	Yes	
Tower lights:		
Beacon	Yes	
Side	Yes	
Building temp.	Yes	
Transmitter on		On
Transmitter overload reset		Reset
Transmitter off		Off
CONELRAD alarm		Start

A block diagram of the functions of station WRRE is shown in Fig. 2-11. This station relays control frequencies on to WRRL and relays telemetering from WRRL back to WRRA, the control point.

Monitoring. A General Electric BM1A-FM station monitor is operated at WRRA for each remote-control station. Since these monitors were intended to be driven with RF directly from the transmitter, it was necessary to build up the signal from receivers through IF amplifiers. A "flip-flop" aural monitor is employed to monitor two stations constantly. By selector switch any two stations can be picked, but under normal circumstances we monitor WRRL and WRRC, the end stations of the network.

These station monitors, in addition to furnishing the aural signal, also provide readings of modulation percentage and frequency deviation, as required by the FCC.

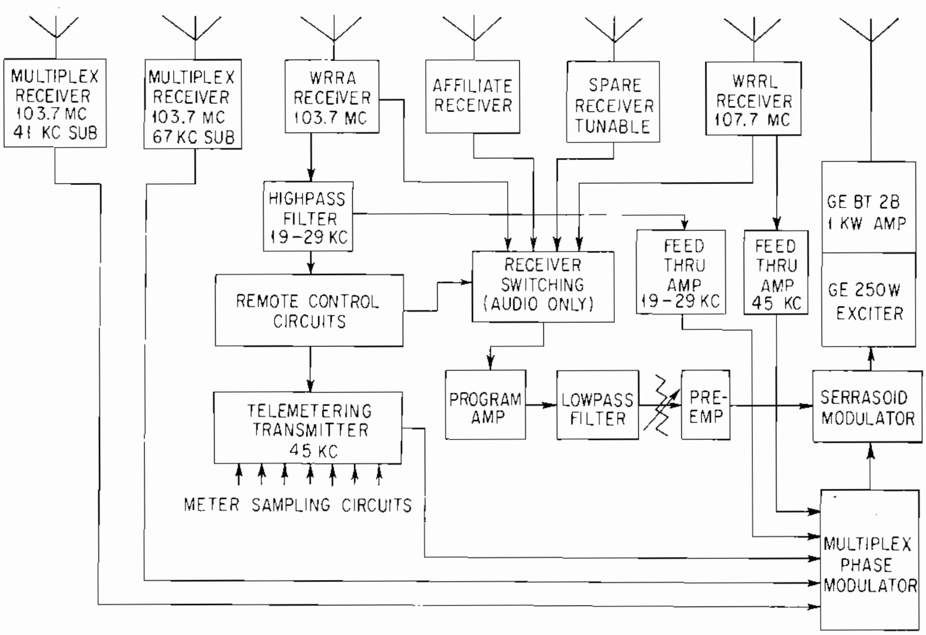

Fig. 2-11. Block diagram of station WRRE, Bristol Center, N.Y.

In addition, each remote station has an identical station monitor for use by the maintenance personnel.

Special "feed-through" amplifiers are used at WRRE and WRRD for passing control tones (19 to 29 kc) on to the end stations and for passing the 45-kc tone back from the end stations to WRRA. These amplifiers have filter circuits to attenuate the unwanted program material.

"Fail-safe" operation is provided by the relay receivers at each remote station. Unless the carrier of the control station is detected, the remote station will not go on the air. If carrier of the control station goes off, all remote stations follow suit.

CONELRAD requirements are met by a motor-driven switching device at each controlled station which removes and restores carrier, after which the tone and announcement are originated at the control station.

It should be noted that the remote-control system for main-channel operation does not affect the subchannel. Program feed on subchannel is always from WRRA regardless of where feed on main channel originates.

Second Subchannel. When we experimented with a 41-kc subchannel in addition to the 67 kc, we knew we would have interference between 41- and the 45-kc telemetering frequency. This proved to be the case, and for experimental purposes only we interlocked the telemetering in such a manner that any use of our telemetering circuitry would remove the 41 kc from the transmitter during the period of usage. Permanent installation of the 41-kc subchannel will require movement of the 45-kc telemetering frequency to 52 kc, where it will cause no interference and will not be interfered with.

The two subchannels operated very well simultaneously with no apparent interference between them. It was discovered, as was expected, that the second harmonic of the 20- and 21-kc control tones did get into the 41-kc subchannel. It would appear that the most logical solution to this problem is the establishment of a third rather low-quality subchannel in the lower range of possibly 22 or 23 kc to handle our remote-control system. This could offer many advantages and improvement to the remote-control system. We anticipate use of this subchannel for possibly one leased service in addition to our own remote control.

Receiving

Ignition noise from automobiles seems to be the one drawback in the multiplexing field today. The signal from the transmitter needs to be strong, but it requires more than a strong signal in some places to eliminate the ignition interference. Tests were made in locations 25 miles from a transmitter where we had a very strong signal and found much ignition noise, whereas a weak signal 55 miles from the same transmitter was clean. Development of some type of inexpensive filter is needed to improve this situation. Several commercial boosters were tried. They do a great deal to bring the strength of the signal up but seem to do nothing to eliminate interference, even though peaked on the operating frequency.

Receiving antennas are one of the most important parts of the system. Multielement Yagis have given the most satisfactory results. The best cure for ignition noise seems to be a high antenna with as much gain as possible, very carefully located. Sometimes moving a few feet one way or the other will make a noisy signal usable. Where noise comes from a definite area, such as a street below, vertically stacked antennas with a null in the horizontal plane should help. An excellent noise generator for such work is a car with the motor running, the hood raised, and a clip lead on one ignition wire.

Much remains to be done in the receiver field to improve the ignition noise situation. Receiver design in the past year has improved noise rejection considerably. A more carefully designed antenna, cut to frequency, that is within reasonable price range is needed.[2]

[2] See preceding discussion by Mr. Harkins.

Automatic Operation

Since this network is set up as a four-station remote-controlled unattended operation, it was necessary that the multiplex relay fit into this picture. For this reason, every attempt was made to keep the operation automatic. The tape equipment originating background-music programming at our control station features two tape playback machines for music, a third playback machine for spot announcements, and a 12-position program selector which sequentially selects any desired programming arrangement from these three tape machines.

To remove the subcarrier subchannel from the air during pauses between musical selections, a silent sensing relay device was built which removed the subcarrier after a pause of about 3 sec. This automatically mutes all multiplex receivers and prohibits cross talk being heard by customers during the silent periods when it would be most prevalent.

An alarm system has been incorporated operating from a multiplex receiver at the control point which rings a bell if programming is removed from the subchannel for a period exceeding 1 min. Thus, if for any reason the operator on duty is not monitoring the subchannel, he becomes aware in a very short time that the program has ceased on the subchannel. Failure of the originating or transmitting equipment of the subchannel also operates the alarm.

Installation of the Serrasoid-type modulators throughout the network has improved the station performance through reduction of distortion, since these units are capable of better performance than the original equipment. These units use mostly receiver-type tubes, which are readily available, and the operating cost is reduced. The old General Electric exciter equipment is available for immediate usage by turning on the power supply and changing one coaxial connector.

Riding gain at the control point is especially critical, since overmodulation on the main channel will cause splatter or cross talk in the subchannel. A General Electric Unilevel amplifier is used on the subchannel to keep the levels constant, and a Langevin Progar on the main channel. The additional limiting in the subchannel receivers from a strong signal holds levels at remote stations constant.

Summary

By moving our background-music service from main channel to subchannel we are able to perform a much better public-service function than formerly. We are at greater freedom to pick what we program on the main channel than we were when we had commitments to broadcast only background-type music during certain portions of the day. We are now able to go to high-fidelity programming, including considerable classical music which was prohibited before except after the hours of background-music service. We feel that our new operation has greater public acceptance than the background-type music, although we had many favorable comments on that programming.

There are many future possibilities for multiplex, contingent upon approval of the FCC. Some of these are news distribution by facsimile, teletype, and teletypesetting; photo relaying; printed information for business use by facsimile; music for transit groups; weather programming; stock-broker ticker tape slow-scan television; special program relay such as baseball games; closed-circuit sports events; electronic computer feed; and stereo sound.

Multiplexing will be a real source of revenue to the FM operator. It is here; it is successful. We can look forward to greater simplicity of equipment and higher standards of operation with the development of the art.

Part 3

A COMPATIBLE SINGLE-SIDEBAND SYSTEM FOR STANDARD BROADCAST STATIONS

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COMPATIBLE SINGLE SIDEBAND *

Introduction

This section describes a new technique which has been developed to convert standard AM broadcast transmitters to single-sideband operation. Conversion is achieved by use of an adapter which can be installed with existing transmitters, and the signal can be received on conventional AM receivers.

The system, known as "compatible single sideband," or CSSB, is quite similar to standard AM transmission, except that the spectrum energy is concentrated on one side of the carrier. Because of this basic difference, the following advantages over normal AM are obtained:

1. An effective 2-to-1 power gain for a given signal fidelity
2. A reduction in adjacent and cochannel interference
3. A reduction in certain types of selective fading distortion
4. A potential improvement in audio fidelity which, besides improving reception of musical programs, improved intelligibility of speech, thus increasing service range
5. A reduction in television-receiver radiation interference

The compatible single-sideband system has been used continuously since the summer of 1956 at the *Voice of America*'s megawatt station in Munich, Germany. Domestic tests with experimental CSSB equipment were made and completed in New York on 50-kw radio stations WMGM and WABC. Production models have been installed at KDKA,[1] the Westinghouse station in Pittsburgh; WSM in Nashville; and KBIG at Catalina Island in California.

* By Leonard R. Kahn.

[1] See reference 6.

Early Proposals

Application of single-sideband techniques with AM broadcasting has previously been considered impractical, since its adoption would involve modifications of home receivers. However, a number of years ago the British Post Office prepared a United Kingdom proposal to use a full-carrier single-sideband system for high-frequency broadcasting. British engineers argued that full-carrier single-sideband signals could be received on conventional AM receivers. However, they confined their proposal to short-wave broadcasting because full-carrier single-sideband waves possess some rather serious limitations. Furthermore, general use would have necessitated the replacement or extensive modification of existing transmitters.

The limitations pointed out in the British study were referred to a full-carrier single-sideband wave modulated by a single tone under peak modulation conditions. It was shown that the envelope wave shape is not sinusoidal and that more than 23 per cent harmonic distortion is present.

It was also noted in the mathematical analysis that the fundamental term has a peak envelope of 67 per cent, relative to the d-c term. Therefore, maximum effective modulation of a full-carrier single-sideband wave is only 67 per cent. This means that a transmitter that can be rated at 1 kw, on either AM or compatible, can be rated at only 444 watts on the full-carrier system. Although distortion can be minimized by reducing sideband level, the effective modulation will become greatly attenuated. When distortion is reduced to 10 per cent, for example, the effective modulation is only 38 per cent. This results in a reduction of over 5.3 db in effective power.

Two proposals [2] have been made for reducing the distortion effect at the lower frequencies by transmitting double sideband for low audio frequencies and single sideband for higher frequencies. However, these systems require more spectrum and are more critical to selective fading than pure single-sideband systems. They also require the replacement of most existing transmitters. Compatible single sideband, however, does not suffer from any of the above limitations.

Compatible Single-sideband System

Before describing the new adapter system, an examination of the structure of a single-sideband wave, as shown in Fig. 3-1, should be of interest.

Figure 3-1*a* shows a plot of the frequency spectrum (voltage vs. frequency) of a single-sideband wave with the carrier and upper sideband equal in amplitude. The upper sideband represents a single sine-wave audio frequency of 600 cycles. The carrier and upper sidebands, shown as two displaced vertical lines, represent two radio frequencies of equal amplitudes.

Figure 3-1*b* is the phasor representation of the single-sideband wave shown in Fig. 3-1*a*. It will be seen that sideband phasor f_s (sideband) revolves past the carrier frequency reference f_r $(C \times r)$ at a velocity equal to the tone frequency of the signal. The resultant of the two frequency components varies in both amplitude and angular velocity. *Therefore, single-sideband waves contain both amplitude- and phase-modulation components.*

Figure 3-1*c* represents the amplitude-modulation envelope of the single-sideband wave (a plot of voltage vs. time) shown in Fig. 3-1*b*. It should be noted that this envelope is identical with the wave shape derived from a full-wave resistance-loaded rectifier when fed a sine wave.

As previously explained, single-sideband waves possess both amplitude- and phase-modulation components. If these components are first isolated and then amplified independently, they can later be combined in such a way as to produce a conventional single-sideband wave.

The CSSB system transmits a full-carrier single-sideband wave produced by the single-sideband generator. The output of the generator is passed through a limiter wherein the phase-modulation component of the wave is isolated. The phase-mod-

[2] See references 4 and 5.

ulated wave is then amplified by Class C amplifiers or, for that matter, any other class of amplifier and finally feeds a modulated stage.

The single-sideband generator also feeds a product demodulator, wherein the sideband of the full-carrier SSB wave is electronically multiplied by the carrier. The

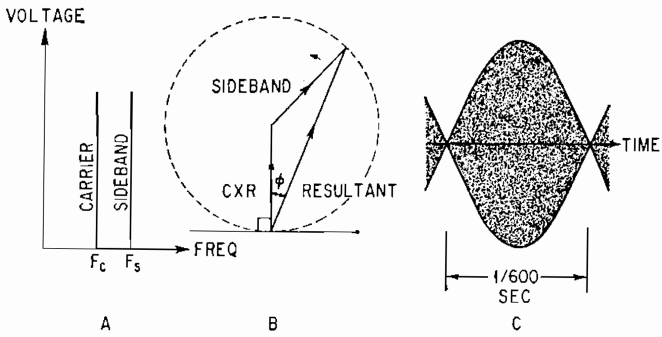

FIG. 3-1. (*A*) Spectrum diagram of single-sideband wave. (*B*) Revolving vector representation of single-sideband wave. (*C*) Envelope waveform of single-sideband wave.

resulting wave possesses spectrum components that are identical with those fed to the input of the single-sideband generator. This wave is amplified and used to modulate the phase-modulation component in the modulated amplifier stage.

If the modulation process is linear, the output envelope wave will be theoretically free of all harmonic distortion, and in practice, figures of less than 1 per cent have been regularly measured. Therefore, demodulation can be achieved in a conven-

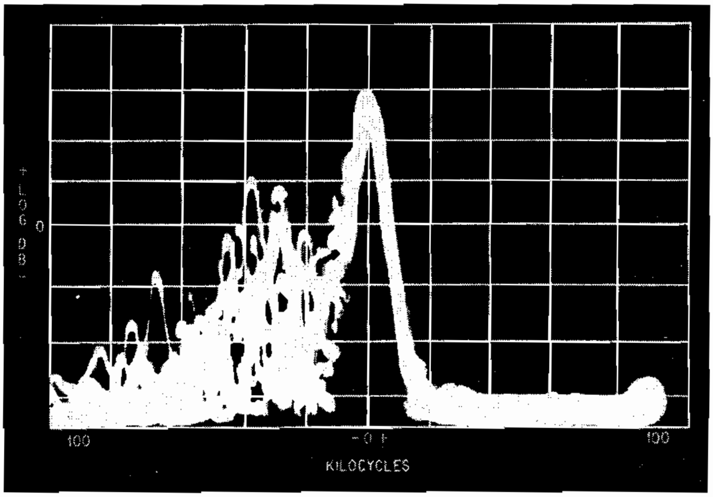

FIG. 3-2. Actual photograph of a major New York network station's 50-kw (200-kw PEP) CSSB wave viewed on a Panoramic Panalyzer. Undesired sideband measures better than 25 db below the desired sideband, including third-order intermodulation products.

tional diode detector with theoretical zero distortion at 100 per cent modulation. This means, of course, that unmodified AM receivers can be employed.

Analysis and measurements show that the undesired sideband of this wave is approximately 30 db below the desired sideband. Even though the compatible single-sideband wave looks exactly like an AM wave on an oscilloscope, the energy of the wave is actually concentrated in only one sideband. Figure 3-2 is a photograph of a 50-kw (200-kw PEP) CSSB wave viewed on a high-resolution Panoramic panalyzer,

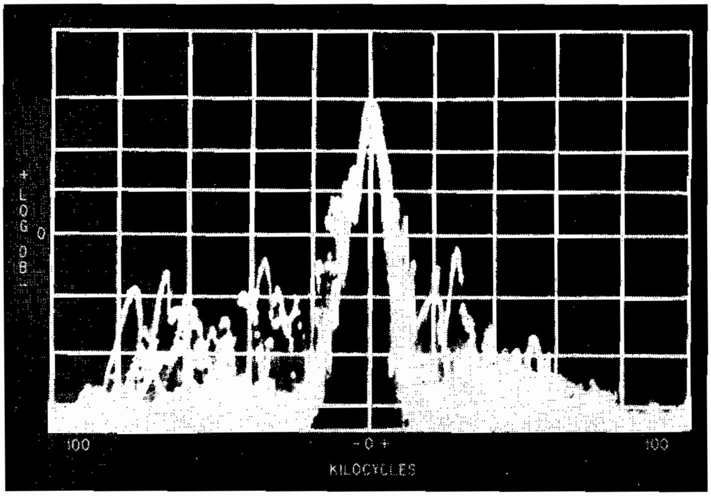

FIG. 3-3. Wave from same transmitter after switching back to conventional double-sideband AM transmission.

showing the asymmetrical concentration of energy. Figure 3-3 shows the waveform from the same transmitter after switching back to conventional AM double-sideband transmission.

Advantages

The advantages of the compatible single-sideband system are as follows:

Reduction of Interference. Since compatible single-sideband systems concentrate energy in only one sideband, CSSB transmissions reduce adjacent- and co-channel interference.

Adjacent-channel Interference. In the case of adjacent-channel interference, the use of the compatible single-sideband system can increase the spacing of adjacent sidebands on one side of the carrier by two times the highest andio frequency transmitted. Thus, the increased effective sideband spacing greatly reduces adjacent-channel interference.

This form of interference comprises three main types: sideband monkey chatter, undesired cross talk, and carrier heterodynes. In the United States, the 10-kc separation between carriers tends to reduce carrier heterodyne interference because of limitations in receiver IF bandwidth and audio fidelity, as well as the aural limitations of the listener. The cross-talk effect is reduced by AM masking, and except for extremely large, undesired signal levels, it is relatively unimportant. Thus, the main source of adjacent-channel interference is sideband monkey chatter wherein the desired carrier beats with the undesired sideband components. If CSSB techniques are correctly applied, the frequency of the monkey chatter can be sufficiently removed from the desired carrier (10 kc) to be relatively unimportant.

Co-channel Interference. If co-channel stations are equipped for CSSB operation, the listener can, by tuning to the desired upper or lower sideband of one station, effectively reduce interference from the other station. The optimum tuning point appears to be 1.5 to 2 kc on the desired sideband side of the carrier, and conventional home receivers offer a co-channel signal-to-interference gain of 5 to 8 db. Moreover, if a listener in a particularly poor region were to purchase a special high-selectivity receiver, approximately 30-db signal-to-co-channel interference gain can be obtained.

In addition, CSSB reduces beat-note distortion, which in AM systems is caused by the "phase beating" of interferring carriers. Reduction in beat-note distortion is discussed in the paragraph devoted to the Reduction of Selective Fading Distortion.

Radiation Interference of Television Receivers. A relatively new type of interference which has assumed very important proportions in the past few years is caused by television-receiver radiation. Poor shielding in many home television sets allows strong horizontal-sweep frequency harmonics to be radiated. They have created considerable interference, not only in the broadcast band, but in the short-wave communications spectrum as well. This problem has, in effect, placed some 68 superpower stations on the air. In view of the extremely crowded conditions of the broadcast band, it appears quite unlikely that there is sufficient room for them, especially when each station effectively covers the entire nation day and night. These signals are spaced 15.75 kc apart throughout the broadcast band. When CSSB is employed, however, the upper or lower sideband, whichever is the farthest removed from the nearest interference frequency, can be selected for transmission. This permits the listener to tune away from the interference and greatly attenuate the interfering beat note.

In order to determine the severity of this problem, a number of questionnaires were recently (1958) mailed to 1,500 individuals selected at random from various New York metropolitan- and suburban-area telephone directories. Out of this total, more than 50 per cent of the 400 replies received stated that TV interference was objectionable to AM broadcast reception. It has been subsequently noted that this interference is possibly even more prevalent in rural sections, where lower interference ratios of AM signal to TV are normally encountered.

Reduction of Selective Fading Distortion. Another advantage of compatible single-sideband operation is the reduction of certain forms of selective fading distortion. In AM reception it can be shown that one of the main causes of fading distortion results from an incorrect relative phasing between the carrier and the sidebands. This condition can be demonstrated by eliminating the carrier from an amplitude-modulated wave and then reinserting it at different phase relationships. When the carrier differs by 90° from its correct phase, the signal will be completely distorted when demodulated in an AM detector. The distortion produced will be independent of the percentage of modulation.

However, when one of the sidebands is suppressed or greatly attenuated, as is the case with CSSB, the relative phase between the carrier and the remaining sideband will be less critical. Therefore, CSSB is less sensitive to this form of distortion.

It should be pointed out that the relative insensitivity of CSSB to phase deviation is another reason for the reduction afforded in co-channel interference. When the undesired AM signal has a carrier frequency approximately equal to that of the desired carrier frequency, the combined carriers will be phase-modulated at low-frequency beat-note rate. This wave will then go in and out of proper phase and produce a form of beating distortion. The compatible single-sideband system reduces this problem because this system is less sensitive to phase discrepancies.

Improved Fidelity and Signal-to-Noise Ratio. Compatible single-sideband waves occupy only one-half of the normal AM spectrum. Therefore, the bandwidth of IF and RF amplifiers used in normal receiver design can be halved. Since the fidelity of most receivers is restricted by the IF amplifiers employed, CSSB offers a means for appreciably improving the effective fidelity of these sets.

Stating it another way, an improvement of 3 db in signal-to-noise ratio will be noted for a given fidelity because receiver bandwidth can be halved. Receivers can also be made somewhat cheaper because more gain can be obtained in narrow-band IF amplifiers than in those of wideband design. It will also be easier to obtain improved selectivity with attendant reduction in co- and adjacent-channel interference.

In field tests, CSSB signal-to-noise gain has measured 3 to 4 db; however, the increase in intelligibility under noise conditions appears to represent a somewhat greater effective increase in signal-to-noise gain. The reason for this is due to a phenomenon in hearing called audio masking, which is somewhat similar to capture effect in frequency-modulation transmission. Thus, when two tones are heard, the stronger tone will bend to mask the weaker tone. In speech the first components to be lost in noise are the high-frequency low-amplitude portions of the voice wave.

Thus, when the noise is slightly greater than the weak high-frequency speech components, the latter actually becomes further reduced in amplitude because of the masking effect. Therefore, significant improvements in fidelity and intelligibility are available with inexpensive receivers through the use of CSSB because higher frequency sounds are heard. Components of the order of 3 kc can be raised in such receivers by a factor of 10 to 15 db.

Because of this improvement, CSSB has been recently proposed for use on the AM channel of an AM-FM stereophonic broadcast system. The advantage accrued is that CSSB will provide audio fidelity on the AM channel approaching [3] that of the FM channel, thereby improving stereophonic broadcast quality.

Installation Procedure

Compatible single-sideband adapters have been used with a number of different types of transmitters including high-level, low-level, and Doherty systems.

Phase-modulated Carrier-frequency Output. There are two outputs from a compatible single-sideband adapter that must be connected to the transmitter. The first contains a phase-modulated wave centered at the carrier frequency. This wave must be connected to the associated transmitter at a low-level point in the circuit. In a typical installation using a Gates 10-kw transmitter, a separate switch position was provided to permit the operator to switch from the two normal crystals to a third position fed by the compatible sideband adapter. Other installations have bypassed the crystal oscillator in order to feed the following amplifier stage. Two to three watts of phase-modulated energy is supplied at a 72-ohm impedance. This is sufficient to drive many low-powered amplifiers, and an increase in drive voltage can be achieved by using the tap-tuned circuit provided. For instance, by tapping a coil or condenser in a parallel-tuned circuit, a gain factor of approximately 10 can be achieved to provide over 100 volts. Of course, the impedance which is seen by the tuned circuit cannot be too great. An amount in the order of 70,000 ohms, however, is satisfactory. When such circuits are used, care should also be taken with the magnitude of the Q's employed. If the Q is too high, the bandwidth of the circuit will be greatly restricted, causing distortion of the phase-modulated wave. An RF bandwidth of at least 30 kc should be provided throughout the AM transmitter, and this is normally quite simple to achieve over the entire broadcast band.

If low-level stages are used with high-Q circuits, it may be necessary to increase loading so as to reduce the Q and thereby increase the bandwidth. It is also quite necessary to make certain that the transmitter is well neutralized, because regenerative characteristics in the transmitter can distort the phase-modulated wave. Such problems as parasitic oscillations, regeneration, and other difficulties which would affect the phase-modulation component must also be carefully eliminated if optimum sideband rejection is to be achieved.

Audio-frequency Output. The second output from the compatible single-sideband adapter is an audio feed which is connected to the input of the aduio system of the transmitter. Once the equipment is set up and the undesired sideband output is minimized, it is extremely important to maintain the polarity of the audio wave being fed from the compatible single-sideband adapter to the transmitter. Therefore, permanent wiring or polarized connectors should be used. It should be noted that the *input* polarity of the wave being fed to the single-sideband equipment is not important. The output audio level from the compatihle single-sideband system is +10 dbm across a 600-ohm line. It may be balanced or unbalanced, as desired.

Test and Adjustment. There is a third connection that must be made from the

[3] Modulation frequency will depend on the adjacent-channel limitations.

transmitter to the adapter. This is the RF sample which is obtained from the output of the transmitter. It is the same feed that is normally used for measuring distortion in AM transmissions, and it is connected to the 72-ohm input of the compatible single-sideband test unit. The RF sample is used to measure and monitor the characteristics of the single-sideband wave.

From the above description, it is evident that the phase- and amplitude-modulation components must reach the modulated stage simultaneously if optimum sideband rejection is to be achieved. Therefore, a phase time-delay network is incorporated

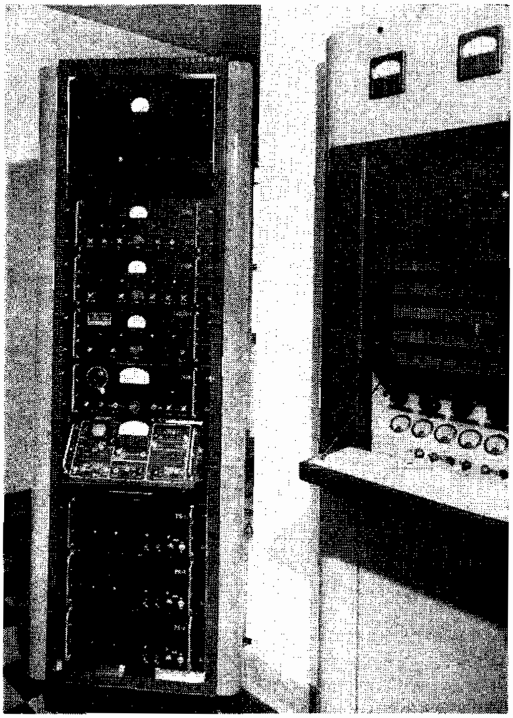

FIG. 3-4. KDKA, Pittsburgh, Pa. showing CSSB equipment.

in the CSSB adapter. Normally, the amplitude-modulation path is slower than the phase-modulation branch because the bandwidth of the modulator is narrower than half the phase-modulation bandwidth. Thus, it is usually necessary to delay the phase modulation in the CSSB adapter by inserting the time-delay network in the PM branch. If it is determined, however, that the modulator time delay is insufficient, causing the phase modulation to arrive ahead of the amplitude-modulation component, the time-delay network can then be inserted in the AM branch. There is a simple method for determining where the time-delay network must be inserted. In order to observe the timing of the phase whip, it is possible to drop the level to the limiters so that when the single-sideband wave goes through zero, an observable pip is produced and thus the timing can be examined.

A test oscilloscope is provided for checking the wave shape of the transmitter as well as other wave shapes in the single-sideband equipment. Measurement of the undesired to the desired sideband ratio is quite simple. It is made by throwing a panel switch to the desired sideband position, adjusting the VI meter for a calibration reading, throwing the switch to the undesired sideband position, and reading the amount of sideband rejection directly in decibels. A multifrequency audio oscillator is also provided in the test unit. It can be operated by throwing a TEST-OPERATE panel switch to the TEST position. Care must be taken to throw the TEST-OPERATE switch to the OPERATE position before resumption of programming. It should be pointed out that a fairly good indication of desired to undesired sideband radiation can be achieved during program operation by observing the peak readings of the meter while throwing the test unit switch from the desired to undesired sideband positions.

Examination of the simplified block diagram of the compatible single-sideband [4] adapter shows that there are, in effect, two modulations taking place in the system. The first takes place in the single-sideband generator, and the second in the AM transmitter. It is very important that the sideband level at the output of the single-sideband generator does not exceed the carrier level. This condition is not noticeable on a normal AM detector, but it negates the spectrum economy of the system and causes interference similar to double-sideband transmission if allowed to continue. Therefore, care must be taken with the levels fed to the CSSB unit. Otherwise, overmodulation effects similar to those in normal double-sideband AM can be produced in the associated transmitter.

It should be noted that once the CSSB adapter is properly, adjusted, a certain percentage of modulation will be achieved for a given input to the sideband adapter. Thus, audio-level gain in the associated transmitter should not be readjusted without checking desired to undesired sideband measurements.

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EXPERIENCE WITH CSSB AT KDKA [a]

The application of the Kahn compatible single-sideband adapter to standard broadcast transmitters was described by Kahn in a paper presented at WESCON in the fall of 1957. Field experiences at WABC, New York; WSM, Nashville; and KDKA, Pittsburgh, all standard broadcast stations, were discussed at the 1958 Engineering Conference of NAB.

G. A. Olive [5] of RCA, Princeton Laboratories, and John P. Costas,[6] General Electric Co., Syracuse, N.Y., have made mathematical analyses of their understanding of the Kahn CSSB adapter.

This paper gives some additional information on the details of its design and operation. It also discusses results of measurements at the transmitter on the radio-frequency spectra radiated and some explanation of the effect of CSSB on typical

[4] See next portion of this part.

[a] By Ralph N. Harmon.

[5] 12th Annual NAB Engineering Conference Paper, April, 1958.

[6] IRE, July, 1958.

receivers with respect to adjacent channel interference, selective fading distortion, and receiver fidelity.

Design, Operation, and Analysis

The Kahn compatible single-sideband adapter should be renamed (a full-carrier compatible single-sideband adapter, i.e., FCC-SSB [7]). When it is used with a standard-band broadcast transmitter, it modifies the spectral output of the transmitter so that under modulation, essentially all the energy is radiated at carrier frequency and on one side of the carrier, either above or below, as desired. Moreover, the

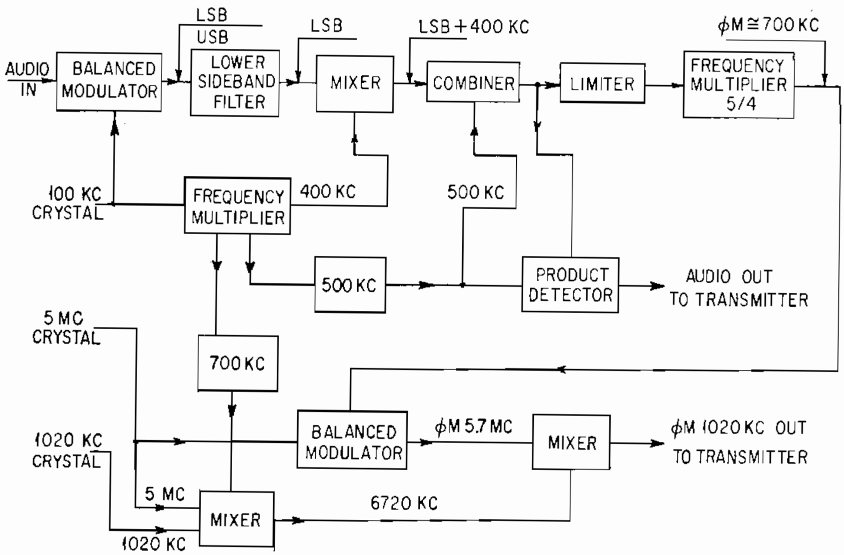


FIG. 3-5. Block diagram of CSSB system.

envelope of the radio-frequency output of the transmitter, when under modulation, is an exact facsimile of the input audio program and, therefore, is receivable on standard receivers without distortion.

Figure 3-5 shows a simplified block diagram of the Kahn adapter. Note that it requires one audio input and has two outputs, one a delayed audio output similar to the audio input, the other a phase-modulated carrier at the assigned carrier frequency of the station. For KDKA this is 1,020 kc. The phase-modulated output of the adapter is connected to the first radio-frequency stage in the transmitter following the crystal oscillator which is not used. The audio output of the adapter is fed to the normal audio input of the transmitter.

It should be noted that the adapter has three crystals, one at 100 kc, another at 5 Mc, and the third at 1,020 kc. Starting at the top left of the figure, it is noted that audio aud 100 kc are fed into the balanced modulator. The output of this modulator is an upper and lower sideband centered around 100 kc.

The next block contains a crystal filter which passes the lower sideband and rejects the upper. The output of the filter is then heterodyned up in frequency by the fourth harmonic of the 100-kc crystal. The signal at this point is a single-sideband one centered just below 500 kc. The carrier signal, the fifth harmonic of the 100-kc crystal, is then combined with the 500-kc single-sideband signal to make the com-

[7] Probably some other terminology should be adopted which would not suggest approval by the Federal Communications Commission (FCC) in the abbreviation.

bined signal a *full-carrier single-sideband signal.* The 500-kc carrier injection is made equal to the amplitude of the single-sideband signal at the 100 per cent modulation level.

This signal is connected to a four-stage limiter which removes all amplitude variations, leaving phase changes only. These phase changes are multiplied by a factor of 7/5 using a frequency multiplier of 7, $7 \times 500 = 3{,}500$ kc, and a divider of 5, $3{,}500/5 = 700$ kc, so that the phase-modulated frequency becomes 700 kc with an increase in phase modulation over the original amount it had at 500 kc. This phase-modulated signal is then raised to the station carrier frequency of 1,020 kc by three steps of processing. First, the seventh harmonic of the 100-kc crystal, the output of the 5-Mc crystal, and the 1,020-kc crystal are combined in a mixer whose output is the sum of these three frequencies, namely, 6,720 kc; second, the 700-kc phase-modulated frequency is fed to a balanced modulator along with the output of the 5-Mc crystal oscillator. The output of the balanced modulator is a phase-modulated wave at 5.7 Mc. Third, the 6,720-kc and the 5.7-Mc phase-modulated waves are mixed, and the output is the difference frequency of 1,020 kc, having the original phase modulation contained on the phase-modulated 700-kc wave. This is fed to the transmitter in place of the regular crystal output at 1,020 kc. The only difference in this 1,020 kc is that when audio is fed to the adapter, the 1,020-kc output of the adapter contains phase modulation.

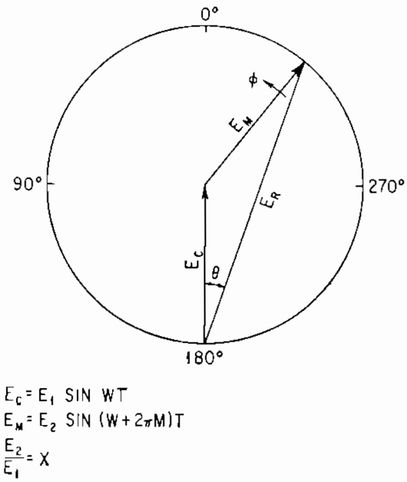


FIG. 3-6. Output of full-carrier SSB adapter before signal is amplitude-limited and when modulated by a single audio frequency.

The second path the 500-kc full-carrier single-sideband signal follows is to a product detector which also has fed into it the fifth harmonic of the 100-kc crystal, resulting in an audio output of the same wave shape as the original input. The only difference is the delay it suffers in going through the modulators and filters of the adapter. This audio is then fed to the audio input of the transmitter after certain minor delay and response equalization adjustments have been made to compensate for the transmitter audio response and delay characteristics. This is necessary in order to maintain envelope coincidence of the phase-modulated wave and the audio as seen at the modulated amplifier of the transmitter.

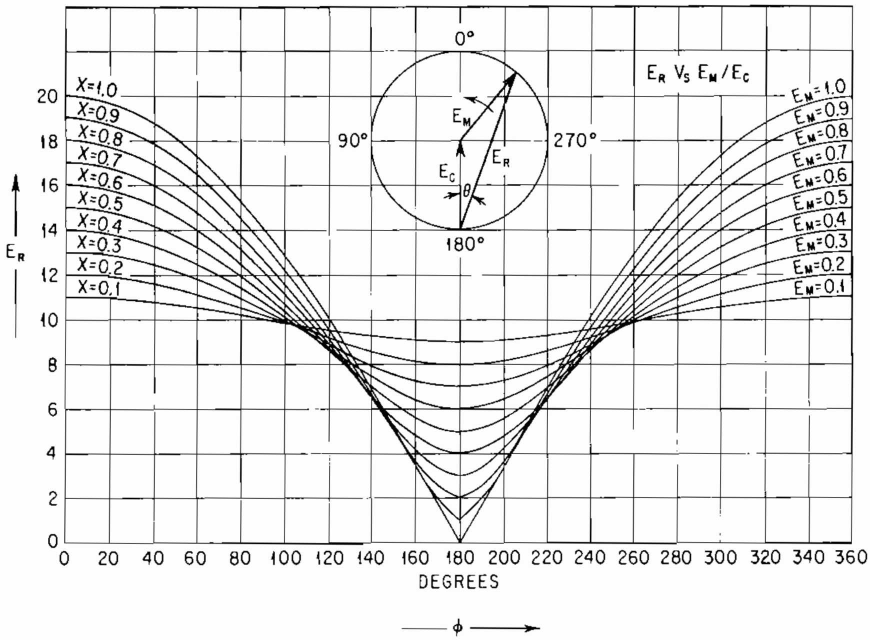
Figure 3-6 [8] shows the output of the full-carrier single-sideband part of the adapter before the signal is amplitude-limited and when modulated by a single audio frequency. Since the two vectors $E_c = E_1 \sin WT$, the carrier frequency, and $E_m - E_2 \sin (W + 2\pi M)T$, the side frequency due to modulating frequency M, differ in frequency by the audio-modulating frequency and rotate with respect to each other at the audio-modulating rate M, this rotation will give a resultant vector E_r whose amplitude will vary with the depth of modulation; i.e., $E_1/E_2 = X$-depth of modulation.

The envelope of E_c for different modulating levels is

$$E_c = \sqrt{1 + X^2 + 2X \cos 2\pi MT}$$

and is shown on Fig. 3-7 for various depths of modulation. It will be noted that at large modulation levels the envelope departs radically from a sine wave. Figure 3-8

[8] M. S. Corrington, Frequency-modulation Distortion, *RCA Rev.*, December, 1946.



ENVELOPE = $E_C\sqrt{1+X^2+2X\cos 2\pi MT}$

FIG. 3-7. E_c envelope for various modulating levels.

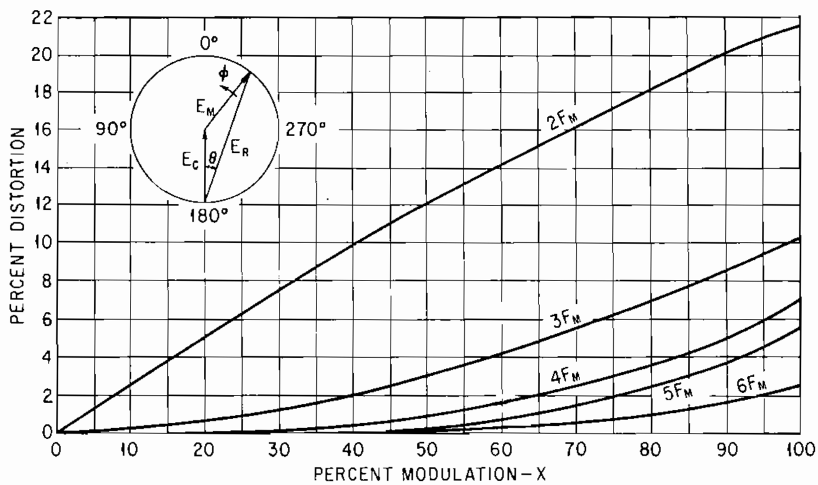


FIG. 3-8. Harmonic distortion with high modulation levels.

shows the various harmonics in this distorted wave. It is clear from these figures that detection of the envelope of E_m and E_c, i.e., E_r for various ratios of E_m and E_c between zero and unity, by an envelope- or diode-type detector will result in large distortion. More will be said about this later.

The phase shift θ of the resultant wave E_r for various depths of modulation is given by

$$\theta = \tan^{-1} \frac{X \sin 2\pi MT}{1 + X \cos 2\pi MT}$$

and is shown in Fig. 3-9 for different values of X, i.e., depths of modulation.

Note that θ = zero at the positive peak of the modulation cycle, i.e., $\phi = 0°$, and also at the most negative point, $\phi = 180°$. However, at the most negative point θ is changing most rapidly and at X equals 1 (Mod. = 1), θ changes from -90 to $+90°$ instantaneously. Also, $d\theta/dt = K$, except at 100 per cent negative modulation; i.e., θ is a sawtooth wave with infinite slope at 100 per cent negative modulation. Note that the phase scale for θ at the left of the figure is for the output of the adapter after phase multiplication of 5⁄4, and at the right side the scale is for the phase shift at the input to the limiter in the adapter.

The instantaneous change of frequency, or $d\theta/dt$, over the modulating cycle is of considerable interest because it will determine the phase shift of the transmitted carrier and, therefore, the phase-modulated sideband spectra.

$$\frac{d\theta}{dt} = \frac{d}{dt}\left(\frac{\tan^{-1} X \sin 2\pi MT}{1 + X \cos 2\pi MT}\right) = fd$$

$$fd = \frac{M}{\dfrac{\cos 2\pi MT + 1/X}{\cos 2\pi MT + X} + 1}$$

fd vs. X, i.e., depths of modulation, is shown in Fig. 3-10, which shows that at 100 per cent modulation the frequency deviation from carrier frequency is constant and equal to half the modulating frequency M for all points of the audio cycle except at the instant the audio cycle passes through the 100 per cent negative modulation point, where the frequency deviation or instantaneous change of frequency is infinite. From a practical viewpoint the frequency-multiplier-divider chain of the Kahn adapter will not follow such a rapid change of frequency, so the 100 per cent modulated point, as far as phase shift is concerned, must be avoided. Even if the Kahn adapter could follow such a rapid phase shift, the standard-band broadcast transmitter would not.

Such a situation is avoided by simply not phase-modulating the adapter above 85 to 90 per cent, which, as shown in Fig. 3-10, holds the instantaneous frequency within reasonable limits. Note that there is considerable disymmetry in the deviation frequency over the modulating cycle.

Since the phase-shift sidebands are a function of the rate of change of phase, and they, in turn, are amplitude-modulated by the audio modulation in the modulated amplifier of the transmitter, there is the necessity for the proper amount of phase shift for each modulation depth as it relates to the audio modulation if sidebands are to be eliminated from one side of the carrier and the resultant radio-frequency envelope is to be an undistorted replica of the original audio.

It should be noted, however, that the Kahn adapter has considerable latitude in the control of the generation of both the phase-shift and, therefore, phase-modulated sidebands and the depth of audio modulation. By using varying depths of modulation as applied to the full-carrier single-sideband portion of the adapter and by applying a phase stretcher device (5⁄4), it has been demonstrated and measured at KDKA that the adapter does permit undistorted reception by envelope detectors in standard broadcast receivers of a full-carrier single-sideband radio-frequency spectra.

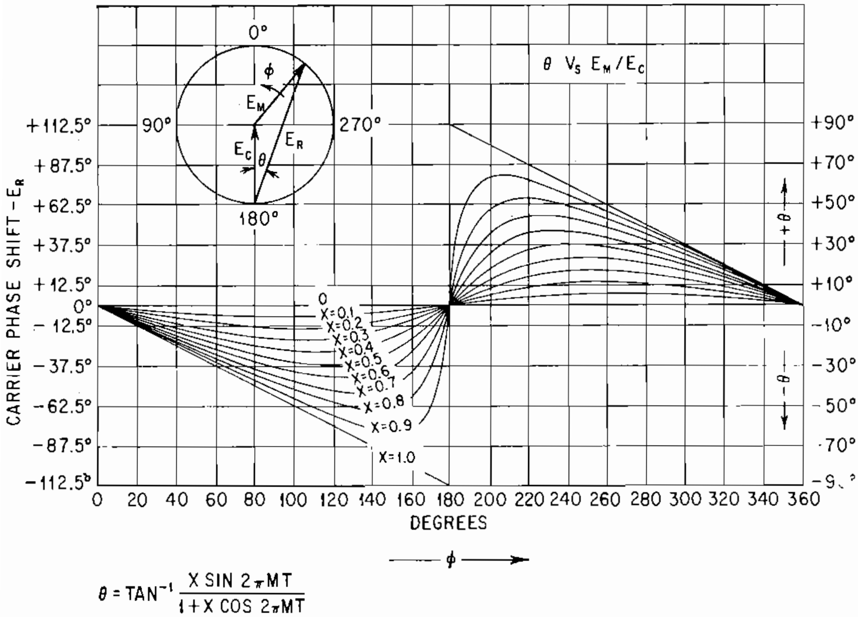


FIG. 3-9. Phase shift with varying modulation depths.

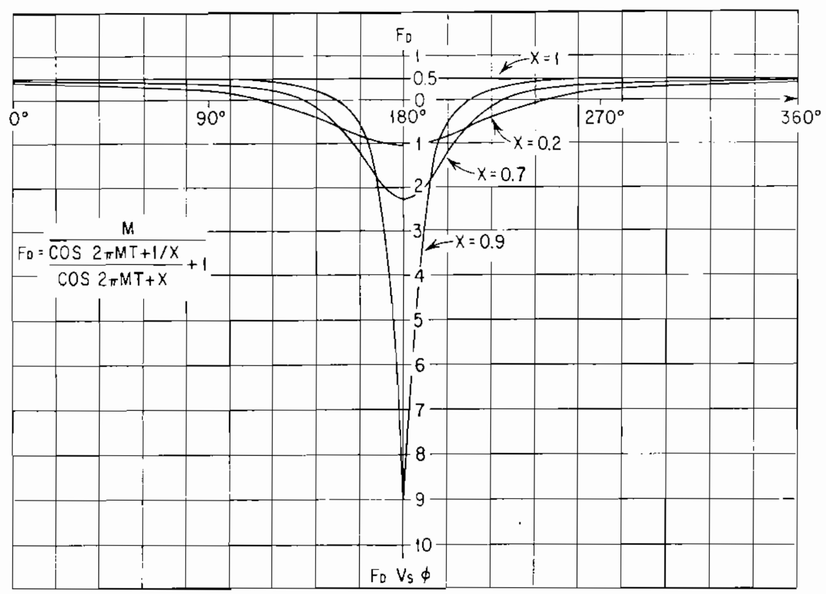


FIG. 3-10. F_d vs. ϕ; note constant frequency deviation from carrier frequency at 100 per cent modulation.

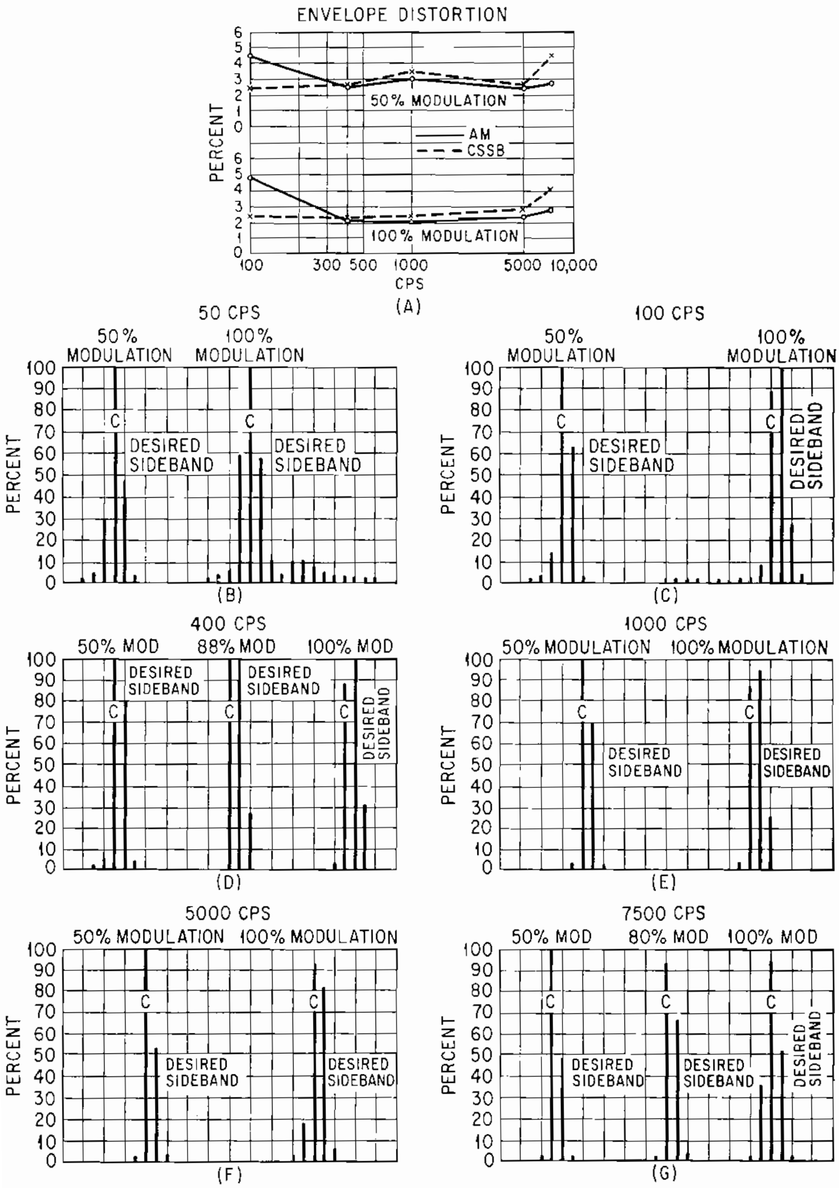


FIG. 3-11. (*A*) Envelope distortion with double and single sideband for modulation percentages of 50 per cent and 100 per cent. (*B*)–(*G*) Sideband distribution for various modulation frequencies and percentages.

Transmitter Measurements

Measurements of the performance of KDKA's transmitter when the adapter was used were considered of prime importance, since the results of field measurements and reception tests would be controlled by the radiated output of the transmitter.

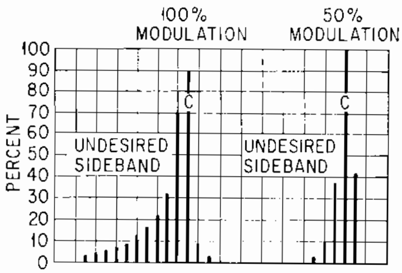


FIG. 3-12. Transmitter sidebands with phase modulation only for 50 and 100 per cent modulation.

Measurements of the frequency response and distortion at all levels of modulation and all frequencies between 50 and 8,000 cycles were made. The transmitter performance was very much the same with CSSB and with normal DSB.

Figure 3-11*A* shows envelope distortion at 50 and 100 per cent modulation for DSB and CSSB types of modulation.

The small difference in envelope distortion with CSSB vs. DSB is easily explained if it is understood that the transmitter is amplitude-modulated with the normal audio and in the normal manner. (KDKA's transmitter is high-level plate-modulated.) Thus, if the input and output radio-frequency circuits of the modulated amplifier are sufficiently broadband, the amplitude modulation of this amplifier when it is also phase-modulated will cause no distortion of the output radio-frequency envelope. The *phase shift merely redistributes the radio-frequency spectra of the output amplitude-modulated envelope.* With little or no phase shift the spectra will be essentially symmetrical, i.e., double sideband. As phase modulation is increased,

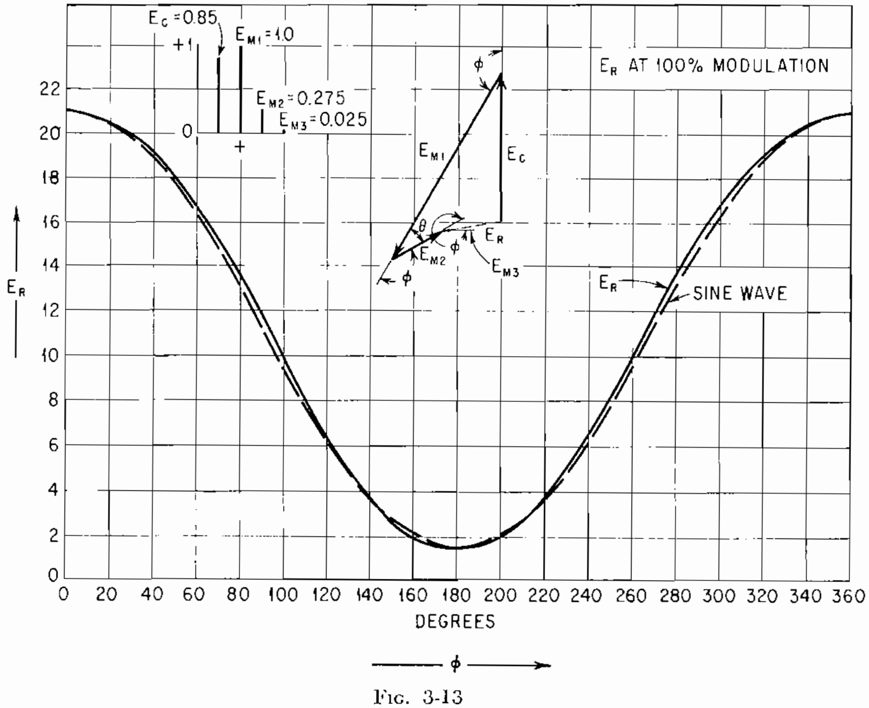


FIG. 3-13

there will be a value of phase shift for each depth of amplitude modulation where output spectra of the radio-frequency-modulated amplifier will be essentially full-carrier single sideband.

Figure 3-12 shows the sidebands in the transmitter output with phase modulation only, for 50 and 100 per cent phase modulation (i.e., zero-amplitude modulation). Note the asymmetry of these sidebands and the number of them, particularly at 100 per cent modulation. When these sidebands are amplitude-modulated, the resultant is a full-carrier single-sideband output as shown in Fig. 3-11*B* to *G* for various frequencies and depths of modulation.

Note that at amplitude-modulation levels above 50 per cent a *second-order* sideband on the desired side is developed which at amplitude-modulation levels approaching 100 per cent is approximately *25 to 30 per cent of the amplitude of the full carrier, which at this point is reduced to about 85 per cent of its zero-modulation amplitude.* Note, also, that the first-order desired sideband is greater than the carrier at this point and is usually equal to the carrier amplitude at zero modulation.

It will be recalled from Figs. 3-7 and 3-8 that it is impossible to have a distortion-free envelope with only two frequency components for each modulating frequency (i.e., carrier and one side frequency), particularly at high levels of modulation.

Since measurements show little envelope distortion, it is clear there is a need for more than one order of side frequency for each modulation frequency. Figure 3-13 shows an example of the components needed at 100 per cent amplitude modulation with all the components on one side of the carrier. Note that the carrier is 0.85, the first-order desired side frequency 1.0, the second-order desired side frequency 0.27, and the third-order desired frequency 0.025. This envelope has less distortion than the nonlinearity of the transmitter, so normally the third-order desired component will be masked by transmitter nonlinearity. It should be noted that the radiated spectra agree quite well with this requirement, particularly at mid audio band.

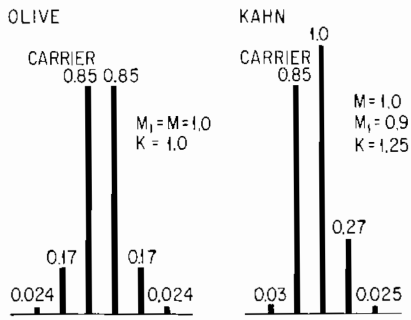


FIG. 3-14

Figure 3-14 is of interest in that it shows the sideband spectra predicted by the C. A. Olive compilations based on a slightly different arrangement of phase shift vs. amplitude modulation from that used in the Kahn adapter and *measured spectra on the transmitter output when the adapter is used at KDKA.* It should be noted that *both spectra have very little envelope distortion.*

Received-signal Observations

Field tests of signals from transmitters using the Kahn adapter have been the subject of considerable controversy, probably partly due to the fact that it is at best a subjective matter and, perhaps not less important, the results are highly dependent on the characteristics of the receivers used and how they are tuned.

Some understanding of the probable characteristics of the output signals can be obtained by referring to Figs. 3-15 to 3-17, which are typical receiver-selectivity curves. It will be noted for the narrowest band receiver that the response will be down about 6 db, 2 kc off resonance and for the widest band receiver only about 1 db down.

It is clear that these three receivers will show different results between double and single sideband.

The wideband receiver will very likely not be able to discern any difference between DSB and CSSB. On the other hand, the narrow-band receiver will certainly show a difference, particularly if it is tuned, as is normally proper on CSSB, off resonance between 1 and 2 kc. Generally, such tuning will make the CSSB signal sound more treble and, if the transmitter isn't modulating heavily on either double or CSSB, make it sound louder.

The reason it will sound louder on CSSB is that off-resonance tuning tends to enhance the amplitude of the side frequencies and attenuate the carrier, giving the

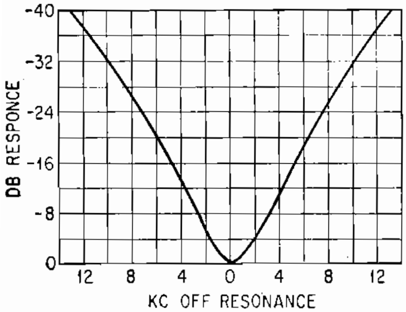


Fig. 3-15

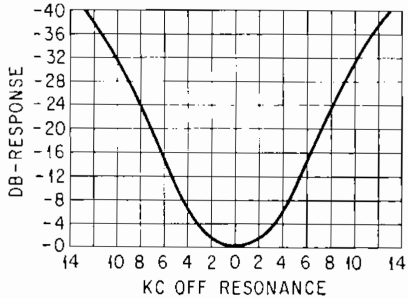


Fig. 3-16

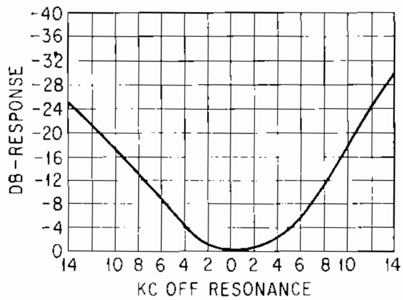


Fig. 3-17

Figs. 3-15, 3-16, and 3-17. Typical receiver-selectivity curves.

effect of increasing the depth of modulation. However, if the transmitter is deeply modulated, it will be found impractical to tune off resonance, but very slightly, owing to the overmodulation distortion effect arising from such tuning.

It must be remembered that the CSSB wave *is very sensitive to envelope distortion* if the several components (carrier and first- and second-order side frequencies) are disturbed in their amplitude relationship; it is clear, especially at high modulation levels, why off-resonance tuning will create large amounts of distortion.

For example, taking the narrow-band receiver and tuning it off resonance by 2 kc would attenuate the carrier with respect to a 2-kc side frequency by 6 db. Now, assume that the transmitter was modulated approximately 50 per cent by a single 2-kc sine wave. The CSSB spectra would be radiated with the carrier at unity, the first-order side frequency at approximately 0.6 with little evidence of any second-order desired side frequency.

The narrow-band receiver, however, would amplify and attenuate these two frequencies 6 db differently. The carrier would end up around 0.5, and the 2-kc side frequency 0.6. Such a relationship would have about 20 per cent envelope distortion and would require a second-order side frequency of about 20 to 25 per cent to reduce the distortion to tolerable values.

The above discussion leads immediately into results of reception tests to determine CSSB ability to reduce selective fading distortion. It is well known that *suppressed-*carrier *single-sideband* transmissions as received by an exalted-carrier-type receiver have a very considerable immunity to selective fading distortion. This is, of course, because of the ability to reinsert a large carrier component at the receiver so that the envelope detector sees a wave which has very small side-frequency components, i.e.,

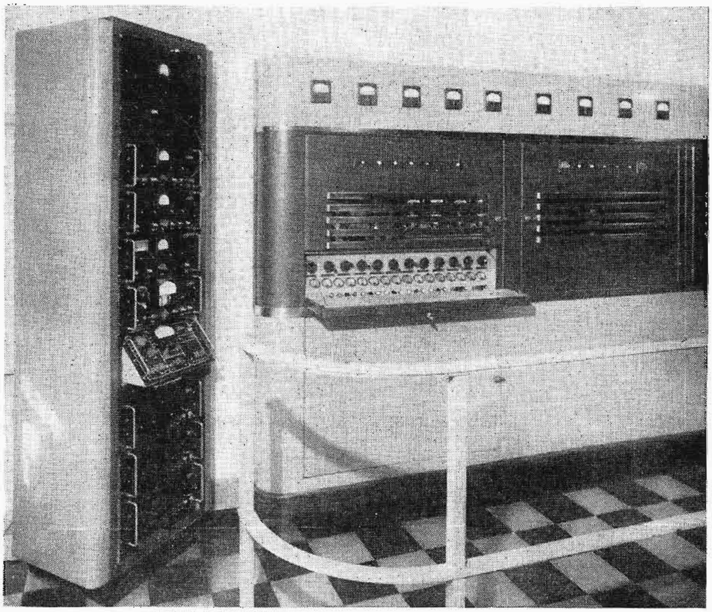


Fig. 3-18. CSSB equipment installed at KDKA, Pittsburgh, Pa.

low modulation, and is therefore not affected by phase or amplitude changes of the side frequencies in so far as distortion is concerned.

This, of course, is not the case for double-sideband transmission, where a change of phase between the carrier and the side frequencies will create large amounts of distortion. In *full-carrier single-sideband* system it would appear that if low depths of modulation could be tolerated, some approach to the immunity of the suppressed-carrier single-sideband system to selective fading distortion could be obtained. (This would also be the case for all levels of modulation on CSSB if an exalted-carrier-type receiver were used.) However, low per cent modulation cannot be tolerated, so any improvement along this line cannot be relied on. On the contrary, with the normally high levels of modulation which will cause the carrier and the first-order desired side frequencies to be approaching each other in amplitude as well as the presence of a second- or even third-order desired side frequency, at least three of the four need to retain *their original amplitude ratios* and phase relations among the three desired side frequencies. Also, if the receiver is narrow banded and tuned off resonance, the distortion due to unequal amplitude fading of the various carrier and side frequencies will be unfavorably affected, as such tuning tends to attenuate the carrier and thus further remove the transmission from immunity from amplitude and phase changes.

Conclusion

In spite of the above facts, not a single complaint of bad reception of any type has been received from KDKA's transmissions on CSSB for a period of over 5 months.

Various measurements on different receivers indicate that, with normal care, any receiver which is acceptable for double-sideband transmissions will be satisfactory for CSSB. Some narrow-band receivers will need to be tuned slightly off resonance for best reception. Broadband receivers give little indication of change of tuning from DSB to CSSB.

In strong signal areas with broadband receivers there is difficulty in choosing between DSB and CSSB.

On CSSB narrow-band receivers show, if tuned off resonance, some gain in treble response and in some cases, particularly if the transmitter is not modulated heavily, a louder signal.

Results in noisy low-signal-level areas favor the CSSB signal, especially if a narrow-band receiver is used and the transmission is predominantly voice.

Results of field tests on selective fading distortion will have to be evaluated on a statistical basis, as the difference is apparently only slightly in favor of CSSB. This is yet to be done, even though a considerable amount of tape recording has been made alternating the transmission between CSSB and double sideband, either under control of the field receiving location or at timed intervals of short periods such as a change from CSSB to DSB every 3 min.

The chief gain to KDKA of using CSSB is the reduction of adjacent-channel interference between KDKA on 1,020 kc and WBZ in Boston on 1,030 kc. The removal of KDKA's upper side frequencies has relieved interference to WBZ's reception, and the ability of receivers tuned to KDKA to tune slightly off resonance away from WBZ and toward the radiated lower sideband of KDKA has also given KDKA some additional immunity from WBZ.

In our experience with the Kahn adapter at KDKA it has been reliable, stable, and simple to operate.

Part 4

UHF TELEVISION TRANSLATORS

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INTRODUCTION

General Considerations

Translator rebroadcasting of television signals has become a proved method of extending service to remote or shielded areas. By this method television has been brought to many communities too small or areas too sparsely populated to support even a single channel of regular television broadcasting. Communities with this type of service are as small as a few hundred people, while larger population groups have as many as five channels operating. Figure 4-1 is a typical translator site.

Translator rebroadcasting retransmits the signal on an assigned channel which can be received by anyone. This service must, therefore, be supported by indirect means such as public subscription or an appropriation by a local governmental unit or by a private group which operates it as a public service. A number of regular TV broadcast stations operate translators as a means of filling in their coverage.

The term "translator" might equally well be applied to any device which changes a signal from one channel to another for any purpose. However, in practice it has come to mean a device which receives an incoming signal off the air and rebroadcasts it on another channel. Any required channel can be received. However, the conversion must result in an output which is on the channel assigned for transmitting, normally one of the UHF channels from 70 to 83.

While several methods of processing the input signal into an output on a new channel could be used, the simplicity and reliability of the heterodyne-repeater method have resulted in its universal selection. Heterodyne repeating takes advantage of the same principle of mixing as used in superheterodyne receivers. However, in this application the sum of two signals rather than the difference is selected to produce an output in the desired part of the UHF band. When an output is produced in a frequency band where licensing is available, similar equipment can be successfully used for many other types of services, such as point-to-point television relays, and for broadcasting, rebroadcasting, or relaying other types of intelligence, such as telemetry carriers. Other types of modulation, such as single-sideband and various types of pulse modulation, can be transmitted. However, in this article, except as otherwise mentioned, the term "translator" will apply to television rebroadcast apparatus with an output in the UHF band on one of the channels assigned for translator service.

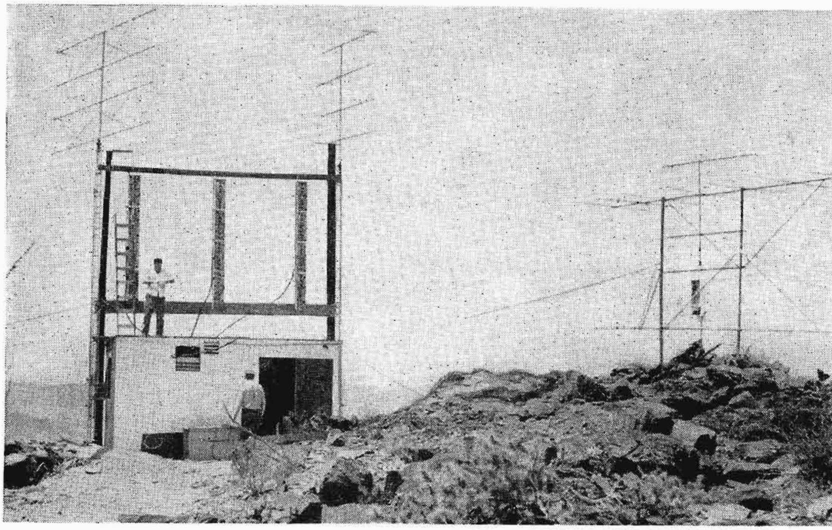


FIG. 4-1. Typical translator installation. Three channels are rebroadcast to Blythe, Calif., in the Palo Verde Valley. The area covered is 50 miles wide by 35 miles deep. The received signals from Phoenix, Ariz., are translated as follows: Channel 3 (KTVK) to Channel 71, Channel 10 (KOOL-TV) to Channel 75, and Channel 12 (KVAR) to Channel 79. (*Courtesy of Industrial Television, Los Angeles, Calif.*)

Elements of a Translator Installation

The three distinct elements found in any translator system are:

1. The signal reception system to deliver an adequate input signal. This signal must contain a minimum of noise and extraneous pickup. Its magnitude must be sufficiently above the input noise of the translator channel amplifier to allow a noise-free picture.

2. A properly designed translator which will reproduce the signal without compression, with adequate and preferably adjustable sound carrier, without cross modulation, and without spurious outputs.

3. A transmitting-antenna system which will make maximum use of the available power output at the end of the transmitter transmission line and deliver this power to the proper area. Directional antennas are almost invariably utilized to deliver the signal to the center of population. The antenna array must have a low VSWR to prevent reflections which would be radiated as "ghosts."

SIGNAL-RECEPTION SYSTEM

Basic Requirements

The signal-reception system for a translator installation is faced with the same basic problems as any other installation of a TV broadcast receiving antenna in a fringe area. The system must deliver a signal of sufficient strength to the translator and discriminate against any interfering signals or noise as completely as possible.

Noise Considerations

The noise of a VHF signal received off the air depends upon noise contributions from two sources. These are noise which is received by the antenna along with the signal and the extraneous noise introduced by the electronic circuits in the translator.

At the low end of the VHF band, the electronic circuits are relatively quiet and the noise received by the antenna relatively high, so the latter is usually the limiting factor. Conversely, at the high end of the VHF band the received noise is significantly less and the electronic circuits are appreciably noisier. Thus, at the top end of the VHF band the limitation is usually found to be the inevitable noise of the translator input circuit.

The noise received by the antenna is specified in terms of a fictitious "equivalent temperature." This is the temperature of an ideal resistance which would have the same available noise output voltage as does the antenna from the noise it receives. Thus, antenna temperatures greater than 290°K correspond to more noise than available from an ideal resistance at room temperature, while antenna temperatures less than 290°K represent correspondingly less noise. The effective antenna temperature will vary with the frequency of the received signal in the VHF region and with the direction to which it is pointed and will be influenced by any local sources of man-made noise, particularly at the low end of the band. Typical equivalent temperatures of a receiving antenna range from 4600°K (12 db noisier than a resistor) at Channel 2 to 180°K (2 db less noisy than a resistor) at Channel 13. The inevitable noise contributed by the electronic circuitry is usually specified in terms of the "noise figure" of the equipment. A rigorous definition of the concept of "noise figure" as a measure of the noise added to a signal by an amplifier must be left to other sources.*

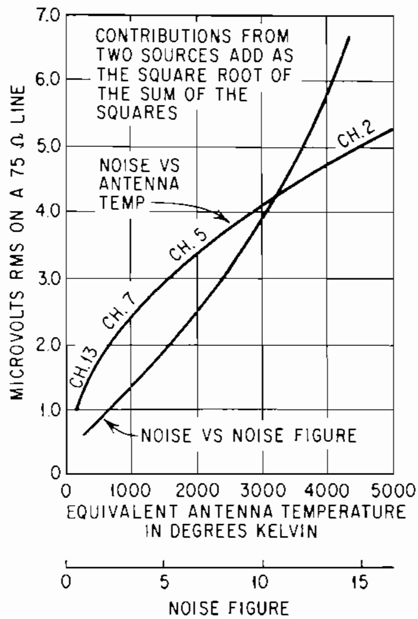


FIG. 4-2. RMS noise voltage contributed by an antenna vs. its equivalent temperature and by a receiver vs. its noise figure. The sum of the noise voltages from these two unrelated (noncoherent) sources is the square root of the sum of the squares of the two voltages. It covers most of the noise added to the signal in a translator installation.

As a practical guide to the installation of translators Fig. 4-2 provides typical values of noise voltage on a 75-ohm line (6-Mc bandwidth) for a range of antenna temperatures and amplifier noise figures.†

A good low-noise preamplifier will have a noise figure of 3 to 4 db on the low VHF channels and about 1 db more on the high channels. Ordinary channel amplifiers exhibit noise figures of 6 to 15 db, again with the better performance on the low channels. The recommended signal strength in microvolts at the output of the transmission line from the antenna is a signal 40 db greater than the rms combination antenna noise and extraneous amplifier noise.

The normal signal strength must be sufficiently above the minimum value to provide a margin for the inevitable fading of fringe-area signals. The depth and duration of fades vary with each location and must be determined as a matter of experience at a particular receiving site. A desirable fade margin would be 20 db above the bare minimum indicated for a 40-db signal-to-noise ratio. In most instances, fades deep enough to produce a noisy picture would then be very infrequent and of short dura-

* Superscript numbers refer to references at end of this part. See Refs. 1 and 2.

† For transmission-line impedances other than 75 ohms, multiply the rms noise voltage by $\sqrt{Z/75}$. More general curves are given in Ref. 1.

tion. In addition, the signal must be of sufficient strength to produce good AGC action in the translator itself.

Amplification at the Antenna

Best results will be obtained if the first amplification of the signal takes place as close to the antenna terminals as possible. The improvement gained in return for the effort of mounting an amplifier in a weatherproof housing at the antenna location can make the difference between a successful and unsuccessful installation in those instances where the signal is marginal. The longer the transmission line between the antenna and the translator, the more important it is that some VHF amplification be provided between the antenna and the transmission line.

Translators are normally constructed with two self-powered VHF channel amplifiers. When dealing with medium to fairly weak signals one of these channel amplifiers can be removed from its normal position in the translator and located at the antenna terminals. For very weak signals best results will be obtained through the use of a separate low-noise channel amplifier. The additional gain of such an amplifier will ensure more than adequate signal at the translator for proper operation of the AGC circuits. Furthermore, such an amplifier designed and tested to have a low noise figure will contribute significantly less noise to the signal than an ordinary channel amplifier.

Preamplification before the transmission line improves the signal-to-noise ratio in three ways. First, even for a long transmission line the preamplifier will more than make up for the cable loss, so the signal at the input to the first channel amplifier in the translator will be well above the internal noise. Second, the attenuation losses in the transmission line are the equivalent of resistance in the circuit, which in turn contributes noise. A preamplifier added to this transmission line raises the signal level well above the noise generated in the cable. Third, with a higher signal level in the transmission line and at the input to the translator, the possibility of picking up extraneous signals at the input of the translator or in the transmission line is minimized. This is particularly important in installations where the translator is located physically close to other transmitters such as the fixed stations associated with mobile systems. In such an installation the receiving antenna may be located some distance from the other transmitter units and their antennas and possibly shielded from them, even though the translator itself shares the same building. Preamplification raises the level of the desired signal before it enters the area where pickup is possible. Thus circuits which could pick up extraneous signals when operated at a low level are, in fact, operated at high level. In cases of extreme interference from other transmitters, power lines, or gasoline-driven generators, double-shielded cable has been found helpful in eliminating pickup.

Receiving Antennas

In order for a translator to transmit a picture of maximum quality, it is necessary that the signal at its terminals be as free from degradation of any sort as possible. In any area local practice with respect to receiving antennas for fringe-area signals is a good starting point. These antennas will have been designed to cope with local conditions, environmental and otherwise. A combination of the best features of local practice and the refinements outlined below should be combined in selecting the receiving-antenna elements. Figure 4-3 is a receiving-antenna installation.

An advantage can be obtained by having the receiving antenna cut for the particular channel of the incoming signal.

High-gain receiving antennas will deliver more signal voltage, which is helpful when the amplifier noise is the limiting factor. When received noise ("antenna temperature") is the limitation, however, a high-gain antenna will not produce an improvement unless a major part of the noise is from a discrete location in a direction well away from the direction of the received signal.

When signals on two or more channels are desired for running multiple translator installations, separate receiving antennas to feed each translator have proved to be most desirable. Not only do broadband antennas represent a compromise on each of the channels on which they are used, but the angle, both vertical and horizontal, from which the signal arrives may be different for the various channels. Even for signals from a common geographical location, the compromise between extraneous pickup and

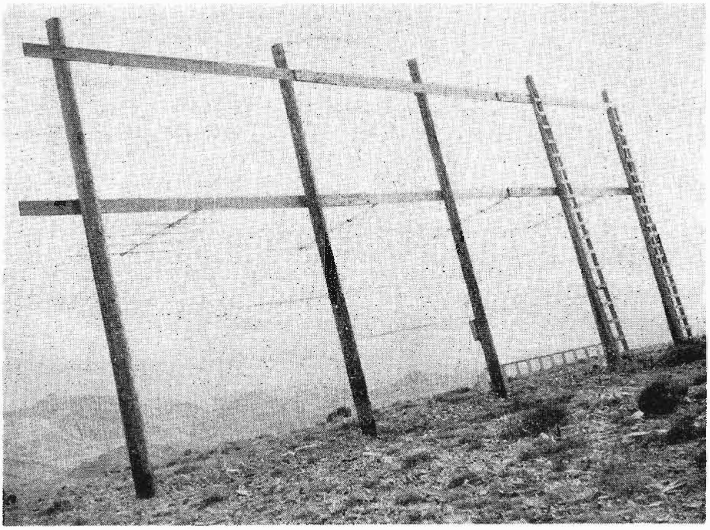


FIG. 4-3. A receiving-antenna installation for Channel 2 located on Serro Gordo Mountain 150 miles northeast of Los Angeles, Calif. Although it is below the "line of sight" from the transmitter, the measured signal strength from the array is 1 mv. Chicken wire stretched across the poles screens the antennas from signals from the rear. Note the preamplifier in a weatherproof box on the center pole. The translator shares a building with two fixed 250-watt VHF mobile-system transmitters, so the cable from the antenna was buried in conduit to minimize pickup. (*Courtesy of Industrial Television, Los Angeles, Calif.*)

the desired signal may be different for each channel. For instance, one received channel may be free from co-channel or on-channel interference from unwanted stations while another channel subject to these interferences may require unusual antenna orientation to minimize them.

TRANSLATORS

Fundamental Block Diagram

A translator must convert a low-level VHF signal to a high-level UHF signal. Ideally it must accomplish this conversion without altering the signal in any way except for changing the frequency of the carriers. Practically it must not degrade the signal in any way in an amount which will be detectable on a good-quality receiver. It is highly desirable that any degradation be held well below the limits of detection so that translators can be run in cascade. In addition, a translator, to comply with the licensing rules, must contain auxiliary circuits for periodic automatic identificaton and for remote control on a fail-safe basis. Before type approval is issued by the Federal Communications Commission for a translator, it must demonstrate the aforementioned features, including the ability to reproduce a picture without degradation, and it must have all spurious emissions radiated either from the antenna with the desired signal or directly from the equipment, reduced to acceptable levels.

A block diagram of a translator meeting these requirements is shown in Fig. 4-4. The VHF preamplifier raises the received signal to a convenient level in the neighborhood of 1 volt. It also exercises the automatic-gain-control function. This signal is combined with a UHF crystal-controlled signal in a vacuum-tube-type mixer. The final ontput channel is the sum of the injection frequency and the input-channel frequencies. The sum signal passes through three stages of linear amplification and a power monitor before being fed to the antenna transmission line.

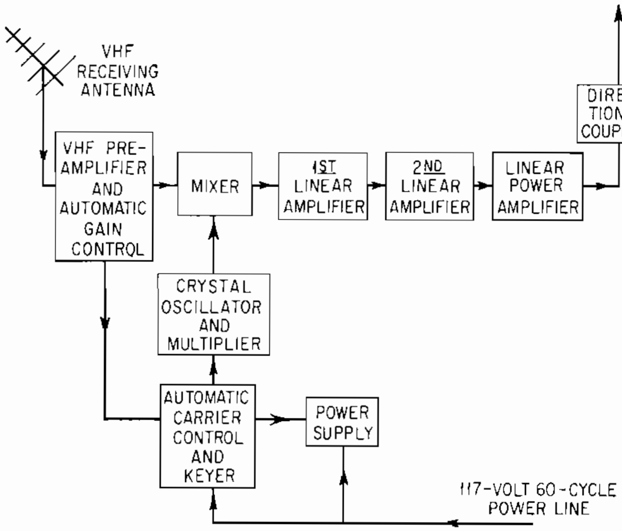


FIG. 4-4. Block diagram of a 10-watt translator.

The automatic-carrier-control and keyer unit controls the plate power of all circuits after the VHF channel amplifiers. It activates these stages only if three conditions are satisfied. These are as follows: A proper VHF signal must be present, a pair of remote-control terminals are closed, and the high-voltage interlocks and the air-flow switches indicate proper operation. In addition, it contains a 30-min timer and the code wheel which periodically identifies the translator station in Internatioual Morse Code.

VHF Amplifier

The VHF channel amplifier must provide the mixer with a constant-value signal even in the presence of fading of the input signal. It must have the power capability to drive the mixer. The VHF amplifier contributes to the over-all bandpass characteristic of the translator, rejecting signals outside the desired channel. By various higher-order mixing combinations, even weak off-channel signals might produce an output in the desired UHF channel, and strong undesired signals which overload the mixer would be quite certain to cause interference.*

Typical system requirements call for the VHF amplifier to deliver 1-volt peak sync, plus sound, to the mixer and to do this with as little as 1-mv normal input signal. This requires 60-db gain. Two typical channel amplifiers connected in cascade which have been used for this purpose have a maximum total gain of 80 db and an AGC

* For instance, if it were not rejected by the VHF amplifier, a frequency which is one-half of some frequency within the desired input channel conld, through second-harmonic generation as well as heterodyning in the mixer, produce a signal in the desired UHF passband.

range of approximately 20 db. If the gain of this combination of amplifiers is reduced 5 db, 15 db of AGC will be left to cover fades and 5 db will be left to take care of any unexpected increases in signal strength without overloading the amplifier. Such a combination will reduce fades of 15 db to a 1.0-db variation in output power. One thousand microvolts (1 mv) has been chosen as the minimum rated input for the normal signal because such a signal can be expected to carry with it occasional fades of 15 db. If the rating were carried to lower input signals, not only would there be insufficient gain in the channel amplifiers but especially during fades the signal would become low enough so that the input noise of the first channel amplifier would be excessive. When translators are required to be operated on a signal smaller than 1,000 mv, an external preamplifier should be included to overcome both the gain and input noise limitations.

Mixers

The function of the mixer is to produce new frequencies at the output channel through the combination of the input-channel frequencies and an injection frequency. The required heterodyne action is the result of a characteristic of nonlinear devices, the outputs of which contain new components which are the sum and difference of the two inputs. In this application, both the visual and aural signals are heterodyned simultaneously to the new band, using the sum of the VHF input and the injection frequency. A typical conversion is shown in Fig. 4-5. If a higher injection frequency were used such that the difference signal instead of the sum fell in the desired band, the visual and aural carriers in the final signal would be inverted and improper operation would result.

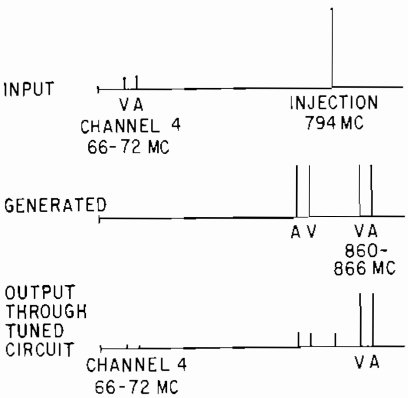
A perfectly linear stage will produce no mixing. In such a stage the only components in the output will be those found in the input. When the output-vs.-input curve departs from linear, it is said to have higher-order terms. The output is in part proportional to the input and in part proportional to the square of the input, the cube of the input, etc. The term which represents an output proportional to the square of the input is the term which produces the desired mixing. Higher-order terms representing outputs proportional to the cube or the fourth power, etc., of the input produce spurious signals such as a combination of the second harmonic of the input signal plus the injection frequency, etc. An ideal mixer would be a device in which the output varied strictly as the square of the input. Even in this case, however, with two carriers as one input being mixed with an injection frequency, spurious outputs will result.*

The nonlinear device produces a 4.5-Mc beat between the two carriers. Spurious signals will also be found 4.5 Mc above and below the two carriers and with decreasing magnitudes at 9 and 13½ Mc, etc. above and below. The spurious products 4.5 Mc above and below the two desired carriers are the most troublesome because they are relatively large components and are close to the passband of the tuned circuits in the UHF stages. Other spurious products, such as a second harmonic of the injection frequency, for instance, will differ enough in frequency from the desired signals so that they will be rejected quite completely by the succeeding tuned circuits. In addition to being difficult to eliminate in the tuned circuits, the components 4.5 Mc above and below the carrier are annoying because they can be tuned in on a receiver by error or conceivably interfere with another desired signal on a nearby channel.

Aside from the generation of spurious products, the linearity of mixing is important in retaining the quality of the picture information, the sync and blanking pulse heights, etc. The desired output sideband will exhibit very satisfactory amplitude linearity as long as the injection signal is much greater than the input-signal frequency. If the

* A diode mixer can be treated as a device in which the current is a nonlinear function of the applied voltage. A triode or pentode mixer can also be treated this way or by considering the variation of gm with grid voltage. See L. B. Arguimbau, "Vacuum Tube Circuits and Transistors," pp. 431 ff. and 291 ff., John Wiley & Sons, Inc., New York, 1956, for details of the two methods. The conclusions stated above follow if the signal is composed of two separate frequencies representing the visual and aural carriers; i.e., $Q(t) = Q_v \sin(\omega_v t + \phi_v) + Q_a \sin(\omega_a t + \phi_a)$, and the injection signal is a third frequency $P(t) = P \sin(\omega_p t + \phi_p)$.

signal amplitude is raised in level to obtain more output, a point will be reached where the nonlinearity of the tube becomes so violent that the higher-order terms, now large in magnitude, contribute serious distortion within the desired output passband. This usually first shows up as moderate sync compression and excessive spurious signals 4.5 Mc above and below the carriers. As the effect becomes more severe, intermodulation products show up as interference in the picture. The video signal will, through this intermodulation, amplitude-modulate the aural carrier to the point where it is difficult or impossible to remove the "sync buzz" in the aural channel of receivers. The same problems arise when the input signal is of proper amplitude but the injection voltage falls sufficiently below normal to result in an unfavorable ratio of the two signals.



	VISUAL	AURAL
CHANNEL 4	67.25	71.75
INJECTION	794.00	794.00
CHANNEL 79	861.25	865.75

Fig. 4-5. Frequency spectrum associated with a typical VHF-to-UHF conversion. The visual and aural carriers have the proper frequency relationship only in the upper sideband. The output circuit which is tuned to the desired sideband partially rejects the other potential outputs.

The most appropriate type of mixer for heterodyning to the higher UHF channels is a grounded-grid triode. The triode mixer allows operation at a considerably higher level than a crystal mixer and has more than unity conversion gain. The amount of amplification needed at UHF is thus reduced. The grounded-grid circuit produces valuable isolation between the plate circuit of the mixer and the input circuits. In such a stage both the VHF signal and the injection frequency source must be introduced on the cathode. Since these frequencies are quite different, it is possible to isolate each of them through a circuit which blocks the other. Thus, the injection-frequency source will not load the cathode circuit at the VHF frequency and vice versa. This is illustrated in Fig. 4-6. The plate circuit of the mixer stage must be tuned to the sum of the VHF input signal and the injection frequency. The necessity for achieving the full 6-Mc bandwidth occupied by the television signal is usually a limiting factor in the design of the plate circuit. It is desirable to have the plate of the mixer working into a double-tuned circuit critically coupled or slightly overcoupled in order to produce a flat top or slightly double humped curve. Optimum amplitude and phase characteristics will then be obtained. These circuits should be designed with a minimum of capacitance for optimum bandwidth. In practice, this means working with the irreducible minimum of stray capacitance present in the physical construction of the circuit. Physically the double-tuned circuit is located partly at the plate of the mixer tube and partly at the input of the succeeding stage, with the coupling supplied by the interconnection coaxial cable.

It is possible through the use of tubes with large power-handling capabilities to build mixers with large outputs. Such an arrangement, however, is not used for several reasons. A very high power injection source would be required for such a large mixer, and the unwanted products and straight-through signals at the output of the mixer would be comparable in size to the desired output of the apparatus. Several stages of filtering would be required to isolate the desired signal from the other products so that the spurious signals fed to the antenna would be reduced to an acceptable level. Furthermore, the generation of the spurious products at a high level would necessitate extreme precautions to prevent them from being radiated directly from the translator itself as cabinet radiation. If mixing is accomplished at a lower level, the succeeding stages of tuned amplification act as filters in themselves, the spurious products are generated at a much lower level, and the cabinet radiation of the injection signal and spurious products is much less of a problem. Typical mixers for

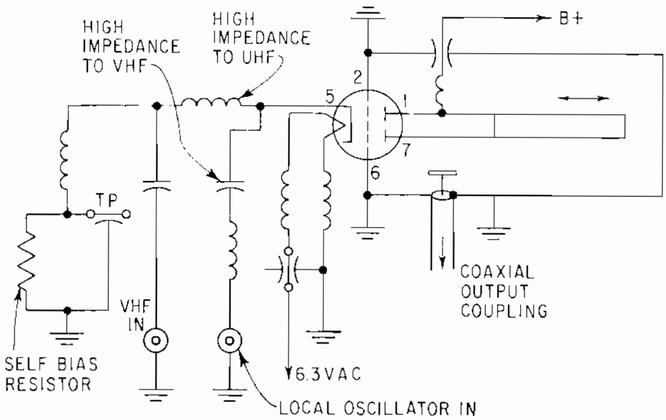


FIG. 4-6. Mixer circuit for heterodyning signals from VHF to UHF. The input circuits are lumped constants, while the output circuit is a half-wave open-circuited transmission line.

this application will generate desired signals of 10 to 100 mw. Above this, diminishing returns are obtained for the extra efforts involved.

Linear Amplifiers

In a practical translator several stages of linear amplification at the final output frequency are required. Because of the linearity requirement Class C stages cannot be used. However, Class B stages are used, especially at higher power levels, where efficiency becomes important as a limit on the maximum output available from a given tube. Intermediate stages are frequently run Class A to obtain maximum gain. At the usual translator frequencies the grounded-grid configuration is most practical as a means of preventing regeneration or oscillation. Self-bias is usually desirable as a means of stabilizing the d-c operating point of the tube, although this prevents complete Class B operation and results in fairly heavily biased AB operation instead. Figures 4-7 and 4-8*a* and *b*, show a schematic and photographs of a typical cavity stage capable of 10 watts output with 10-db gain and 6-Mc flat-top bandwidth. The input circuit of this stage consists of a transmission line terminated with an adjustable short circuit. In addition, the input connection to the transmission line is adjustable so that the signal can be fed into the transmission-line tuned circuit at a point which has an impedance of 50 ohms. Such an arrangement eliminates any loss from impedance mismatching of the input circuit and permits interconnection between cavities without critical dependence upon the length of a cable. The tuned-plate circuit of a driving stage and the input tuned circuit of a driven stage plus interconnecting cable are electrically equivalent to a lumped-constant double-tuned circuit. Since the input to an amplifier stage is inevitably quite lossy at these frequencies, the characteristics of the combination will be those of a double-tuned circuit in which the Q of the secondary is much less than the Q of the primary. A proper bandpass curve is achieved by adjusting the output coupling from the driving plate circuit. The plate circuit is also a concentric transmission line tuned with an adjustable shorting plunger. A short-circuited transmission line of less than one-quarter wavelength appears inductive at the open end.* The short is therefore positioned at a point less than one-quarter wavelength from the tube where the line resonates with the inevitable capacitance of the tube and mounting. It is also possible to use a line slightly less than three-quarters or five-quarters, etc., wavelengths long if the one-quarter wave position

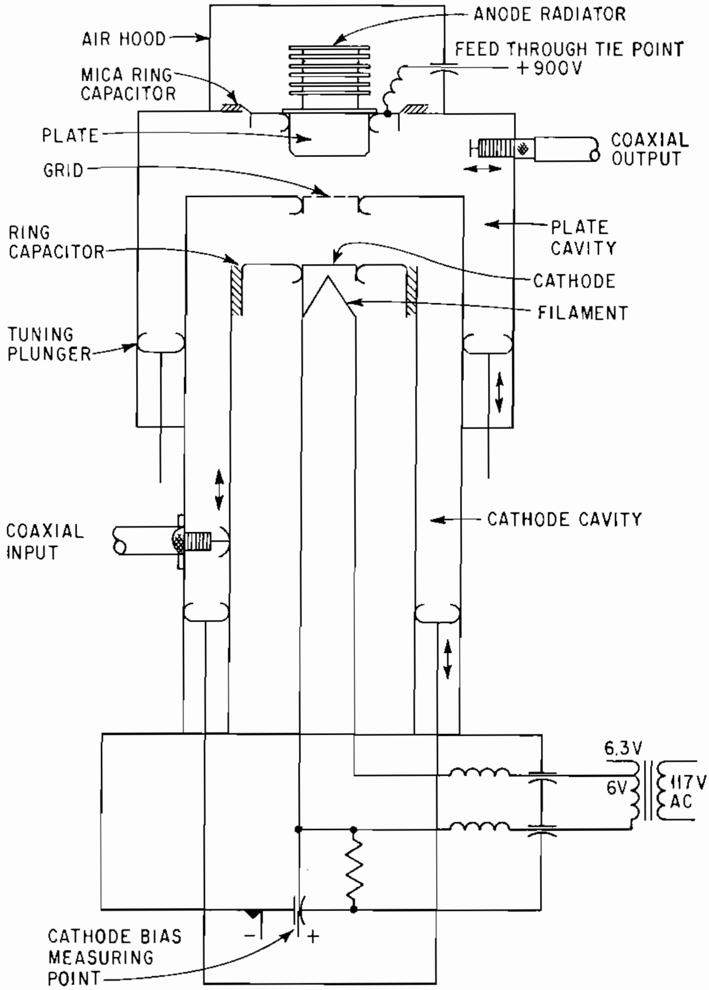
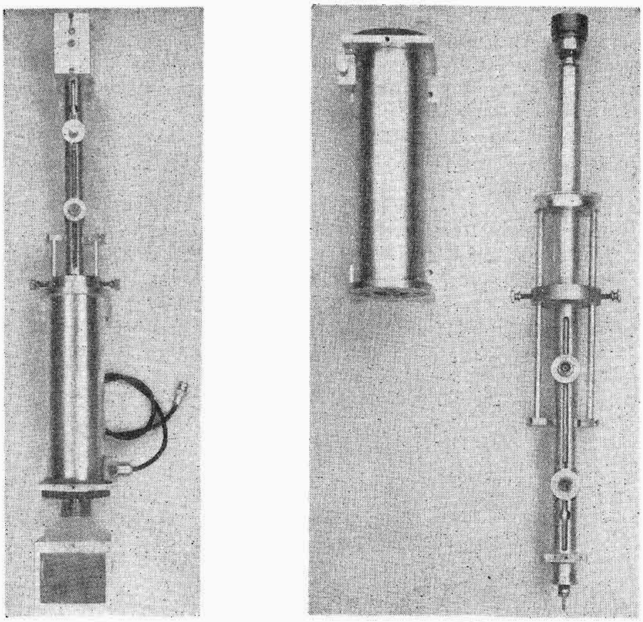


FIG. 4-7. Schematic diagram of a UHF amplifier cavity for the 2C39 family of tubes.

is so close to the tube as to be mechanically impractical. Such higher mode operation, however, results in a poorer gain-bandwidth product and is to be avoided if possible.†

* "NAB Engineering Handbook," 4th ed., pp. 5–1–03 to 5–1–05, National Association of Broadcasters, Washington, D.C., 1949. See also Ref. 1, pp. 567, 577.

† For a complete discussion of coaxial cavity amplifiers see Staff of the Harvard Radio Research Laboratory, "Very High Frequency Techniques," vol. I, chap. 15, McGraw-Hill Book Company, Inc., New York, 1947.



(*a*) (*b*)

Fig. 4-8. (*a*) Photograph of a UHF amplifier cavity with the air-flow hood lifted to show the 2C39 tube in place. (*b*) The same cavity partially disassembled to show the plate circuit inner conductor and shorting plunger. The grid ring of the 2C39 tube is inserted into a ring of flexible fingers at the top of the inner conductor. The tuning range is 450 to 900 Mc. (*Courtesy of Adler Electronics, Inc.*)

Injection Sources

To complement the mixer, an injection signal must be provided. The signal source whose frequency is the difference between the input and output frequencies must supply sufficient power for linear mixing with about 0.005 per cent frequency stability under all possible conditions of temperature and voltage. Higher accuracy is required if translators are to be run in tandem (tolerances will add). Crystal-oscillator tolerances of 0.001 per cent are readily achievable without temperature stabilization and are considered desirable.

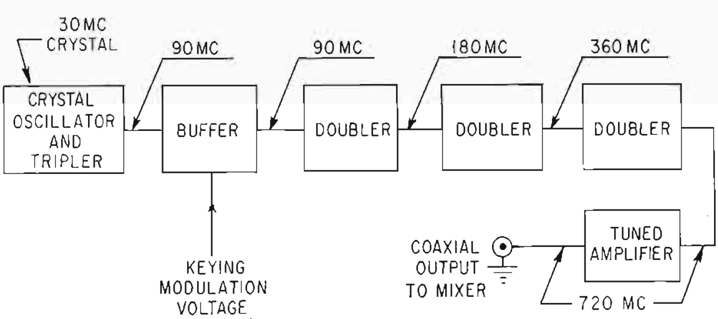


Fig. 4-9. Block diagram of an oscillator-multiplier chain. The output frequency is 24 times the crystal frequency.

In converting from one VHF channel to another relatively low frequency injection signals are required. These are supplied by a crystal oscillator followed by a doubler or tripler stage if required. For conversion to UHF a much higher frequency is required. Multiplication to twenty-four times the crystal frequency is typical. The block diagram of such a multiplier is shown in Fig. 4-9, and the frequencies involved in each possible conversion are listed in Table 4-1.

Certain precautions are necessary in the design of such a high-multiplication injection source. Each stage must be carefully arranged to preclude self-oscillation. Furthermore, each multiplier stage must be carefully isolated to prevent any improper signal components from feeding through. For instance, heater and plate power-supply leads must be electrically isolated with chokes and capacitors to prevent low-frequency components from traveling along these leads and appearing at tbe output of the multiplier chain. Such frequency components would lead to spurious responses in the mixer which in turn might show up in the output channel.

The careful bypassing of the leads mentioned above as well as the use of a housing which militates against RF leakage will both contribute to the reduction of extraneous radiated signals (cabinet radiation) to acceptable levels.

Control Circuitry

Auxiliary circuits must be included to perform functions required by the FCC rules for translators and by good engineering practice. These circuits through their control of the plate power to the stages succeeding the VHF channel amplifiers prevent

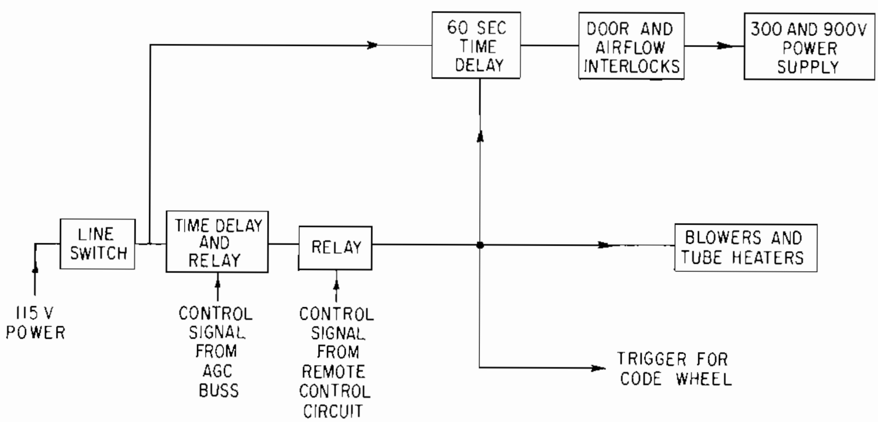


FIG. 4-10. Block diagram of the control circuitry in a translator.

operatiou of these sections of the translator unless the originating station is on the air. The high-voltage circuits are interlocked against the opening of that part of the apparatus that gives access to them and against loss of air flow at the forced-air-cooled UHF amplifier tubes. In addition, a code wheel and keying circuit are included for transmitting identification of the translator at appropriate intervals. Figure 4-10 is a block diagram of the control circuitry.

The first of the circuits in the control chain is the one which is activated when the desired input channel is present in sufficient strength for proper operation. In the absence of such a signal the translator is held inoperative to prevent the translation of spurious signals. The channel amplifiers would not have their gain reduced at all by AGC action. Thus, even a signal which is somewhat off the input channel might go through the translator with sufficient strength to produce a significant spurious output. This spurious output would fall outside the assigned channel of

Table 4-1. UST-10 TV Translator-Transmitter

Key: INJECTION FREQUENCY / OSCILLATOR FREQUENCY

UHF CHANNEL

VHF CHANNEL		70	71	72	73	74	75	76	77	78	79	80	81	82	83
		806-812	812-818	818-824	824-830	830-836	836-842	842-848	848-854	854-860	860-866	866-872	872-878	878-884	884-890
2	54-60	752 / 31.3333	758 / 31.5833	764 / 31.8333	770 / 32.0833	776 / 32.3333	782 / 32.5833	788 / 32.8333	794 / 33.0833	800 / 33.3333	806 / 33.5833	812 / 33.8333	818 / 34.0833	824 / 34.3333	830 / 34.5833
3	60-66	746 / 31.0833	752 / 31.3333	758 / 31.5833	764 / 31.8333	770 / 32.0833	776 / 32.3333	782 / 32.5833	788 / 32.8333	794 / 33.0833	800 / 33.3333	806 / 33.5833	812 / 33.8333	818 / 34.0833	824 / 34.3333
4	66-72	740 / 30.8333	746 / 31.0833	752 / 31.3333	758 / 31.5833	764 / 31.8333	770 / 32.0833	776 / 32.3333	782 / 32.5833	788 / 32.8333	794 / 33.0833	800 / 33.3333	806 / 33.5833	812 / 33.8333	818 / 34.0833
5	76-82	730 / 30.4166	736 / 30.6666	742 / 30.9166	748 / 31.1666	754 / 31.4166	760 / 31.6666	766 / 31.9166	772 / 32.1666	778 / 32.4166	784 / 32.6666	790 / 32.9166	796 / 33.1666	802 / 33.4166	808 / 33.6666
6	82-88	724 / 30.1666	730 / 30.4166	736 / 30.6666	742 / 30.9166	748 / 31.1666	754 / 31.4166	760 / 31.6666	766 / 31.9166	772 / 32.1666	778 / 32.4166	784 / 32.6666	790 / 32.9166	796 / 33.1666	802 / 33.4166
7	174-180	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833	692 / 28.8333	698 / 29.0833	704 / 29.3333	710 / 29.5833
8	180-186	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833	692 / 28.8333	698 / 29.0833	704 / 29.3333
9	186-192	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	689 / 28.3333	686 / 28.5833	692 / 28.8333	698 / 29.0833
10	192-198	614 / 25.5833	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833	692 / 28.8333
11	198-204	608 / 25.3333	614 / 25.5833	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833
12	204-210	602 / 25.0833	608 / 25.3333	614 / 25.5833	620 / 25.8333	628 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333
13	210-216	596 / 24.8333	602 / 25.0833	608 / 25.3333	614 / 25.5833	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833

the translator with the attendant possibility of causing interference to other signals. Similarly, co-channel signals arriving as the result of unusual propagation conditions would not pass through the translator unless they reached and maintained a signal strength comparable to the usual input signal. Translation of a co-channel signal would be undesirable because of its lack of reliability as well as its constituting operation not in accordance with the translator license, which is valid only for the specified originating station.

The action of the control circuit is developed from the AGC voltage generated in the channel amplifiers. An initial control circuit is activated when the AGC voltage rises to within the normal operating range. Since an improper signal might reach this value on a transient basis, a 1-min time delay is imposed upon the operation of the control circuit to prevent the translator from being turned on by such a transient signal.

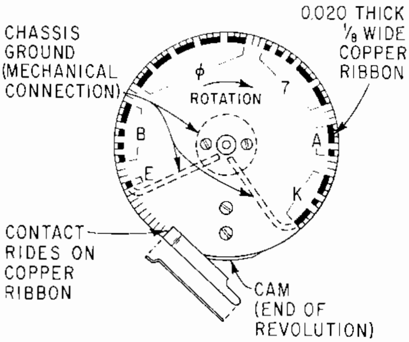


FIG. 4-11. Code wheel for automatic translator identification. The copper ribbon which forms the code characters is continuous, running on the underside of the wheel where no contact is required, and is connected to ground at the hub.

One of the requirements for translator operation imposed by the FCC rules is that the output of the translator be monitored periodically by an operator who, in the event he detects improper operation, will either correct the operation or shut down the translator until the correction can be made. An important adjunct to the operation of all translators where no operator is present is a fail-safe remote-control circuit. This makes it possible to control the translator from a convenient location, even though the translator is at a remote site. A circuit in the translator is brought out to a pair of terminals which must be closed through a rectifier for the circuit to operate. A wire line of virtually any length can then be used to connect the translator to the remote-control point. Only if the line is closed through a rectifier at the control point will the circuit operate. If the wire line is inadvertently broken or short-circuited so an a-c voltage is returned to a circuit sensitive only to direct current, the operation of the translator will be interrupted by an inoperative link in the control chain.

Interlocking is provided for the protection of personnel against high voltage and for the protection of the air-cooled UHF amplifier tubes against the failure of the air supply. The high-voltage interlocking is a conventional interlock switch on the door which gives access to high-voltage circuits. Air-flow interlocking is accomplished by a sensitive switch controlled by a vane in the air stream. When both of these interlock circuits are in proper operating condition, the third step in the control circuit is closed.

When the conditions imposed by the circuits of the three preceding sections are satisfied, power can be supplied to the oscillator-multiplier chain, the mixer, and the UHF amplifiers. In accordance with good engineering practice a time delay is included in the high-voltage circuit so that high voltage is not supplied to these circuits until they are ready to draw current.

The remaining control requirement is fulfilled by the code wheel and keying circuit which identify the translator station in International Morse Code when the station first comes on and at the hour and half hour as operation continues. The keying is most conveniently accomplished by 100 per cent audio tone modulating one of the stages of the oscillator-multiplier chain. This shows up on a home receiver as a series of horizontal bars corresponding to the audio frequency but are of brief duration to avoid annoyance to the viewer.

Since translators run unattended, means must be provided for generating the call-letter codes. A convenient method of accomplishing this is with metallic inserts in an insulated wheel. Contact between a pickup arm and the conducting inserts activates the audio modulation of the oscillator-multiplier chain, and one revolution of the code wheel identifies the translator station. Figure 4-11 is an illustration of such a code wheel.

An auxiliary requirement imposed upon some translator stations by the originating station is a means of controlling the translator with a signal included in the transmission of originating station. A typical means of accomplishing this control is through the inclusion of a supersonic tone such as 20 kc on the aural channel when translator operation is to be permitted. To accomplish this control function circuits are included to demodulate a sample of the frequency-modulated aural carrier. Circuits responsive to a 20-kc signal as low as 10 to 20 db below normal modulation govern an added step in the control chain of the translator.

100-watt Amplifier

When power outputs as high as 100 watts are required, the combination of a 10-watt translator and a 10-db amplifier with a 100-watt capability can be used. The 100-watt amplifier is packaged as a separate unit for a variety of reasons. Among them is the fact that it is larger in physical size and in cost than the entire 10-watt translator. Since the 100-watt amplifier almost doubles the equipment cost of a translator installation, it is frequently added when experience with a given 10-watt installation shows the desirability of increasing the power to bring better coverage to larger areas. In addition, the two-unit construction provides flexibility in carrying equipment over poor roads and installing it in what is sometimes a very small available space. Furthermore, as the power handled becomes greater, the type of construction changes significantly, so that many features are found in a 100-watt amplifier which are not necessary in a 10-watt unit. Figure 4-12 is a photograph of a 100-watt amplifier.

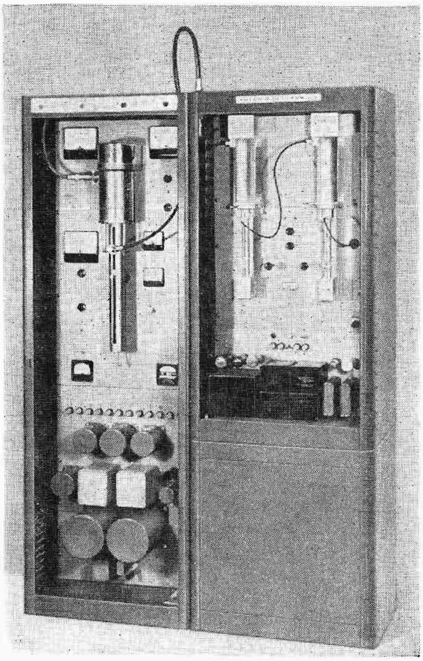


Fig. 4-12. 100-watt amplifier shown connected to the 10-watt translator which drives it. Front doors of both units are removed. The amplifier has a tuning range of Channels 14 to 83.

The cavity for such an amplifier is similar in construction to those described in connection with the 10-watt unit but is designed for a tube of higher power-handling capability and may be designed for a tetrode as shown in Fig. 4-13. In particular the cathode-grid circuit tuning and matching features are the same as for the 10-watt cavity, so that the tuning and matching procedures of such a cavity are the same as previously described.

The ability to adjust the coupling to the last plate circuit of the 10-watt translator and the 100-watt amplifier cathode circuit makes it easy to integrate the two units into an over-all system from an RF point of view and to maintain this integration when tubes are changed in either the driving or final circuit. To complete the integration the power-supply circuits in the 100-watt final amplifier are controlled by the 10-watt translator; thus the 100-watt amplifier functions in every respect as a logical extension of the 10-watt translator with its power supply coming on at the same time power is supplied the UHF stages in the translator.

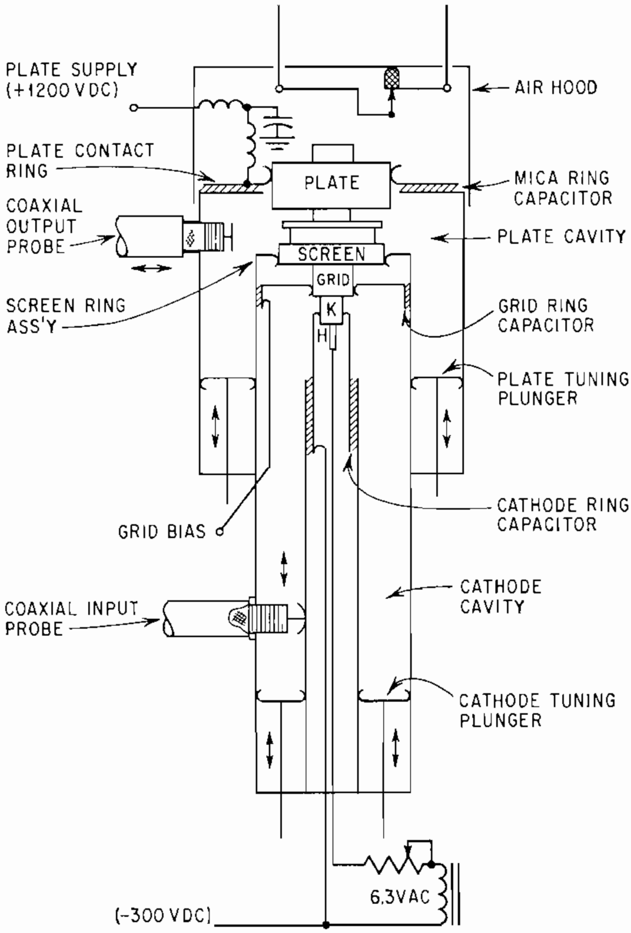


FIG. 4-13. 100-watt UHF amplifier cavity for a tetrode. Position of the input probe is adjustable for impedance matching to the input cable. The output probe is adjusted for proper loading of the plate circuit.

Among the additional refinements appropriate to the higher power operation are an overcurrent relay which shuts off the plate supply voltage if the cathode current becomes excessive, a screen-voltage interlock required for tetrodes which prevents the application of the screen voltage unless the plate voltage is applied, and extensive built-in metering of all supply voltages as well as power-output monitoring.

UHF Input Translators

Translators for operation from a UHF input signal differ only from the previously described VHF input translator by the inclusion of a UHF-to-VHF converter. Conversion to VHF is preferred to straight UHF-to-UHF conversion for a number of reasons. Foremost of these is the relative ease with which the signal can be amplified at VHF frequencies. The approximately 80-db gain achieved at VHF in a regular translator would require a great many stages and/or expensive specialized UHF tubes. Furthermore, many UHF-to-UHF translators require a change of only a few channels and the separation between the input and the output frequencies will be only a few per cent of the output frequency. In this case, the tuned circuits after the mixer will not reduce the input frequency component sufficiently unless special precautions are taken.*

The UHF-to-VHF converter is comprised of three elements: a preselector to pass only the desired signal, a mixer to heterodyne the signal to a VHF channel, and an injection source.†

Conversion should be to a low VHF channel to take advantage of amplifier noise figures, which are lower than at the high VHF channels.

The preselector must eliminate any interfering signals would could produce a signal at the VHF output. The most important of these is the image frequency at twice the VHF frequency below the desired input. Signals which could beat with a harmonic of the mixer would also be troublesome. The preselector will also serve to prevent the injection frequency from being radiated by the receiving antenna. The preselector must be low loss not only to preserve the available signal but to prevent the introduction of noise from the equivalent resistance corresponding to any circuit loss. It should have the bandpass characteristic of a double-tuned circuit critically or slightly overcoupled. The most suitable circuit elements are resonant transmission-line sections, either coaxial or flat-plate type, with proper coupling between the sections.

The mixer consists of a crystal diode in a holder which provides an impedance match between the signal input and the crystal diode, allows the injection signal to be applied to the crystal, and provides an output through a low-pass filter which bypasses the UHF frequencies.‡

The injection source should be crystal controlled, since any frequency error in this conversion will cause a corresponding error in the final frequency. The injection frequency must be below the incoming signal in frequency to prevent inversion of the carriers.¶

The requirements of the injection source are similar to the injection sources previously described for use in VHF-to-UHF translators except possibly for power-output requirements. The requirements here will vary with the cable loss used between the injection source and the mixer, with 10 mw usually required at the mixer.

The preselector and mixer should be located at the antenna to prevent the consequences of signal loss in a long cable. The injection source can be located remotely

* A typical translator might have 30-db gain in and after the mixer for frequencies in the desired output frequency range and −40 db for a signal a few channels off. Thus the input signal would be amplified 60 to 80 db before the mixer and −40 db after or +20 to +40 db net. This could result in ghosts from a signal feed back from the transmitting to receiving antenna with a delay corresponding to the distance between the antennas. In extreme cases where the isolation between the antennas is less than the net gain, oscillation would result.

The same problem exists in VHF-to-VHF translators where the difference between the input and output frequencies is only a few channels.

† New techniques for the use of solid-state diodes as low-noise amplifiers are developing rapidly. At the time of writing, they promise a significant improvement in noise figure over mixing without RF amplification. As the development of these devices continues, they should come to be practical for field installations. At UHF frequencies antenna temperatures are much lower than at VHF. Thus an improvement in the noise figure of the receiving circuit produces a very significant reduction in the value of the minimum usable signal.

‡ For a brief description of this type of mixer see F. E. Terman, "Electronic and Radio Engineering," 4th ed., p. 579, McGraw-Hill Book Company, Inc., New York, 1955. A more detailed discussion can be found in Staff of the Harvard Radio Research Laboratory, *op. cit.*, vol. II, chap. 29.

¶ This is the opposite of regular television receiver practice where the oscillator is above the incoming signals and the carriers are inverted by the conversion to the IF frequency.

provided sufficient signal is available at the end of the cable which brings the signal to the mixer.*

It is usually desirable also to locate the first VHF amplifier or preamplifier at the antenna.†

Table 4-2. Attenuation of Various Cables at Translator Frequencies in Decibels per 100 Ft

UHF

Cable	*Impedance*	*800 Mc*	*900 Mc*
RG 8A/U	50	7.0	7.5
RG 14A/U	50	5.0	5.5
RG 17A/U	50	2.9	3.2
RG 58C/U	50	19	21
⅞ in.*	50	1.4	1.5
1⅝ in.*	50	0.80	0.85
3⅛ in.*		0.32	0.34
RG 11A/U	75	7.8	8.2
RG 59A/U	75	13	14
300 tubular hollow	300	4.0	4.3

VHF

	50 Mc	*200 Mc*
RG 11A/U	1.5	3.3
RG 59A/U	2.5	5.5

* Semiflexible.

Translators in Tandem

Operation of a translator on the signal rebroadcast by another translator has been found entirely practical in a number of installations. Up to four translators in series have been utilized in areas where the original signal may be reliably received only at the first translator. In such operation all translators after the first are necessarily of the UHF-to-UHF type described in the previous section.

In tandem operation any degradation of the signal in each translator will result in poorer performance as the signal progresses through the chain. This type of operation therefore makes more critical demands upon a translator than normal operation. While a translator operated at rated output will not degrade either the video or aural information, it will generally introduce a few per cent of sync compression. This effect is not large enough to be of concern in a single translation, but the cumulative effect may become objectionable. It is then necessary to run each translator at a somewhat reduced power output to minimize the compression at each step. A reduction in power output of 3 db would not normally decrease the coverage of the individual translators appreciably but will reduce the compression to an immeasurable level.

Standard translators singly and in tandem are utilized in many countries for point-to-point relaying by substituting highly directional transmitting and receiving antennas for tbe area-coverage antennas normally used for rebroadcasting. In the United States this technique is used but with the output frequency raised to one of the bands such as 1,990 to 2,110 Mc, where channel assignments are available for the purpose of relaying.

Internal Interferences

In practice, not all input-output channel combinations can be used. All frequencies associated with a desired conversion must be carefully examined for spurious signals which fall within or close to either the input or output channel.

* See Table 4-2 for attenuations of commonly used cables.

† The considerations are much the same as when the signal comes from a VHF antenna. See the discussion nnder Amplification at the Antenna.

The input channel in particular is sensitive to even very low level signals. Thus, if any stage in the oscillator-multiplier chain operates on a frequency, at or near the input channel, it can be expected to produce interference. Table 4-1 shows the interferences which arise from a typical injection source. Sometimes this source of interference can be eliminated by changing the order of multiplication. For instauce, if the second harmonic of the crystal oscillator falls in the input channel, the oscillator-multiplier chain could be changed to a tripler followed by a doubler instead of vice versa. While it is not usually feasible to change the multiplication factor between the crystal frequency and the injection freqnency in a standard oscillator-multiplier unit, this avenue of approach is open if the design of a special oscillator multiplier is justified.

The other aspect of the problem concerns the generation of spnrious products in the mixer which would fall in or near the output channel. Such a problem would arise if the second harmonics of the input carriers fall at or near the ontput chanuel as it would in converting from Channel 6 (aural carrier 87.75 Mc, second harmonic 175.50 Mc) to Channel 7 (174 to 180 Mc). This type of problem is less apt to occur when the output channel is widely separated from the input, as it is in VHF-to-UHF translators.

When two or more translators are to be installed in close proximity, it is necessary to examine the frequencies generated within each translator for possible interference with the input channels of the other units.

AREA-COVERAGE PROBLEMS

Line-of-sight Requirements

Up to this point the techniques and equipment necessary to produce a high-qnality 10- or 100-watt translated signal have been described in detail. This has been done to provide the system designer with the fullest possible understanding of those elements of his system even though he will be working with fairly standardized receiving-antenna techniques and type-approved translating equipment. Providing proper coverage will, on the other hand, be an original problem for each installation, since the terrain and population distribution will be different in each case. It is fortunate, considering the relatively low power available from either a 10- or 100-watt translator, that directional antennas can be used to concentrate energy in the populated areas and that at translator frequencies even highly directional arrays do not require large physical size. Conversely, since there is even less propagation beyond obstacles than at VHF, the transmitting-antenna site must be chosen to provide a clear line of sight to all population areas to be served.*

In this connection, it must be remembered that optical clearance is not sufficient; at least first Fresnel-zone clearance over any obstruction is required. At any point where a potential obstruction exists along the path between transmitting and receiving antennas, the required clearance (first Fresnel-zone radius in feet) can be calculated from †

$$R = 81 \sqrt{\frac{D_1 D_2}{D_1 + D_2}}$$

where D_1 = distance from transmitting antenna to potential obstruction, miles
D_2 = distance from same point to receiving antenna, miles

This shows that the required clearance increases ont to the halfway point between the transmitter and the receiver and decreases beyond that point to zero at the re-

* Required clearance for 850 Mc. For other frequencies multiply by $\sqrt{850/f}$.

† Refraction in the atmosphere bends the waves. Profiles of the terrain used to determine clearance are usually plotted as though the earth radius were 4/3 times its actual value.

ceiving antenna. A more complete discussion of the importance of first Fresnel-zone clearance in line-of-sight propagation can be found in any of several books.*

Transmitting Antennas

The dipole is the simplest practical antenna which could be used for an installation. It could be used where a figure-eight type of pattern in the horizontal plane would be appropriate. However, such an antenna is a very inefficient device in terms of concentrating energy in areas where it will be used. Inasmuch as it radiates energy equally well in all directions in a vertical plane, as much energy is radiated straight up or down as is radiated toward the horizon. Dipoles are therefore normally used as components in an array or with reflecting elements to produce vertical and horizontal directivity. Figure 4-14 shows an antenna with four dipoles fed in phase and stacked vertically with a half-wavelength separation. This combination produces no net radiation above and below the antenna and, with the back plate acting as a reflector, radiates approximately 9 db more energy in the forward horizontal direction than an isotropic radiator.† The lack of net energy in the vertical direction can be predicted by considering the phase of the radiated waves from each of the four dipoles. An electromagnetic field is propagated from each of the four dipoles in the same phase. Because the separation is one-half wavelength, however, the energy from the second dipole will pass the first dipole out of phase. Similarly, energy going in the vertical direction as waves from the fourth antenna will be out of phase with waves from the third antenna. Thus, at a distance many wavelengths from the antenna, where the minor differences in the distances traveled have no effect on the relative signal strengths but do result in the waves arriving out of phase, no net energy will be observed. Conversely, in the forward direction at a point many wavelengths from the antenna, the vertical separation among the elements will cease to have any effect upon the radiation arriving from each of the four dipoles and the waves will add directly in phase. At intermediate angles, such as 45°, the waves from the two pairs of dipoles arrive with a phase-angle difference determined by the different path lengths as shown in Fig. 4-15. Figure 4-16 shows the vertical directivity pattern of such an array of four dipoles fed in phase. The pattern of an array of any complexity can be calculated in similar fashion by considering each dipole as a point source of electromagnetic waves and by establishing the relative phase corresponding to the number of fractional wavelengths traveled from the various point sources.‡ Figure 4-17 is such a plot.

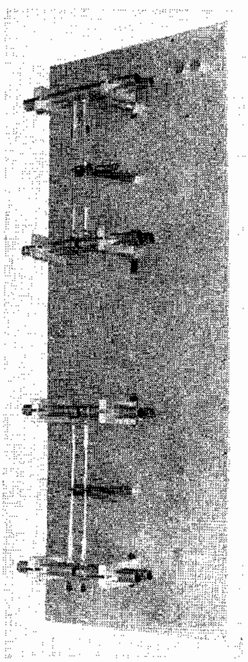


FIG. 4-14. Basic transmitting antenna with fiberglass cover removed. It is used singly and as a building block for arrays. (*Courtesy of Adler Electronics Inc.*)

* For a brief description see Ref. 1 at the end of this part. A more complete discussion is included in Section 4 of this handbook.

† An isotropic antenna is a fictitious point source which radiates equally in all directions. It is frequently used as a reference to which other antennas are compared. A dipole in its maximum direction has 2.15-db gain over an isotropic radiator.

‡ If an array is made up of groups of dipoles with the pattern of each group known, each group can then be considered a point-source radiator at the center of the group and with the same pattern as the group. Note that the patterns cannot be superimposed directly but the contributions at each angle must be added as vectors with relative angles corresponding to the phases of the various contributing signals; i.e., if one signal travels $\lambda/4$ farther than another, it will lag 90° in phase; if $\lambda/2$, then 180° lag, etc.

Frequently exact patterns are not so important as knowledge of the gain to be expected in the direction of maximum intensity. In this case a useful rule of thumb is as follows: Doubling the number of dipoles in an array increases the signal level in the maximum direction by 3 db. If these dipoles are stacked at half-wave intervals vertically, this increase is gained as the result of a narrower vertical pattern. If they are stacked horizontally, the gain is the result of narrowing the horizontal pattern.

The antenna illustrated in Fig. 4-14 has a forward gain of 9 db over an isotropic antenna. Two such units stacked vertically exhibit 12-db gain. Two more such antenna units comprising a vertical stack of eight dipoles can be placed alongside the first combination to produce an additional 3 db in the maximum direction for a total of 15-db gain over an isotropic radiator.

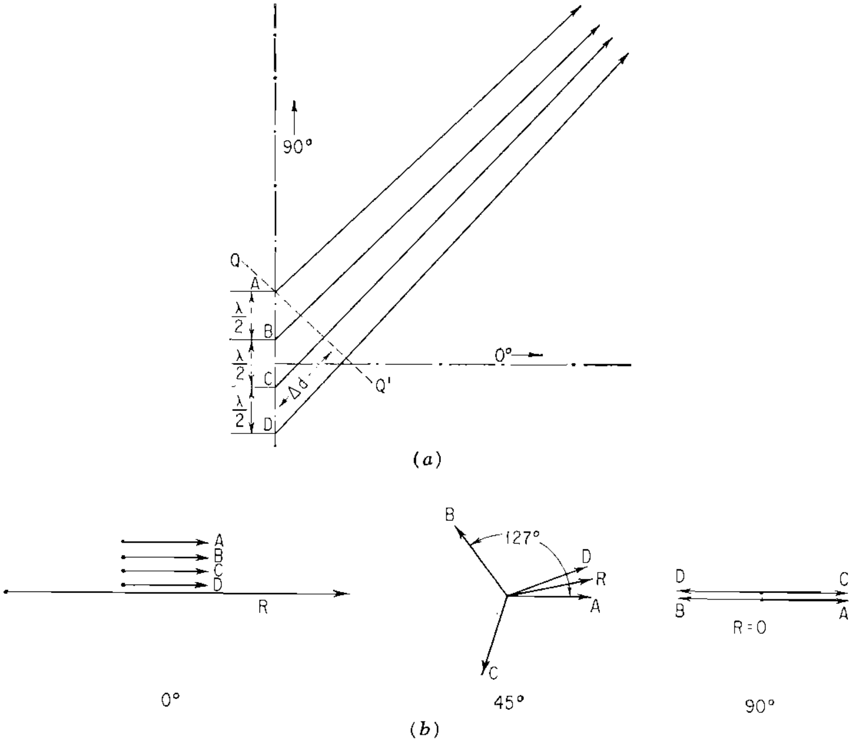


FIG. 4-15. (*a*) Four half-wave dipoles fed in phase. Distances Δd from points *B*, *C*, and *D* to line *QQ′* are the extra path lengths traveled by the waves from the respective antennas. The phase delays generated by these distances are

$$\Delta\phi = (\Delta d/\lambda) \times 360°$$

(*b*) Phase diagram of the contributions from each of the four dipoles. At 0° all are in phase. At 90° they are out of phase in pairs. At 45°:

$$\Delta d_B = (\lambda/2)\sin 45° = 0.707\lambda/2$$
$$\Delta\phi_B = (0.707\lambda/2\lambda)360° = 127°$$
$$\Delta\phi_C = 2\Delta\phi_B = 254°$$
$$\Delta\phi_D = 3\Delta\phi_B = 381°$$

The resultant *R* is the magnitude and phase of the sum of the four contributions. It does not refer to the direction of travel, which is radially outward from the array.

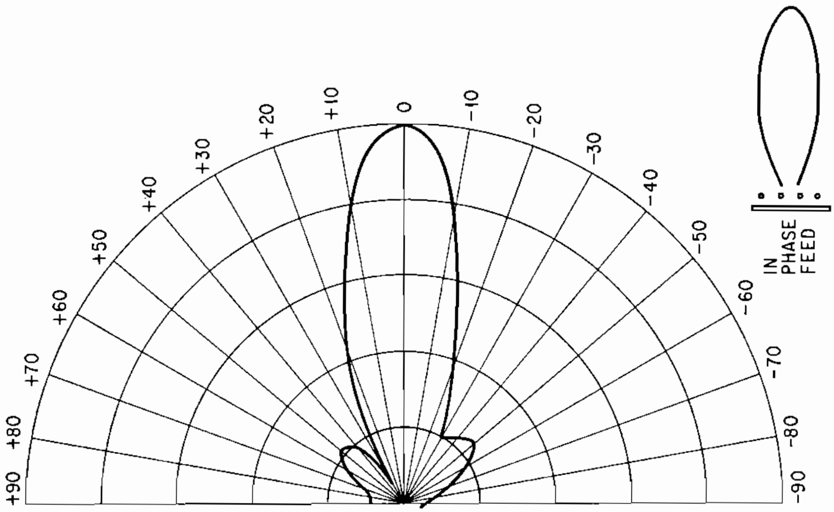


FIG. 4-16. Vertical pattern of four dipoles in front of a reflector and fed in phase (from measured data).

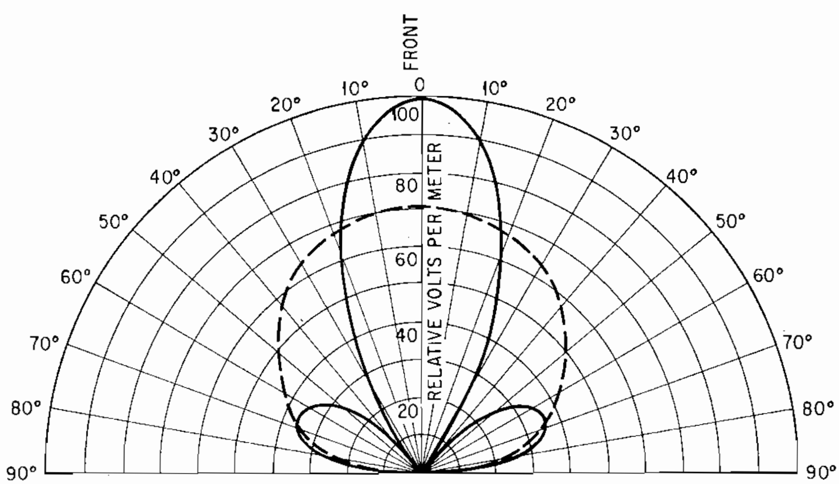


FIG. 4-17. Horizontal pattern of two of the antennas of Fig. 4-14 placed side by side (from calculations as described in text. Dashed line—Pattern of a single antenna; Solid line—Pattern of combination).

When arrays are built up of standard antennas as building blocks, it is most convenient to make the interconnections with coaxial cable of the same impedance as the main transmission line, usually 50 ohms. To maintain this impedance match, impedance transformers must be used where two sections are fed in parallel from a common line. While a number of matching techniques are known, the T transformer with tapered sections is favored for its compactness and the ease with which it can be made weatherproof. An array built up using such transformers is shown in Fig. 4-18.

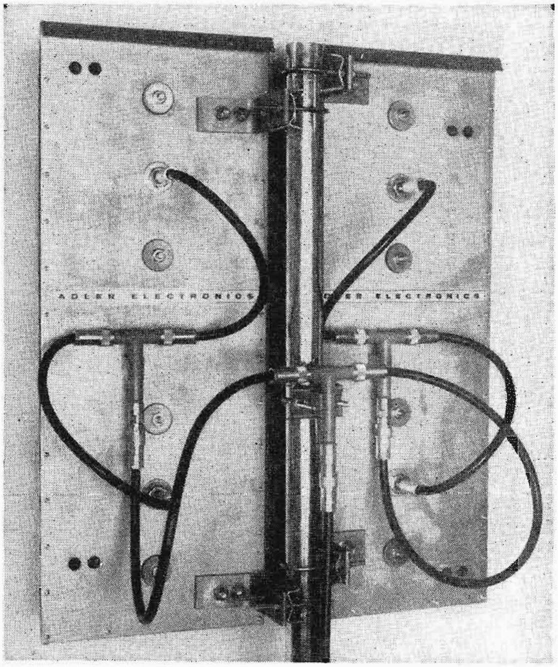


FIG. 4-18. Impedance matching with T transformers. The two halves of an antenna, each of which has a 50-ohm impedance, are joined with a T transformer, providing a 50-ohm impedance for the combination. Two 50-ohm antennas are joined through another T transformer. (*Courtesy of Adler Electronics Inc.*)

While the previously described antenna unit can be used in combinations to solve a great many coverage problems when extreme directivity is required, they become unwieldy and uneconomical compared with other types. Translators installed, for instance, at one end of a long, narrow valley can profitably use a parabolic-reflector-type antenna to concentrate the energy in a very narrow beam. At 800 to 900 Mc such an antenna has a forward gain of more than 20 db for a 6-ft reflector. Such an antenna would provide a given signal strength out to a distance approximately twice as great as an array of 16 dipoles connected as described above. Such an antenna would be suitable for use only when the population is concentrated within a narrow angle from the translator, since the coverage is about 15 to 20° wide.

Coverage Calculations

The desirability of establishing coverage over a wide angle must be balanced against the required forward gain which the antenna must have to reach the maximum distance to be covered. Coverage calculations can be conveniently made with the aid of Fig.

4-19, which shows propagation losses between isotropic antennas for various distances. Other losses between the transmitter and the receiver terminals include the transmission line from transmitter to transmitting antenna and the lead-in at the receiver. Losses for typical transmission line and receiving lead-in are shown in Table 4-2. The gains of the transmitting and receiving antennas, however, reduce the loss, so that the power available at the receiver will be greater by the amount of these two gains. Table 4-3 shows a typical calculation. Field experience has shown that a signal of

Table 4-3. Typical Path-attenuation Calculation

[Conditions chosen for this example are coverage required out to 15 miles, transmitting on Channel 71 (812 to 818 Mc)]

	10 *watt* *	100 *watt*
Transmitter power	+10 dbw	+20 dbw
Antenna transmission-liue loss, 50 ft RG17 at 800 Mc	−1.5 db	−1.5 db
Antenna gain (two of units illustrated in Fig. 4-14)	+12 db	+12 db
Path loss (from Fig. 4-19)	−118 db	−118 db
Receiving-antenna gain (typical corner reflector)	+10 db	+10 db
Receiving transmission-line loss (50 ft 300 ohms tubular)	−2.0	−2.0
	−89.5 dbw	−79.5 dbw

* Adequate signal will be available from the 10-watt translator over the horizontal arc between the 6-db (50 per cent voltage) points of the antenna horizontal pattern.

300 mv on a 300-ohm lead-in is a minimum safe signal for a first-class picture with a typical receiver. This is a power level of 3×10^{-10} watt, or approximately 95 db below 1 watt (−95 dbw). When coverage patterns are set up, every effort should be made to supply this signal as a minimum to the populated area.

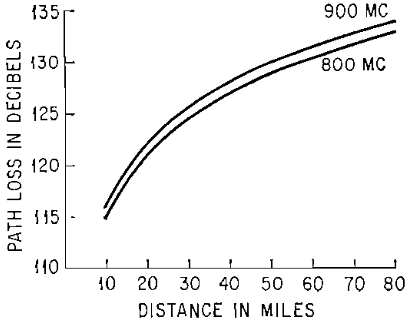


Fig. 4-19. Free-space path loss between isotropic antennas at translator frequencies. The loss between actual antennas is reduced by the gain of each of the antennas.

Sites

The selection of a site is a problem with a great many aspects, no one of which can be compromised beyond a certain point without adversely affecting the ultimate performance. They are listed in order of the firmness of the requirement. The first two are absolute requirements; the others become less stringent but may result in a more complex or costly installation or a less convenient one for maintenance.

1. Path clearance for transmitting the signal to the area to be covered. Only the transmitting antenna need be so situated. A tower to raise the transmitting antenna is sometimes the only solution.

2. Adequate VHF signal for a snow-free picture. While a large array will derive an adequate signal from relatively weak field strengths, the terrain must be suitable for erecting a large array which may spread over linear distances of hundreds of feet. In other instances, particularly where the terrain is relatively flat, there is not enough signal near the ground to get out of the noise with any conceivable array and a tower to elevate the receiving antenna is required. The structure(s) used must hold the antenna(s) rigidly and properly oriented through any combination of environmental conditions such as icing and windstorm which may be encountered.

3. Accessibility at any time with conventional vehicles. If this requirement cannot

be fulfilled, special vehicles capable of traveling over snow must be available when needed or the possibility of extended periods of inoperation must be faced. A site shared with an essential service such as public-safety radio transmitters will usually be accessible a high percentage of the time.

4. Power availability. The availability of commercial power will reduce the complexity and enhance the reliability of the installation. Adequate capacity should exist to permit the use of at least 1,000 watts of test equipment in addition to the translator requirements. Further capacity to permit some heating at least during maintenance periods will be found highly desirable if no other source of heat is available.

5. Adequate shelter. The shelter should protect the translator from the outside environment as fully as possible in two respects. The maximum temperature should be held as low as possible through the use of a fan and thermostat. The expected periods of operation between failures will be significantly increased as the maximum ambient temperature is reduced. Protection against low temperature is not normally a problem, and any drift in the tuned circuits as the ambient changes from summer range to winter range will be corrected by the regular periodic checks of the tuning. The other major problem is dust. Even though the air passed through a translator is filtered at the entrance to the equipment, it is highly desirable to draw air into the shelter through a filter in locations which might be described as even moderately dusty.

INSTALLATION AND MAINTENANCE

Site Layout

The first phase preceding the actual installation of a translator should be careful planning of the site layout. The principal task will be to design an optimum arrangement which will permit the shortest transmission lines, especially from the translator to the transmitting antenna. The shelter should be so located that vehicles can be driven close to it if possible. The receiving antenna can be located somewhat more remotely.

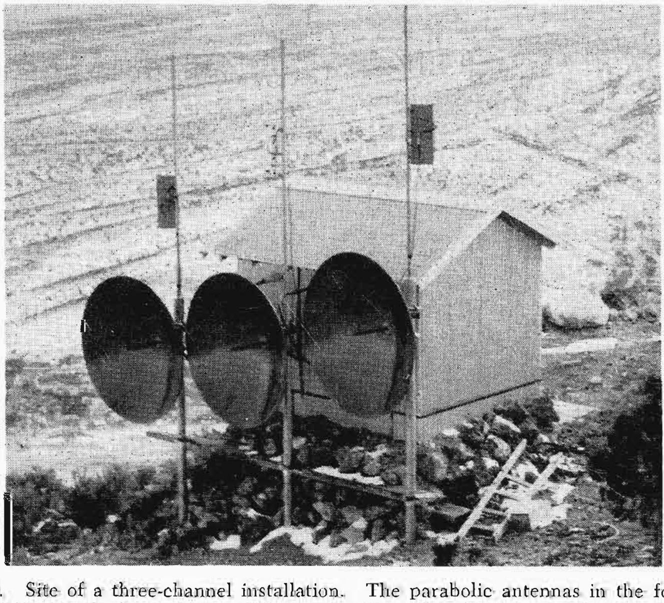


FIG. 4-20. Site of a three-channel installation. The parabolic antennas in the foreground receive UHF signals from three other translators. The three transmitting antennas are raised sufficiently for line-of-sight clearance to McGill, Nev., in the background. (*Courtesy of Industrial Television, Los Angeles, Calif.*)

In particnlar, it shonld be as widely separated from existing power lines as possible, especially when low-channel signals are being received. New power lines shonld approach the shelter from a direction away from the receiving antenna. A compact site is shown in Fig. 4-20.

Installation Details

An installation will be reduced to the least possible effort by advanced planning of all details. A sketch showing all system components, all mounting arrangements down to the individual nuts and bolts, all interconnecting cables and connectors and power wiring fixtures is valuable. It may save a long trip back to town.

The mounting arrangements of the receiving antenna must be determined from the manufacturer's literature. Unless included with the antenna, a means for converting from a balanced circuit to an unbalanced transmission line must be provided at the antenna. Transmission line (usually 75 ohm) and connectors (weatherproof) will be reqnired between the receiving antenna and the translator.

A pedestal or low table is frequently provided for a 10-watt translator to bring it to a convenient height. Power outlets for the translator and for the associated test equipment must be provided near by. Storage facilities for spare tubes and components are desirable.

More cable and connectors will be required for the transmitting transmission line. If air-dielectric or semiflexible cable is used, adapters to small connectors will be needed. It is also desirable to provide a short length of more flexible cable such as RG 8A/U between the heavy cable and the translator and at the antenna. The cable should be supported securely at frequent intervals throughout its entire length outside the shelter. A pump for pressuring air-dielectric cable is desirable.

Mounting provisions for the transmitting antenna will depend upon the type used. The antenna illustrated in Fig. 4-14 mounts with U bolts on a pole up to 1½ in. OD. Parabolic antenuas mount on a 4-in. pipe.

Test Equipment for Installation and Maintenance

Some specific test equipment may be recommended by the translator manufacturer as being particularly well adapted to a specific task. However, the following list is basic and represents the minimum requirements for testing and alignment of translators:

1. Service oscilloscope. To be used for viewing sweep patterns and video waveforms. It should have a vertical amplifier bandpass of 4.5 Mc minimum.
2. 50- and 75-ohm crystal detector. Sierra Electronics model 148A or equal. (Extra 50-ohm disc resistors should be ordered. These can be altered to provide a 75-ohm resistive termination, making the same instrument useful for both 50 and 75 ohms.)
3. RF dummy load, 50 ohms, with a power rating exceeding the output of the translator (10 or 100 watts).
4. Commercial UHF television receivers, one at the transmitter location and another at the remote-control location, both for monitoring.
5. VHF sweep generator RCA model WR 69A * or Kay Electric Company, model RF-P sweeping oscillator.†
6. Multimeter, 100-μa range normally required.

* Earlier models of the WR-59 series will be satisfactory except on the lowest channels, where it is sometimes difficult to obtain adequate sweep width for this application. For either type, assemble the 75-ohm output adapter described in the instruction book. These sweep generators require external markers to delineate the passband. Normally, the carriers from the originating station can be used for this purpose by coupling the receiving antenna lightly to the input circuit.

† Marker pulses for the oscilloscope display are generated within this instrument. No marker signals pass through the system nnder test. This permits a more certain interpretation of the sweep pattern.

Table 4-4. Check List for a Translator Installation

I. Transmitting channel available	
A. Consistent with allocations requirements	See Sec. 4.702(A) and (C) of Federal Communications Commission Rules
B. Does not interfere with other translators	See Sec. 4.702(B) and (D) and 4.703(A) of Federal Communications Commission Rules
II. Site selection	
A. Received signal	Signal-reception System. Signal path to receiving antenna should be clear of foliage
1. Adequate strength	
2. Freedom from extraneous noise	
3. Freedom from interfering signals	Amplification at the Antenna. Tabulate all frequencies generated in nearby equipment. Pay especial attention to strong signals, their harmonics, and beats between them which fall in or near the input channel. Traps in the antenna line are sometimes effective in removing off-channel interferences. Include other translators in tabulation (see Internal Interferences)
B. Transmitting coverage	Line-of-sight Requirements. Count foliage as opaque
1. Line of sight to area to be covered and Fresnel-zone clearance	
2. Coverage feasible	Coverage Calculations. Gain requirements and horizontal pattern required for coverage must be within practical limits of transmitting antennas
C. Terrain at site suitable	
1. Building	Flat area required
2. Receiving and transmitting antenna poles and towers	Bases for towers and/or holes for poles may be required
3. Guy wires	Must be able to dig holes to pour concrete anchors or fasten to rock formations
4. Ground connection	Means must be found to establish a ground connection for shielding and lightning protection
D. Authorization to use site	Such authorization in writing becomes part of construction-permit application
E. Access roads	Access by vehicles essential. Much operating and some test time will be after dark, when foot travel back to the end of the road is hazardous. If road must be built, examine terrain for feasibility
F. Power lines	Considerable expense will be saved by locating at or near existing power lines of adequate capacity.* If reliability of power lines is doubtful, an auxiliary engine-driven generator should be installed for standby
III. Organizational requirements	
A. Incorporation or association documents or other agreements	Information from these documents forms a part of the application for a construction permit, which will not be granted unless the information is in proper form

* 2,000 va for a single 10-watt translator plus 900 va for each additional translator and each 100-watt amplifier is required. Long lines to remote points frequently are subject to wide voltage fluctuations. A constant-voltage transformer for each translator is recommeuded.

Table 4-4. (*Continued*)

B. Engineering personnel	
1. Installation snpervisor	Training by a translator manufacturer or experience with television transmitters desirable. Statement of qualification required on construction-permit application
2. Licensed operator	First- or second-class radio-telephone operator's license required of person making or supervising repairs and adjustments
C. Funds for construction and operation	Balance sheet indicating ability to purchase equipment and finance operation for one year from funds on hand or pledged required with construction-permit application
D. Remote-control point	Must be so located that the licensed operator can easily observe the transmission at the required intervals
E. Permission from originating station	Statement from originating station must be included with the construction-permit application
F. Application for Authority to Construct or Make Changes in a Television Broadcast Translator Station, FCC Form 346	File original and two copies including statement described in *E* above. Obtain required topographical maps in advance
IV. Construction	
A. Power lines	Check power company regarding construction standards. Bring power in first so it can be used for other construction
B. Housing for equipment	Should be erected early to provide storage space and shelter while rest of installation is constructed. Cinder-block, wood, or prefabricated-metal buildings adapted to local conditions have all been used. Provide access holes through bnilding for signal cables
C. Erect receiving-antenna structures and elements	Make field-intensity measurements so any additional receiving equipment can be obtained while rest of constrnction proceeds (see Testing and Alignment)
D. Erect transmitting structure and elements	Include means for reaching transmitting antenna for maintenance
V. Installation	
A. Assemble main and auxiliary equipment and supplies at site	Installations are normally made with the aid of a representative of the translator manufacturer. If this service is not used, follow the planning suggestions under Installation Details
B. Site the translator within the building	Location should permit shortest possible transmitting cable. Enough room should be available to permit easy opening of the front and rear doors and to permit test equipment to be assembled for nse near the translator
C. Follow Testing and Alignment procedure	Testing and Alignment. Tune the translator with a dummy load. Equipment as outlined under Test Equipment for Installation and Maintenance will be required. Operating spares should be on hand
D. Notify the Federal Communications Commission and the engineer in charge of the radio district of intention to conduct on-the-air tests	On-the-air tests can be conducted after this notification
E. Set up station log	See Sec. 4.781 of Federal Communications Commission Rules for log requirements

Table 4-4. (*Continued*)

F. Conduct tests of entire system	Measure bandpass and power-output capabilities of the translator driving the antenna. Establish that a satisfactory signal is reaching the entire area to be covered. Visual aiming of the transmitting antenna is unreliable. Some reorientation may be found desirable when the coverage is sampled. Two-way radio communications equipment such as citizens band transceivers have been found helpful in this phase
G. File Application for Television Broadcast Translator Station, FCC Form 347	Original and two copies required. Station should first be in satisfactory operating condition. Two days after notification of the FCC and the engineer in charge of the radio district interim programming may begin and be continued until action is taken on the license

Testing and Alignment

The receiving antenna should first be tested by observing the signal on the best quality receiver which can be made available at the site. If possible, the actual values of the two carriers should be measured with a field-strength meter.*

The values observed over a period of time should be recorded for future reference to permit the system to be checked for deterioration at a later date.

A visual-to-aural carrier ratio of 2 to 1 in power (1.41 to 1 in voltage) should be maintained. If the received signal has carrier strengths much different from this ratio, the recommendations of the translator manufacturer should be followed in making compensating adjustments or in adding additional devices to adjust the ratio.

When the translator is placed in operation the initial check and alignment instructions of the manufacturer should be followed. This will entail installing any components or subassemblies removed for shipping, checking key operating voltages, and tuning the translator in accordance with a specific procedure.

The transmitting antenna and associated transmission line can be partially checked by observing the sweep, the detected waveform, and the forward and reverse power produced by the translator when connected to a dummy load and when connected to the antenna system. If the reverse power increases appreciably when the antenna is the load, all cables and connectors should be carefully checked. If the problem persists, the trouble can be localized by substituting the dummy load for the antenna at the far end of the transmission line. If the antenna is reflecting power but has no visible defect, the manufacturer should be consulted.

When the antenna is radiating full power, the only remaining untested quantity is the antenna gain and pattern. Since antenna measurements are difficult without special facilities, the best field check will be the presence of adequate signal strength throughout the coverage area.

Experience has shown that the transmission of program material should be held to a minimum until permanent operations can be sustained. Any periods of temporary programming will serve to increase the impatience of the viewers for regular service.

* Model 704B VHF field-strength meter manufactured by Jerrold Electronics Corporation is frequently used for this purpose. If a field-strength meter is not available, relative values can be obtained from the developed AGC voltage in a receiver or channel amplifier. Absolute values can be obtained by substitution if a signal generator with a calibrated output is available. Some ambiguity will result from the use of a continuous instead of pulse-modulated carrier if the AGC is derived from a peak detector.

Maintenance

A maintenance schedule designed to prevent failures before they happen will pay dividends in satisfactory service and eliminating unscheduled trips to the site to rectify failures. Lubrication and cleaning of various parts of the translator will be required as outlined by the manufacturer. In addition, a log of operating voltages at all power supplies and test points will indicate trends toward tube and component failure.

Mechanical inspection of all external equipment for deterioration and tightening of mountings and connectors on a regnlar schedule is desirable.

REFERENCES

1. "Reference Data for Radio Engineers," 4th ed., pp. 768–770, International Telephone and Telegraph Co., New York, 1956.
2. D. G. Fink (ed.): "Television Engineering Handbook," pp. 16–8 to 16–15, McGraw-Hill Book Company, Inc., New York, 1957. A discussion of the design considerations of low-noise circuits follows in Secs. 16.303 to 16.305.

Part 5

REMOTE CONTROL OF BROADCAST STATIONS

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President, Schafer Custom Engineering
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INTRODUCTION

One of the modern operating techniques associated with broadcast stations in recent years is the remote control of transmitters. In 1953, the Federal Communications Commission authorized nondirectional stations up to and including 10 kw to apply for such operation. At the present time there are over 1,500 broadcast transmitters authorized to be operated in this manner.

As a result of considerable data filed with the FCC by the National Association of Broadcasters in 1956, the FCC, in September, 1957, amended the rules in Part 3 to permit the remote control of *all* radio transmitters, AM and FM, with certain conditions. At the present time a limited number of stations have applied for remote-control permission under the amended rules, but the indications are that an increasing number of stations are becoming aware of the potentials of this type of operation. Various provisions of the rules appear to preclude an economical operation, considering the equipment costs, etc., but in the near future it is believed that the largest barriers will be removed.

It is the purpose of this part to outline the necessary conditions for remote control that must be supplied the FCC in the application Form 301-A and supporting exhibits and the reasons therefore.

Nondirectional AM and FM, 10-kw Maximum Transmitter Power

The remote-control application for stations in this category is relatively simple, assuming that the equipment system is satisfactory. The application should be filed on FCC Form 301-A, which consists of three pages. Note that for this category of stations, only items 1 through 5 on page 1 and all of page 3 need be completed. The remaining items on this form apply to either *directional stations* or *stations with a transmitter power in excess of* 10 *kw or both*. The information required is not complicated and can, in most cases, be completed by the station chief engineer. The chief engineer should, of course, be familiar with the pertinent provisions of the Commission's rules on remote control.[1] Installation of the equipment may be done by station personnel or by the manufacturer, and no certification is required that the equipment has been made in a prescribed manner except that it must comply with the general safety and fire underwriters' code. Reference to Fig. 5-1 (Form 301-A)

[1] See Section 1 of this handbook.

FCC Form 301-A
November, 1957

Form Approved
Budget Bureau No. 52-R145.3

File No.

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION

REQUEST FOR MODIFICATION
BROADCAST STATION AUTHORIZATION
(REMOTE CONTROL)

INSTRUCTIONS

A. This form is to be used only by licensees or permittees of Standard, FM and Non-commercial Educational FM Broadcast Stations.

B. Use separate form for each station.

C. Prepare this form in triplicate, swear to one copy, and forward all copies to the Federal Communications Commission, Washington 25, D. C.

D. Number exhibits serially in the space provided in the body of the form and list each exhibit in the space provided on page 3.

E. This application must be executed by applicant, if an individual; by a partner of applicant, if a partnership; by an officer of applicant, if a corporation or association; or by attorney of applicant only under conditions shown in Section 1.303, Practice and Procedure, in which event satisfactory evidence of disability of applicant or his absence from the Continental United States and authority of attorney to act must be submitted with application.

F. Before filling out this application, the applicant should familiarize himself with the provisions of Part 3 of the Commission's Rules and Regulations dealing with remote control.

G. BE SURE ALL NECESSARY INFORMATION IS FURNISHED AND ALL PARAGRAPHS ARE FULLY ANSWERED. IF ANY PORTIONS OF THE APPLICATION ARE NOT APPLICABLE, SPECIFICALLY SO STATE. DEFECTIVE OR INCOMPLETE APPLICATIONS MAY BE RETURNED WITHOUT CONSIDERATION.

1. Name of licensee or permittee

2. Mailing address

Street ....

City ....

State ....

3. Identification of existing station:

Call letters	File No.

Station location

City ....

State ....

Authorized facilities

FREQUENCY	POWER IN KILOWATTS		NON-DIRECTIONAL ANTENNA:
	NIGHT	DAY	DAY ☐ NIGHT ☐
DIRECTIONAL ANTENNA:			SAME CONSTANTS AND POWER DAY AND NIGHT (DA-1) ☐
DAY ONLY (DA-D) ☐			DIFFERENT CONSTANTS OR POWER DAY AND NIGHT (DA-2) ☐
NIGHT ONLY (DA-N) ☐			

4. Request is hereby made for authority checked in the boxes.

☐ Establish a remote control point located as follows: (this is point from which transmitter is controlled)

....
STREET ADDRESS (OR OTHER IDENTIFICATION)
....
....
....

City ....

State ....

☐ Delete remote control point located as follows:

....
STREET ADDRESS (OR OTHER IDENTIFICATION)
....
....
....

City ....

State ....

5. Main Studio Location (if different than that on present authorization)

Street .... City .... State ....

6. Submit as Exhibit No. a statement describing the stability of the directional antenna system during the one year period preceding this application. This statement shall include, but shall not be limited to, such information as the nature and degree of any adjustment required, the maintenance procedures followed and the adequacy of the present monitoring system to indicate changes in the operation of the array.

Fig. 5-1. FCC Form 301-A, application for remote-control authorization.

FCC Form 301-A

Page 2

7. Antenna resistance measurement

Attach as Exhibit No. the following:

a. Qualifications of engineers taking measurements

b. Schematic diagram showing clearly all components of coupling circuits, point of resistance measurement, location of antenna ammeter, connections to and characteristics of all tower lighting isolation circuits, static drains, and any other fixtures, lines, etc., connected to or supported by the antenna, including other antennas and associated circuits.

c. Full description of method used to make measurements.

d. Manufacturer's name of each calibrated instrument used and manufacturer's rated accuracy.

e. Date, accuracy, and by whom each instrument was last calibrated.

f. Table of complete data taken and date taken.

g. The graph drawn of 10 to 12 readings in a band 50 to 60 kilocycles wide with the operating frequency near the center.

8. Operating constants based on data in paragraph 7: (If directional system, give current at point of resistance measurement.)

RF common point or antenna current without modulation for night power in amperes	RF common point or antenna current without modulation for day power in amperes

Actual measured antenna or common point resistance (in ohms) at operating frequency	Actual measured antenna or common point reactance (in ohms) at operating frequency
Night ______ Day ______	Night ______ Day ______

Currents, and phases for directional operation

TOWER	PHASE READING IN DEGREES		ANTENNA BASE CURRENT		REMOTE INDICATION OF ANTENNA CURRENT	
	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY

9. Submit as Exhibit No. the weekly readings of field intensity at each monitoring point specified in the station license for the one year period preceding this application. (Monthly readings will be acceptable where such readings are authorized.)

10. Submit as Exhibit No. the values, for each pattern, of antenna base currents, common point current, phase monitor sample currents or remote base currents, and phase relations, for the thirty day period preceding this application. The values shall be those obtained from readings taken at approximately the same time.

11. Submit as Exhibit No. a partial proof of performance consisting of at least 9 or 10 measurements taken at a distance of from 2 to 10 miles from the antenna on each radial measured in connection with the last complete adjustment of the directional antenna system. These measurements shall be analyzed in accordance with Section 3.186.

12. If application is for remote control of a transmitter with power in excess of 10 kilowatts, submit as Exhibit No. an analysis of the transmitter operating logs, and maintenance logs and records for the 12 month period immediately prior to the application.

13. If the station is a standard broadcast station and is authorized to operate with directional antenna and/or with power in excess of 10 kilowatts, submit as Exhibit No. a description of the equipment which will be installed so that the station can be satisfactorily operated on a CONELRAD frequency from the remote control position.

14. Applicant certifies that remote control operation will be in accordance with the Commission's Rules and Standards.

15. REMARKS:

FIG. 5-1. *(Continued on next page)*

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The applicant hereby waives any claim to the use of any particular frequency or of the ether as against the regulatory power of the United States because of the previous use of the same, whether by license or otherwise, and requests an authorization in accordance with this application. (See Section 304 of the Communications Act of 1934.)

The applicant represents that this application is not filed for the purpose of impeding, obstructing, or delaying determination on any other application with which it may be in conflict.

All the statements made in the application and attached exhibits are considered material representations, and all the exhibits are a material part hereof and are incorporated herein as if set out in full in the application.

The applicant, or the undersigned on the applicant's behalf, states that he has endeavored to supply full and correct information as to all matters which are relevant to this application and that he has done so as to all matters within his own knowledge.

Dated this .... day of ...., 19.......

....
(Name of applicant)

By ....

....
Title

Subscribed and sworn to

before me this ...... day of ...., 19.......

....
Notary Public

(SEAL)

(Notary public's seal must be affixed where the law of jurisdiction requires, otherwise state that law does not require seal.)

My commission expires ....

If applicant is represented by legal counsel, state name and post office address:

EXHIBITS furnished as required by this form:

EXHIBIT NO.	SECTION AHD PARA. NO. OF FORM	NAME OF OFFICER OR EMPLOYEE (1) BY WHOM OR (2) UNDER WHOSE DIRECTION EXHIBIT WAS PREPARED (SHOW WHICH)	OFFICIAL TITLE

I certify that I am the Technical Director, Chief Engineer or Consulting Engineer of the radio station for which this application is submitted and that I have examined the foregoing statement of technical information and that it is true to the best of my knowledge and belief. (This signature may be omitted provided the engineer's original signed report of the data from which the information contained herein has been obtained is attached hereto.)

....
Technical Director, Chief Engineer or Consulting Engineer

F.C.C. - WASHINGTON, D. C.

FIG. 5-1. (*Continued*)

will reveal the general nature and simplicity of the information required in the application.

Nondirectional AM and FM, Transmitter Power Greater than 10 Kw

Except for one item of information, the required information for this category of stations in applying for remote control authorization is the same as in the preceding paragraph for the lower power. This item concerns the reliability of the transmitter. This additional information consists of an analysis of the transmitter operating logs, maintenance logs, and records for the 12-month period immediately prior to the application. This analysis is to include the following items:

1. The number of outages, their cause and duration together with what corrective measures were taken to remedy the malfunction and to prevent such a recurrence
2. The nature and consistency of past maintenance performed and a statement of the maintenance practice and policy to be followed after remote-control authorization

From the above it would be natural to assume that a transmitter would have to be in operation for a period of at least a year prior to submitting the application. This is not necessarily the case. The Commission realizes that no broadcaster would be willing to jeopardize his own operation and public-service responsibility by remotely controlling an unproved transmitter. In the case of a new transmitter, undoubtedly it will have been designed and constructed with remote control as a provision of operation. Most new transmitters have remote-control provisions built in. If the transmitter has been in operation less than 12 months and the operating data attest to its reliability, then the application may reasonably be submitted with a request for waiver of the full 12-month period.

Directional Stations of Any Power [2]

In addition to the normal requirements for remote control, the FCC has included certain items that must be monitored. These relate to the directional antenna and its stability. In the Commission's decision they are stated as follows:

> On the basis of the comments filed and our experience with the problems of directional antenna systems, we have determined that the basic information necessary to establish the stability and proper adjustment of a directional antenna system, and hence, the information which we will require as part of an application to operate a directional antenna by remote control is as follows:
>
> (*a*) A statement describing the stability of the system for the preceding one year period. This statement shall include, but shall not be limited to, such information as the nature and degree of adjustment required, the maintenance procedures followed and the adequacy of the present monitoring system to indicate changes in the operation of the array.
>
> (*b*) Weekly readings of field intensity at each monitoring point specified in the station license for the preceding 1 year period (monthly readings will be acceptable for those stations which are presently authorized to measure monitoring points field intensities on a monthly basis).
>
> (*c*) Readings once each day of antenna base currents (for each pattern) and readings taken at approximately the same time of common point current, phase monitor loop sample currents or remote base currents, and phase indications for the preceding 30 days.
>
> (*d*) A redetermination of the common point impedance of the directional antenna system.
>
> (*e*) A partial proof-performance consisting of at least 9 or 10 measurements taken at a distance of from 2 to 10 miles from the antenna on each radial measured in connection with the last complete adjustment of the directional antenna system, properly analysed in accordance with Section 3.186.

[2] For transmitters over 10 kw, the same reliability factors for the transmitter apply as for nondirectional stations.

CONELRAD Requirements

On the subject of CONELRAD, the Commission indicated that

. . . we believe that we are justified in conditioning an authorization for remote control of a station operating with a directional antenna and/or a power in excess of 10 Kw. upon the installation of equipment that would permit the changeover from the licensed operation to CONELRAD operation to be made from the remote control point. . . .

Applications for remote control involving either a directional array or a transmitter with power output in excess of 10 kw must be accompanied by a description of the equipment which will make it possible for the station frequency to be switched from the regular frequency to either 640 or 1,240 kc by remote control. The station is not required to take part in the CONELRAD program, but it is required to be able to switch to either 640 or 1,240 kc, whichever is assigned, by remote control. A station may also employ an auxiliary transmitter at the remote-control point and operate it on 640 or 1,240 kc.[3]

The equipment to perform switching to 640 or 1,240 kc need not be installed prior to the filing of the application for remote control. The switching to the CONELRAD frequency is normally accomplished with one control operation, throwing relays to change frequency, switching necessary inductances or capacitances to retune the transmitter, any antenna switching or tuning necessary, as well as audio switching if required and provision for automatic operation from cluster control.

The ruling requires a station to be able to transmit at least one-half of its regularly licensed power on the CONELRAD frequency but in no case more than 5,000 watts.[3] As an example, a 1,000-watt station would be required to transmit at least 500 watts on the CONELRAD frequency,[4] a 5,000-watt station would be required to transmit 2,500 watts,[4] but a 50,000-watt station would be required to transmit only 5,000 watts on the CONELRAD frequency. If a station operates a lower power at night, it is necessary to transmit only one-half of the nighttime power on the CONELRAD frequency. If such an interpretation of the ruling were to require a station to transmit a higher power on the CONELRAD frequency than would be necessary for practical operation in a particular CONELRAD cluster, this ruling may be waived. A letter from the CONELRAD authority stating that the lower power is sufficient power for practical operation in this CONELRAD cluster should be made part of the application.

Operator Requirements

In regard to operator requirements, the Commission has covered these in Sec. 3.93 of Part 3 of their Rules which appear in Sec. 1 of this Handbook and are not repeated here.

General Considerations

There has been some confusion regarding the acceptable methods of making RF pickup at the respective towers for a remote indication of base currents at the control point. It is acceptable, of course, to install a RF pickup coil at the base of each tower, rectify and filter the RF for conversion to direct current, and feed it back to the transmitter house for connection into the remote-control system. If such a procedure is not inconvenient, this probably would be the most acceptable method. However, the FCC has indicated to NAB that use of the sampling loops is also satisfactory provided the loop currents are accurately calibrated with the respective tower base currents. The coaxial lines from the sampling loops which feed the phase monitor can be *disconnected* from the latter and connected to a rectifying and filtering unit, which can then be used in conjunction with the remote-control system for remotely reading the tower base currents. Details are provided later in this part.

[3] See Subpart G, Part 3, of the FCC Rules concerning permissible power.

[4] Unless otherwise certified by the FCC CONELRAD supervisor.

One of the most unpalatable provisions of the remote-control rules for directional stations is the requirement for sending a man to the transmitter within 2 hr of a change in pattern or within 2 hr of the beginning of the broadcast day for stations operating with a single pattern. This man is required to read and log at the transmitter location once each day for each pattern (as explained above) common-point current, base currents, phase-monitor loop sample currents, or remote base currents and phase indications. It is understood that the reason for these measurements hinges on the lack of a suitable remotely operated phase monitor. It would appear logical that if such a phase monitor can be purchased and installed and its accuracy established to the satisfaction of the Commission, a station might obtain a waiver of this provision. It is known that such a phase monitor is in the process of development at the time of writing and perhaps may be available by publication date.

A D-C REMOTE-CONTROL SYSTEM

Remote control of a transmitter is normally accomplished over two telephone circuits. It is also possible to control a transmitter remotely over a radio circuit with the metering information being fed back on a radio circuit. The operation is similar to a d-c operation except that the control is accomplished with the use of audio or radio frequencies. The information is fed back to the remote-control point by radio, converted back to a meter reading, and calibrated against the original meter reading at the transmitter.[5]

Telephone-line tariffs may play an important part in establishing the fixed recurring cost of remote controlling a transmitter. Generally, remote-control lines are quite short and the cost very reasonable. In the case of longer runs, however, a broadcaster should take care to see he has ordered his telephone circuits properly and that he is getting the advantage of the proper tariff. In one city where the cost of a program loop between the studio and a transmitter was well over $100 and an order wire cost was well over $50, remote-control circuits were available at a cost of only $25 each. The gap is not always so great. When telephone lines are ordered for a "d-c" remote-control system, order "signal circuits," sometimes referred to as telemetering control (TC) circuits and classed as 0- to 15-cycle lines. They must be metallic circuits and cannot be phantoms or simplexes. On long lines, the telephone company may have more than one way of figuring a circuit. As an example, one radio station found that its telemetering control lines would cost $45 per month on a straight mileage basis, but when the circuit was broken down to a combination intercity and intracity rate, the cost was only $25 per month. Many radio stations remotely control the transmitter over 50 or more telephone-line miles.

Once one is familiar with the rules governing remote control, a decision must be made as to the type of equipment to be used to control the transmitter remotely. Excellent commercial equipment is made by several manufacturers and is available in a wide price range. Composite equipment may be constructed. In either event, this part will describe how to make a remote-control installation.

Most systems employ two metallic telephone circuits and, generally speaking, will meter over one of the telephone lines while performing controlling functions over the other. Smaller systems generally work against ground, whereas larger systems will employ voltage differential and/or polarity switching to effect several operations over a single pair. Voltages and currents to be remotely metered are converted to a low voltage, varying from about ½ (full scale) to about 5 volts (full scale), depending on the system employed. Metering can be accomplished on an arbitrary scale using correlation charts for each meter reading, or direct scales duplicating transmitter meter scales can be employed. Metering accuracy must be maintained within 2 per cent.

The FCC requires that remote-control equipment allow an operator to turn the transmitter on and off and to raise and lower the output of a transmitter. A "fail-safe" circuit must be incorporated to ensure that the transmitter will be automatically

[5] See Part 2 of this section for additional details.

shut down in the event of any trouble which would prevent the operator from controlling the transmitter.

Communication is essential between the transmitter and the remote-control point to allow calibration of the meters. This may be a regular city telephone, a separate

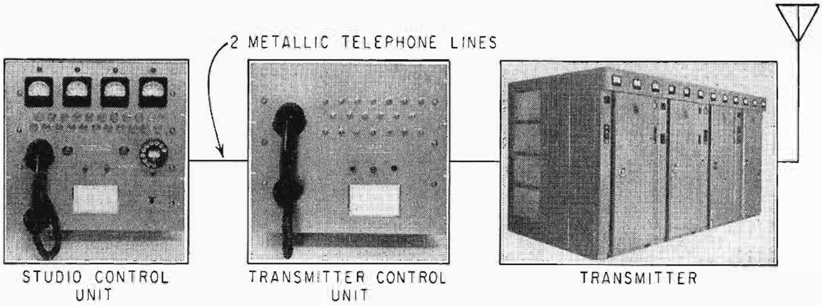


FIG. 5-2. Block diagram of basic remote-control installation.

order wire, a telephone built into the remote-control system, or if the program line is available, it can be used when the station is off the air, although the latter may prove awkward.

An off-air monitor is highly desirable. It can be equipped with an alarm which will sound in the event of loss of carrier or loss of program and will help to hold lost air time to a minimum.

A CONELRAD receiver will be required at the remote-control point of a station regardless of whether or not a direct CONELRAD line is installed at the remote point.

A standby transmitter is considered a good investment by many stations installing remote control. If an operator from a remote-control point can switch to a standby

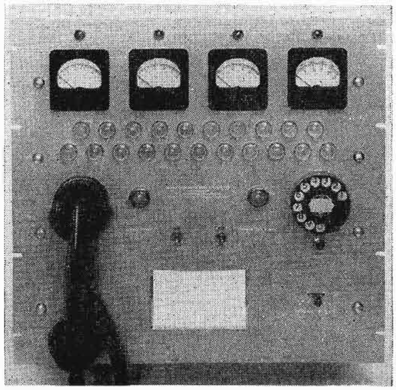


FIG. 5-3. Studio remote-control unit.

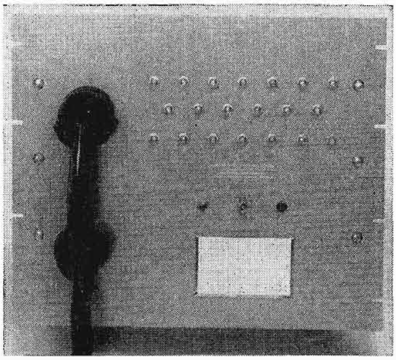


FIG. 5-4. Transmitter remote-control unit.

transmitter in event of the failure of a main transmitter, lengthy outages may be eliminated.

Fire has not been a serious factor. It is possible on any remote-control system to read room temperature or any other temperature remotely, and of course, fire-alarm equipment as well as burglar-alarm equipment can be employed at a transmitter to reduce the possibility of these hazards. In actual practice, fire-extinguishing equipment or fire-alarm circuitry is rarely employed.

When *remote-control* equipment is initially installed, it is wise to operate the transmitter by remote control from the remote point with the transmitter still manned. In this way, an excellent opportunity is afforded to be certain that everything is in perfect working order before actually remotely controlling the transmitter unattended.

Remote-control equipment described here in detail is the Schafer Remote-Control-System Model 400-R. Any system could be connected in a similar manner whether

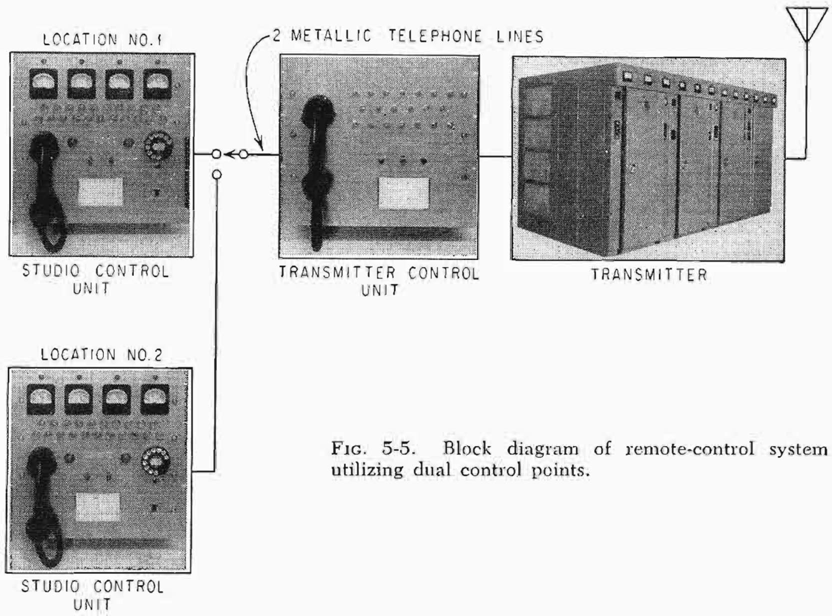


FIG. 5-5. Block diagram of remote-control system utilizing dual control points.

the system be a composite or commercial system. This system is a d-c system, utilizing two pairs of telephone lines between the transmitter and the remote-control point. It utilizes a 26-position stepper, making possible the connection of 26 metering circuits and 52 control circuits.

The basic remote-control installation includes a "studio control unit" and a "transmitter control unit" as shown in Fig. 5-2 (block diagram) and Figs. 5-3 and 5-4. Note the inclusion of the telephone for communication between the transmitter and remote point when making calibrations.

A system which allows remote control from two control points is outlined in Fig. 5-5.

THE REMOTE-CONTROL SYSTEM

The system described herein will operate on any two metallic circuits, each of which has a loop resistance of 10,000 ohms or less. A simplified diagram of the system is shown in Fig. 5-6.

Description of the Operation of the Remote-control System

The metering information is fed from the transmitter to the remote-control point on telephone line 1 except when line 1 is being used for dialing. A holding voltage is fed to the phantom circuit (balanced between the two lines). This is the "fail-safe" circuit. It holds the transmitter power relay closed. When the voltage is tripled, the "phantom" relay is closed.

The voltage is tripled at any time operation of the dial system is taking place, switching telephone line 1 from a metering line to a dialing line. A positive or negative voltage is fed to line 2 to operate the "increase" or the "decrease" relay. These relays will operate through the stepper and will control whatever circuit is dialed up. They can be employed to turn a circuit on or off or to raise or lower a circuit. When a circuit is dialed up, it can be metered continuously and controlled simultaneously. At any time the push button on the transmitter can be depressed, and 60 volts 60 cycles will be fed back to the studio, ringing the bell in the studio control unit. One

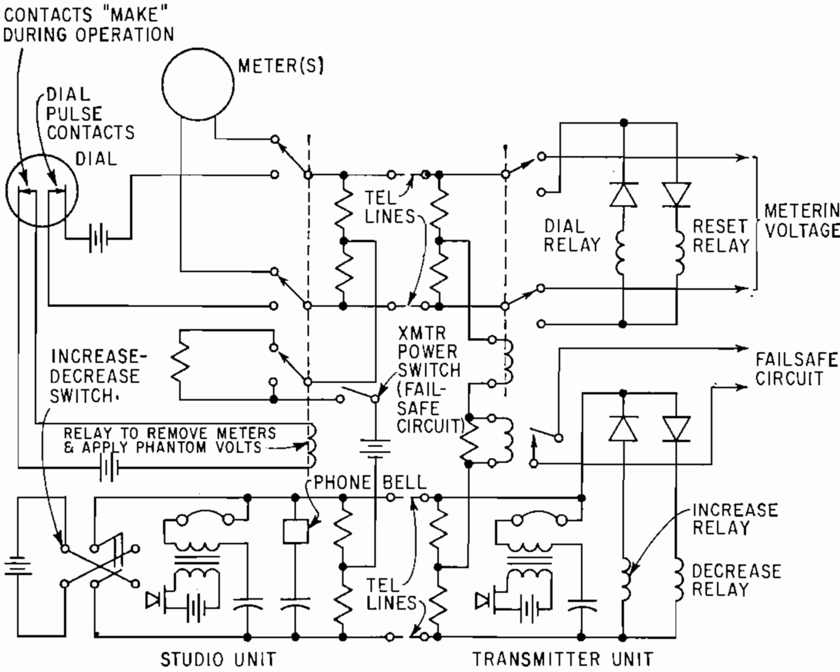


FIG. 5-6. Simplified schematic of typical remote-control system utilizing two metallic circuits.

of the control circuits can be used to ring a bell at the transmitter, thereby providing two-way ringing. At each end a telephone is connected in such a way to feed audio to line 2. In this way the telephone can be used for communication during metering and during controlling.

Because the fail-safe circuit is on a phantom between the two lines, it is possible to retain on-off control of the transmitter even if one side of either or both telephone lines should open.

Figure 5-7 is a diagram of the studio control unit.

Figure 5-8 is a diagram of the transmitter control unit. This is the equipment which takes the voltage and current from the transmitter shunts and enables their transmission over the telephone lines to the remote point.

Figures 5-7 and 5-8 include the complete studio control unit and transmitter control unit. When connected at points 1*A*, 1*B*, 2*A*, and 2*B*, the units will operate together, providing remote control and remote metering for up to 26 circuits. In the commercial model of this system, 20 metering circuits are connected to internal meters. Auxiliary meters can be connected to any of these circuits. Circuits 21, 22, 23, and 24 are brought out to external meters for frequency modulation or any other external

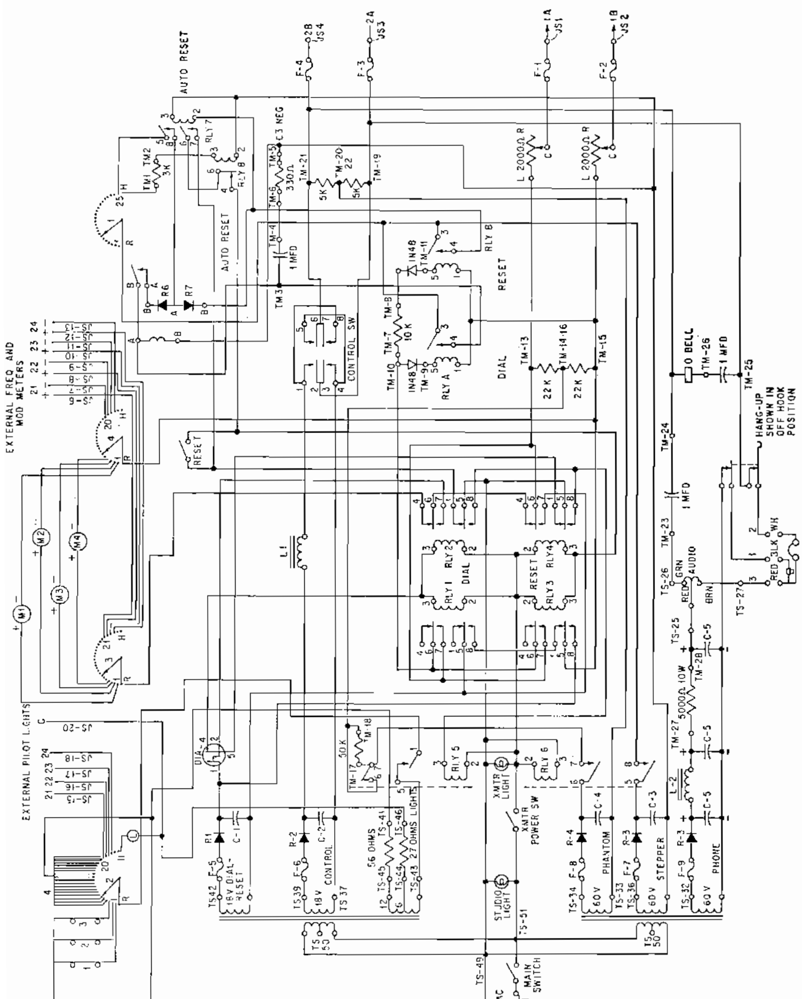


Fig. 5-7. Schematic diagram of studio control unit.

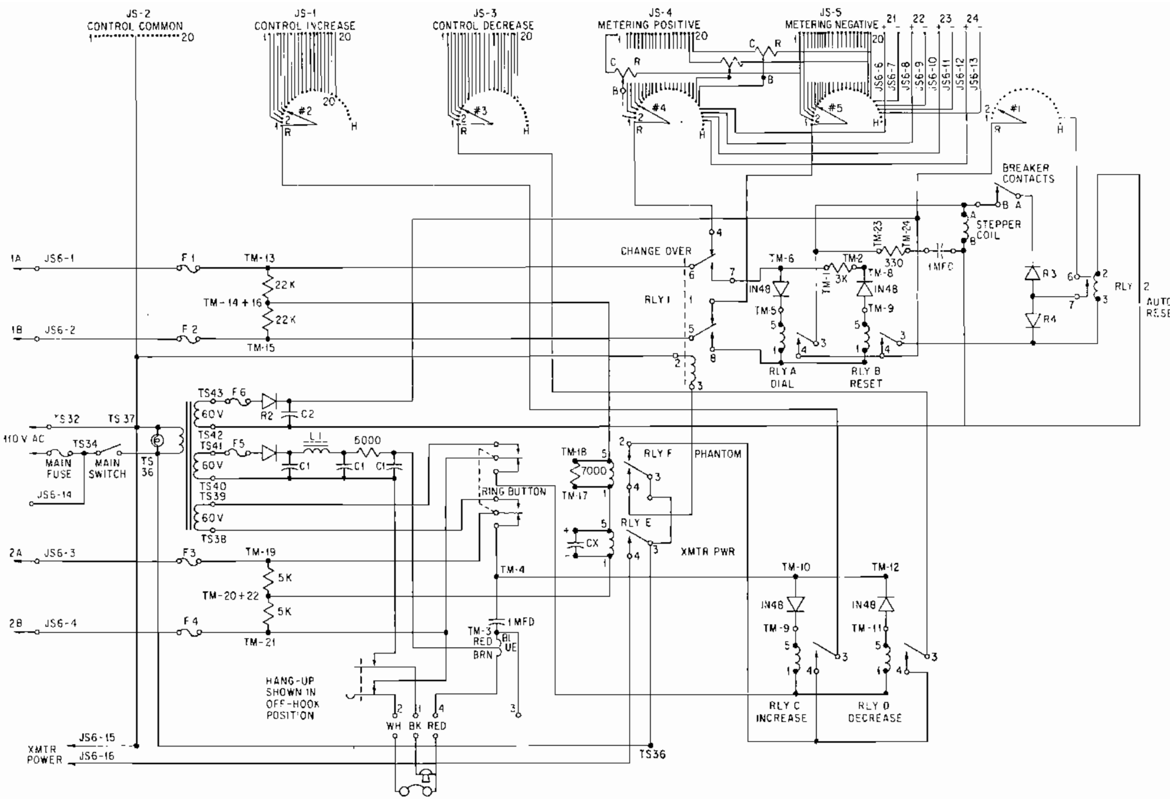


FIG. 5-8. Schematic diagram of transmitter control unit.

meter application. One or more of these external circuits can be used as a spare audio circuit. In the following pages, typical connections of metering circuits as well as control circuits are discussed in detail.

Frequency and Modulation Remote Metering

All current-model frequency and modulation monitors provide external connections for remote meters. Some earlier monitors do not provide external connections, but it is possible to meter frequency or modulation remotely from virtually any frequency or modulation monitor. The remote meter may be a meter duplicating the meter on the monitor or one slightly more sensitive to allow for calibration. Modulation monitor meters range from 0 to 400 d-c to 0 to 600 d-c μa. Most AM frequency monitor meters are 100-0-100 d-c μa. FM frequency monitors employ more sensitive movements.

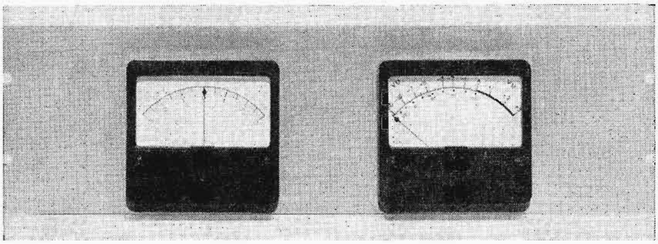


FIG. 5-9. Typical panel mounting of modulation and frequency meters for remote reading.

The remote frequency and modulation monitor meters for AM include typical scales and can be mounted in panels as shown in Fig. 5-9.

The remote frequency and modulation monitor meters for FM can be mounted similarly in a panel. The frequency-deviation meter scale should be 3-0-3 kc or 3,000-0-3,000 cycles.

If the remote meters are more sensitive than the meters in the monitor, the calibration panel such as shown in Fig. 5-10 can be used. A panel such as this has the

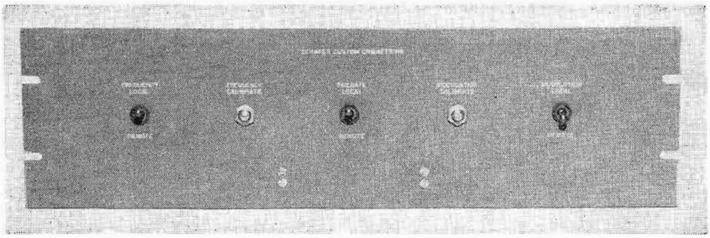


FIG. 5-10. Calibration panel for frequency and modulation monitor.

advantage of providing local and remote switching for these metering circuits as well as for the fail-safe circuit. Because the remote meters are actually in series with the meters in the monitor itself, it is necessary to short out the external meters or replace the external connections with a resistor equal to the line resistance of the telephone line so that local monitoring at the transmitter can be accomplished without error at times when the meter is not dialed up in the remote-control system. Figure 5-11 is a circuit diagram of the connections to the panel shown in Fig. 5-10.

It is possible to meter modulation remotely from any modulation monitor known. Remotely indicating frequency is sometimes slightly more complicated than merely adding a meter. As an example, in the case of the Gates frequency monitor MO-2890

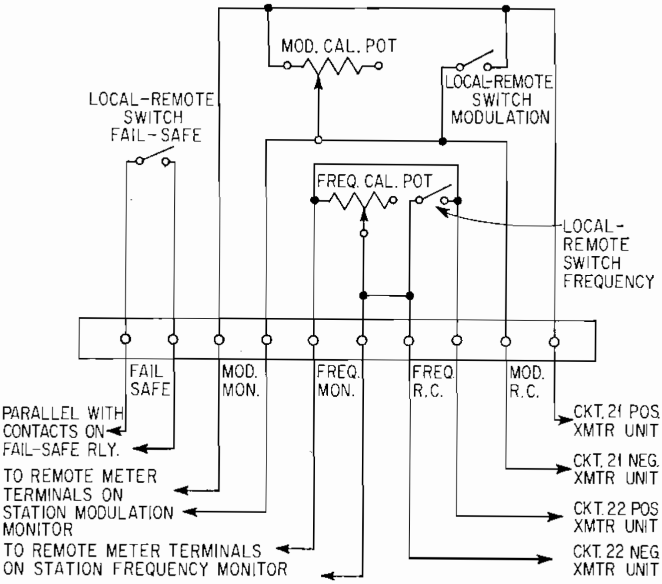


Fig. 5-11. Circuit diagram of the connections to the calibration panel for frequency and modulation monitor.

or the Doolittle frequency meter, it is necessary to use a special remote panel. In these monitors a difference frequency provides a tone which is measured by a reactance device and associated meter. For this reason, it is necessary to take this tone, feed it into the remote-control system over the telephone line, amplify it at the remote-control point, and feed it into a similar reactance device and meter.

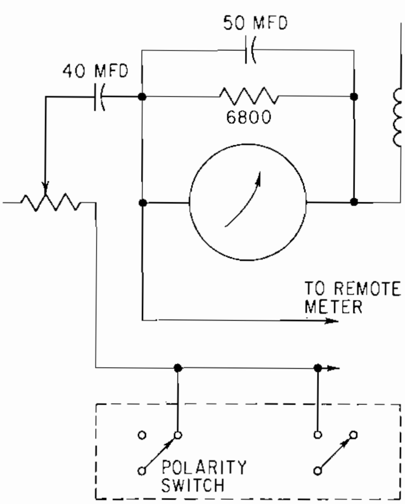


Fig. 5-12. Schematic diagram of remote metering connections to the Hewlett-Packard frequency monitor.

The Hewlett-Packard frequency monitor employs a very sensitive frequency-deviation meter in a bridge-type circuit. In order not to upset the circuit and to get accurate indication of frequency deviation remotely, the circuit in Fig. 5-12 was developed by the engineering department of McClatchy Broadcasting Co.

In the case of the Western Electric 1A or 1C AM frequency monitor, the frequency-deviation meter has a 1-ma movement. Therefore, either a more sensitive meter can be used and calibrated accordingly, or the 1-ma movement can be used. A relay must replace the switch which is to be pushed to provide the remote frequency reading. The second push button on the monitor is actually a capacitor which determines whether the deflection is a difference high or low and is not necessary if the monitor is normally adjusted to indicate, say, 5 cycles high at zero frequency and calculations are made from this reference, making the directional differences obvious.

In the case of any frequency monitor, it is desirable to have a normal reading at some point other than exact zero to be certain that a reading is actually being observed. A zero-center meter will always rest at zero, and should a trouble develop in which no current would be present, no variation could be taken to mean zero deviation. While most stations utilize remote meters, thereby leaving the frequency and modulation monitor at the transmitter, it is also possible to employ a RF amplifier which can be used to drive a frequency and modulation monitor at the remote-control point. The advantage of this is that a constant indication of the frequency and modulation is available at the remote-control point. The disadvantage is that unless duplicate sets of monitors are employed, no frequency or modulation readings are available at the transmitter, which is especially unhandy during maintenance or test periods.

If the Doolittle frequency monitor is operated at a remote-control point, especially a studio location, special care must be taken because the Doolittle frequency monitor transmits the signal approximately 1,000 cycles from the station carrier frequency and the signal is strong enough to produce a "beep note" in any nearby receivers, especially in a nearby air monitor.

Metering Circuits

It is necessary to develop a small d-c voltage proportional to each voltage or current to be metered remotely. In the system herein described, approximately 3 volts will be developed for full-scale deflection of each circuit. In the commercial systems available, the voltage necessary to give proper deflections to the meters will vary from ½ to 5 volts, depending upon the system employed.

Antenna Current

In some cases, the station will have a remote antenna current meter at the transmitter location. If this is a diode meter, the voltage feeding this meter can be used to feed the remote-control system. If the voltage is insufficient to provide the necessary 3 volts, the voltage can be raised by increasing the coupling or by changing the circuit. Care must be taken that adequate calibration is provided to calibrate the "local" remote antenna meter as well as to have adeqnate voltage to feed the remote-control system. If direct current is not readily available, it can be developed by the use of a pickup loop and diode unit as pictured and described in Fig. 5-13. Figure 5-14 is a photograph of the RF pickup coil and rectifying-metering unit.

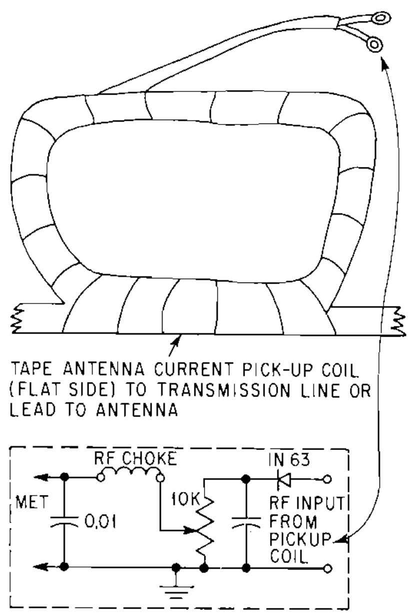


Fig. 5-13. Connections to antenna-current pickup coil for rectifying and filtering RF.

The pickup loop and diode unit described above can be connected to indicate common-point current or base current of any tower by taping it to the appropriate feed line. It should be connected ahead of the regular base-current meter so that the latter will be the final indication of current in the circuit. Likewise in the case of common-point current, the pickup loop should be taped to a point ahead of the regnlar common-point-current meter for the same reason.

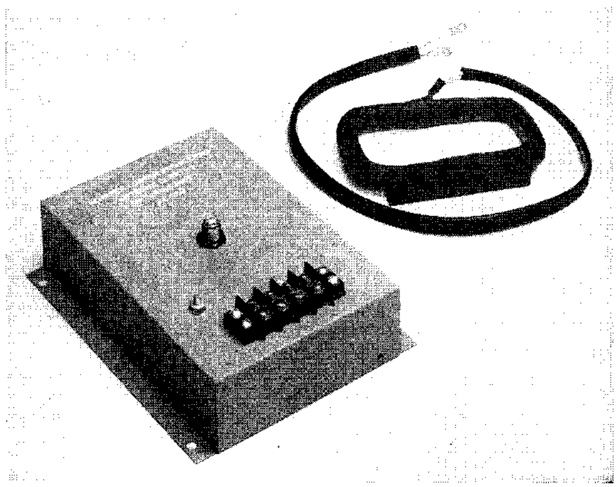


Fig. 5-14

Remote Base Currents in the Directional System

These may present a problem in that many stations employ loop-current meters and do not have remote-base-current meters. In order to provide remote-base-current meters, it may be necessary to run a pair of wires to each tower. Unless this is desirable for some other reason, it is now considered acceptable to use the RF from the pickup loop which feeds the phase monitor to develop direct current for remote reading. *The rule will not permit a diode to be connected directly across the coaxial line, but a switch may be installed to switch the coaxial line from the input of the phase monitor to the diode unit, or a relay may be connected to perform this switching function.* An alternative method would be to construct a chassis with the sufficient number of diode units, and the coaxial lines could be plugged either into the phase monitor or into this chassis. This chassis, in that case, would provide direct current to the remote-control system. Figure 5-15 is a schematic diagram of such a switching unit.

Plate Voltage Metering

This is relatively simple, especially in transmitters which employ a plate voltmeter with 1-ma movement. If the resistor between a plate voltmeter and high voltage is on the order of 1 megohm per 1,000 volts measured, the meter is a 1-ma movement. Virtually all Collins, General Electric, and Gates transmitters employ basic 1-ma plate voltmeter movements, and some meters supplied in RCA, Western Electric, and other transmitters are 1-ma movements. Some RCA, Western Electric, and other transmitter plate voltmeters are 5-ma movements.

In the case of a 1-ma movement, the metering resistor as shown in Fig. 5-16 can be incorporated to develop the remote metering voltage. It will not upset the plate voltage metering in the transmitter.

Plate Voltage Metering Unit PV-10. If your present plate voltmeter has a 1-ma movement and is connected between ground and an external meter multiplier, remove the connection between your present plate voltmeter and ground, and connect the PV-10 between the present plate voltmeter and ground. Connect the terminals from the PV-10 (in addition to connections just described) to the proper metering circuit on the Schafer Remote-Control System. Connection is usually made to metering circuit 1. Observe polarity. Before actual connection is made, the voltage can be checked on a voltmeter across a 10,000-ohm load. If the present voltmeter does not fit the circuit described in the beginning of this paragraph, an external plate voltage metering multiplier will be required.

Care must be taken that the lower end of the plate voltmeter circuit returns to or very close to ground potential. In a case of some RCA 250-watt transmitters, a plate rheostat is employed between B-minus and ground, thereby raising the potential at the low end of the plate voltage metering circuit to as much as 200 or 300 volts above ground. This voltage will cause trouble when placed on a telephone line as it would normally be connected. This difficulty can be overcome in several ways. The taps on the transformer can be changed so that the plate rheostat will be operating near the low-resistance side thus keeping the voltage drop across the rheostat below 50 or 60 volts.

A simple method of correcting this difficulty is to provide a remotely controlled plate rheostat in the high-voltage lead. As long as the manual rheostat is not adjusted after the plate voltmeter is calibrated, this will be perfectly satisfactory.

In this case, or in the case of any transmitter not employing a 1-ma plate voltmeter, the circuit shown in Fig. 5-17 can be employed. Instructions for connecting the unit are as follows:

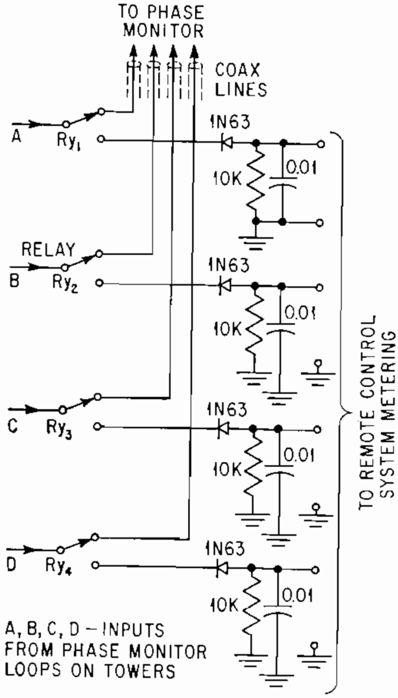


FIG. 5-15. Switching center connection of coax from loops on towers to remote-control system.

Plate Voltage Metering Multiplier (PVMM). Connect one end of the PVMM to the high-voltage source to be remotely measured. Connect the other end of the PVMM to the PV-10 plate voltage metering unit. Connect the remaining end of the PV-10 to the negative end of the high-voltage power supply to be measured. Connect the PV-10 (in addition to the connections already made) to the metering circuit on

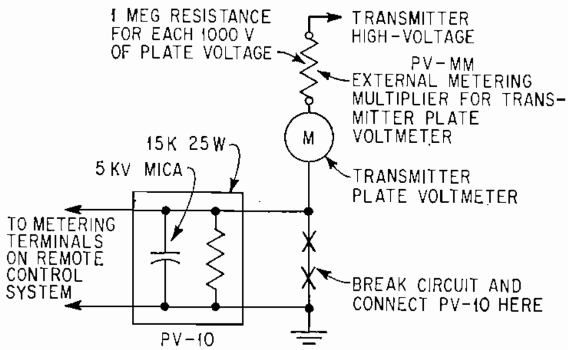


FIG. 5-16. Instructions for connecting metering voltage units supplied with Schafer remote-control system.

the Schafer Remote-Control System. Observe polarity. Metering circuit 1 is generally used for the plate voltage. If other high-voltage sources are to be measured, connection is made in a similar manner to the metering circuit on which reading is desired.

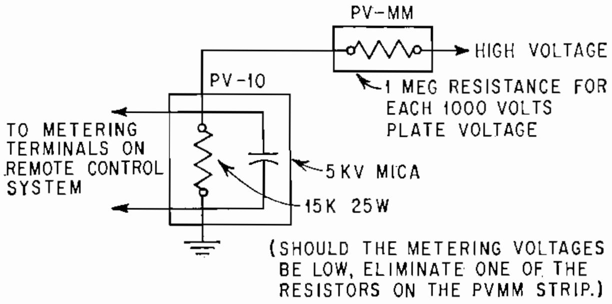


Fig. 5-17. Plate voltage metering multiplier (PVMM).

Plate current metering remotely is accomplished by inserting a fairly low value resistor in series with the plate return, actually indicating cathode current. The circuit normally employed is shown in Fig. 5-18. In making connections to this unit select a point in the circuit of your transmitter which can be broken, through which will flow the total cathode current of the stage to be metered. This point will usually be found at the center tap of the filament transformer of the stage on which plate current is to be measured, or where the cathode circuit returns to ground. At this point break

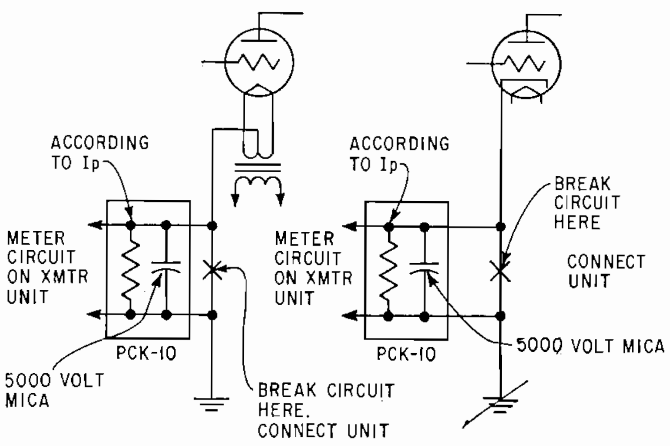


Fig. 5-18. Diagram of plate current metering unit (PCK-10).

the circuit, and insert the PCK-10 metering unit. Observe polarity, and be certain this point has no high-voltage reference to ground.

If the total plate current is 300 ma, a 10-ohm resistor is used on PCK-10.
If the total plate current is 500 ma, a 5-ohm resistor is used on PCK-10.
If the total plate current is 1 amp, a 3-ohm resistor is used on PCK-10.
If the total plate current is 2 amp, a 2-ohm resistor is used on PCK-10.
If the total plate current is 5 amp, a 1-ohm resistor is used on PCK-10.
If the total plate current is 10 amp, a 1-ohm resistor is used on PCK-10.
A photograph of Unit PCK-10 is shown in Fig. 5-19.

Plate current metering in some Collins transmitters does not require the above resistor to be inserted. Some Collins transmitters have a resistor in the circuit to provide audio output of the transmitter, and the voltage drop across this resistor is just about right for remote metering. In some other transmitters, the voltage drop across the coil of an overload relay may be just right to develop the proper voltage.

Plate current metering with d-c filaments may be impossible at a low-voltage potential. Where it has been found impractical, the Commission has waived the requirement, although thus far this situation has been limited to older transmitters used as standby or CONELRAD transmitters.

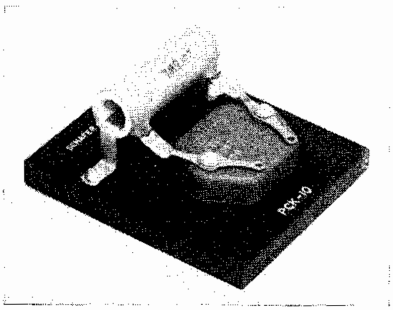


FIG. 5-19

Filament Voltage Metering

In the case of a-c filaments as found in most transmitters, this is a matter of selecting the filament source to be metered and reducing it to a few volts d-c. If the circuit shown in Fig. 5-20 is used, the filament voltage is merely rectified and filtered, and the voltage reduction is accomplished by the calibrating potentiometer in the remote-control system. Connect the terminals marked FIL to the filament voltage to be measured. The unit is designed for any a-c voltage to 15 volts. Connect the terminals marked MET to the metering circuit on the remote-control system. Observe polarity. Metering circuit 4 is usually used for this purpose.

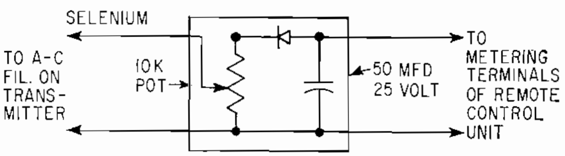


FIG. 5-20. Filament voltage metering unit.

Filament voltage metering in the case of d-c filaments requires only a simple voltage-divider circuit to drop the voltage to the metering voltage required. In most cases, the calibration potentiometer on the remote-control system will act as voltage divider and the filament voltage can be fed directly to the remote-control system.

Filament voltage metering is often most easily accomplished by actually measuring the line voltage (usually 230 volts) feeding the input of the filament transformers. In this case, the connection is the same as described below for line voltage metering except that the 115, 230, or 440 volts is taken from the input of the filament transformer circuit.

Line Voltage Metering

This is accomplished by reducing the line voltage of 440, 230, or 115 volts to a low voltage, then rectifying and filtering the low voltage. Line voltage metering can be done on a single phase or all three phases of more than one source as required. Circuitry for a single phase is shown in Fig. 5-21.

Tower-light Current Metering

This is accomplished by converting the current feeding one or more tower-light circuits to a small d-c voltage. The circuit in Fig. 5-22 shows the manner in which

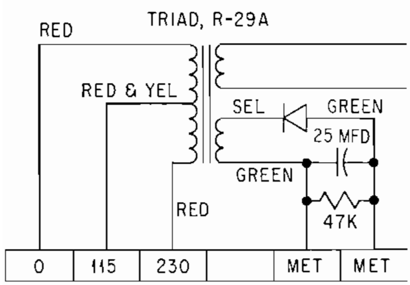


FIG. 5-21. Line voltage metering unit.

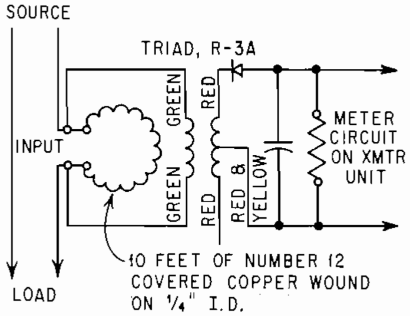


FIG. 5-22. Tower-light current metering unit.

the small resistance capable of handling high current is developed by using No. 12 wire. The small voltage drop across this resistance is fed into a transformer, stepped up by the transformer, then rectified and filtered. The output is direct current, proportional to the tower-light load. It is possible to tell how many side lights are burning and how many beacons are flashing by variations in this direct current. Usually one unit is used for each flasher. Connections to the TC-25 unit should be as follows: Connect the terminals marked AC in series with the line feeding alternating current to the tower lights. Connect the terminals marked MET to the metering circuit on the Schafer Remote-Control System. Adjust the potentiometer on the unit so the calibrating pot on the remote-control system itself (for that particular circuit) is operating in the top half of its range. The output voltage from the metering unit in this case will be approximately 5 volts when the tower light load is approximately 1,550 watts. If the tower-light load is not enough to develop the 3 volts required for remote metering, the voltage can be increased by connecting the unused RED transformer wire to the point where the RED and YELLOW wire is now connected.

Voltage metering circuits of any kind can be incorporated into remote-control systems by following the basic theory. Reduce the voltage to a few volts by using a voltage divider. The voltage divider should be designed to draw about 1 ma. Remember that the 10,000-ohm load across the metering circuit of the remote-control system will be present across the metering load at all times.

Current metering circuits of any kind can be incorporated into a remote-control system by following the familiar theory that it is necessary merely to convert to a small voltage. The remote-control system will have little or no effect on the circuitry because the 10,000 ohms will be quite high as compared with the few ohms required to develop the voltage required in most circuits.

Miscellaneous metering is practical with most remote-control systems because sufficient extra metering circuits are available so that anything which can be converted to direct current can be metered, such as room temperature, wind velocity and direction, and almost anything else imaginable.

Remote Controlling of Circuits

This is a matter of installing relays and motors to do what is normally performed manually. *Anything electrical which can be done manually can be done remotely.* Anything controlled by a switch can be controlled by a relay. Anything controlled by a knob can be controlled by a motor. Automatic controls are often desirable. Some stations have employed locks on the remote-control systems so that only specified personnel can control any circuits, or in some cases, locks are provided so that only certain personnel can control certain circuits in a remote-control system.

Remote control of any circuit locally controlled by a switch can be accomplished by the use of a latching relay as shown in the circuit of Fig. 5-23 and the photograph in Fig. 5-24. Instructions for use are as follows: A circuit now controlled by a switch must be remotely controlled with a latching relay. A latching relay is a relay with two coils. When one coil is momentarily energized, a pair of contacts are closed. When the other coil is momentarily energized, the pair of contacts open. For this

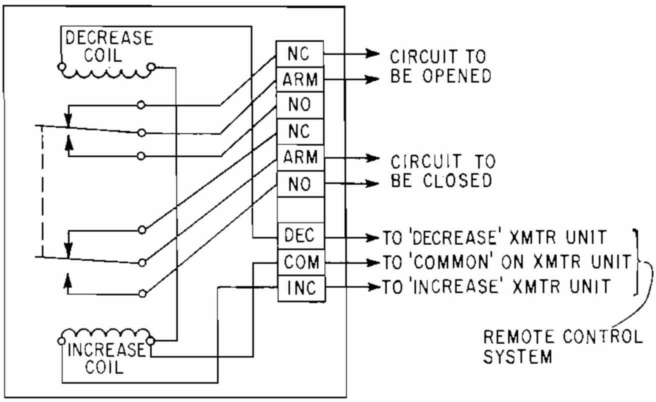


Fig. 5-23. Latching relay circuit diagram.

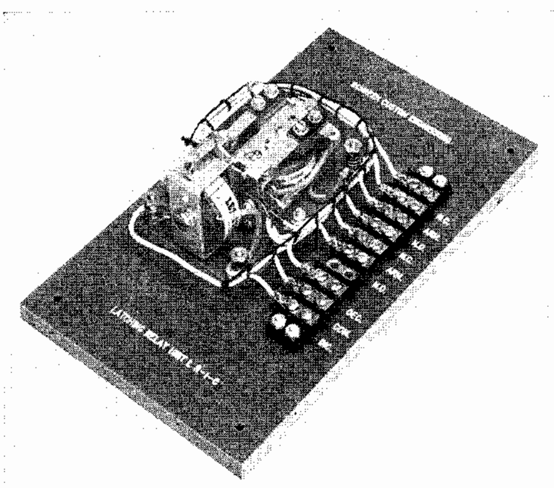


Fig. 5-24

reason, one coil can be connected to a control "increase" circuit, and the other connected to a control "decrease" circuit, and in this way remote control of a circuit locally controlled by a switch is a simple matter. Two push buttons are provided so local control of the latching relay can be connected as shown in Fig. 5-23. If a circuit is normally controlled with a manual circuit breaker, and if the protection the circuit breaker provides is important to the safe operation of the transmitter, a remotely controlled primary circuit breaker should be used for remote control of this circuit.

Remote control of any circuit locally controlled by push buttons can be accomplished by the use of momentary relays as shown in Fig. 5-25. This relay unit, MR-2-C, shown in Fig. 5-26, consists of two momentary relays the coils and contacts of which are connected to a terminal strip, all mounted on sturdy black spauldite. An MR-2-C is used for two-way on-off circuits, such as filament voltage on-off, plate voltage on-off, etc. The MR-2-C is used to control a circuit remotely which is locally controlled by

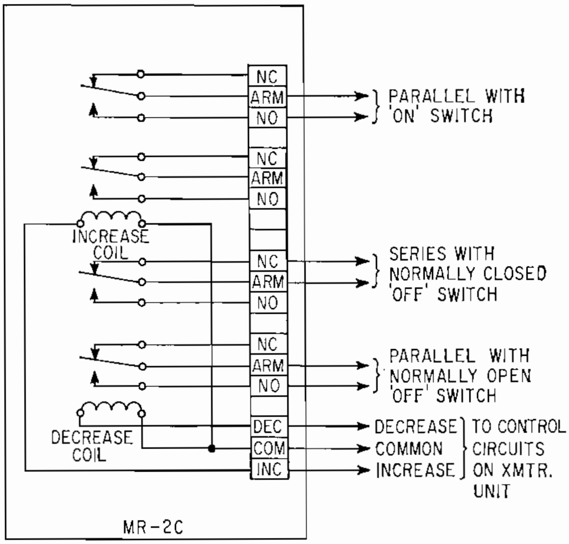


FIG. 5-25. Momentary relay circuit diagram.

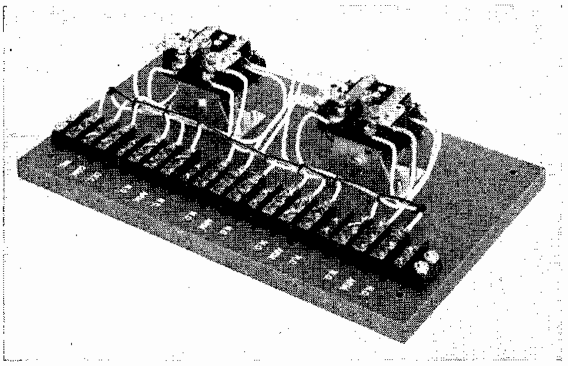


FIG. 5-26

push buttons. The relays are connected to perform the same function as the push buttons now perform. Care must be taken to connect the unit accordingly. While most ON buttons momentarily "make" a circuit, some OFF buttons break a circuit or simultaneously make and break a circuit. Obviously the relay should be wired in series with normally closed circuits and in parallel with normally open circuits.

Remote control of a circuit locally controlled by a motor is possible by merely remote-controlling the push buttons which now control the motor with a circuit similar to that shown in Fig. 5-25.

Remote control of an operation locally controlled by a knob can be achieved by connecting a motor to the shaft and remotely controlling the motor. Provision should, of course, be made for locally controlling the motor as shown in Fig. 5-27. Figure 5-28 is a photograph of such a motor control unit.

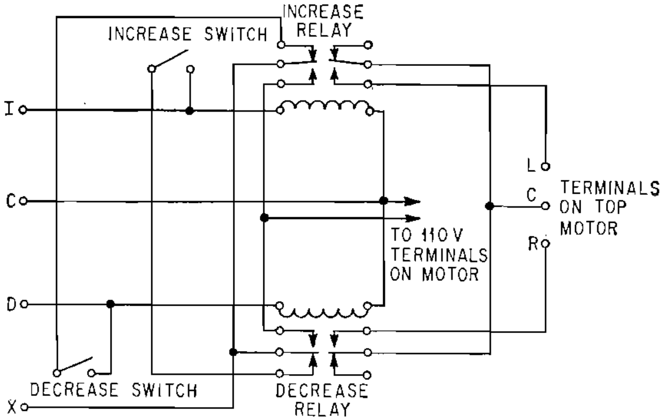


FIG. 5-27. Motor control unit.

Remote control of a circuit locally controlled by a circuit breaker requires a decision as to the importance of the circuit breaker and the experience with the breaker. If the breaker never drops out, it may be safe to connect a latching relay in series with it and retain the protection of the breaker while remotely controlling the latching relay and thereby the circuit. If the circuit breaker has a tendency to drop out, it may be desirable to connect a latching relay in parallel with the breaker, thereby eliminating the breaker from the circuit and, of course, eliminating the protection it affords. In any event it may be considered very desirable to include a secondary overload relay which can be reset by remote control as shown in Fig. 5-29.

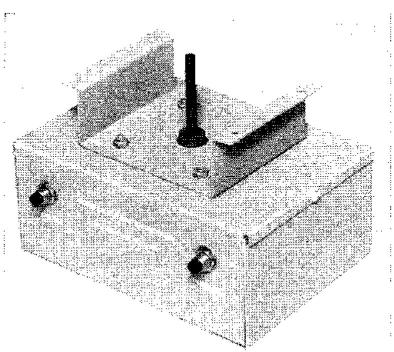


FIG. 5-28

Laying Out the Pattern for Connection of a Remote-control System

A remote-control installation may be as simple as to provide for the turning on and off of a transmitter and the reading of plate voltage, plate current, antenna current or may be complicated and involve several transmitters and more than one remote-control system. First, determine what you want metered and controlled. Then plan a logical layout for these metering and control circuits, bearing in mind that only one circuit can be controlled while a given circuit is being metered, although circuits can be cross-connected to provide for one circuit to be controlled on one or more metering circuits, or vice versa. Once you plan what circuits to meter and control, lay them out in a logical pattern. The following is a typical pattern for a basic installation:

Dial circuit	*Metering circuit*	*Control circuit*
1	Plate voltage	Plate voltage on-off
2	Plate current	
3	Antenna current	Power output—raise-lower
4	Filament voltage	Filaments on-off
5–20	Miscellaneous	
21	Frequency deviation	
22	Percentage of modulation	

The circuit for such a pattern is shown in Figs. 5-30 and 5-31 for both metering and control.

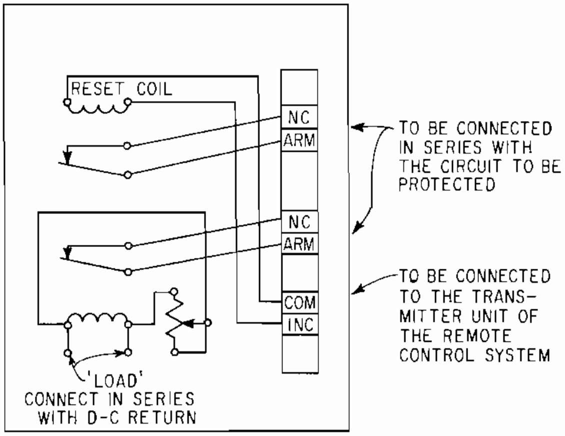


Fig. 5-29. Secondary overload relay unit.

CONCLUSION

Remote control of broadcast transmitters is an acceptable modern technique for operation of these stations. Concurrent with the application of remote control is the requirement for a stable transmitter. For directional stations, this requirement includes the stability of the array as well. There is no technical reason why remote control of television transmitters could not also be performed satisfactorily assuming that the preceding requirements are satisfied. Associated with remote-control systems are automatic logging and control of broadcast transmission parameters which are covered in Part 6 of this section. Application of both techniques to broadcast transmitters, both radio and television, will be a long stride forward in the modernization of our broadcast operating program.

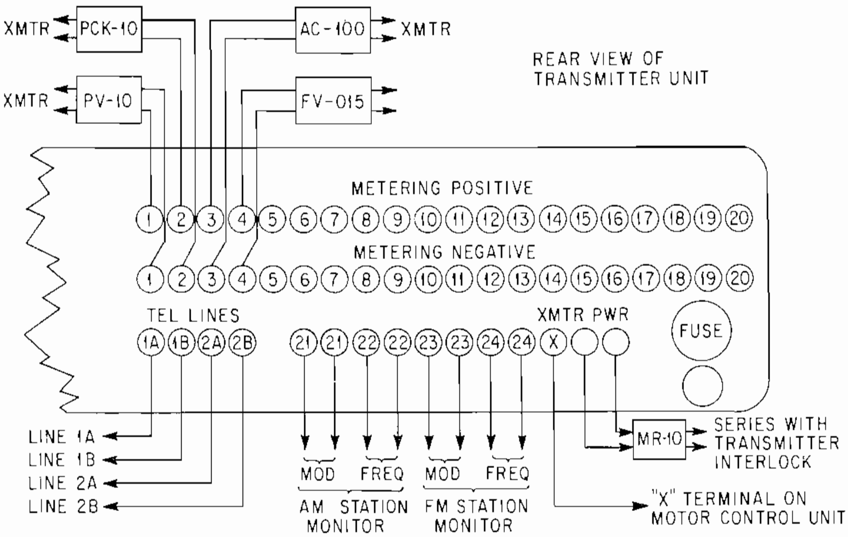


FIG. 5-30. Typical metering connections in a simple installation.

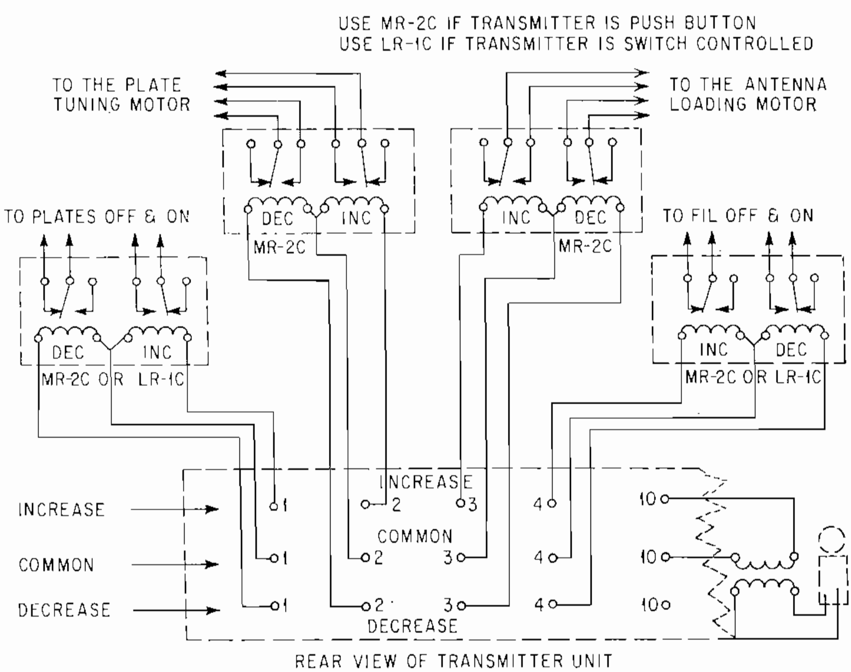


FIG. 5-31. Typical control connections on a simple installation.

Part 6

AUTOMATIC LOGGING AND CONTROL OF BROADCAST TRANSMISSION PARAMETERS

NAB Engineering Department

INTRODUCTION

For many years the Federal Communications Commission, in Part 3 of their Rules, has required broadcast stations to keep a transmitter log of specified circuit values. These meter readings have been made by the transmitter operator and written in a log sheet for a record of the performance of the transmitter. The existing rules of the FCC still require such a manually kept transmitter log. NAB intends to file a request with the FCC (July, 1960) to permit keeping the transmitter log for both radio and television stations by mechanical-electrical means.

Countless other nonregulated industries have applied automatic devices for years in recording information necessary to their operations. There is no valid reason why such techniques should not also be incorporated in the operating equipment of broadcast stations. The application of these techniques to broadcast transmitters must be in such a manner that the fundamental requirements of the regulating body (the FCC) are satisfied. Basically, the FCC is responsible for and validly concerned with four fundamentals: the operating frequency, the audio and video characteristics of the equipment used for transmitting including the degree of modulation, the performance of the antenna system in terms of the license specifications, and the power output or radiated power. These basic parameters are all related to the orderly operation of a broadcasting system in the United States, taking into account the effect of such operation on other countries in the North American region. If these fundamentals are satisfactorily controlled, it would appear that the governing body for broadcasting would have no valid objection to agreeing that the licensee should conduct his technical operations in a manner that satisfies both his own operating requirements and the public responsibility incumbent on each licensee of a broadcast station. Such techniques and even a vast simplication of automatic logging have been used for some time by government-owned and -operated broadcasting stations in other countries. The 150-kw medium-wave station at Daventry, England, operated by the British Broadcasting Corporation has only two operating controls, a START and STOP button. All other monitoring functions are performed by an off-the-air instrument which measures performance of the transmitting equipment. A necessary factor to be taken into account in such operation is maintenance of the equipment.

Although some engineers will argue with the premise, it has been demonstrated that in the vast majority of stations, transmitting equipment will operate unattended with no more outages than when an engineer is present during the operating period. There is even considerable evidence that the equipment performs better under such circumstances. Such statements are not made without regard to some basic criteria which often are lost sight of in relation to modern operating techniques:

1. A stable, completely reliable transmitter that will operate day in and day out with no "babying" or coaxing, designed and built for unattended operation and having provisions incorporated in it to ensure its continued electronic health throughout its normal life

2. An antenna system which meets the terms of the license not only when installed but during continued operation in order to provide both service to the intended area and a prescribed minimum of interference to other stations

Undoubtedly a large percentage of stations installed in recent years have transmitters which meet the first criterion. There are many stations, however, with old transmitters which do not measure up. These transmitters, in all fairness, are still doing a creditable job with engineers in attendance, but in some instances, they should not be expected to operate unattended. Some of the low-serial-number transmitters in the 50-kw category have been operating 25 years and holding up well but with the requirement for operating techniques as old as the transmitters.

Antenna systems fall into two categories, omnidirectional and directional with varying degrees of complexity. In both cases, we are finding that as in all things, age and deterioration are taking their toll. Towers themselves can usually be made to last indefinitely if good maintenance and inspection procedures are carried out. Ground systems are somewhat like the internal organs of man—you may know something is wrong but sometimes surgery is necessary to locate and correct the trouble.

LOGGING PHILOSOPHY

Logging parameters which are of fundamental concern of the FCC and those which a licensee may wish to record in the interest of his own technical operation can be discussed together.

Frequency

For standard broadcast stations, it has been demonstrated beyond any doubt that the average frequency stability today is ± 3 cps of the assigned frequency.[1] This is well within the permitted tolerance of ± 20 cps. The existence of such stable oscillators in the transmitters raises the question whether a frequency monitor should be required or the entire responsibility of maintaining frequency should be on the licensee without the requirement in the Rules of the FCC for specific equipment. It certainly is no difficult task for an engineer to make use of the standard frequency transmissions of WWV or WWVH[2] to calibrate a secondary frequency standard and multivibrator and determine to the cycle the frequency of a standard broadcast transmitter at any time. Such transmissions are radiated on frequencies which should make reception at any location in the United States and possessions relatively easy. Although, at the present time, the FCC Rules require logging of the frequency deviation, it seems reasonable that sometime in the future this responsibility may be placed on the licensee without specific instructions as to how the frequency shall be maintained.[3]

FM and television broadcast stations are not yet in the same situation with regard to frequency tolerance. Insufficient evidence is on file at NAB to enable similar conclusions for these stations. It is true that as the frequency increases, the stability under normal operating conditions is not so easy to maintain, even within a larger

[1] The average of frequency deviation obtained from 1,700 standard broadcast stations in the United States.

[2] See Section 1 of this handbook.

[3] NAB has filed a petition and substantiating data with the FCC requesting amendment of the rules to permit logging the frequency monitor at the beginning and end of the broadcast day and for 24-hr stations once in each 12-hr period. No action has been taken by the Commission.

percentage of tolerance. There are signs, however, that even for these stations, frequency-tolerance compliance may in the near future become somewhat equivalent to that for standard broadcast stations. Obviously, such compliance could be maintained now with additional equipment with more rigid accuracy specifications.

Characteristics of Audio and Video Equipment

The FCC has established standards applicable to broadcast equipment, and these are contained in Part 3 of their Rules. Any system of high performance, such as broadcasting, must have such criteria. Compliance with these standards is ensured by means of the proof-of-performance measurements which must be made and kept on file at the station. These requirements are not a part of the daily operating log but are important in maintaining the reputation for "broadcast quality" which has accrued to the industry.

Antenna System

The Rules of the Commission require logging of certain parameters of the antenna depending upon whether it is directional or nondirectional. These are set forth in Part 3 of the Rules. While there may be variations in the necessary readings to ensure that an antenna is performing in accordance with the terms of the license, the FCC believes that those now required are the proper ones. There is no difficulty in adapting automatic logging equipment to take care of these values. This will be made clear later in this part.

Power Output

Power is a basic factor in any radio allocation system. Together with the antenna characteristics, it determines the degree of service and also the interference potential (with due regard to propagation and noise considerations). Early in the development of broadcasting, maintenance of power level was not so simply accomplished as today with our modern methods of voltage regulation, including those associated with the primary power source. While relatively simple to maintain, it is a fundamental factor to be considered by the FCC and can easily be included in the logged readings.

AUTOMATIC LOGGING EQUIPMENT

The ideal operating situation would be to start and stop a transmitter and leave the rest of the considerations to electronic compensating and regulating devices. There is no technical barrier to such a system at the present time. Economics would enter the picture, although the additional cost would be small. In anticipation of the probable desires of the licensee and considering the existing and probable requirements of the FCC for the future operation of broadcast stations (AM, FM, TV), the NAB initiated discussions with manufacturers which have resulted in the production of equipment to perform the transmitter logging and control functions. Single-circuit simple recording voltmeter types of equipment have been used by broadcasters for years, and the FCC does permit their use in transmitters, but *not in lieu* of the manually kept transmitter log.

One type of automatic logging and control system has been developed by the Brown Instrument Division, Minneapolis-Honeywell Regulator Company. This equipment is used to log automatically in sequence, on a 12-in.-wide strip chart, various parameters. Each parameter is identified by a printed number on the chart, and the point by the number registers the position of the chart scale to give the measured value. Time lines on the chart give the time of measurement, because the chart is driven by a synchronous motor.

This equipment is designed to operate in conjunction with any of the standard remote-control systems and utilizes for logging purposes one of the two normally required pairs of lines (i.e., the metering line). During logging operations, the metering line is connected to the logging equipment. Should a remote dial-up operation be desired using the remote-control equipment, the logging equipment is disconnected by means of a switch and the normal functions performed. The logging equipment *should be located at the remote-control point,* which in most instances is the studio location.

The Minneapolis-Honeywell automatic logger consists of two units, a logger transmitter and a logger receiver. All circuits to be recorded by this equipment must be either d-c voltage or direct current. RF can, of course, be rectified, filtered, and converted to an equivalent d-c voltage or direct current with one side at ground potential. Consequently, any and all circuit values pertaining to the transmitter of an AM, FM, and TV station or the requirements of the FCC such as the frequency-monitor reading can be logged and, if desired, controlled with appropriate apparatus deriving its exciting signal from this equipment. The accuracy of this equipment is 0.25 per cent, which is well within the FCC tolerance for remote indicating devices (2 per cent).

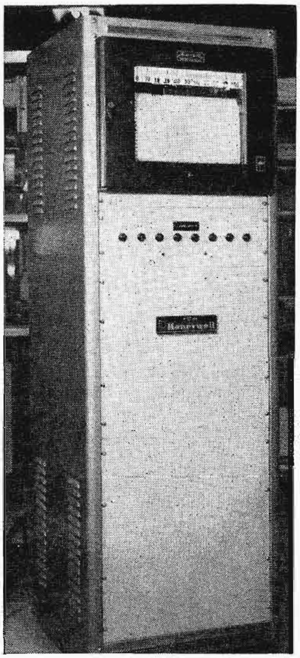


FIG. 6-1. Recording instrument and alarm light panel.

Reference to Fig. 6-2 will indicate the general system and its capabilities in a broad sense. All the required log functions of a radio and television transmitter can be handled by the equipment. The signal through the logger transmitter (see Fig. 6-3) starts from the input circuits *A, B, C, D, E, F* through the input selector switches S_1 to the measuring and control circuit M_1 then to the telemeter T_1 for transmission over a telephone line K_1 to the logger receiver. One input parameter signal is transmitted every 30 sec. At the end of each 15-parameter sequence there is a 30-sec interval of time before the next 15-point sequence starts, during which time the synchronizing pulse-generating circuit in the telemeter transmits a pulse to signal the receiver when the next sequence of 15 input parameter signals will start.

The input parameter signal from the telephone line (K_1) to the logger receiver is fed directly to the signal measuring M_1, recording R_1, and alarm circuit A_1 (see Fig. 6-3). The synchronizing pulse from the telephone line to the logger receiver is fed directly to the print wheel and alarm-timing switch motor-control circuit. The print-wheel motor-control circuit in the logger receiver stops the print-wheel motor after each sequence of 15 parameters, and the synchronizing pulse from the logger transmitter starts the print-wheel motor again. The logger-transmitter input-selector switch is driven by a synchronous motor in the receiver. Since these motors are geared to drive the transmitter input-selector switch and the recorder print wheel at the same rate, the receiver print wheel and the transmitter input-selector switch will remain synchronized through each 15-point sequence.

Logger-transmitter Input Circuits

On the right of the Fig. 6-3 diagram there are six types of input circuits from *A* through *F*.

Type *A* input circuits will accept voltages from a tower-lighting transducer (see Fig. 6-11). The light-circuit transducer converts the navigational tower-light-circuit alternating currents to d-c voltages. The transducer response time to input current changes is slow enough to provide a steady output voltage even when the tower lights are flashed on and off at the rate of forty times per minute with approximately equal on and off times. The output voltage from a light-circuit transducer is fed to the input of a circuit of type *A* (Fig. 6-3). From the input of a circuit of type *A* the signal passes through a radio-frequency filter to a voltage-divider circuit with two adjustments. The first voltage-divider adjustment provides a means of calibrating

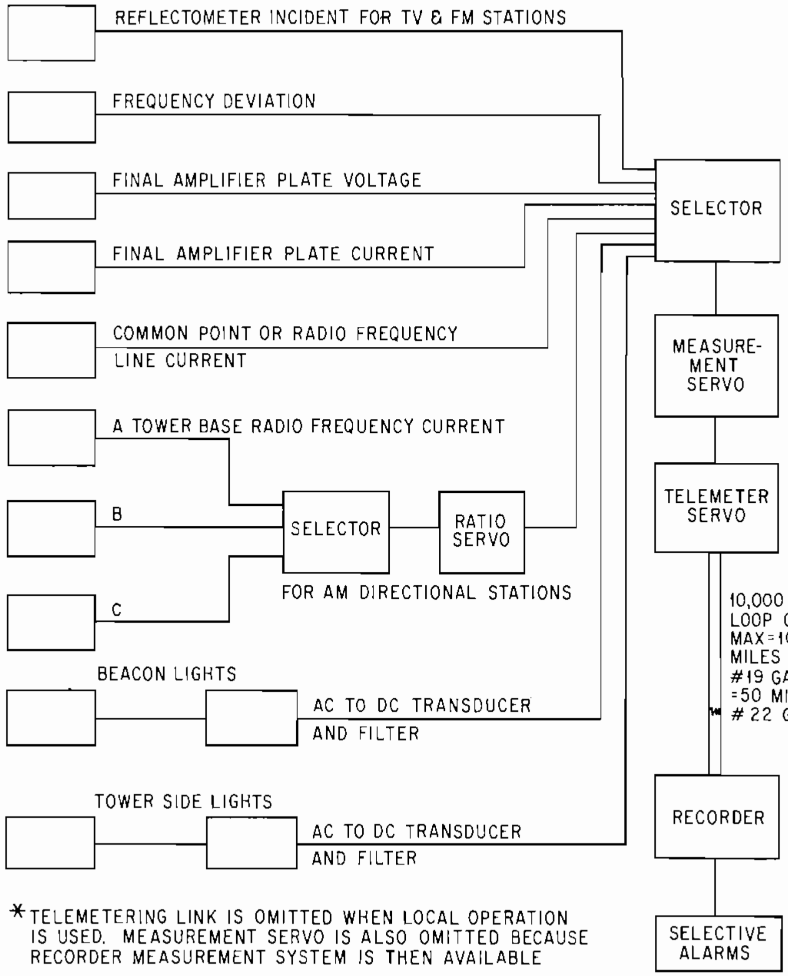


Fig. 6-2. Block diagram of Minneapolis-Honeywell automatic logging and control system.

the divider output voltage to a fixed full-scale value when tower light bulbs are replaced without disturbing the operation of the logging system. This is done by adjusting the voltage at one point in the divider circuit to equal a fixed reference voltage as detected by a reference voltage and galvanometer circuit. This means that the recorder will always indicate approximately the same point on the scale for all lights on, even though the total current drawn by the new lamps is not exactly the same as that drawn by the lamps they replaced. The second adjustment permits the operator to choose a point in the upper 20 per cent of the scale of the receiver recorder for indicating the "all lights on" condition that will not be in line with other points needing more exact scale readings. A maximum of 10 type *A* circuits can be obtained.

Type *B* input circuits (Fig. 6-3) receive d-c voltages such as might come from

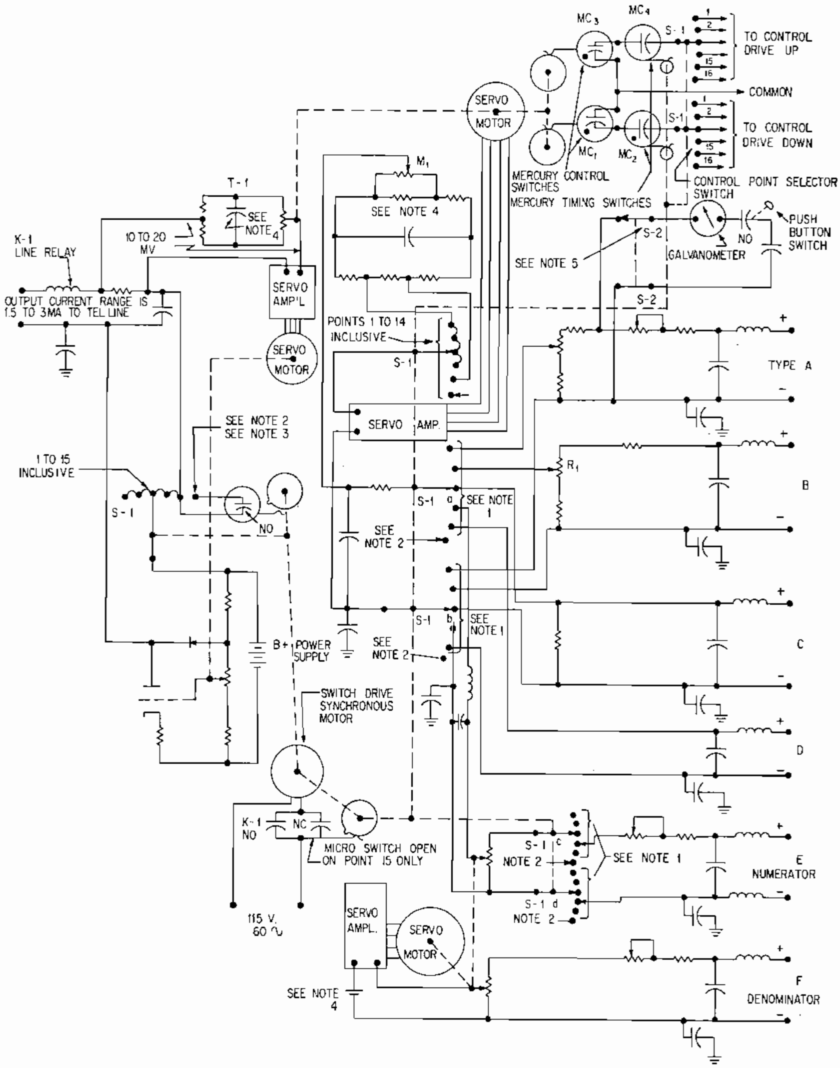


FIG. 6-3. Automatic logger-transmitter circuits.

the radio-transmitter final amplifier plate current, plate voltage, and common-point RF current circuits. At the input of the type *B* circuit these voltages are fed through a radio-frequency filter to an adjustable voltage divider R_1. The circuit can be equipped with dividers to accept 0 to 1, 0 to 5, 0 to 8, or 0 to 10 volts d-c with a ± 10 per cent span adjustment. The input resistance for a type *B* circuit is 40,000 ohms/volt. A maximum of 15 type *B* circuits can be obtained.

Type *C* input circuits receive direct currents from the radio-station equipment (such as frequency deviation monitors). This current signal is fed through an RF filter to a 10-mv d-c shunt. It can be designed for any current between 0 to 25 μa to 0 to 10 ma with no provision for span adjustment. A maximum of 15 type *C* circuits can be provided.

Type *D* circuits will accept 0 to 10 mv from any d-c source. As may be noted, only RF filtering is provided. The span of the measuring circuit of the transmitting equipment is 0 to 10 mv. If all measurements from a transmitter are brought out at

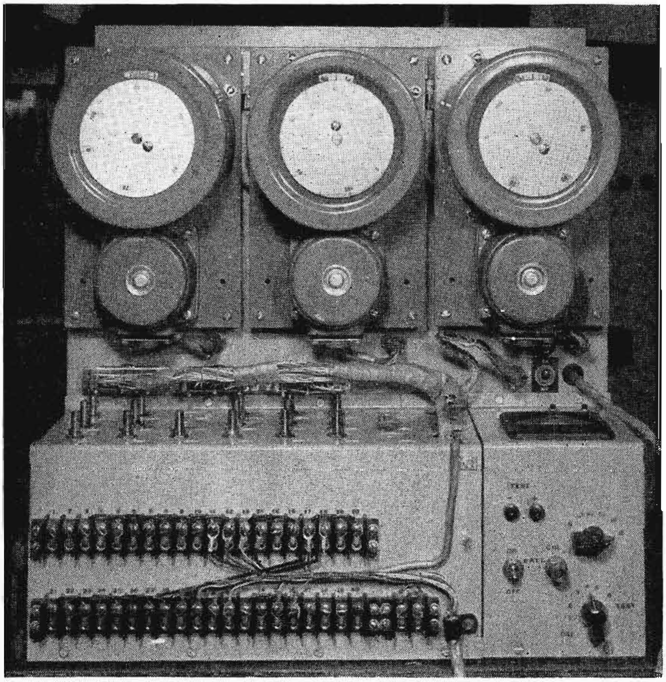


Fig. 6-4. Back of transmitter showing ratio, measuring, and telemetering servos and input terminals.

a 0- to 10-mv value, no adjustment would be required in the input circuits of the transmitting unit. A maximum of 15 type *D* circuits is available.

Type *E* and *F* input circuits form the numerator and denominator of a ratio circuit. These circuits provide RF filters, voltage dropping resistors, and span adjustments for d-c voltage inputs to the d-c voltage ratio computer. The maximum full-scale voltage to these circuits should not exceed 10 volts, and the minimum denominator voltage should not be less than one-tenth of the maximum denominator voltage. The type *F* denominator circuit places a maximum current drain on the voltage being ratioed of 115 μa, and the type *E* numerator circuit places a maximum current drain on the voltage being ratioed of 45 μa or less, depending upon the full-scale ratio desired. The circuits can be provided for any full-scale ratio span between ½ to 10.

If suitable circuits are provided for converting the tower RF currents to proportional DC voltage signals *the ratio computer can be used to indicate the tower RF current ratios.*

The maximum number of total input circuits (circuit type A + type B + type C + type D + type E and F) permissible is 15.

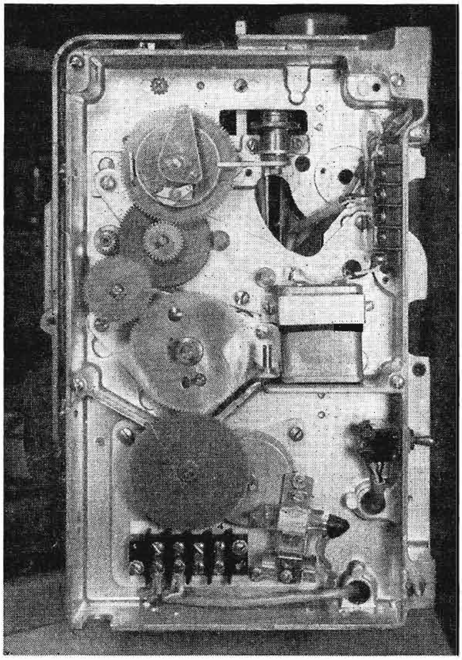


FIG. 6-5. Side view of transmitter showing sequencing gears.

Logger-transmitter Ratio-computer Circuit

The two ratio-computer input circuits are electrically isolated from each other. The slidewire position of the denominator circuit servo varies inversely with the denominator input voltage. The numerator-circuit slidewire is mechanically ganged with the denominator slidewire and, therefore, multiplies the inverse of the denominator voltage by the numerator voltage to produce an output millivoltage which is proportional to the ratio of the numerator and denominator voltages.

Logger-transmitter Signal-measuring and Control Circuit

The 0- to 10-mv signals from the type *A*, *B*, *C*, *D* input circuits in Fig. 6-3 and the ratio computer are coupled to the signal-measuring circuit by the input selector switches on a time-sequence basis. The measuring circuit is a potentiometer-type servo null-balance-measuring circuit which produces a servo slidewire position proportional to the input signal. A transmitting slidewire is ganged to the measuring slidewire to transmit the signal to the telemeter circuit. Also ganged to the measuring slidewire are two control mercury switches MC_1 MC_2 MC_3 MC_4 one of which closes if the signal is below a desired value and the other closes when the signal is above a desired value. The signal-level zone where neither switch closes is adjustable. These control switches are wired in a circuit with selector switches ganged to the input selector switches and with timing switches such that the appropriate control drive motor is selected and then connected to the control switches to be driven up or down scale after the signal being measured has been recorded and just before the next signal is connected. About 10 sec is allowed for control action on each point. Since parameters to be controlled do not normally drift in the 8-min intervals between control actions, the 10-sec control time (using slow-moving control driving motors) should be sufficient to bring a parameter back to its desired value should an extraordinary change occur.

The logger transmitter has a maximum capacity of two control set points. For this reason all input circuit spans for input parameters that are to be equipped

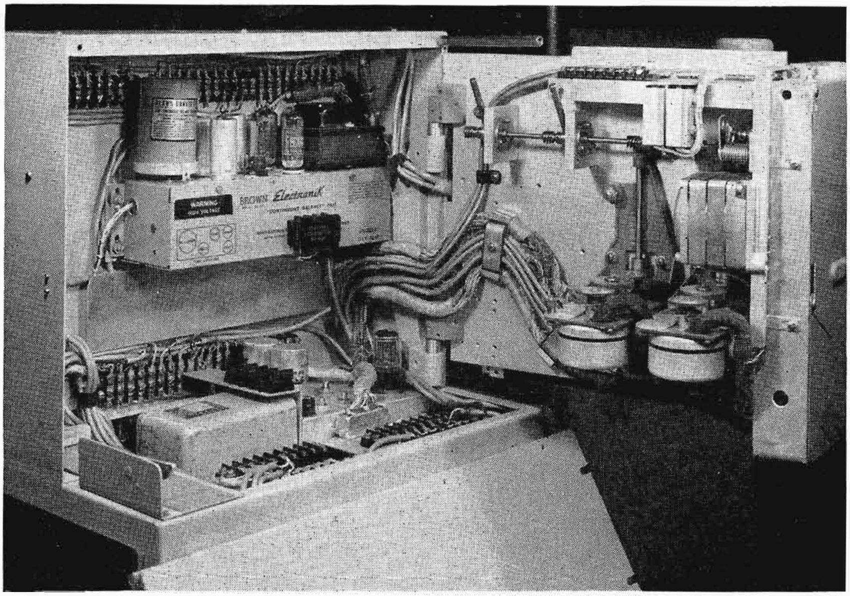


FIG. 6-6. Transmitter showing input selector switches on back of amplifier panel. Note space left for automatic-control selector switches.

with automatic control by the transmitter must be chosen so that the desired operating point of the measuring circuit servo will be at one of the two positions chosen for the set points.

Logger-transmitter Telemeter Circuit

The telemeter consists of a regulated voltage source whose output voltage is made to vary with a servo slidewire position. This voltage is connected across the telephone line, and a precision resistor is inserted in series with the telephone line so that all the telephone-line current must pass through the resistor. The telemeter servo amplifier compares the voltage across this precision resistor to the voltage from the d-c measuring circuit transmitting potentiometer slidewire circuit and drives the telemeter output voltage until the signals are equal. In this way the telephone-line current is made to be linearly proportional to the d-c measuring servo position and thus proportional to the input parameter signal. The function of the synchronizing pulse-generating circuit in the telemeter is covered in the next part of this description.

Transmitter Selector Switch and Print Wheel Synchronizing

The synchronizing circuit is shown partly on the logger-transmitter drawing (Fig. 6-3) and partly on the logger-receiver drawing (Fig. 6-10).

When the telephone-line loop is closed, the logger-transmitter switch drive synchronous motor runs continuously. This is because the K_1 telephone-line relay will always be in the actuated condition owing to the telephone-line current except during the interval of time that the synchronizing pulse is being transmitted. This pulse is transmitted only during part of the interval of time that the switch S_1 is on position 16. The microswitch which parallels the K_1 contact can be open only during the time that S_1 is on position 15, and therefore the switch-drive motor is always energized.

When the telephone-line loop is closed, the logger-receiver motor will run continuously on all its S_1 switch positions except point 16, because its K_1 telephone-line relay will be in the actuated position (except during the interval of time that the synchronizing pulse is being transmitted). When the receiver switch S_1 is driven

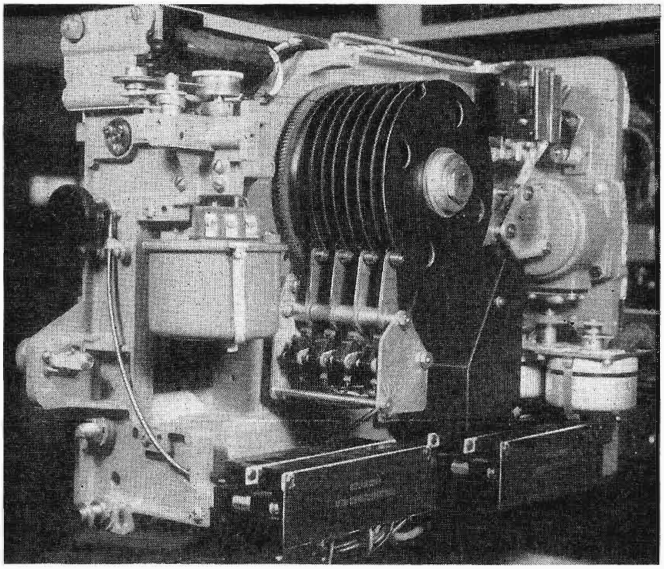


FIG. 6-7. Receiver chassis swung out showing selective alarm adjustable cam switches.

to point 16, the synchronous motor, which drives this switch and the print wheel, will stop in about 3 sec when the arc suppression switch opens, since the motor circuit through point 16 and the K_1 relay contact will be open at the relay contact. S_1 in the logger receiver requires 30 sec of motor-drive time for all points except point 16, where only 6 sec of motor-drive time is required. The S_1 switch in the logger transmitter requires 30 sec of synchronous-motor-drive time for all points. About 15 sec before the logger transmitter is switched from point 16 to point 1, the synchronizing timing switch in the transmitter opens the telephone line (this timing switch is open for about a 6-sec interval), which allows the K_1 relay in the logger receiver to release and start the print wheel synchronous motor in the receiver. The receiver then drives to point 1 in about 3 sec, and 12 sec later the logger transmitter will switch to point 1. During the next 15 sec the logger transmitter will drive the point 1 parameter to its proper value by means of the control switches (if it differed from the control set point) and switch to point 2. During the next 15 sec the receiver would balance to the point 2 value and print point 2, etc., through the 15-point sequence.

If the logger receiver and recorder are disconnected from the telephone line (as, for example, when the telephone line is to be temporarily used for remote-control metering), both the logger-receiver print wheel and transmitter selector switch

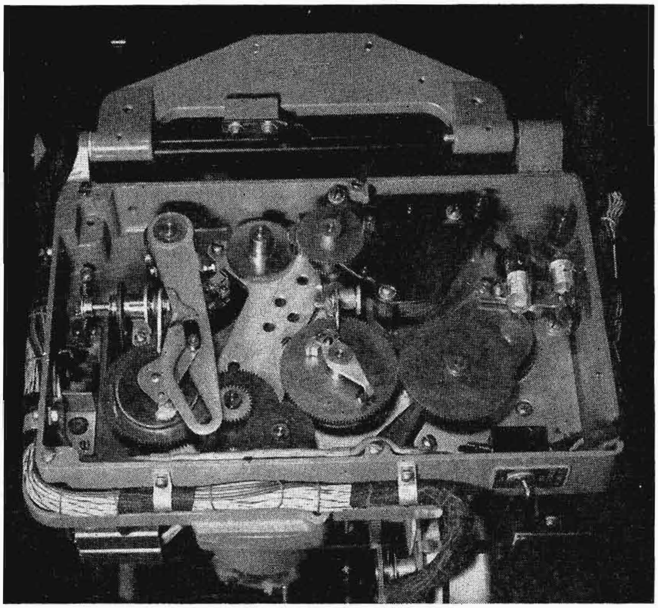


Fig. 6-8. Side of receiver chassis showing printing mechanism and synchronizing gears.

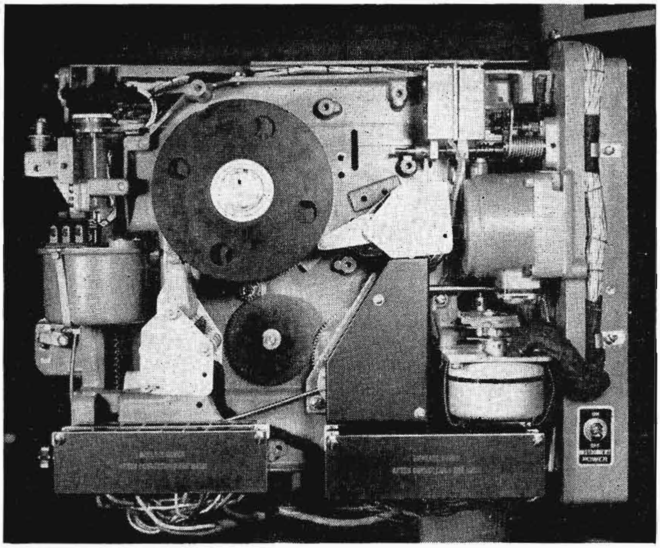


Fig. 6-9. Receiver chassis, full rear view.

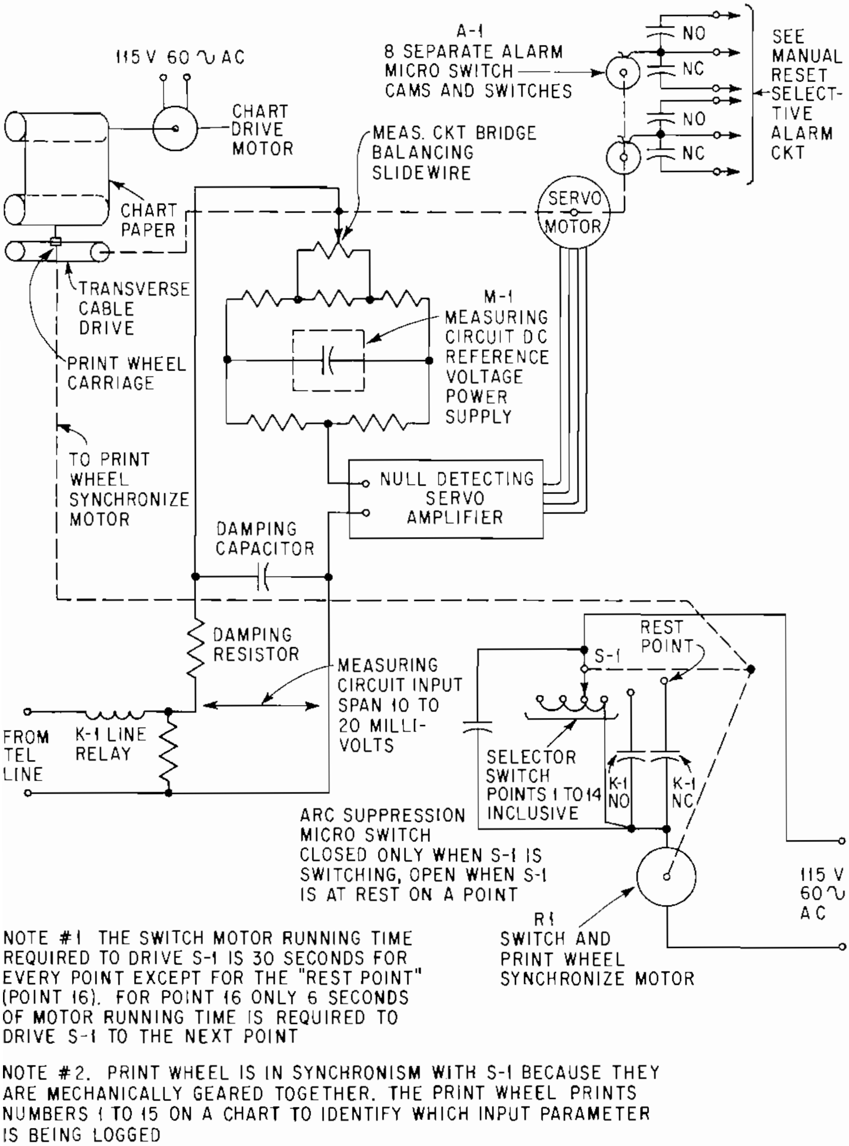
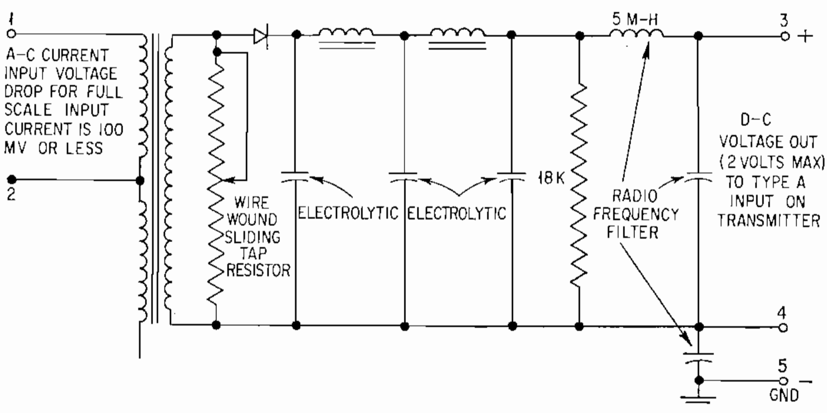


Fig. 6-10. Automatic logger-receiver circuits.

synchronous-drive motor will stop just as they reach point 15 because the K_1 relay in both units will be deenergized. Therefore, no control, alarm, or recording will occur until the telephone line is again connected. When the telephone line is reconnected, the K_1 relays will close simultaneously, starting both units out in synchronism on point 15 and continue the logging operation as before for a closed telephone-line loop.

Logger-receiver Measuring Circuit

The logger-receiver measuring circuit (see Fig. 6-10) is of the potentiometer null-balance type. A servo motor driven by the null-detector amplifier drives the potentiometer slidewire to a position such that the millivoltage of the measuring circuit equals the millivoltage of the input signal. The telephone line signal direct current is fed through a precision resistor at the input to the potentiometer measuring circuit,



NOTES:

1. INPUT CURRENT TO BE IN THE RANGE FROM 2 TO 10 AMPERES.
2. FOR INPUT CURRENT RANGES IN EXCESS OF 10 AMPERES USE STANDARD 100 M-V A-C CURRENT METER SHUNT ACROSS INPUT TERMINALS 1 AND 2.
   THE CURRENT RATING FOR THE SHUNT TO EQUAL THE DIFFERENCE BETWEEN DESIRED INPUT CURRENT AND 10 AMPERES, FOR EXAMPLE: FOR 15 AMP. INPUT USE 5 AMP. A-C METER SHUNT DESIGNED FOR USE WITH A 100 M-V METER MOVEMENT.

Fig. 6-11. Schematic for tower-light alternating current to d-c voltage transducer.

creating the signal millivoltage which is measured. The receiver measuring circuit servo drives the print-wheel carriage to the proper position on the chart to make a permanent chart record of the signal value.

The chart is continuously driven by a synchronous motor at the rate of 8 in./hr, thus providing the chart record time base. At the rate of 8 in./hr each chart will record 7½ days.

The measuring circuit servo also drives the eight alarm-set-point cams to actuate the alarm microswitches if the signal level is above (or below) the predetermined alarm set points (circuit tolerance).

Logger-receiver Alarm Circuit

The logger-receiver alarm circuit, which is actuated by microswitches of the recorder signal-measuring servo, is as shown by Fig. 6-12.

If each parameter is not within its alarm set points at the time it is recorded, the

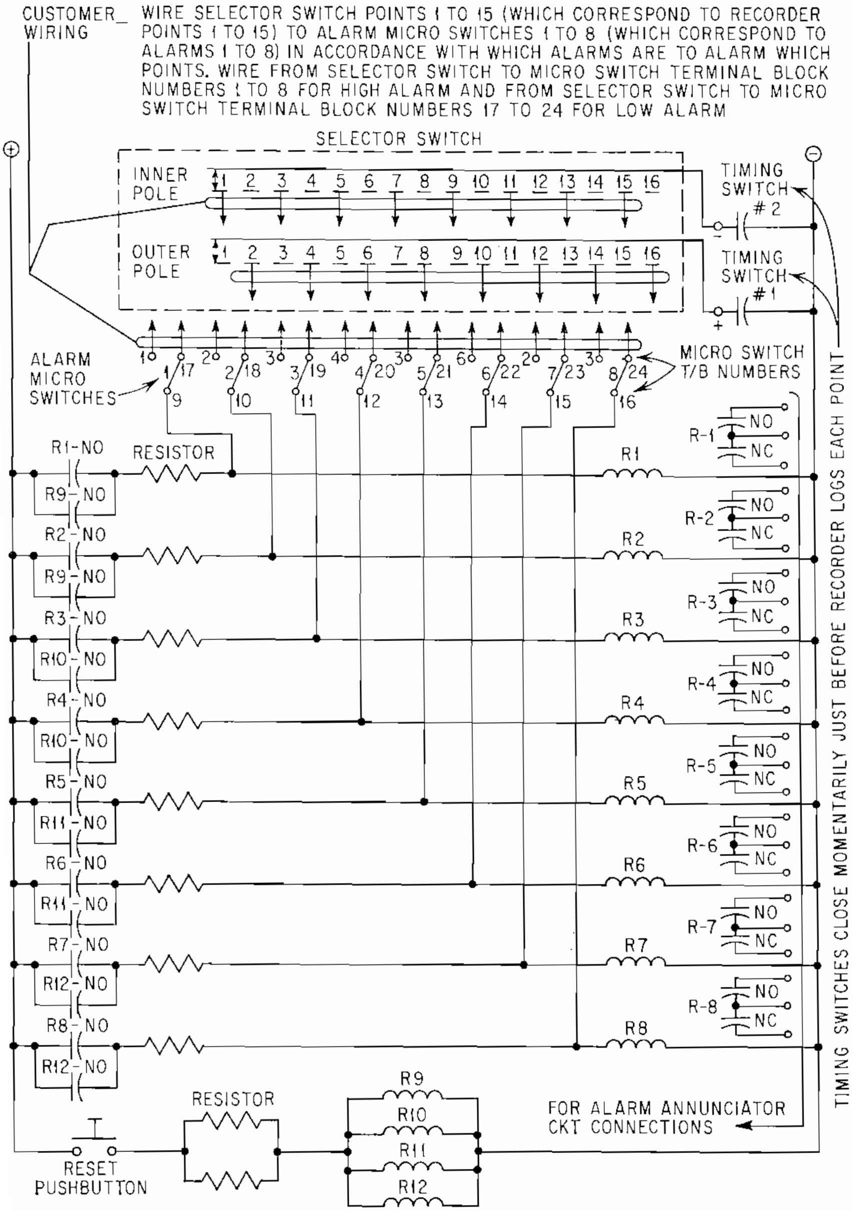


Fig. 6-12. Alarm schematic.

associated alarm relay will momentarily be short-circuited, causing it to drop and lock out.

Reset is accomplished by a manual reset push button, and reset relays and all alarms are reset simultaneously.

Since the alarm-circuit timing switches are closed only during the interval of time that a parameter is actually being recorded, no alarms will occur except when a parameter is out of limits during that interval of time.

Local Operation

Systems can be supplied for a consolidated station as well as for remote transmitters.

CONCLUSION

There are, of course, other types of equipment that can be used to record the varions parameters of a broadcast transmitting plant. The ordinary single-circuit strip chart recorder which has been used extensively in recording field strength can be adapted to this use. However, when more than a few circuits are to be recorded, the use of such equipment could become both expensive and cumbersome and would not have the advantage of having been designed for the job. Although it is known that other manufacturers are developing equipment which will be comparable to that described herein, the Minneapolis-Honeywell automatic equipment is the only type known to be on the market as a complete recording-control system for broadcast stations. It has been installed at WTOP, Washington, D.C., where it records all the FCC requirements of the transmitter log for their 50-kw AM, FM, and television transmitters, and at KFI, Los Angeles, Calif., in conjunction with their 50-kw AM main transmitter and auxiliary.

As a final note, it should be pointed out that as this is being written, *the FCC has not yet changed their rules to permit this equipment to be used in lieu of a manually kept transmitter log*. On this basis, it would be the decision of the stations to utilize it in conjunction with the preseutly required log. There is no doubt that such a recorded log would provide a most accurate indication of the "electronic health" of the equipment with which it can be used. Maintenance of equipment components could be immensely facilitated with such a recorded indication of performance, and undoubtedly the utilization of manpower could be made more efficient. There is no valid reason why such recording and control equipment should not be incorporated in broadcast transmitter operation in lieu of the presently required manually kept transmitter log.

Part 7

CONELRAD

(*CON*trol of *EL*ectromagnetic *RAD*iation)

NAB Engineering Department

BACKGROUND

Before the decision was made to adopt the "pseudo-synchronous-sequential" mode of operation for the CONELRAD system of emergency broadcasting,* a great many possible combinations and procedures were investigated. The utilization of straight synchronous operation of transmitters within a particular city seemed to hold promise of meeting the main criteria of intelligible coverage of the metropolitan area and adequate navigational deception. In investigating the possibilities of common-frequency operation, it was recognized that fairly high sky-wave field limitations would prevail in addition to whatever distortion or "mush" zones were produced.

A fairly substantial amount of information was available on common-frequency operation, most of which was concerned with actual operation of either two standard broadcast stations or one station and its associated booster. For a regular broadcast service, experience had shown that the carrier frequency difference should be less than 1.0 and, preferably, 0.5 cps in order to obtain the full potential benefits of synchronous operation. Study of the resulting distortion produced when the signals from two stations approach the same order of magnitude for varying degrees of modulation and audio phase differences indicated that a ratio of carrier field strengths of 6 db (2 to 1) would not result in objectionable interference even for relatively large audio delays except for the most critical condition when the RF carriers were 180° out of phase. This 2-to-1 ratio for synchronous operation is comparable to the usual 20-to-1 desired-to-undesired ratio commonly used in standard broadcast operation. With this ratio, the effect of audio delays is not particularly important until the delay time becomes

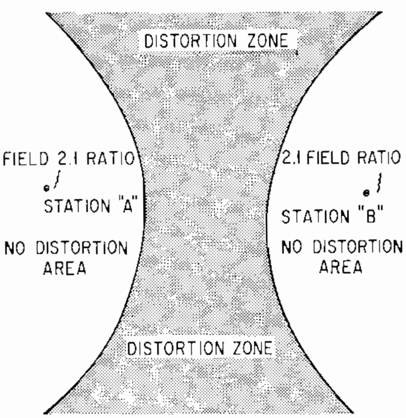


Fig. 7-1. Production of distortion zones, or "mush" areas, by signals from synchronized transmitters arriving 180° out of phase.

* See Ref. 7 under Bibliography on page 8-156.

sufficiently large to produce a noticeable echo. This aspect of the problem was not considered at all important for an emergency system, mainly in view of the improbability of the audio delays reaching such proportions over short lines.

The distortion zones computed using the 2-to-1 ratio of field strengths do not necessarily represent zones of total loss of service (see Fig. 7-1). The distortion actually occurs in narrow bands having the configuration of spherical hyperbolas, which at 1,000 kc are spaced approximately 500 ft apart. These zones are the areas where the signal strengths are of equal values and 180° out of phase, resulting in almost complete cancellation of the carrier. The width of these bands is reduced as the audio delay is reduced and as the field-strength ratio departs from the 1-to-1 value. With reasonable attention to these factors, the distortion bands actually represent only a small percentage of the possible area of distortion. Another factor which tends to discount the importance of these bands is the use of a receiving antenna which has a directivity factor of 6 db in favor of one of the signals.

Intelligibility Standard

The evaluation of these previously mentioned factors from an emergency-system standpoint was then approached. It was considered important that a 100 per cent intelligible signal be present over the entire metropolitan area of our cities so that survival information, such as evacuation instructions, might be received by the general public. Although the previous discussion would indicate that the distortion

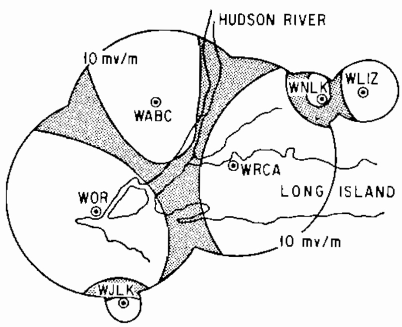


FIG. 7-2. Distortion zones produced by several transmitters operating synchronously.

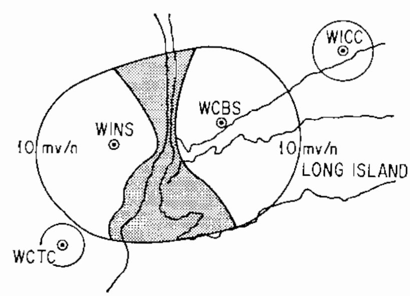


FIG. 7-3. Distortion zones from two stations on 750 kc.

zones for normal broadcast use of synchronous operation were not too serious, it was reasoned that in view of the large number of receivers which use short indoor antennas, the use of the area within the 2-to-1 ratio might be seriously restricted from the criterion of 100 per cent intelligibility. An attempt was made (on paper) to arrange broadcast stations in such a manner that the area encompassed by the distortion zone on one channel would lie either wholly or partly outside the distortion zone of the station arrangement on another channel. The initial attempt at such an arrangement used the frequencies 640, 750, and 870 kc. Actually, before an opportunity was presented to test the system from the standpoint of navigational deception, such an arrangement was completed on paper for all the standard broadcast stations on the eastern seaboard from Maine to Florida. It would be difficult to show a composite of that entire system. However, Figs. 7-2 to 7-4 show the manner of arrangement for one of the cities in the eastern part of the country.

Once consideration was given to other parts of the country, one of the difficulties encountered was the paucity of stations that could possibly be integrated into such a system. Density of standard broadcast stations varies considerably throughout the country, and it was found that almost abruptly first one and then the second channel had to be abandoned for this reason. This left much to be desired from the navigational aspect, for certain groups of stations were more or less left "high and dry" on the periphery of the area of use of the initial or second channel with no appreciable protection. Throughout the consideration of such an arrangement, it was also contemplated that the radiated powers of the various stations might be sufficiently equalized to provide whatever deception was needed with the common type of automatic direction finder used in most aircraft. Such a figure was not available in terms that could be reduced to field ratios. At this point in the development work, it became possible to conduct observations both on the ground and in an aircraft of such a contemplated system. Three standard broadcast stations, WRCA, WABC, and WOR, made the necessary transmitter changes and adjustments to permit rough synchronous operation (±3 or 4 cycles) on 640 kc utilizing a common program source. Unfortunately, equalization of their radiated powers was not feasible on this

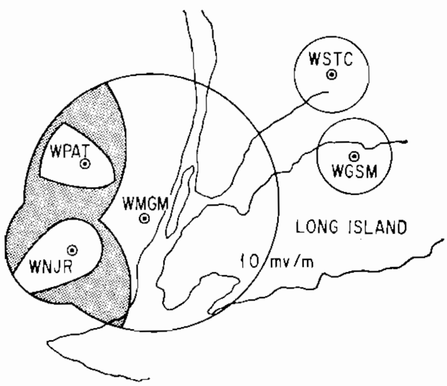


FIG. 7-4. Service areas and distortion zones from five stations.

test. Although both WOR and WABC were using powers in the range from 5 to 10 kw as against about 2 kw at WRCA, the antennas used by the first two stations mentioned were of the auxiliary variety and their efficiencies were quite low. WRCA was able to use its main antenna system for the test with consequent better efficiency.

Intelligible Signal

Observations on the ground showed that for the most part, an acceptable 100 per cent intelligible signal was provided over the areas of metropolitan New York City that could be covered by the mobile units during the test period. An interesting fact brought to light was that the distortion bands inside the 2-to-1 field ratio zones could not be detected by the human ear. It was mentioned earlier that the radio carrier frequencies were not in strict synchronism. This resulted in displacement of the distortion bands at a sufficient velocity that they could not be discerned by listening to ordinary speech. Of course, the beats between the carriers were present, but this did not appear to destroy the intelligibility appreciably.

In the air, observations were commenced from a 15,000-ft altitude at a distance of about 100 miles. A fairly good bearing indication was noted on the aggregate signal from the three stations at that point. This was to be expected in view of the small angle of separation of the stations. It was expected that as the aircraft approached New York City, the azimuth indicator on the ADF would become erratic and inaccurate. A constant check on the position of the aircraft was obtained by means of radar. Instead of becoming erratic, the homing signal became more useful, and the pilot, following instructions of the radio operator-navigator "homed" directly over the antenna system of WRCA as indicated on the radar screen. The route of the aircraft followed the track indicated in Fig. 7-5.

At the point indicated by the circled *X*, the ADF indicator shifted from WRCA to WOR. Subsequent information obtained on the powers and probable antenna efficiencies of the stations involved in this test resulted in calculations of the field ratio of 2 to 1 at the point where the ADF shifted from the control of one station to the other. This value, of course, has no relation to the same figure as it relates to the distortion zones but is a function of the automatic-direction-finder unit itself. Although a 6-db equalization of fields does not appear to be particularly difficult, a closer examination of the various metropolitan areas and the potentialities of their broadcast stations in this respect seemed to urge a further study of other possibilities. The most attractive that came to attention was merely a slight variation of the straight synchronous mode whereby, instead of all the transmitters being on the air continuously with a common program, they would be switched on and off in a random sequence. Such a procedure immediately eliminated any major concern over distortion zones, beats between carriers, equalization of radiated power, or any other such features which tend to complicate a system. Preliminary tests utilizing the same three stations mentioned before gave good ground coverage and in addition made orientation of an aircraft by means of the ADF extremely difficult within any reasonable period of time.

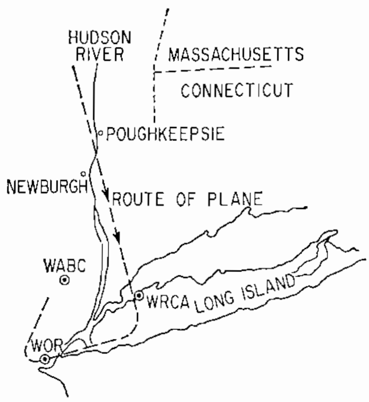


FIG. 7-5. Route of aircraft "homing" on signals from three stations.

Results Confirmed

Subsequent tests using a greater number of stations confirmed the results obtained, not only as to ground coverage but for both long-range and short-range navigational deception. During the past few years, the system has been initiated throughout the entire country, and today there are prepared for instant operation over 200 clusters of stations and approximately 500 single stations in the "on-off" category. Recent developments in the operation of the CONELRAD system seem to indicate that there will be less of the latter type of operation. This appears feasible in view of changes in the aircraft potential from an operational standpoint. Additional stations are being continnously added to the system.

ALERT SYSTEM

Ideally, the perfect alert system for such an emergency arrangement of broadcast stations would be one which instantaneously informed every station that a particular situation was in effect. While there is no technical reason that such a system is not available, the economics up to this time has made it necessary to he satisfied with something less than the perfect system.[1]

Air defense alerts can be initiated by various centers of command throughout the United States, depending upon the situation. It is purposely kept flexible, even though somewhat more complicated, because of the demands imposed upon even a passive defense aspect of the national complex. Basically, the Radio Alert is disseminated through a combination of wire lines to particular *key stations* and thence to other stations via off-the-air pickup by means of normal transmissions. All stations are aware of the particular means whereby the alert is received through information provided by the Federal Communications Commission. *It is the responsibility of each*

[1] An instantaneous type of alert system is now under consideration.

station to be able to obtain the alert signal whenever it is transmitted, either on a test basis or in an actual alert.[2] Should difficulty be experienced in the reception of the alert signal, such stations should immediately notify the appropriate FCC CONELRAD field supervisor, who is obligated to advise the stations of the remedial action to be taken. For obvious reasons, no specific information is given here concerning the actual alerting system for the broadcast service. Each station is aware of its own particular instrnctions, and information applicable to other stations is not pertinent. Those stations receiving information via wire lines are also required to maintain alert receivers as a backup method of receiving the information.

Alert Receivers

The FCC Rules specify that alerting information shall be preceded by carrier breaks followed by the transmission of a 1,000-cycle tone in a specific manner.[3] For convenience of operating personnel, it is important that such an alert receiver be muted for normal periods of operation and that it actually produce an alert signal during either test or actual alert conditions. Various arrangements have been devised to accomplish this. For the information of stations, some of the more satisfactory circuits and operating information applicable to these receivers are provided herein.

General Considerations

In determining the method to be used in an alerting system, consideration of relatively fixed parameters of the broadcasting system had to be taken into account. Theoretically, the use of subaudible, audible, and supersonic frequencies is possible in such an alert signal. The practical aspects, however, have generally precluded the establishment of such systems. The major shortcomings in this area relate to the characteristics of program lines, audio amplifiers, modulators, and the entire audio portion of a broadcasting plant. Frequencies below 20 cps and over 20 kc would be subject to extreme attenuation in passing through the audio equipment of a station, and considerable expense would be involved in making suitable modifications. The installation of additional oscillators would be another economic factor.

The alert method that was established and is still being improved utilizes a combination of carrier breaks and audio tone within the normal passband of both station equipment and ordinary receivers. Several devices have been developed based on those criteria. Essentially they are all variations of the fundamental circuit which makes use of a properly inserted device in the AVC circuit of the receiver and which operates one or more relays to provide the desired visual or audible signal notifying that an alert is being transmitted.

AM Alert Units. As mentioned previously, a great many variations of the fundamental circuit have been devised. No purpose would be served by providing all such modifications. A typical alert attachment device which has been used satisfactorily in conjunction with AM receivers is shown in Fig. 7-6. This was developed by Mr. Robert D. Linx, Federal Communications Commission.

Referring to Fig. 7-6, the receiver is tuned to a station providing the radio-alert signal. A signal voltage from the receiver applied to point *A* is amplified and actuates the plate circuit relay, making contact between points *B* and *C* to light the green light. When the signal voltage is interrupted, owing either to an interruption of the carrier of the alerting station or to failure of the receiver, minimum cnrrent will flow through the coil of the plate circuit relay, causing contact to be made between points *B* and *D*, which will, depending on individual treatment, light the red light or cause an audible alarm to operate.

Any relay designed to work in the plate circuit should be SPDT, with a coil having approximately 3,500 to 5,000 ohms' resistance, and provided with a locking arrange-

[2] See Subpart G, Part 3, Rules of the FCC.
[3] See Subpart G, Part 3, FCC Rules.

ment so that the alarm (or light) will continue to operate until the relay is manually reset.

In some cases, connection can be made directly to the grid of the first or second IF stage. Some experimentation may be required in order to secure maximum plate current variation.

It is suggested that the plate voltages be adjusted so as to provide a relay current of approximately 10 to 12 ma.

Another more elaborate alert attachment has been developed by Mr. David O. Cooper, Federal Communications Commission. Although the circuit is relatively

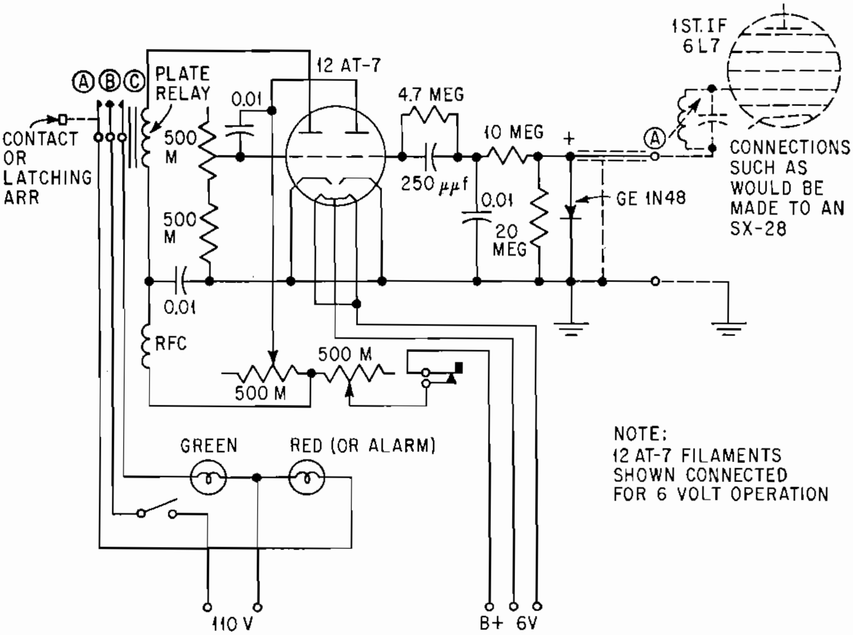
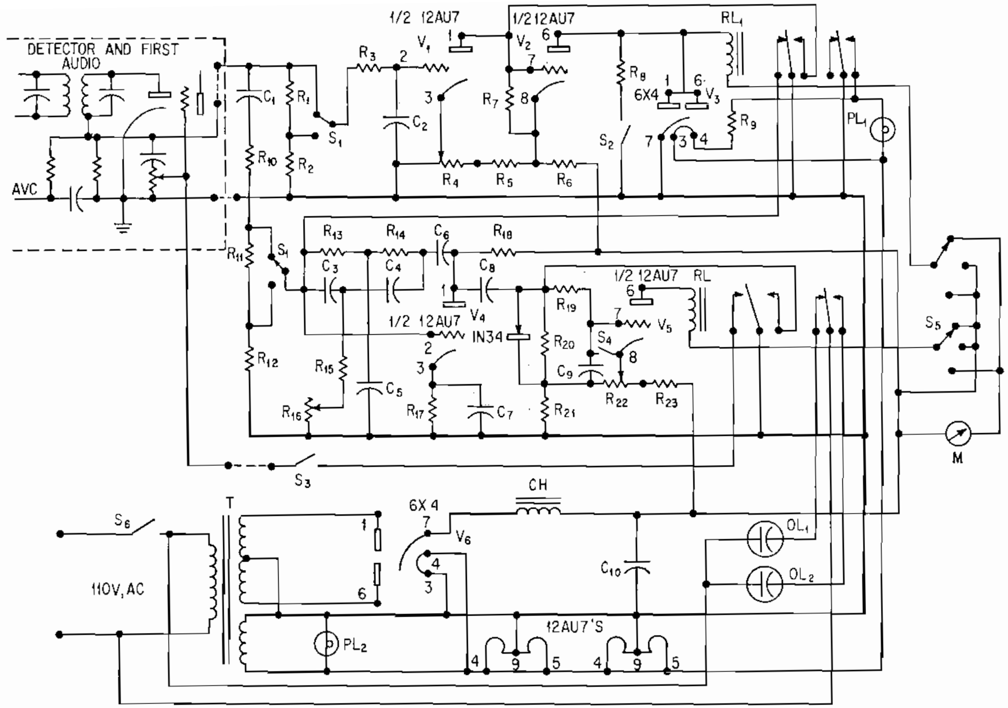


FIG. 7-6. Typical alert device which can be attached to any standard broadcast receiver to provide both a visual and audible alarm when the carrier of the alerting station is interrupted.

simple (see Fig. 7-7), the provisions incorporated in this attachment will appeal to many broadcasters who desire something more than just the basic requirements. In operation, the receiver associated with the attachment will be tuned to a key station but the speaker will be silent.

A clock connected to the 110-volt outlet OL_1 will operate and indicate the correct time. A visual or audible alarm connected to the other 110-volt outlet will not operate, and the red pilot light PL_1 will be off. When the carrier of the key station is interrupted, the red pilot light will come on but the clock will continue to run, the speaker will remain silent, and the alarm will not operate. If a 1,000-cycle tone is broadcast by the key station within 45 sec after the carrier interruption, the clock will stop, indicating the time the alert was received. The speaker will come on, so the 1,000-cycle tone and the alert message can be heard, and the visual or audible alarm will operate. If a 1,000-cycle tone is not broadcast within 45 sec after the carrier interruption, the red pilot light will go out and the circuit will return to normal. A 1,000-cycle tone broadcast at any time other than within 45 sec after a carrier interruption will not affect the alarm.

Connections are made using shielded wire between the alarm and the electrical



R_1, R_{11}, R_{19}—10 Meg, ½ watt
R_2, R_3, R_{10}, R_{12}—3.3 Meg, ½ watt
R_4, R_{22}—1,000-ohm control
R_5—8.2 K, 2 watts
R_6, R_{23}—27 K, 2 watts
R_7—270 K, ½ watt
R_8—18 K, 2 watts
R_9—7.5 ohm, 2 watts
R_{13}, R_{14}—160 K, ½ watt
R_{15}—22 K, ½ watt
R_{16}—10 K control
R_{17}, R_{21}—1.5 K, ½ watt
R_{18}—47 K, 1 watt
R_{20}—470 K, ½ watt
C_1, C_8—0.01, 400 volts
C_2—0.05, 400 volts
C_3, C_4—0.001; C_5—0.003 mic
C_6—0.1, 400 volts
C_7—25, 25 volts
C_9—0.25, 400 volts
C_{10}—10, 450 volts
S_1—rotary switch, 2 pole, 2 position
S_2, S_4, push-button switch
S_3, S_6, slide switch
S_5—rotary switch, 2 pole, 3 position
PL_1, PL_2—6.3-volt pilot light
OL_1, OL_2—110-volt outlets
M—meter, 0–10 ma
T—power transformer, Stancor PC8418 (460 VCT at 50 ma; 6.3 volts at 2.5 amp)
CH—filter choke, Stancor C-1003 (16 H at 50 ma; 580 ohms)
RL_1, RL_2—relay, Potter Brumfield LM-11 (5,000-ohm coil: DPDT contacts)

FIG. 7-7. More elaborate alert unit circuit used with any standard broadcast receiver.

ground, AVC, and grid of the first audio of the associated receiver. These connections can be made conveniently by use of a three-way plug. If the alarm is to be used in a weak signal area, the associated receiver should have good selectivity and sensitivity and be provided with an antenna located as far as practicable from sources of local interference.[4]

Resistor R_7 is a plate load for triode V_1 and a grid bias resistor for V_2. The voltage drop across R_7 caused by the plate current in V_1 is applied as a grid bias to V_2. When the receiver is tuned to a key station, maximum AVC voltage will be applied as grid bias to V_1; minimum current will flow in R_7, applying minimum bias to the grid of V_2; and maximnm plate current will flow in V_2, closing relay RL_1.

R_4 controls the fixed bias on V_1 and should be adjusted so that relay RL_1 will remain closed when the receiver is tuned to the key station but will open when the carrier is interrupted. In weak signal areas, it may be advantageous to increase C_2 to 0.25 μf in order to increase the time constant of the R_3, C_2 circuit. This will smooth out variations in the AVC voltage due to fast fading and reduce the number of false alarms.

When the carrier of the key station is interrupted, the AVC voltage is reduced to minimum, the plate current increases in V_1 and rednces in V_2, and relay RL_1 opens. When RL_1 opens, the gronnd is removed from the input to the 1,000-cycle amplifier, making this circuit operational. The grid of V_2 is grounded, holding relay RL_1 open; the pilot light PL_1 comes on; and the filament of the rectifier V_3 heats np.

Relay RL_1 can be manually reset by momentarily closing the push-button switch S_1. The conduction of current through the rectifier V_3 has the same effect as closing S_1. The normal time required for V_3 to heat up and start conducting is increased to 45 sec by inserting R_8 in the filament circuit. Thus, 45 sec after RL_1 opens, it will automatically reclose. When RL_1 closes, the filament circuit is opened and the rectifier cools.

Triode V_4 has a parallel-T network connected as a feedback circuit between its plate and grid and becomes a sharply tuned 1,000-cycle amplifier, the frequency of which can be changed within narrow limits to the exact frequency of the tone broadcast by the key station by adjusting R_{14}. Relay RL_1 will remain open for 45 sec following any carrier interruption. During this time the audio signal from the receiver is applied through C_1 to the 1,000-cycle amplifier, the output of which is rectified by the 1N34 crystal diode and applied as a negative voltage through the time-delay circuit R_{19}, C_9 to the grid of V. Normal program voltage occurs across R_{20}. These fluctuations are smoothed out by the R_{19}, C_9 circuit, and the average value is applied to the grid of V_5. R_{22} is adjusted so that RL_2 remains closed when RL_1 is open and normal program is being received. A sustained 1,000-cycle tone received during the time RL_1 is open will build up a negative bias on the grid of V_5 sufficient to open relay RL_2.

When RL_2 opens, the voltage across R_{21} is applied to the grid of V_5, biasing the tube to cutoff and holding RL_2 open. The ground is lifted from the grid of the first audio of the associated receiver, causing the loudspeaker to come on; the circuit to the 110-volt outlet OL_1 is opened, causing the clock to stop; and the circuit to OL_2 is closed, thus operating the visual or audible alarm.

Relay RL_2 will remain open until the reset push-button switch S_4 is momentarily closed, shorting the grid of V_5 to its cathode, discharging condenser C_9, and causing maximum plate cnrrent to flow through the relay.

The meter switch S_5 should be a shorting-type switch so the plate circuit of either V_2 or V_5 will not be momentarily opened when the meter is switched in or out of these circuits. When in series with RL_1, the meter can be used as a signal-strength meter to aid in tnning the receiver accurately to the key station.

The "local-distant" switch S_1 cau be omitted, and the circuit connected permanently for either local or distant station operation. For most installations, the circuit should be connected for distant reception with S_1 in the position shown in the diagram. If the receiver is very close to the key-station transmitter, improved operation will be obtained by reducing the signal input to both the d-c amplifier and the 1,000-cycle amplifier by connecting the circuit as it would be with S_1 in the lower or local position.

[4] Refer to information later in this part.

Still referring to Fig. 7-7, the resistor R_6 acts as a plate load for triode V_1 and as a grid bias resistor for triode V_2. The voltage across R_6 caused by the plate current in V_1 is applied as a grid bias to V_2. When the associated receiver is tuned to the key station, V_1 is biased to minimum plate current by the AVC voltage. A minimum bias is therefore applied to V_2, and a maximum current will flow in the plate circuit, energizing the relay. With the relay and S_2 closed, the grid of the first audio is shorted to ground, muting the speaker; the 110-volt outlet OL_1 is on, so the clock will run; and OL_2 is off, so a lamp or audible alarm plugged into this outlet will be off. The speaker can be operated at any time without affecting the circuit adjustment by opening S_2.

When the carrier of the key station is interrupted, the AVC voltage is reduced to minimum, the plate current increases in V_1 and reduces in V_2, and the relay opens. When the relay opens, the ground is removed from the grid of the first audio and the speaker operates, the clock stops, and the alarm light or bell goes on. In addition, the grid of V_2 is grounded, causing maximum current to flow in R_6 and minimum plate current in the relay, locking it out regardless of the control voltage at the grid of V_1.

The push-button switch S_1 is normally open. When it is momentarily closed, the relay closes, lifting the ground from the grid of V_2, and the circuit is back to normal.

R_3 controls the fixed bias on V_1. On strong local signals, it can be eliminated and the cathode of V_1 can be connected directly to ground, as the AVC voltage will be great enough to bias V_1 to cutoff. On weaker signals, R_3 should be adjusted to a point where the relay will remain closed when the receiver is tuned to the key station but will open when the carrier is interrupted. On weak signals it may also be advantageous to increase C_1 from 0.05 to 0.25 mf. This will smooth out variations in input signal and eliminate some operations due to fading.

FM Alert Unit. Another alert attachment which has been used with considerable satisfaction in conjunction with FM receivers and tuners was developed by Mr. Philip Whitney, chief engineer, WINC, Winchester, Va. The circuit shown in Fig. 7-8 will monitor any FM station for "carrier-off" condition by ringing a bell or lighting a warning flasher at the operating or control positions.

The audio output of the tuner can be applied to a 1,000-cycle filter circuit and relay control for the tone warning circuit. A 6,500-ohm plate relay is used, but most types of plate relays up to 10,000 ohms are satisfactory.

Negative voltage developed in the discriminator stage of this particular tuner keeps the 6C4 relay control tube biased to cutoff. The critical point can be reached by adjustment of the sensitivity control. It was found that in the WINC application this control was not needed but may be of advantage in some installations. It may be necessary in some remote locations to use a booster ahead of the tuner. Thus, a station 75 miles away can be monitored consistently. (It helps, of course, to use an efficient antenna.)

The relay and control tubes were mounted on the tuner chassis. An outlet plug on the rear of the chassis was utilized for the warning contact terminals. A 100-watt light above the operator at the control position increases room lighting perceptibly when the carrier of the monitored station is interrupted. This immediately attracts his attention and does not interfere with an open microphone.

The filter condenser across the negative voltage supply was eliminated to reduce the time constant of the circuit. If needed, a 0.1- to 0.5-μf capacitor (paper) can be installed across the relay coil to prevent chatter.

This attachment could also be utilized in the FM audio section of a television receiver should it be appropriate to utilize a TV station for the alert monitoring function.

Special antennas for FM reception can be constructed whenever necessary for reliable reception of a more distant FM station. Such antennas can be of the Yagi type, phased arrays, V or rhombic antennas, or low-band VHF television receiving antennas, which in most instances perform quite satisfactorily.

Commercial Equipment Available. In addition to the "home-brew" type of alert equipment, there are several commercially available attachment and entire receiver alert systems. In the attachment field, Heathkit's model CA-1 connects to the usual

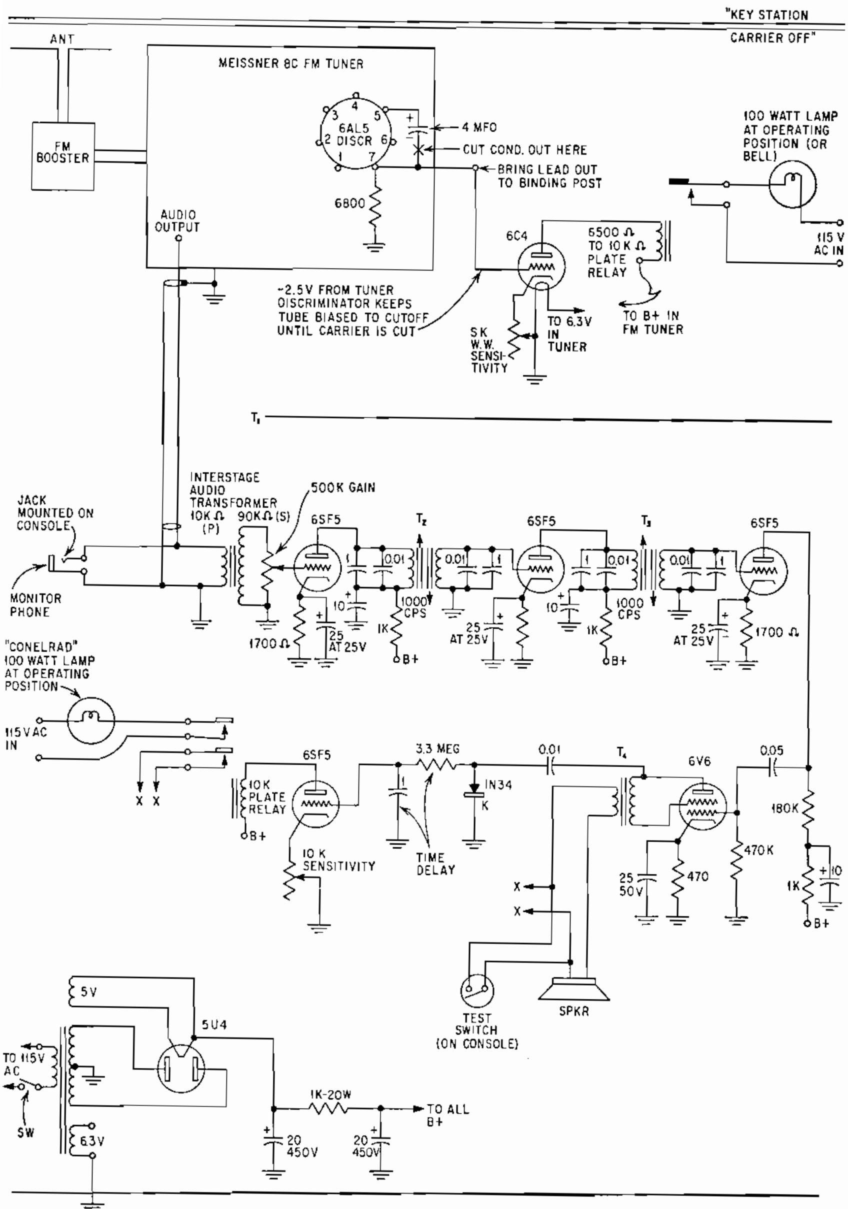


Fig. 7-8. Circuit of alert unit used with an FM tuner or receiver. T_2 and T_3 are surplus Hammarlund coils from the "Fleet Control" units. They normally tune from 3,000 to 6,000 cps with the 0.01-μf condensers contained inside the cans. They resonate at 1,000 cps when a 0.1-μf condenser is added. T_4 is a "garden variety" of output transformer.

AVC system in an ordinary receiver. It can be used on an a-c–d-c type receiver as well as others.

The following is a partial list of CONELRAD alert receivers which are on the market today.

Brand Designation	*Manufacturer*
AMECO	American Electronics Co., New York
Paul Revere	Allen B. Dumont Laboratories Inc., Mobile Communications Dept., Clifton, N.Y.
CONALERT II	Kaar Engineering Corp., 2995 Middlefield Road, Palo Alto, Calif.
Air Alert I	Miratel, 1080 Dionne St., St. Paul, Minn.
Air Alert II	Same
Moradco CONELRAD monitor	Morrow Radio Mfg. Co., P.O. Box 1627, Salem, Ore.
CONELRAD monitor, desk type DS9661-B, rack mount DS9660-B	Motorola Communications and Electronics Inc., 4501 W. Augusta Blvd., Chicago 51, Ill.
CONELRAD receiver, type CR-17B	Radio Corporation of America, Camden, N.J.

Special Reception Techniques

In certain instances either where stations are at a critical distance from another station or where receiving conditions are generally difficult by reason of directional operation, atmospherics, etc., extraordinary means are sometimes necessary to ensure the reception of the alert signal from another station. The Federal Communications Commission has provided information concerning the use of special receiving antennas which are applicable for such purposes.[5] The application of this information, in many situations, will enable satisfactory reception of stations which ordinarily are completely unintelligible.

Shielding and Filtering

In cases where applicable, it is advisable to locate the antenna as far from a source of interference (or radio transmitter antenna) as possible and use coaxial or shielded transmission line to the receiver input terminals. In extreme cases, the receiver itself may have to be enclosed in a shielded box with appropriate filtering and bypassing of power leads in order to eliminate the possible effect of high RF fields on the reception of the desired signal. The antenna transmission line to the receiver may have to incorporate trap circuits to filter out the local transmitter radiation. For low-impedance receiver input, the trap circuit may be a parallel-resonant trap connected in series with the inner conductor of the coaxial. For high-impedance receiver input, the trap will perform most satisfactorily if connected directly across the input terminals, tuned to the frequency of the local station. Sometimes, both traps are required when the local RF field is high and/or when the cross-modulation products produced in a superheterodyne receiver cause adverse reception effects or when the undesired radiation is on a different frequency from the desired.

Loop Antenna

When the desired and undesired stations are on the same or very nearly the same frequencies, a directional antenna is often necessary. Such an antenna is also necessary in areas of weak signal strength from the desired station. A simple type of such antenna is the loop antenna, which is of maximum effectiveness only when the signals under consideration are within the ground-wave area. When this antenna is used, the null (obtained broadside to the plane of the loop) is oriented toward the undesired

[5] From an FCC memorandum by Benjamin Wolf and Adolph Anderson.

station. Maximum voltage is induced in the loop when the plane of the loop points toward the desired station. Since the antenna is bidirectional, a station on the back side may produce sufficient signal to cause interference, in which case a more elaborate directional receiving antenna may be required (see Fig. 7-9).

Beverage, or "Wave," Antenna

A very effective receiving directional antenna is the Beverage type. The theory of this antenna has been well covered in texts for many years and is not included here. Among the desirable properties of the Beverage, or the "wave," antenna for reception are:

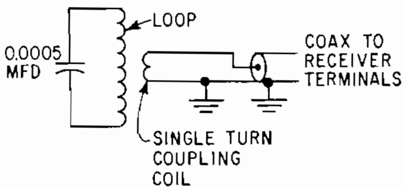


FIG. 7-9. Simplified schematic of a loop antenna with construction details. *Loop dimensions:* 13 turns of #20 wire wound on a 12-in. square form, with ⅛ in. spacing between turns. The coupling coil is a single turn wound inside the loop and spaced approximately 1 in. from the loop. The mechanical mounting is optional, but for best results the loop should be mounted in the clear and away from metallic objects. Experiments with various turns in the coupling coil and using a coaxial cable from the loop to the receiver might prove beneficial. Shielding the loop is important in direction-finding work but is not important for ordinary reception.

1. It delivers a stronger signal over the entire standard broadcast band than a good simple antenna of the single-wire variety.
2. When terminated, it is unidirectional but can be used as a bidirectional antenna either by switching the termination or by being unterminated.
3. Atmospherics and industrial interference are considerably reduced, especially when the source is in a direction other than that of the main lobe of the antenna.
4. The antenna is low in cost, has long life, and is usually easy and simple to erect provided the space is available.

Length. The optimum length for a broadcast band "wave" antenna is approximately 1,800 ft. This length delivers peak signal strength at close to 550 kc and again at one-half its wavelength in meters, or about 1,100 kc. The peaks are, however, rather broad, and the signal delivered is considerably stronger than that from a good simple antenna throughout the entire band. Near the antenna peaks, the increase in microvolts to a receiver may reach more than 400 per cent.

Whereas space is a consideration, the length can be reduced to 1,400 or even 1,000 ft, but the signal-strength delivery and directivity will be proportionately reduced, and at less than 1,000 ft the slight advantage of a wave antenna for the broadcast band over a good simple antenna does not warrant its erection.[6]

Conductor Height. The surge impedance of the wave antenna is determined by its height above the ground and by soil conditions in respect to moisture, etc. If the conductors are erected at a minimum of 10 ft above the ground, the surge impedance remains more nearly constant during all seasons than when they are erected at a lower height. If they are erected at a height greater than 15 ft, the pickup of the vertical leads at the far and near terminals may considerably reduce directive properties. If a greater height is required at gates or other passages, the higher poles should be erected at the sides of the opening and the conductors brought down vertically, proceeding at the selected height after the high point has been bridged. Reasonably uniform height of the conductors throughout their length is, of course, preferable.

Pole Erection. The standard practice of telephone-line construction is followed. The poles should be spaced approximately 100 ft apart, and for mechanical strength the conductors should be No. 12 B & S hard-drawn copper or copperweld. The line should generally follow the earth's contour, but small knolls are disregarded, and the

[6] Instances are known where ordinary Signal Corps field telephone wire strung out across trees and bushes provided a considerable increase in received field strength with a length of wire less than 1,000 ft.

tops of the poles after planting can be trimmed for general or even grading of the conductors.

For single, unidirectional reception or single-conductor antennas, the conductor can be mounted on ordinary pole brackets attached to the poles.

For unidirectional reception from front or rear or both, the two-conductor type of construction is required. The conductors are mounted on short, standard cross arms without braces, with the locust insulator pins spaced 16 in. between centers. This, with ordinary telephone-line glass insulator, gives the desired or adopted 18-in. spacing of conductors of the finished antenna.

Grounds. For maximum efficiency the resistance of the ground system at both the far and near ends of the antenna should approach zero or at least be less than 30 ohms. The ground resistance is best determined by the voltmeter-ammeter alternating-current method, but reasonably satisfactory results can be obtained by the use of the battery and voltmeter voltage-drop method.[7]

For measurement of a single ground, the planted conductors are divided into equal halves and measured and the result divided by 2 or the far and near terminal resistances measured through the antenna conductors for the combined resistance of the two terminals or the series resistance of the entire system.

If the voltage-drop method of measurement is used and should polarization or other direct-current effects produce absurd readings such as negative resistance, a resistance of 100 ohms or more can be placed in series with the circuit and two measurements taken with changed polarity. The average of the two recorded values divided by 2 in the case of a divided system less the added external resistance can then be considered a reasonable approach to the actual resistance. Because of polarization, readings of instruments should be taken at the moment of contact.

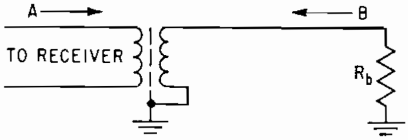


FIG. 7-10. Single-conductor Beverage antenna for forward reception.

In respect to the diagrams contained in Figs. 7-10 to 7-12, all factors are the same as the single-conductor type except that the surge impedance will be lower as a result of the two conductors in parallel. In reception, the signal builds up until it reaches *B*, where the phase is reversed by grounding one of the conductors and leaving the other free, after which it is reflected back to *T*, using the antenna conductors as an untransposed transmission line. The signals from the *B* direction are dissipated either completely or partially in impedance *R* connected from the center tap of *T* to ground. It will be noted that Figs. 7-10 and 7-11 are the same except with respect to far and near terminal connections. When it is changed as shown, the antenna can be made unidirectional for either forward or rear reception but not for both forward and rear reception simultaneously.

When the wavelength of the signal to be rejected is a multiple of one-half wave of the length of the antenna, it is either completely or largely absorbed in resistances R_b or R_n. Odd multiple frequencies of one-quarter wavelength of the antenna length deliver a greater residual or undesired signal to the receiver.

In order to balance out an undesired signal originating at an angle of more than 90° from the source of a desired signal originating in the direction of maximum reception of the antenna, a part of the undesired signal is reflected back to *T* in proper phase and magnitude to cancel itself out. This is accomplished by the insertion of a tuned circuit in series with a variable resistor at the far terminal, as in Fig. 7-13 for rear-signal rejection and as in Fig. 7-14 for forward-signal rejection.

[7] Normal considerations for obtaining low-resistance ground connections apply equally for receiving antennas. For a permanent installation requiring high efficiency, probably a buried ground radial system would be the most satisfactory.

Techniques have been developed to utilize the Beverage antenna for simultaneous reception in both the forward and backward directions on a unidirectional basis on either the same or different frequencies in the broadcast band. Such an application is not usual and probably would never be required in the reception of a key station in the CONELRAD system.

Transmission Lines. Transmission lines between the coupling and impedance matching devices should be coaxial cable.[8] It is unimportant whether they be 50 or

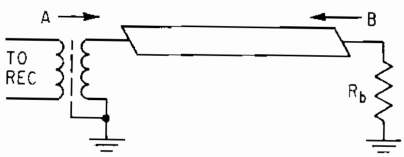


FIG. 7-11. Two-conductor Beverage antenna for forward reception.

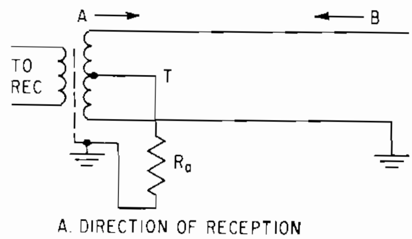


FIG. 7-12. Two-conductor Beverage antenna for rear reception.

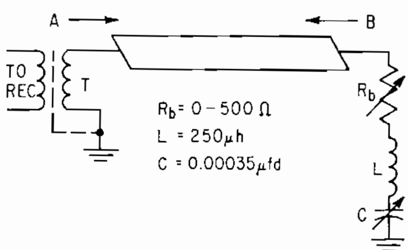


FIG. 7-13. Two-conductor Beverage antenna for forward reception with interference cancellation circuit.

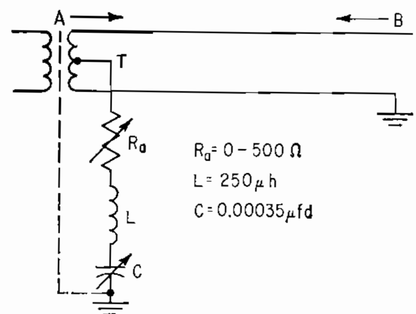


FIG. 7-14. Two-conductor Beverage antenna for rear reception with interference cancellation circuit.

75 ohms or even a higher impedance because the matching can take place regardless of the value of the transmission-line impedance. A convenient method of checking impedance matching would be to shock-excite the antenna with a local oscillator of a few watts power (or perhaps use the local broadcast station) and use an impedance bridge of the VSWR type, which can serve as an accurate check on matching and over-all adjustment of the antenna. A bridge of relatively high sensitivity should be used which would indicate values of current in the microampere range. In most cases with ordinary communications-type receivers, a satisfactory match to the receiver itself will occur without a matching transformer between the coaxial line and the receiver input terminals. Should this not be the case, a simple π-network coupler could be inserted.

Lightning Protection. Lightning protection to such an antenna will be found necessary. Rather high voltages can also be built up on the antenna during dust or snow storms, etc., when static potentials of several hundred volts will occur. Such voltages are apt to open the terminating resistors of the antenna. Therefore, if the

[8] From purely an operational standpoint, RG58 or RG59 coaxial cable would be satisfactory. However, the heavier types such as RG-8 or RG-11 would be mechanically more suitable and would provide more satisfactory over-all operation.

operation of the antenna should appear changed subsequent to a storm, those resistors should be checked for an "open." Ordinary inert-gas type of lightning arresters will be found satisfactory and should be inserted at both the near and far ends of the antenna itself. In some instances, it may be wise to take further precautions within the transmission lines, depending on their length and method of installation from the matching point to the receiver. Such coaxial-line lightning arresters are commercially available and can be adjusted to flash over at a relatively low voltage.

TRANSMITTER OPERATION ON CONELRAD CHANNELS

In the early stages of CONELRAD operation, a great many stations built composite transmitters of usually lower power than the licensed value of the main transmitter. Such transmitters enabled a quick shift to the assigned CONELRAD channel for emergency purposes. Difficulties in obtaining satisfactory coverage, particularly in the larger metropolitan areas, soon indicated that such lower power transmitters were not adequate for the type of emergency coverage required.

Various engineers throughout the country made conversions of existing transmitters to enable them to operate on the normal licensed frequency and on either 640 or 1,240 kc, whichever was assigned the station. The following information was submitted by station engineers to the Federal Communications Commission, who has made it available for reproduction.

Transmitter: Collins Type 20T, 1 Kw

Frequency Change: 1,600 to 1,240 Kc

Submitted by Radio Station KASH

This transmitter can be operated on the CONELRAD channel specified by insertion of the appropriate crystal and oven assembly and following the tuning procedure provided by the manufacturer. In this instance, no antenna tuning changes were required with a single tower, which resulted in a measured field strength of 120 mv/m at 0.75 mile with a power output of 500 watts.

Transmitter: Gates, Type BC-1-F, 1 Kw

Frequency Change: 1,150 to 1,240 Kc

Submitted by Radio Station KBKH

The 1,240-kc CONELRAD crystal is installed in the "spare" position. To retune the transmitter to 1,240 kc the filaments of the transmitter were first turned on; this also applies plate voltage to the oscillator and buffer (807) stages.

For operation on 1,240 kc it is necessary to screw out the slug in the oscillator plate inductance to make the crystal oscillate. The plate circuit of the 807 is then tuned to resonance.

The crystal trimmer and the oscillator plate inductance are adjusted so as to obtain a zero beat with the 1,240-kc signal from a nearby broadcast station. A small set-screw-type knob placed on the plate inductance screw makes it much easier to adjust.

Once the preliminary stages are tuned up, a plate lead to one of the 872's is disconnected, thus applying only half voltage on the amplifier tubes for tuning up the rest of the transmitter. The driver stage is easily tuned, but tuning of the final amplifier requires changing the tap on the tank coil to a marked position which has been previously determined.

In some cases it might be necessary to change the fixed tank condenser as well in order to tune the final amplifier to 1,240 kc. After the transmitter was tuned up the first time on 1,240 kc, readings of all tuning controls were noted in order to permit fast change-over in the future. Owing to the fact, however, that the oscillator plate inductance is not calibrated, it is necessary to zero-beat the 1,240-kc crystal each time that the frequency is shifted, and a receiver should be available for this purpose.

Transmitter: Raytheon, Type RA-250-A, 250 Watts

Frequency Change: 1,340 to 640 Kc

Submitted by Radio Station KIHR

This transmitter consists of a 6J5 crystal oscillator, an 807 first RF amplifier, an 813 second RF amplifier, and push-pull 810's in the final RF amplifier.

The plate circuits of the 6J5 and the 807 are broadband untuned, so that additional capacitance is required across both plate coils. This was secured by mounting two 0- to 250-$\mu\mu$f variable condensers on a board, with attached leads about 2 ft long terminated with alligator clips. When in use, this unit is placed on top of the power transformer and the leads clipped onto the proper circuits. At resonance, adequate grid drive is provided for the 813 stage (the 640-kc crystal is left in the "spare" holder at all times).

The changes required to resonate the final amplifier tank circuit on 640 kc would be quite involved, so it was decided to use the 813 as the final amplifier for CONELRAD operation. To secure a modulated voltage on the plate of the 813, the plate caps of the 810's are removed and a clip lead is tapped onto the center of the 810 tank and brought down to the plate cap of the 813 (the regular plate cap lead of the 813 is, of course, left off).

A surplus antenna tuning unit (BC-306A) was modified to serve as an external π-network type of tank circuit, which was coupled directly to the plate of the 813 through a blocking condenser. This circuit also served to match the output to a 330-ft-long wire antenna used for CONELRAD operation.

The modulated signal from the transmitter operating in this manner, of course, is not of broadcast quality, since only the plate of the 813 is being modulated (this could be improved by applying the modulated plate voltage through a proper dropping resistor to the screen of the 813 as well).

When in operation, the external tuning unit is placed behind the transmitter and a lead run through the ventilating louvre in the door to the 813 tank circuit.

Transmitter: Collins, Type 21B, 5 Kw

Frequency Change: 1,150 to 1,240 Kc

Submitted by Radio Station KFJI

For CONELRAD operation an external oscillator operating on 1,240 kc is used. A switch is installed in the exciter bay to switch from the regular (1,150-kc) oscillator to the external (1,240-kc) oscillator. To change frequency for CONELRAD operation the procedure is as follows:

1. Push the plate on-off switch to cut the carrier.
2. If applicable, change the antenna from directional to nondirectional.
3. Turn on the external (1,240-kc) oscillator.
4. Throw the switch to feed the output of the external oscillator to the input of the first buffer amplifier.
5. Change the tap on the buffer plate tank coil located in the rear of the exciter bay on the back of the front panel. Move the tap up one turn so lower 14 turns are shorted out.
6. Change the tap on the final amplifier grid tank coil located in the rear of the exciter bay on the upper right-hand side. Move the tap 2 turns toward the front of the bay, leaving 25 turns in the circuit.
7. Change the tap on the final power-amplifier plate tank coil, which is reached

from the front of the final bay and is the inductance at the top of the bay. Move the tap two turns to the right, leaving 23 turns in the circuit.

8. Place the TUNE-HI-LO switch in the TUNE position and the exciter bay meter switch in the BUFFER CATHODE and TUNE position. Pull the plate on-off switch to turn on the intermediate voltage and tune for *minimum* on the test meter.

9. Place the exciter bay meter switch in the INT. AMP. GRID and TUNE position and tune for minimum intermediate amplifier plate current.

10. Place the TUNE-HI-LO switch in the LO position, and tune the final amplifier in the normal manner for minimum plate current. It will be necessary to increase the loading some so as to be able to tune the final amplifier properly.

The antenna has a resistance of 80 ohms at 1,150 kc. With no change in the antenna tuning, an antenna current of a little over 2 amp was obtained on 1,240 kc.

Transmitter: RCA, Type BTA-1-L, 1 Kw

Frequency Change: 590 to 640 Kc

Submitted by Radio Station KUGN

The following is a copy of the instructions posted for the station operators:

1. Turn off the plate switches on both the power amplifier and the exciter.
2. Turn off the frequency monitor and phase monitor, and switch to nondirectional.

After doing this you are ready to start the tuning procedure.

Go to the rear of the transmitter and open the doors of both the exciter and the power-amplifier unit. Start with the exciter, remove the 590-kc crystal from the socket in the oscillator unit, and install the 640-kc crystal. Put the 590-kc crystal in the crystal holder in the rear of the chassis to keep it warm. Next, turn the black knob on the 1-*L*-11 (upper left-hand corner) six turns counterclockwise. After doing this, close the doors on the exciter and go to the power-amplifier unit. There is only one change in the power amplifier—move the clip on the top of *L*-7 down five turns; then move the clip on the bottom of *L*-7 up five turns. This completes all changes in the rear of the transmitter, so be sure that all doors are closed.

Then go to the front of the transmitter and make the following dial settings:

Control	640 *kc*	590 *kc*
Buffer	57.5	38.1
Power amplifier neutralization	70.6	54.5
Power amplifier plate	50.1	33.6
Loading	50.0	42.0
Power amplifier plate (final)	33.1	39.1
Power	Maximum I_p [a]	Rated output

[a] In some cases this may be too much plate input. If this is the case, adjust the output until the input to the 833's is approximately 600 ma.

Now apply plate voltages to both units in the normal manner, and everything should be just about normal except for the plate voltage and plate current on the final. The current will be about 470 ma, and the plate voltage will be about 2,400 volts. After you are satisfied that all is well with the transmitter, go over to the modulation monitor, tune for the maximum on the carrier meter, and then adjust the carrier level in the normal manner. All should be in readiness, then, for CONELRAD operation.

Transmitter: RCA, Type BTA-10-F, 10 Kw

Frequency Change: 1,090 to 1,240 Kc

Submitted by Radio Station KING

It was unnecessary to change any of the transmitter components in order to shift frequency for CONELRAD operations.

The transmitter contains two separate crystal oscillators, one of which is maintained ready for operation on 1,240 kc. The oscillators are changed by pressing oscillator switch S-2, which operates relay *E*-1 to select the proper crystal. The buffer tank coil *L*-4, the driver neutralizing coil *L*-6, and the driver tank coil *L*-7 are rotated to predetermined positions (marked on coil) to resonate at 1,240 kc.

The final tank coil (*L*-13 and *L*-16 in series) is motor-operated and is all set so that when the motor hits the mechanical stop, the coil is resonated on 1,240 kc. This output circuit is a π network designed to work into a 70-ohm load on the licensed frequency.

The phasing unit feeding three towers is bypassed by lifting a switch to one of the towers and connecting the transmitter output to the transmission line for that tower. This is accomplished by moving two clips. The tower is tuned by moving two clips on a T-net matching network to predetermined positions.

The complete change requires only 5 min.

Transmitter: Western Electric, Type 355-E-1

Frequency Change: 560 to 640 Kc

Submitted by Radio Station KPQ

The oscillator in this transmitter is a WE 700-C plug-in type. A separate oscillator unit containing a 640-kc crystal is used for CONELRAD operation.

The first amplifier is untuned, and no change is required when switching to 640 kc.

In order to retune the second amplifier it is necessary to change the fixed capacitance, C-43A, to a slightly lower value (0.00025 mf). After making this change, it was possible to tune this stage to 560 kc by means of normal tuning controls.

The third amplifier is tuned to both frequencies without any changes being made, and since the grid circuit of the 343-A's is an integral part of the third tank, it should not be retuned. Hence, a change of C-18A on the front panel is all that is necessary to obtain grid drive to the final.

Retuning the final tank requires opening the doors and shifting the tank coil clips of L-1D inward two turns on each end to marked points. This makes it possible to resonate the circuit by means of the front-panel loop adjustment.

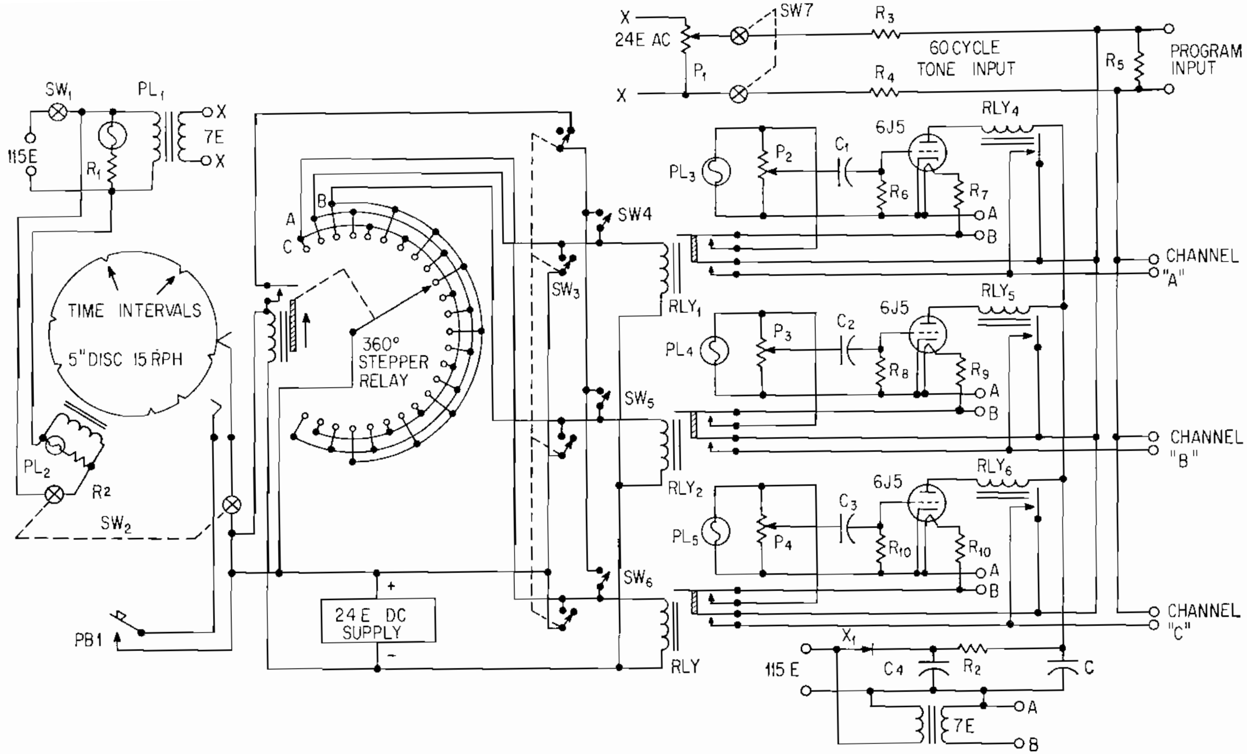
Reloading and retuning the antenna were accomplished by inserting a condenser in series with the nondirectional-antenna lead-in in the phase cabinet. The value of this condenser is such as to make the reflected load down the line look O.K. to the mismatched loading circuit.[9] In this instance a 0.0006-mf condenser was used; thus, in changing frequency it is not necessary to shift either the load adjustment or the antenna matching tuning.

The total cost for the CONELRAD conversion is about $46, plus about $125 for the additional oscillator unit if required.

SEQUENTIAL SWITCHING OF TRANSMITTERS

In the cluster mode of operation, transmitters are switched on and off automatically with practically a "no-repeat" sequence of operation. One such switcher has been designed and built by Mr. Ross Beville, vice-president for engineering, WWDC Inc., Washington, D.C. This switch, shown in Fig. 7-15, will presently handle three channels but can be extended to more if necessary. Six stations could be handled by paralleling two on each channel. The time disc shown on the drawing does not show the actual time intervals but has been constructed so as to vary the interval that each station will be on the air from 6 to 40 sec. The switch has been constructed so that it will run unattended for 1 hr 40 min before beginning to repeat the sequence. Manual operation of the stepper is provided in the operation of a push button appearing on the front panel and labeled PBI in Fig. 7-15. Means for eliminating any channel in the event of failure of a station is provided by the selective operation of *SW*4, *SW*5, or *SW*6 as required. Operation of the ganged switch *SW*3 provides dis-

[9] That is, it tends to cancel out the inductive reactance.



*P*1—1000-ohm pot, 3 watts
*P*2—50-ohm pot, 3 watts
*P*3—50-ohm pot, 3 watts
*P*4—50-ohm pot, 3 watts
*PL*1—pilot light (input)
*PL*2—pilot light (motor)
*PL*3—Ch. "A" Talley light
*PL*4—Ch. "B" Talley light
*PL*5—Ch. "C" Talley light
*PB*1—momentary push button for manual operation
*SW*1—power switch
*SW*2—motor switch
*SW*3—all channel switch
*SW*4—Ch. "A" on-off
*SW*5—Ch. "B" on-off
*SW*6—Ch. "C" on-off
*SW*7—tone, on-off
*R*1, *R*2—750 ohms, ½ watt
*R*3, *R*4—500 ohms, ½ watt
*R*5—250 ohms, ½ watt
*R*6, *R*8, *R*10—500 K, ½ watt
*R*7, *R*9, *R*11—7.5 ohms, 1 watt
*R*12—5,100 ohms, 1 watt
*C*1, *C*2, *C*3—1 μf
*C*4, *C*5—8 μf
*X*1—60 ma, selenium rectifier
RLY 1, 2, and 3—Guardian 200
RLY 4, 5, and 6—Potter Brumfield, Type LS, 10 K

FIG. 7-15. Circuit diagram of CONELRAD sequential switch designed by Ross Beville, WWDC, Washington, D.C.

tribution of program failures either sequentially or simultaneously. Simultaneous distribution is useful in test operations of cluster connecting lines and in transmitting "all clear" notices at the termination of an emergency.

The 6J5 vacuum tubes working in connection with relays 4, 5, and 6 provide the necessary overlap when switching from channel to channel. This is to prevent breaks in programming. Overlap time can be varied from ½ to 2 sec by the operation of *P*2, *P*3, or *P*4. The 60-cycle-tone input to each channel was included so as to make possible the use of *tone*-actuated relays at each transmitter in the cluster. Since *program*-actuated relays are presently being used, this feature is not operative but is available for use at a later date if necessary.

Figure 7-16 shows in block form the manner of operation of one of the clusters in a major city on the east coast. The radio stations *A* through *F* are connected to

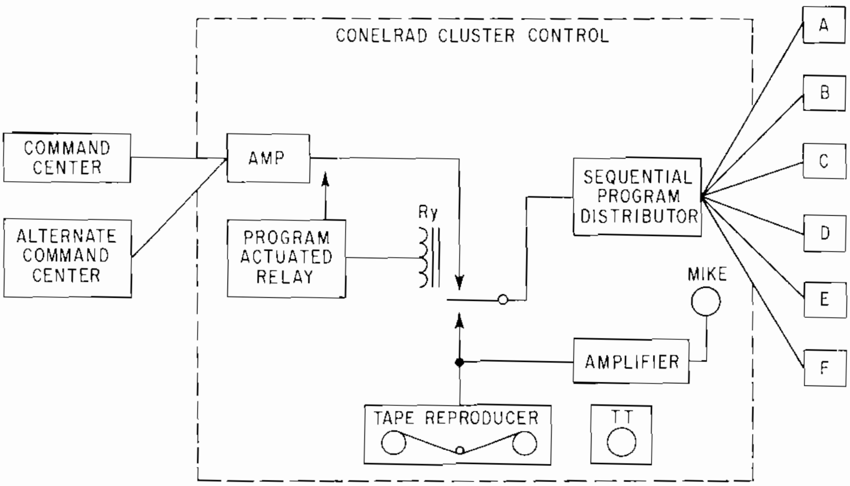


Fig. 7-16. Typical six-station CONELRAD cluster.

the sequential program distributor unit at the cluster control station by schedule *F* lines. The distributor unit automatically switches the program from one station to another. At the station end of each of the lines is a program-operated amplifier and associated relay with a time-delay circuit to hold the transmitter on for whatever period is desired so that pauses in speech or music will not cause the transmitter to go off the air. It will be seen that programs can be directed into the distributor from both sides of the relay. One side takes the program from the Industry Control Center or Alternate Center. The program-actuated relay shown has the feature of preempting the circuit whenever survival instructions or information are required. During pauses in speech, the relay switches over to the studio control and momentarily takes whatever program is being provided by the cluster control station.

Some difficulty has been experienced as a result of the time-delay feature utilized to keep the transmitters on the air during pauses in speech. The chief trouble occurs at the switch-over point from one station to another when the carrier of the first station is still on the air without modulation. This situation is particularly troublesome when the first carrier is somewhat stronger than the second, which results in the AVC action of the receiver holding down the volume, so that the received signal from the second station is below the easily readable level. Then, too, if there is any appreciable frequency difference between the two stations, the RF carrier beat note adds to the difficulty. It was also learned during one test of the system that in order to provide intelligible coverage of a large metropolitan area, a relatively efficient antenna system must be used or the power must be increased to compensate for the inefficiency. In certain instances where the broadcast transmitters are located a considerable distance from the center of the city, it is quite impractical to expect a 250-watt station, even with an efficient antenna, to provide the needed coverage. This is chiefly a matter of limitation imposed by sky-wave signals on the same channel. It was calculated that the effective service area of a cluster of stations during CONELRAD operation would be within the 6- or 8-mv/m contour. Generally speaking, this has proved to be a practical value. There are a few areas where the intelligible service contours extended out to approximately the 2-mv/m contour. Where it is required to utilize stations in the 250-watt-power category for a cluster, it may be necessary to broadcast survival information on a sectionalized metropolitan area basis,[10] that is, broadcasting information designed for a particular section of the city only over the station that is known to give adequate coverage to that section. General types of programs such as music, etc., could then be broadcast in the usual manner for cluster operation without any particular regard for the 100 per cent intelligibility factor.

OVER-ALL CAPABILITIES

Although a detailed discussion of the navigational-deception aspects of the CONELRAD System is not appropriate here, it is proper to say just a few words about the system from the over-all standpoint of its potential capabilities. There has been some confusion on this point. The United States Air Force has integrated the entire program of electromagnetic radiation control into what they term "passive defense." It has never been thought of or intended that any such system of controlled operation of broadcast stations or those of any other service could prevent a good navigator from bringing an aircraft to within a very close distance from the desired point. We know our navigators are able to do it, so probably those of other countries can too. However, if any difficulties arise in other navigating methods or procedures, it is agreed that one of the most useful adjuncts to navigation would be the radio compass. Consequently, normal operation of standard broadcast stations would immediately provide a multitude of sources for orientation of aircraft. It is common procedure for certain types of navigation, both in the military and in commercial aviation, to use broadcast stations as a signal source for the ADF with excellent accuracy. In one section of our country where radio ranges and beacons are not too plentiful, even the 250-watt broadcast stations render an excellent navigational service. So the CONELRAD system was never intended to prevent an enemy flight from reaching its target but only to make it more difficult by rendering practically useless its radio facilities for direction finding.

USE OF REMOTE-PICKUP FACILITIES IN CONELRAD

Throughout the period of operation of the broadcast CONELRAD system, the program and control distribution to the various stations in the clusters has been via wire lines leased from the common carrier.[11] Such a system is most reliable under normal conditions, except for errors in patching up at the local exchange board. Such errors do not occur frequently, however, and the use of lines has proved satisfactory. Discussions within the National Industry Advisory Committee, the Federal Communications Commission, the Office of Civil and Defense Mobilization, and other agencies of the government have recognized the vulnerability of such a program-dissemination and control system should an emergency occur. In view of this, consideration is now being given to utilizing radio circuits for both the program dissemination and control and switching of the stations operating in CONELRAD clusters.

[10] That is, selected segment operation, which has proved most efficient in terms of providing good coverage.

[11] At no expense to the broadcaster.

A logical choice for the selection of both equipment and frequencies for this purpose would be that which could normally be used by the broadcaster in everyday operations whenever there is a requirement for a remote pickup. Vast experience in the practical operation of such equipment was available from the industry as well as the FCC. While over half of the remote-pickup authorizations to radio broadcast stations are for use of the 25- and 26-Mc band, it was considered advisable to utilize a higher order of frequency. The 153-Mc band is shared with the Industrial Service, which has first priority of use. With certain geographical limitations, 166.25 and 170.15 Mc are shared with the government. Therefore the next higher band(s) 450, and 455 Mc, which are allocated exclusively to the Broadcast Service, were considered the most appropriate choice.

Aside from the exclusivity feature of the 450- to 455-Mc allocation, the physical dimensions of antennas and equipment for such operation were additional attributes. Parabolic or other type of beam antennas can be used to concentrate the radiated signal and provide considerable power gain in the desired direction. Operational tests between mobile units and a base station indicated a good reliability figure even in a large metropolitan area such as New York City. Such tests were made without the benefit of "dish" antennas, and consequently the success of the contemplated fixed type of application for CONELRAD appeared technically assured. Those benefits would be equally applicable to the normal type of operation for remote-pickup use. Not only would it be possible in this manner but under developed conditions could be used for intercity relay as well as intracity purposes.

A system of utilizing such frequencies in the 450- to 455-Mc bands has been worked out and is commonly known as the "checkerboard" system (see Fig. 7-17). The name was derived from the letter designation of areas to which channels have been assigned for both transmitting and receiving to the contiguous areas. Referring to the letter block and the subsequent block diagrams of the areas (see Figs. 7-19 through 7-26), area *A* could transmit to area *B* on 450.15 Mc to area *D* on 450.35 Mc and receive from areas *B* and *D* on 455.15 and 455.75 Mc, respectively. In addition, transmission to a mobile news unit could be made on 450.25 Mc and for cluster control, programming and switching, cueing and calling, and communications to Weather Bureau, police, and local civil defense on 450.95 Mc. Provision is also made for mobile unit channels to both transmit and receive as indicated. Similar provision is made for the other areas shown.

Such use is not necessarily restricted to the 450- to 455-Mc bands. In some areas of the country the other remote-pickup frequencies allocated, even though shared with industry and government, might be usable on a noninterference basis. Frequencies in the 25- and 26-Mc bands could also be used, although the physical dimensions of the antennas make those bands less desirable. A similar assignment plan could be formulated for those frequency bands. Such systems are already in the process of being initiated in several areas of the country. It is believed that efficient use of the remote-pickup frequencies allocated to the Broadcast Service will not only provide an emergency communication and control system of high reliability but also enhance the pickup facilities of the normal broadcast program. As more information is being gathered concerning the use of the higher frequencies (450 Mc), their advantages are becoming more apparent.

A	B	C	D	A	B	C
B	C	D	A	B	C	D
C	D	A	B	C	D	A
D	A	B	C	D	A	B

Fig. 7-17. "Checkerboard" area block diagram. See Fig. 7-18 for details of frequency use between areas designated by letters, and Figs. 7-19 through 7-26 for more detailed usage of channels in the 450- and 455-Mc bands.

AREA A T-450.15 PGM R-455.75 455.15-R PGM 450.35-T WX (T-455.45 T-455.75 R-450.15	AREA B R-450.15 T-455.35 PGM PGM 455.15-T 450.75-R	AREA C T-450.55 PGM R-455.35 455.55-R PGM 450.75-T	AREA D R-450.55 T-455.75 PGM PGM 455.55-T 450.35-R	AREA A T-450.15 PGM R-455.75 455.15-R PGM 450.35-T WX (T-455.45 T-455.75 R-450.15	AREA B R-450.15 T-455.35 PGM PGM 455.15-T 450.75-R	AREA C T-450.55 PGM R-455.35 455.55-R PGM 450.75-T
AREA B R-450.15 T-455.35 PGM PGM 455.15-T 450.75-R	AREA C T-450.55 PGM R-455.35 455.55-R PGM 450.75-T	AREA D R-450.55 T-455.75 PGM PGM 455.55-T 450.35-R	AREA A T-450.15 PGM R-455.75 455.15-R PGM 450.35-T WX (T-455.45 T-455.75 R-450.15	AREA B R-450.15 T-455.35 PGM PGM 455.15-T 450.75-R	AREA C T-450.55 PGM R-455.35 455.55-R PGM 450.75-T	AREA D R-450.55 T-455.75 PGM PGM 455.55-T 450.35-R
AREA C T-450.55 PGM R-455.35 455.55-R PGM 450.75-T	AREA D R-450.55 T-455.75 PGM PGM 455.55-T 450.35-R	AREA A T-450.15 PGM R-455.75 455.15-R PGM 450.35-T WX (T-455.45 T-455.75 R-450.15	AREA B R-450.15 T-455.35 PGM PGM 455.15-T 450.50-R	AREA C T-450.55 PGM R-455.35 455.55-R PGM 450.75-T	AREA D R-450.55 T-455.75 PGM PGM 455.55-T 450.35-R	AREA A T-450.15 PGM R-455.75 455.15-R PGM 450.35-T WX (T-455.45 T-455.75 R-450.15
AREA D R-450.55 T-455.75 PGM PGM 455.55-T 450.35-R	AREA A T-450.15 PGM R-455.75 455.15-R PGM 450.35-T WX (T-455.45 T-455.75 R-450.15	AREA B R-450.15 T-455.35 PGM PGM 455.15-T 450.75-R	AREA C T-450.55 PGM R-455.35 455.55-R PGM 450.75-T	AREA D R-450.55 T-455.75 PGM PGM 455.55-T 450.35-R	AREA A T-450.15 PGM R-455.75 455.15-R PGM 450.35-T WX (T-455.45 T-455.75 R-450.15	AREA B R-450.15 T-455.35 PGM PGM 455.15-T 450.75-R

FIG. 7-18

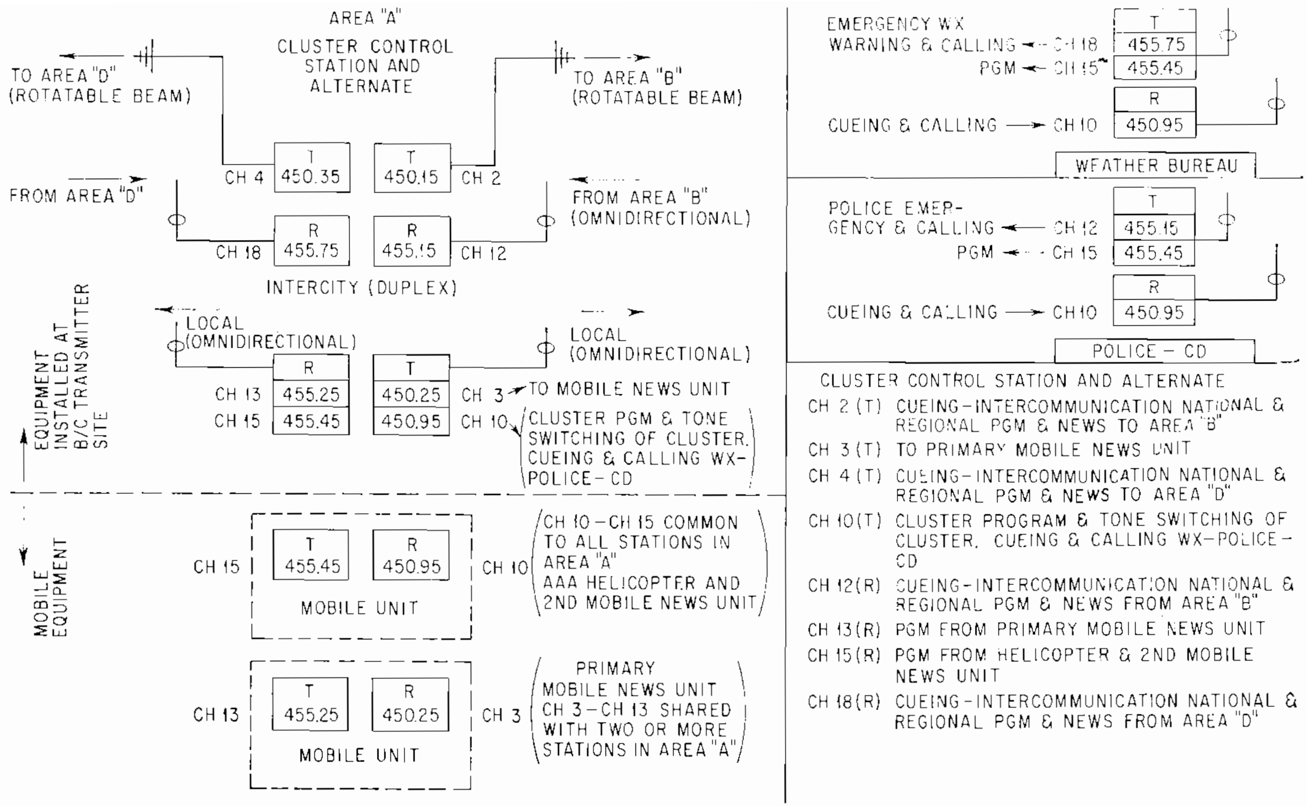

AREA "A"
CLUSTER CONTROL STATION AND ALTERNATE
TO AREA "D" (ROTATABLE BEAM)
TO AREA "B" (ROTATABLE BEAM)
FROM AREA "D"
FROM AREA "B" (OMNIDIRECTIONAL)
CH 4
T 450.35
T 450.15
CH 2
CH 18
R 455.75
R 455.15
CH 12
INTERCITY (DUPLEX)
LOCAL (OMNIDIRECTIONAL)
LOCAL (OMNIDIRECTIONAL)
R
CH 13 455.25
CH 15 455.45
T
450.25 CH 3
450.95 CH 10
TO MOBILE NEWS UNIT
CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD
EQUIPMENT INSTALLED AT B/C TRANSMITTER SITE
MOBILE EQUIPMENT
CH 15
T 455.45
R 450.95
MOBILE UNIT
CH 10
CH 10-CH 15 COMMON TO ALL STATIONS IN AREA "A" AAA HELICOPTER AND 2ND MOBILE NEWS UNIT
CH 13
T 455.25
R 450.25
MOBILE UNIT
CH 3
PRIMARY MOBILE NEWS UNIT CH 3-CH 13 SHARED WITH TWO OR MORE STATIONS IN AREA "A"
EMERGENCY WX WARNING & CALLING CH 18
PGM CH 15
T 455.75 455.45
CUEING & CALLING CH 10
R 450.95
WEATHER BUREAU
POLICE EMERGENCY & CALLING CH 12
PGM CH 15
T 455.15 455.45
CUEING & CALLING CH 10
R 450.95
POLICE - CD
CLUSTER CONTROL STATION AND ALTERNATE
CH 2 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "B"
CH 3 (T) TO PRIMARY MOBILE NEWS UNIT
CH 4 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "D"
CH 10 (T) CLUSTER PROGRAM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD
CH 12 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "B"
CH 13 (R) PGM FROM PRIMARY MOBILE NEWS UNIT
CH 15 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 18 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "D"

Fig. 7-19

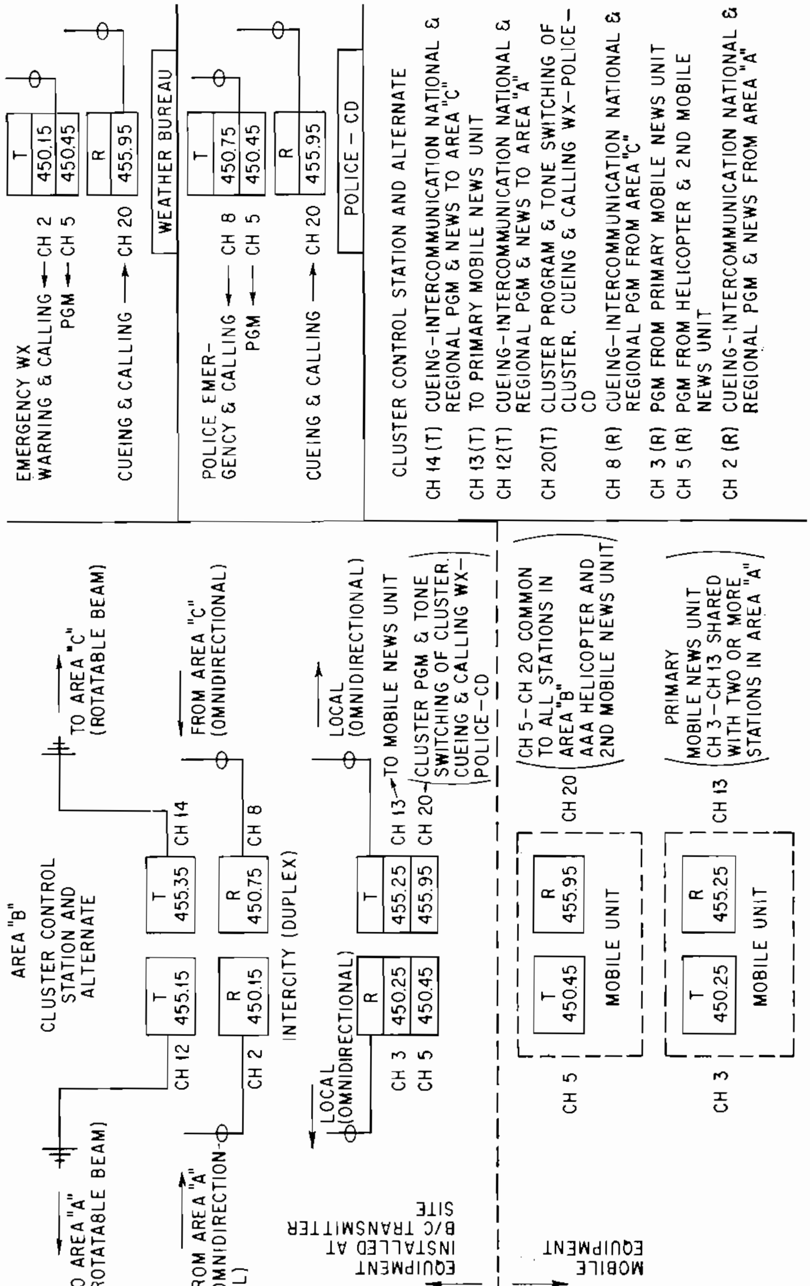
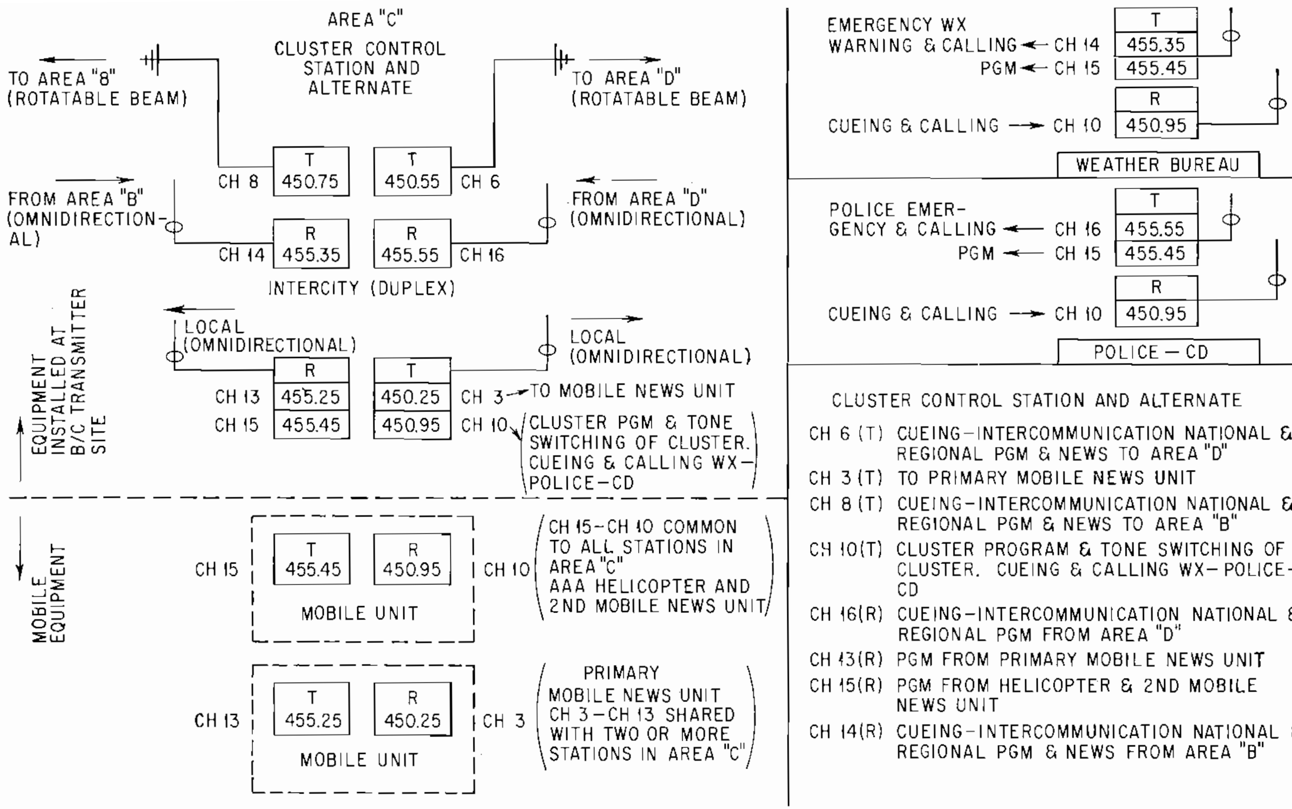

AREA "B"
CLUSTER CONTROL STATION AND ALTERNATE
TO AREA "A" (ROTATABLE BEAM)
TO AREA "C" (ROTATABLE BEAM)
FROM AREA "A" (OMNIDIRECTIONAL)
FROM AREA "C" (OMNIDIRECTIONAL)
T 455.15 CH 12
T 455.35 CH 14
R 450.15 CH 2
R 450.75 CH 8
INTERCITY (DUPLEX)
LOCAL (OMNIDIRECTIONAL)
LOCAL (OMNIDIRECTIONAL)
R 450.25 450.45
T 455.25 455.95
CH 3
CH 5
CH 13 → TO MOBILE NEWS UNIT
CH 20 → CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX–POLICE–CD
EQUIPMENT INSTALLED AT B/C TRANSMITTER SITE
MOBILE EQUIPMENT
CH 5
T 450.45
R 455.95
MOBILE UNIT
CH 20
CH 5–CH 20 COMMON TO ALL STATIONS IN AREA "B" AAA HELICOPTER AND 2ND MOBILE NEWS UNIT
CH 3
T 450.25
R 455.25
MOBILE UNIT
CH 13
PRIMARY MOBILE NEWS UNIT CH 3–CH 13 SHARED WITH TWO OR MORE STATIONS IN AREA "A"
EMERGENCY WX WARNING & CALLING → CH 2
PGM → CH 5
T 450.15 450.45
CUEING & CALLING → CH 20
R 455.95
WEATHER BUREAU
POLICE EMERGENCY & CALLING → CH 8
PGM → CH 5
T 450.75 450.45
CUEING & CALLING → CH 20
R 455.95
POLICE – CD
CLUSTER CONTROL STATION AND ALTERNATE
CH 14 (T) CUEING–INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "C"
CH 13 (T) TO PRIMARY MOBILE NEWS UNIT
CH 12 (T) CUEING–INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "A"
CH 20 (T) CLUSTER PROGRAM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX–POLICE–CD
CH 8 (R) CUEING–INTERCOMMUNICATION NATIONAL & REGIONAL PGM FROM AREA "C"
CH 3 (R) PGM FROM PRIMARY MOBILE NEWS UNIT
CH 5 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 2 (R) CUEING–INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "A"

FIG. 7-20



AREA "C"
CLUSTER CONTROL STATION AND ALTERNATE
TO AREA "B" (ROTATABLE BEAM)
TO AREA "D" (ROTATABLE BEAM)
CH 8
T 450.75
T 450.55
CH 6
FROM AREA "B" (OMNIDIRECTIONAL)
FROM AREA "D" (OMNIDIRECTIONAL)
CH 14
R 455.35
R 455.55
CH 16
INTERCITY (DUPLEX)
LOCAL (OMNIDIRECTIONAL)
LOCAL (OMNIDIRECTIONAL)
R
CH 13 455.25
CH 15 455.45
T
450.25 CH 3 → TO MOBILE NEWS UNIT
450.95 CH 10 (CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX—POLICE—CD)
EQUIPMENT INSTALLED AT B/C TRANSMITTER SITE
MOBILE EQUIPMENT
CH 15
T 455.45
R 450.95
MOBILE UNIT
CH 10
(CH 15—CH 10 COMMON TO ALL STATIONS IN AREA "C" AAA HELICOPTER AND 2ND MOBILE NEWS UNIT)
CH 13
T 455.25
R 450.25
MOBILE UNIT
CH 3
(PRIMARY MOBILE NEWS UNIT CH 3—CH 13 SHARED WITH TWO OR MORE STATIONS IN AREA "C")
EMERGENCY WX WARNING & CALLING ← CH 14
PGM ← CH 15
T
455.35
455.45
CUEING & CALLING → CH 10
R
450.95
WEATHER BUREAU
POLICE EMERGENCY & CALLING ← CH 16
PGM ← CH 15
T
455.55
455.45
CUEING & CALLING → CH 10
R
450.95
POLICE — CD
CLUSTER CONTROL STATION AND ALTERNATE
CH 6 (T) CUEING—INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "D"
CH 3 (T) TO PRIMARY MOBILE NEWS UNIT
CH 8 (T) CUEING—INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "B"
CH 10 (T) CLUSTER PROGRAM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX—POLICE—CD
CH 16 (R) CUEING—INTERCOMMUNICATION NATIONAL & REGIONAL PGM FROM AREA "D"
CH 13 (R) PGM FROM PRIMARY MOBILE NEWS UNIT
CH 15 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 14 (R) CUEING—INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "B"

FIG. 7-21

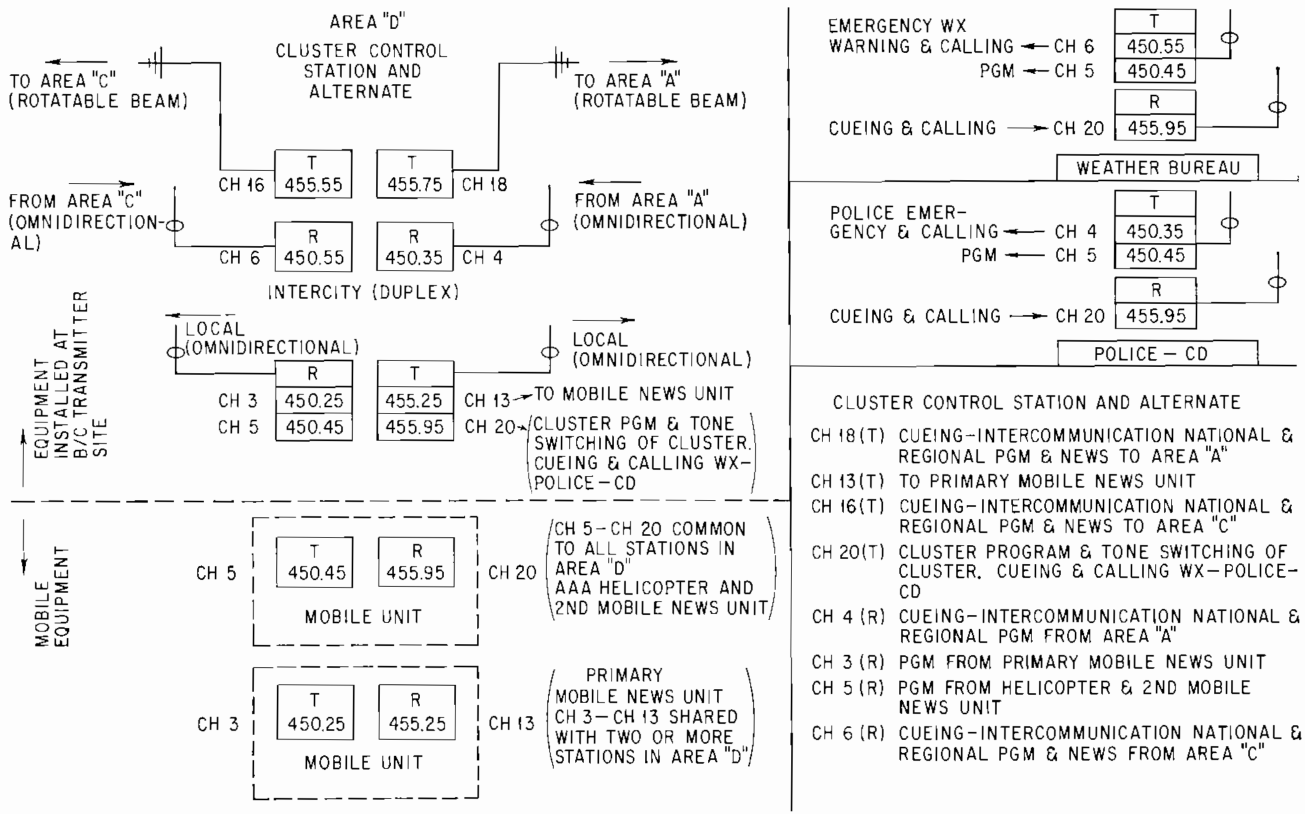
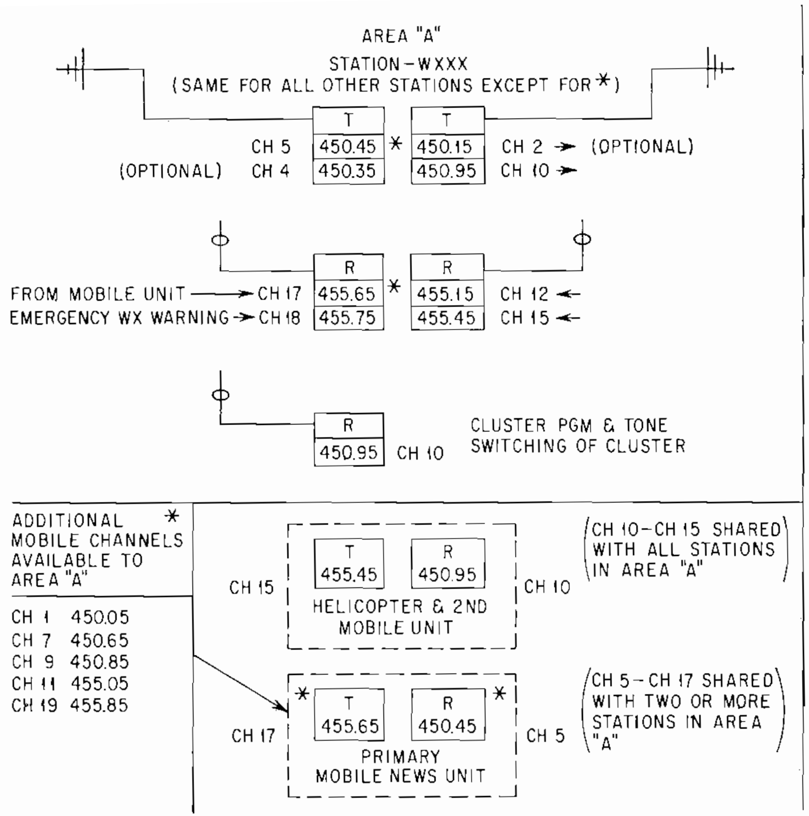

AREA "D"
CLUSTER CONTROL STATION AND ALTERNATE
TO AREA "C" (ROTATABLE BEAM)
TO AREA "A" (ROTATABLE BEAM)
CH 16
T 455.55
T 455.75
CH 18
FROM AREA "C" (OMNIDIRECTIONAL)
FROM AREA "A" (OMNIDIRECTIONAL)
CH 6
R 450.55
R 450.35
CH 4
INTERCITY (DUPLEX)
LOCAL (OMNIDIRECTIONAL)
LOCAL (OMNIDIRECTIONAL)
R
CH 3 450.25
CH 5 450.45
T
455.25 CH 13 → TO MOBILE NEWS UNIT
455.95 CH 20 → (CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD)
EQUIPMENT INSTALLED AT B/C TRANSMITTER SITE
MOBILE EQUIPMENT
CH 5
T 450.45
R 455.95
MOBILE UNIT
CH 20
(CH 5-CH 20 COMMON TO ALL STATIONS IN AREA "D" AAA HELICOPTER AND 2ND MOBILE NEWS UNIT)
CH 3
T 450.25
R 455.25
MOBILE UNIT
CH 13
(PRIMARY MOBILE NEWS UNIT CH 3-CH 13 SHARED WITH TWO OR MORE STATIONS IN AREA "D")
EMERGENCY WX WARNING & CALLING ← CH 6
PGM ← CH 5
T
450.55
450.45
CUEING & CALLING → CH 20
R
455.95
WEATHER BUREAU
POLICE EMERGENCY & CALLING ← CH 4
PGM ← CH 5
T
450.35
450.45
CUEING & CALLING → CH 20
R
455.95
POLICE - CD
CLUSTER CONTROL STATION AND ALTERNATE
CH 18 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "A"
CH 13 (T) TO PRIMARY MOBILE NEWS UNIT
CH 16 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "C"
CH 20 (T) CLUSTER PROGRAM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD
CH 4 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM FROM AREA "A"
CH 3 (R) PGM FROM PRIMARY MOBILE NEWS UNIT
CH 5 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 6 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "C"

FIG. 7-22



CH 2 (T)	CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "B"
CH 4 (T)	SAME TO AREA "D"
CH 5 (T)	TO MOBILE NEWS UNIT
CH 10 (T)	(ALTERNATE) CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX – POLICE – CD. CUEING 2ND MOBILE UNIT
CH 10 (R)	SAME AS ABOVE FROM CLUSTER CONTROL & ALTERNATE CLUSTER CONTROL
	AAA HELICOPTER & 2ND MOBILE NEWS UNIT
CH 12 (R)	CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "B", CALLING FROM POLICE & CD
CH 15 (R)	PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 17 (R)	PGM FROM PRIMARY MOBILE UNIT
CH 18 (R)	CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "D"
	CALLING FROM WX BUREAU
	EMERGENCY WX WARNINGS

Fig. 7-23

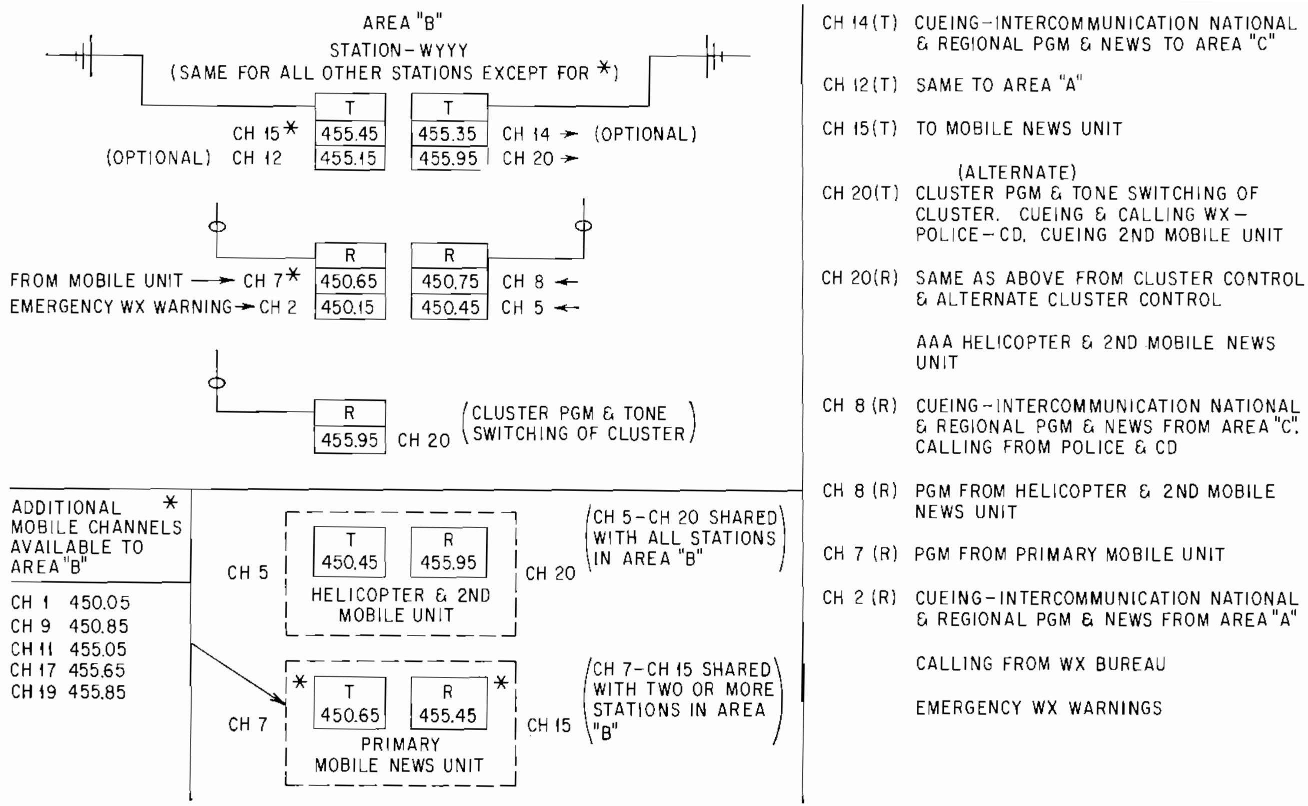

AREA "B"
STATION-WYYY
(SAME FOR ALL OTHER STATIONS EXCEPT FOR *)
T
T
CH 15*
455.45
455.35
CH 14 → (OPTIONAL)
(OPTIONAL) CH 12
455.15
455.95
CH 20 →
R
R
FROM MOBILE UNIT → CH 7*
450.65
450.75
CH 8 ←
EMERGENCY WX WARNING → CH 2
450.15
450.45
CH 5 ←
R
455.95
CH 20
(CLUSTER PGM & TONE SWITCHING OF CLUSTER)
ADDITIONAL MOBILE CHANNELS AVAILABLE TO AREA "B" *
CH 1 450.05
CH 9 450.85
CH 11 455.05
CH 17 455.65
CH 19 455.85
CH 5
T 450.45
R 455.95
HELICOPTER & 2ND MOBILE UNIT
CH 20
(CH 5-CH 20 SHARED WITH ALL STATIONS IN AREA "B")
CH 7
* T 450.65
R 455.45 *
PRIMARY MOBILE NEWS UNIT
CH 15
(CH 7-CH 15 SHARED WITH TWO OR MORE STATIONS IN AREA "B")
CH 14(T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "C"
CH 12(T) SAME TO AREA "A"
CH 15(T) TO MOBILE NEWS UNIT
(ALTERNATE)
CH 20(T) CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD. CUEING 2ND MOBILE UNIT
CH 20(R) SAME AS ABOVE FROM CLUSTER CONTROL & ALTERNATE CLUSTER CONTROL
AAA HELICOPTER & 2ND MOBILE NEWS UNIT
CH 8 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "C". CALLING FROM POLICE & CD
CH 8 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 7 (R) PGM FROM PRIMARY MOBILE UNIT
CH 2 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "A"
CALLING FROM WX BUREAU
EMERGENCY WX WARNINGS

FIG. 7-24

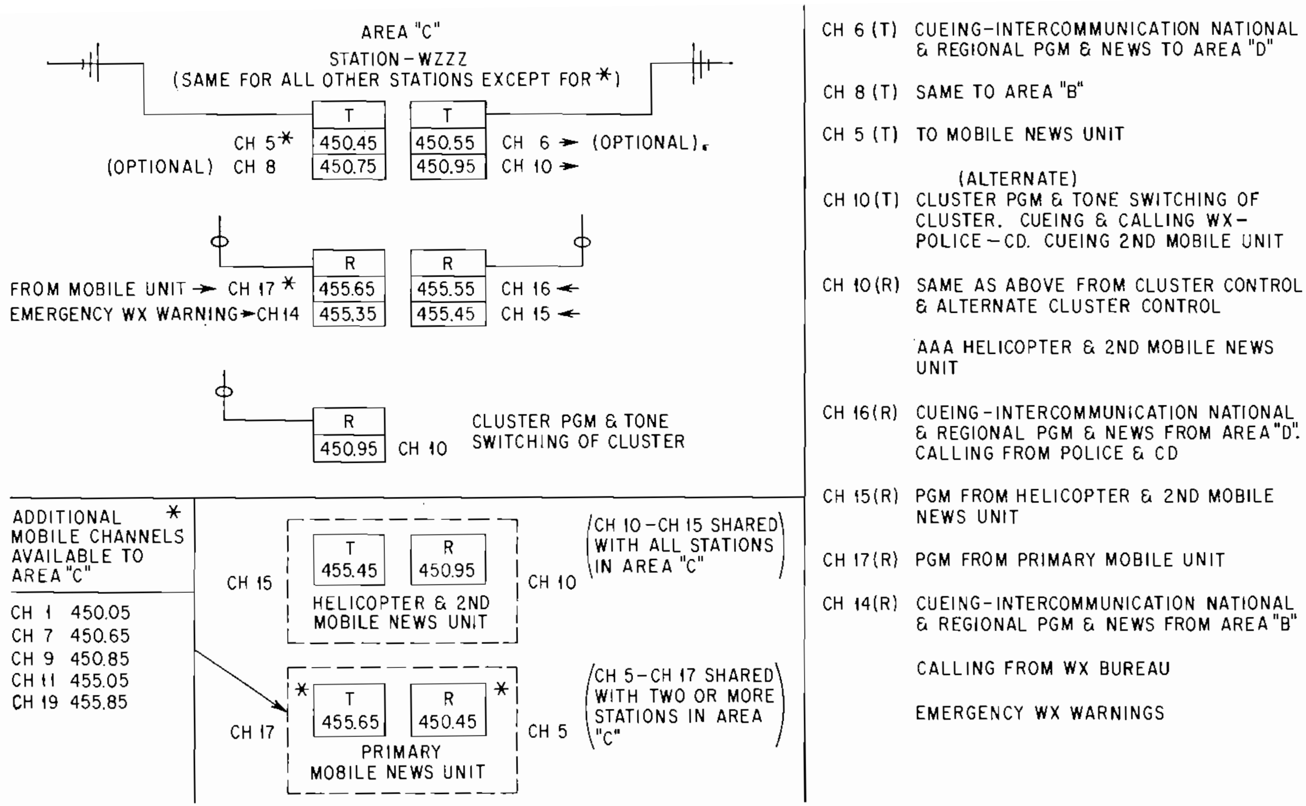

AREA "C"
STATION-WZZZ
(SAME FOR ALL OTHER STATIONS EXCEPT FOR *)
T
T
CH 5*
450.45
450.55
CH 6 → (OPTIONAL)
(OPTIONAL) CH 8
450.75
450.95
CH 10 →
R
R
FROM MOBILE UNIT → CH 17 *
455.65
455.55
CH 16 ←
EMERGENCY WX WARNING→CH 14
455.35
455.45
CH 15 ←
R
450.95
CH 10
CLUSTER PGM & TONE SWITCHING OF CLUSTER
ADDITIONAL MOBILE CHANNELS AVAILABLE TO AREA "C" *
CH 1 450.05
CH 7 450.65
CH 9 450.85
CH 11 455.05
CH 19 455.85
CH 15
T
455.45
R
450.95
HELICOPTER & 2ND MOBILE NEWS UNIT
CH 10
(CH 10-CH 15 SHARED WITH ALL STATIONS IN AREA "C")
CH 17
*
T
455.65
R
450.45
*
PRIMARY MOBILE NEWS UNIT
CH 5
(CH 5-CH 17 SHARED WITH TWO OR MORE STATIONS IN AREA "C")
CH 6 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "D"
CH 8 (T) SAME TO AREA "B"
CH 5 (T) TO MOBILE NEWS UNIT
(ALTERNATE)
CH 10 (T) CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD. CUEING 2ND MOBILE UNIT
CH 10 (R) SAME AS ABOVE FROM CLUSTER CONTROL & ALTERNATE CLUSTER CONTROL
AAA HELICOPTER & 2ND MOBILE NEWS UNIT
CH 16 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "D". CALLING FROM POLICE & CD
CH 15 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 17 (R) PGM FROM PRIMARY MOBILE UNIT
CH 14 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "B"
CALLING FROM WX BUREAU
EMERGENCY WX WARNINGS

FIG. 7-25

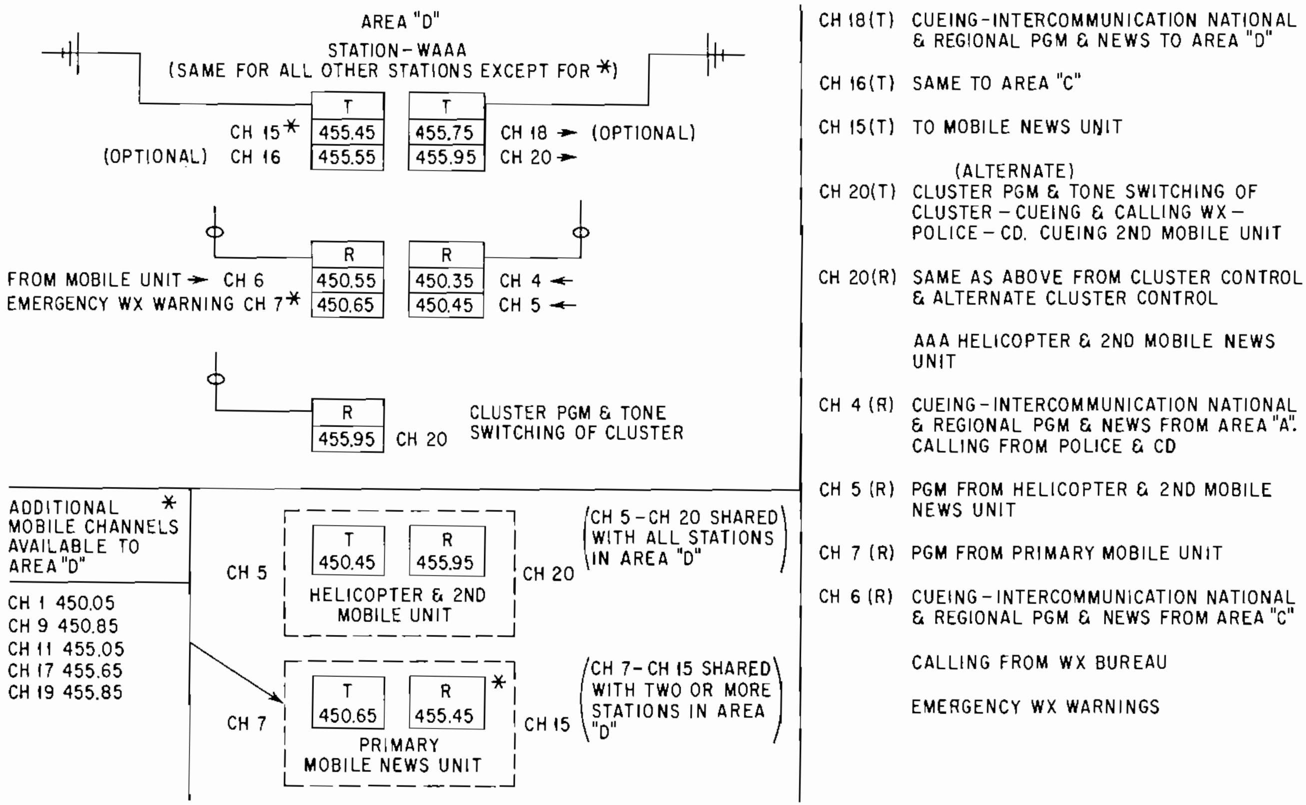

AREA "D"
STATION-WAAA
(SAME FOR ALL OTHER STATIONS EXCEPT FOR *)
CH 15* T 455.45
(OPTIONAL) CH 16 455.55
T 455.75 CH 18 → (OPTIONAL)
455.95 CH 20 →
FROM MOBILE UNIT → CH 6 R 450.55
EMERGENCY WX WARNING CH 7* 450.65
R 450.35 CH 4 ←
450.45 CH 5 ←
R 455.95 CH 20
CLUSTER PGM & TONE SWITCHING OF CLUSTER
ADDITIONAL MOBILE CHANNELS AVAILABLE TO AREA "D" *
CH 1 450.05
CH 9 450.85
CH 11 455.05
CH 17 455.65
CH 19 455.85
CH 5
T 450.45
R 455.95
HELICOPTER & 2ND MOBILE UNIT
CH 20
(CH 5-CH 20 SHARED WITH ALL STATIONS IN AREA "D")
CH 7
T 450.65
R 455.45 *
PRIMARY MOBILE NEWS UNIT
CH 15
(CH 7-CH 15 SHARED WITH TWO OR MORE STATIONS IN AREA "D")
CH 18(T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "D"
CH 16(T) SAME TO AREA "C"
CH 15(T) TO MOBILE NEWS UNIT
(ALTERNATE)
CH 20(T) CLUSTER PGM & TONE SWITCHING OF CLUSTER - CUEING & CALLING WX - POLICE - CD. CUEING 2ND MOBILE UNIT
CH 20(R) SAME AS ABOVE FROM CLUSTER CONTROL & ALTERNATE CLUSTER CONTROL
AAA HELICOPTER & 2ND MOBILE NEWS UNIT
CH 4 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "A". CALLING FROM POLICE & CD
CH 5 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 7 (R) PGM FROM PRIMARY MOBILE UNIT
CH 6 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "C"
CALLING FROM WX BUREAU
EMERGENCY WX WARNINGS

FIG. 7-26

METHODS FOR OBTAINING EQUIPMENT FOR CONELRAD BROADCAST STATIONS *

CONELRAD broadcast station equipment (e.g., CONELRAD crystals, emergency power generators, alternate CONELRAD transmitters) can be obtained through the Federal Contributions Program (whereby the Federal Government pays half of the cost). From time to time such equipment also may be available through the Surplus Property Program.

The following is a brief description of the procedures to follow in each of the two methods of obtaining the equipment. Additional details on acquiring civil defense equipment through the Federal Contributions Program may be found in the OCDM Federal Contributions Manual, M 25-1. Additional information on acquiring civil defense equipment through the Surplus Property Program may be found in the OCDM Surplus Property Manual, M 6-2.

A. Federal Contributions Method:

1. Make sure the desired equipment is not available through the Surplus Property Program (see section B, 1, below). Equipment will not be approved for procurement on a matching-fund basis if it is available as surplus property.
2. To get the equipment through the Federal Contributions Program, a CONELRAD broadcast station manager should provide his local civil defense director with the following information:
   (a) OCDM equipment item number. (Get this from the lists of civil defense equipment in Annex 9-B, Chapter 9, Federal Contributions Manual, M 25-1.)
   (b) Description of items.
   (c) Number of units and cost.
   (d) Conversion and installation costs. (In addition to the cost of the equipment, the Federal Government will pay half the cost of converting and installing CONELRAD crystals, and modifying transmitter, control, and antenna circuits.)
   (e) Total estimated cost.
3. The local civil defense director should prepare the necessary OCDM project application forms, and submit them through the State civil defense office to the OCDM Regional Office. (The project application should be made out in the name of the local civil defense organization.)
4. When the equipment is received, the State civil defense office may hold title to it or transfer the title to the local civil defense organization. Title may not be transferred to an individual, company or private organization (even though the CONELRAD broadcast station pays half the cost of the equipment). However, transfer of possession of the equipment to private concerns is permitted if such transfer is on custody receipts.

B. Surplus Property Method:

1. To find out whether the CONELRAD equipment needed is available from surplus property, the broadcast station manager should contact his local civil defense director, whether Federal surplus property of the type requested is available.
2. If the equipment is available, the State civil defense director makes a request for it through the State Agency for Federal Surplus Property.
3. The State Agency for Federal Surplus Property makes out a warehouse issue sheet transferring the property title to the State civil defense organization. This warehouse issue sheet shows the following information:
   (a) Name and address of donee.
   (b) Quantity.
   (c) Description.
   (d) Original acquisition cost to the Government.
   (e) Handling charges (freight and warehouse costs).

* From information provided by the Office of Civil and Defense Mobilization.

4. Local handling and transportation charges must be paid by the recipient of the property.
5. When the equipment is received, the State civil defense office may hold title to it or transfer the title to the local civil defense organization. Title may not be transferred to an individual, company, or private organization. However, transfer of possession of the equipment to private concerns is permitted if such transfer is on custody receipts.
6. When surplus property is in such condition that it requires rehabilitation to meet a civil defense need, the costs are approvable under the Federal Contributions Program. However, these costs shall not exceed 50 per cent of the original acquisition cost as stated on the warehouse issue sheet or transfer document. (*Exception:* The Federal Government will not pay rehabilitation costs on equipment that had an original unit acquisition cost of less than $2,500.)

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2. "Automatic Alarm Receivers for Use in CONELRAD," Federal Communications Commission, Office of the Chief Engineer, No. 4519.
3. "Antennas for Reception of Standard Broadcast Signals," *FCC Publ. 19458.*
4. NAB Engineering Department: "CONELRAD Simplified."
5. "Emergency Control of Electromagnetic Radiation Concerning AM, FM and TV Broadcast Stations," Federal Communications Commission, Office of the Chief Engineer, No. 56999.
6. Keen, R.: "Wireless Direction Finding."
7. Walker, A. Prose: "CONELRAD—Practical Operating Considerations," *Tele-Tech and Electronic Industries,* June, 1954.

In addition to the above publications, considerable information was obtained from the U.S. Supervisor, CONELRAD, FCC, Kenneth W. Miller, and from Ernest C. Thelemann, Robert D. Linx, and David O. Cooper on the CONELRAD staff of the FCC. Appreeiation for their assistance is hereby acknowledged.

Part 8

LIGHTNING PROTECTION FOR BROADCAST STATIONS

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Introduction

The sudden discharge of a large quantity of potential energy through the antenna system of a standard broadcast facility frequently produces considerable equipment damage and service interruption. It is for this reason that most broadcast engineers approach the seasons of intense electrical-storm activity with apprehension. This is an effort to present some practical ways that the broadcast engineer can arrange his equipment so that a minimum of equipment damage and service interruption will occur under such conditions.

The most commonly observed form of electrical discharge in nature is lightning. This type of discharge may contain potential energy of considerable magnitude. Many lightning strokes are repetitive in nature even though only one stroke appears to the eye. The duration of each stroke is generally a few microseconds. It is for this reason that the energy in a stroke of lightning has such destructive power. The amount of power involved can thus reach astronomical values involving large values of voltage and current. In view of this condition, all circuits where lightning is anticipated should have high insulation and current-carrying ratings.

The free-space charge generated in cloud formations will in turn induce an opposite charge in the earth below. For this reason the ground system associated with the antenna should have as much metallic surface in contact with the earth as practically possible in order to form a low-impedance path to redistribute the charge in the earth when the air space between earth and cloud breaks down. It is commonly believed that the lightning stroke begins in the clouds. However, it is not uncommon for the breakdown (ionization) of the air to start at the earth. High-speed motion pictures have been made to prove this point.

In addition to the lightning discharges, considerable trouble can develop from static generated in the antenna system. The discharge of static to ground often is accompanied by an RF power "follow-up" which will in some cases cause transmitter overloading, resulting in interruption. In some points in the circuit continuous arcing will follow static discharge and continue until a burnout failure occurs. If the static formed is kept continually drained off or discharged, the arcing may be avoided. The static may be generated in any metallic part of the antenna system. The highest rate of generation occurs during the blowing of cool, moist wind from an approaching rainstorm. The wind is charged and, owing to physical contact

* Supplemented by material from Continental Electronics Manufacturing Co.

with the tower and guys, generates a static charge therein. This charge builds up on insulated parts until a sufficiently high voltage is developed to rupture the air insulation at some point. This effect is most dramatically demonstrated by the flashover of guy-wire insulators.

It is the intention of the author to present here practical means for combating the damaging effects of electrical charges generated in nature and not to present the physical processes in nature by which such charges are generated. Should the reader be interested in this physical process, his attention is directed to an excellent paper The Electrification of Precipitation and Thunderstorms, *Proc. IRE*, vol. 45, pp. 1331–1357, October, 1957, by Ross Gunn.

Lightning Protection

For the sake of clarity it is thought that the practical aspects of the subject might be best presented by a description of a simple antenna system to which optimum protection features from electrical discharge have been incorporated. Such an antenna system is described below by presenting the salient items required.

Towers

Install a 6-ft whip of stainless steel (regular mobile antenna rod) on the top plate of the tower adjacent to the beacon light base. This whip protects the lamp from damage and also tends to ionize the air and provide a discharge of the air and cloud formations before the charge potential reaches a large magnitude. This will also discourage direct strikes to the lighting circuits.

Discharge gaps are generally supplied with the towers at installation. These gaps are in many forms, and no information is generally provided as a guide in setting the gap spacing. In order to make the gaps most useful, they should be set at the minimum usable spacing. The most practical method to set the spacing is to modulate the transmitter with a piece of the "wildest" music to be used until 100 per cent modulation on negative peaks is obtained. With this operating condition, reduce the gap spacing (do not take any chances of physical harm—use a special insulated tool) until arcing begins to occur. With the transmitter off, open the gap spacing an additional ⅛ in. and test again for arcing.

Guy Wires

Each tower guy should have at least three close-coupled insulators in series at the end where the guy is fastened to the tower, and the guy anchors should be electrically connected to the ground system. This will tend to make static discharge and direct strokes to the guys go to ground through the anchor end rather than to the tower. Insulator flashover from static build-up can be avoided by using insulators having some finite resistance to act as a leakage path. This applies to all insulators except those adjacent to the tower. This last item is not normally used owing to difficulty in procuring the special "lossy" insulators. In this manner, the gap may be set for minimum spacing. One of the problems with gaps is that when they are set to minimum spacing, freezing rain and snow will frequently cause the gap to discharge. It is well to remember that the larger the curvature of the gap surface, the smaller will be the spacing of the gap. For this reason, gaps made of large balls are not satisfactory for this type of setting. If it is necessary to use such gaps, then a protective weather covering should be placed above them. Horn-type gaps formed from ½- to ¾-in. copper tubing have been found to be very satisfactory. This type of gap will make a sustained arc rise until its length is such that it will not be self-sustaining. Figure 8-1 is a drawing of a typical horn gap. The use of a horn gap at both ends of the RF transmission line from tower

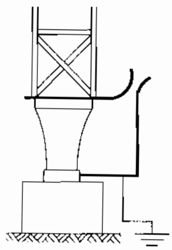

FIG. 8-1. Horn-gap installation.

to transmitter is desirable as backup protection. These gaps may be made of heavy wire and small in size. The method of setting is the same.

Most of the damage caused by lightning occurs in the tuning unit located at the base of the tower. The main reason for this is that most of the poorly insulated points in the system occur within this unit.

Meter Protection

Antenna ammeter switches of the shorting type should never be used if full ammeter protection is desired. Strange to say, this is the most commonly used type. The proper type of switch should be a "make-before-break" type, which completely disconnects both sides of the meter. This switch should be well insulated with porcelain- or glass-bonded type of insulation. Laminated phenolic insulation is not

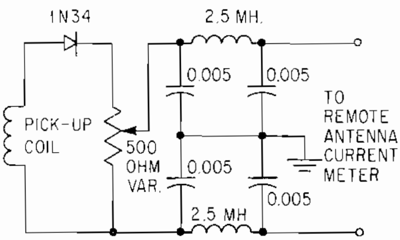

FIG. 8-2. Remote meter-protection circuit.

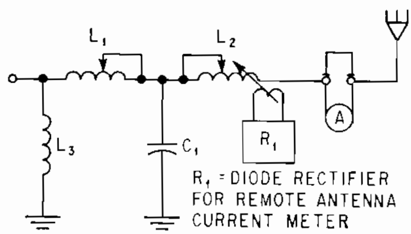

FIG. 8-3. Proper placement of pickup coil for remote antenna current meter.

satisfactory for use anywhere within this unit because of its affinity for moisture between layers. Many such failures of this material have been observed. The humidity in the tuning units is high at times. All meters should be mounted on a piece of appropriate insulation.

Another weak spot is the coupling unit for the remote-reading antenna current meter. The conventional thermocouple with its coupling transformer is the device most often damaged. This is because of the small air spacings used between primary and secondary. The secondary should contain more turns and have much higher spacing from the primary loop. All sharp corners and edges should be avoided. This problem can be alleviated by use of a small diode unit similar to that shown by Fig. 8-2. The pickup coil can be lightly coupled to the antenna input coil (L_2) as shown by Fig. 8-3. The use of this system has the great advantage of high-level isolation from the antenna circuit and is thus largely immune from lightning. Units of this type are available from the Rust Industrial Co. at a reasonable price with an appropriate meter supplied. A remote meter having a 200-μa movement with appropriate scale will be satisfactory for use with this circuit. This unit will read average current values and therefore will not follow the modulation as does the thermocouple. This is an advantage for reading during modulation of the transmitter.

The current rating of capacitor C_1 as shown by Fig. 8-3 should not be less than 20 kv. This will make the condenser rather large and expensive for low-power installations. However, the durability will repay this cost.

The static drain choke L_3 in Fig. 8-3 should be placed as shown. Most current installations will have this coil connected between antenna and ground. This placement next to the antenna has some disadvantages in that any change in the coil will affect the antenna impedance. Also on towers having impedance values in excess of 50 ohms the RF voltage across the choke will be higher with probable higher losses. In the proposed position, coils L_1 and L_2 will act as surge suppressors for the coil L_3 in case of a lightning surge and will drive the surge onto the tower base gaps instead of wrecking the choke L_3. Where it is necessary to use a series capacitor, the position of L_3 should then be between the series capacitor and the antenna but never ahead of the antenna ammeter. In some cases a third winding on the lighting choke can be used as static drain, but this often produces higher than desirable antenna loading.

The use of a one- or two-turn coil in the connection between the antenna tower and the coupling unit is of dubious value. It has the disadvantage of the coil becoming deformed and changing the equivalent antenna impedance from the value originally measured. In some cases the input inductance value is very critical.

Grounding

A 4-in.-wide ground strap or its equivalent should be used to bond the coupling-unit housing to the common point of the ground radial system. It is desirable to provide the equivalent of a 4-in. strap to connect the common point of the ground radial system to the ground of transmitter building. This strap should form the ground bus to which all equipment is connected, including the power system neutral. Where it is possible to do so, the ground bus should be bonded carefully to the cold-water line leading to the building. This is often a better ground than the ground radial system. Do not permit the use of plastic pipe between the water main and the building. Single driven copper rods are nearly worthless!

Tower-light Protection

The use of an Austin-type lighting transformer in place of a conventional-type lighting choke is desirable to provide protective isolation of the lighting circuit. It also has the great advantage of less antenna loading than the choke, and it cushions the starting surge to beacon lamps. This surge cushioning will tend to increase lamp life and will also keep the modulation of power-line voltage to a minimum.

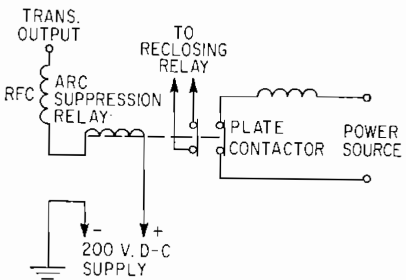

FIG. 8-4. Arc-suppression circuit.

Arc Suppression

Where power follow-up of a lightning surge will cause the transmitter to unload but continue arcing, an arc-suppression circuit can be used. Figure 8-4 shows the schematic diagram of a typical arc-suppression circuit. This circuit works on the principle of using the power arc to conduct the direct current through the arc to the arc-suppression relay, which in turn will open the plate contactor on the transmitter, thus interrupting the power arc. Following this operation a delayed-action relay can be used as recloser to reclose the plate contactor and thus restore the transmitter to normal operation.

"MAGNIPHASE" PROTECTION SYSTEM

Introduction

The Continental Electronics type 19876-B Magniphase line protection unit is an all-electronic device used to protect the radio-frequency transmission lines, antennas, and antenna tuning equipment from damage due to line faults or to arcs and overloads at any of these points. An arc-over is usually caused by a lightning discharge, which in itself may do little damage. The major damage occurs if the transmitter is allowed to remain on and to supply sustaining energy to this arc. This energy may be a small percentage of the total output of the transmitter, and damage may therefore be done before it is detected by overload devices in the transmitter.

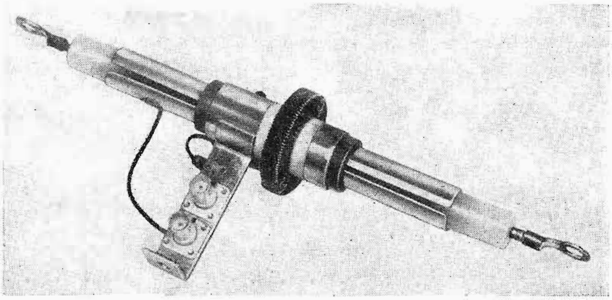

FIG. 8-5. Line coupler, 10 kw maximum.

The Magniphase system will detect an arc at any point in the antenna system and will convey this information to the transmitter and squelch the transmitter output in a matter of microseconds. It can be adjusted over a wide range of sensitivity to suit operating conditions and can be used over a wide range of frequency, transmission-line impedance, and transmitter power output.

The system consists of two units:

1. A line coupler, which is inserted in the transmission line at the transmitter output.

2. A bridge unit, which can be located on the transmitter front panel or at any other location near the transmitter.

The units are interconnected by two coaxial cables of the required length.

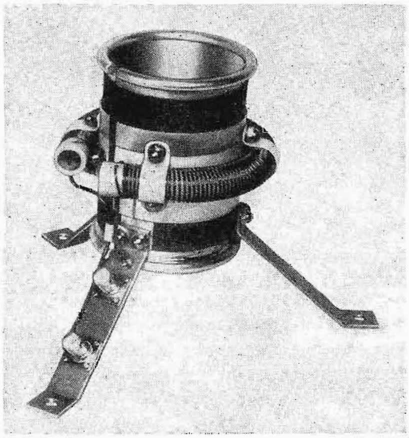

FIG. 8-6. Line coupler, 50 kw maximum.

The Magniphase system is designed for use with any transmitter operating in the standard broadcast band, with output power of 5 to 50 kw, and into impedances from 50 to 250 ohms. Two coupler types are available which are basically the same, except for power-handling capacity. One is for use with power levels of up to 10 kw, and the other for 50 kw.

In cases where power-cutback operation or directional-antenna systems are employed, combinations of several couplers may be desirable in order to obtain increased protection and sensitivity.

General Description

The Magniphase line-protection system is expressly designed to detect an impedance change in the load seen by the transmitter. The most usual disturbance in an antenna system is an arc-over caused by a nearby lightning discharge. Such an arc-over will cause an impedance change which is sensed by the Magniphase unit as an unbalanced condition at the bridge input, thereby cutting off the transmitter for a period of about 60 msec. The transmitter will then be reenergized, but if the arc still exists, it will drop off again. The arc should burn itself out very rapidly without sustaining RF energy.

The line coupler unit is both capacitive and inductive in nature and can therefore sample both voltage and current. The two RF samples from the coupler are fed to a balanced bridge circuit which, with the remaining Magniphase circuitry, is mounted in a self-contained subchassis on the transmitter front panel. The two RF samples can be balanced from the unit front panel so that no direct current will flow in the bridge output circuit unless there is a change in one or both of the samples. In this manner, the bridge is sensitive either to a change in voltage and current magnitude or to a change in phase. An arc or other disturbance at any point in the system will cause either or both of the above changes to occur.

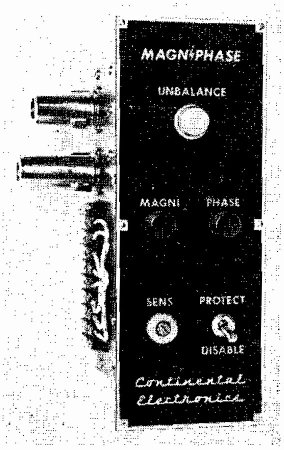

FIG. 8-7. Balanced bridge unit.

The bridge output network is connected to a thyratron which can be set to operate at any desired sensitivity. The thyratron plate circuit is usually connected directly to the transmitter RF buffer amplifier grid, so that as the thyratron fires, a high negative bias is applied to the buffer grid and is held on the grid by a relay for about 60 msec. When the relay releases, the bias is removed and the thyratron is ready to fire again if a fault is still present on the line. The bias is applied independently of the relay, which is necessary for the fast action required in this application.

Because of the fast action of the thyratron, cutoff bias is applied to the buffer amplifier in a matter of microseconds. (If biasing off a low-level stage is found to be impractical in some transmitters, auxiliary relay contacts are provided which can be used to remove excitation by other means. This involves an additional delay of only a few milliseconds, which is not objectionable in the majority of cases.)

In addition to the sensitivity control, there are two balancing controls and a "disable" switch on the front panel. The balancing controls are used for nulling an external meter during initial bridge balance. The disable switch prevents the transmitter from being cut off while the bridge balance or the sensitivity is adjusted.

Two BNC jacks are mounted on the bridge chassis for connection to the coupler. A terminal strip on the side is provided for connecting the meter, 117-volt a-c power, bias cable, and other auxiliary connections. A normally lighted neon lamp is mounted on the unit front panel. In case of a fault, the lamp will flash at a rapid rate until the fault clears or until the transmitter is manually cut off.

Circuit Description

The Magniphase line coupler unit consists of a capacitor and a toroid inductor which sample transmission-line voltage and current, respectively. These two RF samples are fed via coaxial cables to the bridge unit. At the bridge input circuit, the voltage sample is connected to a capacitive divider, and the current sample connects through a phase-shift network. A 6AL5 tube, V1, is used as a bridge rectifier, connected so that no current will flow when the bridge is balanced. A change in phase or voltage and current magnitude will then cause a bridge unbalance. When the tube is properly connected and balanced, the voltages measured on either side of V1, from pin 1 or pin 2 to ground, should be approximately equal as measured with a vacuum-tube voltmeter. The external null meter should produce minimum indication under these conditions.

A bridge unbalance causes a voltage difference across grid resistor *R*4 of the 2D21 thyratron *V*2. The voltage necessary to fire the thyratron depends on the tube bias,

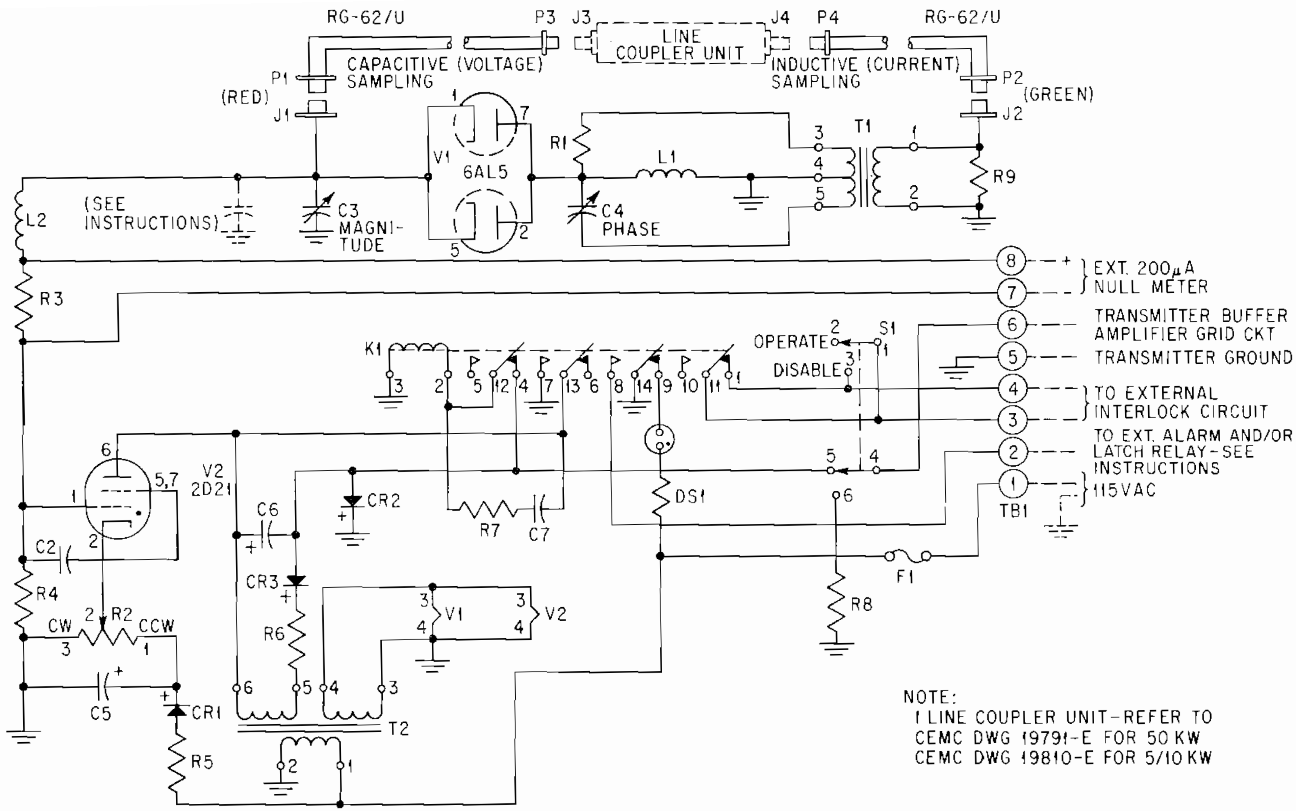

Fig. 8-8. Schematic, line-protection unit.

which is adjusted by sensitivity control *R*2. The point at which this control should be set is dictated by the conditions of operation.

Upon bridge unbalance, the thyratron will fire and will produce a voltage of approximately 100 volts negative at the Magniphase output. This voltage appears at terminal *TB*1-6 and can be connected via a shielded wire to the grid circuit of a low-level stage in the radio transmitter. This stage is usually the buffer amplifier following the crystal oscillator, and the grid bias developed is sufficient to remove transmitter excitation immediately.

In order to provide for instantaneous transmitter cutoff action, the negative bias is applied independently of the action of relay *K*1. The relay is then energized, shorting the thyratron and holding the bias present for about 600 msec. Upon relay release the transmitter excitation is restored, thereby resetting the sequence of operation. Should an unbalance still exist, the transmitter excitation will again be interrupted until the trouble is cleared.

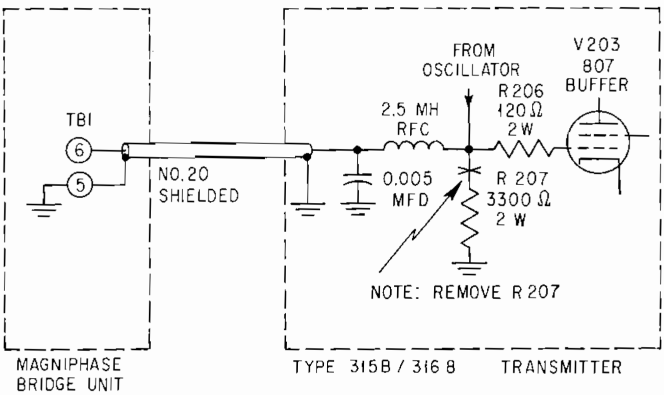

Fig. 8-9. Bias cutoff circuit, 315B/316B transmitter.

During normal operation, the coil of relay *K*1 serves as a grid resistor for the transmitter buffer amplifier stage. For test and balance procedures, OPERATE-DISABLE switch S1 is placed in the DISABLE position, thereby connecting grid load resistor *R*8 in place of the relay coil. Magniphase testing can then proceed without disturbing transmitter operation.

The connections and mode of operation described in the preceding paragraphs are applicable to Continental Electronics transmitters employing low-level Regulinear screen modulation and to other transmitters utilizing linear final amplifiers. In some transmitters, notably those using high-level plate modulation, it may be found that transmitter cutoff by instantaneous interruption of excitation is unsatisfactory. This is so because of the possibility of continuing modulation after the modulation transformer load has been removed. To prevent this occurrence and to prevent possible damage to the modulation components, an external relay circuit should be installed to interrupt the transmitter audio input before excitation is removed. Additional contacts are provided on relay *K*1 and are available at the Magniphase unit terminal strip for this purpose. A typical circuit for this connection is shown in the drawings section.

Special-purpose Arrangements

The operation of the Magniphase system in the event of an arc is quite rapid, and the resulting interruption is likely to go unnoticed by the transmitter operator. Since the frequency of operation of the protective system is an indication of antenna-system stability, it may be desirable to install a warning alarm system.

The Magniphase bridge unit has a spare relay contact appearing at unit terminal

*TB*1-2 which is available to actuate such an alarm. From this terminal, a simple bell or chime can be connected to sound at each operation of the unit. Alternately, a latching relay can be utilized to give a continuous alarm on unit operation until manually reset.

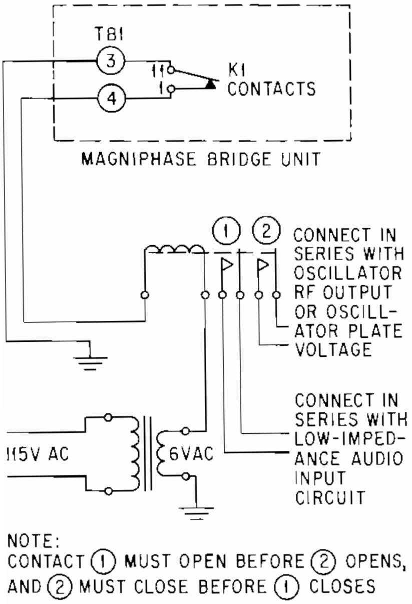

FIG. 8-10. Relay cutoff circuit.

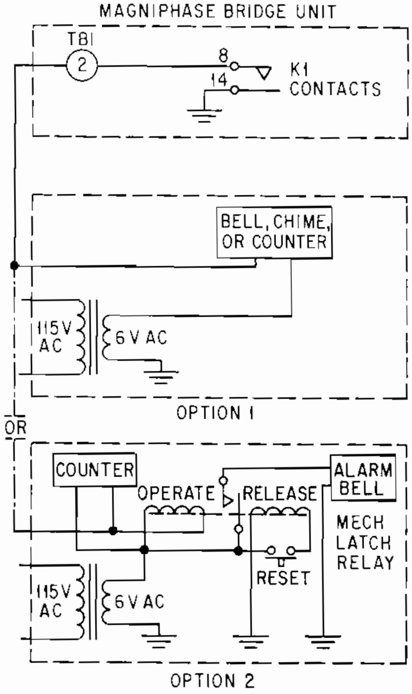

FIG. 8-11. External alarm and counter circuit.

A further variation of interest is the inclusion of an electrically operated counter to register the number of interruptions experienced within a given period. Typical circuits for these arrangements are shown in Fig. 8-11.

Magniphase Specifications

1. Frequency range: 0.54 to 1.6 Mc
2. Transmission-line impedance: 50 to 250 ohms, unbalanced
3. Transmission-line coupler: available in 5–10-kw and 50-kw models
4. Outputs:
   a. Instantaneous bias cutoff output for transmitter squelching
   b. Relay-contact cutoff circuit for externally operated transmitter cutoff
   c. Relay-contact output for operation of external alarm
5. Meter: externally mounted to indicate null at bridge balance
6. Tube complement: 6AL5, 2D21
7. Power input: 115 volts ±10 per cent, 60 cycles, 25 watts
8. Size:
   a. Bridge unit: front-panel size, 2½ by 9½ in.; projection behind panel, 5½ in.
   b. Line coupler: 5⁄10 kw, 2 in. diameter by 11½ in. long; 50 kw, 5 in. diameter by 6½ in. high
9. Shipping weight per system: 10 lb, approximate

Part 9

MAINTENANCE OF TELEVISION AND RADIO EQUIPMENT[1]

NAB ENGINEERING DEPARTMENT

PREVENTIVE VS. CASUAL MAINTENANCE

Many television broadcasters have come into the field from AM-FM broadcasting bringing with them the same theories of operations which they followed in aural broadcasting. In a large number of areas, this thinking serves admirably—certain techniques are similar or, at most, require only such changes as come from adding sight to sound. There are fields, however, where the change experienced in transferring from audio to video seems to present much greater problems. One of these is maintenance. A study made by NAB in the early part of 1952 revealed that, of the 108 television stations then operating, a typical medium-sized station employed 61 people. Twenty-two of these were in the engineering department, and of the 22, 2 were full-time maintenance engineers. That is, two men were scheduled full time to check equipment in an attempt to prevent equipment failures. Hereafter, when the term "preventive maintenance" is used, it is this type of operation we mean. "Casual maintenance" is considered to be only routine checks or repairs made after equipment failures. The television broadcaster may wonder at first why a regular preventive-maintenance schedule should be necessary for television when he has been getting along very well with casual maintenance in aural broadcasting. The answer lies partly in the far more complex equipment needed for television and partly in the higher expense and income associated with television.

As an illustration of the latter reason, the failure of a single relay or contact in a switching system could result in the loss of a commercial spot announcement. Going back to the typical medium-sized station mentioned above, this means a loss in the neighborhood of $200, this loss being a little more than the amount needed to pay the maintenance man's salary for a week according to the same NAB survey mentioned above.

In all fairness to those broadcasters who firmly believe casual maintenance is enough in the television station, it must be pointed out that some highly successful operations have no maintenance engineers as such. An examination of their methods will reveal, however, that transmitter and studio technicians spend a certain amount of their time checking equipment not in use while the station is on the network or in other ways fitting some maintenance into their daily working schedules. Furthermore, these technicians will be found to be highly experienced men who are familiar with the circuitry of the equipment and excellent "troubleshooters." It will thus be seen that while no formal preventive-maintenance schedule is in force in the station, a

[1] Although this material was written with the stress on television equipment, practically all the information, where applicable to radio equipment, is equally valid for radio stations.

larger percentage of the working day is being spent in maintenance in the television station than is usually spent in maintenance in an FM or AM station. It remains a problem requiring a decision to be made by each broadcaster as to whether he will hire maintenance men who can keep the equipment in good operating condition and be able to use less experienced men at the transmitter and studio or he will hire technicians who have the experience, knowledge, and "feel" for maintenance and who can get the station back on the air quickly in the event of equipment failure. It may be mentioned, too, that his decision may have to be based on union classification.

In this part, a suggested preventive-maintenance schedule is shown and a few suggestions of a general nature are listed in the hope it may provide the prospective broadcaster with a beginning to which he can add such procedures as are pertinent to his particular type of equipment. Each piece of television equipment will have its own individual characteristics, and specific operating procedures for each equipment item are furnished by the manufacturer. It is suggested that a collection of all the instruction books for the equipment in the new station be gathered together, and from this collection, specific details can be drawn to supplement the general material which follows.

The object of any maintenance program, whether it be preventive or casual maintenance, is to keep the equipment operating at optimum—to satisfy the regulations set forth by the FCC—and to keep operating costs down. Although the most careful and thoughtful maintenance program cannot always prevent occasional equipment failures, the symptoms of impending failure can often be observed during the day's operation, and a well-defined system of reporting to the regular maintenance crew should be developed. At the transmitter, the log is the logical place. If it is a chart-recorded log, so much the better. At the studio, the workshop should have a regular place to put notices of equipment troubles. After the maintenance man checks the item noted as being faulty, he makes such adjustments or repairs as are necessary and initials the notice with the notation "adjusted," "tube changed," or whatever work was done. The sheets or logs are kept on file after completion of the work, and over a period of time they provide a good source of study for the idiosyncrasies of each equipment item. From a collection of this nature, conclusions can be drawn as to what type of trouble to expect from each piece of equipment, and in many cases equipment failures can be foreseen and corrected in advance of failure.

In the following pages, a general outline of preventive maintenance is given. Complete details applicable to all kinds and makes of equipment naturally cannot be given, nor is it the purpose of this part to replace the specific instructions given by the manufacturer for the care and maintenance of each equipment item. The purpose of the discussion is rather to supplement these specific instructions by a few notes and suggestions made by station operators as a means of gathering together in one place the beginning of a maintenance manual. The value of such a manual to each station depends entirely on supplementation by recommendations drawn from (1) the manufacturers' instruction manuals and (2) the experience of the chief engineer and his staff as the station develops.

STUDIO PREVENTIVE-MAINTENANCE SCHEDULE

Daily

Dust.

Check for signs of overheating on all equipment.

Check pickup equipment for abnormal conditions such as position of control knobs and poor picture quality which may not have been reported.[2]

Check cameras for geometric distortion, alignment, and resolution.

The scanning system of the film photographic sound track must be checked. The alignment of the exciter lamp filament with the optical assembly should be checked.

[2] During camera setups, need for unusual control settings should be observed by the operator and reported.

Optical assemblies and any apertures in the light path should be cleaned. Dust can be removed by blowing air across the lens faces with a syringe bulb and wiping with lens tissue. Photocells should be examined for oil on the glass.

Projection leuses should be wiped with lens tissue. Coated lenses should be cleaned very carefully in accordance with the manufacturer's instructions.

Check the need for unusual control-knob settings on the synchronizing generator.

Clean film projectors in accordance with manufacturers' instructions, checking especially for accumulations of dust, lint, and emulsion on gate, pressure shoe rollers, teeth, picture aperture, etc.

Visually check the microphone and other cables for serious abrasions from pinching, kinks, etc., which may lead to broken wires internally.

Weekly

Thorough internal and external cleaning of cameras, camera controls, monitors, and power supplies. Check insulation on lead wires to power lines and replace lines if necessary.

NOTE: On delivery or after a major repair job or change in equipment, a thorough inspection should be made of all connections, checking for rosin joints and poorly soldered connections by firmly pulling on wires and leads. Connections incapable of passing the required electrical current can be corrected before equipment failures.

Check and record cable socket voltages on cameras.

Run test checks on cameras and projectors using test charts, slides, or films such as those recommended by EIA or SMPTE.

Check the amplitude and pulse widths of the synchronizing generator.[3] Aging of tubes may cause some small variations which can be overcome by adjustment.

Oil film projectors.

Check and clean fader controls on both audio and video equipment.

Check microphones for proper output. *Warning:* Do not use an ohmmeter or other circuit checker, since they may damage the ribbon or diaphragm.

Check the air filter on the power supply, and clean or replace if it is clogged.

Lubricate the wheels and moving parts of camera dollies and booms, microphone booms, pulleys for studio lights, and mechanical parts of studio cameras (pan and tilt and optical focusing mechanisms, etc.).

Monthly

Record and compare cable socket voltages on all equipment. Check adjustment of all control knobs, and readjust where necessary.

Check tubes on all equipment, using a good mutual-conductance tube tester. Generally, tubes should be replaced in the same sockets from which they were removed. Tubes with weak emission should be replaced with spares known to be good. After tube checks, equipment should be operated and tests run to ensure that no unusual conditions have resulted from tube removals and replacements.[4]

Check and clean relays and switch contacts in all equipment. Some relays in more recent systems are protected sufficiently from dust and dirt and may not need such frequent inspection.

Low-level audio tubes and audio amplifiers with "plug-in" chassis should be moved in and out a few times to renew the contact between fins and sockets.

NOTE: Voltage and waveform charts for each type of equipment will be furnished by the manufacturer and should be regarded as standards by which to compare test checks.

[3] Some manufacturers recommend that this be done daily.

[4] An interesting discussion of tube testing in regard to spotting early failures is contained in *Electronics,* vol. 32, no. 30, July 24, 1959.

After 1,000 Hours

Blowers should be cleaned and oiled in accordance with instructions furnished by manufacturer.

FIELD PICKUP (REMOTE) PREVENTIVE-MAINTENANCE SCHEDULE

(This is also applicable to STL)

NOTE: These daily, weekly, and monthly schedules will naturally be revised in accordance with usage given equipment.

Daily

Check the switching system for abnormal conditions such as poor picture output when compared with input.

Check cameras for geometric distortion, alignment, and resolution.

Check pickup equipment for abnormal conditions (see Studio Preventive-maintenance Schedule).

Check all equipment for overheating.

Dust.

Weekly

Clean cameras and power supplies internally and externally (see notes on Studio Preventive-maintenance Schedule).

Check and readjust controls.

Inspect and tighten cable connectors and clamps.

Check amplitude and pulse widths of synchronizing generator. (Some manufacturers recommend that this be done daily.)

Lubricate moving parts of cameras (see Studio Preventive-maintenance Schedule).

Check and clean fader controls on both audio and video equipment.

Visually check weatherproofing of cables, connectors, and other parts of equipment subjected to weather.

Check batteries on audio equipment.

Monthly

Check tubes on all equipment (see Studio Preventive-maintenance Schedule).

Record and compare cable socket voltages.

Check the air filter on the power supply, and clean or replace if it is clogged.

Check and clean relays and switch contacts in all equipment (see Studio Preventive-maintenance Schedule).

After 1,000 Hours

Blowers should be cleaned and oiled in accordance with instructions furnished by the manufacturer.

If a field-power generating system is used, the internal-combustion engine and the generator should be given equal weekly and monthly attention. See manufacturer's instructions on this.

TRANSMITTER PREVENTIVE-MAINTENANCE SCHEDULE

Daily

Check the filament line voltages every hour, and adjust if required. FCC Rules governing transmitter logs require that the operating constants of the last radio stage of the aural transmitter (total plate current and plate voltage), transmission-line meter readings for both transmitters, and frequency monitor readings be observed and recorded half hourly.

Check visual and aural monitoring circuits, observing both voltage and current meters. Changing current or voltage indicates either deteriorating tubes or equipment. If the operator observes any rapid changes, a sufficient note should be left with the log as instructions for the maintenance crew.

Dust and generally inspect for overheating or other signs of abnormal operation.

Weekly

Check all tubes which are not metered in the transmitter.

Clean the internal parts of the transmitter (insulators, etc.). Check of noise, distortion, and frequency characteristics of aural transmitter generally. Check the visual frequency and broadband characteristics of the visual transmitter generally.

(On the last two mentioned checks, spot checks will ordinarily suffice on a weekly basis. However, in this case, a more thorough check should be made monthly.)

Inspect blowers and flow meters. Clean and/or lubricate if required.

Test door interlocks and disconnect switches, being certain that they result in interruption of high voltage when access doors and windows are opened.

Check and operate all relay contacts. Observe closely for heating.

Check transmission lines for tightness by observing gas or air pressure.

Add distilled water to cooler unit if required.

Correct all meter needles to normal nonenergized readings.

Monthly

Inspect and lubricate small blower motors.

Test spare tubes.

Clean socket contacts if necessary.

Service relay contacts if necessary.

Check air filters, and clean or replace as necessary.

Visually check the condition of the water in the cooling system.

Quarterly

Operate all spare mercury-vapor tubes for 30 min. (See instructions furnished by the manufacturer.)

Inspect every unit in transmitter in detail, using tests recommended by the manufacturer.

Service all power contactors if necessary after inspection. Flush and refill the water-cooling system.

Make a visual inspection of the physical condition of the antenna tower and transmission line.

Inspect and test tower-lighting equipment according to Part 17 of FCC Rules.

Semiannually

Tighten all connections, both electrical and mechanical, in the transmitter and associated equipment.

Lubricate exhaust fans.

Lubricate high-pressure blowers, and check the operation of the air interlocks.

Lubricate the water-cooling system.

Check the outdoor protection to the water-cooler intake before cold weather and for free circulation before summer.

SAFETY

Every possible means of affording maximum protection to personnel working in the television station should be considered. Television equipment has been designed to operate safely as long as reasonable care and judgment are exercised, but it cannot be too strongly impressed on every person coming into contact with the equipment that the safety rules for handling each item must be observed, since the high voltage of certain components is sufficient to endanger life. Some general safety precautions are given below, and more will probably suggest themselves to the station operator and can be added.

1. Inspect safety interlocks regularly for proper functioning. Check leads and connections to grounding hooks.

2. Check ground connections for tightness.

3. Check insulation on all leads regularly. Never use leads with broken insulation.

4. All high-voltage capacitors should be discharged before they are touched by the operator. Although "bleeder" resistors do discharge capacitors after a reasonable time, in consideration of the voltages used, it will still be safer to discharge the capacitor with a shorting bar. Due precaution must be observed in the removal of the shorting bar.

5. Rubber gloves should be worn when working on high-voltage equipment, and a rubber sheet should be placed over the sill of the transmitter compartment or over any place where it is possible for the employee to come into contact with live equipment.

6. Before repairs are made on high-voltage areas of equipment, instruction books and schematics should be closely studied so that the maintenance man is thoroughly acquainted with the equipment before starting work. It may also be pointed out here that *high voltage sometimes appears at unexpected points in defective equipment.*

7. Ground leads of oscillographs should not be connected to a high-voltage point, since the ground lead of most instruments is connected internally to the case.

8. When high voltages are measured, consideration should be given to both a-c and d-c voltages present, and peak voltages should be taken into account when selecting voltmeters and multipliers.

9. Rubber gloves and blankets will not afford protection against high radio-frequency voltages. When work is done on circuits carrying high RF voltages, the circuit should be inoperative before work is begun.

10. Extreme care must be used when touching tubes that have been in operation for a considerable length of time, since serious burns can result. This is true even of small tubes.

11. Pressure developed on the envelope of large vacuum tubes is extremely high, and when the tube envelope is broken, it must be remembered that the tube will implode—not explode. This means that there is a possibility of the tube base being projected through another portion of the tube. For this reason, tubes should be kept in cartons until time for their actual use. Safety goggles and gloves should be worn when handling large vacuum tubes. Spectators should be kept at a safe distance whenever a tube is outside its carton.

A means of disposition of these tubes must be found, bearing the above hazards in mind, to prevent the scattering of shattered glass and the possibility of the tube elements and base flying free. One suggestion is that the tube should be placed in a shipping container, the container sealed, and a crowbar or similar instrument driven through its top. Another suggestion is that the tube should be placed in a shipping container, leaving the neck or gun end of the tube exposed. A tarpaulin or burlap bag is thrown over the neck to deflect any glass, and the neck is struck sharply with a hammer.

12. It is not generally known that carbon tetrachloride is a strong toxic chemical and that continued breathing of the fumes is cumulative and can become injurious to health. Its use as an open cleaning agent is not recommended. The Navy has discontinued its use for projector cleaning and recommends that alcohol be used wherever possible.

It must be remembered, however, that alcohol and naphtha are both inflammable, and proper precautions must be taken in using either.

GENERAL

In the following pages, some amplification of the preventive-maintenance schedules will be found. In some cases, it may seem that the emphasis has been shifted from "preventive" to "casual" maintenance or from maintenance to operation principles. These are the areas where experience of presently operating stations has indicated a need for calling special attention of the technical staff of the new station.

Certain principles of maintenance are common to all types of equipment. For example, throughout this article, frequent mention is made of the removal of dust from equipment. This is extremely important because, among other things, excessive dust may lead to current leakage or arc-over between high-voltage points. Obviously, dust will do more damage to open equipment than to completely enclosed equipment, but daily efforts must be made to keep the collection of dust at a minimum on all equipment.[5] We are reminded of the story of a government agency which was said to have employed both "high dusters" and "low dusters," each having specified areas of work and each employing different tools and practices of dusting. The problem of dusting in the television station requires tools ranging from soft, lint-free cloths and absorbent pads to vacuum cleaners. A small hand-type vacuum which can be reversed and used as a blower may be a wise investment for the station. Various sizes of paint brushes will be helpful in removal of dust and lint from small equipment items. When cloths and brushes are used, they should be absolutely dry or moistened with a volatile liquid such as carbon tet, alcohol, naphtha, etc.[6]—never with oil.

All equipment tests should be made as soon as possible after the close of the day's programming or after the last use of the equipment item during the day. After tests or checks are completed, the equipment should be placed in operating condition to be sure that it is functioning properly. Before any tests are begun, instruction books and schematics should be closely studied and safety precautions observed. Inspection can be made by feel (for overheating), by smell (this often locates an overheated part such as a transformer or reactor), and visually inspection for loose, broken, warping, or cracked connections and broken parts, insulations, or wires.

Before dismantling any part of the equipment, be certain the correct input signals and voltages are being applied. (In other words, there is no use dismantling the engine of a car if it's just out of gas.) The correct input signals and voltages are supplied by the manufacturer as part of the operating instructions.

Be logical—check the obvious first. In the section relating to the synchronizing generator, it is pointed out that personnel should be briefed at least semiannually on the possible causes of failure. This same procedure may well be used with all other major equipment items in the station. Also, as mentioned above, instruction books, schematic drawings, and other technical data on the equipment should be readily available to all technical personnel.

The notes on tube checks found under Camera Chains apply to all tubes used in the television station as do the notes on regular cleaning and inspection of cable connectors and the measuring of cable socket voltages.

TESTS AND TEST EQUIPMENT

Many television stations initially going on the air have underestimated the need for appropriate test equipment only to find themselves later on faced with the need for purchasing more such equipment. In addition to the more common test equipment such as tube testers, volt-ohm meter, etc., normally associated with aural stations, television stations require one or more good oscilloscopes, video sweep generators, audio oscillators, noise and distortion meters, and a device for checking scanning linearity such as a grating or bar generator. Depending upon the complexity of the installation more or less equipment may be required. The FCC requires that certain standards with respect to the over-all attenuation characteristics of the visual transmitter must be maintained, and the aural transmitter and entire audio

[5] Many stations have installed electrostatic filters in the air-conditioning system to remove dust before it enters the building. Such filters are also installed in the blower system of air-cooled transmitting compartments and tubes.

[6] See Note 12 under Safety.

system must meet certain well-defined operational characteristics with respect to distortion and frequency response.

Film Projectors

Specific details for the operation and maintenance of each of the many types of film projectors will be furnished by the manufacturer. These instructions should be carefully read by every operator who handles the projector and kept handy for ready reference at all times. There are, however, a few general remarks that can be made on the subject of film projectors:

1. *Cleanliness.* The projector film path should be cleaned thoroughly daily, and accumulations of emulsion or other dirt removed with a toothbrush or flat, pointed toothpick and cloth moistened with carbon tetrachloride or alcohol, which must not leak into the mechanism. In cleaning lens surfaces, do not blow on the surface of the lens, as this may force vapor back into the lens mount. The lens tissue can be moistened with the breath or lens cleaning fluid.

2. *Oiling.* Always use the type of oil recommended by the manufacturer. Different weights of oils are recommended for different parts of the projector, and substitutions can cause trouble. Oil flows more freely and penetrates faster when the machine is hot. Be extremely careful not to overoil the projector, since the oil may leak onto the film. For the same reason, be careful not to spill oil about the projector.

3. *Handling lamps.* Before placing a new lamp in the projector, wipe off the lamp surface with a clean, lintless cloth. Fingerprints left on the surface of the lamp will bake into the glass and be difficult to remove later.

4. *Spares.* A complete set of tested spare lamps, tubes, fuses, belts, and other parts subject to wear should be kept on hand at all times. In replacing fuses, be sure that the new fuse does not have a higher power rating than the old one.

Following are some of the major "troubles" which occur in the film projector. It will be noted that many of these troubles arise from the presence of dirt, improper control settings, or tube failures—all of which can be anticipated to some extent by a sound preventive-maintenance schedule.

Loses film loops—tears sprocket holes: Feed the sprocket or film pressure shoe out of adjustment. Adjust as explained in manufacturer's instructions. Other possible causes are dirty or worn claws, claws out of adjustment, torn film, or bad splices. Daily cleaning will prevent accumulation of dirt and emulsion on claws, sprockets, and pressure shoes. Proper splicing and preediting will save time and trouble in the long run.

Noisy projector mechanism: Check the adjustment of claws, roller chain, drive chain, and gears. Adjust as recommended by the manufacturer.

Travel ghosts and picture jump: Check the projector synchronization of the shutter with the pull-down mechanism. The trouble may be a shutter out of adjustment, improper threading, claws worn or out of adjustment, worn rails or camshaft. Bad or poorly made film causes the same symptom. It is well to check the projector with standard film selected for this purpose.

Indistinct picture or low illumination: The projection lens, condenser lens, or reflector may be dirty, or the projection lamp may need replacement. Dense film may cause the trouble. Check with the standard film.

Film scratched: Film shoe, pressure roller, aperture plate, or guide rollers may be dirty or emulsion coated. On 35-mm projectors, check the fire rollers in the upper and lower magazines for accumulations of fuzz and grit, which will scratch film.

Note: *The last three troubles mentioned may be on the film in use. Previewing of all film is recommended.*

Picture, but sound weak or distorted or no sound: First, check the audio-level control and threading system. These are the principal causes. Open or shorted cables, burnt-out fuses or lamps, improper seating of photoelectric tubes, and improperly adjusted sound mirror are also frequent causes. Check for obstruction of light beam by foreign matter. If the trouble is still not located, check further by manufacturer's instructions.

Sound, but no picture: The projection lamp may be burnt out.

Oscillation in preamplifier: Loose ground wires, output leads too near the input leads, or defective bypass capacitor may be the cause.

Hum level high: Check the shield on the audio line or photoelectric cell; filtering of photoelectric-cell voltage or bad tubes may be the cause.

No photoelectric-cell voltage: The a-c power may be off. Also check filter capacitors and rectifier tubes in the preamplifier and the fuse in the a-c line to the preamp and for open resistors and broken or shorted wires.

Microphonics: This may be caused by loose connections, poor contact between plug and socket, loose elements in PEC, or oil-soaked wiring. Also check the projector mechanism for excessive vibration. (Preamplifier tubes are often microphonic.)

Distortion: The cause is most often found to be tube trouble, defective PEC, or sound optics out of adjustment. Other causes are due to leakage in speech lines or open coupling capacitor.

Tone unsteady—wows: Check the tension of the pressure roller. The sound drum may be dirty or damaged. Check also for dirty pressure rollers and dirty guide rollers. The sound drum shaft or bearings may be loose or worn. A defective motor or drive mechanism could cause unsteady tone.

Motor Repairs

All adjustments and repairs to the film-projector motor should be made with *power turned off*. Try to avoid loosening the shutter from the rotor shaft, as this will require readjustment of the shutter for proper synchronization. Failure of the drive motor to start, not running at proper speed, acceleration time too long, or the drive motor starting then stopping usually indicates excessive loads or improper line or field voltages. Check for open switches, loose connections, or breaks in power wiring. Regular maintenance schedules should include proper cleaning and oiling to prevent overheating of bearings in the blower motor and drive motor. Check and tighten the motor coupling and attachment of the motor to the bed plate. (In tightening screws, avoid forcing them and damaging threads. If necessary, remove the screw and replace with a new one.) Included in the regular maintenance schedule should also be repairs and replacements of brake resistors and relays on projector mechanism.

The following section on Precision Adjustments was provided through the courtesy of the Society of Motion Picture and Television Engineers.

Precision Adjustments

Television Test Film. This film is designed to indicate the condition of operation of those portions of the television-film-reproducing system which depend upon the relation between the film projector and the television system.

Use of the test film on a routine operational basis is recommended, since it will indicate errors of adjustment and equipment malfunction before they might otherwise be detected and before they adversely affect the quality of the transmitted picture.

Several test sections and a selection of scenes comprise the complete film, which is available in 16- and 35-mm widths. The test sections are a series of geometrical patterns intended to present information on the factors most likely to be degraded in television-film reproduction. The test targets appear in the following order: alignment and resolution, low-frequency response, medium-frequency response, storage characteristic, gray scale, and brightness control. Each section is preceded by an explanatory title. For the following tests, 16-mm test films are used.

Sound Optical Assembly Adjustment. Two types of film are available, a 7,000-cycle record for precision adjustments following overhaul and a 5,000-cycle record for quick service adjustment. Both films are original recordings rather than print. Each carries a special square-wave track which was chosen because its output changes more rapidly with changes in the focus of the assembly than the output from the usual sine-wave high-frequency track and also gives a sensitive indication of the errors in azimuth adjustment. Films are used as loops, and adjustments are made for maximum output meter readings.

Alignment of the Sound Record with the Scanning Beam. Buzz track test film is used for this purpose. The track consists of an 0.076-in. opaque center with a square-wave signal frequency of 300 cycles recorded just outside that area on the picture side and another of 1,000 cycles just outside that area on the side nearest the film edge. Guides should be adjusted so no sound is heard from either frequency.

Standard sound-record widths are 0.060 to 0.072 in. Some sound optical assemblies produce a light of sufficient length to reproduce both frequencies when the assembly is only slightly out of adjustment.

Buzz track film is an original recording made on a special machine built for that purpose.

Uniformity of Scanning-beam Illumination. This film requires the use of an output meter and a picture projected light on the screen. A narrow sound track 0.005 in. wide modulated at constant level by a 1,000-cycle tone sweeps across the scanning light beam from one end to the other at a uniform rate, the position of the sound track relative to the ends of the light beam at any instant being shown by an animated diagram appearing in the picture area.

If the scanning-beam illumination were absolutely uniform across the width of the scanned area, the output of the 1,000-cycle tone would be constant. In practice, however, some variation of the meter reading will always be observed. The film is made up into loops of 34 ft for the laboratory type and 3½ ft for the service type. By running a loop continuously and observing the indications of the output meter while adjustments are made, it is usually possible to correct unevenness of illumination and bring the variations of output within a limit of ± 1.5 db. Sometimes a new exciter lamp will correct uneven meter readings.

Flutter. The 3,000-cycle flutter-test film is a direct positive original recording and carries a 3,000-cycle tone having extremely low flutter content for use in measuring the flutter introduced by sound reproducers. A flutter meter is required to make this measurement. The total flutter content of the film at the time of shipment is less than 0.1 per cent.

System Frequency Response. The multifrequency test film is a direct positive original recording and is used to obtain the electrical frequency response at the output of the power amplifier. Each film is individually calibrated and contains 14 frequencies each preceded by a spoken announcement. The deviation of the test-film record from the intended flat-response characteristic is stated as a correction for each frequency which will give a true level when it is added algebraically to the output level measurement obtained when using the film.

Calibration data and instructions are packed with each film.

System-gain Test. The 400-cycle signal-level test film is a direct positive original recording designed to furnish as nearly as is practicable an absolute standard of recorded signal level for use in measuring the effective amplification and output of sound systems, taking into account the sound optical system and phototube as well as the amplifier.

Travel-ghost Test. Travel ghost is a blurring effect in the picture as seen on the screen and evidenced by vertical tails or light streaks added to the projected images of the transparent area on the test film. It is caused by the projector shutter being out of synchronism with the intermittent mechanism.

The test-film travel-ghost target shows improper timing of the shutter quite readily and gives a clear indication of the correct adjustment.

Picture-steadiness Test. This film permits the unsteadiness of a projected film image to be measured. As a steadiness reference there are three round holes punched in the picture area. The two lower holes are produced by a single punch stroke that is indexed from the adjacent standard film perforation, the one that locates that particular frame in the aperture on many projectors. The upper hole is produced by the succeeding stroke. Relative motion between the upper hole and the lower pair is a direct indication of inherent unsteadiness of the film resulting from expected inaccuracies in the perforating of the film because it is a plastic material.

Simultaneous motion of the upper hole with the lower pair permits the image unsteadiness produced by the projector under test to be observed. Residual unsteadiness of films approved for sale is no greater than 0.05 per cent of picture width.

Check of Final Results. A film containing picture and sound of known quality should be selected.

The Research Council sound-projector test film contains three dialogue samples, a female solo sample, and orchestral and piano music.

The SMPTE produces a sound service test film which contains title music, buzz track, sound focusing test, constant frequencies from 50 to 6,000 cycles, dialogue, and piano music. This film is intended to provide an inexpensive over-all quick test of projector performance.

A complete list of 35- and 16-mm test films is shown in the catalogue of the Society and is available for the asking.

Camera Chains

The most frequent cause of trouble here is small tube failure which can be prevented to a large extent by regular tube checks. Tubes with weak emission can be replaced by ones known to be good. Spares should be kept at hand at all times for quick replacement if trouble occurs while the camera chain is operating. In making replacements, be certain that power is *off*, and that capacitors are *discharged*. Here, as in most constantly operating equipment, serious burns can result from carelessly touching tube envelopes.

Another frequent source of improper operation is failure to check control settings. It is suggested here that the approximate control settings be written or typed on a small card to be fastened to the camera for the benefit of inexperienced personnel.

Tube Checks

One simple method of testing the tubes in a circuit for the presence of microphonics is to tap each tube lightly with the eraser end of a pencil. A "noisy" tube can be located by observing the raster of the picture monitor during the test.

When tube checks are made, tube testers of the emission type should be avoided, using mutual-conductance tube testers instead where applicable. A permanent log of the usage on all image orthicons, iconoscopes, etc., is suggested. Experience has shown that such logs (or card files) will often point out tubes likely to go bad in the near future and may often show up repeated failures of a certain tube which can then be traced to defective or partially defective circuitry or possibly to a defective lot of tubes.

Waveform and voltage charts will be furnished by the manufacturer of each type of camera and should be regarded as standards to be used in tests on each individual camera.

In addition to the monthly tube checks suggested in the preventive-maintenance schedule, frequent checks on cameras for geometric distortion are suggested. These may be effected by use of test pattern charts, slides, and film as recommended by EIA and SMPTE.

When faulty operation of the camera occurs, the four major circuits of the camera ordinarily can be checked quite easily as follows:

Vertical deflection: Check waveform.

Horizontal deflection: Check waveform.

Operating potentials of picture tube: Remove the tube and check voltage and control ranges.

Picture amplifier: Touching the grid terminal of the input stage with a screwdriver or other small "antenna" will usually produce oscillations if the amplifier is all right. If no activity is indicated, checking for lighted heaters in all stages or for cathode bias voltages will often lead to the trouble point.

With these relatively simple checks, the defective area can be isolated and a more detailed examination made. It will be found that the manufacturer's instructions in each case are very explicit.

Synchronizing Generator

The timing, formation, and shaping of a television picture signal which will conform to the standards set by the FCC start with the proper functioning of the synchronizing generator. Fortunately, the newer types of synchronizing generators give very little trouble over long periods of time. It has been suggested that since this is the case, an effort be made at least semiannually to acquaint personnel with the possible causes of failure so that when trouble is experienced, the operator will have some idea where to look for the cause.

Two of the most common causes of failure of the synchronizing generator are variations in the power supply and tube failures.

Deviations in the power supply will, among other results, cause the picture to "roll." This can be guarded against by regular checks on power supplies and tolerances in voltage-regulation equipment, which, in most cases, is required to ensure reliable operation.

As the tubes in the synchronizing generator grow old, they may cause small variations in the amplitude and pulse widths of the output signals or may cause unwanted pulses to appear in the positive region of the output signal. Unless tubes or voltages vary greatly from normal, pulse shapes can be returned to standard by adjustment of external controls.

The small vacuum tubes used in this equipment item are relatively stable, but quite often slight variations in operating characteristics of similar types of tubes dictate that each tube be replaced in its former socket after it has been removed for testing. (This may be found to be good practice throughout all other equipment in the station.) After a tube has completely failed or as a result of the tube tests is expected to fail soon and is replaced, the synchronizing generator should be checked for proper operation and adjustments made immediately rather than waiting until the next day's operation begins only to find that, owing to the change of one small tube, the generator is not functioning properly.

It has been considered a good policy in many stations to have a second synchronizing generator for use as a spare and to test both before beginning the day's programming to be certain they are both operating properly.

In all equipment of this nature where a large number of small tubes is employed, many stations have found it profitable from a standpoint of economics, as well as trouble-free operation, to keep the equipment running on a 24-hr basis. This practice is applicable in many sections of the equipment of the station where the daily thermal cycles definitely cause deterioration of tubes and parts.

Field Pickup (Remote) Equipment

Periodic inspection and cleaning of equipment used outside the studio is especially important, since it is constantly subjected to jolting, to conditions of excessive dust and moisture, and possibly to wide variations in primary sources of power.

Particular attention should be paid to the removal of dust, which may cause current leakage or arc-over between high-potential points. Needless to say, all surface dust should be removed before internal cleaning is begun in order to prevent dust particles from falling inside, where they may be hard to dislodge. All bushings and terminal boards should be kept free of dust.

Frequent visual electrical and physical inspection of wires and terminals becomes even more important on field equipment, where connections may become strained from jolting during moving from one location to another. Good, firm (but careful) pulls on lead wires may reveal high resistance or broken connections, which can then be repaired before failure occurs.

When fuses are renewed, fuse cartridge caps should be clean and dry to ensure good contact and to prevent fuse heating due to contact resistance.

One of the more frequent causes of trouble in field equipment is the improper setting of controls. Controls can be properly set before the equipment leaves the station, but it may be also found helpful to record the approximate settings on a small card, which can then be attached to the equipment item and referred to at the remote point. This is particularly true when the equipment is operated by several different technicians rather than by one man who always has the responsibility for remote setups.

Camera lenses should be removed before leaving the station, covered with the lens caps, and stored in felt-lined carrying cases. Such cases should be both moisture- and dustproof.

The remote vehicle should have spare tubes, cables, fuses, and other parts subject to wear within instant reach of the technicians.

Tubes

It has been found that a television station equipped for both film and live telecasting employs around 1,800 tubes in the over-all system of studios and transmitter. These tubes range from the inexpensive miniature type to the image orthicons, which cost about $1,200 each. Naturally, it is impossible in an article of this type to cover the idiosyncrasies of such a variety of tubes completely, but since tube failure is one of the major causes of equipment failure, it may be well to point out a few general precautions to be observed in their handling.

To begin with, the life expectancy of a tube used in video circuitry is not always so great as that of the same tube when used in audio equipment. However, many tubes can be transferred to audio service when they are found to be no longer useful in video, provided, of course, that the length of service in video has not been too great. A supply of pretested tubes should be instantly available to the operator for quick substitution when necessary. It may be found desirable to have certain tubes premarked for location.

A record of test readings and hours in use on all critical tubes is considered desirable. In addition to revealing tubes which are likely to fail in the near future,[7] such a record may also reveal types of tubes which are not giving satisfactory service and which should be studied closely to determine the cause of failures (see notes on Camera Chains). Either a card file or a loose-leaf notebook will be suitable for tube records.

Spare tubes, particularly of the transmitting, cathode-ray, and image-orthicon type, should be operated regularly to prevent them from becoming "gassy."

When transmitter tubes are first received at the station, they should be tested at a time outside the regular hours of operation or into a dummy antenna if this is available. The "tube biography" is then begun with the date of test and condition in which the tube was received being the first entries. Transmitter tubes are guaranteed for a minimum number of hours, and a prorated rebate is made by the manufacturer if failure occurs before the completion of the guarantee. Therefore, a record of the number of hours in operation and other pertinent data is essential for each tube until it is eliminated from service, since hundreds of dollars are involved.

Water-cooled Tubes

The proper care and maintenance of water-cooled tubes is of primary importance in ensuring good service. These suggestions are made as a general outline. They should be checked against the instructions given for different types of water-cooled tubes by the manufacturer, since such instructions will vary.

1. Installation of the water-cooling system and of each new tube placed in service should be in strict accordance with the manufacturer's instructions. Improper operation for only a few minutes can ruin a tube.

2. Always use distilled or water of equal purity in the system. Tap water or even the spring water used for office water coolers often contains impurities which become

[7] See previous note concerning monthly maintenance schedule.

electrostatically precipitated and form scale, which interferes with the proper operation of the system.

3. Remove the filter strainer regularly, and clean out any sludge that has formed. This should be done quite frequently during the run-in period and periodically thereafter.

4. After the system is cleaned, water should be circulated for a short time and then the entire system refilled with fresh distilled or equally pure water. Never allow chlorinated water to enter the system, as it greatly increases the corrosion rate of the pipes and ducts in the tubes.

5. Regular oiling and greasing of the system motor should be a part of the maintenance routine.

6. Avoid operating the water-cooling system at too high a pressure, since this will cause excessive water turbulence in the tube passages with the possibility of an increase in microphonics.

7. It is highly important to protect the outside intake of the water-cooling system before cold weather begins. (In one station, the intake system was installed in the basement of the transmitter house with no further protection. The first night the temperature dropped below freezing, the intake system froze, causing a great deal of damage and expense before the situation could be corrected.)

Air-cooled Tubes

In general, the maintenance of air-cooling systems is relatively simple. Air filters should be regularly inspected and cleaned or replaced when necessary. Small strips of cloth tied to the blower will give an instant visual check on whether or not the system is working. A suggestion has been made that when the system is first placed in operation, the temperature of the intake and outgo air should be noted and the differential established as an operating standard for the system. (Each system will be found to have its own differential.) The same temperature measurements can be made monthly, and as soon as a wide departure from the standard appears, a check on the system can be made to determine the cause. In making such a check, try the filters first. The cause will usually be found in a clogged filter. Periodically, jackets should be removed from the tubes and fins cleaned with a soft, lint-free cloth. Fins, of course, should be perfectly clean on initial installation. Fan and motor bearings must not be overlooked. Lubrication will depend on whether the bearings are sealed or open. Sealed bearings require attention only every few years.

High-power Radio Tubes

During the past several years, a substantial number of 50-kw radio stations (AM) have operated their transmitters 24 hr per day with only either a minimum maintenance period of a few hours each week or none for several weeks. These stations have reported to NAB that, contrary to expectation, their reliability of operation and outage records seem not to have deteriorated as a consequence of reduced maintenance.

Manufacturing techniques over the past years have greatly increased the reliability and life of high-power transmitting tubes. Stations in some foreign countries experience some difficulty in maintaining a stock of spare high-power tubes, and concern has been expressed at the consequence of placing spare tubes in operation for limited periods for purposes of degassing and to ensure satisfactory operation. There is always the risk involved of breakage, particularly of tubes that have been operated for several thousand hours, when such tubes are removed and replaced in a transmitter.

Experience over the years has indicated that one of the sources of tube failure is the mechanical stress resulting from repeated heating and cooling whenever the tubes are shut down. In certain installations, it is the accepted practice never to turn off the filaments of the tubes completely. Tubes are operated either continuously at rated filament voltage or at reduced voltage during the periods when no plate voltage is applied. During such periods care must be taken that adequate cooling of the seals is accomplished according to the manufacturer's specifications. It is suggested that for stations subject to the previously mentioned situation, increased life of tubes can be accomplished by application of these general procedures.

Transistors

No specific maintenance procedures are included in this Part for transistors. The reader is referred to Part 1 of this Section for appropriate operating and handling criteria.

LIFE EXPECTANCY AND OPERATING NOTES ON THE IMAGE-ORTHICON TYPES 5820 AND 6474/1854

From time to time the question is raised of how long an image-orthicon tube can be expected to perform satisfactorily. This is an area where no hard-and-fast rules can be laid down, but instead the decision to remove the tube from service must be made on a subjective basis. During the month of January, 1954, the Engineering Department of NAB undertook a survey of 35 member operating television stations in an effort to determine the useful life which was being obtained from image orthicons. It was believed that an exchange of information on the subject would be helpful to station operators. The results of the original survey were acclaimed throughout the industry and were regarded as instrumental in a better understanding of correct operating techniques when using this particular tube.

Since our original report was published, much has happened in the television industry. Our first undertaking reported the findings of only 35 stations as against 225 in our latest survey. Color has now entered the picture, bringing with it a new image-orthicon tube, type 6474/1854. Manufacturers have made tremendous strides in tube development. After reviewing these facts we were of the opinion that the original survey should be revised, using more stations and citing the latest techniques.

It is not our intention to recommend the period of usable life to be expected from the tube. This must remain, as it has in the past, a period to be determined by weighing the picture quality against the cost of replacing the tube. We are merely providing the results of a survey conducted among some of the operating television stations so that you may know what other stations have found as answers to the "cost vs. quality" question.

The Questionnaire

Our questionnaire dealt with two types of tubes: the type 5820, which is used in black-and-white studio equipment, and the type 6474/1854, which is used in the color studio equipment. Our 5820 questionnaire covered seven questions dealing with average life experienced at the station, minimum and maximum life periods, the period of time used to determine these answers, and the criteria used for deletion of the tube from service. We also asked if there were any special techniques used which were believed to lengthen the useful life of the tube.

Our 6474/1854 questionnaire covered six questions dealing with approximately the same subjects as mentioned above.

The Sample

The 5820 questionnaire went to 320 of our member stations. The 6474/1854 questionnaire was sent to 26 of our member stations.

5820 Image-orthicon-tube Survey

201 replies:

11 were not used in this report because (*a*) they did not give filament time, (*b*) they employed *used tubes*, or (*c*) they gave insufficient information for tabulation.

190 questionnaires were used in this report.

#1. *The average life of image-orthicon tube (190 reported):*

	Range	
Average	*Low*	*High*
796 hr	375 hr	2,000 hr

#2. *The minimum life (excluding duds) (189 reported):*

	Range	
Average	*Low*	*High*
519 hr	100 hr	1,835 hr

#3. *The maximum life (189 reported):*

	Range	
Average	*Low*	*High*
1,188 hr	450 hr	3,035 hr

#4. *The criteria used for deletion of tube from service:*

1. Image retention or "sticking"	100%
2. Poor picture quality	46%
3. Lack of target control	8%

NOTE: This does not add up to 100 per cent because some gave more than one criteria.

"Poor picture quality" included loss of sensitivity, resolution, poor gray scale, noise, and lack of contrast.

#5. *Have you noticed any difference in the quality of image orthicons during the last 3 years?*

5 stations gave no answer to this question.

55 answered little or no difference.

17 answered tubes were not as good for various reasons.

3 answered in detail via letters.

110 indicated improvements:

35 stations indicated an improvement in picture quality through use of the new 750 micro mesh tubes.

The main improvement of this tube is the elimination or lessening of moiré. Other improvements in this tube are as follows: better resolution; improved sensitivity; less initial alignment; improved gray scale, contrast, and definition; more uniform in operating characteristics; less noise; higher voltage output; crawling effect reduced; swirl effect reduced; and fewer duds.

A total of 75 stations indicated the following improvements:

	Stations	*Per cent*
Longer life	20	27
Increased sensitivity	16	21
Better gray scale or improved shading conditions	12	16
Better resolution	10	13
Less rejects or fewer duds	7	9

Approximately 15 per cent indicated better quality control and more consistent operating characteristics per tube and between tubes.

Approximately 23 per cent gave the following improvements: decrease in target spots or defects, fewer dynode spots, less noise, better definition, and better beam landing.

NOTE: This does not equal 100 per cent because of combination improvements.

#6. *Do you have any special technique that you believe prolongs the life of these tubes?*

85 stations reported "no" or no answer.

15 indicated used manufacturer's recommendations.

3 gave detailed answer in letters.

The majority of suggested techniques were much the same as those suggested by the manufacturer, i.e., capping of camera when not being used or when on standby and careful attention to lens stops, lighting, temperature, etc.

Approximately 15 stations use the rotation and rest method. The hours varied from 100 to 500 and the periods of rest varied too.

Approximately 12 stations found that resting the tube had no value or that tubes had longer life if used continually. One station indicated that taking tubes out to rest, etc., entails too much handling, which, in itself, could be detrimental to its life.

Other suggested techniques that may be of interest are as follows:

"We have a special flashlight mounted in a lens position on the turret to wipe off the retained image. It picks up 6.3 volts through the iris control connector. This enables us to use tubes that would otherwise be too sticky."

"For the past six months we have experimentally operated camera chains with filaments and plates ON 24 hr per day. Beam and target are turned down when cameras are out of service more than 1 hr. On the basis of limited experience to date, it appears life will be increased. Experiment will continue."

"Beam switch. Interrupts beam during warm up and standby periods. Seems to have increased average life slightly, probably due to operational procedures rather than any electrical effect on tube life."

"Do *not* burn out sticking images on a white background. This has made considerable difference in gray scale and resolution as the tube ages."

"Keep tube from overheating by cleaning out camera regularly. Try to keep light in studio well balanced and prevent overlighting on limbo's and easels. Watch iris openings closely. Never allow a camera to be left uncapped for a long period of time in a lighted area, or a camera to be pointed into lights, strong flares, or bright sunlight without filters on lenses. Also, I do not believe in resting the tubes because it does not help the burning problems. Check power-supply voltage and target control setting regularly. Also I have observed that in finding the knee of a new tube, the tube with the higher iris setting will last longer in service."

Electronic capping was mentioned several times and seems to be satisfactory.

Electronic lens capping is accomplished by replacing the present "target set" switch with a three-position switch. In the center and lower positions, the switch is wired to perform the present functions. In the "up" position, the switch is wired to connect 6–8 volts negative bias to the target and remove the voltage from and ground the photocathode.

A camera thus equipped can be set up on a scene ready to go on the air and the switch thrown to the "up" position, which activates the electronic lens cap, with no fear of burn-in on the orthicon. The switch can be thrown to "operate" position seconds before the director calls for the shot, and there are no adjustments to make. The video man thus has control of capping the cameras and does not have to depend on a cameraman to wave the camera around to prevent sticking.

The photocathode voltage must be removed and the photocathode grounded for the electronic lens cap to work in all cases. Cameras have been set up in bright sunlight for up to an hour with no trace of sticking.

6474/1854 Image-orthicon-tube Survey

24 replies:

11 indicated image-orthicon tube still in service or only one set of tubes used. These 11 gave insufficient informatiou for tabulation; consequently only 13 questionnaires were used in this report.

#1. *The average life of image-orthicon tube:*

	Range	
Average	*Low*	*High*
714 hr	270 hr	1,306 hr

#2. *The minimum life (excluding duds):*

	Range	
Average	*Low*	*High*
460 hr	100 hr	825 hr

#3. *The maximum life:*

	Range	
Average	*Low*	*High*
1,000 hr	400 hr	2,080 hr

#4. *The criteria used for deletion of tube from service:*

1. Image retention or "sticking" .... 12 out of 13, 92%
2. Poor picture quality .... 7 ont of 13, 54%

NOTE: Some gave more than one criterion.

"Poor picture quality" included loss of sensitivity and resolution, poor gray scale, etc.

#5. *Special techniques (4 reported):*

The following comments were made in relation to improvement of usable life:

1. Not overheating. Do not leave on unnecessarily. Proper scanning. Gentle handling.
2. Do not stay uncapped on gray scale for excessive periods.
3. Operate as few hours per show as possible.
4. Cut beam on standby. Switch on each camera to energize protection circuit for beam cutoff.

Operating Precautions

By no means all the sources of difficulty with the image orthicon arise from the tube itself. There are many important precautions and considerations which have been pointed out by the manufacturer and the users. One of these is the position of the tube, not only during its operations but also during shipment and storage. During the manufacture, it is sometimes unavoidable that minute particles become loose and lodge in the neck of the tube. If the tube is placed in a vertical position with the base upward, it is possible that such particles might fall on the target and become adhered. It has been recommended that the tube never be positioned so that the axis of the tube makes an angle of less than 20° with the perpendicular. It is also suggested that all personnel handling the tubes be cautioned never to rest the tube on the optical face of the image end for the above reason as well as the possibility of scratching the surface.

Recommended operating temperatures should be closely followed and checked frequently. Variations from such tolerances may produce afterimage effects and reduced resolution. Recommended temperature range from the target area is from 35 to 50°C, and the bulb temperature should not be more than 5°C hotter at any point. Under ordinary circumstances, the focus and deflection coils and amplifier tubes will maintain proper operating temperatures which can be controlled by forced-air cooling along the entire bulb envelope. Under conditions of extreme cold it may be necessary to use target heating to keep within the temperature tolerance specified, but care should be exercised not to heat the target excessively, thus causing cesium evaporation and reduced tube performance.

The manufacturer (RCA) provides a list of "Do's" and "Don'ts" which apply to the 5820 and the 6474/1854 and which *do not appear per se in the technical bulletin for either type.*

Do's

1. Allow the tube to warm up for ¼ to ½ hr with the camera lens capped and with grid 1 voltage adjusted to give a small amount of beam current.
2. Hold the temperature of the tube within specified operating range.
3. Make sure the alignment coil is properly aligned.
4. Check scene illumination and uniformity of illumination before televising.
5. Determine the proper operating point with the target voltage adjusted to exactly 2 volts above target cutoff.
6. Select a lens stop to permit operation with the highlights above the knee of the light-transfer characteristic for the 5820 in black-and-white cameras and below the knee for the 6474 in color cameras.
7. Use the lowest beam current for best signal-to-noise ratio and gray-scale reproduction.
8. Adjust the beam-focus control for best usable resolution.
9. Cap the lens during standbys.
10. If the lens is left uncapped during standbys, cut off the voltage applied to the photocathode and to the target in order to prevent unnecessary aging of the tube.
11. Give the tube an idle period every 200 hr.
12. Condition spare tubes by operating several hours once each month.

Don'ts.

1. Don't force the tube into its shoulder socket.
2. Don't operate the tube without scanning.
3. Don't underscan the target.
4. Don't focus the tube on a stationary bright scene.
5. Don't turn off the beam while voltages are applied to photocathode, grid 6, target, dynodes, and anode during warm-up or standby operation.
6. Don't operate a tube having an ion spot.

Type 6474/1854 in Black-and-white TV Cameras Gives Outstanding Picture Quality

Use of the 6474/1854 image orthicon in black-and-white TV cameras can give greatly improved picture quality. The 6474, usually referred to as the "color image orthicon," has a target-to-mesh spacing much closer than that in the 5820 image orthicon, and therefore, it has a higher target capacitance. As a result, the 6474 has a light-transfer characteristic featuring a longer dynamic range (gray scale) and an improvement in signal-to-noise ratio.

When used with gamma correction or "black-stretch" circuits for the lowlights, the 6474 can produce pictures with excellent tone rendition and a pleasing photographic effect. Aperture correction can be used to advantage and results in excellent resolution.

TV stations desiring outstanding picture quality should experiment with the 6474 for black-and-white pickup. Such use of the 6474 is common practice in many European TV studios in order to meet the public demand for TV pictures of superior quality.

Discussion of the image-orthicon tube would not be complete without reference to a recent development known as the image-orthicon saver. It has several different trade names depending on the manufacturer. Through the work of Mr. John Wilner, vice-president for engineering, the Hearst Stations, such a device was offered to television stations by these manufacturers. Mr. Wilner's "orthicon saver" used a rotating lens plate with electronic compensation for the mechanical motion. It was for his work which led to the introduction to the industry of this equipment that he was awarded the first NAB engineering award at the 13th NAB Broadcast Engineering Conference, Chicago, Ill., Mar. 18, 1959. The equipment, installed on a television camera, has extended the life of image orthicons substantially and enabled reuse of tubes which had previously been discarded for "sticking."

Hitherto unpublished information indicates that "freezing" of retired image-orthicon tubes at 0°F for periods of 60 days or more fantastically reduces signal-to-noise output and to some extent relieves sticking. The scientific explanation for the phenomenon is not yet clear. It is known that engineers of the American Broadcasting Company and the Westinghouse Broadcasting Company, Inc., have experimented extensively with this new technique.

References

Neuhauser, R. G.: "Optimum Performance of Image Orthicons and Vidicons in Broadcast Service," Reprint ST-893.

Rotow, A. A.: "Reduction of Spurious Signals in Image Orthicons," Reprint ST-752.

Copies of these reprints can be obtained on request to RCA Commercial Engineering, Harrison, N.J.

Miscellaneous

A few other general suggestions on studio equipment maintenance may be mentioned here.

Switching Systems

If a switching system is properly installed and adjusted, little or no maintenance is required. Most modern relay systems are enclosed and have a self-cleaning feature for contacts. Such systems should be tampered with as little as possible. Covers are to be kept dust-free so that, should it become necessary to open them, dust will not fall into the relays. A daily routine of operating each relay will be found of great use in improving the operating record of the equipment and in showing up other equipment failures. Switches in a push-button electronic system require the same care. This should, of course, be done after regular operation hours. Audio faders must be wiped clean frequently, using a soft, lint-free cloth moistened by carbon tet. If relay contacts in either audio or video circuits must be cleaned, this should be done with a blower using clean air and with a burnishing tool made for the purpose.

Monoscope Camera

Other than dusting and cleaning and the regular tube checks, little maintenance is required for the monoscope. Checks on its nonlinearity are easily made during the time the camera is being used to show the test pattern.

Monitors

The monitors are of extreme importance to studio personnel; both technical and production people depend on them for producing programs of optimum quality. In addition to the regular dusting, cleaning, and tube checks, frequent tests should be made for nonlinearity as well as tests for resolution and gray scale. It has been observed in some stations that monitors are poorly maintained as to linearity and focus and are very often made of broken-down or cast-off receivers. Such practice is deemed improper, not only from the technical standpoint but from the psychological effect on producers, directors, actors, and others who may not have the technical knowledge to evaluate the resultant picture.

Stabilizing Amplifier

Improperly adjusted controls and tube drift account for most of the troubles here. Correct signal voltages (as recommended by the manufacturers) should always be available at the input jacks. Regular cleaning and inspection of cable connectors and tube checks will avoid most failures. In addition to the tube checks, cable socket voltages should be regularly measured.

Capacitors

Dust must be removed regularly from high-voltage capacitors, since its accumulation tends to cause arc-overs and increases chances of equipment failure. If the method of cleaning with lint-free cloths is used instead of a bellows, extreme caution must be exercised to see that the capacitor is inoperative and *discharged* before handling. Leads and terminal connections must be regularly checked for loose or broken connections, and the insulators checked for cracks.

An excessive rise in the temperature of a high-voltage capacitor can be detected by placing the palm of the hand against it after a long period of operation. Be certain that the capacitor is inoperative and *discharged* and that the case is grounded before touching these capacitors. High-resistance paths to ground have been known to develop, and a normally "grounded" case conductor can become very "hot" electrically. This may be an indication of impending failure from dielectric leakage or improper ventilation. Prompt replacement will avoid loss of air time from overheated capacitors.

Low-voltage capacitors do not require so much care as those of the high-voltage type but should be kept free of dust, oil deposits, and other foreign matter. Since the leads used here are not so rugged as those in the high-voltage type, greater care is necessary in inspection for loose or poorly soldered connections.

Different organizations have found widely differing lengths of service for electrolytic units. Twelve to thirty months seems to be the minimum and maximum periods of service. Dried-out capacitors are one cause of hum bars in the television image. Excessive temperature rises often result in nonlinear scanning, since the capacitance is known to vary with temperature changes.

Resistors

Check load resistors and terminating resistors at least once each year, and replace if there is a critical deviation. Dust should not be permitted to collect on any resistor, especially in high-voltage circuits. Snap-in resistors should have firm, clean contacts to prevent heating at the terminals. If a resistor is removed for cleaning, be certain to follow through, making sure that it is properly replaced; otherwise damage may result to the equipment when it is energized.

Patch Panels and Cables

In both video and audio systems, jacks and plugs should, of course, be maintained in perfectly clean condition. If a faulty cable develops, it should be removed from service and sent to the repair shop immediately. Plugs in audio equipment should be polished regularly. Visual inspection of the connections is very important.

FIRST AID AND RESUSCITATION POLICY [8]

It should be required that each and every man in technical operations be thoroughly familiar with first aid procedures in the event of an emergency so that his life or the life of one of his coworkers can be saved. *He should be ready to act immediately in any emergency.*

Heads of the technical divisions should *be held responsible* for the carrying out of the program which includes the proper setting up of training classes at regular intervals (preferably every three months), the insistence that each man under his direction duly attends and qualifies, and the maintenance of safety bulletin boards and distribution of pertinent safety information.

The training should include a thorough instruction in resuscitation by a competent instructor, also training in *first aid* with particular emphasis on the type of injuries likely in our operations such as control of bleeding and treatment of burns and general injuries.

General Foreword

Experience, particularly in use of electrical equipment, has shown that all engineers, at times, expose themselves to danger: new engineers because of inexperience, older ones because of overconfidence and habits of work which they have formed. In an endeavor to reduce such exposures, these suggestions have been included.

Although these suggestions cover most of the common accidents, it would be practically impossible to make them cover all, especially those of changing conditions and methods. The purpose is to create the tendency always to *think and act in terms of safety.* In case of electrical shock, it is always important when attempting to free the victim to

1. *Protect yourself* with dry insulating material.
2. *Break the circuit* by opening the power switch or by pulling the victim free of the live conductor. *Be careful and move fast—seconds count. Don't touch the victim with your bare hands until the circuit is broken.*

Procedure to Follow for Prone Pressure Method of Resuscitation

As soon as possible, feel with your fingers in the patient's mouth and throat and remove any foreign body (tobacco, false teeth, etc.). If the mouth is shut tight, pay

[8] Much of this material was obtained from the NBC Engineering Department "Safety Handbook."

no more attention to it until later. Do not stop to loosen patient's clothing, but immediately begin actual resuscitation. Every moment of delay is serious. Proceed as follows:

1. Lay the patient on his belly, one arm extending directly overhead, the other arm bent at the elbow and with the face turned outward and resting on hand or forearm so that the nose and mouth are free for breathing.

2. Kneel, straddling the patient's thighs. Place the palms of the hands on the small of the back with fingers resting on the ribs, the little finger just touching the lowest rib, with the thumb and fingers in a natural position, and the tips of the fingers just out of sight (see Fig. 9-1*a*).

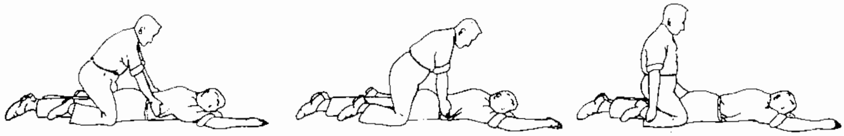

FIG. 9-1. Prone pressure method of resuscitation.

3. With arms held straight, swing forward slowly so that the weight of your body is gradually brought to bear upon the patient. The shoulder should be directly over the heel of the hand at the end of the forward swing. *Do not bend your elbows!* This operation should take about 2 seconds (see Fig. 9-1*b*).

4. Now immediately swing backward so as to remove the pressure completely (see Fig. 9-1*c*).

5. After 2 seconds swing forward again. Thus repeat deliberately 12 to 15 times a minute the double movement of compression and release, a complete respiration in 4 or 5 seconds.

6. Continue artificial respiration without interruption until natural breathing is restored, if necessary 4 hours or longer, or until a physician declares that the patient is dead.

7. As soon as artificial respiration has been started and while it is being continued, an assistant should loosen any tight clothing about the patient's neck, chest, or waist. *Keep the patient warm. Send for a doctor.* Do not give any liquids whatever by mouth until the patient is fully conscious.

8. To avoid strain on the heart, when the patient revives, he should be kept lying down and should not be allowed to stand or sit up. If the doctor has not arrived by the time the patient has revived, he should be given some stimulant, such as one teaspoonful of aromatic spirits of ammonia in a small glass of water or a hot drink of tea or coffee. Keep him warm!

9. Resuscitation should be carried on at the nearest possible point to where the patient received his injuries. He should not be moved from this point until he is breathing normally of his own volition and then moved only in a lying position.

10. A brief return of natural respiration is not a certain indication for stopping the resuscitation. Not infrequently the patient, after a temporary recovery of respiration, stops breathing again. Watch, and if breathing stops, resume artificial respiration.

11. In carrying out resuscitation it may be necessary to change the operator. This change must be made without losing the rhythm of respiration. By this procedure no confusion results at the time of change of operator and a regular rhythm is kept up.

It is important that resuscitation effort continue when a patient does not revive. *Sometimes a period of 4 hours may be required.*

Control of Severe Bleeding in the Event of an Emergency

Severe bleeding requires immediate and prompt action, and its control may save a life. All stations should be provided with suitable tourniquets, and all personnel *should be ready to act in any emergency. A second person should send immediately for a doctor.*

1. *Venous bleeding:* When a vein has been cut, the blood is *dark red* and flows steadily. Pressure, if required, should be applied *below* the wound, or *away* from the heart, to stop bleeding.

2. *Arterial bleeding:* When an artery has been cut, the blood is *bright red* and flows in *spurts.* Pressure should be applied *above* the wound, or *between* the wound and the heart, to stop bleeding. Pressure is best applied by a *tourniquet,* although the fingers and hand can be used temporarily (see Fig. 9-2).

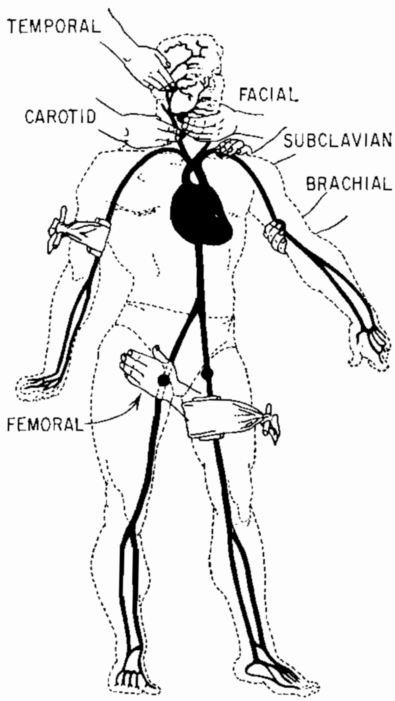

Fig. 9-2. Pressure points for control of severe bleeding.

3. *A tourniquet* is a strip of cloth, bandage, or other material tied above the wound. Place a thick pad, such as a folded handkerchief, on the inside of the arm or leg and under the tourniquet. Loosely tie a simple double knot in the cloth, place a stick or other rigid member between the knots, and tighten the outer knot by pulling the outer ends of cloth. Twist the stick or rigid member until bleeding stops. *Do not* maintain such pressure longer than 15 minutes at a time.

4. *If bleeding continues* after the tourniquet is loosened, allow blood to flow for 30 to 60 seconds and then reapply pressure. Continue this procedure until bleeding has stopped.

5. *Obtain medical services as soon as possible.*

Treatment and Avoidance of Electrical Injuries

Electric shock may be induced either by currents of high voltage or by comparatively low voltage. More people are killed on 110 volts a-c than any other voltage. We are all well aware of cases of shock and burns which result from high voltages, yet the vast majority of serious electrical injuries come from currents of low voltage. The severity of an electrical burn depends upon whether the current is alternating or direct, the voltage and amperage of the current, the character of the ground connection (remember, a concrete floor is *not* an insulator), duration of contact, and the extent of surface involved.

Electrical injuries can be classified as follows:

1. Shock, animation suspended and arrested respirations
2. Electrical flashes or glare injuries to the eyes
3. First-degree burns, with red dry skin as in sunburn followed early by blister formation and pain
4. Second-degree burns, where skin continuity is destroyed
5. Third-degree burns, where there is destruction en masse of the tissue, perhaps including muscle, nerve, and bone.

In shock due to low voltage, such as used for our domestic household appliances, using 110 to 120 volts, the usual cause of accident is neglect to dry hands or other portions of the body properly.

An accident was reported where a woman answered the telephone and neglected to

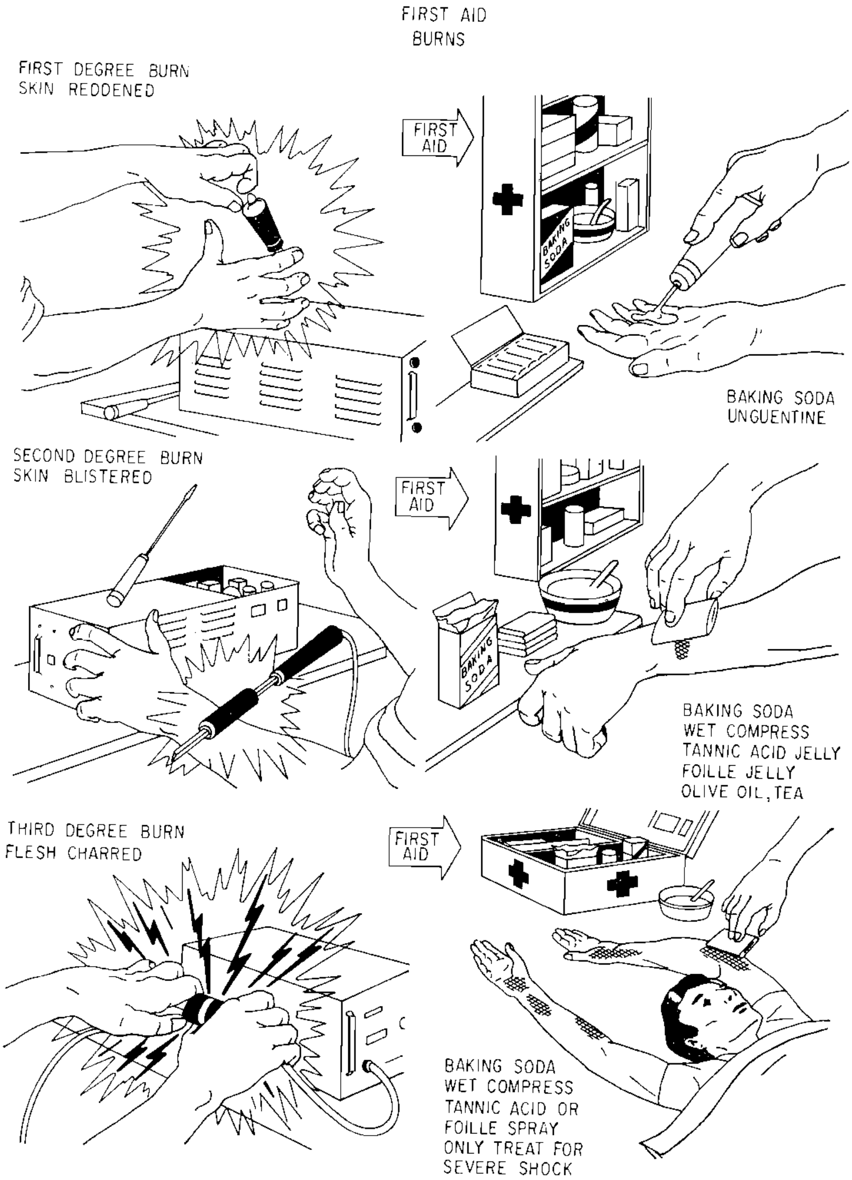

FIG. 9-3. Treatment for burns.

dry her hands. As she reached up to turn on a light, she received a severe shock and had intense pains in her right shoulder. As she was unable to move her arm, her doctor ordered an X ray. There was no history of a fall or other injury. The picture revealed a dislocation of the shoulder joint and complete avulsion of the greater tubercle. Attempts to reduce the dislocation resulted in fracture of the neck of the humerus. Open reduction through surgery was resorted to, and it was found that the electric current had completely changed the character of the bone, which now was filled with thousands of tiny fissures. Similar effects have been noted in inorganic substances such as glass, porcelain, and metal.

Both *high-* and *low-*tension currents have the same lethal effect, and death is produced, not by amperage or voltage, but by a combination of several physiochemical and physiological phenomena. *Alternating currents are more dangerous than direct. A good rule to follow when working on or servicing "live" equipment is to keep one hand in your pocket, thus reducing the possibility of a ground return through the upper portion of the body.*

One point which cannot be stressed too often is the importance of dry skin when working around any electrical apparatus. Never touch any electrical fixture when your hands or other parts of your body are wet, especially when there are cuts or abrasions of the skin and particularly where there is a ground current.

These higher voltages usually cause an immediate violent contraction of the muscles, and if the hand has grasped the wire, it cannot be released. Such unfortunates are said to be "frozen" as long as the current continues. Under no circumstances attempt to pull such a victim free or you may share his fate. Rush for the main switch if it is at hand, or otherwise disconnect all current first. Dry wood, dry rope, or a dry coat may help in pulling a victim free, but the location of the switch should be known to everyone in the laboratory. Such an electric shock may and usually does produce severe burns and, if the current is not shut off in time may even char the bones.

In severe cases of electric shock, leaving out burns and their treatment for the moment, we find that the patient has become unconscious. Respiration has stopped completely, but the heart continues to beat until asphyxia intervenes. A certain number of cases develop a ventricular fibrillation; that is, the electrical impulses which regulate the heartbeat are thrown out of order so that the pacemaker is no longer in control, and instead of a normal of 70 to 80 beats per minute, we have 200 to 400. These cases, as a rule, end fatally.

Fortunately, in most cases, there is merely a prolonged apnea—stoppage of breathing. *Artificial respiration by the prone or Schaefer method must be started at once and continued if necessary for* 8 *to* 10 *hours. Cases pronounced dead by all medical tests have suddenly been revived as late as* 8 *hours after the accident.* Injections of cardiac or respiratory stimulants are worthless and a waste of time in electrical shock.

After electric-shock treatment has been started, there is time to treat any burns. However, severe bleeding must be stopped before proceeding with resuscitation.

Radiation Hazards

Excessive exposure to X rays produced by high-voltage electronic equipment and by radioactive materials may produce serious burns and permanent internal injury.

A periodic physical examination should be made on all personnel having occasion to expose themselves to X rays. Blood counts should be made every 6 weeks or as the medical staff physician designates.

A definite value of 0.1 r (roentgens) is the permissible daily dose. If this value is exceeded or the measurement is greater than 0.0002 r/min, steps should be taken to shield the equipment in order to keep the dosage rate down to the safe limit. Measurements should be made at the normal position of the operating personnel and the surrounding area.

All equipment with electronic-tube devices having potentials in excess of 10,000 volts should be checked for the presence of X rays.

Treatment for Shock (Not Electrical)

Cots and blankets should be provided for caring for the patient until the doctor arrives. Shock cases require the use of blankets as stated below.

1. Any person severely injured is potentially a patient in shock and should be regarded and treated as such. It is important to conserve body heat, particularly in cold weather; prevent added injury or danger; and get medical services as soon as possible.

2. *Keep the patient lying down* in a comfortable position. Never permit him to stand or walk.

3. *Keep the patient warm.* In many cases the only first aid measure necessary and possible is to wrap the patient underneath, as well as on top, to prevent further loss of heat. Blankets, robes, coats, or any other available woolen material can be used.

General Rules

1. Unconscious persons take cold very easily. Pneumonia is a very frequent complication. Keep the patient warm by use of hot pads or hot-water bottles, but remember that an unconscious man cannot tell you when he is being burned.

2. If necessary to move the patient, keep him lying down and do not permit him to help himself.

3. Never try to give an unconscious person a drink. It will choke him.

4. Never stop artificial respiration in less than 4 hours if the patient has not fully recovered, and if there has been any sign of recovery, continue at least 8 hours.

5. Start artificial respiration at once, and have someone telephone for the emergency squad.

Part 10

THE POSSIBLE USE OF FACSIMILE IN BROADCASTING

A. G. Cooley

Director of Engineering
Times Facsimile Corp.

INTRODUCTION

Several attempts have been made since 1928 to establish broadcast facsimile services. The principal obstacles to success were the unavailability of radio channels and low-cost equipment and the lack of supporting revenues. Through the device of FM multiplexing, channels are now available.

Prospects for low-cost equipment are improving as production increases to meet the growing needs for military and commercial applications. Substantially all major weather stations and airfields in the United States depend upon weather maps transmitted by facsimile. Approximately 40,000 offices are equipped with facsimile for transmitting or receiving messages. Although the use is growing rapidly, at the present stage of equipment development, recorders suitable for broadcast service (synchronized independently of power lines) would have to sell for around $2,500.

Supporting revenues for facsimile broadcasters would depend upon the type of market served and the type of service rendered. All attempts of facsimile broadcasting up to the present time were directed at the urban areas, where newspapers were readily available. The material transmitted was of a news-bulletin type, which included a generous display of pictures. The number of homes equipped with facsimile was never large enough to interest advertisers. The cost of equipment and recording paper was high enough to discourage general usage. A different market must be served. There is good reason to believe that this market exists if provided with a full program of weather maps, market reports, and information on factors which affect the markets.

To transmit so much information in detail, the speed of transmission must be greater than that previously employed. The amount of copy would be far greater than most subscribers would be interested in. An automatic control system, however, could be provided that would be set by a subscriber to key-out any type of unwanted material.

TRANSMISSION MATERIAL

Weather bureaus are able to deliver only a small portion of their observation and forecast information to the public. Generalized forecasts made five or six times a day are voice-recorded and made available over telephone facilities. This information is usually not adequate to guide the many industries and activities which are vitally affected by weather, such as the planning of building construction, ship loading, private plane flying, winter trucking, highway snow removal, generation of electric power, etc. In many cases private weather-forecast services are engaged because the Weather Bureau cannot maintain a sufficiently large staff with adequate telephone facilities to answer all the inquiries.

Weather maps showing the conditions and forecasts in a region could be transmitted on multiplexed FM channels to subscribers. When hazardous weather conditions develop, special maps could be transmitted to pin-point the areas to be affected.

Prompt reception of stock market and commodity market reports is important to many business offices. A graphical presentation such as a facsimile recording is very desirable, particularly because facsimile is substantially error-free in operation.

It is probable that within a short time facsimile equipment can be sold at a reasonable price. There is a limited but financially strong market waiting to be served. Revenue derived from subscribers and supplemented by advertisers would probably be sufficient to support a facsimile service. The supersonic-control-tone system would make it possible to charge for the service on the basis of the type of program material used.

FACSIMILE EQUIPMENT

There are several types of facsimile transmitters in production that are suitable for broadcast work. Prices are in the $2,500 to $5,000 range for single units. For broadcast work it is helpful to employ two transmitters and use them alternately.

The facsimile receivers in production at the time of publication are considered too expensive for most broadcast services. Design simplifications and mass production are prerequisites to wider use of facsimile.

Direct-recording facsimile receivers are generally classified by the kind of recording paper used. Marking signals are recorded on *electrolytic* process recorders by the passage of current through a damp paper saturated with an electrolyte that changes color by the passage of current. Blackness of the record can be increased by electroplating metal on the paper.

Marking signals are recorded on *dry electrosensitive paper* recorders by the passage of current through a white masking coating over a black conducting paper (Teledeltos). A thin black conducting layer of carbon on a white bond paper constitutes a modified type of dry recording paper (Timefax). The recording is localized to an area under the point of a stylus.

Pressure recording is accomplished in a variety of ways. In one case a magnetically actuated stylus presses on a carbon paper, causing a transfer of the carbon wax to a white sheet of paper behind or underneath. In another case a stylus, helix wire, or small wheel is inked. The ink is pressed into the recording paper. In another form, a blackened paper is covered with a wax or soaplike masking coating. The cover coating is made to appear white by minute air bubbles. Pressure applied to the coating collapses the bubbles and reveals the black undercoating. A similar paper has a dye in the bubbles or cells. In this case the coating is on a white paper. Pressure will break the bubbles and expose the dye.

Photographic recording cannot be ruled out as a possible method for broadcast service. Recently developed rapid developers and fixers provide 2-sec processing. Other favorable developments are expected. Photographic recordings can be made at video speeds with existing equipment at the rate of more than 2,000 words per second.

SPEED OF TRANSMISSION

The scanning process in the facsimile transmitter in effect divides the copy into elemental areas similar to the dots in a half-tone picture which are then transmitted at a speed determined by the capacity of the communications channel. An 8-kc channel can handle approximately 6,500 elemental areas per second. When scanning at the rate of 100 lines per inch, this channel capacity is approximately 40 sq in./min. If the scan is at the rate of 200 lines per inch, the channel capacity is approximately 10 sq in./min. The 100-line scanning rate is the most commonly used as a compromise between speed and detail sharpness. It is satisfactory for elite typewriter type.

It is marginal in transmitting newspaper copy of 7½-point type size. Two-hundred-line scanning is required to reproduce the fractions of the financial pages properly. A rough formula for speed of transmission is:

$$\text{Sq in./min} = \frac{(f_2 - f_1)60}{d^2}$$

where $f_2 - f_1$ = usable channel width
d = definition of lines per inch

The usable channel width is generally 80 to 90 per cent of the nominal channel width when single-sideband transmission is used.

This is only an approximation, because the requirements for sharp printing vary considerably with opinion. The style of type as well as the size also influences the speed-determining factors.

Usable channel width is limited by cross talk from or into other channels and by phase distortion. Phase distortion is created primarily by channel-separation filters. For example, a 48-kc telephone channel containing several sections may have a usable bandwidth for facsimile purposes of only 12 kc. In radio work a relatively large percentage of the channel can be used if only a transmitter and receiver are involved. If a radio relay chain is employed, the usable bandwidth will be considerably less unless phase-correcting devices are employed.

SYNCHRONIZATION

When a certain elemental area is scanned and transmitted, the recorder must record this area in its correct position on the recording paper. To do this within acceptable displacement tolerances (a skew of ⅛-in. in an 8½- by 11-in. copy), the transmitter and recorder mechanisms must be synchronized to an accuracy of 0.001 per cent, which corresponds to a time error of less than 1 sec per day. If the error is divided equally between the transmitter and recorder, the requirement for each machine is 0.0005 per cent. Such an error can be tolerated only when transmitting letter-size copy at 100-line-per-inch scanning. Precision of synchronization requirements increases in proportion to the area and the square of the lines per inch.

The driving motors are generally controlled by tuning-fork oscillators unless the transmitter and recorder are operated from synchronized a-c power lines. In some parts of the country, very large areas, covering several states, have synchronized power systems. In other cases, it is not possible to use the power lines for synchronizing short distances. New York City is not synchronized with Jersey City across the river, although it is synchronized with Detroit, Mich.

Another method is signal synchronizing, and there are various ways of transmitting synchronizing signals along with the picture signals. There is work yet to be done to determine whether signal synchronizing is competitive with a fork oscillator system.

Power-line synchronizing was used for the home-broadcast facsimile systems. It is satisfactory in many areas. It is quite probable, however, that it would not be considered satisfactory in many important metropolitan areas. It is desirable because of equipment simplicity and cost. One system that has been proposed is to transmit a synchronizing signal that is required and used only by the recorders that are not connected to the same power grid as the transmitting station.

FM MULTIPLEXING EQUIPMENT

Facsimile transmissions have been successfully made through FM multiplexing systems supplied by both Hogan Laboratories and Multiplex Services Corporation. The Hogan system made use of amplitude modulation of the subcarrier frequency. The Multiplex Services equipment employed the Halstead system, which frequency-modulated the subcarrier.

Multiplexing equipment is now commercially available through several companies including:

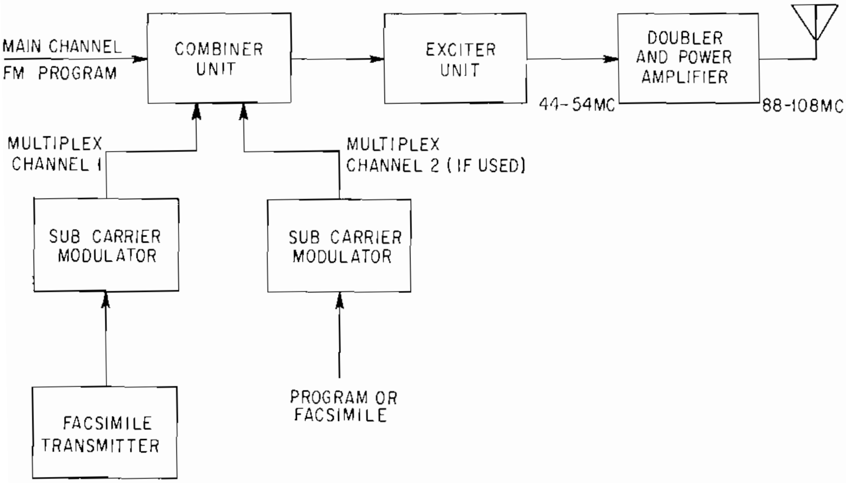

Fig. 10-1. FM and multiplex facsimile using direct mixing system.

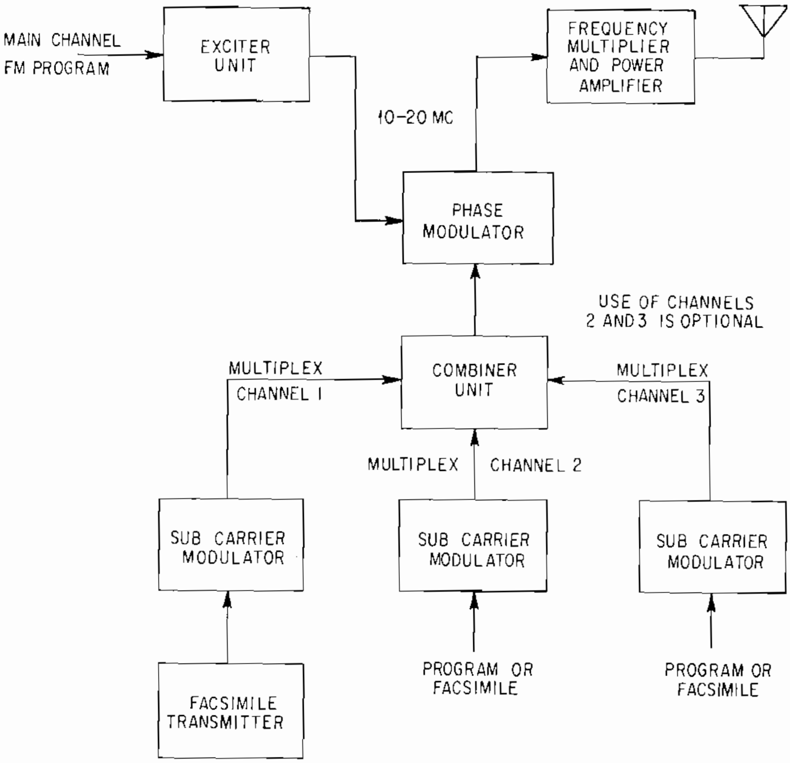

Fig. 10-2. FM and multiplex facsimile using phase modulation.

Crosby Laboratories, Inc., Syosset, N.Y.
Gates Radio Company, Quincy, Ill.
General Electronic Laboratories, Inc., Cambridge 42, Mass.
Harkins Radio Company, Phoenix, Ariz.
Multiplex Transmitter Corporation, New York 68, N.Y.
Radio Corporation of America, Camden, N.J.
Radio Engineering Laboratories, Inc., Queens, N.Y.

If the entire multiplex spectrum of the FM channel is employed for facsimile, a theoretical working speed of 250 sq in./min could be expected at 100-line scanning. This is equal to approximately two 8½- by 11-in. pages per minute. Sufficient tests

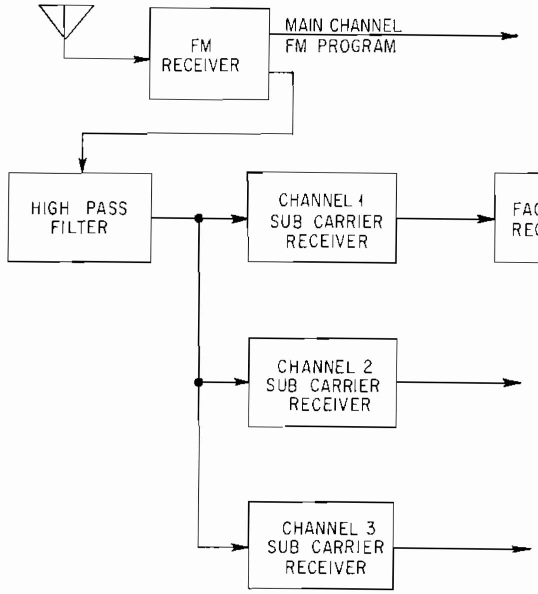

FIG. 10-3. FM and multiplex facsimile receiver.

have not as yet been made to determine the limiting speeds when repeating through a series of FM stations.

Subcarrier FM multiplex can be used to provide two or three channels in addition to the regular main-channel program source. The additional channels are provided by supersonic frequencies in the range of 20 to 75 kc, which cause only a small deviation of the main FM carrier frequency.

The signals needed to operate the facsimile receiver are taken directly from the discriminator of the FM receiver. A high-pass filter in the multiplex receiving equipment removes the main program frequencies from the multiplex channels. If more than one multiplex channel is used, the individual channels are separated by bandpass filters. Each channel is demodulated by its individual discriminator to deliver the same type of signal used at the FM transmitting station. Better signal-to-noise ratios are obtained if only one multiplex channel is used.

The direct mixing system (Fig. 10-1) combines these supersonic frequencies with the main program sound before the FM portion of the transmitter is reached. The combining is usually done at a high level point to ensure proper response to these supersonic frequencies and to prevent intermodulation. A typical installation uses frequencies in the range of 30 to 70 kc with a subcarrier deviation of 7.5 kc for 100 per cent modulation. The signal-to-noise ratio in the facsimile channel of 50 db with a maximum distortion of 2 per cent is feasible. Two additional channels may be provided with this system.

A second system (Fig. 10-2) will handle up to three additional channels. A deviation of 6 kc is used with typical subcarrier frequencies of 26.5, 47.5, and 68.5 kc. These subcarrier frequencies are combined and used to phase-modulate the main-channel FM signal between two multiplier stages of the transmitter which are in the range of 10 to 20 Mc. This type is suitable for relaying through a chain of FM stations. No demodulation and remodulation of the multiplex subcarriers is required at the relay stations, which can be operated on an unattended basis. The multiplex frequencies do not pass through the main-channel equipment at a relay station but are again recombined by phase modulation in the same manner as at the originating station.

FCC Regulations

The first FCC rules (Docket 9425) pertaining to multiplexing of facsimile signals on an FM channel made provisions for both amplitude and frequency modulation of the subcarrier. Apparently, these rules have not been rescinded, although subsequent rulings state that frequency modulation must be employed in subsidiary communications multiplex operations. Section 3.310(i) states that "multiplex transmission as applied to FM broadcast stations means the transmission of facsimile or other signals in addition to regular broadcast signals." For complete details of the FCC Rules governing facsimile transmission, refer to Section 1 of this handbook.

Part 11

AUDIO-FREQUENCY PROOF-OF-PERFORMANCE MEASUREMENTS

GEORGE P. ADAIR

George P. Adair Engineering Co.
Washington, D.C.

GENERAL

The Federal Communications Commission's Rules and Regulations require that certain measurements of aural characteristics be made at yearly intervals by AM and FM broadcast stations and that such measurements be submitted as a part of the application for licenses to cover construction permits of FM broadcast stations. While in general the same information and measurements are required for both, there are distinct differences in the measurements required and the method of making such measurements; differences in the response, distortion, and other characteristics; differences in the time required for making the measurements; and differences as to what are to be done with the measurements after making them. Therefore, engineers responsible for making such measurements should be fully familiar with all requirements for the type of station concerned. In the following pages a sincere effort is made to digest the requirements for each type of station for the convenience of station engineers and to set up step-by-step procedures for making the measurements. Texts of the pertinent rules are included in Section 1 of this handbook. However, each engineer concerned with such measurements should obtain and have available for reference up-to-date copies of Parts 1, 2, and 3 of the Federal Communications Commission's Rules and Regulations.

Reason for Measurements

The ultimate reason for the measuring procedure is to afford a means of locating and correcting defective equipment and to make certain the equipment is performing at its maximum capabilities. This may be termed a "preventive-maintenance procedure." Obviously, preventive maintenance is best carried out as a continuing process rather than an intermittent one where test equipment is available only for a short period once a year.

Who May Make Measurements

Any qualified engineer may make the measurements. A station may purchase the equipment and the station engineer make the measurement, or a qualified consulting engineer may be employed. Since it is desirable that the measurements be a continuing process, the FCC recommends that stations purchase their own equipment.

However, a word of caution is not out of order here: The equipment purchased must have the minimum requirements, must be maintained so as to be kept in proper calibration, and must be properly used. Measurements are made preferably by the same engineer each time. However, it may be desirable to have the measurements checked every two or three years by a qualified consulting engineer. Following the procedures set forth later, almost any engineer should be able to make the measurements without difficulty. The difficulties arise when the measurements show inadequate performance, and while often simple adjustments will correct this, sometimes correction is extremely difficult and time consuming, particularly where the equipment is barely capable of meeting the FCC requirements when adjusted for top performance.

When to Make Required Measurements

For AM Stations

The rules for AM stations require that measurements be made yearly and that one such set of measurements shall be made during the 4-month period preceding the date of filing the application for renewal of license. As the application for renewal of license must be filed at least 90 days before the expiration date of the license, this means that the measurements for that year must be made from 7 to 3 months prior to the expiration date. Where measurements are made once a year, it is suggested that they be made the first year during the period to coincide with that required for the renewal year. The periods for making measurements to comply with the renewal requirements for AM stations are as follows by location:

Delaware, Indiana, Kentucky, Pennsylvania, Tennessee, and Texas: Jan. 1 to Apr. 30.

Arizona, District of Columbia, Idaho, Maryland, Michigan, New Mexico, Nevada, Ohio, Utah, Virginia, West Virginia, and Wyoming: Mar. 1 to June 30.

California, Illinois, North Carolina, South Carolina, and Wisconsin: May 1 to Aug. 31.

Alaska, Florida, Guam, Hawaii, Iowa, Missouri, Oregon, Puerto Rico, Virgin Islands, and Washington: July 1 to Oct. 31.

Alabama, Colorado, Connecticut, Georgia, Maine, Massachusetts, Minnesota, Montana, New Hampshire, North Dakota, Rhode Island, South Dakota, and Vermont: Sept. 1 to Dec. 31.

Arkansas, Kansas, Louisiana, Mississippi, Nebraska, New Jersey, New York, and Oklahoma: Nov. 1 to Feb. 28.

For FM Stations

The time for making measurements to comply with the renewal requirements for FM stations is the same as for AM stations, except that in addition, measurements must be made and filed with the application for license to cover the construction permit. Therefore, unless the times happen to coincide, two sets of measurements will be required for the year when such application is filed.

What to Do with Measurements

For AM Stations

Measurements of AM stations should be kept on file at the station for presentation to the FCC inspector if he so requests. Do not file them with the FCC unless specifically requested.

For FM Stations

Measurements of FM stations made during equipment tests under a construction permit must be filed, together with diagrams and descriptions of measurement procedures, with the application for license to cover the construction permit. The yearly measurements should be kept in the station file for presentation to the FCC inspector if he so requests. Do not file them with FCC unless specifically requested.

What Measurements Are Required

For AM Stations

1. Over-all audio-frequency response from 30 to 7500 cps for approximately 25, 50, 85, and 100 (if obtainable) per cent modulation
2. Audio-frequency harmonic content for 25, 50, 85, and 100 per cent modulation for fundamental frequencies of 50, 100, 400, 1,000, 5,000, and 7,500 cps (either arithmetical or root-sum-square values up to tenth harmonic or root-sum-square values up to tenth harmonic or 16,000 cps
3. Percentage carrier shift for 25, 50, 85, and 100 per cent modulation with 400-cps tone
4. Carrier hum and extraneous noise generated within the equipment
5. Spurious radiations including radio-frequency harmonics
(See Section 3.47 of FCC Rules)

For FM Stations

1. Audio-frequency response from 50 to 15,000 cps for approximately 25, 50, and 100 per cent modulation. Measurements must be made for at least 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 cps. (Frequency swing of plus and minus 75 kc is considered 100 per cent modulation.)
2. Audio-frequency harmonic distortion for 25, 50, and 100 per cent modulation for the fundamental frequencies of 50, 100, 400, 1,000, and 5,000 cps and audio-frequency harmonic distortion for 100 per cent modulation for the fundamental frequencies of 10,000 and 15,000 cps. Measurements shall include harmonics to 30,000 cps.
3. Output noise level (frequency modulation) in the band 50 to 15,000 cps in decibels below the audio-frequency level representing a frequency swing of 75 kc.
4. Output noise level (amplitude modulation) in the band 50 to 15,000 cps in decibels below the audio-frequency level representing 100 per cent amplitude modulation. [See Section 3.254 of FCC Rules and Section II-B (11) of FCC Form 302.]

What Equipment Is Required

The Commission does not attempt to set up the procedures or to recommend the equipment to be employed. There are a number of methods of making the required measurements, and numerous makes and models of equipment which are suitable for this purpose are available. In general, however, means must be provided for an audio input signal of known frequency and level and means for measuring the output in the terms desired. The specifications for such equipment must necessarily be considered in connection with the performance standards established by the Commission. It is obvious that the equipment must have such accuracy as to be well within the limits of the operation specifications for the station. (In general it should be noted that radio-service-type equipment will not meet these specifications.)

The following equipment is suggested:

1. Audio Oscillator. This instrument should preferably have a fundamental range of 30 to 17,000 cps or more. The audio-frequency harmonic content over the entire range should not exceed 1 per cent. (Instruments are available where the distortion does not exceed 0.1 to 0.25 per cent.) Accuracy of calibration should be within 3.0 per cent, although much greater accuracy will be found in the higher grade instruments. Both high- and low-impedance outputs are desirable.

2. Attenuator or Pad. To control the signal fed to the microphone terminals from the audio oscillator an accurate attenuator or pad is required. It must be capable of attenuating the signal from at least 50 to 80 db. (Some audio oscillators have a suitable attenuator built into the unit.)

3. Level Indicator. The purpose of this item is to measure the input level and/or output level. It is usually available at the station in the form of a VU meter or vacuum-tube voltmeter. It is also included in some audio signal generators.

4. Isolation and Matching Transformer. This is used to isolate the test equipment from the station circuits and to match the impedances of the two. The requirements for this unit depend on the input impedance (normally 600 ohms) and the output impedance of the attenuator.

5. Distortion and Noise Meter. This instrument should have a scale permitting distortion readings as low as 0.5 and as high as 20 to 30 per cent. For carrier noise and hum measurements the meter reading should extend to at least 60 db (preferably lower) below an audio-frequency signal of 0 dbm (the term dbm means the power level expressed in decibels referred to 1 mw). High and low input impedance must be available, and the low input impedance is preferably of the bridging type.

6. Modulation Monitor. This item is required by the FCC in each broadcast station and is, therefore, assumed available.

7. Field-strength Meter or Communications-type Receiver. With regard to the observations required on the radio-frequency transmissions of the standard stations, the Commission's Rules state that field-strength measurements are preferred but that observations made with a communications-type receiver will be accepted. To conduct such observations considerable care must be exercised in the selectiou of the receiver as well as in its actual use. As a general rule this receiver should have at least one stage of RF ahead of the first detector. It should be well shielded, and the frequency range should permit observations to at least the tenth or fifteenth harmonic of the fundamental frequency of the station. A means of making comparative signal-strength checks such as an "S meter" is very desirable and almost essential if suitable and meaningful observations are to be made. Amateur communications receivers will often meet these requirements. Although such observations are not required with respect to FM stations, it is a wise precaution to check spurious and harmonic radiations. Particular attention should be given to the second harmonic to avoid causing interference to television stations.

8. Oscilloscope. Although an oscilloscope is not essential, it is often very useful in analyzing and correcting difficulties which prevent compliance with the requirements.

Estimated Cost of Equipment

Equipment of various grades is now available upon order, and these purchases should be carefully considered on the basis of what use is to be made of the various components, as well as to the cost. Suitable and satisfactory equipment will have the following approximate price ranges:

Audio oscillator or signal generator, $115 to $600
Calibrated attenuator, from a few dollars to several hundred
Level indicator, $50 to $100 and up
Isolation and matching transformer, $10 to $25
Distortion and noise meter, $400 to $650
Communications-type receiver, $125 and up
Oscilloscope, $75 and up

HOW TO MAKE MEASUREMENTS

Detailed instructions for the operation of the particular piece of equipment are normally supplied by the manufacturer and should be followed. Some manufacturers include procedures for making the measurements required by the FCC, but this practice is far from universal. To assist in overcoming this lack and for the benefit of stations assembling the equipment from units purchased from different manufacturers, a step-by-step procedure for making the required measurements is set forth below, together with precautions that should be taken in setting up the equipment and making the measurements.

Precautions

1. All measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna output, including telephone lines, preemphasis circuits, and any equalizers employed except for microphones, and without compression if a compression amplifier is installed unless otherwise noted.

Where au AM station operates DA-2 or DA-N, it is not required to make measurements under both conditious of antenna operation unless there is reason to believe some unusual condition exists. The practice of making two sets of measurements, however, is considered advisable. If the antenna systems are adjusted so that the transmitter is feeding in exactly the same impedances under both conditions, there should be no difference. (Some difficulty may be experienced at the higher audio frequencies when the common-point impedance(s) for sidebands is greatly different from that at the carrier frequency.)

2. Audio systems of most broadcast stations use balanced 600-ohm ungrounded circuits. This, however, is not universal, and before attempting to make measurements, the facts in this regard must be determined. Otherwise, the measurements obviously will be in error and serious damage may result to the station equipment, the measuring equipment, or both.

3. It is very important to guard against stray fields affecting the accuracy of the measurements. This is particularly true with respect to use of the distortion and noise meter and of the VTVM when used in the presence of the transmitter. Difficulties of this nature are usually evidenced by residual readings. It is suggested that:

a. Use short power cord and bypass it; also reverse plug for lowest residual reading.

b. The chassis of the instrument must be firmly grounded with as short a lead as possible to the station ground bus.

c. Use short voltmeter leads with RF chokes, and bypass. It may also be necessary to shield the terminals and the instrument itself. In some cases shielding the front will be adequate.

Procedure for AM Stations

Audio-frequency Response

1. Adjust all equipment from microphone preamplifier input terminals to the antenna for normal program operation.

2. Bypass any limiting amplifiers.

3. Connect the audio-signal-generator equipment as shown in Fig. 11-1. Details of

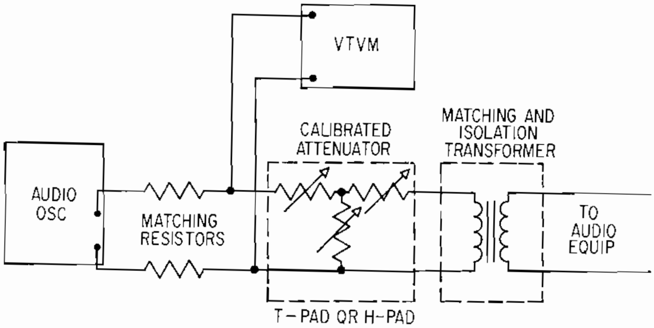

FIG. 11-1. Basic method of connecting audio-signal-generator equipment.

this will depend on the type and impedances of the oscillator, attenuator, and the station audio circuits. (*Do not connect to input terminals yet.*)

4. Adjust the oscillator to 1,000 cps.
5. Adjust the oscillator amplitude control until the VTVM reads zero.
6. Adjust the attenuator to approximately 40 or 50 db.
7. Connect the signal generator to the microphone preamplifier input circuit.
8. Adjust the amplitude control until the VTVM reads approximately 15 dbm.
9. Adjust the attenuator until the station modulation monitor indicates 25 per cent modulation, at the same time making certain that the VTVM still reads the same as step 8. If it does not, readjust the amplitude control and attenuator until the modulation monitor shows 25 per cent at the same time that the VTVM shows the same as in step 8.
10. Record the attenuator setting in all the upper spaces of the form shown on Form AFP-1 for 25 per cent modulation and also in the second space under 1,000 cps.
11. Adjust the oscillator to 30 cps.
12. Adjust the amplitude control and attenuator until the modulation monitor reads 25 per cent at the same time the VTVM reads the same as in step 8.
13. Record the attenuator setting in the second space down under 30 cps in Form AFP-1.
14. Subtract the entry in the second space down from that in the first space, and enter the difference in the third or lower space.
15. Repeat steps 11 to 14 for 100, 400, 5,000, and 7,500 cps. There should not be more than approximately 0.2-db difference between any two successive readings. If there is, readings should be taken at intermediate frequencies.
16. Repeat steps 9 through 15 for 50, 85, and 100 per cent modulation. (If 100 per cent modulation is not obtainable, use the highest percentage that is obtainable.)
17. Plot all readings in the lower spaces for each percentage of modulation on the graph sheets on Form AFP-2.
18. If the decibel variation between 100 and 5,000 cps is greater than 2 db from that at 1,000 cps, operation is in violation of the Commission's Rules. Appropriate corrective steps should be taken, and the measurements repeated.

Audio-frequency Harmonic Distortion

1. Repeat steps 1 through 9 above.
2. Connect the distortion and noise meter to the output of the transmitter. This connection depends on the instrument employed, and the instructions of the manufacturer should be followed. In general, there are two principal types: one in which the detector circuit is built into the meter and the other where a separate detector must be provided. In the latter case it is normal to use the detector in the modulation monitor.
3. Following the instructions of the manufacturer of the distortion and noise meter determine the harmonic content for 1,000 cps and record in the space provided on Form AFP-3.
4. Repeat steps 9 through 12 under Procedure for AM Stations and step 3 above for 30, 50, 100, 400, 5,000 and 7,500 cps.
5. Repeat steps 4 through 12 under Audio-Frequency Response and steps 3 and 4 above for 50, 85, and 100 per cent modulation.
6. Plot the data on graphs on Form AFP-3.
7. If the harmonic content is greater than 5 per cent from 0 to 84 per cent modulation or 7.5 from 85 to 95 per cent modulation, operation is in violation of the Commission's Rules. Appropriate corrective steps should be taken and the measurements repeated.

Percentage Carrier (Current) Shift

1. Adjust all equipment from the microphone preamplifier input terminals to the antenna for normal program operation.

2. Bypass any limiting amplifiers.

3. Connect the audio signal generator equipment as shown in Fig. 11-1. Details of this will depend on the type and impedances of the various units and of the station audio circuits. (*Do not connect to the input terminals yet.*)

4. Adjust the oscillator to 400 cps.

5. Adjust the oscillator amplitude for minimum output.

6. Adjust the attenuator to 40 or 50 db.

7. Connect to the microphone preamplifier input.

8. Connect a d-c voltmeter having a very high input impedance so as to read the d-c potential in the detector circuit used in the output of the transmitter as described under Audio Harmonic Distortion.

9. If the detector in the distortion and noise meter is used, adjust the control until maximum d-c voltage is obtained.

10. Read and record in the spaces provided on Form AFP-4. (This is the "no-modulation" reading.)

11. Increase the input by adjusting the oscillator amplitude control and the attenuator until the modulation monitor reads 25 per cent.

12. Read the d-c voltage and record it in the space provided on Form AFP-4. (This is the reading with 25 per cent modulation.)

13. Enter the difference between the reading without modulation and the reading with modulation in the space provided.

14. Calculate and enter in the space provided in the per cent carrier shift for 25 per cent modulation. Per cent carrier shift is the difference between the readings with and without modulation divided by the reading without modulation and multiplied by 100.

15. Repeat for 50, 85, and 100 per cent modulation.

16. If the carrier shift is greater than 5 per cent at any percentage of modulation, operation is in violation of the Commission's Rules. Appropriate corrective steps should be taken and the measurements repeated.

Carrier Hum and Extraneous Noise

1. Adjust all equipment from the microphone amplifier input terminals to the antenna for normal program operation.

2. Bypass any limiting amplifiers.

3. Connect the audio-signal-generator equipment as shown in Fig. 11-1. Details of this will depend on the type and impedances of the various units and of the station audio circuits. (*Do not connect to the input terminals yet.*)

4. Adjust the oscillator to 400 cps.

5. Adjust the amplitude control to 15 db.

6. Adjust the attenuator to approximately 40 db.

7. Connect to the input of the microphone preamplifier.

8. Adjust the attenuator until the modulation monitor indicates 100 per cent modulation.

9. Connect the distortion and noise meter to the output of the transmitter. This connection depends on the instrument employed, and the instructions of the manufacturer should be followed. In the event the instrument does not have a detector circuit built into it, the detector of the modulation monitor can be employed provided it has a low hum and noise level, as this will be added to that of the transmitter in the readings.

10. Follow the instructions of the manufacturer, which will be, in general, to adjust the sensitivity so as to obtain a full-scale reading with the output meter set for maximum reading.

11. Disconnect the audio signal generator, and connect a 600-ohm (wire-wound) resistor across the input terminals of the main studio amplifier. If the input impedance is other than 600 ohms, use the corresponding value of resistor. (The signal generator can be turned off and 20 to 30 db inserted by the attenuator, but the resistor connected across the input is the preferred method.)

12. Increase the sensitivity of the output meter until a reading is obtained. Read and record.

13. Calculate the combined hum and noise. In per cent this is the reading obtained in step 12 divided by the reading in step 10 and multiplied by 100. The hum and noise ratio to the 100 per cent value can be converted to decibels in the usual manner. Both should be recorded on Form AFP-4.

14. If the hum and noise is less than 50 db below 100 per cent modulation between 150 and 5,000 cycles or less than 40 db below 100 per cent modulation outside that range operation, it is in violation of the Commission's Rules. Appropriate corrective steps should be taken and the measurements repeated.

Spurious Radiations

1. All equipment, including any limiting amplifiers, should be in normal adjustment with a program or test tone at as high a percentage of modulation as is ever used.

2. With the communications receiver, make observations at a distance of approximately ½ mile from the antenna or closer if possible for spurious emissions including harmonics. With the gain control turned to a maximum, tune around the frequency of the station and on up to the tenth or fifteenth harmonic of the assigned frequency. By means of the S meter determine and record the approximate signal strength of the spurious emissions that are found.

3. In the event any of consequence are found, steps should be taken to eliminate or reduce them as far as possible. In the event that any disagreement arises with the Commission, it may be necessary to take actual field measurements. It is not acceptable for the radiations on other than the assigned frequency to exceed 60 db below the fundamental, and they should be 70 or 80 db down.

Procedure for FM Stations

Audio-frequency Response

1. Repeat the procedure outlined under Procedure for AM Stations *except:* Use audio frequencies of 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 cps at 25, 50 and 100 per cent modulation.

(These measurements should be made without deemphasis; however, standard 75-μsec deemphasis can be employed in the measuring circuit or in the system provided the accuracy of the deemphasis circuit is sufficient to ensure that the measured response is within the prescribed limits.)

2. Record in the spaces provided on Form AFP-5.

3. Plot the data on Form AFP-6.

4. Reference should be made to Appendix B, Section 3.317, to determine whether the operation is satisfactory.

Audio-frequency Harmonic Distortion

1. Repeat the procedure outlined under Procedure for AM Stations, Audio-Frequency Harmonic Distortion, for AM stations *except:* Use audio frequencies of 50, 100, 400, 1,000, and 5,000 cps for 25 and 50 per cent modulation and audio frequencies of 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 cps for 100 per cent modulation. (These measurements should be made with standard 75-μsec deemphasis in the measuring circuit or system and should include harmonics to 30,000 cps.)

2. Record in the spaces provided on Form AFP-7.

3. Plot the data on Form AFP-7.

4. If this distortion exceeds the following values, operation is in violation of the Commission's Rules and the equipment should be readjusted and the measurements repeated: 50 to 100 cps, 3.5 per cent; 100 to 1,500 cps, 2.5 per cent; 7,500 to 15,000 cps, 3.0 per cent.

Output Noise (FM)

1. Repeat the procedure outlined under Carrier Hum and Extraneous Noise for AM stations using FM detection and standard 75-μsec deemphasis and VU meter.
2. Record in spaces provided on Form AFP-8.
3. If the noise is in excess of 60 db down from the audio level representing a frequency swing of ±75 kc, operation is in violation of the Commission's Rules and appropriate corrective steps should be taken and the measurements repeated.

Output Noise (AM)

1. Shunt the 600-ohm wire wound resistor across microphone preamplifier input.
2. Determine the audio voltage equivalent to 100 per cent modulation. This may be considered as equal to the d-c voltage across the meter determining the power level in the monitor.
3. By use of the distortion and noise meter with standard 75-μsec deemphasis and VU meter, determine the audio voltage at the same point for the same carrier level.
4. Compute the per cent AM modulation by dividing the andio voltage by the carrier level voltage and multiply by 100. Convert to decibels down from 100 per cent modulation. Record in spaces provided on Form AFP-8.
5. If the noise is in excess of 50 db below the audio level representing 100 per cent modulation, operation is in violation of the Commission's Rnles. Appropriate corrective steps should be taken and the measurements repeated.

HOW TO USE THE MEASUREMENTS

Compliance with the Commission's Rnles in regard to filing the measnrements was covered earlier. However, the measurements were required in the first place to determine whether the emissions of the station are satisfactory and in accordance with the Rules and good engineering practice. Obviously, if the distortion, hum, noise, RF harmonics, or other spurious emissions are not within the Rules, appropriate corrective steps must be taken and new measurements made. Even if the measurements are within the requirements, there are very likely adjustments or changes that can be made with little or no expense which would materially improve the operation or correct a weakness or border-line operation which may otherwise cause off-the-air time later.

In other words, these measurements should not be considered just a necessary nuisance to comply with the Commission's requirements but should be used for station improvement. If the station purchases the equipment, a procedure should be established for making the measurements at regular intervals and the measnrements kept on file, together with a record of the adjustments that have been made from time to time to maintain proper operation. This will often indicate potential sources of complete failure at inopportune times, particularly in bad weather, when lines and equipment are more prone to fail and more difficult to repair.

FORMS AFP-1 TO AFP-8

The following forms, reproduced for the sake of clarity here, are available in booklet form as a service to NAB member stations at no cost. This service has been initiated in an attempt to standardize audio proof-of-performance measurements and records.

Station KC , City State

OVERALL AUDIO FREQUENCY RESPONSE DATA

25% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

50% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

85% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

100%(or %) MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

(1) RECORD THE ATTENUATOR READING FOR THE 1000 CPS REFERENCE SIGNAL IN EACH SPACE IN THIS ROW.

(2) RECORD THE ATTENUATOR READINGS FOR THE SPECIFIED FREQUENCIES IN THIS ROW.

(3) RECORD THE AUDIO FREQUENCY RESPONSE VARIATION IN THIS ROW WHICH IS OBTAINED BY SUBTRACTING ROW (2) FROM ROW (1) THESE FINAL FIGURES ARE TO BE USED IN PLOTTING THE GRAPHS.

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Engineer

Form No. AFP-1

FIG. 11-2*a*. Form AFP-1.

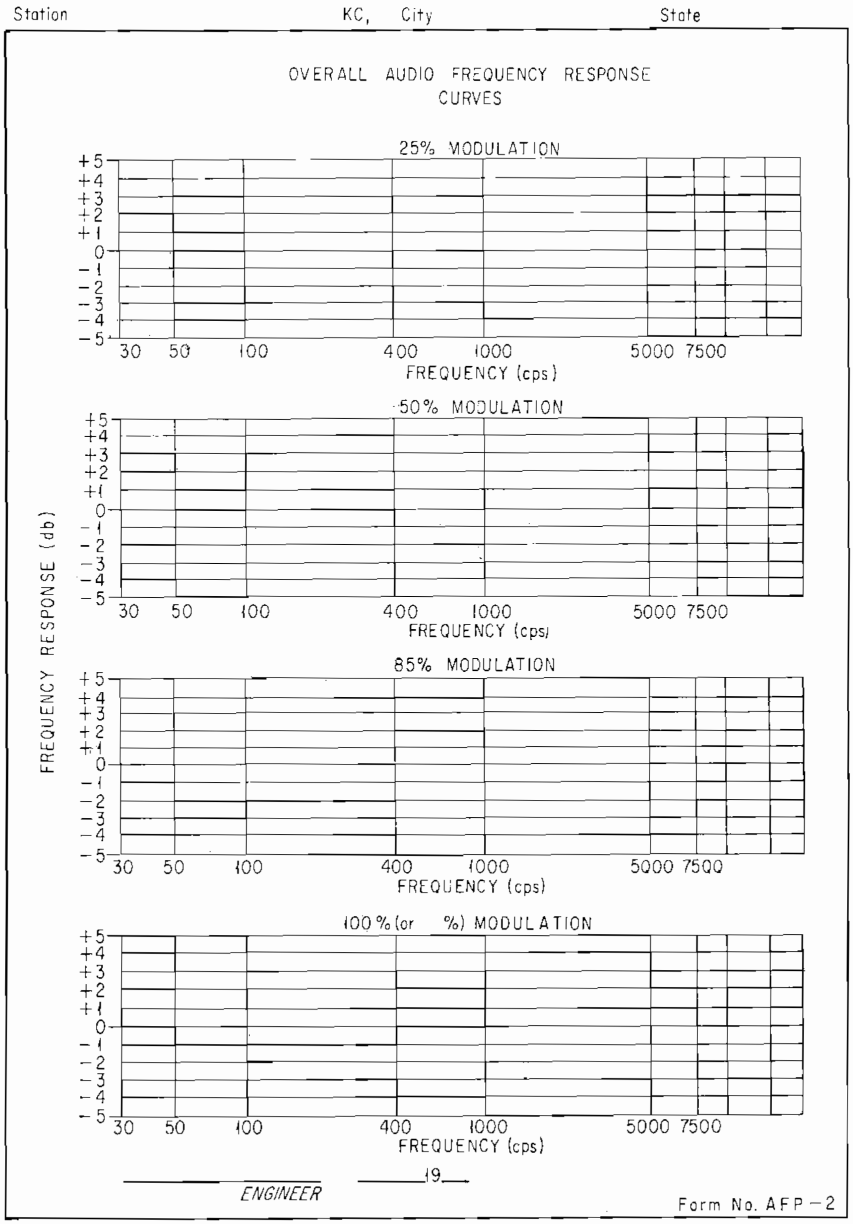


FIG. 11-2*b*. Form AFP-2.

Station KC, City State

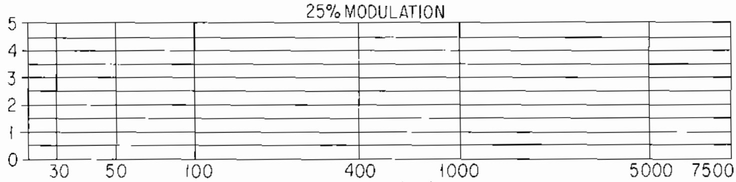
AUDIO FREQUENCY HARMONIC CONTENT
DATA AND CURVES

HARMONIC DISTORTION

	CPS	30	50	100	400	1000	5000	7500
% MOD.	25							
	50							
	85							
	100							

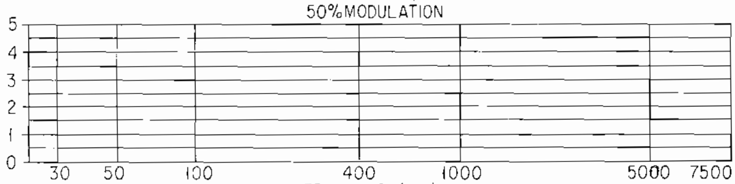
% DISTORTION

25% MODULATION



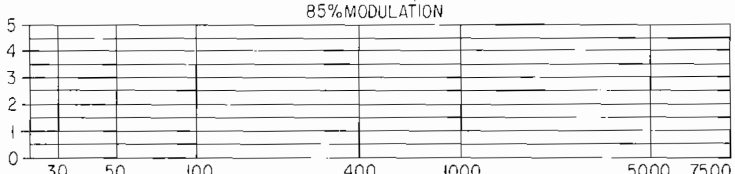
FREQUENCY (cps)

50% MODULATION



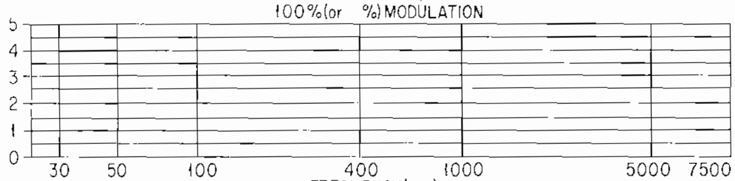
FREQUENCY (cps)

85% MODULATION



FREQUENCY (cps)

100% (or %) MODULATION



FREQUENCY (cps)

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Engineer

Form No. AFP – 3

Fig. 11-2*c*. Form AFP-3.

Station KC, City State

CARRIER SHIFT AND COMBINED
NOISE AND HUM DATA

CARRIER SHIFT DATA (at 400 cps)

% MOD.	25	50	85	100
(1)				
(2)				
(3)				
(4)				

(1) RECORD DC VOLTMETER READING WITHOUT MODULATION IN EACH SPACE IN THIS ROW.

(2) RECORD DC VOLTMETER READINGS WITH MODULATION IN THIS ROW.

(3) SUBTRACT ROW (2) FROM ROW (1) AND RECORD DIFFERENCE IN THIS ROW.

(4) COMPUTE CARRIER SHIFT BY EQUATION: $\frac{\text{ROW (3)}}{\text{ROW (1)}} \times 100$, AND RECORD RESULTS IN THIS ROW.

COMBINED NOISE AND HUM READING

DB	%

____________ ______ 19____

Engineer

Form No. AFP – 4

Fig. 11-2*d*. Form AFP-4.

Station ________ Ch. ________ City ________ State ________

OVERALL AUDIO FREQUENCY RESPONSE DATA

25% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

50% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

100% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

——% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

(1) RECORD THE ATTENUATOR READING FOR THE 1000 CPS REFERENCE SIGNAL IN EACH SPACE IN THIS ROW.

(2) RECORD THE ATTENUATOR READINGS FOR THE SPECIFIED FREQUENCIES IN THIS ROW.

(3) RECORD THE AUDIO FREQUENCY RESPONSE VARIATION IN THIS ROW WHICH IS OBTAINED BY SUBTRACTING ROW (2) FROM ROW (1). THESE FINAL FIGURES ARE TO BE USED IN PLOTTING THE GRAPHS.

________________ Engineer ________ 19____

Form No. AFP – 5

Fig. 11-2*e*. Form AFP-5.

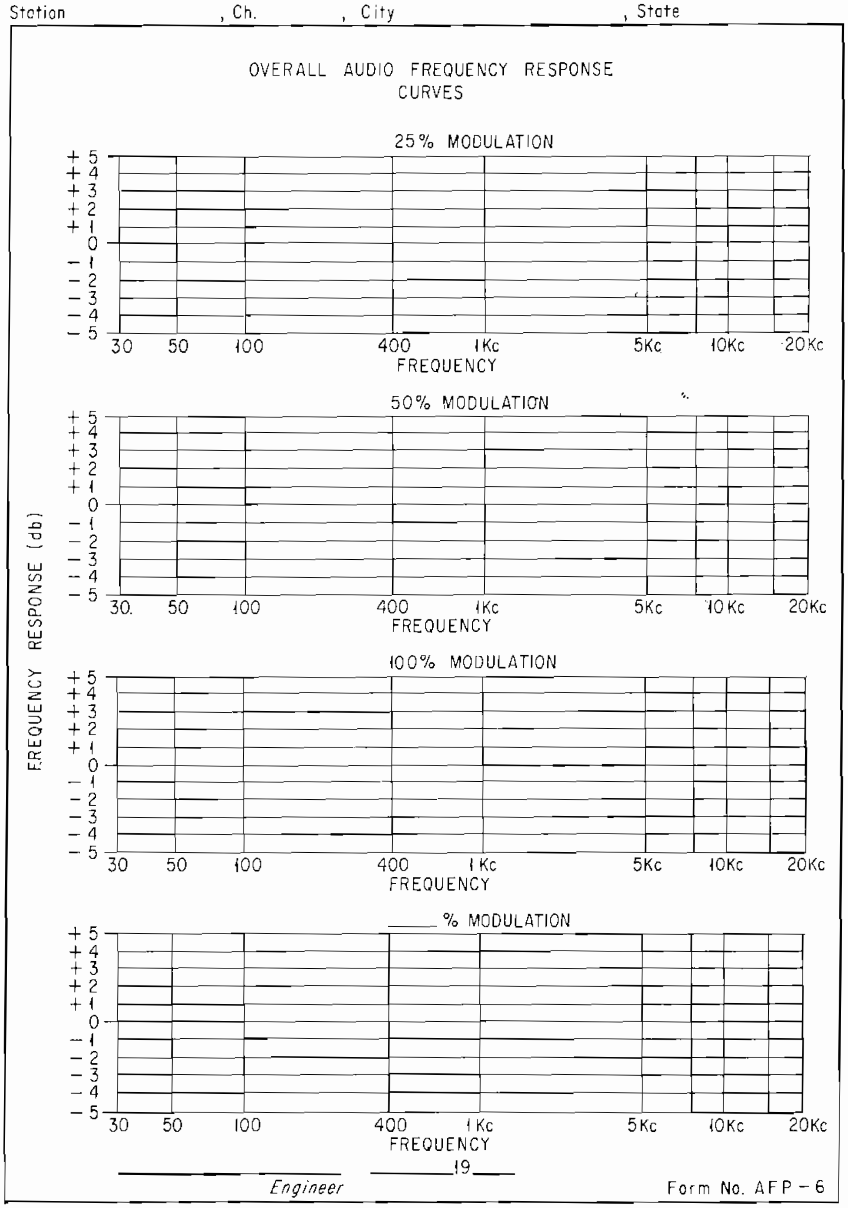


Fig. 11-2*f*. Form AFP-6.

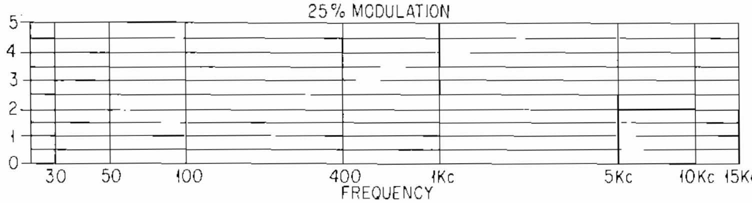
Station Ch. City State

AUDIO FREQUENCY HARMONIC CONTENT
DATA AND CURVES

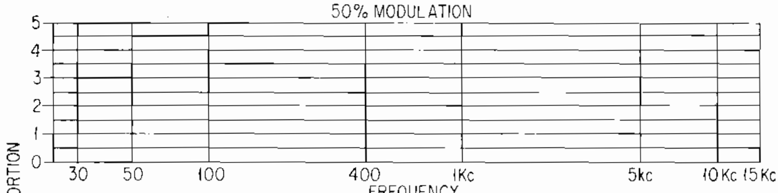
HARMONIC DISTORTION

% MOD.	CPS	50	100	400	1000	5000	10000	15000
	25							
	50							
	100							

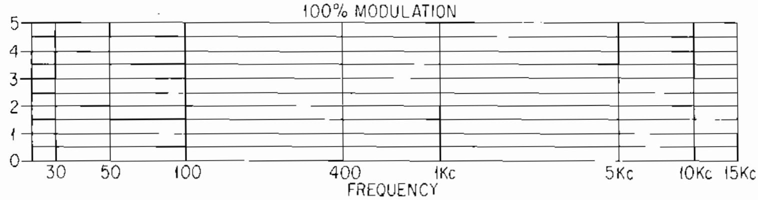
25% MODULATION



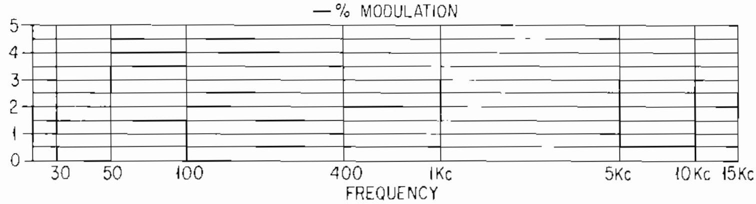
50% MODULATION



100% MODULATION



—% MODULATION



_____________ Engineer _______19____

Form No. AFP-7

FIG. 11-2g. Form AFP-7.

Station Ch. City State

OUTPUT NOISE LEVEL DATA

OUTPUT NOISE LEVEL (Frequency modulation)

VM READING AT 100% MODULATION	NOISE VOLTAGE	% NOISE: $\frac{\text{COLUMN 2}}{\text{COLUMN 1}} \times 100$	DB DOWN

OUTPUT NOISE LEVEL (Amplitude modulation)

VM READING AT 100% MODULATION	NOISE VOLTAGE	% NOISE: $\frac{\text{COLUMN 2}}{\text{COLUMN 1}} \times 100$	DB DOWN

Engineer 19

Form No. AFP – 8

Fig. 11-2*h*. Form AFP-8.

Part 12

PROOF OF PERFORMANCE FOR A TELEVISION STATION

JOSEPH L. STERN

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New York, N.Y.

WHY A PROOF OF PERFORMANCE

Proof of performance is required by the FCC when an application is filed for a license for a television broadcast station. It assures both the operator and the Federal Communications Commission that construction and operation have been in accordance with the formal authorizing instruments of the Commission. When modifications are made after the initial licensing, submission of a "proof" is required as evidence of continued compliance with the Regulations. In addition, the proof provides an opportunity for the station operator to assess the performance of his plant for his own benefit.

After a proof has been accepted by the Commission and the Program Test Authority granted, it is incumbent on the licensee to make periodic proof measurements for three reasons. This should be done in order (1) to have the information available as proof to an FCC inspector that the station is operating within the Rules and Regulations, (2) to have available as a reference in license renewal applications, and (3) to indicate to the operator that his equipment is operating at peak performance, transmitting pictures and sound of the highest possible quality at all times. The transmission of a "standard television signal" is a requirement of the Rules and the proof attests to compliance with the Rules.

In making a proof, the operator establishes a method of operational maintenance which will guide him in a continuous quality assessment. A properly executed proof, done with the full understanding of the operating staff, is a very valuable tool to the station. The measurements carried out for the proof can be established as required periodic maintenance measurements within the plant. The formal submission of these data or their inspection by the FCC can be equated to an audit of a carefully kept set of accounting records, confirming the soundness of the operation. For many operators a proof has the onus of something very special and difficult. It is often thought that unusual and obscure measurement techniques are required just to satisfy a special governmental regulation. The following explanation of the performance of a proof will show that the measurements are simple to undertake. These measurements not only satisfy the requirements of the FCC but in addition assure the operator that he is getting the maximum return from his equipment and manpower investment.

Broadcast Application — FEDERAL COMMUNICATIONS COMMISSION — Section II-C

LICENSE APPLICATION ENGINEERING DATA
TELEVISION BROADCAST

Name of applicant

1. Facilities authorized in construction permit

Call letters	Channel No.	File No. of construction permit

Frequency	Carrier frequency
______ Mc.	Visual .... Mc Aural .... Mc

Effective Radiated Power (visual)	Effective Radiated Power (aural)	Antenna height above average terrain
In dbk:	In dbk:	
In kw:	In kw:	feet

2. Station location (principal community)

State	City or town

3. Transmitter location

State	County
City or town	Street Address (or other identification)

4. Main studio location

State	County
City or town	Street address

5. Transmitters Installed

Visual

Make	Type No.	Rated power
		In dbk: In kw:

Aural

Make	Type No.	Rated power
		In dbk: In kw:

Operating constants

Visual transmitter (while transmitting black)

D. C. plate current in last radio stage, in amperes	Applied D. C. plate voltage of last radio stage, in volts

Transmitter power output (after vestigial sideband filter, if used, and after multiplexer, if combined)	Multiplexer loss in db, if separate:	Input to transmission line in dbk:
In dbk: In kw:		

Transmission line power loss in db:	Antenna input power in dbk:	Antenna power gain in db:	Effective radiated power
			In dbk: In kw:

Attach as Exhibit No. complete information concerning the method of power output determination. If power is measured at output of multiplexer, so state.

Reading of power output meter (transmission line voltage, current or power; indicate which) while operating at authorized power:

Aural transmitter

D. C. plate current in last radio stage, in amperes	Applied D. C. plate voltage of last radio stage, in volts
Plate input power to last radio stage in kilowatts	Efficiency factor F of transmitter at operating power, in percent
Transmitter power output In dbk: In kw:	RF transmission line meter reading

6. Antenna and transmission line

Antenna make and Type No.	Number of sections	Power gain in db

Antenna supporting structure

Overall height of antenna system above ground in feet

Geographical coordinates of antenna (to nearest second)
North latitude ° ′ ″ West longitude ° ′ ″

If directional antenna is used, give full details including horizontal and vertical plane radiation patterns, as Exhibit No.

Is electrical or mechanical beam tilting employed? Yes ☐ No ☐
If so, describe fully in Exhibit No. , including horizontal and pertinent vertical radiation patterns.

Has antenna been altered to provide null fill-in? Yes ☐ No ☐
If so, describe fully in Exhibit No.

Transmission line

Make	Type No.	Coaxial or waveguide
Size (nominal inside transverse dimensions) in inches	Length in feet	Power loss in db for this length

Multiplexer

Make	Type No.

If emergency antenna or transmission line measures are provided, describe in Exhibit No.

7. Modulation monitors

(a) Visual monitor or monitoring equipment

Make	Type No. (or describe in Exhibit No.)

(b) Aural monitor

Make	Type No.

8. Frequency monitors

(a) Visual monitor

Make	Normal limits of deviation of carrier frequency shown by monitor
Type No.	cps. high/low to cps. high/low

FIG. 12-1*a*. FCC Form 302, Sec. II-C, p. 1.

Broadcast Application — TELEVISION BROADCAST ENGINEERING DATA — Section II-C, Page 2

8. (Continued)

(b) Aural monitor

Make	Normal limits of deviation of carrier frequency shown by monitor
Type No.	high cps. to cps. high / low low

If either frequency monitor indicates any carrier deviation in excess of the permissible tolerance, describe in Exhibit No. and state the corrective measures taken.

If the carrier frequencies have been measured by other means, describe in Exhibit No. , giving the date, method used or frequency measuring service employed, the results obtained and the monitor readings (high or low) at the time.

9. Performance data - Visual transmitter

a. Attach as Exhibit No. data showing the following:

1. Overall attenuation versus frequency of the visual transmitter;
2. Field strength or voltage of the lower side-band for a modulating frequency of 1.25 mc. or greater, and of the upper side-band for a modulating frequency of 4.75 mc. or greater;
3. A description of the equipment and technique used in making these measurements.

b. Attach as Exhibit No. data demonstrating that the waveform of the transmitted signal conforms to that specified by the standards. Until the form of those measurements may be specified by the Commission, the character of this data is left to the discretion of the applicant.

c. Attach as Exhibit No. a photograph of a test pattern taken from a receiver or monitor connected to the transmitter output.

10. Performance data - Aural transmitter

Attach as Exhibit No. data, diagrams, and appropriate graphs together with description of measurement procedures and instruments with regard to the following: (All measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna output, including telephone lines, pre-emphasis circuits and any equalizers employed except for microphones, and without compression if a compression amplifier is installed.)

a. Audio frequency response from 50 to 15,000 cycles for approximately 25, 50 and 100 percent modulation. Measurements shall be made on at least the following audio frequencies: 50, 100, 400, 1000, 5000, 10,000 and 15,000 cycles. The frequency response measurements should normally be made without deemphasis; however, standard 75 microsecond deemphasis may be employed in the measuring equipment or system provided the accuracy of the deemphasis circuit is sufficient to insure that the measured response is within the prescribed limits.

b. Audio frequency harmonic distortion for 25, 50 and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1000 and 5000 cycles. Audio frequency harmonics for 100 percent modulation for fundamental frequencies of 10,000 and 15,000 cycles. Measurements shall normally include harmonics to 30,000 cycles. The distortion measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

c. Output noise level (frequency modulation) in the band of 50 to 15,000 cycles in decibels below the audio frequency level representing a frequency swing of 25 kilocycles. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

d. Output noise level (amplitude modulation) in the band of 50 to 15,000 cycles in decibels below the level representing 100 percent amplitude modulation. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

11. In what respect, if any, does the apparatus constructed differ from that described in the application for construction permit or in the permit?

I certify that I am the Technical Director, Chief Engineer or Consulting Engineer for the applicant of the radio station for which this application is submitted and that I have examined the foregoing statement of technical information and that it is true to the best of my knowledge and belief. (This signature may be omitted provided the engineer's original signed report of the data from which the information contained herein has been obtained is attached hereto.)

Date ______________________ ______________________

Technical Director, Chief Engineer or Consulting Engineer

FIG. 12-1*b*. FCC Form 302, Sec. II-C, p. 2.

THE PERFORMANCE OF A PROOF

As an absolute minimum, the proof is a series of exhibits detailing information requested in Section II-C of FCC Form 302, License Application Engineering Data—Television Broadcast as amended (Fig. 12-1*a* and *b*). As a practical minimum, the "proof" is what the name implies, proof (1) that the facility for which license application has been made is, in fact, constructed in accordance with the Construction Permit and (2) that the facility is capable of operating in conformance with the Rules and Regulations—that it has transmitted a "standard television signal."

To measure the performance of the television plant, all the normal segments of the plant must be included. The main studio, as well as the transmitting plant, should be included in the measurement, for this is the source of the original signals. While program content is not a part of the reported measurements, the handling of program material, both audio and video, is the object of the measurements.

Most of the visual transmitter characteristics described in the Rules specify the transmitter as the item being measured but, at the same time, define the transmission standards as applying to the radiated signal. Thus, it is incumbent on the operator to prove the performance of the transmitter where it is specifically requested and to prove that the entire system can meet the transmission standards. If it is not possible to measure the complete system at one time, an attempt should be made to provide the transmitting plant with operating tolerances more stringent than those in the Rules, allowing for some degradation in the studio plant and studio-to-transmitter circuits.

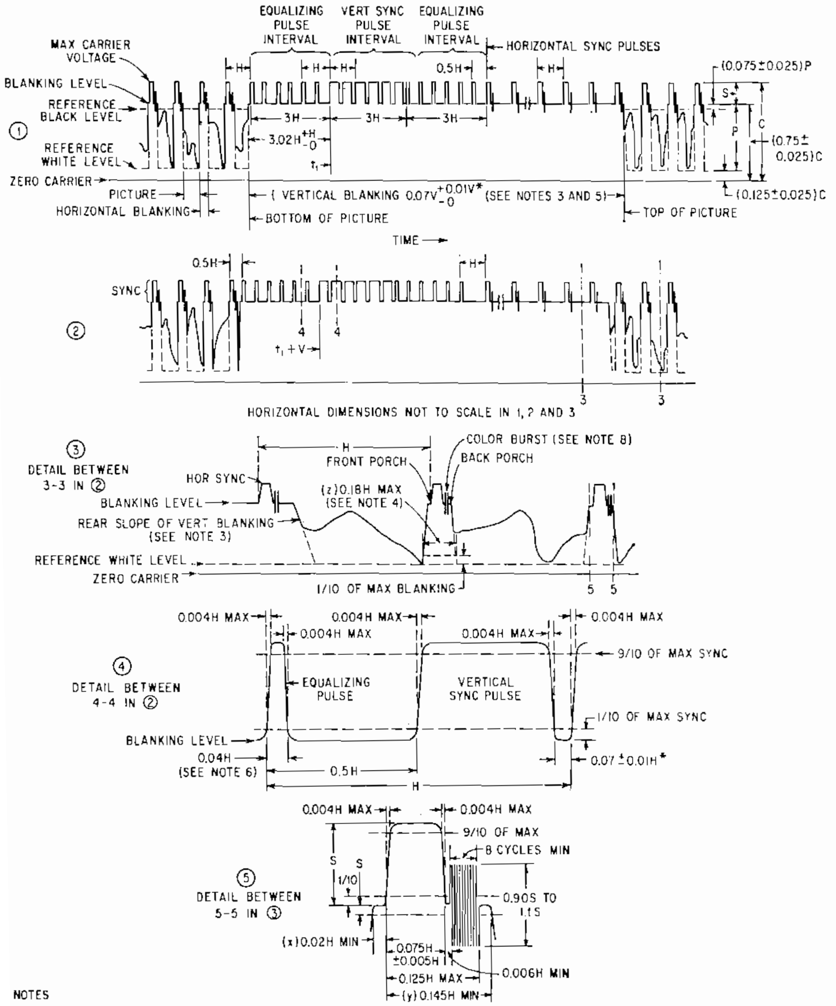
The aural transmitter is defined in two ways: as a transmitter for some measurements and as a transmitting system for others. Transmission measurements for the aural system must be made through this entire system starting with the microphone preamplifier, while the operating characteristics of the aural transmitter alone can naturally be measured on the aural transmitter itself. In all cases, however, for both the aural and visual transmitters, it must be remembered that the "transmitter" input terminals are the *input terminals of the "plant"* and not those physically on the transmitter cabinet. Here the intent of the regulations is quite clear: Those normally used preemphasis and auxiliary components required for proper operation of the transmitter, within the transmitting plant, *are all considered as being a part of the transmitter.*

Examination of FCC Form 302, Section II-C (Fig. 12-1*a* and *b*) will aid in demonstrating the performance of a "proof." All information that can be definitely listed is requested in the blank form but the information that requires detailing is requested in exhibit form.

Determination of Transmitter Power Output

The first exhibit requested is complete information concerning the method of power-output determination (II-C-5). The Rules and Regulations (3.689-a-1) [1] stipulate that the peak output power of the visual transmitter shall be measured at the output of the vestigial-sideband filter (if one is used) while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission-line surge impedance while transmitting a standard black picture. The object is simply to provide a means for measuring the output power of the transmitter while operating into a load substantially equal to the load normally seen by the transmitter. To accomplish this end it is necessary to know the impedance characteristics both of the antenna and of the dummy load being used. This can be ascertained by standard impedance-measuring techniques utilizing bridges, admittance meters, or RF sweep techniques. Once the similarity of the antenna and the dummy load wattmeter have been established, a simple power reading can be made. It should be recognized during this measurement, however, that there are many components between the transmitter output and the antenna system input that can have small losses. The use of harmonic filters, lower sideband notch filters, diplexers, and triplexers must be taken into consideration, and

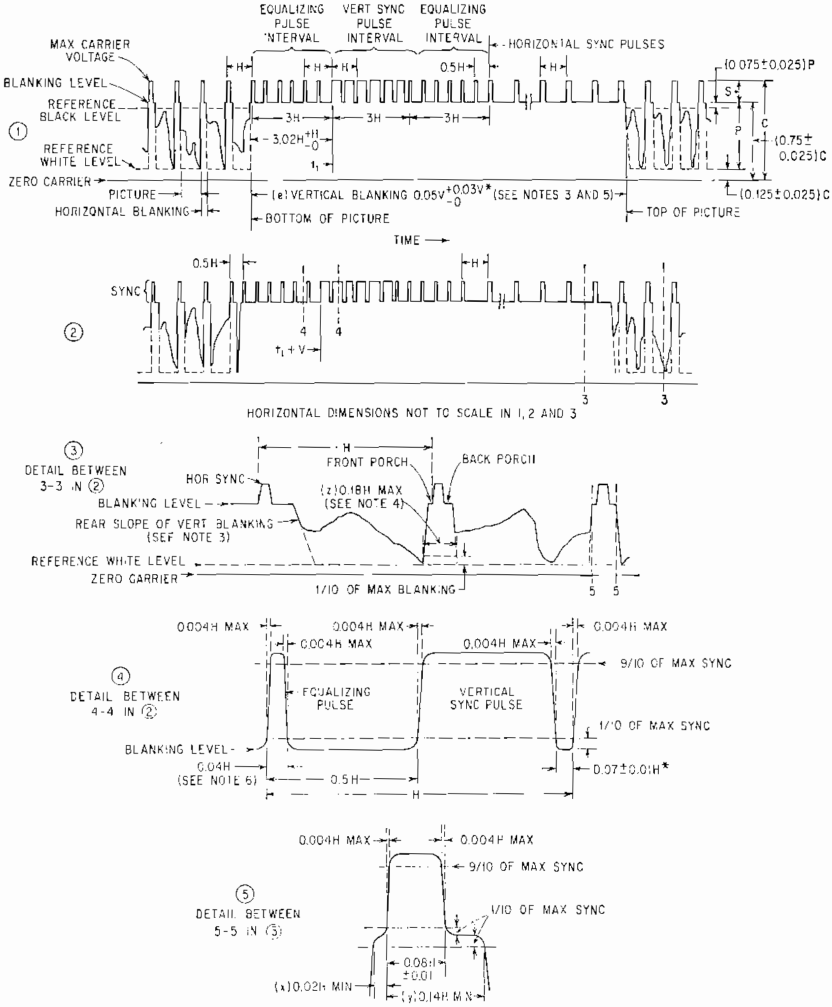
[1] Here and in the following pages, applicable paragraphs of the FCC Rules and Regulations, effective Jan. 2, 1956, are referenced parenthetically (see Sec. I).



NOTES

1 H = TIME FROM START OF ONE LINE TO START OF NEXT LINE.
2 V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD.
3 LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H.
4 LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x+y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT.
*5 DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES.
6 EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE.
7 COLOR BURST FOLLOWS EACH HORIZONTAL PULSE, BUT IS OMITTED FOLLOWING THE EQUALIZING PULSES AND DURING THE BROAD VERTICAL PULSES
8 COLOR BURSTS TO BE OMITTED DURING MONOCHROME TRANSMISSION.
9 THE BURST FREQUENCY SHALL BE 3.579545MC. THE TOLERANCE ON THE FREQUENCY SHALL BE ±10 CYCLES WITH A MAXIMUM RATE OF CHANGE OF FREQUENCY NOT TO EXCEED 1/10 CYCLE PER SECOND PER SECOND.
10 THE HORIZONTAL SCANNING FREQUENCY SHALL BE 2/455 TIMES THE BURST FREQUENCY.
11 THE DIMENSIONS SPECIFIED FOR THE BURST DETERMINE THE TIMES OF STARTING AND STOPPING THE BURST, BUT NOT ITS PHASE. THE COLOR BURST CONSISTS OF AMPLITUDE MODULATION OF A CONTINUOUS SINE WAVE.
12 DIMENSION "P" REPRESENTS THE PEAK EXCURSION OF THE LUMINANCE SIGNAL FROM BLANKING LEVEL, BUT DOES NOT INCLUDE THE CHROMINANCE SIGNAL. DIMENSION "S" IS THE SYNC AMPLITUDE ABOVE BLANKING LEVEL. DIMENSION "C" IS THE PEAK CARRIER AMPLITUDE
13 REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

FIG. 12-2*a*. FCC television synchronizing waveform for color transmission.



NOTES

1. H = TIME FROM START OF ONE LINE TO START OF NEXT LINE
2. V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD
3. LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H
4. LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x + y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT

*5. DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES

6. EQUALIZING PULSE ARE SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE
7. REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

FIG. 12-2b. FCC television synchronizing waveform for monochrome transmission.

their losses attributed to the antenna or transmitter system (as was originally outlined in the equipment description included in the application for construction permit).

When the power measurement is made on the visual transmitter, the peak output power of the transmitter, operating with black picture and standard sync (Fig. 12-2*a* and *b*), is determined by reading the average power directly from the dummy load wattmeter and multiplying this value by 1.68.[2] It is advisable to make this measurement at a number of different power levels so that it will be possible to plot a graph of peak power output vs. the reading of the power-output monitor device of the transmitter. This graph will allow the operating staff to determine readily that they are always operating within the plus 10 minus 20 per cent output power variation permitted by the Rules and Regulations (3.689-b-1).

Paragraph II-C-5 of Form 302 requests information to allow determinations of the output power of the aural transmitter by the indirect method (3.698-a-2). Unfortunately, this method does not take into account possible tube-efficiency variations due to the varying loading conditions possible for the final stage of the transmitter. For the condition of operation for which the transmitter is tuned, the correct stage efficiency can be determined from a power measurement with a dummy load wattmeter, as above. This dummy load measurement also allows the power to be measured at varying levels to obtain a plot of output power vs. RF transmission-line meter readings to allow for conformance with the plus 10 minus 20 per cent power limits allowed (3.689-b-2). Information developing the output power by the indirect method must be supplied on Form 302, Section II-C-5, and the direct measurement determination may also be supplied.

Antenna and Transmission Line

The next portion of Form 302 requesting exhibit information asks for data on the antenna system. Full information recording the special characteristics of the antenna, if any, should be included here. The same holds true for the case where emergency antennas or transmission lines are provided.

Frequency Monitors

Section II-C-8-6 requests an exhibit explaining any difficulties that may have caused the frequency monitor of the station to indicate excessive frequency deviation and the measures that have been taken to correct this deficiency. In addition, information is requested as to "outside" readings of the operating frequencies that may have been taken by means other than the station's own frequency monitor. Even though the station will be using a type-approved frequency monitor, it is still necessary to check against an "outside" standard to ensure that the long-time drift of the monitor is periodically corrected. This can be done at the station by comparing the station monitor readings with a signal received from WWV or WWVH[3] or by having the frequency of the station measured by an independent frequency-measuring service. For either of these cases the "outside" measurement should be described in detail and, of course, the station monitor should be corrected if found in error.

The performance of the visual transmitter is the subject of Sec. II-C-9. In addition to the information requested in II-C-9 there are further data required for color transmitters. These additional items have been detailed in FCC memoranda issued in 1954 and are included in the Rules and Regulations, dated effective Jan. 2, 1956. In essence, the exhibits submitted in response to II-C-9 should show that the visual transmitter meets all the required transmitter and operational characteristics outlined in Part 3 of the Rules.

Variation of Output

Variation of output (3.682-a-16) is the peak-to-peak change in signal amplitude during a period not exceeding one field in length. Variation of output results from such things as hum, noise, and incorrect low-frequency response. The Rules state that

[2] The factor 1.68 is valid only if standard sync height and width are maintained.

[3] See Section 1 of this handbook.

the variation of output at sync peak level and at blanking level shall not exceed 5 per cent of the average of the peak signal amplitude.

Method of Measurement. A sample of the transmitter output signal shall be detected, and the resulting video signal viewed on an oscilloscope. Means for establishing a zero reference must be provided. The sync peak should be calibrated in terms of peak power. The height of the highest and lowest sync peaks and the highest and lowest blanking levels shall be measured. Their respective differences shall not exceed 4.5 per cent of the highest sync peak. This will assure less than 5 per cent variation of the average peak signal amplitude. The over-all accuracy of the measuring equipment shall be sufficient to allow measurement of variation of amplitude with an accuracy of ± 1 per cent of the total peak amplitude. The input test signal shall contain a slightly nonsynchronous 60-cycle sine wave whose peak-to-peak amplitude is not less than 75 per cent of the excursion from reference black to reference white.[4]

(It should be noted that the FCC does not enforce this requirement at this time, per 3.682-a-16).

Over-all Attenuation

A measurement of over-all attenuation vs. frequency (3.687-a-1, 2; 3.699-Fig. 5) is requested for frequencies from zero to 4.75 Mc. This measurement is detailed in the Rules and Regulations and is, in essence, a diode measurement of the transmitter output when the transmitter is fed a video sweep signal. The limits of this measnrement are also established in the Rules. It is specified that this measurement be made into the antenna system (for color), but if the characteristics of the antenna and the dummy load have been measured to be substantially the same (as in the power measurement), a case can be made for the use of the dummy load in place of the antenna if this makes the measurement more convenient.

Method of Measurement. A modulating signal shall be applied to the transmitter input terminals in place of the normal composite television video signal. The signal applied shall be a composite signal composed of a synchronizing signal to establish peak output voltage plus a variable-frequency sine-wave voltage occupying the interval between synchronizing pulses. The axis of the sine wave in the composite signal observed in the output monitor shall be maintained at an amplitude of 0.45 of the voltage at synchronizing peaks. The amplitude of the sine-wave input shall be held at a constant value with this constant value such that at no modulation frequency does the maximum excursion of the sine wave observed in the composite output signal monitor exceed the value of 0.75 of reference-white to reference-black voltage in the double-sideband region. With a 200-kc modulating signal applied to the transmitter, the amplitude of the detected signal should be measured and designated 0 db as a basis for comparison. The frequency of the modulating signal shall then be varied over the desired range, and the detected signal measured.

As an alternate method of measuring in those cases in which the automatic d-c insertion can be replaced by manual control, the above characteristic can be taken by the use of a signal generator and without the use of blanking and synchronizing pulses. The transmitter operating level shall be set for mid-characteristic operation at 0.45 of the voltage corresponding to synchronizing peak.[5]

Field Strength or Voltage of Upper and Lower Sidebands

The field strength or voltage of the upper and lower sidebands (3.687-a-4) is to be measured for modulation frequencies from 200 kc to 5 Mc for the lower sideband and from 200 kc to 8 Mc for the upper sideband. It should be noted at this time that the rules require measurements of spurious emissions removed in frequency in excess of 3 Mc above or below the respective channel edge (3.687-i-1), and these measurements can often be performed at the same time as the upper and lower sideband measurements. In that it may be extremely difficult to make actual field-strength measurements to obtain the above data reliably, it is noted in the Rules that measure-

[4, 5] This method of measurement is currently being considered by the Electronics Industries Association.

ments made using a probe in the transmission line feeding a dummy load will be accepted. In the measurement of the upper and lower sidebands it is imperative that the input to the transmitter be held constant throughout the measurement. The detector for this measurement can be an accurately calibrated field-strength meter or a receiver system utilizing a substitution signal generator for calibration. In either case care must be taken to ensure that the field-strength meter or the receiver has a pass-band characteristic sufficiently narrow to allow only the sideband being measured to register. This is particularly important when the 200-kc component is being measured, for this is the reference for the entire measurement. The upper and lower sideband measurement can also be made using a sideband analyzer, but if this is done, great care must be taken to calibrate the device for amplitude linearity. The analyzer is not a perfectly linear device, and if it is used for this measurement, the use of calibrated attenuators is required to obtain the accuracy of measurement desired. The receiver or field-strength meter provides a much more rigorous proof of performance than the analyzer, but the analyzer is most helpful in making a rough check of the system prior to making precise measurements.

Throughout the measurement of the upper and lower sidebands the transmitter is adjusted to operate at mid-characteristic and the output is monitored to ensure that 0.75 peak output voltage is never exceeded. Ideally there should be an oscilloscope bridged across the input to the transmitter to monitor the input level at a constant voltage and a demodulator and a modulation monitor on the output to make sure that the modulation limits are not exceeded.

During the setup for this measurement special attention should be paid to the frequencies of minus 1.25, minus 3.58, minus 4.25, plus 4.75, and plus 7.75 Mc. These frequencies are the boundaries of the sideband characteristics (−1.25 and +4.75 Mc down 20 db), lower sideband of the color subcarrier (−3.58 Mc down 42 db) (3.687-a-3), and out-of-band radiation beyond 3 Mc above and below the assigned band edges (−4.25 and +7.75 Mc 60 db *below peak power*) (3.687-i-1). The region beyond minus 4.25 and plus 7.75 Mc should then be checked to ascertain that there are no spurious signals in these regions. This out-of-band measurement can also be made by applying test-pattern modulation to the transmitter and searching the out-of-band region with the receiver or field-strength meter used above.

Method of Measurement. It is recommended that the sideband characteristic of a visual transmitter be measured by the application of a modulating signal to the input terminals of the transmitter in place of the normal composite television video signal. The signal applied shall be a composite signal consisting of the normal television synchronizing pulses plus a variable-frequency sine wave occupying the intervals between pulses. The axis of the sine wave observed in the output monitor shall be maintained at an amplitude of 0.45 of the voltage of the synchronizing pulse peaks. The amplitude of the applied sine wave shall be maintained at a constant value such that at no modulation frequency does the maximum peak of the sine wave exceed 0.75 of the peak output voltage. The amplitude of the upper 200-kc sideband when using a 200-kc modulating frequency shall be measured by means of a field-strength meter or equivalent and used as the reference level. The modulating frequency shall then be varied over the range from 200 kc to 8 Mc, and the corresponding amplitudes of the upper and lower sidebands measured.

As an alternate method of measuring in those cases in which automatic d-c insertion can be replaced by manual control, the above characteristics can be taken by the use of a signal generator and without the use of blanking and synchronizing pulses. The transmitter operating level shall be set for mid-characteristic operation—0.45 of the voltage corresponding to synchronizing peak.[6]

Out-of-band Emissions

The Rules state that "all emissions removed in frequency in excess of 3 Mc above or below the respective channel edge shall be attenuated no less than 60 db below the

[6] This method of measurement is currently being considered by the Electronics Industries Association.

visual transmitted power" (3.687-i-1). The measurements described above determine the voltage of the upper and lower sidebands and not the relationship of these values to the transmitter peak power. To relate measurements of this type to the transmitter peak power for the purpose of determining compliance with the out-of-band requirements, additional calculations are required. It is necessary to (1) add an additional 6 db to the measured value to cover the case of one sideband of a 100 per cent modulated amplitude-modulation system, (2) add 3.5 db to compensate for the modulation index of 75-15/90, and (3) add 6.9 db to correct for the fact that the axis of the modulation is at a point equal to 45 per cent of carrier peak and not at carrier peak. Thus, the emission below peak transmitted power is determined by establishing the voltage level below the 200-kc point (assuming that it is the maximum point) as above and adding to that value a correction of 16.4 db to relate this figure to emission below the peak transmitted power.

Attenuation of RF Harmonics

The out-of-band emissions requirements also cover radio-frequency harmonics for both aural and visual transmitters. It is specified that these shall be as low as the state of the art permits and in no case attenuated less than 60 db below the visual peak transmitted power. There are a number of methods that can be used to measure the level of the radio-frequency harmonics, and the simplest is the use of a field-strength meter that has sufficient selectivity and rejection of the fundamental to allow accurate measurements. It is also possible to use a fundamental rejection filter with a field-strength meter that does not have sufficient isolation at the fundamental frequency. A second method which can be used is the substitution method wherein a calibrated receiver, fundamental rejection filter, and a substitution signal generator are used to simulate a calibrated field-strength meter. A third method is the General Radio Company's system utilizing rejection notch filters, heterodyning oscillators, IF amplifier, and detector. Any of the above systems are acceptable to the FCC provided sufficient data are included with the measurement to attest to the accuracy of the method used.

In all cases the harmonic measurements should be made in the transmission line following the harmonic filters, if used. In the case of UHF transmitting plants the FCC has indicated that they will accept transmitter measurements provided by the manufacturer. Measurements are not required beyond 1,000 Mc for transmitters on Channels 2 to 13 or beyond 3,000 Mc for Channels 14 to 83.

Transmitted Signal Waveform

Transmission standards for the transmitted signal waveform are fully detailed in the Rules (3.687-a-7, 8; 3.682-a-5, 6; 3.699-Figs. 5, 6, and 7). Section II-C-9-b of Form 302 requests an exhibit demonstrating conformance to these standards. It also notes that "Until the form of these measurements may be specified by the Commission, the character of this data is left to the discretion of the applicant."

As in all other data required, the burden of proof is on the applicant. The FCC has accepted many different presentations covering this proof of conformity to the Rules, but not all of them are of the type that gives definite infornaiton. It has been thought by some that the submission of a waveform or pulse-cross photograph (Figs. 12-3 and 12-4) taken from the CRO fed by the station demodulator will suffice to show conformity to the transmitted-waveform requirement. A careful check of the resolution possible in such a photograph and an analysis of the technique involved show that the errors possible in interpreting such a display are far greater than the tolerances allowed in the Rules.

A simple and straightforward method of preparing such an exhibit is simply to extend the normal maintenance techniques for the sync generator. Measure all the pertinent waveforms accurately on an oscilloscope having the facility for the addition of timing pulses and having sufficient rise time, magnification, and line-selection ability to show individually the section of the signal being studied (Figs. 12-5 to 12-7). A

Tektronix type 524, Dumont type 280, or similar oscilloscopes serve this purpose adequately.

Since the source of the synchronizing waveform is the main studio sync generator,

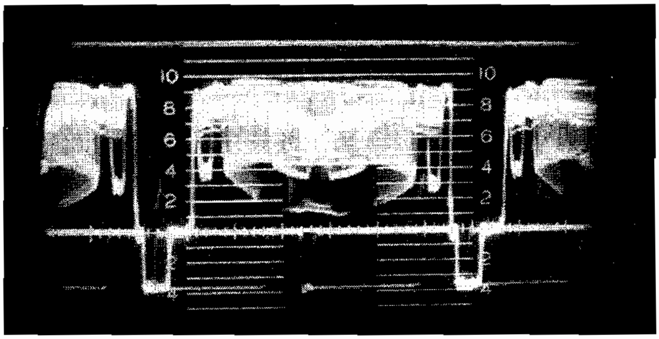


FIG. 12-3. CRO photograph of H presentation same as or similar to photograph presented in KMOX-TV proof.

the first part of this test should carefully measure the signals as they arrive at the transmitting plant. This is a normal maintenance procedure of the television plant and checks out not only the alignment of the sync generator but the processing and distribution amplifiers that may be used in the master control location and the studio-to-transmitter circuit. After it has been determined that the sync signal arriving at

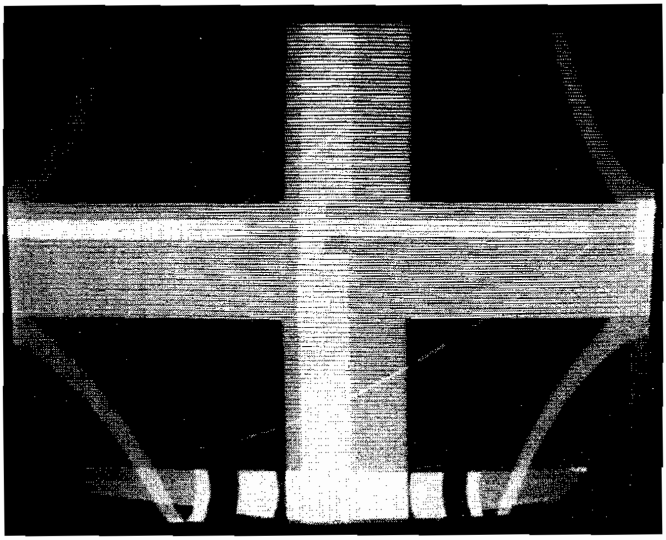


FIG. 12-4. Photograph of pulse cross display obtained from A/V.

the transmitter plant is "standard," it is fed to the transmitter. The transmitted characteristics can then be measured using a probe in the output transmission line to the antenna or the dummy load. An example of this technique and a method of reporting the measurement are shown in the sample "proof" below.

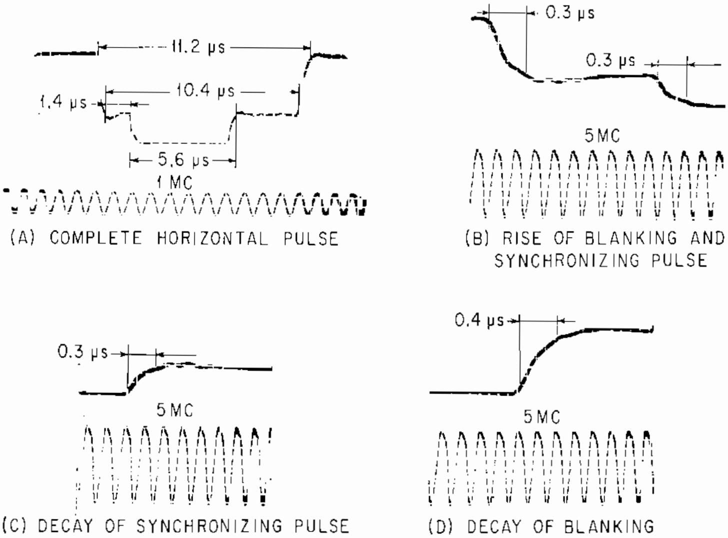


FIG. 12-5. Waveform times of horizontal synchronizing pulses.

Transmitted Test Pattern

Section II-C-9-c of Form 302 requests that an exhibit be prepared containing a photograph of the transmitted test pattern from a receiver or a monitor connected to the transmitter output. This is a straightforward task easily accomplished. The addition of one other photograph, that of the test pattern signal that is fed to the input of the transmitter, will add a wealth of information to the proof. A comparison of the "in" and the "out" can then be made to see if any degradation in the out test pattern is caused by the transmitter or is present in the incoming signal.

For color transmission there are a number of measurements required that are not listed on Form 302 but are noted in FCC mimeographs and detailed in the Rules (3.687-a-5, 9; 3.682-a-5, 20-VII). Conformity to the color-transmission standards requires measurements of transfer characteristic, differential gain, differential phase, and envelope delay as well as all the previously measured transmission characteristics.

Transfer Characteristic

Low-frequency linearity and differential gain, defined in the Rules as the transmitter transfer characteristic (3.687-a-9), can be measured rather simply. The Rules state that the transfer characteristic shall be substantially linear and assign no values to the degree of linearity. It behooves the color broadcaster to maintain maximum linearity for faithful color transmission. Extreme variations from linearity will also affect the fidelity of the monochrome transmissions. A stairstep generator is the simplest tool for this type of measurement. This unit along with a high-pass filter and an oscilloscope will allow accurate measurements of linearity or transfer characteristics to be made in very short order. Such a measurement is described below in the sample proof. Once again it is advisable, while making this measurement on the transmitter system, to make a similar measurement on the over-all studio-transmitter system for the information of the technical staff. Submission of this extra data is not required, but it allows a check to be made to ensure that there is no predistortion of linearity being used to compensate for the deficiencies of one or more elements of the transmitter-studio plant.

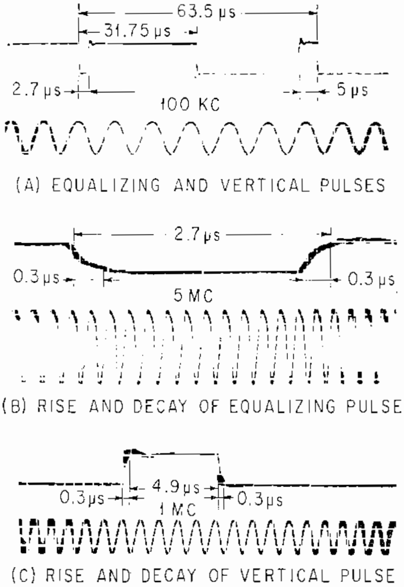


FIG. 12-6. Waveform times of vertical synchronizing pulses.

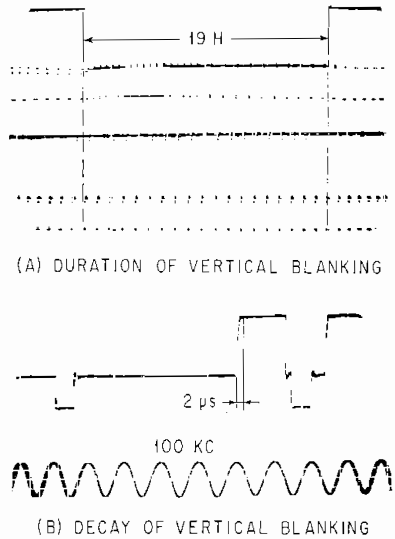


FIG. 12-7. Waveform times of vertical blanking pulse.

Low-frequency Linearity

The low-frequency linearity is defined as that characteristic which describes the change in RF output signal amplitude resulting from and corresponding to a change in input signal amplitude. No FCC specification is given, but it is advisable as a minimum standard to keep the linearity within 1.5 db for 10, 50, or 90 per cent average picture level when using a stairstep signal having 10 steps of equal amplitude covering the reference-white to blanking-level region.

Method of Measurement. The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a stairstep signal having at least 10 steps of equal amplitude. The test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a linear display monitor of the RF signal or of the RF envelope, the amplitudes of the different steps are compared using the greatest amplitude step as the reference. The linearity will be the ratio, expressed in decibels, of the amplitude of the tallest step to the amplitude of the shortest.[7]

Differential Gain

Differential gain is the difference in gain of the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal upon which it is superimposed. With no specific FCC specification but interpreting the color-signal specification in the Rules (3.682-a-20), it is advisable that the differential gain be maintained below 1.5 db for 10, 50, and 90 per cent average picture levels.

Method of Measurement. The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a low-frequency signal with a superimposed 3.58-Mc sine-wave signal whose peak-to-peak amplitude is 20 per cent of the low-

[7] This method of measurement is currently being considered by the Electronics Industries Association.

frequency signal amplitude between blanking and reference white. This composite test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a linear demodulator, the visual transmitter output is sampled, detected, and passed through a high-pass filter to an oscilloscope or any other suitable means of observing the 3.58-Mc component of the test signal. Any deviation from a constant amplitude display of the 3.58-Mc signal when viewed at the line-rate frequency is the differential-gain variation. The differential gain at any point is the ratio, expressed in decibels, of the amplitude of the maximum amplitude region referred to the amplitude of the point under consideration.[8]

Differential Phase

Conformity with the color-signal specifications of the Rules (3.682-a-20) can be further assured by a measurement of differential phase. Differential phase is the difference in phase shift through the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal on which it is superimposed. Interpreting these color standards it is advisable to adjust the station equipment so that the differential phase shall be less than 7° at 3.58 Mc when the reference burst region of a 50 per cent average picture level signal is used as reference. In addition, the total differential phase between any two levels shall not exceed 10°.

Method of Measurement. The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a low-frequency signal with a superimposed 3.58-Mc sine-wave signal whose peak-to-peak amplitude is 20 per cent of the low-frequency-signal amplitude between blanking and reference white. This composite test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a diode demodulator, the visual transmitter output is sampled, detected, and passed to any suitable phase-measuring equipment. The differential phase error is the difference in phase of the 3.58-Mc wave between the burst region of the composite signal and any other level under consideration.[9]

If the station is capable of generating local color signals and has a color-bar generator and Vectorscope, compliance with the color-signal specifications can be proved by a measurement of the phase and amplitude of the transmitted color bar, *I* and *Q* signals.

Although color specifications are under Transmission Standards in the Rules and not specifically listed as a transmitter characteristic, it is usually satisfactory to make these measurements at the transmitter plant. The same measurements should, however, be made from the studio plant to ensure that the transmission of color signals will be proper under the normal program routing. If it can be done, these measurements should be made from the main studio, checking the entire system for conformity to the transmission standards as the synchronizing waveforms were checked above.

As an added reminder—care must be taken during all the above measurements to assure that the transmitter and all the input equipment in the transmitting plant and in the component links between the studio and the transmitter are operating at their normal settings. The input to the transmitter modulator should be adjusted for the normal program excursions, and the output signal as viewed from the station demodulator should indicate that there is no overloading of the circuits. In brief, normal conditions should prevail.

Envelope Delay

At this writing, the only practical method of making envelope-delay measurement is through the use of a device known as an envelope-delay curve tracer. This measurement is outlined briefly in the sample proof below and more fully in the instructions for the use of the instrumeut.

[8, 9] This method of measurement is currently being considered by the Electronics Industries Association.

There are instruments presently under development which will provide simpler methods of making this measurement, and industry committees are at work attempting to develop simple coincidence checks to ascertain compliance with the requirements of the Rules (3.687-a-5). Graphical analysis of square-wave measurements can be used in making this check, but it is an extremely time-consuming effort, requiring a host of accurate measurements and resulting in answers whose possible errors may exceed the tolerances allowed in the Rules.

If equipment to measure the envelope-delay characteristics of the transmitter is not available, reference can be made to the fact that the envelope-delay-correction filters installed for the particular transmitter have been designed and adjusted by the manufacturer to provide the proper over-all envelope-delay characteristic. The approximate accuracy of this adjustment can be checked by observing the fidelity of a color-bar test signal and also by checking a square-wave signal for equality of "ringing" before and following a transition when the signal is observed through an ideal demodulator. Even though the envelope-delay-correction filters are passive, an attempt should be made at the earliest opportunity to make an actual measurement of the over-all system to ensure that the proper predistortion and correction are being made. It is hoped that new devices for this measurement will be available shortly.

Envelope delay is the first derivative of the phase vs. angular velocity characteristic at a particular frequency. In essence it is a measure of the coincidence of arrival of chrominance and luminance information and, per the FCC specifications, the predistortion introduced to produce this coincidence in a color receiver.

Method of Measurement. Envelope-delay measurements shall be made with commercial envelope-delay-measuring equipment under the same operating conditions as described above for over-all attenuation measurements. The RF demodulator shall be an ideal vestigial demodulator with sound trap switched out. An RF diode can be used for measurements above 1.25 Mc. (Further information is given in the sample proof below.) [10]

It must be kept in mind here, as above, that even though the specifications in the Rules are for the transmitter, the envelope delay in the entire studio and link system should be kept within the FCC tolerances in order to provide the highest fidelity of color transmission within the specifications of the NTSC system. For the benefit of the station the envelope delay of this entire system should be measured periodically as both a maintenance tool and a proof of performance.

Section II-C-10 of Form 302 requests exhibits describing fully measurements of performance of the aural system including "all circuits between the main studio microphone terminals and the antenna output, including telephone lines, pre-emphasis circuits and any equalizers employed except for microphones, and without compression if a compression amplifier is installed." The Rules list the operational characteristics required of the system (3.687-b-1,2,3,4,5,6,7) and further recommend that none of the three main divisions of the system (transmitter, studio-to-transmitter circuit, and audio facilities) shall contribute more than half of the allowable total degradation for the entire system. This requires that not only the system as a whole be measured but that measurements be made separately on each of the three main divisions.

Audio-frequency Response

The measurement of the audio-frequency response of the aural system is a straightforward type of measurement but requires modifications of the usual "amplifier" testing techniques truly to measure the performance of the aural transmission system. Since there is a difference in peak voltages reached by pure sine-wave and normal program signals for equivalent volume-indicator readings, adjustments of the input level of the test signals should be made to compensate for this difference. One method is to use an "elevated" level 10 db above normal (−50 dbm at microphone input) to simulate 100 per cent modulation. This technique will measure the frequency re-

[10] This method of measurement is currently being considered by the Electronics Industries Association.

sponse for normal program transmission and not simply the response of the system to sine waves. The detailed procedure for this measurement is described in the sample proof below.

Distortion

System distortion should be measured with the same setup used for the frequency-response measurement above in order to save time and minimize setup errors.

FM and AM Noise

Frequency-modulation noise on the carrier is the residual frequency modulation resulting from disturbances produced in the transmitter itself within the band of 50 to 15,000 cycles. The level is expressed as the ratio of the residual frequency swing in the absence of modulation to the full frequency swing with modulation as weighted by the effect of a standard 75-μsec deemphasis circuit. FM-noise-level measurements can be made with the distortion-measurement equipment used for the above measurement.

Method of Measnrement. The frequency-modulation noise level can be obtained by demodulating a sample of RF output of the transmitter and comparing the rms voltage developed by the demodulator in the absence of modulation voltage to the rms voltage obtained with 100 per cent, 400-cycle modulation. The audio input terminals of the transmitter shall be shunted by a resistance equal to the transmitter input impedance. The frequency-response characteristic of the demodulator shall be within ± 1 db of the standard 75-μsec deemphasis curve from 50 to 15,000 cycles.[11]

The amplitude-modulation noise level on an aural transmitter carrier is the ratio of the rms value of the amplitude-modulation component (50 to 15,000 cycles) of the carrier envelope to the rms carrier value in the absence of applied modulating voltage.

Measurement of the carrier amplitude-modulation noise level can be accomplished by the use of a linear peak-carrier-responsive AM detector with 75-μsec deemphasis coupled to the output of a transmitter. Readings are made of the d-c voltage and the rms value of the a-c component across the detector load resistor. The d-c voltage must be multiplied by 0.707. These measurements shall be made in the absence of modulating voltage. The audio input terminals of the transmitter shall be shunted by a resistance equal to the transmitter input impedance. Equipment for this measnrement is commercially available or can be assembled by the station.

In all cases, the equipment used for any of the measurements should be described by manufacturer, type, and serial number, and if composite, a general description of the device shonld be included in the "proof."

THE PROOF OF PERFORMANCE

Herein follows a composite sample "proof" made up from six "proofs" submitted to the FCC by CBS over the past ten years. A composite of these "proofs" was chosen rather than a sample of one proof in order to illustrate as comprehensively as possible the method of proving performance.

[11] This method of measurement is currently being considered by the Electronics Industries Association.

(SAMPLE PROOF OF PERFORMANCE)

CBS TELEVISION NETWORK

ENGINEERING DEPARTMENT

(STATION CALL, CITY)

AURAL AND VISUAL PERFORMANCE

REPORT (NUMBER)

(EXAMPLE)

STATE OF NEW YORK } SS:
COUNTY OF NEW YORK }

JOSEPH L. STERN, being duly sworn upon his oath, deposes and says:

1. That he is employed by the Columbia Broadcasting System as a Senior Project Engineer in the CBS Television Network Division, 485 Madison Avenue, New York 22, New York.
2. That he is a graduate of the University of Conneeticut with the degree of B.S.E.E.
3. That his qualifications as an engineer are known to the Commission, having been accepted in many previous applications and engineering reports filed with and acted upon by the Federal Communications Commission.
4. That he has prepared the attached engineering report and that the adjustments, measurements, and calculations discussed therein were made by him personally or under his supervision and direction.
5. That the facts stated herein are true of his own knowledge, except such facts as are stated to be on information or belief, and as to such facts, he believes them to be true.

____
Joseph L. Stern

Subscribed and sworn to before
me this ______ day of ____________

(NOTE: Affidavit not required if engineer performing or directing measurements signs Form 302, Section II, page 2, attesting to validity of measurements.)

(SAMPLE)

REPORT (NUMBER)

SUMMARY

This report details aural and visual performance measurements made at television station (*call*), (*city*), (*state*), following the installation of ____________________ in accordance with Television Broadcast Station Constructing Permit ____________________, dated ________________________. The measurements reported herein are submitted as engineering exhibits associated with application for television broadcast statiou license for station (*call*), and establish that the (*call*) transmitter and studio equipments are operating in full conformity with the Rules and Regulations as established by the Federal Communications Commission.

INTRODUCTION

In association with Section II of subject application for license this exhibit answers fully all questions pertaining to the operation and technical performance of (*call*). All of the measurements reported herein were made on the complete transmitting plant and reflect the true and normal operation of television station (*call*) for the effective radiated power specified in Construction Permit _____________, dated ____________. Construction authorized by this permit was begun on ____________________________ and was completed on __________________________.

In addition to the measurements specified in Form 302 additional measurements have been made to ensure that the entire plant meets the more rigid requirements for color transmission and they are described herein.

Transmitter Power-output Determination (II-C-5)—(Example)

The power output of both the visual and aural transmitters was measured by the use of a calibrated dummy-load wattmeter, the impedance of which was measured and found to be substantially equivalent to the transmitting-antenna impedance. Impedance measurements of the dummy-load wattmeter and the antenna system were made with a General Radio type 1602-A admittance meter to establish that the impedance of the antenna system was equivalent to that of the dummy load wattmeter for power-determination purposes. The VSWR of the dummy load was found to be less than 1.05 in a 51.5-ohm line over the 54- to 60-Mc band, and the antenna system VSWR was 1.11 or less over the 54- to 60-Mc band as shown in Fig. P-1. The wattmeter (General Electric Co. model 19193) contains a calibrated voltmeter which reads average power directly. The visual transmitter is equipped with a peak-reading voltmeter coupled to the output transmission line as well as a reflectometer which indicates the forward and reverse voltage in the transmission line. The aural transmitter also contains a reflectometer unit for the measurements of forward and reverse voltage in the output transmission line. Figure P-2 shows the voltage standing-wave ratio of the antenna system and transmission lines. This figure was obtained from the data given in Fig. P-1.

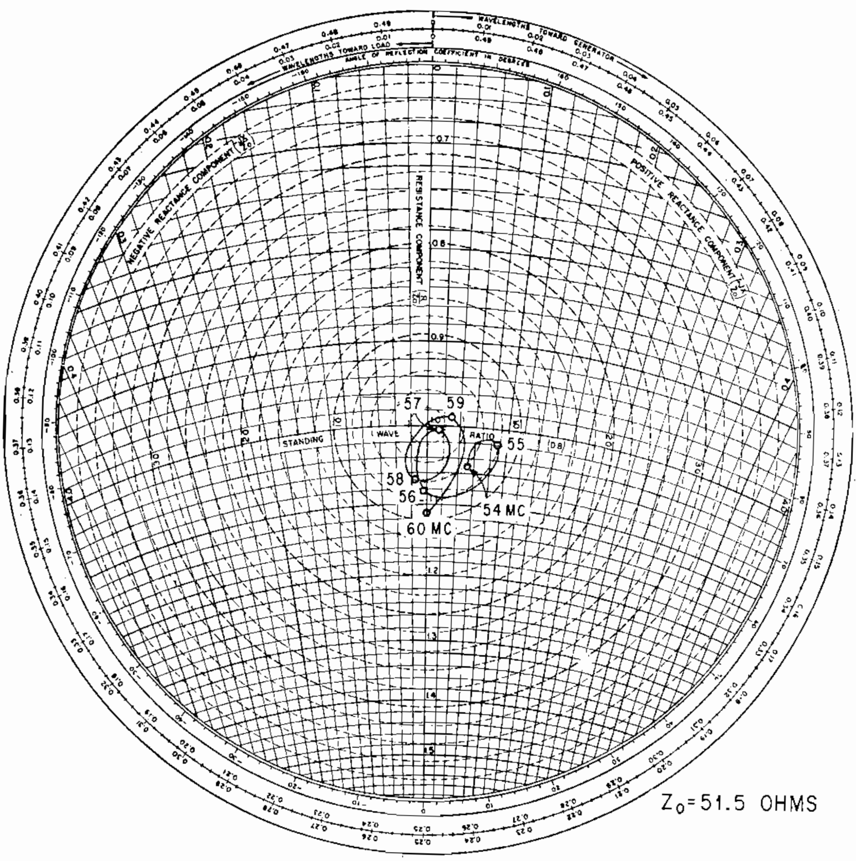


Fig. P-1. Measured impedance of KNXT antenna at diplexer input.

In measuring the power output of the visual transmitter, the output of the transmitter was connected directly to the dummy-load wattmeter. The transmitter was then modulated with an all-black picture and the standard 25 per cent sync. The average power was read on the wattmeter indicator, and the peak power (power during sync pulse) was obtained by multiplying the average power by a factor of 1.68. Reflectometer readings were noted for several adjustments of transmitter power output, and a graph of the relationship was prepared. This graph is presented in Fig. P-3 and serves as a calibration of transmitter peak power output during normal operation.

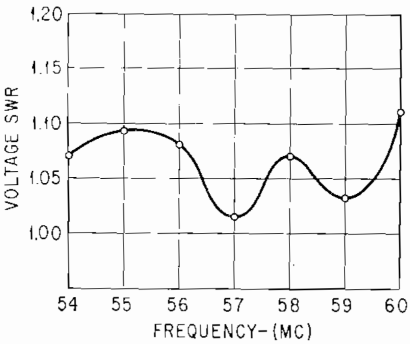


FIG. P-2. Voltage standing-wave ratio of antenna and transmission line.

The power output of the aural transmitter was measured by connecting the transmitter output directly to the dummy-load wattmeter, described above. The efficiency factor F was determined from this measurement and used in completing paragraph II-C-5 of FCC Form 302. The transmitter was adjusted for a number of different operating levels, and the average power was read directly from the indicating meter of the dummy-load wattmeter. A plot of the transmitter output vs. aural reflectometer reading is presented as Fig. P-4. Thus calibrated, the reflectometer reading serves as an indication of transmitter output power during normal operation.

The (*call*) antenna system has a VSWR of 1.11 or less over the 54- to 60-Mc band. This means that the reflection coefficient is less than 0.052 and that the power reflected from the antenna system is less than $(0.052)^2$, or 0.27 per cent of the power reaching the antenna. Therefore, the reflectometer and peak-reading voltmeter give a true measure of the power entering the antenna system.

After the measurements described above had been made, the visual transmitter was adjusted to give a peak output power of 11.7 dbk (14.8 kw) at the output of the diplexer. The power gain of the antenna system is 5.65 db at visual frequency, and the transmission-line efficiency is 86 per cent, representing a loss of 0.67 db. The diplexer being a hybrid device has a negligible loss and, accordingly, this combination results in an effective radiated power of 16.7 dbk (46.8 kw) as specified in the construction permit.

The aural transmitter was adjusted for an output of 8.7-dbk (7.4 kw) average power with an antenna gain of 5.65 db and a transmission-line efficiency of 86 per cent, representing a loss of 0.67 db, thus giving an effective radiated power of 13.7 dbk (23.4 kw).

ANTENNA AND TRANSMISSION LINE (SECTION II-C-6)–(EXAMPLE)

There are complete regular and auxiliary transmitting facilities at the (*call*) plant as well as complete regular and auxiliary antenna and transmission lines. Either transmitter can be

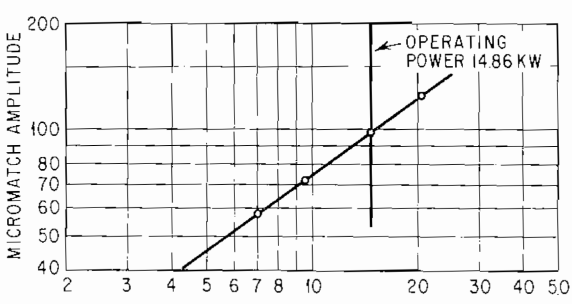


FIG. P-3. Reflectometer calibration visual transmitter.

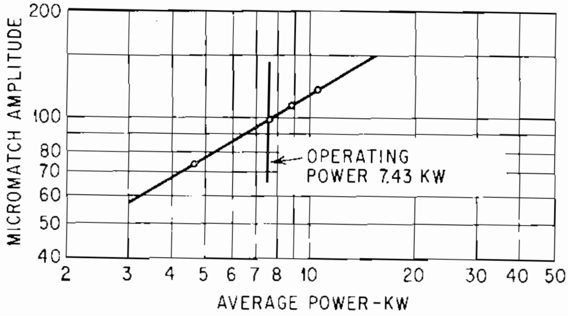


Fig. P-4. Reflectometer calibration aural transmitter.

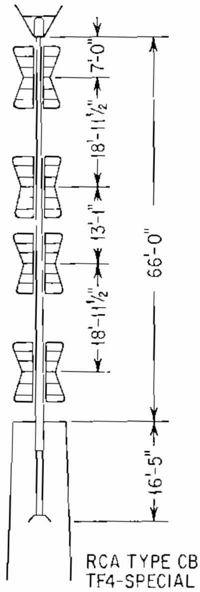


Fig. P-5. Transmitting antenna (designed for null fill-in).

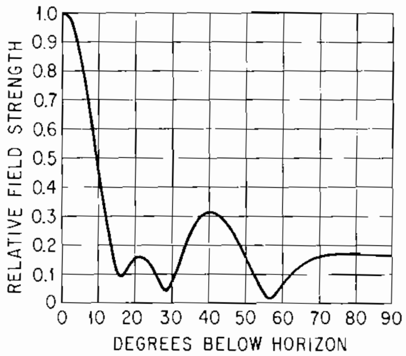


Fig. P-6. Calculated vertical radiation pattern.

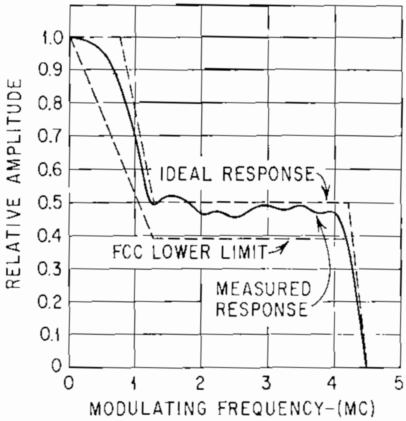


Fig. P-7. Over-all attenuation vs. frequency of visual transmitter (as measured with a diode on the RF transmission line).

fed to either antenna by means of a patch panel. The auxiliary antenna and transmission line are described in the application for construction permit BPCT-1802 (File No.) dated Feb. 2, 1954.

The regular transmitting antenna is an RCA type CB-TF4-special. The essential details of this antenna are shown in Fig. P-5. This antenna is designed for null fill-in, and the calculated vertical-radiation pattern is shown in Fig. P-6.

Frequency Monitors (II-C-8)–(Example)

In addition to regular readings of the station visual and aural frequencies made on the station monitors, measurements have been made by (*Name*) Measurements Company, (*Address*), (*City*), (*State*), for the purpose of adjusting the station monitors, with the following results:

Date and time	*Trans-mitter*	*T and T Measurements Company, cycles*	*Station monitor measurement, cycles*
Nov. 6, 1958 1:38 A.M.	Visual	55,249,912	55,250,900
Nov. 6, 1958 1:40 A.M	Aural	59,750,330	59,750,200
Nov. 20, 1958 2:05 A.M.	Aural	59,750,317	59,750,300
Nov. 20, 1958 2:08 A.M.	Visual	44,249,939	55,249,930

The assigned frequency is 55,250,000 cycles for the visual transmitter and 59,750,000 cycles for the aural transmitter.

Performance Data–Visual Transmitter (II-C-9)

Variation of Output–(Example)

The peak-to-peak variation of transmitter output within one frame of the video signal was measured while the transmitter was being fed with a 60-cycle sine wave and standard synchronizing signals and was found to be 4 per cent of the average sync peak amplitude.

Over-all Attenuation vs. Frequency (II-C-9-a-1)–(Example)

Figure P-7 is a plot of the measured over-all attenuation vs. modulation frequencies from 0 to 5 Mc. These data were obtained by feeding the transmitter input system (containing all corrective equipment required to meet the FCC Rules and Regulations) with a video sweep signal and observing the output of a diode coupled to the RF transmission line feeding the antenna system. This plot was prepared by taking data from the CRT of a Tektronix type 524-D oscilloscope using inserted single-frequency marker signals for frequency determinations. Figure P-8 is a block diagram of the equipment setup used in making these measurements.

Field Strength or Voltage of Upper and Lower Sidebands (II-c-9-a-2)–(Example)

Figure P-9 is a plot of the relative voltage amplitude of the (*call*) transmitter upper and lower sidebands from 5 Mc below carrier to 8 Mc.

These measurements were all made at the output of the transmitter which was connected to the dummy load. The measuring equipment was set up as shown in Fig. P-10. The field-strength meter was tuned successively to the upper and lower sideband for each modulating frequency used, the input being held constant at all frequencies, and the amplitude was recorded. As shown by Fig. P-9 the attenuation of the upper and lower sidebands of the (*call*) transmitter fully meets the Commission's Rules concerning the relative levels of upper and lower sidehands also shown on Fig. P-9.

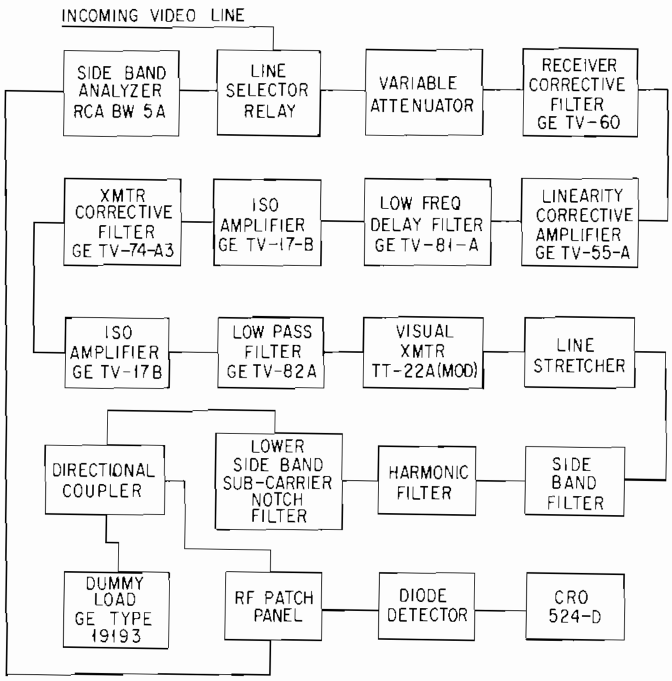


Fig. P-8. Block diagram for over-all attenuation measurements.

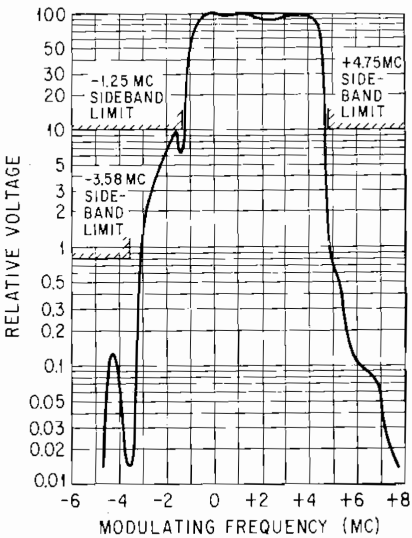


Fig. P-9. Measured voltage amplitude of upper and lower sidebands.

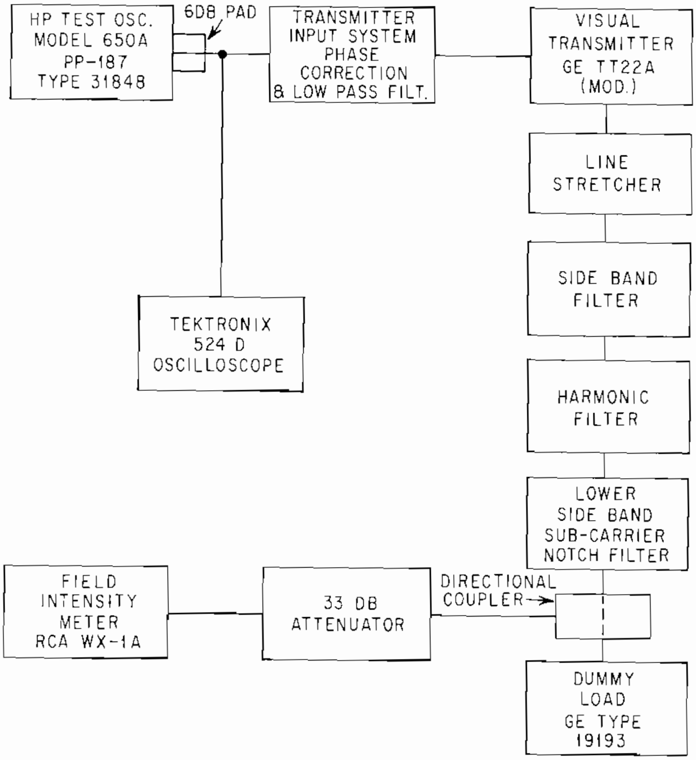


FIG. P-10. Block diagram of equipment used for measuring voltage of upper and lower sidebands.

Out-of-band Emissions—(Example)

Section 3.687 (i) 1 of the Rules states that "all emissions removed in frequency in excess of 3 Mc above or below the respective channel edge shall be attenuated no less than 60 db below the visual transmitter power." As shown in Fig. P-9 the voltage amplitude for a frequency 4.25 Mc below carrier, relative to a 200-kc reference, is 57.8 db down. To relate this measured value to the actual emission, relative to visual transmitted peak power, it is necessary to (1) add an additional 6 db for the case of one sideband of a 100 per cent modulated amplitude-modulation system, (2) add 3.5 db to compensate for the modulation index of 75-15/90, and (3) add 6.9 db to correct for the fact that the axis of the modulation is at a point equal to 45 per cent of carrier peak and not at carrier peak. Thus, the emission at −4.25 Mc is at least 57.8 db + 6 db + 3.5 db + 6.9 db = 74.2 db below visual transmitted peak power.

In the case of the upper-band-edge requirement, Fig. P-9 shows a measured value of −77.2 db for a frequency 7.75 Mc above visual carrier. Adding the correctiou factors, as above, the emission is 77.2 db + 6 db + 3.5 db + 6.9 db = 93.6 db below transmitted peak power.

Attenuation of RF Harmonics—(Example)

Figure P-11 shows the equipment setup that was used for the measurement of the attenuation of RF harmonics in the output of the aural and visual transmitters. The operation of the equipment shown herein was carefully checked in the CBS-TV Network Engineering Laboratory, and data were obtained to prove that this heterodyning technique is sufficiently accurate for measurements of this type. The notching filters shown in Fig. P-11 were measured in the laboratory, and their characteristics are shown in Fig. P-12 with the curve extrapolated using data provided by the manufacturer. An investigation was also made of the variation of indicated level with variations in the heterodyning oscillator amplitude, the results of which are shown in Fig. P-13. In addition, the accuracy of this method of measurement was checked at the second and third harmonics of Channel 2, using an RCA WX-1A field-strength meter. In this check the two measurement methods agreed within 3 db,

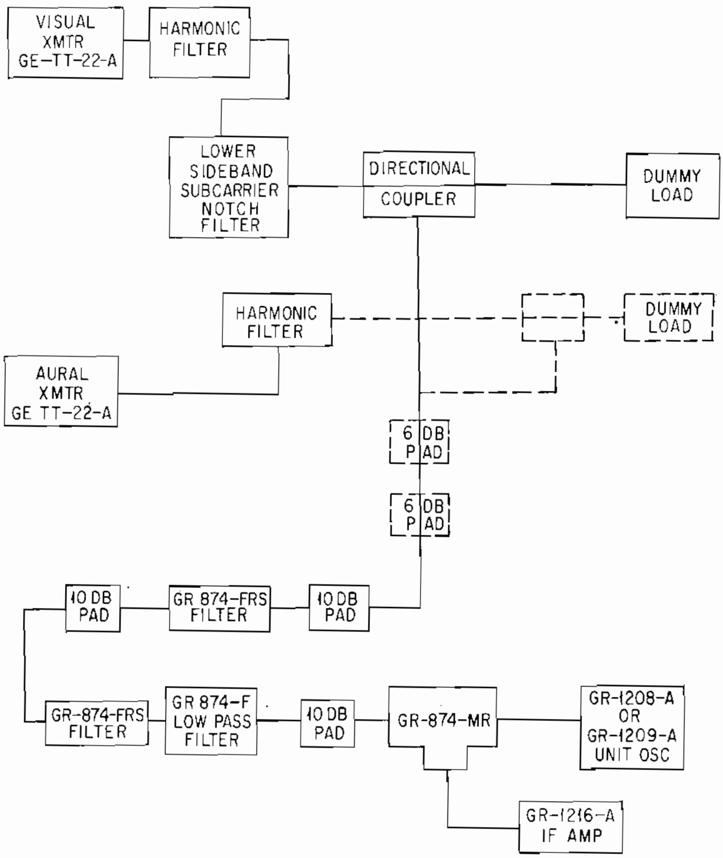


Fig. P-11. Block diagram of equipment used to measure attenuation of RF harmonics.

which indicated that the heterodyning method was entirely usable as long as the indicated level exceeded the Commission Requirements by at last 3 db.

Using the equipment shown in Fig. P-13, measurements were made of the attenuation of the aural and visual harmonics with the transmitters feeding a General Electric type 19193 dummy load. A directional coupler was used to probe the transmission line in these measurements. The variations of output voltage vs. frequency of this coupler were compensated for during these measurements. The results of these measurements are shown in Fig. P-14 and P-15 and prove that the harmonic attenuation of the (*call*) transmitters are well within the Commission's requirements.

Transmitted Signal Waveforms (II-C-9-b)—(Example)

The FCC Rules and Regulations specify that the transmitted waveforms shall conform to paragraphs 3.682-a-5, 6; 3.687-a-7, 8; 3.699 Fig. 2 5, 6, and 7, as modified by vestigial

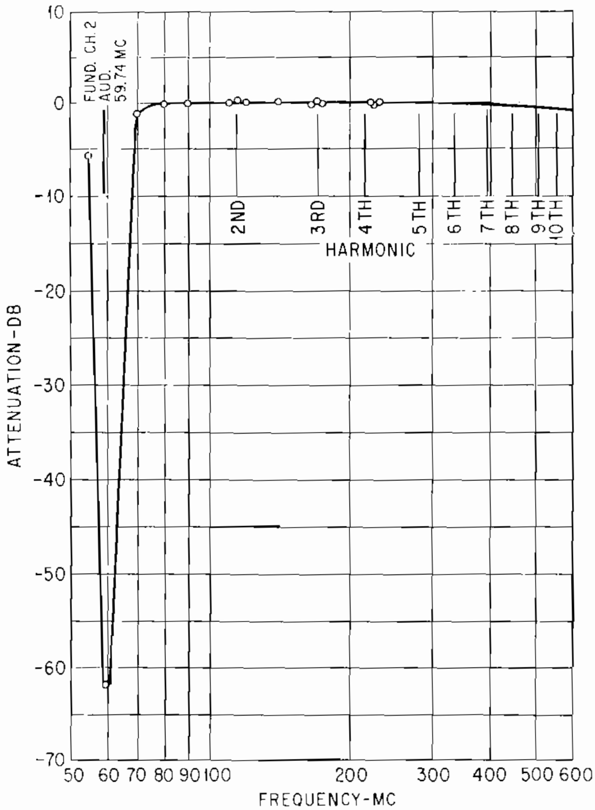


FIG. P-12. Response characteristics of two-section General Radio type 874 FRS filter.

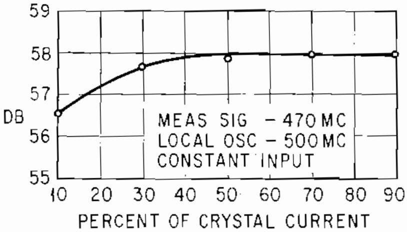


FIG. P-13. Detector characteristic for RF harmonic measurements using General Radio Type 1216-A unit I.F. amp. and G.R. type DNT detector.

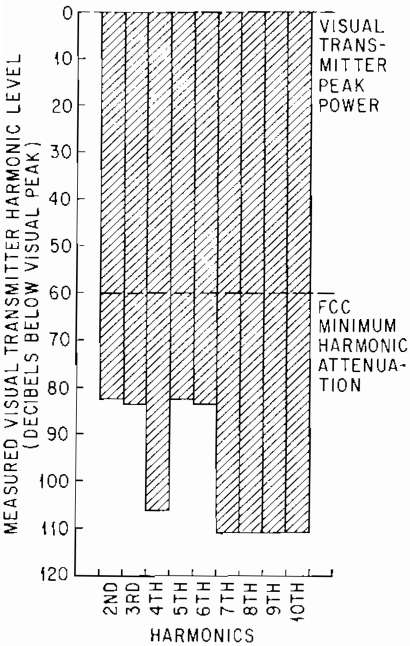


FIG. P-14. Measured visual transmission-line harmonic content.

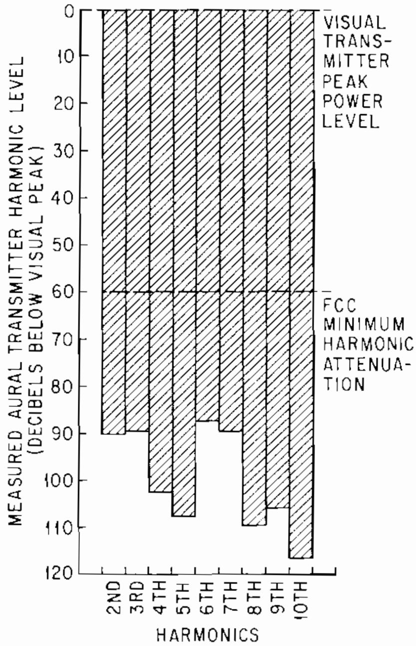


FIG. P-15. Measured aural transmission-line harmonic content.

sideband operation. Synchronizing and blanking pulse durations and slopes are specified, not taking into account the effects of vestigial sideband operation.

A studio camera was set up in typical fashion, but with the pedestal control adjusted to give a maximum white picture and the gain reduced to eliminate noise. This signal with sync was fed to the transmitter through the normal master control routing, and the transmitter was modulated in the normal fashion. The signal was so adjusted that blanking was 75 per cent of sync and white was 10 per cent of sync. An RF diode probe in the antenna transmission line was used to feed a Tektronix 524-D oscilloscope, and photographs were taken of pertinent waveforms. Timing signals were also inserted in the oscilloscope. These photographs were enlarged to a convenient size, and graphical measurements made of the pertinent durations and slopes. These data are presented in Table 1 along with the requirements of the Rules. Some of the rise and decay times do not conform exactly with those specified in the Rules, and these discrepancies are attributable to the vestigial-sideband operation which is known to lengthen the rise and decay times of pulses of this type. These rise and decay times of the signals fed into the transmitter system were measured and found to be within the specifications of the Rules and Regulations. Table I lists the output-waveform characteristics only.

Photograph of Transmitted Test Pattern (II-C-9-c)—(Example)

Figure P-16 is a photograph of a (*call*) test pattern, taken from a monitor connected to the input of the visual transmitter. Figure P-17 is a photograph of a (*call*) test pattern, taken on a monitor fed by the station demodulator coupled to the output transmission line feeding the dummy load.

Transfer Characteristics—(Example)

The transmitter transfer characteristic was measured using a stairstep generator and associated equipment as shown in Fig. P-18. During this test a 50 per cent duty cycle was maintained, as preliminary checks showed no significant differences in transmitter transfer

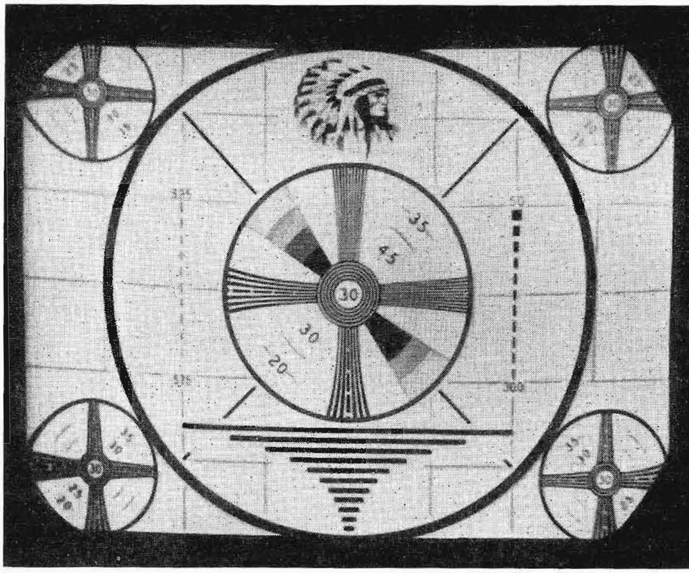


FIG. P-16. Photograph of test pattern—transmitter input.

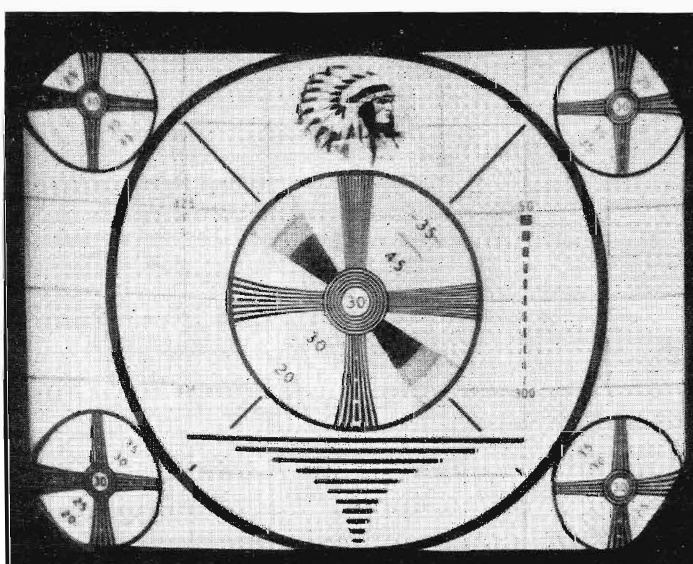


FIG. P-17. Photograph of test pattern—transmitter output.

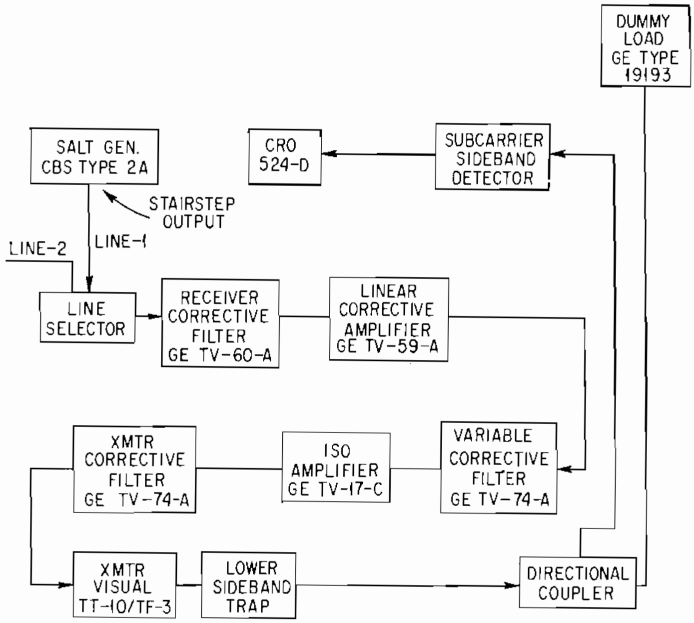


Fig. P-18. Block diagram for transfer-characteristic measurements.

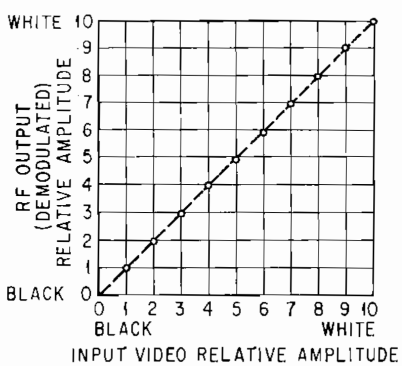


Fig. P-19. Measured transfer characteristic.

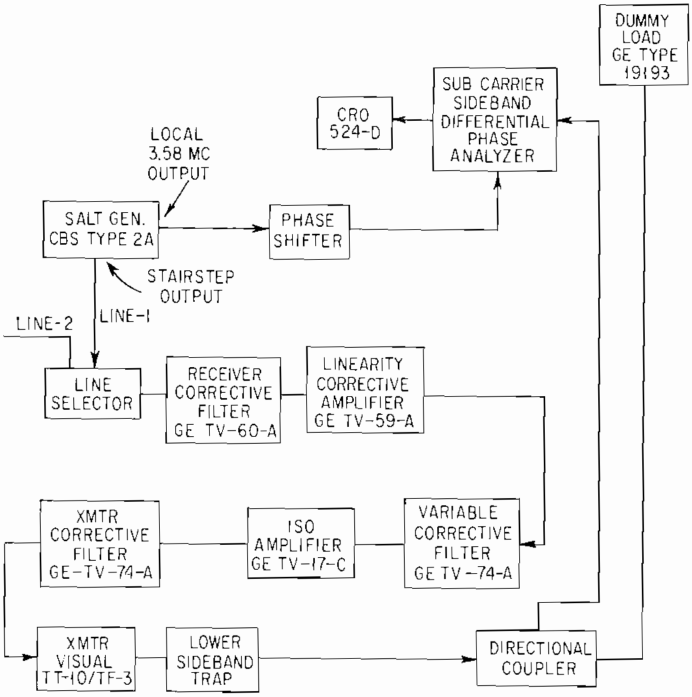


FIG. P-20. Block diagram of equipment for phase vs. amplitude characteristics.

characteristic for the 10, 50, or 90 per cent duty cycle. The results shown in Fig. P-19 indicate that the relationship between the RF output and the video signal input is substantially linear between reference-black and reference-white levels.

Differential Phase—(Example)

The differential phase or phase-vs.-amplitude characteristic of the transmitter was measured using a CBS-2A SALT (sweep-amplitude-linearity-test) generator feeding the video system input as shown on Fig. P-20. Using a stair-step signal (sync with 10 steps, each step containing a superimposed 3.58-Mc sine wave with a peak-to-peak amplitude of 20 per cent of the total amplitude of the 10 steps) feeding the input system, the output of the dummy-load directional coupler is fed into the sideband phase detector, where the "stripped" 3.58-Mc signal is "bucked out" by an external 3.58-Mc signal from the SALT generator through the use of a calibrated phase shifter. The balancing of these signals is observed on the cathode-ray tube of a Tektronix type 524-D oscilloscope. Measurements were made at three different duty cycles, 10, 50, and 90 per cent, and the maximum phase shift between the black step and the white step was measured and is listed below.

	Phase shift between steps 1 and 10	
Duty cycle, %	*Modulator output, deg*	*Transmitter output, deg*
10	1.0	6.5
50	2.0	9.0
90	2.0	4.5

COLOR-SIGNAL CHARACTERISTICS—(EXAMPLE)

Color-bar amplitudes and phase angles were measured at the input to the transmitter and compared with signals taken from the station demodulator connected to the output trans-

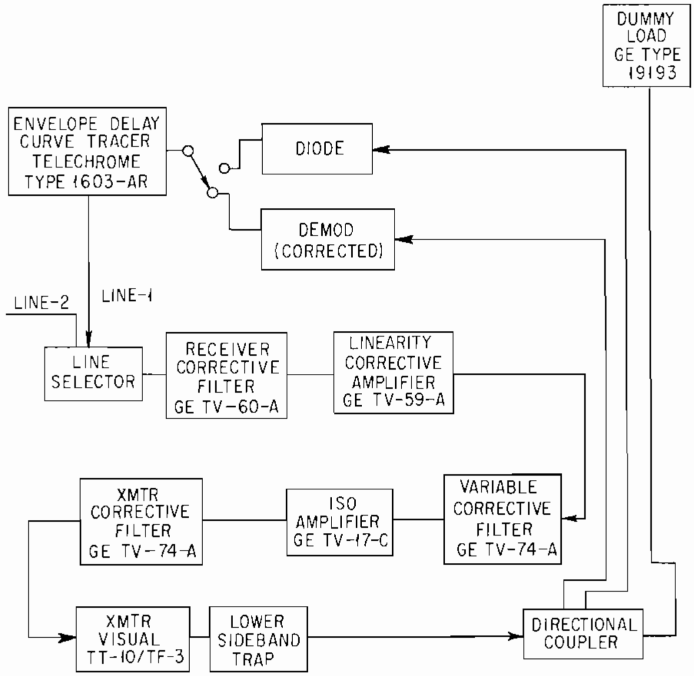


FIG. P-21. Block diagram for phase envelope-delay measurements.

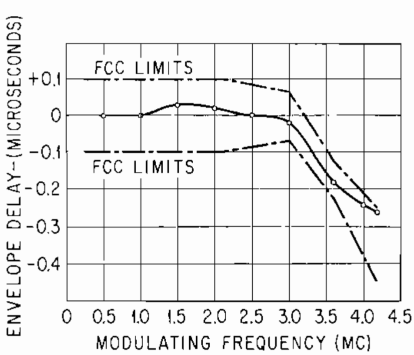
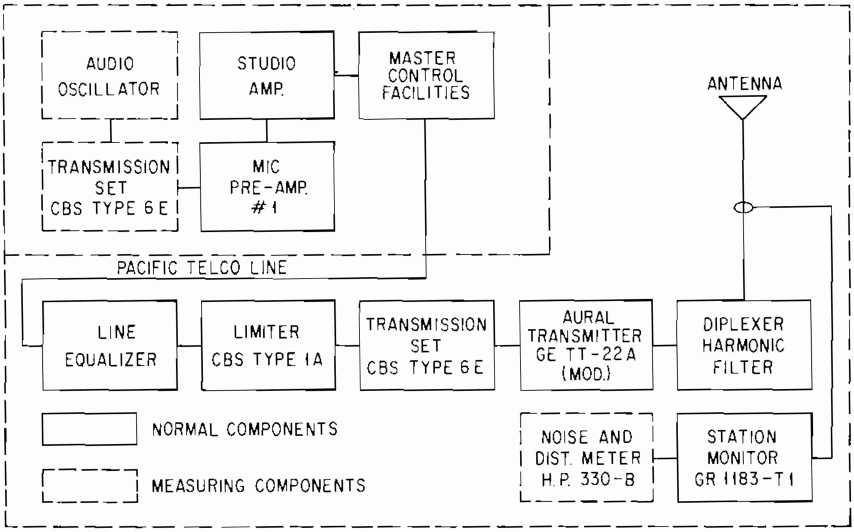


FIG. P-22. Envelope delay of radiated signal.



BLOCK DIAGRAM OF MEASURING SET-UP

CONDITIONS FOR MEASUREMENT

STUDIO	TRANSMITTER	ANTENNA
NO. D	TYPE GE TT-22 A	TRANSMISSION LINE
INPUT TO PREAMP. NO. 1	POWER 7.43 KW	OUTPUT POWER 7.43 KW
GAIN SETTING (MIXER) 11	PLATE VOLTAGE 7300 VLTS	TYPE RCA CB-TF-4 SPEC.
GAIN SETTING (MASTER) 11	PLATE CURRENT 2.6 AMPS	POWER GAIN 3.66
PROGRAM LINE REGULAR (REGULAR OR SPARE)	FIL. VOLTAGE 12.0 VLTS	

MEASURING EQUIPMENT

	MANUFACTURER	TYPE	SERIAL NO.
AUDIO OSCILLATOR	HEWLETT-PACKARD	201-B	815
DISTORTION AND NOISE METER	HEWLETT-PACKARD	330-B	
TRANSMISSION MEASURING SET	DAVEN	6-E	E-75092
DECADE ATTENUATOR			
AM DEMODULATOR	GENERAL RADIO	1932 P-1	149

Fig. P-23. Measurement data, TV aural data sheet 1.

25% MODULATION

	30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING–DB	*	2.8	3.0	4.3	5.0	11.6	19.2	21.4
CONSTANT **	*	5.5	5.5	5.5	5.5	5.5	5.5	5.5
FREQUENCY RESPONSE	*	−2.3	−2.5	−1.2	−0.5	6.1	13.7	15.9

50% MODULATION

	30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING–DB	*	2.5	3.0	4.3	5.1	11.5	19.1	21.2
CONSTANT **	*	5.6	5.6	5.6	5.6	5.6	5.6	5.6
FREQUENCY RESPONSE	*	−3.1	−2.6	−1.3	−0.5	5.9	13.5	15.6

100% MODULATION

	30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING–DB	*	2.7	3.6	4.2	5.1	11.5	19.1	21.3
CONSTANT **	*	5.6	5.6	5.6	5.6	5.6	5.6	5.6
FREQUENCY RESPONSE	*	−2.9	−20	−1.4	−0.5	+5.9	+13.5	15.7

* NOT REQUIRED BY FCC

** ADD OR SUBTRACT AN ARBITRARY CONSTANT TO BRING THE RESPONSE CURVE WITHIN THE REQUIRED TOLERANCE SHOWN ON FM DATA SHEET-3

OUTPUT NOISE LEVEL (FM) __58__ db BELOW 100% MODULATION
(± 25 Kc FM at 400 cps)

OUTPUT NOISE LEVEL (AM) __55__ db BELOW 100% MODULATION
(AM at 400 cps)

FIG. P-24. Over-all audio-frequency-response data and output-noise-level data, TV aural data sheet 2.

mission line. The results, listed below, indicate that amplitudes and phase angles fall within the limits specified in the Commission's Rules and Regulations.

Color bars	*Transmitter input* Amplitude	Angle	*Demodulator output* Amplitude	Angle
Burst	0.40	0	0.40	0
Yellow	0.65	+1	0.62	+1
Red	1.0	+3	1.0	+4
Magenta	0.98	0	0.96	+2
Q	0.40	−2	0.45	−2
Blue	0.65	−3	0.65	−1
I	0.40	0	0.45	+1
Cyan	1.0	+3	0.96	+4
Green	0.98	−1	0.90	0

Envelope-delay Measurements—(Example)

Figure P-21 is a block diagram of the equipment setup used for measuring the phase envelope delay of the visual transmitter. Figure P-22 shows the measured envelope delay and the FCC limits for color transmission.

Aural-transmitter Performance (II-C-10)—(Example)

Performance measurements of aural transmitters are to include a typical chain of equipment from a microphone input to transmitter output. Figure P-23 contains a block diagram

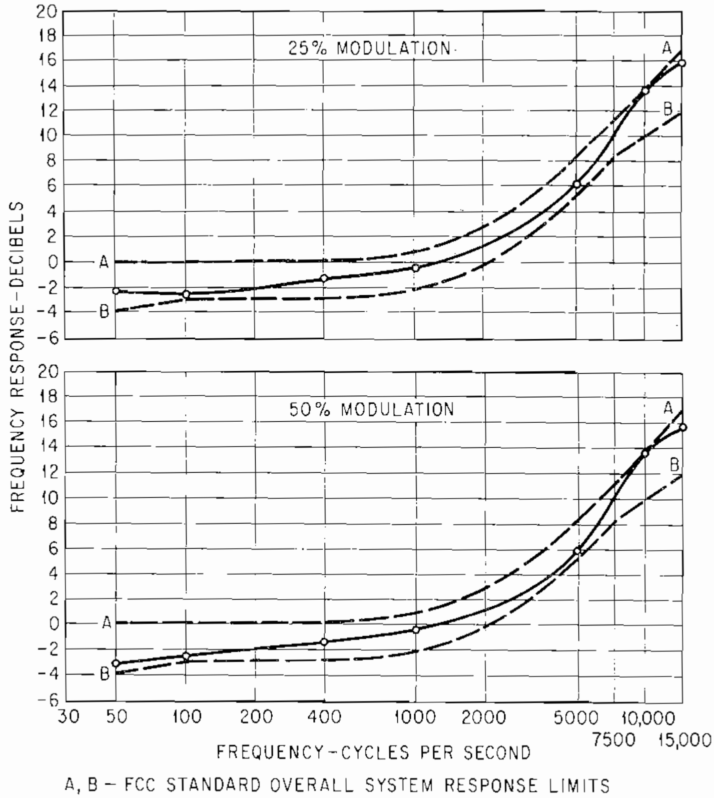


FIG. P-25. Over-all audio-frequency-response graphs, TV aural data sheet 3A.

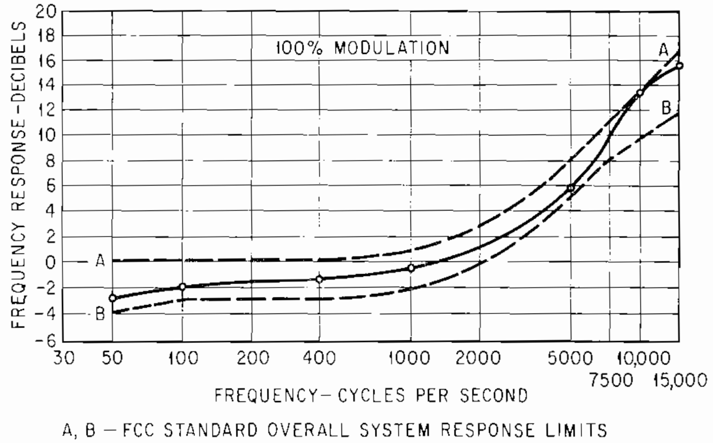
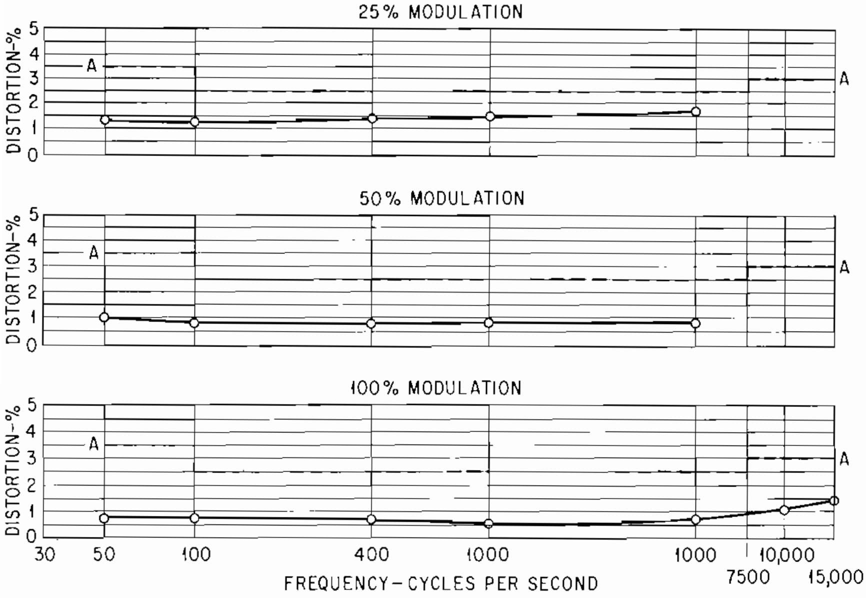


FIG. P-26. Over-all audio-frequency-response graph, TV aural data sheet 3B.

	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10,000 CPS	15,000 CPS
25% MODULATION	1.4	1.3	1.4	1.5	1.7	*	*
50% MODULATION	1.0	0.8	0.8	0.9	0.9	*	*
100% MODULATION	0.8	0.8	0.7	0.6	0.7	1.0	1.4



*–NOT REQUIRED BY FCC

A–FCC STANDARD OVERALL SYSTEM TOTAL HARMONIC DISTORTION LIMITS

FIG. P-27. Audio-frequency harmonic distortion, TV aural data sheet 4.

of the equipment setup and pertinent data concerning the conditions under which these performance measurements were made.

Frequency Response, Distortion, AM and FM Noise (II-C-7-a, b, c, d)—(Example)

Since there is a difference in peak voltages reached by pure sine-wave and normal program signals for equivalent volume indicator readings, an "elevated" level of 10 db above normal (−50 dbm at microphone input) was used throughout the system shown in Fig. P-23 to simulate 100 per cent modulation. With sine-wave input the normal settings of all controls produced 100 per cent modulation. The limiting circuit of the limiting amplifier (CBS type 1-A) was completely disabled during all of these measurements.

A constant level of −50 dbm (for the condition of 100 per cent modulation) was fed to the microphone preamplifier at all frequencies involved, and the CBS transmission set attenuator at the transmitter input was adjusted so that the modulation as indicated on the General Radio type 1183-T1 modulation monitor was always 100 per cent. The attenuator settings were recorded for each measurement frequency, and the distortion was measured for each frequency using the Hewlett Packard 330B noise and distortion meter. This procedure was repeated with microphone input levels reduced so as to produce transmitter modulation levels of 50 and 25 per cent, respectively. Figures P-24, P-25, and P-26 are plots of the system frequency response, and Fig. P-27 shows the system distortion for the three modulation levels used.

AM and FM noise levels were measured with a reference frequency of 400 cycles, and the data are shown in Fig. P-23.

It is recommended in the Rules and Regulations that none of the three parts of the system, studio, studio-transmitter link, and transmitter, contribute more than half of the total degradation allowed for the entire system. Each part of the system was measured, and it was determined that no one part of it does contribute more than half of the allowable degradation.

(EXAMPLE)

TABLE 1

ANALYSIS OF SYNCHRONIZING WAVEFORMS

Portion of synchronizing signal	*Measured * times*		*FCC Rules and Regulations specifications*	
Duration of horizontal blanking (10% black)	11.0	μsec	11.44	μsec max
Duration of horizontal blanking (90% black)	10.9	μsec	10.48	μsec min
Duration of horizontal pulse	5.8	μsec	5.08 4.45	μsec
Rise of horizontal pulse	0.183	μsec	0.254	μsec max
Decay of horizontal pulse	0.196	μsec	0.254	μsec max
Rise plus decay of horizontal blanking	0.62	μsec	0.957	μsec max
Duration of front porch	1.42	μsec	1.27	μsec min
Duration of equalizing pulse	2.6	μsec †	2.54	μsec
Rise of equalizing pulse	0.195	μsec	0.254	μsec max
Decay of equalizing pulse	0.152	μsec	0.254	μsec max
Rise of vertical pulse	0.21	μsec	0.254	μsec max
Decay of vertical pulse	0.21	μsec	0.254	μsec max
Duration of serration in vertical pulse	4.7	μsec	3.81 5.08	
Duration of vertical blanking	20	H	17.8 20.4	H H
Decay of vertical blanking	2.5	μsec	6.355	μsec max
Back porch from horizontal pulse to start of color burst	0.6	μsec	0.381	μsec min
Number of cycles in color burst	8½	cycles	8	cycles min

Rise of vertical blanking not listed but observed to be same as decay.

* The measured times are for waveforms at the output of the transmitter and, therefore, include the effects of the vestigial sideband system.

† The area of the equalizing pulse should be 45 to 50 per cent of the horizontal pulse. It was measured from the photograph to be 49 per cent of the horizontal pulse.

Part 13

AUDIO PROGRAM TRANSMISSION STANDARDS FOR TELEVISION

CBS Television Network

New York, N.Y.

INTRODUCTION

Late in 1957, as a result of continuing listener complaints of abnormal audio volume levels of television commercials, CTD Engineering undertook an extensive study of CTD volume-level practices. On Dec. 6 of the same year, Engineering Report E-2179-A, "Audio Transmission Level Study—Interim Report," containing recommendations based on the first few weeks of observation was released.

This present report summarizes the findings of the completed study and presents recommendations which will substantially improve television audio program levels and make our programs more pleasing to the listener in so far as sound levels are concerned.

OBSERVATIONS AND FINDINGS

It is standard practice in both radio and television broadcasting to transmit audio program material at a uniform peak volume level as read on the standard volume indicator. Under these circumstances, it is reasonable to expect that various portions of the program material should sound equally loud. However, quite early in this study it became evident that, as listeners had reported, some television program material sounded louder than other material. Commercials were a frequent offender in this respect, although they were not the only portion of programs that sounded too loud. Other offending material included some program opening and closing announcements and station-break announcements.

Reasons for Loudness Discrepancies

As the study continued, it was found that there are three distinct reasons for differences in the loudness of various portions of programs, viz.,

1. *Program Peaking Practices.* The first and most significant factor (and the one which will provide by far the greatest improvement in correcting loudness discrepancies) is the correct peaking of program levels at the audio console of the studio control room. Over ten years ago, after an extensive investigation, program transmission standards were established by CBS [1] in order to make the audio portion of our pro-

[1] Howard A. Chinn and Philip Eisenberg, New CBS Program Transmission Standards, *Proc. IRE,* vol. 35, December, 1947.

grams as pleasing as possible to the listener. An early finding in the current study was that these program transmission standards were not always followed.

2. *Modification of Audio Signal.* Another factor that was found to influence the apparent loudness of audio program material is the use of techniques which alter the waveform (and hence the subjective effect) of an audio signal. The following practices all result in the altered audio signal sounding louder than the original, even though both are transmitted at the same peak value as measured by a standard volume indicator:

- *a. Volume Compression.* Program material that has been compressed, thereby restricting its original amplitude range, will sound louder than similar uncompressed program material.
- *b. Reverberation.* Reverberant program material will sound louder than acoustically "dead" material. This is true whether the reverberation is natural or artificial. This principle was the basis of J. P. Maxfield's "Liveness in Broadcasting"[2] technique introduced in 1947 and still in common use in radio broadcasting and phonograph-record manufacture. Maxfield reported the possibility of a 6- to 8-db apparent increase in loudness using acoustically live program pickup techniques.
- *c. Bandwidth Restriction.* When wave filters are employed to attenuate low frequencies, a considerable portion of the energy is removed from an audio signal and its level, as read on a standard volume indicator, must often be raised if standard transmission level is to be maintained. Furthermore, most of the remaining sound energy occurs in the middle-frequency range, where the ear is most sensitive. Program material so restricted in bandwidth will, therefore, usually sound louder than full-bandwidth program material (although it suffers in faithfulness of reproduction). By the same token, sounds having predominantly mid-frequency components will exhibit a similar apparent increase in loudness.

All the above techniques are commonly employed (individually or severally) in making the sound track of sound-on-film commercials and other program inserts. To a considerable extent, these practices account for such material sounding louder than the unmodified live-studio sound pickup.

3. *Listener Reaction.* The third factor that influences the apparent loudness of program material is associated with listeners' subjective reactions to certain types of sound, viz.,

- *a. Irritating Sounds.* An irritating voice, like any irritating sound, often seems louder than a pleasant one, even though both may be reproduced at the same volume level.
- *b. Strident Delivery.* Speech delivered in a rapid-fire, strident, or "staccato" manner with few pauses, if any, sounds louder than speech delivered in a more conversational manner. It has been observed that commercials intended to attract attention are often delivered in a rapid, urgent manner by an announcer with a slightly irritating quality in his voice. The effective loudness of such announcements is greater than that of the accompanying studio program material.

DISCUSSION AND RECOMMENDATIONS

As indicated above, the place at which the greatest improvement can be made in balancing loudness discrepancies is the studio control-room audio console. Observations made during this study showed conclusively that careful adherence to existing CBS program transmission standards[3] will, in itself, overcome many of the sound-level discrepancies that were observed during this study.

However, strict adherence to transmission standards alone will not reduce the apparent loudness of the types of program material described under Reasons for Loud-

[2] See Section 6, Part 1.

[3] Chinn and Eisenberg, *loc. cit.*

ness Discrepancies, paragraphs 2 and 3, above. This type of program material, which includes most film and many live commercials, requires special treatment to make it match in loudness other portions of the show.

The recommended solution to this problem entails the use of an automatic-gain-control amplifier and associated gain-reduction meter in each studio audio channel.

Automatic Gain Control

An automatic-gain-control (AGC) amplifier is one which automatically reduces its gain when an audio signal passing through it exceeds a predetermined "threshold" level. By its fast and automatic action, the AGC amplifier provides an excellent means of holding varying audio signals at a safe level. An associated gain-reduction meter indicates in decibels the amount the gain of the amplifier has been reduced to handle an audio signal that exceeds the threshold level.

Such an automatic level-controlling device is of considerable help in controlling widely varying audio levels and helps the audio operator do a better job of gaining a show. However, the automatic level-controlling action, in itself, does nothing to balance loudness differences that do not indicate as such on a volume indicator. On the other hand, the gain-reduction meter associated with the AGC amplifier does provide a new monitoring means which supplies quantitative data that permits the operator to make simple adjustments that will equalize loudness discrepancies.

Assume that an AGC amplifier is installed in a studio audio channel and adjusted so that gain reduction takes effect just below the volume-indicator reference point. If the audio operator now gains the program in such a manner that 6 db of gain reduction is indicated on normal program material but no gain reduction is indicated on program material that is louder than normal, loudness discrepancies will be greatly alleviated or even entirely eliminated. This balancing of unequal loudness levels results because an amount of volume compression has been applied to the normal program material, thereby slightly increasing its apparent loudness.

The method of adjusting audio levels described above reduces itself to the following general operating procedures:

1. Use 6 db of gain reduction on live program material (except music and commercials)
2. Use no gain reduction on commercials, music, or recorded program material

These generalized procedures are set forth in more detail in the following discussion.

Revised CBS Program Transmission Standards

To cover operation in studios equipped with automatic-gain-control amplifiers and associated gain-reduction meters, revisions are necessary to the CBS program transmission standards. The revised standards are given in Table 13-1.

IMPLEMENTATION

Based on carefnl study and observation, the following action is recommended to correct existing discrepancies in CTD audio program levels.

1. Install an automatic-gain-control amplifier and associated gain-reduction indicating instrument in all CTD studios.
2. Adhere to the revised CBS program transmission standards (see Table 13-1). Pending installation of AGC equipment in CTD studios, adherence to the existing CBS program transmission standards should be observed.
3. Establish quality-control points at CTD plants where network programs regularly originate (including VTR delayed-broadcast operations) where levels of programs can be measured, recorded, and monitored. Assign a CBS engineer in charge with full responsibility for reviewing the recorded data and issuing the necessary orders to correct faulty practices.

ADDITIONAL BENEFITS

In addition to the improvement in sound transmission already described, the above recommendations will also provide the following additional benefits:

Table 13-1. Revised * CBS Audio Program Transmission Standards for Television

		VI peaks	*Gain reduction* †
A. Speech (live)	1. Normal passages	Peaks of 100	6 db
	2. Low-level passages	Not less than 40	None
B. Music (live) *C. Recorded programs* (film, transcriptions, and magnetic tape) *D. Commercials* (both recorded and live ‡) *E. Program openings and closings, station-break announcements*	1. Normal passages	Peaks of 100	None
	2. Low-level passages	Not less than 40	None
F. Symphonic music	1. Normal passages	Peaks of 100	None
	2. Pianissimo passages	Must always move VI	None
G. Applause and audience reaction		Maximum peaks of 70	None

H. Transition

The transition from a low-level passage to a normal-level passage (or vice versa) must be in steps of not more than 4 db, preferably less (i.e., peaks of 40, then 60, and finally 100, or vice versa). Similarly, two succeeding passages (voice, then music or voice, then a sound effect, etc.) must not differ in level by more than 4 db, preferably less, even when a contrast is intentional.

I. Peaking practice

Peaking program material according to the prescribed standards means gaining in such a manner that the maximum VI peaks reach the specified values as frequently as possible without being inconsistent with the program content. It is understood that occasional peaks beyond the prescribed values are unavoidable, but these are to be kept to a minimum.

* For original standard refer to Howard A. Chinn and Philip Eisenberg, New CBS Program Transmission Standards, *Proc. IRE*, vol. 35, December, 1947.

† Indication on gain-reduction meter of studio automatic-gain-control amplifier.

‡ Excluding live commercials presented in a conversational manner. These should be treated as in *A*.

1. Listeners have sometimes reported that musical portions of television programs sound too loud. The AGC amplifier, together with the revised program transmission standards, will also improve or entirely eliminate this loudness discrepancy.

2. By automatically controlling unanticipated high program peaks, the AGC amplifier permits the audio operator to do a better audio mixing job.

SUMMARY

This report has given an account of the findings made during a recently completed study of CTD audio program level practices. It was found that complaints of listeners are justified; portions of CTD programs, including commercials, are too loud. The reasons are analyzed, and specific recommendations made (involving both operating techniques and technical facilities) to overcome these loudness discrepancies.

ADDENDA

Subsequent to the completion of this report, automatic-gain-control amplifiers with transfer characteristics specially tailored for his application have been installed in all studios of the CBS Television Network. Since these new amplifiers were placed in operation (a period of several months), no complaints have been received from viewers regarding unbalanced audio levels. Furthermore, careful listening tests indicate that audio transitions on CBS programs are now quite pleasing and unobtrusive.

Part 14

STEREOPHONIC BROADCASTING

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INTRODUCTION

The word "stereophonic" is defined by Webster as "giving the effect of coming from two or more directions;—of sound reproduced." This directional quality of reproduced sound introduces an element of realism which is impossible to achieve with monaural sound. The most perfect high-fidelity system one could imagine, with each element perfectly matched with the other to reproduce any sound or combination of sounds audible to the human ear with no distortion and with unlimited dynamic range, would be lacking one important quality if it were not a stereophonic system, that of direction. A man blindfolded and led into the room would know immediately that the performance was not "live." However, if the element of direction was added, a quality of realism would be achieved which, under ideal conditions, would make it difficult to discern from the live performance.

Just as our two eyes transmit two images to our brain, making us conscious of depth in things we see, our two ears add direction to our sound perception by noting the differences in sound picked up by each. In order to reproduce electronically what our two ears would hear at a concert, we must have at least two sources of sound which must be kept separated through the entire chain of electronic equipment from microphones to speakers. If proper separation is maintained, along with correct placement of microphones and speakers, the realistic effect is often quite startling. Direction is as important to faithful reproduction of sound as is frequency response or dynamic range, and the art of stereophony will be applied more and more in a never-ending effort to bring the concert hall into the home.

Stereophonic broadcasting is, of course, not new. In the early 1950s KWKW in Pasadena, Calif., demonstrated the possibilities of stereo by using this technique to broadcast the sounds heard on a busy street corner in Pasadena, the sound of a train and sounds at a baseball game. Two microphones were used, one for AM and one for FM. Later live pickups were made from the Pasadena Civic Auditorium. One of the early pioneers in Los Angeles was Calvin Smith, general manager of KFAC-AM and FM, who has broadcast the opening concert at the Philharmonic Auditorium via stereo each year, starting in October of 1953. This AM-FM outlet has also broadcast the opening event at the famous Hollywood Bowl stereophonically since July 1954. One Bowl concert was broadcast on three channels, KFAC-AM and FM with KHJ-FM carrying the third leg. In 1956, KABC-AM and FM broadcast a live stereo pickup each week from the Aragon Ballroom in Santa Monica, Calif., featuring Lawrence Welk. Los Angeles has also heard stereo via AM-TV using the facilities of KRCA (TV) and KFI (AM) and via FM-TV using KTTV (TV) and KFAC (FM).

In 1957 the first regularly scheduled daily stereophonic broadcast using the facilities of two high-fidelity FM stations was inaugurated in Los Angeles. The two stations, KMLA and KCBH, are ideally situated for this type of broadcast, since they both use the same tower for antenna mounting and both transmit power in excess of 60 kw. The regular stereo programs from these two stations are from stereophonic tapes and records, on which they also claim a "first." This type of stereo transmission, FM-FM, combined with high-quality receiving equipment, offers the ultimate in high-fidelity listening for those who demand the finest. In 1957, on an experimental basis, KMLA in Los Angeles broadcast stereo with multiplex, using only the one station. Later in 1958 other multiplex stereo broadcasts were presented by KBMS in Glendale, Calif., and WGHF in Brookfield, Conn. There have been many other pioneers in stereophonic broadcasting in other parts of the country who deserve credit, such as WQXR in New York. We happen to be more familiar with the picture in Los Angeles and offer it as an example of what has been done in the past—with all due respect to others who have devoted much time and money to further the cause of this form of broadcasting.

PROGRAM SOURCES

The source of material for stereophonic broadcasting is the same as for monaural broadcasting: tape recordings, disc recordings, and live pickups. Stereo tapes entered the high-fidelity field prior to stereo discs and obviously excel in quality. Practically all the major recording companies were producing and distributing stereo tapes by 1957. In the fall of that year there were some 40 different stereo tape labels accounting for more than 500 stereo recordings with the prospect of approximately 100 new recordings each month. In addition to the quality advantage which stereo tapes enjoy, they offer a time advantage which is very important in the recording of lengthy musical works and also the factor of unlimited use without apparent loss of fidelity.

Tape

In order to broadcast stereophonic sound via tape, the originating station must have a stereo tape deck. The "stacked" head variety is preferable over the "staggered" type, since most of the new recordings are recorded for playback via the stacked (or "in-line") method. When stereo tapes are purchased, it is essential to note whether they are for stacked or staggered machines, since they are not compatible. If the tape deck contains the necessary preamps, no additional equipment is needed for stereophonic broadcasting. The output of one head through its preamp is fed into one transmitter, usually through a mixer for control, and the output of the second head to the other transmitter. If either of the transmitters is located at some distance from the originating point, it may be necessary to transmit one or both of the signals over land lines owned by the telephone company. In such cases proper equalization is essential in order to maintain fidelity.

Disc

Early in 1958, stereo discs began to appear on the market using the Westrex 45°–45° system of recording. This set off a chain reaction which revolutionized not only the recording industry but also the allied Hi-Fi component manufacturers. Later in the year most recording companies were making plans to produce stereo discs via this method in quantity for the mass market. This system of recording makes it possible to reproduce the sound on the disc with a single stylus. One channel is picked up by the lateral action of the stylus, and the other channel by its perpendicular action. The energy generated by each action is fed into separate coils and then passed on through a normal two-channel system. Stereo discs are particularly well suited for stereophonic broadcasting, since conversion is very simple and inexpensive. A stereo cartridge and a preamplifier for feeding the second channel are the only items that need be added to a monaural system of broadcasting providing the second channel of transmission is available. The stereo cartridge is more susceptible to turntable rumble than is the monaural cartridge and should be used only on the best of tables if this factor is to be diminished. The cartridge and tone-arm assembly should be mounted so the stylus pressure is equally distributed on each side of the groove. Stereo cartridges are compatible with monaural LP recordings; however, the reverse is not true. A monaural cartridge can soon ruin a stereo recording.

LIVE PICKUPS

General Considerations

Live pickups are, of course, the most difficult to do stereophonically. Here we run headlong into a maze of problems which have plagued the recording industry for many years. In order to get first-hand information regarding some of these problems, we asked Mr. Russ Molloy, executive director of the Bel Canto Recording Company and a pioneer in the stereo recording field, to write the following:

Present day techniques of recording live Stereo have departed from the older style of "binaural" where the two microphones were spaced eight (8) inches apart and the playback system was earphones. Today we normally record (and here the factors are group size, room and effects desired) with microphones on booms at a height of 8 to 10 feet and sometimes 30 feet apart.

Normal recording presents the usual problems of instrument placement, but in Stereo work this becomes far more critical. Since the producer may demand the rhythm section on one channel, the physical distance the drummer (for example) is removed from his normal playing position often tends to break the coordination of the group. Fill-in mikes are used to obtain special instrument effect or presence; and in the case of large groups it is often necessary to record on ½ inch three channel tape. This method assures a completely controlled balance on the orchestra while the solos, (voice or instrument), are controlled on the third track. Final mixing will blend this "voice" to obtain either a center position or on either channel.

Artificial reverberation is not advised on the original recording, since damaging inter-channel bleeding may occur. Final editing with test runs will allow the maximum degree of echo mixing.

Following specifications of master tape recording equipment is, of course, vital since we need the 55 DB separation between channels, (Ampex Corp. specs), for optimum recording characteristics. Bias problems are to be watched, since the operation of recording Stereo is now audible on two channels rather than the nominal one and differentials here are of grave importance.

It is well to remember that the philosophy of playing back Stereo is to create the audio illusion of "group width" and that the techniques required to produce this "sound illusion" are not the same for a trio as they are for an 86 piece orchestra. In attempting to explain basic principles of Stereo recording to the beginner, it almost seems that we are making the approach one of a witch-doctor, but in truth the art of Stereo is relatively new—one that has only been used to any extent since 1955. Those of us who have been recording Stereo even before that time are continually changing our philosophy and techniques.

These comments by Mr. Molloy will be particularly interesting to those who plan to make stereo recordings as well as those who are setting up live pickups for immediate broadcast release, since many problems such as microphone placement are common to both.

Microphone Placement

Definite rules regarding the positioning of microphones are impossible to formulate, since no two pickups are the same. The placement for a small group would be completely different from that necessary for a full orchestra. The size and acoustical quality of the room or auditorium would also make a difference. If there is time and the equipment is available, it is advisable to record a few test runs with the microphones in different positions so the best placement can be determined by actually listening to the playback of the test tape. In most cases this method is not practical and rules of logic must be relied on. For the uninitiated, it is recommended that only two microphones be used in order to keep it as simple as possible and that a few general rules be followed. Generally speaking, it is easier to produce a realistic stereo effect with a large group than it is with a small group. This is true because "group width" already exists and the only problem is the placement of microphones to pick up what we already have, whereas, with a small group such as a trio, there is the additional problem of positioning the musicians in order to simulate group width. Here is a rule of thumb which can be used for positioning two microphones for a large group pickup such as a symphony orchestra: Draw an equilateral triangle, the base of which is the first row of chairs in the orchestra and the apex out toward the audience somewhere in the center aisle of the hall. The microphones would then be placed on the two lines forming the sides of the triangle, approximately 15 ft in front of the orchestra and elevated approximately 15 ft above the stage so as to increase the pickup from the back row of instruments in relation to the front row.

Channel Separation

Good channel separation is essential and often necessitates the use of directional microphones. However, care should be taken not to have too much "separation," which causes a "hole" in the middle. Separation is the difference in the volume of sound pickup from a given instrument by microphone *A* and microphone *B*. In order to check separation the gain control on each amplifier should be set the same. Then let us assume that we are standing at the front of the stage facing the orchestra with microphone *A* on our right. Now ask the musician in the front row on our extreme right to play a sustained note and check the level of each channel. Channel *A* should read 15 to 20 db higher than Channel *B* if there is good separation. Now ask for a tone from the center of the stage to be sure there are no holes. This should be the same level on each channel and approximately the same level as the first tone registered on Channel *A*. This is one method of checking separation. Of course, there are others, but regardless of the method used, adequate separation must be maintained if true stereophonic sound is to be achieved.

USE OF MULTIPLEX FOR STEREO

The advent of multiplex made it possible to broadcast stereo on a single station as opposed to the earlier two-station method. It also made possible "compatible stereo," the sum-and-difference technique which allows the monaural listener to hear a complete (both legs) program on the main channel while the stereo devotee enjoys the directional qualities he demands by listening to the main channel and a multiplex subchannel. Compatible stereo was developed by Mr. Murray G. Crosby, Crosby Laboratories, Inc., Hicksville, N.Y., and was described by Mr. Crosby in a paper presented before the Audio Engineering Society, New York, on Oct. 11, 1957, from which we quote.[1]

> It is the object of this paper to describe an improved method of transmitting Stereophonic sound on an FM transmitter with many advantages for both the monaural and stereo listener. An outstanding advantage is obtained for the monaural listener who is equipped to receive only the main channel without the benefit of Stereo reception. With the system to be described, that listener has a compatible reception with the program properly balanced with respect to microphone pickup. The advantages obtained for the Stereo listener include a 6 DB improvement in signal-to-noise ratio realized from the relatively poor signal-to-noise ratio on the subcarrier channel, together with a balancing of the signal-to-noise ratios on the two channels so that a more pleasing response is obtained.

Figure 14-1 shows the conventional FM multiplexing system which has been used to demonstrate stereophonic transmission by Armstrong and Halstead. In this sys-

[1] One of many systems being considered by the National Stereophonic Radio Committee.

tem microphone *A* is fed to the main channel of the FM transmitter and microphone *B* is fed to the subcarrier generator which is applied as a multiplex modulation on the FM wave. Application of the subcarrier modulation can also be accomplished by the use of an auxiliary phase modulator following the main FM modulator with the same basic result in the wave transmitted. This transmitting system is shown in

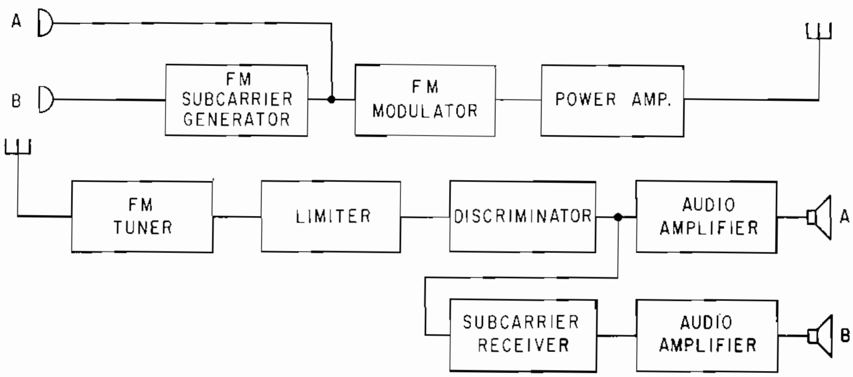


FIG. 14-1. A simplified FM multiplex system.

Fig. 14-2.[2] It utilizes a form of multiple phase modulation, applied to successive stages, so that the resultant modulation is the sum of the separate modulations. Use of this principle for subcarrier modulation is described by E. H. Armstrong.

The conventional techniques in which the separate microphone outputs are transmitted over the separate channels, as shown in Figs. 14-1 and 14-2, have several disadvantages. First of these is the lack of compatibility for the monaural listener. Since that listener will tune in the main channel only, a degraded program pickup is received by virtue of the reception of the output due to one microphone only. That single microphone will receive its pickup from one side of the stage only, so that the instruments near it will be overemphasized and those near the other microphone will be deemphasized. The pickup of a soloist who happens to be nearest to the opposite microphone will be especially degraded.

The second disadvantage of the conventional system is the unbalance of the signal-to-noise ratios on the main and snbcarrier channels. The subcarrier channel has an

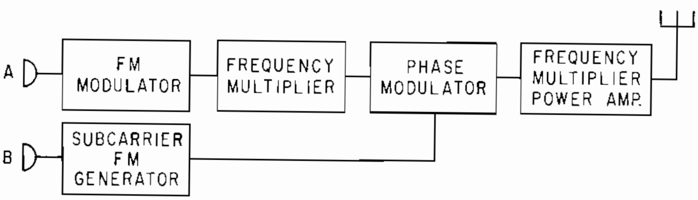


FIG. 14-2. A simplified FM multiplex transmitting system.

efficiency of transmission which is much less than that of the main channel, so that the signal-to-noise ratio on one loudspeaker may be as much as 25 db poorer than that on the other. This produces an annoying one-sidedness to noise disturbances

[2] Although this system is the only one included by the author, it should not be construed by the reader that this is in any manner a recommendation by NAB as superior to other similar systems. The FCC has not yet established stereo standards for broadcasting.

which impairs the pleasantness of reception. With the sum-and-difference technique to be described, the signal-to-noise ratios on both loudspeakers are the same and the effective transmission of the subcarrier channel is improved by 6 db. The 6-db improvement in subcarrier signal-to-noise ratio is equivalent to a 4-to-1 increase in power of the transmitter, since with the stereo system the performance is only as good as that of the poorest channel. Accordingly the sum-and-difference technique results in an increase in the effective range of the stereo transmission.

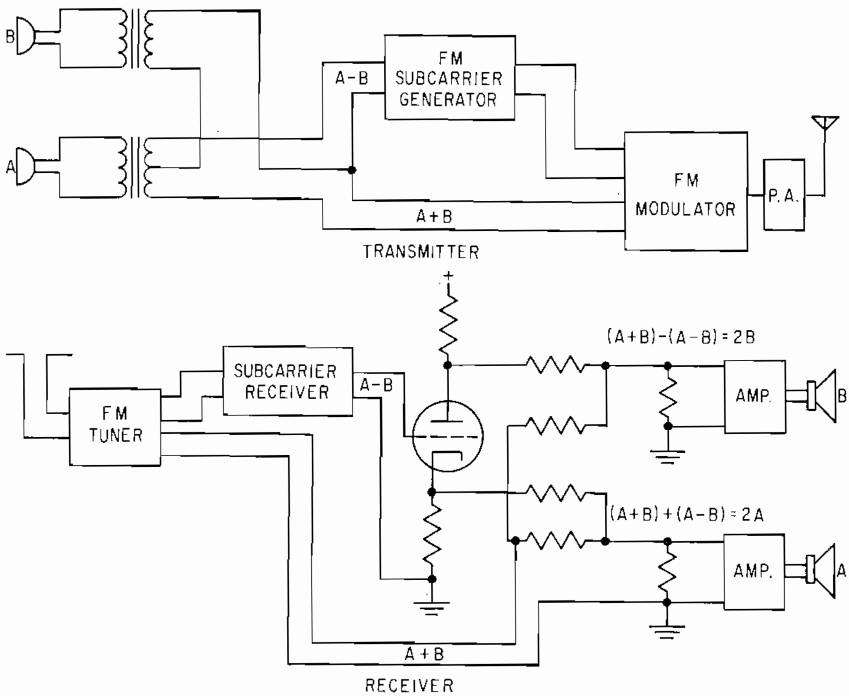


FIG. 14-3. Sum and difference technique in the production of a multiplex stereophonic signal.

This 6-db improvement in signal-to-noise ratio may, under certain conditions, be realized as a 6-db improvement in over-all hum and distortion. If it so happens that the hum is predominately from either the subcarrier channel or the main channel taken alone, the result is a 6-db reduction in hum. This is brought about by the signals from the sum-and-difference combinations adding in phase to produce twice the voltage while the hum remains at a value equal to that of the channel with the highest hum. The only condition in which this improvement would not be realized would be that of an equal hum level in both main and subcarrier channels which was so phased as to add up to twice voltage in the sum-and-difference combination. This would be a rare coincidence. In the case of distortion, the same situation exists; the channel with the lowest distortion aids the channel with the highest distortion by a factor of 6 db in the over-all system. In experimental work it has been observed that the subcarrier channel has the least distortion and hum. Under these circumstances the sum-and-difference combination is responsible for a 6-db reduction in both hum and distortion as well as noise in the over-all system response.

Figure 14-3 shows the sum-and-difference technique of applying a twin-channel stereo system to the FM multiplex system. Microphones *A* and *B* are mixed, so that the sum combination $(A + B)$ is fed to the main channel of the FM transmitter and the difference combination $(A - B)$ is fed to the subcarrier channel. The sum combination is readily recognizable by its improved bass response, since the difference combination results in a microphone directive array which tends to cancel lower frequencies.

At the receiver the outputs of the main-channel discriminator and the subcarrier adapter are fed to a mixing system utilizing a phase inverter such that one amplifier and speaker receives the combination:

$$(A + B) - (A - B) = 2B$$

and the other amplifier and speaker

$$(A + B) + (A - B) = 2A$$

This addition and subtraction separate the individual microphone outputs from their sum-and-difference combinations just as though the A and B microphones fed the A and B speakers directly.

It will be noted that the program on the main channel of the transmitter is the desired $A + B$ combination of microphones which provides the compatible balanced program for the monaural listener. Since the subcarrier channel is superaudible, the monaural listening is unimpaired by the stereo transmission.

With the sum-and-difference technique, the resulting signal fed to one loudspeaker is an addition of the signal from the main channel and that from the subcarrier channel. This combination doubles the amplitude of the signal and adds the noises from the two channels by rms addition. The noise from the subcarrier channel is so much greater than that on the main channel that the rms addition of the two noises results in a noise having an amplitude equal to that of the subcarrier channel. Since the signals have been doubled and the noise is equal to that on the subcarrier channel, the resulting signal-to-noise ratio fed to either loudspeaker input is equal to 6 db above the normal signal-to-noise ratio on the sub-carrier channel.

Multiplex and a compatible system along with stereo tapes and discs and improved FM receivers in conjunction with high-quality amplifiers and speaker systems have made stereophonic broadcasting practical both technically and financially. The future of this form of broadcasting is very bright, and it is the belief of the author that FM-multiplex stereophonic transmission will eventually become the accepted method of broadcasting.

Editor's Note:

The reader may wonder why more stereophonic programming techniques have not been included. Radio broadcast programs of the type which would be suitable for stereophonic reproduction are seldom originated at the local station. Disc and tape have and undoubtedly will continue to provide the bulk of stereophonic program material for many years.

The basic considerations involved in the local production of a stereophonic broadcast are pointed out in this part. More detailed specifications for a particular production would be almost impossible because each production is a "custom installation" requiring individual evaluation.

The National Stereophonic Radio Committee has been established under the sponsorship of the Electronic Industries Association (EIA). The function of the NSRC is to make detailed technical studies of the several possible methods of providing compatible stereo sound for the AM, FM, and TV broadcast services. The objectives of these studies have been:

1. To clarify the technical issues as between the several possible systems for each of these services

2. To verify the technical conclusions through appropriate field tests and obtain such information as may be necessary for channel utilization purposes for the determination of the choice of standards

3. To delineate appropriate signal specifications for the several services based upon the best scientific information and field test data available to the committee

The NSRC is composed of six Panels which have been charged with particular objectives as follows:

PANEL 1—SYSTEM SPECIFICATIONS

Scope: Panel 1 shall consider system proposals for compatible stereophonic broadcasting; shall identify the technical issues in said proposals and refer them where necessary to other panels for detailed study; shall formulate a consistent set of transmission specifications for each form of broadcasting; and shall provide an over-all evaluation of the system performance implied in the specifications.

PANEL 2—INTERCONNECTING FACILITIES

Scope: Panel 2 shall study and recommend technical characteristics of interconnecting lines, networks, studio-transmitter links and related stereo-transmission facilities between program origination points and the transmitters proper, said characteristics to include tolerable limits on cross talk, relative time delay, frequency response, gain, and such other matters as must be controlled to assure a stereo signal of adequate quality at the transmitter input.

PANEL 3—BROADCAST TRANSMITTERS

Scope: Panel 3 shall study the system proposals referred to it by Panel 1 with particular regard to (1) the feasibility of the proposed transmission method and (2) methods of adapting the proposals to existing broadcast transmitters.

PANEL 4—BROADCAST RECEIVERS

Scope: Panel 4 shall study the system proposals referred to it by Panel 1 with particular regard to (1) the performance of existing monophonic receivers when tuned to the stereophonic signal (receiver compatibility), (2) the performance of stereophonic receivers designed for the stereophonic signal (stereo performance) and (3) the performance of stereophonic receivers when tuned to monophonic signals (reverse receiver compatibility).

PANEL 5—FIELD TESTING

Scope: Panel 5 shall study and compare the system proposals referred to it by Panel 1, with particular regard to coverage, interference effects, and other matters related to channel utilization; and shall conduct field tests with the advice and assistance of the other Panels.

PANEL 6—SUBJECTIVE ASPECTS

Scope: Panel 6 shall provide to the other panels scientific information on the subjective aspects of stereophonic sound.

The NSRC studies have been devoted to the study of compatible stereophonic radio systems. A compatible stereophonic radio signal might be defined as one that could be produced with existing monophonic equipment in such a manner as to provide an acceptable composite of the stereophonic signal. Before stereophonic broadcasting can be initiated nation-wide, it is necessary to establish uniform standards for each broadcast service. Except for the "two-facility" type of stereo broadcast (which is not a compatible system), stereophonic broadcasting is a "lock and key" type of system, similar to television. Obviously, the same system standards must be used nation-wide; otherwise a receiver purchased for one particular system would not function on another. The establishment of transmission standards is solely the responsibility of the Federal Communications Commission which has taken such steps in their proposed rule making, Docket 12517, for FM broadcasting. It would appear that it is the intent of the Commission to similarly establish stereophonic transmission standards for AM and TV broadcasting. The NSRC report to the FCC is now scheduled to be presented by March 15, 1960 (except for field tests), subsequent to which it is expected that the Commission will initiate concluding procedures leading to acceptable standards.

Section 9

CHARTS AND GRAPHS

Table 9-1. Decibels

Power ratio	Voltage or current ratio	−Db+	Voltage or current ratio	Power ratio	Power ratio	Voltage or current ratio	−Db+	Voltage or current ratio	Power ratio
10^{-1}		10		10	0.316	0.562	5.0	1.78	3.16
10^{-2}	10^{-1}	20	10	10^{2}	0.309	0.556	5.1	1.80	3.24
10^{-3}		30		10^{3}	0.302	0.550	5.2	1.82	3.31
10^{-4}	10^{-2}	40	10^{2}	10^{4}	0.295	0.543	5.3	1.84	3.39
10^{-5}		50		10^{5}	0.288	0.537	5.4	1.86	3.47
10^{-6}	10^{-3}	60	10^{3}	10^{6}	0.282	0.530	5.5	1.88	3.55
10^{-7}		70		10^{7}	0.275	0.525	5.6	1.91	3.63
10^{-8}	10^{-4}	80	10^{4}	10^{8}	0.269	0.519	5.7	1.93	3.72
10^{-9}		90		10^{9}	0.263	0.513	5.8	1.95	3.80
10^{-10}	10^{-5}	100	10^{5}	10^{10}	0.257	0.507	5.9	1.97	3.89
1.000	1.000	0	1.00	1.00	0.251	0.501	6.0	2.00	3.98
0.977	0.989	0.1	1.01	1.02	0.246	0.496	6.1	2.02	4.07
0.955	0.977	0.2	1.02	1.05	0.240	0.490	6.2	2.04	4.17
0.933	0.966	0.3	1.04	1.07	0.234	0.484	6.3	2.07	4.27
0.912	0.955	0.4	1.05	1.10	0.229	0.479	6.4	2.09	4.37
0.891	0.944	0.5	1.06	1.12	0.224	0.473	6.5	2.11	4.47
0.871	0.933	0.6	1.07	1.15	0.219	0.468	6.6	2.14	4.57
0.851	0.923	0.7	1.08	1.18	0.214	0.462	6.7	2.16	4.68
0.832	0.912	0.8	1.10	1.20	0.209	0.457	6.8	2.19	4.79
0.813	0.902	0.9	1.11	1.23	0.204	0.452	6.9	2.21	4.90
0.794	0.891	1.0	1.12	1.26	0.200	0.447	7.0	2.24	5.01
0.776	0.881	1.1	1.14	1.29	0.195	0.442	7.1	2.27	5.13
0.759	0.871	1.2	1.15	1.32	0.191	0.437	7.2	2.29	5.25
0.741	0.861	1.3	1.16	1.35	0.186	0.432	7.3	2.32	5.37
0.724	0.851	1.4	1.18	1.38	0.182	0.427	7.4	2.34	5.50
0.708	0.841	1.5	1.19	1.41	0.178	0.422	7.5	2.37	5.62
0.692	0.832	1.6	1.20	1.45	0.174	0.417	7.6	2.40	5.75
0.676	0.822	1.7	1.22	1.48	0.170	0.412	7.7	2.43	5.89
0.661	0.813	1.8	1.23	1.51	0.166	0.407	7.8	2.46	6.03
0.646	0.804	1.9	1.25	1.55	0.162	0.403	7.9	2.48	6.17
0.631	0.794	2.0	1.26	1.59	0.159	0.398	8.0	2.51	6.31
0.617	0.785	2.1	1.27	1.62	0.155	0.394	8.1	2.54	6.46
0.603	0.776	2.2	1.29	1.66	0.151	0.389	8.2	2.57	6.61
0.589	0.767	2.3	1.30	1.70	0.148	0.385	8.3	2.60	6.76
0.575	0.759	2.4	1.32	1.74	0.145	0.380	8.4	2.63	6.92
0.562	0.750	2.5	1.33	1.78	0.141	0.376	8.5	2.66	7.08
0.550	0.741	2.6	1.35	1.82	0.138	0.372	8.6	2.69	7.24
0.537	0.733	2.7	1.37	1.86	0.135	0.367	8.7	2.72	7.41
0.525	0.724	2.8	1.38	1.91	0.132	0.363	8.8	2.75	7.59
0.513	0.716	2.9	1.40	1.95	0.129	0.359	8.9	2.79	7.76
0.501	0.708	3.0	1.41	2.00	0.126	0.355	9.0	2.82	7.94
0.490	0.700	3.1	1.43	2.04	0.123	0.351	9.1	2.85	8.13
0.479	0.692	3.2	1.45	2.09	0.120	0.347	9.2	2.88	8.32
0.468	0.684	3.3	1.46	2.14	0.118	0.343	9.3	2.92	8.51
0.457	0.676	3.4	1.48	2.19	0.115	0.339	9.4	2.95	8.71
0.447	0.668	3.5	1.50	2.24	0.112	0.335	9.5	2.99	8.91
0.437	0.661	3.6	1.51	2.29	0.110	0.331	9.6	3.02	9.12
0.427	0.653	3.7	1.53	2.34	0.107	0.327	9.7	3.06	9.33
0.417	0.646	3.8	1.55	2.40	0.105	0.324	9.8	3.09	9.55
0.407	0.638	3.9	1.57	2.46	0.102	0.320	9.9	3.13	9.77
0.398	0.631	4.0	1.59	2.51	0.1000	0.316	10.0	3.16	10.00
0.389	0.624	4.1	1.60	2.57	0.0977	0.313	10.1	3.20	10.23
0.380	0.617	4.2	1.62	2.63	0.0955	0.309	10.2	3.24	10.47
0.372	0.610	4.3	1.64	2.69	0.0933	0.306	10.3	3.27	10.72
0.363	0.603	4.4	1.66	2.75	0.0912	0.302	10.4	3.31	10.96
0.355	0.596	4.5	1.68	2.81	0.0891	0.299	10.5	3.35	11.22
0.347	0.589	4.6	1.70	2.88	0.0871	0.295	10.6	3.39	11.48
0.339	0.582	4.7	1.72	2.95	0.0851	0.292	10.7	3.43	11.75
0.331	0.575	4.8	1.74	3.02	0.0832	0.288	10.8	3.47	12.02
0.324	0.569	4.9	1.76	3.09	0.0813	0.285	10.9	3.51	12.30

Table 9-1. Decibels (*Continued*)

Power ratio	Voltage or current ratio	—Db+	Voltage or current ratio	Power ratio
0.0794	0.282	11.0	3.55	12.59
0.0776	0.279	11.1	3.59	12.88
0.0759	0.275	11.2	3.63	13.18
0.0741	0.272	11.3	3.67	13.49
0.0724	0.269	11.4	3.72	13.80
0.0708	0.266	11.5	3.76	14.13
0.0691	0.263	11.6	3.80	14.45
0.0676	0.260	11.7	3.85	14.79
0.0661	0.257	11.8	3.89	15.14
0.0646	0.254	11.9	3.94	15.49
0.0631	0.251	12.0	3.98	15.85
0.0617	0.248	12.1	4.03	16.22
0.0603	0.246	12.2	4.07	16.60
0.0589	0.243	12.3	4.12	16.98
0.0575	0.240	12.4	4.17	17.38
0.0562	0.237	12.5	4.22	17.78
0.0550	0.234	12.6	4.27	18.20
0.0537	0.232	12.7	4.32	18.62
0.0525	0.229	12.8	4.37	19.05
0.0513	0.227	12.9	4.42	19.50
0.0501	0.224	13.0	4.47	19.95
0.0490	0.221	13.1	4.52	20.42
0.0479	0.219	13.2	4.57	20.89
0.0468	0.216	13.3	4.62	21.38
0.0457	0.214	13.4	4.68	21.88
0.0447	0.211	13.5	4.73	22.39
0.0437	0.209	13.6	4.79	22.91
0.0427	0.207	13.7	4.84	23.44
0.0417	0.204	13.8	4.90	23.99
0.0407	0.202	13.9	4.96	24.55
0.0398	0.200	14.0	5.01	25.12
0.0389	0.197	14.1	5.07	25.70
0.0380	0.195	14.2	5.13	26.30
0.0372	0.193	14.3	5.19	26.92
0.0363	0.191	14.4	5.25	27.54
0.0355	0.188	14.5	5.31	28.18
0.0347	0.186	14.6	5.37	28.84
0.0339	0.184	14.7	5.43	29.51
0.0331	0.182	14.8	5.50	30.20
0.0324	0.180	14.9	5.56	30.90
0.0316	0.178	15.0	5.62	31.62
0.0309	0.176	15.1	5.69	32.36
0.0302	0.174	15.2	5.75	33.11
0.0295	0.172	15.3	5.82	33.88
0.0288	0.170	15.4	5.89	34.67
0.0282	0.168	15.5	5.96	35.48
0.0275	0.166	15.6	6.03	36.31
0.0269	0.164	15.7	6.10	37.15
0.0263	0.162	15.8	6.17	38.02
0.0257	0.160	15.9	6.24	38.90
0.0251	0.159	16.0	6.31	39.81
0.0246	0.157	16.1	6.38	40.74
0.0240	0.155	16.2	6.46	41.69
0.0234	0.153	16.3	6.53	42.66
0.0229	0.151	16.4	6.61	43.65
0.0224	0.150	16.5	6.68	44.67
0.0219	0.148	16.6	6.76	45.71
0.0214	0.146	16.7	6.84	46.77
0.0209	0.145	16.8	6.92	47.86
0.0204	0.143	16.9	7.00	48.98
0.0200	0.141	17.0	7.08	50.12
0.0195	0.140	17.1	7.16	51.29
0.0191	0.138	17.2	7.24	52.48
0.0186	0.137	17.3	7.33	53.70
0.0182	0.135	17.4	7.41	54.95
0.0178	0.133	17.5	7.50	56.23
0.0174	0.132	17.6	7.59	57.54
0.0170	0.130	17.7	7.67	58.88
0.0166	0.129	17.8	7.76	60.26
0.0162	0.127	17.9	7.85	61.66
0.0159	0.126	18.0	7.94	63.10
0.0155	0.125	18.1	8.04	64.57
0.0151	0.123	18.2	8.13	66.07
0.0148	0.122	18.3	8.22	67.61
0.0145	0.120	18.4	8.32	69.18
0.0141	0.119	18.5	8.41	70.79
0.0138	0.118	18.6	8.51	72.44
0.0135	0.116	18.7	8.61	74.13
0.0132	0.115	18.8	8.71	75.86
0.0129	0.114	18.9	8.81	77.62
0.0126	0.112	19.0	8.91	79.43
0.0123	0.111	19.1	9.02	81.28
0.0120	0.110	19.2	9.12	83.18
0.0118	0.108	19.3	9.23	85.11
0.0115	0.107	19.4	9.33	87.10
0.0112	0.106	19.5	9.44	89.13
0.0110	0.105	19.6	9.55	91.20
0.0107	0.104	19.7	9.66	93.33
0.0105	0.102	19.8	9.77	95.50
0.0102	0.101	19.9	9.89	97.72
0.0100	0.100	20.0	10.00	100.00

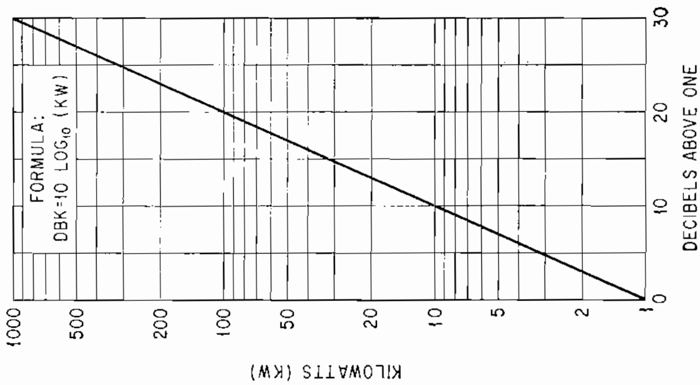


FIG. 9-2. Transformation of kilowatts to decibels above 1 kw.

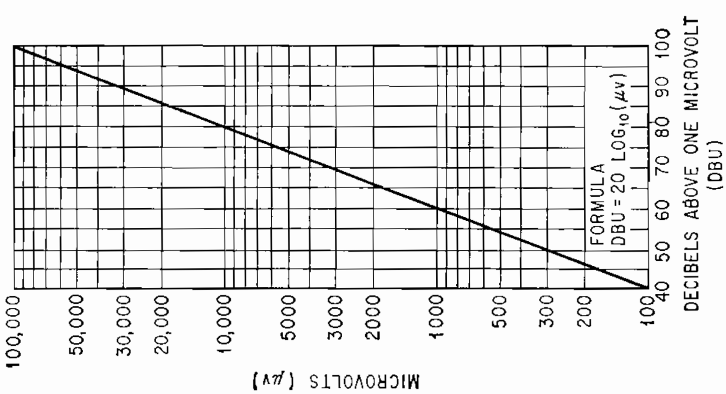


FIG. 9-1. Transformation of microvolts to decibels above 1 μv.

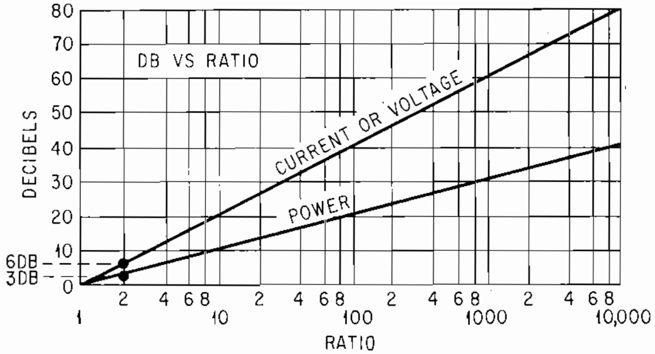


FIG. 9-3. Decibels vs. ratio.

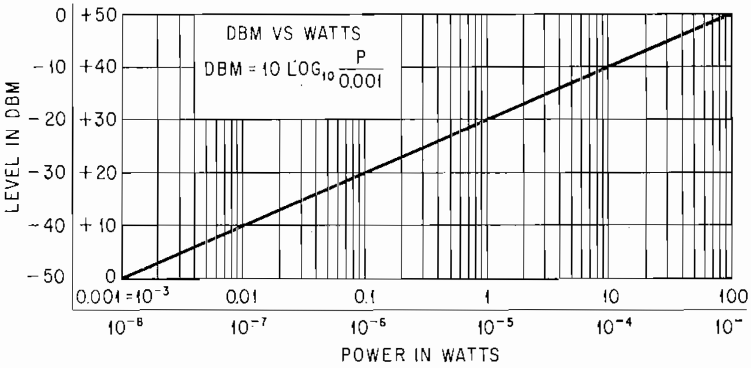


FIG. 9-4. Dbm vs. watts.

Table 9-2. Volume Level to Power and Voltage Conversion

Reference Level

0 dbm = 1 mw, 600 ohms

Milliwatts	Volts	Dbm
0.000001	0.0007746	−60
0.000010	0.002449	−50
0.000100	0.007746	−40
0.001	0.02449	−30
0.010	0.07746	−20
0.100	0.2449	−10
1.000	0.7746	0
Watts	**Volts**	**Dbm**
0.001000	0.7746	0
0.002512	1.228	+4
0.006310	1.946	+8
0.01000	2.449	+10
0.1000	7.746	+20
1.000	24.49	+30
10.00	77.46	+40

RESISTANCE VALUES OF SYMMETRICAL ATTENUATION NETWORKS *

For ready reference and to satisfy most of the practical needs of the various artificial line pads, the following charts have been prepared:

Figures 9-5 to 9-7, inclusive, are curves for determining the three components of pads which are symmetrical but have different input and output impedances. The curves are marked to indicate pad ratios for which it was calculated, and the values of *A* are for the higher pad series leg resistances shown in Fig. 9-5, while *C* values for the lower pad series leg resistances are shown in Fig. 9-7. *B* is for the shunt or transverse resistor shown in Fig. 9-6.

There is a minimum loss for each impedance ratio for which a pad can be designed and for convenience each curve on the figures is terminated by a circle at the lower value of resistance which corresponds to this minimum pad loss. For L networks double the values of *A* and *C*.

Figure 9-8 gives the resistance values for the series legs *A* of symmetrical pads having 1-to-1 impedance ratios. Figure 9-9 gives the transverse resistance values for these pads. For values not shown multiply the valne shown for 100 ohms by the ratio of the desired value to 100. Double the series leg values for L networks.

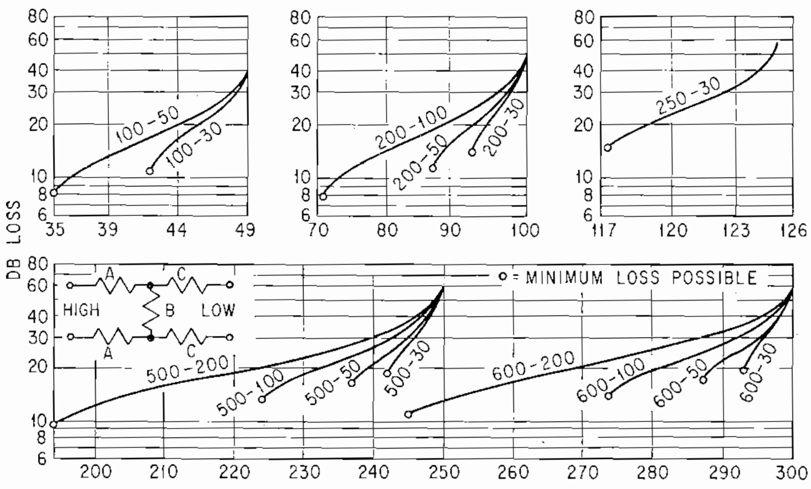


FIG. 9-5. Symmetrical attenuation networks for standard ratios—values of *A*.

* By Frank H. McIntosh, Consulting Radio Engineer, Washington, D.C.

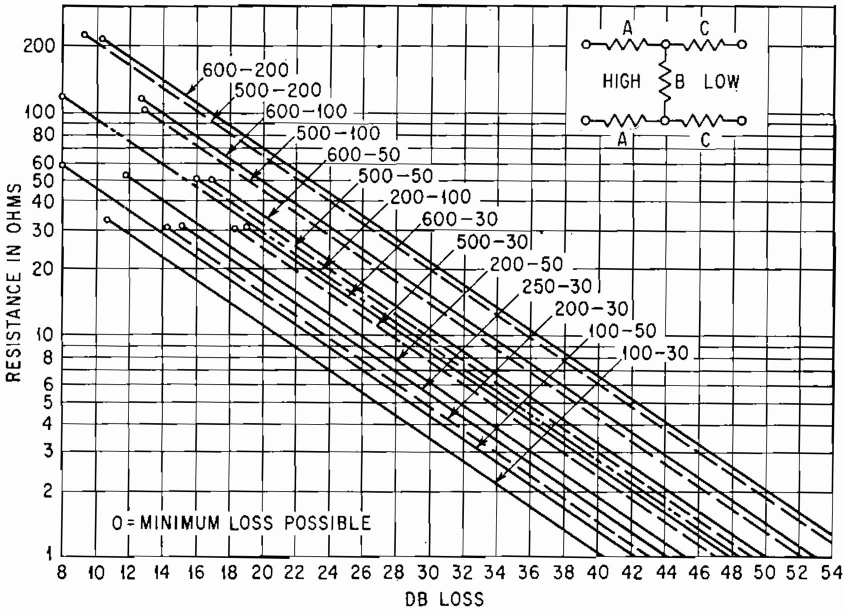


Fig. 9-6. Symmetrical attenuation networks for standard ratios—values of *B*.

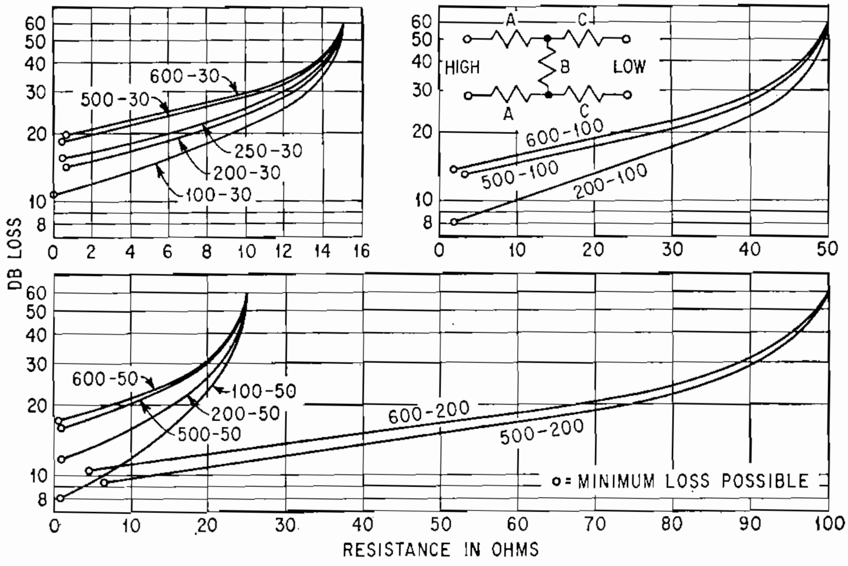


Fig. 9-7. Symmetrical attenuation networks for standard ratios—values of *C*.

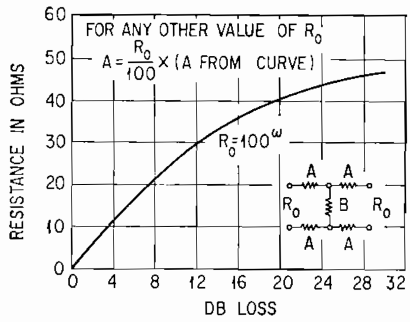


Fig. 9-8. *H*-type artificial line—value of series resistance *A*.

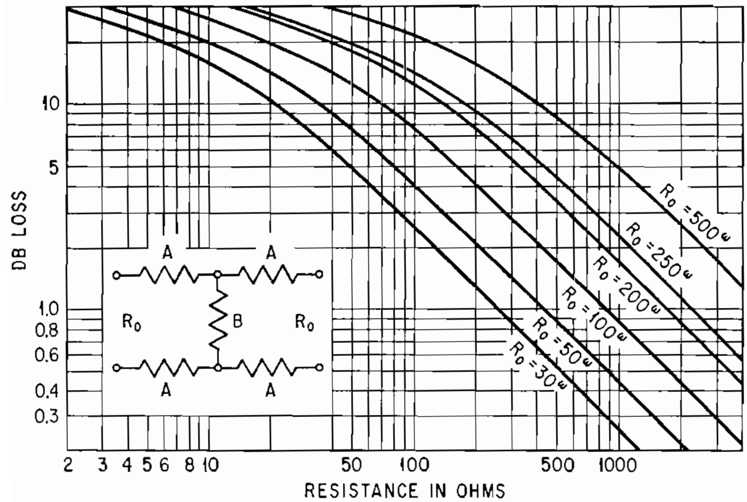
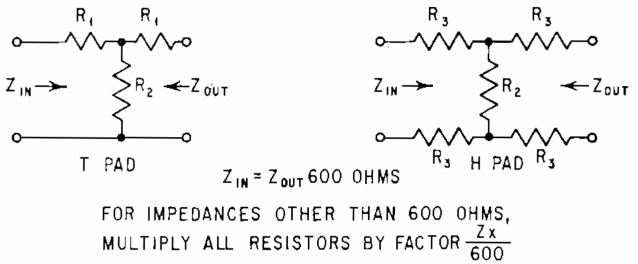


Fig. 9-9. *H*-type artificial line—value of transverse resistauce *B*.

Table 9-3. Resistive Pads

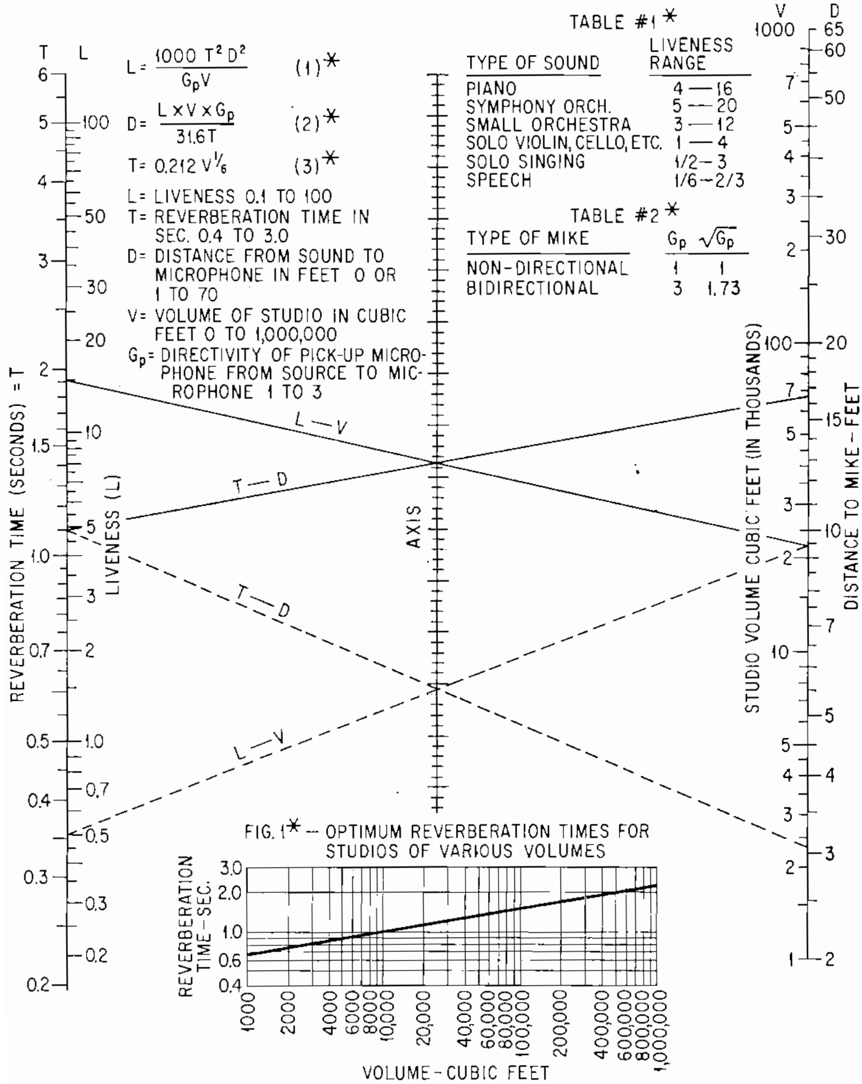


For impedances other than 600 ohms, multiply all resistors by factor $Zx/600$.

$Z_{in} = Z_{out} = 600$ ohms

Loss	EIA resistor values *			Loss	EIA resistor values *		
	R_1	R_2	R_3		R_1	R_2	R_3
½	18	10,000	8.2	16	430	200	220
1	36	5,100	18	17	470	180	220
2	68	2,700	36	18	470	150	240
3	100	1,800	51	19	470	130	240
4	130	1,200	68	20	510	120	240
5	160	1,000	82	22	510	100	270
6	200	820	100	24	510	75	270
7	220	680	110	26	560	62	270
8	270	560	130	28	560	47	270
9	300	470	150	30	560	39	270
10	300	430	160	32	560	30	300
11	330	360	160	34	560	24	300
12	360	330	180	36	560	18	300
13	390	270	200	38	560	15	300
14	390	240	200	40	560	12	300
15	430	220	200				

* EIA resistor values nearest to the exact values are given.



*COURTESY OF WESTERN ELECTRIC CO.

FIG. 9-10. Nomograph for microphone distances in liveness broadcasting. (*Reprinted from Tele-Tech.*)

Constants $V = 22{,}000$ cu ft; $T = 1.1$ sec.

Example 1 (solid lines): Placement of general microphone. From Table 1 use liveness of 15. Connect 22,000 on V and 15 on L. Mark reference on the axis. Then extend a line from 1.1 on T through reference on axis to 16.5 ft on D. *Answer:* 16½ ft from mike to sound source.

Example 2 (dash lines): Placement of solo vocal microphone. From Table 1 use liveness of ½. Connect 22,000 on V and ½ on L. Mark reference on the axis. Then extend line from 1.1 on T through this reference to 3 ft on D. For bidirectional mike multiply 3 ft by $\sqrt{3}$, or 1.73. This yields 5 to 6 ft for actual distance.

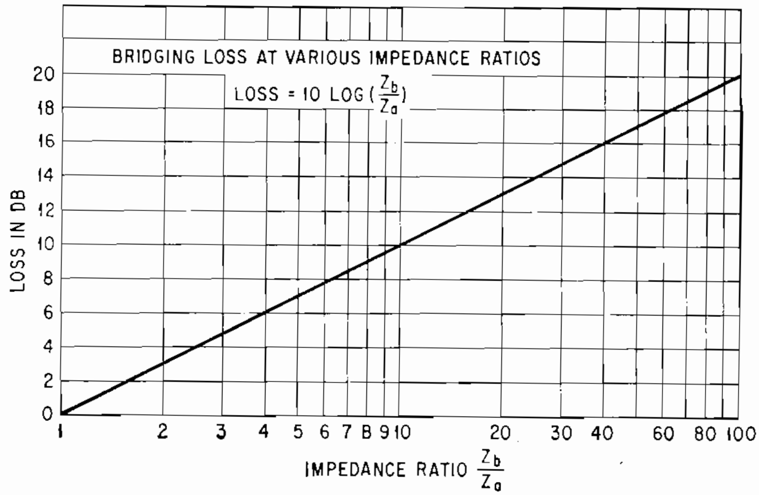


FIG. 9-11. Bridgiug loss at various impedance ratios. Loss = 10 log Z_b/Z_a.

PARALLEL-T NOMOGRAPH *

Summary: Values of five parameters for parallel-T networks are obtained directly with one setting of a straightedgc, for freqnencies in audio and nltrasonic ranges, to expedite the design of the network used directly in an amplifier chain to eliminate a single frequency. The same network can be used in a negative feedback path to enhance a single frequency.

This nomograph (Fig. 9-12) facilitates calculating parallel-T networks for experimental work in multiplex FM equipment design. The subcarrier frequencies used are in the range from about 20 to 75 kc. With one setting of a straigbtedgc, all parameters of the parallel-T network needed to eliminate the undesired frequency f can be obtained to three significant figures.

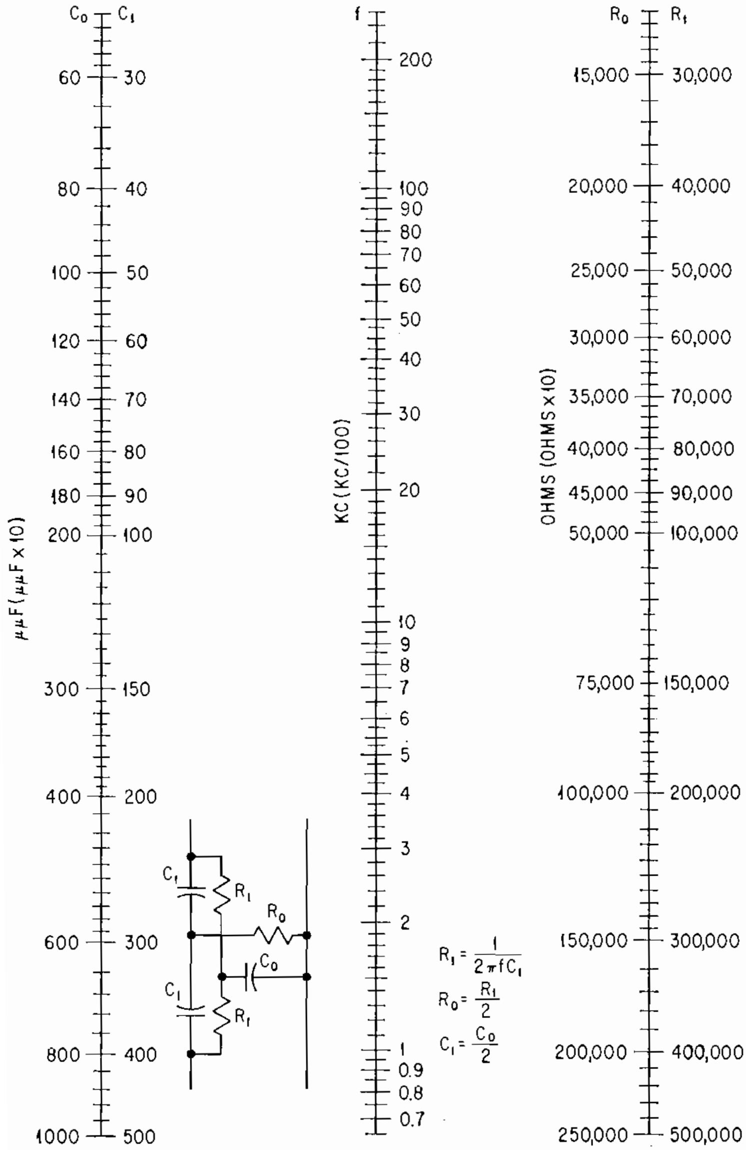
Example. If a specific frequency f of 10 kc is to be eliminated and C_1 is selected by the designer to be 100 $\mu\mu$f, run a straightedge from 100 $\mu\mu$f on the C_1 scale through 10 kc on the f scale. All other values can now be read directly from the nomograph. Thus, R_1 is 159,000 ohms, R_0 is 79,500 ohms and C_0 is 200 $\mu\mu$f.

Any two of the five parameters can be selected as the initial starting point of design. The other three can then be found with one setting of the straightedge.

If the f scale is divided by 100, the C and R scales must be multiplied by 10. This changes the range of the nomograph to cover from 7 cps at the low end to about 2,000 cps at the high end.

For a 100-cps elimination network and a value of 1,000 $\mu\mu$f for C_1, these scale-multiplying factors must be used. The other parameters are then R_1 = 1.59 megohms, R_0 = 795,000 ohms, and C_0 = 2,000 $\mu\mu$f.

* By Donald F. Carter, Chief Electrical Engineer, Harkins and Hershfield, Phoenix, Ariz. Reprinted from *Electronics*, Nov. 1, 1957.



CENTER SCALE GIVES FREQUENCY ATTENUATED BY PARALLEL-T NETWORK

Fig. 9-12. Parallel-T nomograph.

MICROPHONE NOMOGRAPH *

Summary: The chart (Fig. 9-13) relates sound pressure level, microphone sensitivity, and output in decibels and volts as an aid in the design of microphone systems and related equipment. Typical sound levels for common sounds are indicated.

Microphone response is usually expressed in decibels referred to 1 volt/dyne/cm². Thus a microphone which produces 1 volt when exposed to a sound pressure of 1 dyne/cm² has a response of 0 db. Most microphones are far less sensitive than this.

Unless otherwise specified, the open-circuit voltage is used in arriving at the response figure.

The nomograph is based on the definition of pressure response in the American Standard Specification for Laboratory Standard Microphones.

Expressed symbolically, this definition becomes

$$\rho = 20 \log \frac{e_o}{p} \tag{9-1}$$

where ρ = pressure response

e_o = open-circuit output voltage

p = pressure, dynes/cm²

Equation (9-1) can be rewritten

$$= 20 \log e_o - 20 \log p \tag{9-2}$$

Sound pressure is commonly expressed in decibels relative to a reference pressure $p_0 = 2 \times 10^{-4}$ dynes/cm². When so expressed it is called sound pressure level (SPL) and is defined by

$$SPL = 20 \log \frac{p}{p_0} \quad \text{db} \tag{9-3}$$

Equations (9-2) and (9-3) yield

$$\rho = 20 \log e_o - \text{SPL} + 74 \text{ db} \tag{9-4}$$

Should absolute sound pressures be required, they can be filled in on the left-hand scale by noting that 100 db = 20 dynes/cm², 80 db = 2 dynes/cm², 60 db = 0.2 dyne/cm², and so forth.

A microphone with a response of −50 db is to be used to measure sound levels of 35 db or more. For what minimum input voltage should the amplifier be designed?

A straight line drawn between 35 db on the SPL scale and −50 db on the ρ scale intersects the e_o scale at about 35 μv. This is the open-circuit microphone voltage.

Sound level in a jet-engine test control room is 112 db; a pneumatic chipper at a distance of 5 ft has a sound level of 122 db. At takeoff and 80 ft from the tail, an F-84 has a sound level of 130 db, all typical values.

* By William B. Conover, Transformer Laboratories Department, General Electric Company, Pittsfield, Mass. Reprinted from *Electronics*, October, 1955.

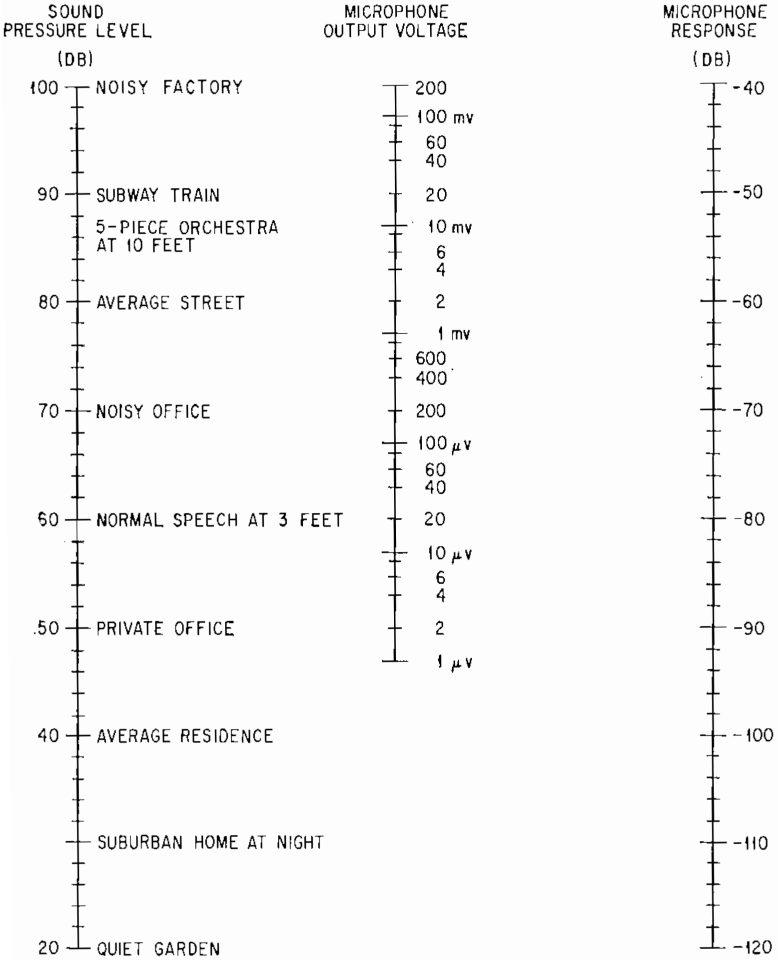

SOUND PRESSURE LEVEL (DB)
MICROPHONE OUTPUT VOLTAGE
MICROPHONE RESPONSE (DB)
100 NOISY FACTORY
90 SUBWAY TRAIN
5-PIECE ORCHESTRA AT 10 FEET
80 AVERAGE STREET
70 NOISY OFFICE
60 NORMAL SPEECH AT 3 FEET
50 PRIVATE OFFICE
40 AVERAGE RESIDENCE
SUBURBAN HOME AT NIGHT
20 QUIET GARDEN
200
100 mv
60
40
20
10 mv
6
4
2
1 mv
600
400
200
100 μv
60
40
20
10 μv
6
4
2
1 μv
-40
-50
-60
-70
-80
-90
-100
-110
-120

Fig. 9-13

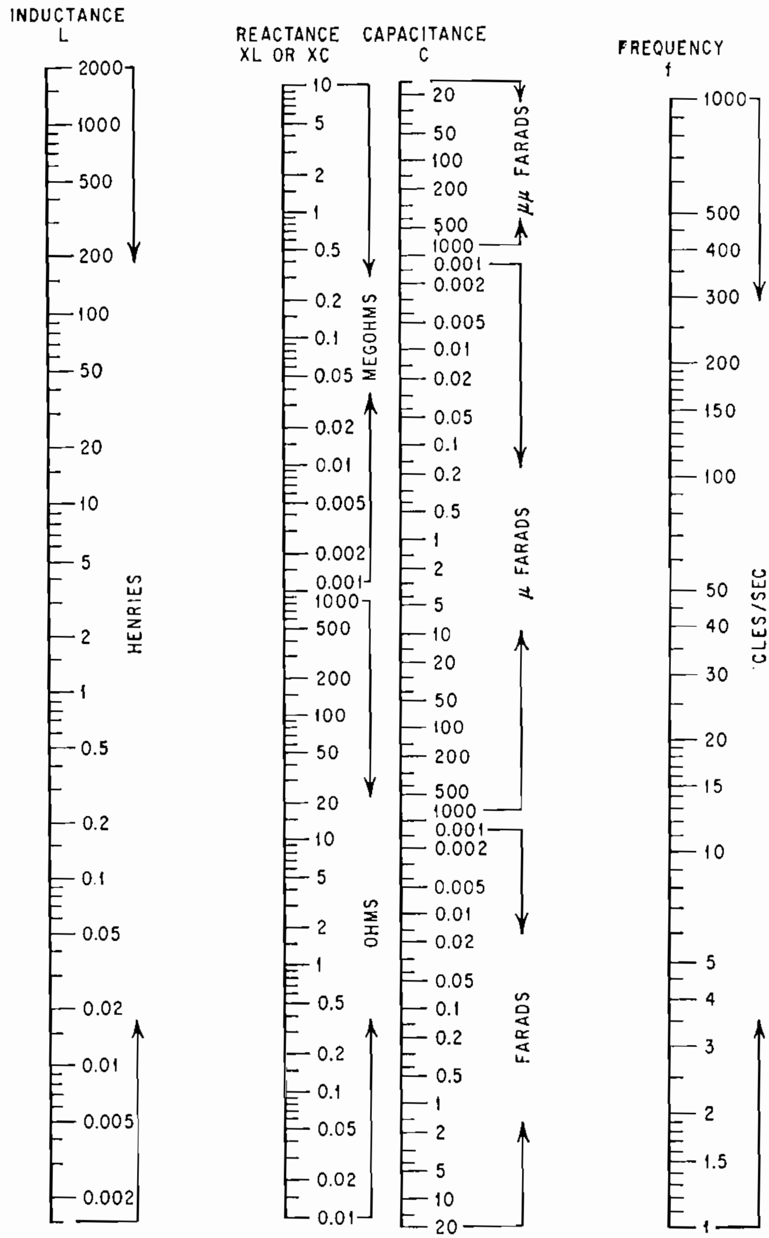

INDUCTANCE
L
HENRIES
2000
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
REACTANCE
XL OR XC
MEGOHMS
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
OHMS
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
CAPACITANCE
C
μμ FARADS
20
50
100
200
500
1000
μ FARADS
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
200
500
1000
FARADS
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
FREQUENCY
f
CLES/SEC
1000
500
400
300
200
150
100
50
40
30
20
15
10
5
4
3
2
1.5
1

FIG. 9-14*a*

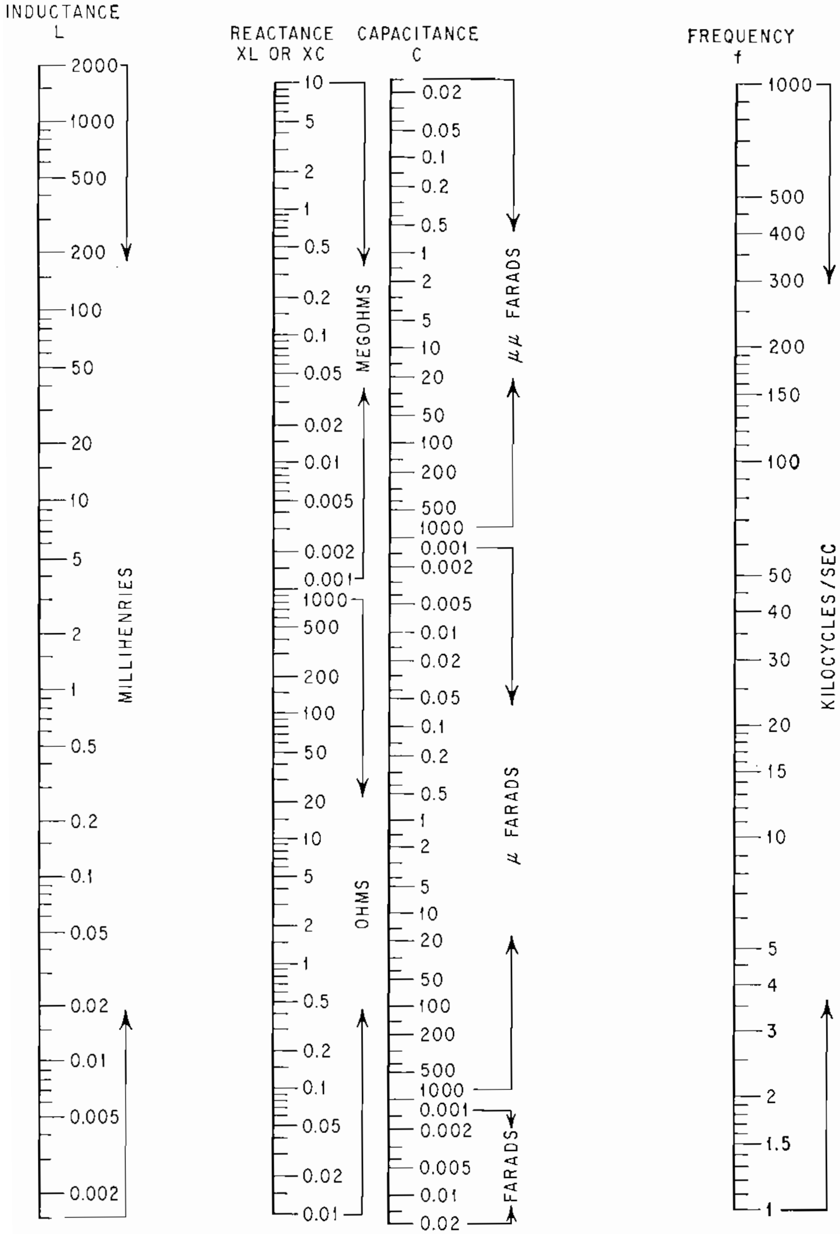

INDUCTANCE
L
MILLIHENRIES
2000
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
REACTANCE
XL OR XC
MEGOHMS
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
OHMS
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
CAPACITANCE
C
μμ FARADS
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
200
500
1000
μ FARADS
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
200
500
1000
FARADS
0.001
0.002
0.005
0.01
0.02
FREQUENCY
f
KILOCYCLES/SEC
1000
500
400
300
200
150
100
50
40
30
20
15
10
5
4
3
2
1.5
1

Fig. 9-14*b*

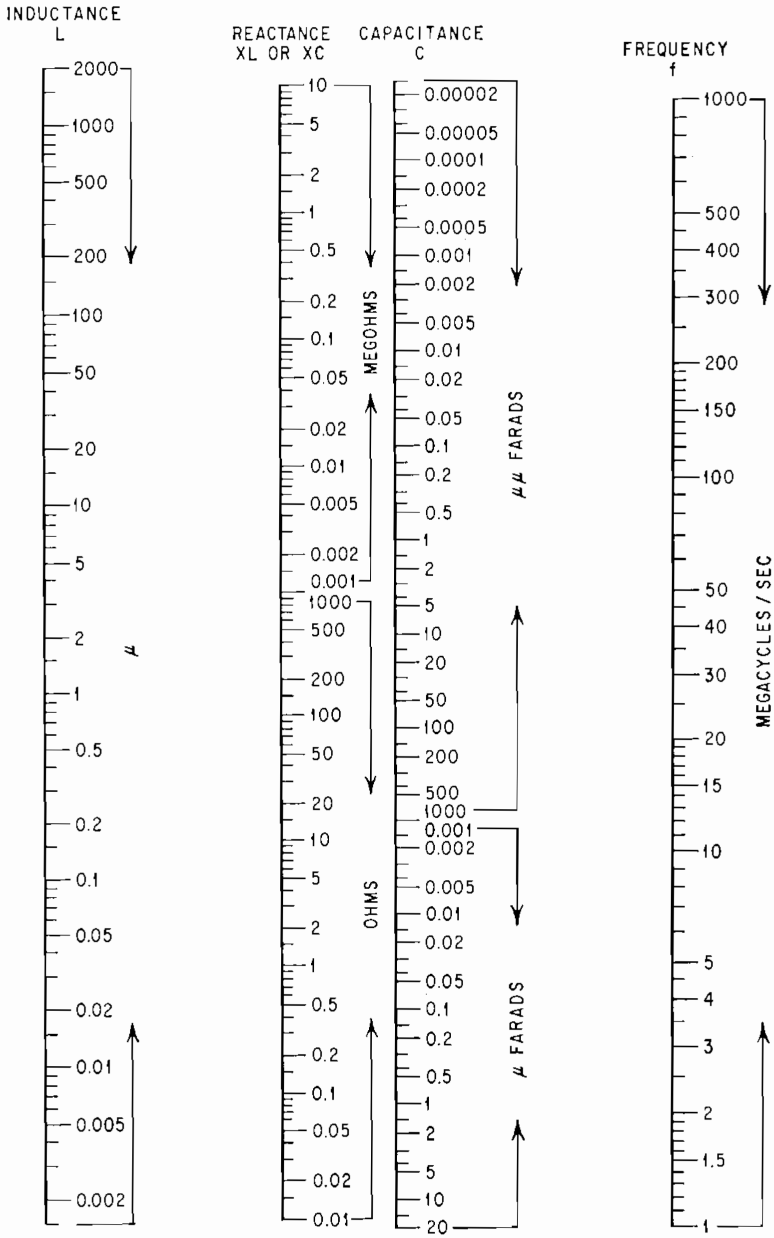

INDUCTANCE
L
μ
REACTANCE
XL OR XC
MEGOHMS
OHMS
CAPACITANCE
C
μμ FARADS
μ FARADS
FREQUENCY
f
MEGACYCLES / SEC

FIG. 9-14c

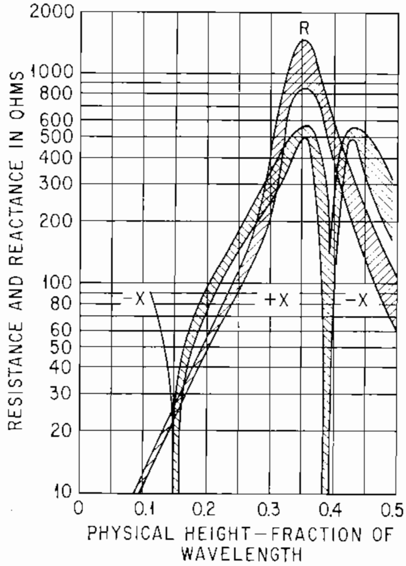


FIG. 9-15. Average characteristics for guyed radiators of uniform cross section. Data compiled from measurements of KNX and KIRO's 4-ft triangular radiators and a large number of 12- to 18-in. triangular radiators. (*Prepared by J. B. Hatfield.*)

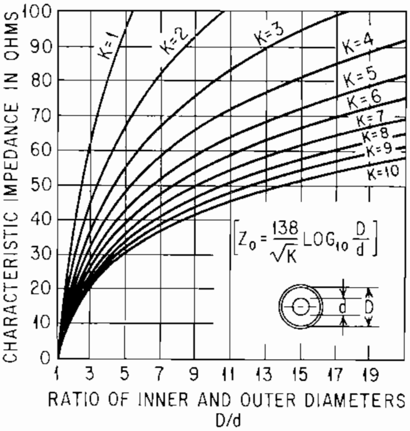


FIG. 9-16. Characteristic impedance of coaxial lines with various dielectrics.

COAXIAL-LINE IMPEDANCE CHART *

Summary: Characteristic impedances of coaxial lines are related graphically to dielectric constants and the ratios of outer to inner conductor diameters. Dielectric constants of common materials are also tabulated.

This chart (Fig. 9-16) simplifies the solution for the characteristic impedance of a single coaxial line.

Example. If a characteristic impedance of 50 ohms is desired and the insulating material is air, then from the chart the D/d ratio is 2.3. If metal tubing with an inside diameter $D = 0.250$ in. is chosen for the outer conductor, the outside diameter of the metal inner conductor is 0.109 in.

* By Herbert L. Levin, Electron Tube Laboratory, Federal Telecommunication Laboratories, Nutley, N.J. Reprinted from *Electronics*, Nov. 1, 1957.

Dielectric Constant K from 1 to 10,000 Mc at 25°C

Ceramics		*Plastics*	
Alumina 85%	8.3–8.0	Bakelite BM 120	3.7
Alumina 95%	8.9–9.3	Epoxy resin	3.1
Alumina 97%	9.0–9.6	Formica XX	3.6
Aluminum silicate	5.5–5.2	Kel-F	2.3
Fosterite	6.2–6.0	Micarta 254	3.4
Magnesium silicate	5.9–5.3	Nylon 610	2.8
Steatite	6.5–5.3	Plexiglass	2.6
Porcelain, standard electrical	5.5	Polystyrene	2.6
		Styrofoam 103.7	1.03
Porcelain, zircon	9.2	Teflon	2.1
		Tenite II	2.9
		Vinylite VG 5901	2.9

Glasses		*Miscellaneous*	
Corning:		Air	1
7052	5.1	Butyl rubber	2.4
7070	4.0	Mica	5.4
7720 nonex	4.7	Neoprene 38% GN	4.0
7740 Pyrex	4.6	Silastic 120	5.7
7900 Vycor (96% silica)	3.8	Silastic 152	2.9
8871 (lead potash)	8.4		
9010 (lead free)	6.5		
Quartz, fnsed	3.78		
Sapphire, synthetic	8.6–10.6		

If a ceramic such as Alumina 95 per cent with $K = 9$ were introduced as the dielectric and the Z_o of 50 ohms were still desired, then from Fig. 9-16 $D/d = 12.3$. If the D of 0.250 were also still desired, then $d = 0.020$ in.

The chart shows that if in this example d were not changed when the ceramic material replaced air, then Z_o would drop from 50 to 16.5 ohms.

COUPLING AND TUNING CAPACITOR FOR VARIOUS ANTENNAS

Figure 9-17 has been found to be a useful tool for adjusting the transmitter output circuit using capacity coupling to the antenna or transmission line. The values of capacity shown are approximate, but sufficiently close for practical purposes, since stray capacity of leads and components has not been taken into account. The capacity shown is the total capacity required for both the first and second sections of the low-pass filters.

The introduced resistance is the net resistance component when section is adjusted resulting from the effect of the R_a (antenna or line resistance) and the coupling capacity (CC).

The Z is the load impedance for the tubes determined by the dynamic characteristic for the particular tube and its operating voltages.

The value of introduced resistance used generally now lies between 50 and 100 ohms with the upper limit determined by the stray capacity. Formerly with high C ratios, introduced resistances were from 7 to 20 ohms, which resulted generally in higher circuit losses.

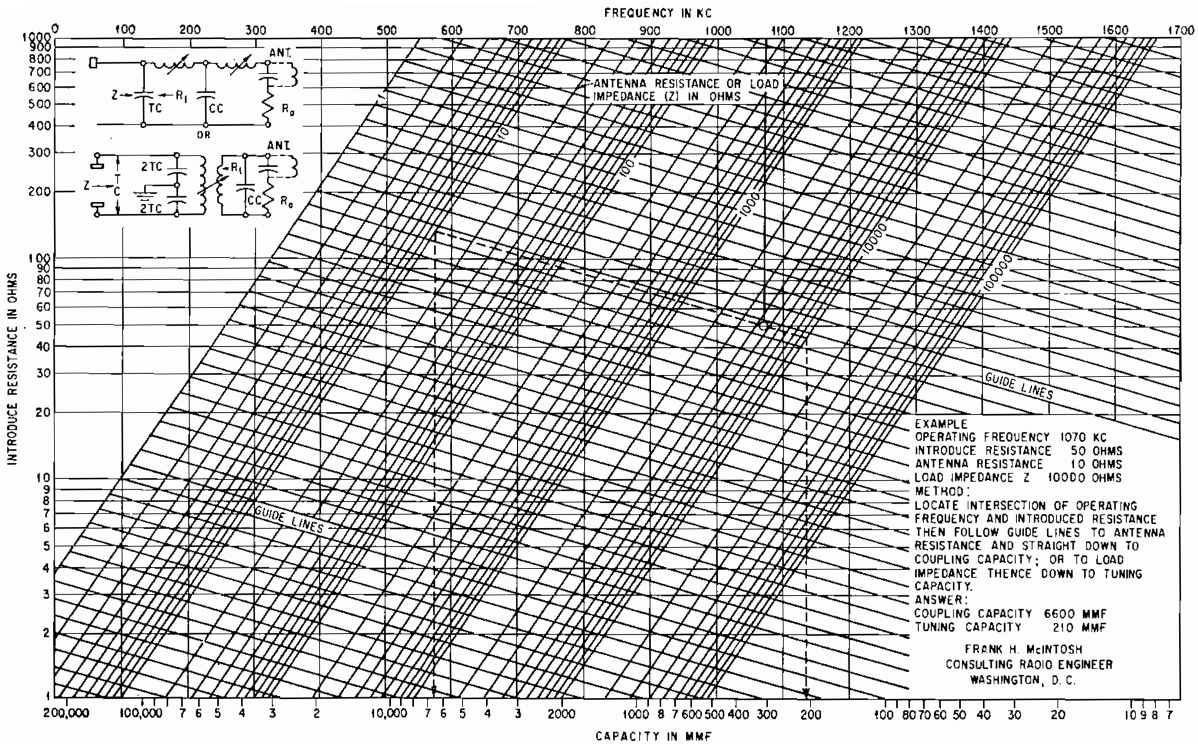


Fig. 9-17. Capacity-coupled circuits. Chart showing coupling and tuning capacities for various antenna resistances, tube load impedances, and introduced resistances for various given frequencies.

APPLICATION OF PROXIMITY-EFFECT CURVE *

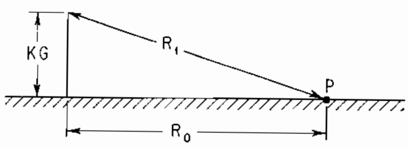
1. The curve in Fig. 9-18 shows the amount by which the measured field strength, as measured by a field-strength meter which employs a shielded loop, will depart from an inverse distance function because of induction field or proximity effect due to measuring close to the antenna.
2. It is based upon the calculation of the horizontal component of magnetic field close to an antenna, after the manner of George H. Brown.
3. It can be used first as a guide determining how close one can measure to a given antenna before the correction due to proximity would be expected to exceed a given percentage.
4. It can be used to correct out the error due to proximity before plotting field-strength measurements to determine accurately the inverse distance field. This permits measurements to be made sufficiently close to the tower to eliminate the effects of conductivity.

Derivation

1. G. H. Brown, Directional Antennas, *IRE*, January, 1937, on page 81 and in formula (7) gives the general formula for the magnetic flux density at any point in space from a vertical radiator over a perfectly conducting earth. By restricting this point P to the earth's surface, certain simplifications can be made in Brown's formula. Specifically Z goes to zero and $r_1 = r_2$ and $r_0 = x$.
2. The simplified formula becomes:

$$B_\phi = \frac{j2 \times 10^{-9} I_0}{r_0 \sin kG}[\epsilon^{-jkr_1} - \epsilon^{-jkr_0} \times \cos kG]$$

where $k = \dfrac{2\pi}{\lambda}$



3. Now when the distance r_0 becomes so great that $r_0 \approx r_1$

$$B_\phi(\text{far field}) = \frac{j2 \times 10^{-9} I_0}{r_0 \sin kG}[1 - \cos kG] \times \epsilon^{-jkr_0}$$

4. Now let $57.3kr_1 = r_1$ (degrees); $57.3kr_0 = r_0$ (degrees); $57.3kg = G$ (degrees).
5. Also convert from exponential to trigonometric form.
6. The resulting ratio is

$$\frac{B_\phi}{B_\phi\ (\text{far field})} = K = \frac{\{[\cos r_1 - \cos G \times \cos r_0]^2 + [\sin r_1 - \cos G \times \sin r_0]^2\}^{1/2}}{[1 - \cos G]}$$

7. Therefore:

$$\frac{\text{Field measurement}}{K} = \text{adjusted field}$$

* Silliman, Moffet, and Rohrer.

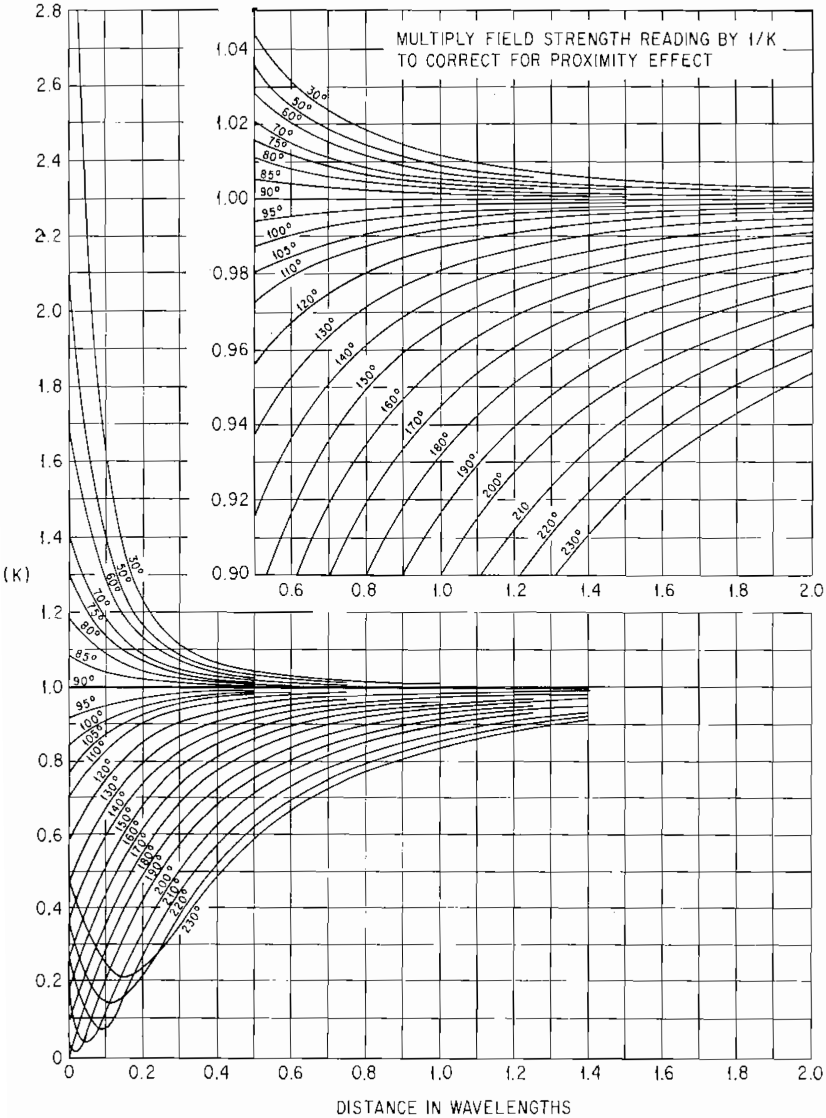


FIG. 9-18. Proximity effect for various tower heights.

WAVEGUIDE LOSS CHARTS *

Summary: Graphical presentation of attenuation values provides data for typical commercial microwave equipment. When effective resistivity is known or estimated, attenuation in decibels per foot can be determined at 1 to 75 kmc. Internal rectangular dimensions are also given.

Attenuation per foot of a particular commercial rectangular waveguide at a given frequency can be computed from published information, but for rapid extrapolation or comparison the accompanying charts (see Fig. 9-19) offer a ready solution.

One must know or be able to estimate the effective resistivity of the conducting surface. This is the product of d-c resistivity and a surface roughness factor K_T, which is unity for an ideal polished surface. Materials having low d-c resistivities require smooth surfaces for low effective resistivity and low loss. In materials having high d-c resistivities the current penetrates deeper into the material and K_T is near unity even for moderately rough surfaces. Thus surface roughness has almost no effect on high-resistivity materials.

Nominal Internal Dimensions for Standard Hollow Rectangular Waveguides

WR No.	*Wide*	*Narrow*	*WR No.*	*Wide*	*Narrow*
10	0.100	0.050	112	1.122	0.497
12	0.122	0.061	137	1.372	0.622
15	0.148	0.074	159	1.590	0.795
19	0.188	0.094	187	1.872	0.872
22	0.224	0.112	229	2.290	1.145
28	0.280	0.140	284	2.840	1.340
34	0.340	0.170	340	3.400	1.700
42	0.420	0.170	430	4.300	2.150
51	0.510	0.255	510	5.100	2.550
62	0.622	0.311	650	6.500	3.250
75	0.750	0.375	770	7.700	3.850
90	0.900	0.400	975	9.750	4.875

Another factor is the size of the hollow waveguide cross section. Lowest losses are obtained by use of the largest possible waveguide. The chart shows the penalty resulting from use of a smaller size.

Measured attenuation of two sizes of rectangular copper waveguides shows that the effective resistivity is about 2.2×10^{-6} ohm-cm from 4 to 6 kmc. This is about 28 per cent above the d-c resistivity of 1.72×10^{-6} ohm-cm. Measurements on WR-229 drawn of 90-10 brass show an effective resistivity of 4.3×10^{-6} ohm-cm at 4 kmc, which is about 7.5 per cent above the d-c resistivity of 4×10^{-6} ohm-cm.

Plotting points on the graph were determined from the equation

$$\alpha = \frac{5.963(RK_T/\lambda)^{1/2}(1/b + \lambda^2/2a^3)}{\sqrt{1 - \lambda^2/4a^2}}$$

where α = attenuation in rectangular waveguide, db/ft
R = d-c resistivity of conducting surface, ohm-cm
a = wide dimension of waveguide, in.
b = narrow dimension of waveguide, in.
λ = free-space wavelength, in.
K_T = surface roughness factor
RK_T = effective resistivity of conducting surface, ohm-cm

* By A. F. Pomeroy, Bell Telephone Laboratories, Murray Hill, N.J. Reprinted from *Electronics*, October 1, 1957.

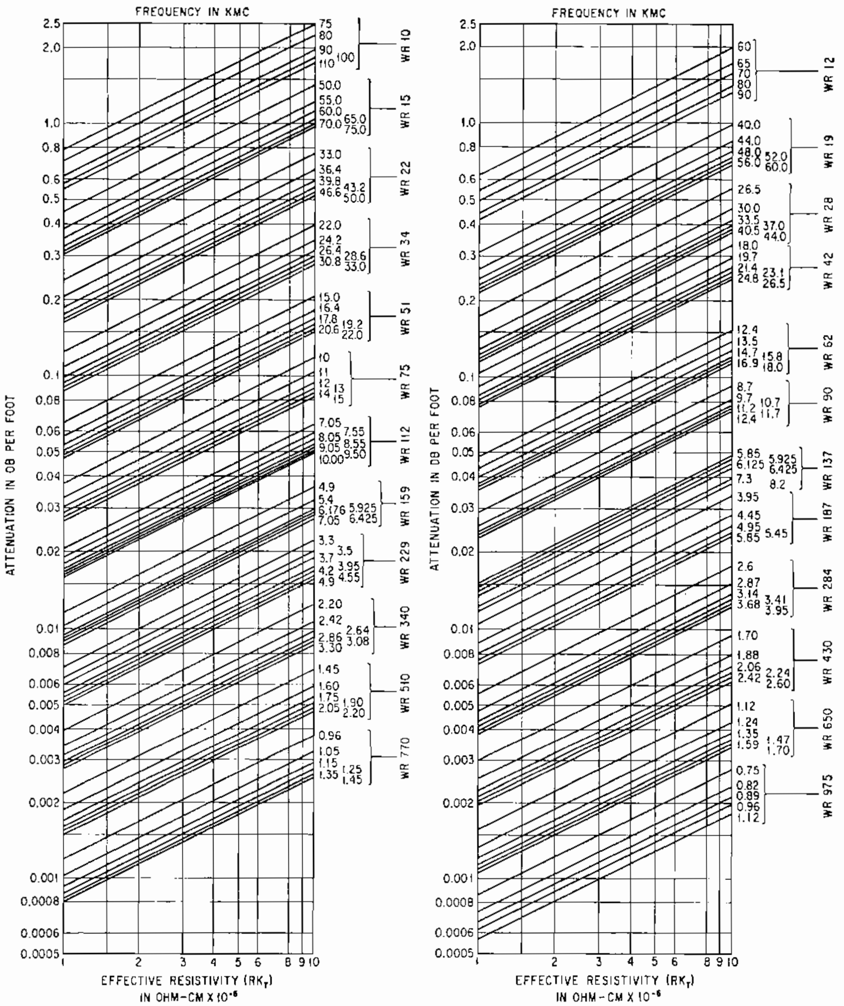


FIG. 9-19. Waveguide loss charts.

Example. Suppose it is necessary to find the attenuation of WR51 made of high-conductivity copper at frequencies from 16.4 to 20.6 kmc. Using 2.5×10^{-6} ohm-cm as an effective resistivity, we read on the chart 0.092 db/ft at 16.4 kmc and 0.078 db/ft at 20.6 kmc. The attenuation of other sizes can be found in a similar manner.

Representative frequencies in the recommended ranges were chosen for each size shown in Fig. 9-19. Interpolation between the characteristics to find the loss for other frequencies is straightforward.

The effective resistivity should be nearly constant over a small frequency interval, which leads to another use of these characteristics. To find an average effective resistivity over a band of frequencies, measured values of decibels per foot can be plotted on the characteristics and an ordinate drawn through the average value of effective resistivity. This result is probably more accurate than any one of the individual determinations.

Thanks are due Miss J. D. Goeltz and Mrs. Dolores G. Hill for their work in computing the attenuations used in plotting the characteristics.

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Pomeroy, A. F., and E. M. Suarez: Determining Attenuation of Waveguide from Electrical Measurements on Short Samples, *IRE Trans. RGMTT*, April, 1956, p. 122.

Benson, F. A.: Waveguide Attenuation and Its Correlation with Surface Roughness, *Proc. IRE*, 100, part III, p. 85, March, 1953.

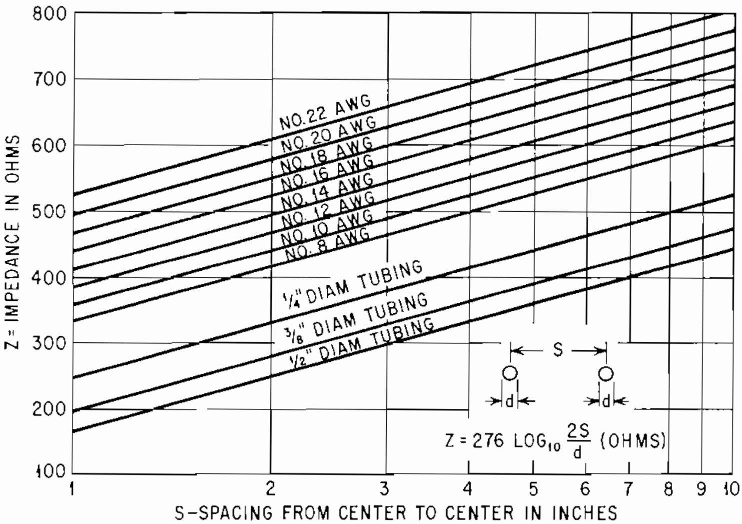


FIG. 9-20. Characteristic impedance of parallel-line wires.

L-NETWORK DESIGN *

Summary: Technique for using Smith chart to speed design of L matching networks for transmission lines and waveguides using lumped parameters. Shaded-area charts show at a glance impedance ranges that can be matched with each type of L network.

The familiar Smith chart for transmission lines is also a useful tool for designing matching networks. As an example, consider the case where it is desired to match an impedance $Z_L = (0.3 - j1.6)R_o$ to R_o with the L matching network shown in Fig. 9-21. It is assumed that the inductances are lossy so that $R_1 = X_1 \tan\theta = 0.2X_1$ and

* By H. F. Mathis, Goodyear Aircraft Corp., Akron, Ohio. Reprinted from *Electronics*, Feb. 1, 1957.

$G_2 = -B_2 \tan \theta = -0.2B_2$. All impedances and admittances are normalized with respect to R_o and $G_o = 1/R_o$, respectively.

Let $Z_A = Z_L + R_1 + jX_1$ and $Y_A = 1/Z_A$. Since $Y_A + G_2 + jB_2 = 1$, Y_A must lie on curve $Y = 1 - k(\tan \theta - j)$, where k is a real variable. This curve is circle OA' with center C. To locate C, lines OC and OD are drawn as indicated in Fig. 9-20. Point D bisects its line. Point C is located as indicated.

Point C is inverted to obtain C' on line OC so that $C'O = OC$. Since Y_A must lie on circle OA', Z_A must lie on circle OH whose center is C'. To determine Z_A, plot curve $Z = Z_L + p(\tan \theta + j)$, where p is a real variable. Point A, where this curve intersects circle OH, is the desired value of Z_A. The value of Y_A is found by inverting point A to obtain A'. Finally, $R_1 + jX_1 = (Z_A - Z_L)R_o = (0.498 - j0.610) - (0.3 - j1.6)R_o = (0.198 + j0.990)R_o$ and $G_2 + jB_2 = (1 - Y_A)G_o = 1 - (0.803 + j0.985)G_o = (0.197 - j0.985)G_o$.

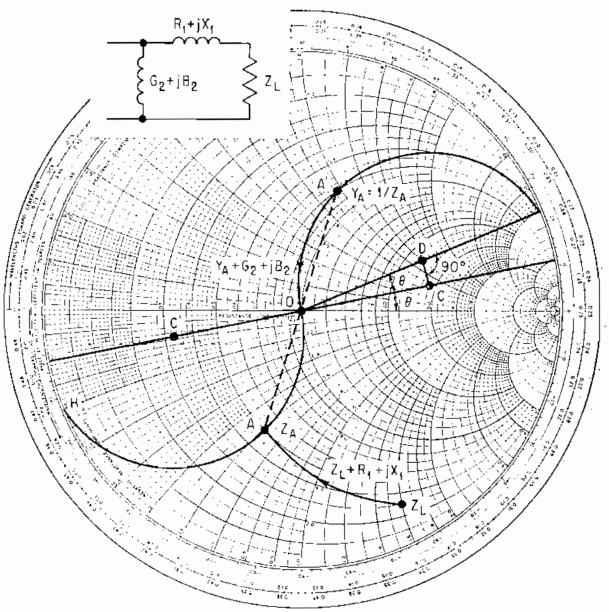


FIG. 9-21. Smith-chart procedure for determining parameters of L matching network.

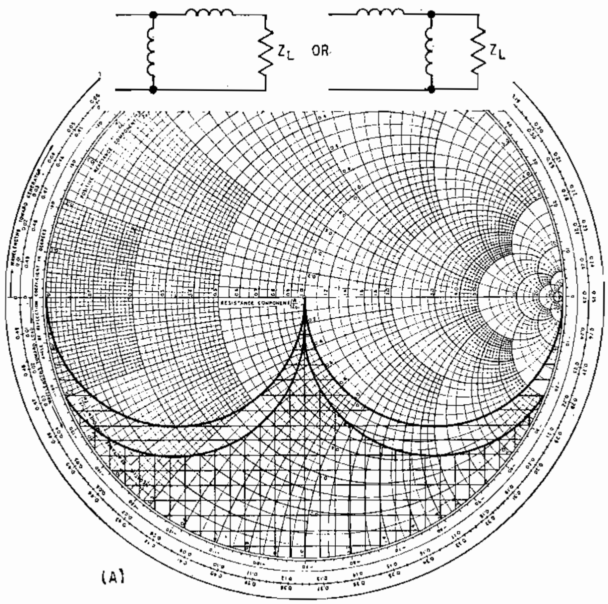
General Procedure. In general, for L matching networks plot Z_L or Y_L first on the Smith chart. Next, plot the impedance or admittance into which Z_L is to be transformed, and find a suitable path connecting these points.

It is impossible to match all possible values of Z_L with a given type of L network. For example, if $Z_L = 0.5R_o$, the matching network shown in Fig. 9-21 could not be used. Impedances which can be matched with a given type of L network are shown as areas on Smith charts in Fig. 9-22. It is assumed that it is desired to transform Z_L into R_o and that Z_L is normalized with respect to R_o.

Bibliography

Smith, P. H.: Transmission-line Calculator, *Electronics*, January, 1939, p. 29.

Smith, P. H.: An Improved Transmission-line Calculator, *Electronics*, January, 1944, p. 130.



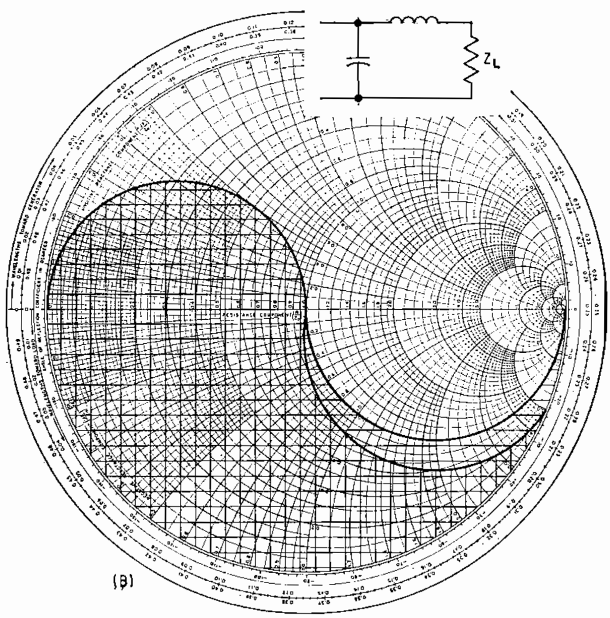
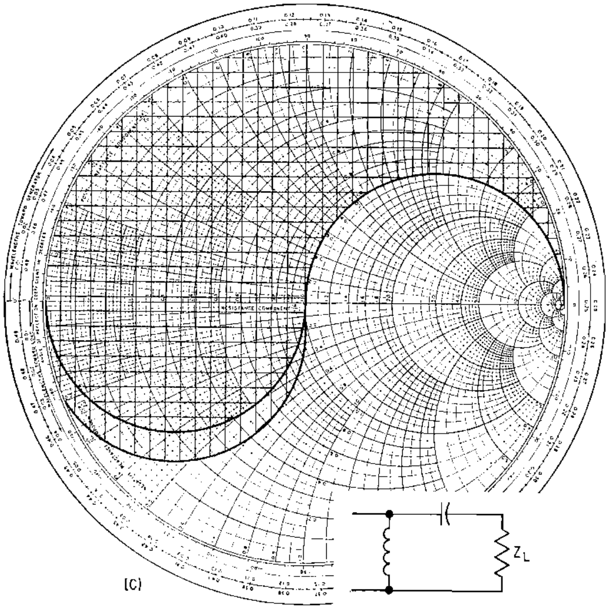
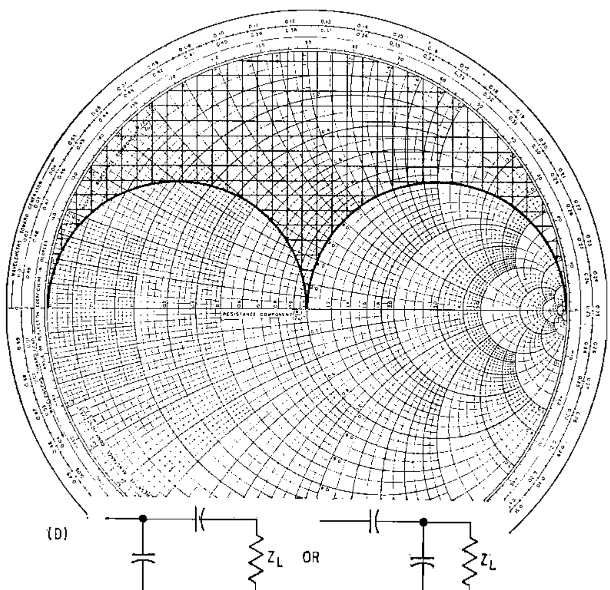


Fig. 9-22. For each network, horizontally shaded areas on the accompanying Smith chart show impedances which can be matched with lossless reactance. Vertically shaded areas can be matched with reactances for which tan θ = 0.2.



(C)



(D)

Fig. 9-22. (*Continued on next page.*)

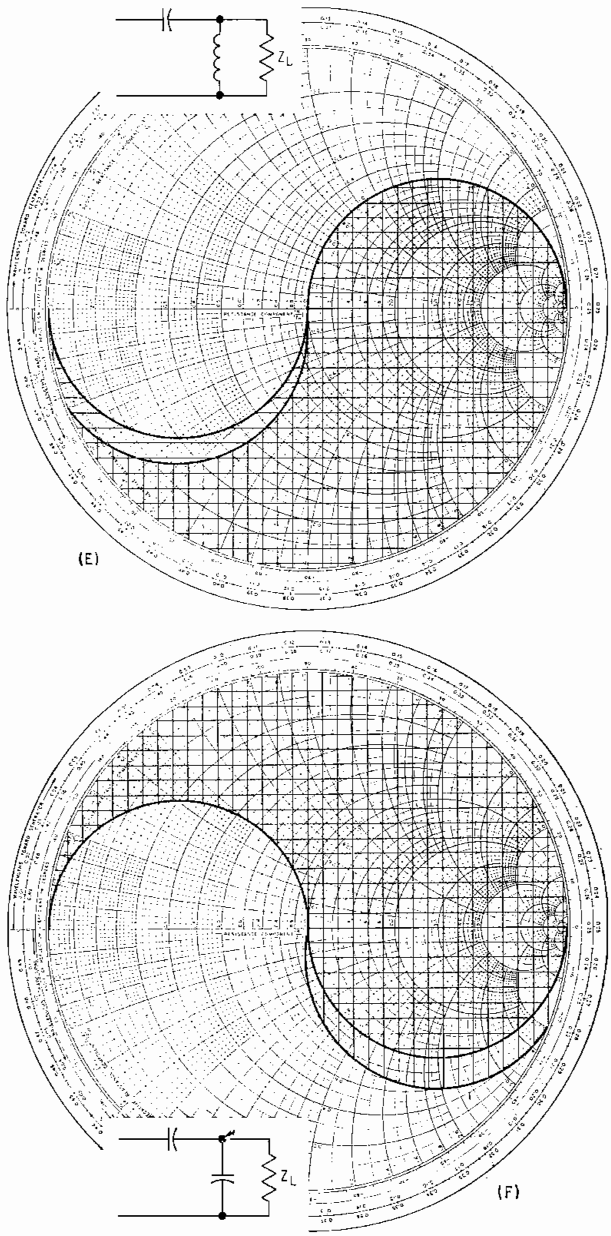


FIG. 9-22. (*Continued.*)

Table 9-4. Comparison of Open-wire Solid-dielectric Lines and Waveguides

Characteristics	Parallel open wires	Bead supported	Stub supported	Solid dielectric (Polyethylene)	Coaxial rubber	Waveguide	Pulse cables
Insulation resistance	O.K. in dry air, drops in rain	O.K. in dry air or nitrogen	O.K. dry or slightly wet	O.K. dry or wet	O.K. dry, drops when wet. Varies with temperature	O.K.	Same as rubber
Corona voltage and dielectric strength	Depends on dry air and spacing, low	Depends on dry air, depends on size, low	Depends on size, low	Depends on size, high	Depends on dry air, size, medium high	Depends on size, dry air, pressure, low	Depends on size, dry air, high
Dielectric constant	Low, air (1)	Low, air plus beads (1+)	Low, air (1)	Medium (2.3)	Medium high (3–4)	....	High (5–6)
Power factor	Low in dry air, goes up in wet	Low in dry air, goes up in wet	O.K. dry or slightly wet	O.K. dry or wet	High dry, higher wet. No good for HF	....	Same as rubber
D-c conductor resistance	Low, goes down with size	Same	Same	Higher than concentrics, goes down with size	High, goes down with size	Low, goes down with size	High, goes down with size
Ease of installation	Easy	More difficult	Difficult	Easier than concentric	Same as solid dielectric	Same as bead-supported	Same as rubber
Ease of maintenance	Easy	Very difficult	Not very	Easy	do	Easy	
Flexible	Somewhat, depends on size	Some, depends on size	No	Yes, flexibility goes down with size	Yes, more than solid dielectric	No	Same as rubber
Mechanically strong	Yes, but separators are weak points	Yes, beads are weak points	Yes, but stubs are fragile	Yes, but can be mistreated	Yes	Yes, but can be crushed	Yes
Can be sealed	Yes	Yes, but you have to do the right job	Yes	Yes	Yes	Yes	Yes
Self-shielding (electrical)	No	Yes	Yes	Yes, depends on the braid construction	Same as solid dielectric	Yes	Same as solid dielectric
Fire resistive	Yes	Yes	Yes	Yes, except largest size	Not completely	Yes	Same as rubber
High-temperature resistant	Yes, depends on material of separators	Yes, depends on rubber gaskets or solder	Yes, same as bead supported	180–200°F for short time	220–250°F for short time	Yes, depends on rubber gasket or solder	Same as rubber
Transmission at high frequency	Limited by spacing	Good at low, medium frequency losses high at microwave	Good at high frequency not at low, need spec for each	Good, at low and medium not so good at microwave	Poor, loss too high	Best, but each frequency needs spec guide	Poor, loss too high
Stand shock vibration	Good	Fair, beads are weak points	Good, stubs are weak points	Very good	Very good	Very good	Very good
Low temperatures	Yes	Yes, but allow for expansion	Same as beaded	Yes	Yes	Yes, but allow for expansion	Yes

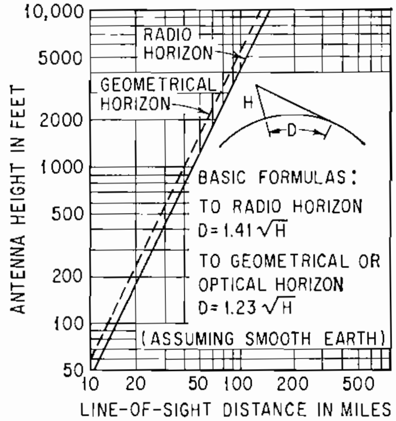


FIG. 9-23. Distance to horizon vs. height of transmitting antenna.

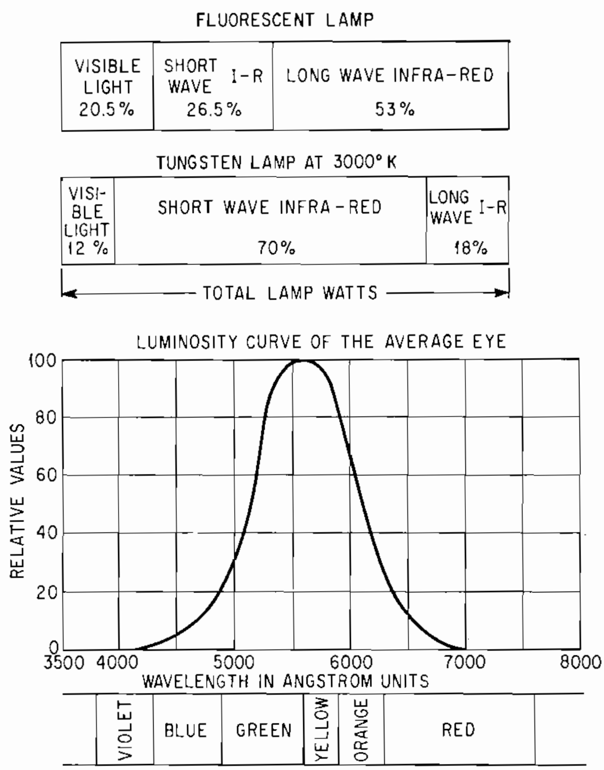


FIG. 9-24. Fluorescent and tungsten lamp spectral distribution and luminosity curve of the average human eye.

HEATER SURGE CHART *

Summary: The effect of heater current surges when voltage is applied to cold tube and efficiency of surge-restricting arrangements can be evaluated with this chart. Hot and cold characteristic curves are typical for most tubes.

To minimize damaging effects of high initial current when heater voltage is applied to a cold tube, starting current surges should be restricted.

The magnitude of heater current surges under various conditions can be calculated by use of the graph (Fig. 9-25), which consists basically of two curves plotted on coordinates of heater current and voltage relative to normal full-voltage conditions. The first curve, a straight line, represents the resistance of a cold heater. It represents a resistance which is 0.15 of the normal operating resistance. This is typical of most receiving tubes. The second curve shows the locus of points at which thermal equilibrium is obtained for steadily applied voltages. Deviations from this curve are relatively small for common receiving-type tubes.

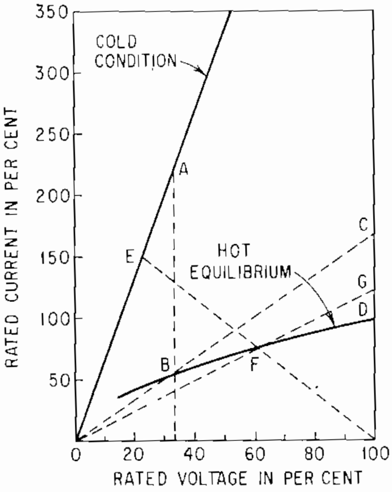


FIG. 9-25. Current-voltage plot for hot and cold tube conditions used to evaluate surge.

The results of applying heater voltage in steps can be shown by simple constructions. If a line is constructed at a chosen value of initial voltage, the magnitude of the initial cold-resistance surge is shown by point *A* and thermal equilibrium occurs at point *B*. A line through the origin and point *B* represents the heater resistance attained in the partially heated equilibrium condition. If 100 per cent voltage is then applied, a current surge of magnitude indicated by point *C* occurs, and final equilibrium is attained at the normal operating point *D*.

The effect of applying 100 per cent rated voltage through a series resistor can be shown by the construction of a line having a slope based on the ratio of the series resistance to the normal hot resistance of the tube. The cold-tube surge is indicated by point *E*, and equilibrium occurs at *F*. Construction of a line from the origin through point *F* then represents this equilibrium heater resistance. If the resistor is then shorted out, 100 per cent voltage will be applied and will result in a momentary current indicated by point *G*. Final equilibrium will occur at the normal operating point *D*.

* By M. P. Feyerherm, Defense Electronic Products, Radio Corporation of America, Camden, N.J. Reprinted from *Electronics*, June 1, 1957.

A CONVENIENT SLIDE-RULE SHORT CUT TO CONVERT ELECTRICAL DEGREES TO FEET, OR VICE VERSA WHEN FREQUENCY AND EITHER FEET OR DEGREES IS KNOWN

From the expression

$$\text{Feet} = \frac{\text{degrees}}{360°} \times \frac{300}{f(\text{Mc})} \times 3.281 = \text{degrees} \times \frac{2.734}{f(\text{Mc})}$$

the following ratio may be set up on the slide rule using *C* and *D* scales:

$$\frac{2.734}{f(\text{Mc})} = \frac{\text{feet}}{\text{degrees}}$$

Set 2.734 on scale *C* over frequency in megacycles on scale *D*; read feet and degrees on scales *C* and *D*, respectively. In some instances it may be convenient to use the folded scales *CF* and *DF*.

GREAT-CIRCLE DISTANCE AND BEARING CALCULATIONS

The need often arises in allocations problems for a simple and reliable method of computing the position of one radio station or area with respect to another expressed in degrees clockwise from true north. It is often equally important that the distance between these two points be known.

Bearings and distance can be computed in many ways. The method set forth here utilizes a table developed by Lieutenant Arthur A. Ageton, USN, which permits the simple solution of navigational problems. If the table is properly read and interpolations carefully made, the bearings and distances derived through use of the calculation sheet will be found to be in very close agreement with lengthy mathematical computations.

To use this method one must first obtain Hydrographic Office Publication No. 211, entitled "Dead Reckoning Altitude and Azimuth Table" from the Hydrographic Office, Washington, D.C., or the Superintendent of Documents, Government Printing Office, Washington, D.C.

The calculation sheet can be shortened in some respects if used only for determining bearings and distances between points within a limited area such as the United States or North America. As shown, bearings and distances can be calculated between any two points on the surface of the earth if the latitude and longitude of the two positions are known.

If a considerable number of calculatious are to be made, it is suggested that the calculation sheet be duplicated in quantity. Furthermore, it is suggested that until one becomes thoroughly acquainted with the method the various *steps* be check-marked as they are completed.

Great Circle Distance and Bearing Calculation Sheet

(Based on Ageton, *H.O. Publ.* 211, Tables)

FROM: Location ______________ (La) ___°___′___″ (Lo) ___°___′___″
TO: Location ______________ (La′) ___°___′___″ (Lo′) ___°___′___″

Symbols Used

- *A* Numbers in the *A* columns of the H.O. 211 tables
- *B* Numbers in the *B* columns of the H.O. 211 tables
- *t* (*Lo* ∼ *Lo′*) The smaller angle between the two meridians, *Lo* and *Lo′*
- *C* Bearing East or West of 0° true
- *D* Great-circle distance when converted to minutes of arc
- *K* An arc used in the calculations
- *Dn* The great-circle distance in nautical miles
- *Ds* The great-circle distance in statute miles
- (*K* ∼ *La*) The magnitude of the difference between arc *K* and *La*

Rules

If *La* and *La′* are in the same hemisphere: (N or *S*)

- *K*: Take *K* from bottom of columns in H.O. No. 211 tables if *t* is greater than 90°.
- *D*: Take *D* from bottom of columns in H.O. No. 211 when *t* and (*K* ∼ *La*) are each greater than 90°.
- *C*: Take *C* from bottom of columns in H.O. No. 211 when *K* is less than *La*.
- (*K* ∼ *La*): Subtract *K* and *La* to find difference.

If *La* and *La′* are in different hemispheres: (N and *S*)

- *K*: Take *K* from bottom of columns in H.O. No. 211 tables if *t* is greater than 90°.
- *D*: If *t* and (*K* ∼ *La*) are each less than 90°, take *D* from top of table, *otherwise*, from *bottom*.
- *C*: Take *C* from bottom of tables in H.O. No. 211 tables unless (*K* ∼ *La*) is greater than 180°.
- (*K* ∼ *La*): Add *K* and *La* to find magnitude. If (*K* ∼ *La*) exceeds 180°, subtract 180° before entering H.O. No. 211 table to find *B*3.

Calculations

[Follow rules closely for *K*, *D*, *C*, and *B*3—also (*K* ∼ *La*)]

	ADD	SUBTRACT	ADD	SUBTRACT
Lo′ ______	*A*1 ______	*A*3 ______	*B*2 ______	*A*2 ______
Lo ______	*B*1+ ______	*B*2− ______	*B*3+ ______	*A*5− ______
t = ______	*A*2 = ______	*A*4 = ______	*B*4 = ______	*A*6 = ______
La′ ______				
K = ______				
La ______				
(*K* ∼ *La*) = ______				

D = ______°______′______″
D: ______° × 60 = ______ + ______′ = *Dn* ______ miles
Dn ______ miles × 1.152 = *Ds* ______ miles

*C** = ______°______′______″ E/W of 0° true

* Note: When *Lo′* is *west* of *Lo*, *C* will indicate bearings in degrees *west* of 0° true. When *Lo′* is *east* of *Lo*, *C* will indicate bearings in degrees *east* of 0° true.

Steps

1. List coordinates for locations.
2. Subtract *Lo* and *Lo′* to find arc *t*.
3. Enter H.O. No. 211 with *t* to find *A*1.
4. Enter table with *La′* to find *B*1 and *A*3.
5. Add *A*1 and *B*1 for *A*2.
6. Enter table with *A*2 to find *B*2.
7. Subtract *B*2 from *A*3 for *A*4.
8. Enter table with *A*4 for arc *K*.
9. Determine arc for (*K* ∼ *La*).
10. Enter table with (*K* ∼ *La*) for *B*3.
11. Add *B*2 and *B*3 for *B*4.
12. Enter table with *B*4 to find *A*5 and arc *D*.
13. Subtract *A*5 from *A*2 for *A*6.
14. Enter table with *A*6 for bearing *C*.
15. Follow steps shown to find *Ds* and *Dn*.

Table 9-5. Temperature-conversion Chart *

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
−200	−328.0	−100	−148.0	0	32.0	0	32.0	100	212.0	200	392.0	300	572.0	400	752.0	500	932.0	600	1,112.0	700	1,292.0
−201	−329.8	−101	−149.8	−1	30.2	1	33.8	101	213.8	201	393.8	301	573.8	401	753.8	501	933.8	601	1,113.8	701	1,293.8
−202	−331.6	−102	−151.6	−2	28.4	2	35.6	102	215.6	202	395.6	302	575.6	402	755.6	502	935.6	602	1,115.6	702	1,295.6
−203	−333.4	−103	−153.4	−3	26.6	3	37.4	103	217.4	203	397.4	303	577.4	403	757.4	503	937.4	603	1,117.4	703	1,297.4
−204	−335.2	−104	−155.2	−4	24.8	4	39.2	104	219.2	204	399.2	304	579.2	404	759.2	504	939.2	604	1,119.2	704	1,299.2
−205	−337.0	−105	−157.0	−5	23.0	5	41.0	105	221.0	205	401.0	305	581.0	405	761.0	505	941.0	605	1,121.0	705	1,301.0
−206	−338.8	−106	−158.8	−6	21.2	6	42.8	106	222.8	206	402.8	306	582.8	406	762.8	506	942.8	606	1,122.8	706	1,302.8
−207	−340.6	−107	−160.6	−7	19.4	7	44.6	107	224.6	207	404.6	307	584.6	407	764.6	507	944.6	607	1,124.6	707	1,304.6
−208	−342.4	−108	−162.4	−8	17.6	8	46.4	108	226.4	208	406.4	308	586.4	408	766.4	508	946.4	608	1,126.4	708	1,306.4
−209	−344.2	−109	−164.2	−9	15.8	9	48.2	109	228.2	209	408.2	309	588.2	409	768.2	509	948.2	609	1,128.2	709	1,308.2
−210	−346.0	−110	−166.0	−10	14.0	10	50.0	110	230.0	210	410.0	310	590.0	410	770.0	510	950.0	610	1,130.0	710	1,310.0
−211	−347.8	−111	−167.8	−11	12.2	11	51.8	111	231.8	211	411.8	311	591.8	411	771.8	511	951.8	611	1,131.8	711	1,311.8
−212	−349.6	−112	−169.6	−12	10.4	12	53.6	112	233.6	212	413.6	312	593.6	412	773.6	512	953.6	612	1,133.6	712	1,313.6
−213	−351.4	−113	−171.4	−13	8.6	13	55.4	113	235.4	213	415.4	313	595.4	413	775.4	513	955.4	613	1,135.4	713	1,315.4
−214	−353.2	−114	−173.2	−14	6.8	14	57.2	114	237.2	214	417.2	314	597.2	414	777.2	514	957.2	614	1,137.2	714	1,317.2
−215	−355.0	−115	−175.0	−15	5.0	15	59.0	115	239.0	215	419.0	315	599.0	415	779.0	515	959.0	615	1,139.0	715	1,319.0
−216	−356.8	−116	−176.8	−16	3.2	16	60.8	116	240.8	216	420.8	316	600.8	416	780.8	516	960.8	616	1,140.8	716	1,320.8
−217	−358.6	−117	−178.6	−17	1.4	17	62.6	117	242.6	217	422.6	317	602.6	417	782.6	517	962.6	617	1,142.6	717	1,322.6
−218	−360.4	−118	−180.4	−18	−0.4	18	64.4	118	244.4	218	424.4	318	604.4	418	784.4	518	964.4	618	1,144.4	718	1,324.4
−219	−362.2	−119	−182.2	−19	−2.2	19	66.2	119	246.2	219	426.2	319	606.2	419	786.2	519	966.2	619	1,146.2	719	1,326.2
−220	−364.0	−120	−184.0	−20	−4.0	20	68.0	120	248.0	220	428.0	320	608.0	420	788.0	520	968.0	620	1,148.0	720	1,328.0
−221	−365.8	−121	−185.8	−21	−5.8	21	69.8	121	249.8	221	429.8	321	609.8	421	789.8	521	969.8	621	1,149.8	721	1,329.8
−222	−367.6	−122	−187.6	−22	−7.6	22	71.6	122	251.6	222	431.6	322	611.6	422	791.6	522	971.6	622	1,151.6	722	1,331.6
−223	−369.4	−123	−189.4	−23	−9.4	23	73.4	123	253.4	223	433.4	323	613.4	423	793.4	523	973.4	623	1,153.4	723	1,333.4
−224	−371.2	−124	−191.2	−24	−11.2	24	75.2	124	255.2	224	435.2	324	615.2	424	795.2	524	975.2	624	1,155.2	724	1,335.2
−225	−373.0	−125	−193.0	−25	−13.0	25	77.0	125	257.0	225	437.0	325	617.0	425	797.0	525	977.0	625	1,157.0	725	1,337.0
−226	−374.8	−126	−194.8	−26	−14.8	26	78.8	126	258.8	226	438.8	326	618.8	426	798.8	526	978.8	626	1,158.8	726	1,338.8
−227	−376.6	−127	−196.6	−27	−16.6	27	80.6	127	260.6	227	440.6	327	620.6	427	800.6	527	980.6	627	1,160.6	727	1,340.6
−228	−378.4	−128	−198.4	−28	−18.4	28	82.4	128	262.4	228	442.4	328	622.4	428	802.4	528	982.4	628	1,162.4	728	1,342.4
−229	−380.2	−129	−200.2	−29	−20.2	29	84.2	129	264.2	229	444.2	329	624.2	429	804.2	529	984.2	629	1,164.2	729	1,344.2
−230	−382.0	−130	−202.0	−30	−22.0	30	86.0	130	266.0	230	446.0	330	626.0	430	806.0	530	986.0	630	1,166.0	730	1,346.0
−231	−383.8	−131	−203.8	−31	−23.8	31	87.8	131	267.8	231	447.8	331	627.8	431	807.8	531	987.8	631	1,167.8	731	1,347.8
−232	−385.6	−132	−205.6	−32	−25.6	32	89.6	132	269.6	232	449.6	332	629.6	432	809.6	532	989.6	632	1,169.6	732	1,349.6
−233	−387.4	−133	−207.4	−33	−27.4	33	91.4	133	271.4	233	451.4	333	631.4	433	811.4	533	991.4	633	1,171.4	733	1,351.4
−234	−389.2	−134	−209.2	−34	−29.2	34	93.2	134	273.2	234	453.2	334	633.2	434	813.2	534	993.2	634	1,173.2	734	1,353.2

−235	−391.0	−135	−211.0	−35	−31.0	35	95.0	135	275.0	235	455.0	335	635.0	435	815.0	535	995.0	635	1,175.0	735	1,355.0
−236	−392.8	−136	−212.8	−36	−32.8	36	96.8	136	276.8	236	456.8	336	636.8	436	816.8	536	996.8	636	1,176.8	736	1,356.8
−237	−394.6	−137	−214.6	−37	−34.6	37	98.6	137	278.6	237	458.6	337	638.6	437	818.6	537	998.6	637	1,178.6	737	1,358.6
−238	−396.4	−138	−216.4	−38	−36.4	38	100.4	138	280.4	238	460.4	338	640.4	438	820.4	538	1,000.4	638	1,180.4	738	1,360.4
−239	−398.2	−139	−218.2	−39	−38.2	39	102.2	139	282.2	239	462.2	339	642.2	439	822.2	539	1,002.2	639	1,182.2	739	1,362.2
−240	−400.0	−140	−220.0	−40	−40.0	40	104.0	140	284.0	240	464.0	340	644.0	440	824.0	540	1,004.0	640	1,184.0	740	1,364.0
−241	−401.8	−141	−221.8	−41	−41.8	41	105.8	141	285.8	241	465.8	341	645.8	441	825.8	541	1,005.8	641	1,185.8	741	1,365.8
−242	−403.6	−142	−223.6	−42	−43.6	42	107.6	142	287.6	242	467.6	342	647.6	442	827.6	542	1,007.6	642	1,187.6	742	1,367.6
−243	−405.4	−143	−225.4	−43	−45.4	43	109.4	143	289.4	243	469.4	343	649.4	443	829.4	543	1,009.4	643	1,189.4	743	1,369.4
−244	−407.2	−144	−227.2	−44	−47.2	44	111.2	144	291.2	244	471.2	344	651.2	444	831.2	544	1,011.2	644	1,191.2	744	1,371.2
−245	−409.0	−145	−229.0	−45	−49.0	45	113.0	145	293.0	245	473.0	345	653.0	445	833.0	545	1,013.0	645	1,193.0	745	1,373.0
−246	−410.8	−146	−230.8	−46	−50.8	46	114.8	146	294.8	246	474.8	346	654.8	446	834.8	546	1,014.8	646	1,194.8	746	1,374.8
−247	−412.6	−147	−232.6	−47	−52.6	47	116.6	147	296.6	247	476.6	347	656.6	447	836.6	547	1,016.6	647	1,196.6	747	1,376.6
−248	−414.4	−148	−234.4	−48	−54.4	48	118.4	148	298.4	248	478.4	348	658.4	448	838.4	548	1,018.4	648	1,198.4	748	1,378.4
−249	−416.2	−149	−236.2	−49	−56.2	49	120.2	149	300.2	249	480.2	349	660.2	449	840.2	549	1,020.2	649	1,200.2	749	1,380.2
−250	−418.0	−150	−238.0	−50	−58.0	50	122.0	150	302.0	250	482.0	350	662.0	450	842.0	550	1,022.0	650	1,202.0	750	1,382.0
−251	−419.8	−151	−239.8	−51	−59.8	51	123.8	151	303.8	251	483.8	351	663.8	451	843.8	551	1,023.8	651	1,203.8	751	1,383.8
−252	−421.6	−152	−241.6	−52	−61.6	52	125.6	152	305.6	252	485.6	352	665.6	452	845.6	552	1,025.6	652	1,205.6	752	1,385.6
−253	−423.4	−153	−243.4	−53	−63.4	53	127.4	153	307.4	253	487.4	353	667.4	453	847.4	553	1,027.4	653	1,207.4	753	1,387.4
−254	−425.2	−154	−245.2	−54	−65.2	54	129.2	154	309.2	254	489.2	354	669.2	454	849.2	554	1,029.2	654	1,209.2	754	1,389.2
−255	−427.0	−155	−247.0	−55	−67.0	55	131.0	155	311.0	255	491.0	355	671.0	455	851.0	555	1,031.0	655	1,211.0	755	1,391.0
−256	−428.8	−156	−248.8	−56	−68.8	56	132.8	156	312.8	256	492.8	356	672.8	456	852.8	556	1,032.8	656	1,212.8	756	1,392.8
−257	−430.6	−157	−250.6	−57	−70.6	57	134.6	157	314.6	257	494.6	357	674.6	457	854.6	557	1,034.6	657	1,214.6	757	1,394.6
−258	−432.4	−158	−252.4	−58	−72.4	58	136.4	158	316.4	258	496.4	358	676.4	458	856.4	558	1,036.4	658	1,216.4	758	1,396.4
−259	−434.2	−159	−254.2	−59	−74.2	59	138.2	159	318.2	259	498.2	359	678.2	459	858.2	559	1,038.2	659	1,218.2	759	1,398.2
−260	−436.0	−160	−256.0	−60	−76.0	60	140.0	160	320.0	260	500.0	360	680.0	460	860.0	560	1,040.0	660	1,220.0	760	1,400.0
−261	−437.8	−161	−257.8	−61	−77.8	61	141.8	161	321.8	261	501.8	361	681.8	461	861.8	561	1,041.8	661	1,221.8	761	1,401.8
−262	−439.6	−162	−259.6	−62	−79.6	62	143.6	162	323.6	262	503.6	362	683.6	462	863.6	562	1,043.6	662	1,223.6	762	1,403.6
−263	−441.4	−163	−261.4	−63	−81.4	63	145.4	163	325.4	263	505.4	363	685.4	463	865.4	563	1,045.4	663	1,225.4	763	1,405.4
−264	−443.2	−164	−263.2	−64	−83.2	64	147.2	164	327.2	264	507.2	364	687.2	464	867.2	564	1,047.2	664	1,227.2	764	1,407.2
−265	−445.0	−165	−265.0	−65	−85.0	65	149.0	165	329.0	265	509.0	365	689.0	465	869.0	565	1,049.0	665	1,229.0	765	1,409.0
−266	−446.8	−166	−266.8	−66	−86.8	66	150.8	166	330.8	266	510.8	366	690.8	466	870.8	566	1,050.8	666	1,230.8	766	1,410.8
−267	−448.6	−167	−268.6	−67	−88.6	67	152.6	167	332.6	267	512.6	367	692.6	467	872.6	567	1,052.6	667	1,232.6	767	1,412.6
−268	−450.4	−168	−270.4	−68	−90.4	68	154.4	168	334.4	268	514.4	368	694.4	468	874.4	568	1,054.4	668	1,234.4	768	1,414.4
−269	−452.2	−169	−272.2	−69	−92.2	69	156.2	169	336.2	269	516.2	369	696.2	469	876.2	569	1,056.2	669	1,236.2	769	1,416.2
−270	−454.0	−170	−274.0	−70	−94.0	70	158.0	170	338.0	270	518.0	370	698.0	470	878.0	570	1,058.0	670	1,238.0	770	1,418.0
−271	−455.8	−171	−275.8	−71	−95.8	71	159.8	171	339.8	271	519.8	371	699.8	471	879.8	571	1,059.8	671	1,239.8	771	1,419.8
−272	−457.6	−172	−277.6	−72	−97.6	72	161.6	172	341.6	272	521.6	372	701.6	472	881.6	572	1,061.6	672	1,241.6	772	1,421.6
−273	−459.4	−173	−279.4	−73	−99.4	73	163.4	173	343.4	273	523.4	373	703.4	473	883.4	573	1,063.4	673	1,243.4	773	1,423.4
−273.2	−459.7	−174	−281.2	−74	−101.2	74	165.2	174	345.2	274	525.2	374	705.2	474	885.2	574	1,065.2	674	1,245.2	774	1,425.2

Absolute zero.

Table 9-5. Temperature-conversion Chart * (*Continued*)

°C °F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Absolute Zero	−175	−283.0	−75	−103.0	75	167.0	175	347.0	275	527.0	375	707.0	475	887.0	575	1,067.0	675	1,247.0	775	1,427.0
	−176	−284.8	−76	−104.8	76	168.8	176	348.8	276	528.8	376	708.8	476	888.8	576	1,068.8	676	1,248.8	776	1,428.8
	−177	−286.6	−77	−106.6	77	170.6	177	350.6	277	530.6	377	710.6	477	890.6	577	1,070.6	677	1,250.6	777	1,430.6
	−178	−288.4	−78	−108.4	78	172.4	178	352.4	278	532.4	378	712.4	478	892.4	578	1,072.4	678	1,252.4	778	1,432.4
	−179	−290.2	−79	−110.2	79	174.2	179	354.2	279	534.2	379	714.2	479	894.2	579	1,074.2	679	1,254.2	779	1,434.2
	−180	−292.0	−80	−112.0	80	176.0	180	356.0	280	536.0	380	716.0	480	896.0	580	1,076.0	680	1,256.0	780	1,436.0
Formulas:	−181	−293.8	−81	−113.8	81	177.8	181	357.8	281	537.8	381	717.8	481	897.8	581	1,077.8	681	1,257.8	781	1,437.8
	−182	−295.6	−82	−115.6	82	179.6	182	359.6	282	539.6	382	719.6	482	899.6	582	1,079.6	682	1,259.6	782	1,439.6
	−183	−297.4	−83	−117.4	83	181.4	183	361.4	283	541.4	383	721.4	483	901.4	583	1,081.4	683	1,261.4	783	1,441.4
$C = \frac{5}{9}(F - 32)$	−184	−299.2	−84	−119.2	84	183.2	184	363.2	284	543.2	384	723.2	484	903.2	584	1,083.2	684	1,263.2	784	1,443.2
	−185	−301.0	−85	−121.0	85	185.0	185	365.0	285	545.0	385	725.0	485	905.0	585	1,085.0	685	1,265.0	785	1,445.0
$F = \frac{9}{5}C + 32$	−186	−302.8	−86	−122.8	86	186.8	186	366.8	286	546.8	386	726.8	486	906.8	586	1,086.8	686	1,266.8	786	1,446.8
	−187	−304.6	−87	−124.6	87	188.6	187	368.6	287	548.6	387	728.6	487	908.6	587	1,088.6	687	1,268.6	787	1,448.6
	−188	−306.4	−88	−126.4	88	190.4	188	370.4	288	550.4	388	730.4	488	910.4	588	1,090.4	688	1,270.4	788	1,450.4
	−189	−308.2	−89	−128.2	89	192.2	189	372.2	289	552.2	389	732.2	489	912.2	589	1,092.2	689	1,272.2	789	1,452.2
	−190	−310.0	−90	−130.0	90	194.0	190	374.0	290	554.0	390	734.0	490	914.0	590	1,094.0	690	1,274.0	790	1,454.0
	−191	−311.8	−91	−131.8	91	195.8	191	375.8	291	555.8	391	735.8	491	915.8	591	1,095.8	691	1,275.8	791	1,455.8
	−192	−313.6	−92	−133.6	92	197.6	192	377.6	292	557.6	392	737.6	492	917.6	592	1,097.6	692	1,277.6	792	1,457.6
	−193	−315.4	−93	−135.4	93	199.4	193	379.4	293	559.4	393	739.4	493	919.4	593	1,099.4	693	1,279.4	793	1,459.4
	−194	−317.2	−94	−137.2	94	201.2	194	381.2	294	561.2	394	741.2	494	921.2	594	1,101.2	694	1,281.2	794	1,461.2
	−195	−319.0	−95	−139.0	95	203.0	195	383.0	295	563.0	395	743.0	495	923.0	595	1,103.0	695	1,283.0	795	1,463.0
	−196	−320.8	−96	−140.8	96	204.8	196	384.8	296	564.8	396	744.8	496	924.8	596	1,104.8	696	1,284.8	796	1,464.8
	−197	−322.6	−97	−142.6	97	206.6	197	386.6	297	566.6	397	746.6	497	926.6	597	1,106.6	697	1,286.6	797	1,466.6
	−198	−324.4	−98	−144.4	98	208.4	198	388.4	298	568.4	398	748.4	498	928.4	598	1,108.4	698	1,288.4	798	1,468.4
	−199	−326.2	−99	−146.2	99	210.2	199	390.2	299	570.2	399	750.2	499	930.2	599	1,110.2	699	1,290.2	799	1,470.2

* Reprinted from *Electronics*, May 1, 1957.

Table 9-6. Conversion Table for Units of Length

MULTIPLY NUMBER OF → BY TO OBTAIN NUMBER OF ↓	ANGSTROMS	MICRONS	MILS	INCHES	FEET	MILES	MILLIMETERS	CENTIMETERS	KILOMETERS
ANGSTROMS	1	10^4	2.540×10^5	2.540×10^8	3.048×10^9	1.609×10^{13}	10^7	10^8	10^{13}
MICRONS	10^{-4}	1	2.540×10	2.540×10^4	3.048×10^5	1.609×10^9	10^3	10^4	10^9
MILS	3.937×10^{-6}	3.937×10^{-2}	1	10^3	1.2×10^4	6.336×10^7	3.937×10	3.937×10^2	3.937×10^7
INCHES	3.937×10^{-9}	3.937×10^{-5}	10^{-3}	1	12	6.336×10^4	3.937×10^{-2}	3.937×10^{-1}	3.937×10^4
FEET	3.281×10^{-10}	3.281×10^{-6}	8.333×10^{-5}	8.333×10^{-2}	1	5.280×10^3	3.281×10^{-3}	3.281×10^{-2}	3.281×10^3
MILES	6.214×10^{-14}	6.214×10^{-10}	1.578×10^{-8}	1.578×10^{-5}	1.894×10^{-4}	1	6.214×10^{-7}	6.214×10^{-6}	6.214×10^{-1}
MILLIMETERS	10^{-7}	10^{-3}	2.540×10^{-2}	2.540×10	3.048×10^2	1.609×10^6	1	10	10^6
CENTIMETERS	10^{-8}	10^{-4}	2.540×10^{-3}	2.540	3.048×10	1.609×10^5	0.1	1	10^5
KILOMETERS	10^{-13}	10^{-9}	2.540×10^{-8}	2.540×10^{-5}	3.048×10^{-4}	1.609	10^{-6}	10^{-5}	1

TRANSISTOR CHARACTERISTICS FOR CIRCUIT DESIGNERS [*]

Summary: Tables indicate physical properties, maximum electrical ratings, small-signal low-frequency parameters, and average characteristics for grounded-base, grounded-emitter, grounded-collector, and switching circuits for 218 transistor types: 106 junction triodes, 46 high-frequency triodes, 6 tetrodes, 23 high-power units, 25 point-contact, and 12 phototransistors.

Abbreviations Used in Tables

α	Current gain	I_e	Emitter current
β	Base-current amplification factor	I_{eo}	Emitter cutoff current
BW	Bandwidth	NF	Noise figure
C_c	Collector capacitance	r_b	Base resistance
f_{co}	Alpha cutoff frequency	r_c	Collector resistance
g-b	Grounded base	r_e	Emitter resistance
g-c	Grounded collector	R_g	Generator resistance
g-e	Grounded emitter	R_i	Input resistance
I_b	Base current	R_L	Load resistance
I_{b2}	Second base current (tetrode)	R_o	Output resistance
I_c	Collector current	V_c	Collector voltage
I_{co}	Collector cutoff current		

[*] By Seymour Schwartz, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Mass. Reprinted from *Electronics*, January, 1956.

Successful transistor circuit design requires not only familiarity with transistor equivalent circuits and characteristic curves but also an understanding of the behavior of the parameters describing the transistor and the variation of these parameters with bias and temperature. Tables 9-7 to 9-12 have been compiled as a systematic presentation of data necessary for transistor circuit design.

Each of the charts presents physical properties; maximum electrical ratings; typical small-signal low-frequency parameters; average characteristics for grounded-emitter, grounded-base, and grounded-collector circuits; and switching characteristics. Figure 9-27 illustrates the circuits referenced in Tables 9-8 and 9-9.

Small-signal parameters are expressed as resistances. This permits a familiar physical representation of the transistor in circuit design. The box on page 9-50 enables transformation between h and r parameters.

All the characteristics are for fixed-bias conditions. However, these values vary with operating conditions. Examples of these variations are shown in Fig. 9-26*a* to *c*.

Figure 9-26*a* illustrates how collector capacitance C_c varies with colleetor voltage V_c. In designing an IF tuned circuit, the tuning capacitor must be large enough to swamp out the effects of the variation of collector capacitance. If the IF stage is a grounded-emitter rather than a grounded-base stage, the collector capacitance is magnified by the base-current amplification factor β.

In IF stages where neutralization is used to maximize gain by balancing out C_c, instability may occur when the battery voltage decreases. This variation of C_c with V_c permits use of the transistor as a reactance element in FM applications.

At low current bias (Fig. 9-26*b* to *d*) the noise factor of the transistor decreases and emitter resistance r_e, base resistance r_b, and collector resistance r_c increase, providing increased power gain and larger values of input and output impedance. This is advantageous in hearing aids where low bias currents are used.

Temperature Effects

In the germanium transistor, noticeable chauges in α, β, and I_{co} take place at approximately 60°C as shown in Fig. 9-26*e*. These changes can lead to instability at high temperatures by α becoming equal to or greater than unity or by I_{co} increasing and causing a collector runaway effect due to self-heating.

Temperature problems are minimized in silicon transistors as seen in Fig. 9-26*f*. The value I_{co} becomes almost negligible in design consideration as the upper limit or temperature range is above 100°C. In such special applications as d-c amplifiers, the slightest change in α over the normal temperature operating range can produce a significant change in d-c gain of the grounded-emitter stage.

The low-frequency low-power triode junction transistor, Table 9-7, is most commonly used. The majority are utilized in hearing aids, audio systems, low-power control systems, and low-speed computing circuits. Present units are available in the *p-n-p* and *n-p-n* fused germanium, the *n-p-n* grown silicon types. Of the fused type of transistor, the *p-n-p* is more available commercially and consequently has found a wider range of applications. The *n-p-n* fused type is suitable for complementary symmetry circuitry. The grown silicon type is used for high-temperature and low-I_{co} applications.

The germanium and silicon grown transistors are used in almost the same manner as the fused transistor. Freqnently, the grown types, owing to their lower value of collector capacitance and higher value of a cutoff, can be employed as high-frequency transistors.

The maximum power ratings on most of the low-power transistors are of the order of 50-mw collector dissipation at room temperature. Some of these uuits have external heat sinks and are able to dissipate considerably more power.

The rating most commonly employed is the maximum power rating. Maximum current and maximum voltage ratings cannot be achieved simultaneously because the product of these two ratings usually exceeds maximum rating. The maximum voltage rating is set at a value safely below the collector voltage breakdown value while the maximum current is selected where β has not decreased to too low a value.

Table 9-8, high-frequency transistors, includes *p-n-p* and *n-p-n* fused junction, *n-p-n* grown junction, and *p-n-p* surface-barrier units. Except for the *n-p-n* grown type, which is of either germanium or silicon, all these units use germanium.

Physically, one of the main distinctions between these units and the low-frequency units is the closer spacing between emitter and collector junctions. Electrical characteristics are higher α cutoff, lower collector voltage breakdown, and in many units lower collector capacitance and lower base resistance. The widest application is in radio receivers and high-speed switching circuits.

In selecting a high-frequency transistor for a grounded-emitter IF amplifier, note that the β-cutoff frequency of the amplifier is equal to a cutoff frequency divided by β.

Table 9-9 lists tetrode junction transistors which are high-frequency triode *n-p-n* grown junction transistors with an extra base lead and a narrower base region. The electrical characteristics of the grown tetrode transistor are almost identical to the grown triode transistor except for a lower value of base resistance and higher value of α-cutoff frequency. The extra base lead makes the tetrode applicable in specialized control circuits and AVC applications. Bias for the extra base lead is usually obtained from a bleeder across the main supply.

High-power Units

The high-power transistor, Table 9-10, is in most cases the largest of all transistors. One element is attached to the container. In most units the case can be connected to the chassis either directly or through a thin mica spacer. The types used as power transistors are the germanium *p-n-p* fused and silicon *n-p-n* grown.

The *p-n-p* fused transistors are usually the high-power units whose larger physical size provides collector power dissipation up to 20 watts. The larger physical size also contributes a high collector capacitance and lower α-cutoff frequency. Medium-power *p-n-p* and *n-p-n* fused units which retain their smaller physical size and most of the electrical characteristics of the low-power transistors are used in applications requiring collector power dissipation below ½ watt.

The characteristics peculiar to the high-power transistor are the lower values of input resistance, output resistance, and α, resulting from the higher values of bias currents employed. Bias stability techniques are used to minimize the effect of runaway due to self-heating of the collector.

The point-contact transistor, Table 9-11, is limited to high-speed switching circuitry. Phototransistor devices, Table 9-12, are divided into two basic types: the two-lead and three-lead devices. In the two-lead unit, one lead is attached to the base and the other to the collector. The three-lead device has leads going to the emitter, base, and collector, respectively.

The two-lead device is used in circuits providing d-c amplification for unmodulated light, while the three-lead device can be used in circuits employing a-c amplification for modulated light.

Acknowledgment is given to Ann M. Field and Elizabeth A. Sewell for their assistance in compiling these data.

Table 9-7. Junction-triode

Manufacturer	Type No.	Type	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max ambient temp, °C	Small-signal low- Bias V_c, volts	I_e, ma	β	r_e, ohms
Amperex Electronic Corp.	OC70	p-n-p fused [a]	25 (45°C)	−10	−10	45	−2	0.5	30	39
230 Duffy Ave., Hicksville, N.Y.	OC71	p-n-p fused [a]	25 (45°C)	−10	−10	45	−2	3	47	6.5
CBS-Hytron	2N36	p-n-p fused	50	−20	−8	50	−6	1	45	30
Danvers, Mass.	2N37	p-n-p fused	50	−20	−8	50	−6	1	30	30
	2N38	p-n-p fused	50	−20	−8	50	−6	1	15	25
	HA-1	p-n-p fused	50	−20	−8	50	−3	0.5	40	24
	HA-2	p-n-p fused	50	−20	−8	50	−3	0.5	30	35
	HA-3	p-n-p fused	50	−20	−8	50	−3	0.5	35	30
	HC-1	p-n-p fused	50	−20	−8	50	−6	1	45	30
Germanium Prod. Corp.	NPN-3/ 2N103	n-p-n grown	50 (25°C)	35	10	75	4.5	−1	4	25
26 Cornelison Ave., Jersey City, N.J.	RD2517A/ 2N97	n-p-n grown	50 (25°C)	30	10	75	4.5	−1	13.3	25
	RD2518A/ 2N97A	n-p-n grown	50 (25°C)	40	10	85	4.5	−1	13.3	25
	RD2521A/ 2N98	n-p-n grown	50 (25°C)	40	10	75	4.5	−1	40	25
	RD2522A/ 2N98A	n-p-n grown	50 (25°C)	40	10	85	4.5	−1	40	25
	RD2523A/ 2N99	n-p-n grown	50 (25°C)	40	10	75	4.5	−1	40	25
	RD2525A/ 2N100	n-p-n grown	25 (25°C)	25	5	50	4.5	−1	140	25
General Electric Co.	2N43	p-n-p fused	150 (25°C)	−45 [e]	−50	100	−5	1	49	32
Electronics Park	2N44	p-n-p fused	150 (25°C)	−45 [e]	−50	100	−5	1	21.2	26.5
Syracuse, N.Y.	2N45	p-n-p fused	150 (25°C)	−45 [e]	−50	100	−5	1	11.5	20
	2N43A	p-n-p fused	150 (25°C)	−45 [e]	−50	100	−5	1	43.4	15
	2N43A USAF	p-n-p fused	150 (25°C)	−45	−50	100	−5	1	43.4	15
	2N76	p-n-p fused	50 (25°C)	−20 [e]	−10	60	−5	1	19	17
General Transistor Corp.	GT-14	p-n-p fused	70 (50°C)	−25	.....	85	−4.5	1	28	30
95-18 Sutphin Blvd.	GT-20	p-n-p fused	70 (50°C)	−25	.....	85	......	......	45	30
Jamaica, N.Y.	GT-34	p-n-p fused	70 (50°C)	−25	.....	85	......	......	15	30
	GT-81	p-n-p fused	70 (50°C)	−25	.....	85	......	......	65	30
	GT-83	p-n-p fused	70 (50°C)	−25	.....	85	......	......	45	30
	GT-87	p-n-p fused	70 (50°C)	−25	.....	85	......	......	28	30
	GT-88	p-n-p fused	70 (50°C)	−25	.....	85	......	......	65	30
	2N34	p-n-p fused	70 (50°C)	−25	.....	85	−4.5	1	40	30
	2N36	p-n-p fused	70 (50°C)	−25	.....	85	−4.5	1	45	30
	2N37	p-n-p fused	70 (50°C)	−25	.....	85	−4.5	1	30	30
	2N38	p-n-p fused	70 (50°C)	−25	.....	85	−4.5	1	15	30
	2N39	p-n-p fused	70 (50°C)	−25	.....	85	−4.5	1	45	30
	2N40	p-n-p fused	70 (50°C)	−25	.....	85	−4.5	1	28	30
	2N42	p-n-p fused	70 (50°C)	−25	.....	85	−4.5	1	13	30
Hughes Aircraft Co.	HA5001	n-p-n alloyed	500 (25°C)	30	100	85	5	1	65.6	16.5
Culver City, Calif.	HA5002	n-p-n alloyed	500 (25°C)	20	100	85	5	1	27.5	16
	HA5003	n-p-n alloyed	500 (25°C)	20	100	85	5	1	99	26
Hydro-Aire Inc.	J-1	p-n-p fused	150 (25°C)	−40	−10	50	−6	1	34	30
Burbank, Calif.	J-2	p-n-p fused	150 (25°C)	−40	−10	50	−6	1	15	30
	J-3	p-n-p fused	150 (25°C)	−40	−10	50	−6	1	9	30
	HA-1	p-n-p fused	100 (25°C)	−20	−10	50	−6	1	40	30
	CQ-1	p-n-p fused	150 (25°C)	−40	−10	50	−6	1	9	30
Nat'l Union Electric	2N39	p-n-p fused	47 (25°C)	−27	−12	60	−4.5	1	32.4	.....
350 Scotland Rd.	2N40	p-n-p fused	47 (25°C)	−27	−12	60	−4.5	1	15.7–32.4	.....
Orange, N.J.	2N42	p-n-p fused	47 (25°C)	−18	−12	60	−4.5	1	9	.....
	T34D	p-n-p fused [a]	56 (25°C)	−27	−12	70	−4.5	1	32.4	20
	T34E	p-n-p fused [a]	56 (25°C)	−27	−12	70	−4.5	1	15.7–32.4	20
	T34F	p-n-p fused [a]	56 (25°C)	−18	−12	70	−4.5	1	9	20
Philco Corp.	2N47	p-n-p fused [a]	50 (25°C)	−35	−20	...	−5	1	39	25
4700 Wissahickon Ave., Philadelphia, Pa.	2N49	p-n-p fused [a]	50 (25°C)	−35	−20	...	−5	1	39	25
RCA	2N104	p-n-p fused [b]	110 (25°C)	−30	50	85	−6	1	44	24.5
Harrison, N.J.	2N77	p-n-p fused [a]	35 (25°C)	−25	15	50	−4	0.7	40	36
Raytheon Mfg. Co.	CK721	p-n-p fused [c]	....	−15 [f]	−10	70	−6	1	45	25
55 Chapel St., Newton, Mass.	CK722	p-n-p fused [c]	....	−22 [f]	−10	70	−6	1	22	25
	CK725	p-n-p fused [c]	....	−12 [f]	−10	70	−6	1	90	25
	CK727	p-n-p fused [c]	....	−6 [f]	−10	70	−1.5	0.5	35	50
	2N63	p-n-p fused	....	−22 [f]	−10	85	−6	1	22	25

Low-power Transistors

frequency parameters						Grounded-emitter connection					Grounded-base				Grounded-collector			
r_b, ohms	r_c, megohms	f_{aco}, Mc	C_c, $\mu\mu f$	I_{co}, μa	NF, db	I_b, ma	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db
1,000	1.43	......	..	−8	10													
500	0.625	......	..	−8	10													
450	0.95	0.5	..	....	..	....	.....	30,000	1,000	40								
350	0.55	0.5	..	....	..	....	.....	30,000	1,000	36								
350	0.5	0.5	..	....	..	....	.....	30,000	1,000	32								
700	1.7	......	..	−12	12	....	.....	30,000	1,000	30								
350	0.8	......	..	−12	27	....	.....	30,000	1,000	30								
450	0.6	......	..	....	..	....	.....	1,200	1,000	35								
450	0.95	0.7	..	−12	..	....	.....	30,000	1,000	40								
100	2.0	0.75	20	5	22	0.25	225	100,000 matched		33	45	250,000 matched		30	2,500	500 matched		7
100	3.0	1.0	19	2	20	0.07	400	100,000 matched		38	35	250,000 matched		32	7,000	500 matched		11
100	10.0	1.0	19	2	15	0.07	400	100,000 matched		38	35	250,000 matched		32	7,000	500 matched		11
150	5.0	2.5	14	2	20	0.025	850	100,000 matched		47	35	250,000 matched		35	20,000	500 matched		15
150	10.0	2.5	14	2	15	0.025	850	100,000 matched		47	35	250,000 matched		35	20,000	500 matched		15
150	5.0	3.5	10	2	15	0.025	850	100,000 matched		47	35	250,000 matched		35	20,000	500 matched		15
400	5.0	5.0	14	2	20	0.007	3,500	100,000 matched		53	45	250,000 matched		35	70,000	500 matched		20
400	1.0	1.0	40	−10	22	....	1,000	30,000	600	39	60	50,000	100	28	30,000	600	30,000	15
300	1.0	1.0	40	−10	22	....	700	30,000	600	38	55	50,000	100	28	15,000	600	15,000	12
250	1.0	1.0	40	−10	22	....	450	30,000	600	36	50	50,000	100	28	7,500	600	7,500	11
575	1.43	1.0	40	−5	10	....	1,000	30,000	600	39	60	50,000	100	28	30,000	600	30,000	15
575	1.43	1.0	40	−5	30	....	1,000	30,000	600	39	60	50,000	100	28	30,000	600	30,000	15
300	1.0	1.0	40	−5	18	....	1,000	30,000	600	38	55	50,000	100	28	15,000	600	15,000	12
800	1.5	0.65	..	−10	16													
800	1.5	0.65	..	−10	16													
800	1.5	0.65	..	−10	16													
800	1.5	0.65	..	−10	16													
800	1.5	0.70	..	−10	16													
800	1.5	0.50	..	−10	16													
800	1.5	1.0	..	−10	16													
350	2.0	......	..	−15	24													
850	2.0	......	..	−15	24													
600	2.0	......	..	−15	24													
400	2.0	......	..	−15	24													
850	2.0	......	..	−15	24													
600	2.0	......	..	−15	24													
400	2.0	......	..	−15	24													
900	2	2.5	15	5														
400	1	0.8	..	12	15													
400	1	1.5	..	10	15													
400	1.0	1.0	..	−10	11	....	.....	......	.....	40								
300	0.7	0.5	..	−15	22	....	.....	......	.....	35								
300	0.5	0.5	..	−20	33	....	.....	......	.....	30								
350	0.75	......	..	−10	20													
200	0.5	0.5	..	−20	33													
.....	1–2	......	..	−10	20	....	.....	30,000	500	39								
.....	1–2	......	..	−10	24	....	.....	30,000	500	38								
.....	0.5–2	......	..	−20	28	....	.....	30,000	500	36								
.....	1–2	......	..	−10	20	....	.....	30,000	500	39								
.....	1–2	......	..	−10	24	....	.....	30,000	500	38								
.....	0.5–2	......	..	−20	28	....	.....	30,000	500	36								
600	1.0	1.0	49	−10	15	....	1,000	50,000 matched		42								
600	1.0	1.0	49	−10	12	....	1,000	50,000 matched		42								
750	2.25	0.7	..	−10	12	....	1,200	50,000 matched		43	140	400,000 matched		32.8	500,000	20,000 matched		13.9
560	2.3	0.7	...	−10	9	....	1,350	50,000 matched		42.6	130	400,000 matched		33.2	10,000	300 matched		16.2
700	2.0	......	..	−6	22	....	1,500	20,000 matched		41	70	100,000 matched		31	600,000	20,000 matched		15
250	2.0	......	..	−6	25	....	500	20,000 matched		36	45	100,000 matched		32	200,000	20,000 matched		10
1,500	2.0	......	..	−6	20	....	2,700	20,000 matched		42	110	100,000 matched		30	1,000,000	20,000 matched		16
500	2.0	......	..	−6	12	....	.....	20,000	1,000	36	...	200,000	100	28	540,000	10,000	100,000	14
350	2.0	......	..	−6	25	....	800	20,000 matched		39	50	100,000 matched		32	350,000	20,000 matched		13

Table 9-7. Junction-triode Low-

Manufacturer	Type No.	Type	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max ambient temp, °C	Small-signal low-			
							Bias			
							V_c, volts	I_e, ma	β	r_e, ohms
Raytheon (*Continued*)	2N64	*p-n-p* fused	. . . .	-15^f	−10	85	−6	1	45	25
	2N65	*p-n-p* fused	. . . .	-12^f	−10	85	−6	1	90	25
Sylvania Electric 1740 Broadway New York, N.Y.	2N34	*p-n-p* fused	50 (25°C)	−40	−10	. . .	−6	1	40	26
	2N35	*n-p-n* fused	50 (25°C)	−40	−10	. . .	6	−1	40	26
Texas Instruments 6000 Lemmon Ave. Dallas, Tex.	200	*n-p-n* grown	50 (25°C)	30	5	50	5	−1	9	22
	201	*n-p-n* grown	50 (25°C)	30	5	50	5	−1	19	22
	202	*n-p-n* grown	50 (25°C)	30	5	50	5	−1	49	35
	206S	*n-p-n* grown [a]	50 (25°C)	30	5	50	2.5	−0.5	35	. . . . .
	207S	*n-p-n* grown [a]	50 (25°C)	30	5	50	2.5	−0.5	19	. . . . .
	208S	*n-p-n* grown [a]	50 (25°C)	30	10	50	2.5	−10	19	. . . . .
	300	*p-n-p* fused	50 (25°C)	−30	−10	50	−5	1	9	. . . . .
	301	*p-n-p* fused	50 (25°C)	−30	−10	50	−5	1	19	. . . . .
	903	*n-p-n* grown	150 (25°C)	30	10	150	5	−1	9–19	150
	904	*n-p-n* grown	150 (25°C)	30	10	150	5	−1	19–39	150
	905	*n-p-n* grown	150 (25°C)	30	10	150	5	−1	$\geq$ 39	150
	904A	*n-p-n* grown	150 (25°C)	30	10	150	5	−1	$\leq$ 19	150
	210	*n-p-n* grown	50 (25°C)	30^g	5	50	22.5	−2	. . . .	. . . . .
	302	*p-n-p* fused	50 (25°C)	−30	−10	50	−5	1	44	. . . . .
	350	. . . .	50 (25°C)	−12						
Transitron 407 Main St. Melruse, Mass.	2N85	*p-n-p* fused	750	−45	−100	100	−12	10	40	2.5
	2N86	*p-n-p* fused	750	−60	−100	100	−12	10	20	2.5
	2N87	*p-n-p* fused	750	−30	−100	100	−12	10	20	2.5
	2N88	*p-n-p* fused [a]	25	−12	−10	85	−1.3	0.5	25	50
	2N89	*p-n-p* fused [a]	25	−12	−10	85	−1.3	0.5	25	50
	2N90	*p-n-p* fused [a]	25	−12	−10	85	−1.3	2.5	40	10
	2N91	*p-n-p* fused	125	−15	−500	85	−3	30	25	1.5
	2N92	*p-n-p* fused	125	−25	−200	85	−3	5	30	5
	2N34	*p-n-p* fused	125	−25	−20	100	−6	1	40	18
	2N36	*p-n-p* fused	125	−25	−20	100	−6	1	45	18
	2N37	*p-n-p* fused	125	−25	−20	100	−6	1	30	20
	2N38	*p-n-p* fused	125	−25	−20	100	−6	1	15	20
	2N43	*p-n-p* fused	375	−45	−50	100	−6	1	33	20
	2N44	*p-n-p* fosed	375	−45	−50	100	−6	1	16	20
	2N45	*p-n-p* fused	375	−45	−50	100	−6	1	9	20
	2N63	*p-n-p* fused	125	−25	−20	100	−6	1	20	20
	2N64	*p-n-p* fused	125	−25	−20	100	−6	1	30	20
	2N65	*p-n-p* fused	125	−25	−20	100	−6	1	50	18
Tnng-Sol Electric 100 Eighth Ave. Newark, N.J.	DR126	*p-n-p* fused [d]	50 (25°C)	-10^g	. . . . .	85	−1.5	0.5	24	26
	DR128	*p-n-p* fused [d]	50 (25°C)	-10^g	. . . . .	85	−1.5	0.5	49	34
	DR129	*p-n-p* fused [d]	50 (25°C)	-25^g	. . . . .	85	−1.5	0.5	32.4	26
	DR130	*p-n-p* fused [d]	50 (25°C)	-25^g	. . . . .	85	−1.5	0.5	13	20.5
	DR154	*p-n-p* fused [d]	50 (25°C)	-25^g	. . . . .	85	−1.5	0.5	124	55
Western Electric 120 Broadway New York, N.Y.	2N27	*n-p-n* grown	50 (60°C)	30	5	85	4.5	−1	19–198	50
	2N28	*n-p-n* grown	50 (60°C)	30	5	85	4.5	−1	5–198	125
Westinghouse Box 284 Elmira, N.Y.	2N54	*p-n-p* fused [a]	200 (25°C)	−45	−10	60	−6	1	33	25
	2N55	*p-n-p* fused [a]	200 (25°C)	−45	−10	60	−6	1	20	20
	2N56	*p-n-p* fused [a]	200 (25°C)	−45	−10	60	−6	1	13	5

All sockets A to H except where otherwise noted.
[a] Socket type A.
[b] Socket types B to H.
[c] Socket types A, I, and J.
[d] Socket type not given.

power Transistors (*Continued*)

frequency parameters						Grounded-emitter connection					Grounded-base				Grounded-collector			
r_b, ohms	r_c, megohms	f_{aco}, Mc	C_c, μμf	I_{co}, μa	NF, db	I_b, ma	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db
700	2.0	......	..	−6	22	......	1,500	20,000 matched		41	70	100,000 matched		31	600,000	20,000 matched		15
1,500	2.0	......	..	−6	20	......	2,700	20,000 matched		42	110	100,000 matched		30	1,000,000	20,000 matched		16
800	2.0	0.6	15	−5	18	−0.03	1,200	30,000	500	40	...	......	...	....	20,000	500 matched		16
800	2.0	0.8	18	5	16	0.03	1,200	30,000	500	40	...	......	...	....	20,000	500 matched		16
150	0.4	0.9	15	10	26	......	480	20,000	500	37	35	100,000	60	30	9,500	500	15,000	12
170	0.4	1.1	17	10	23	......	970	20,000	500	40	40	100,000	60	30	15,500	500	15,000	14.5
200	0.4	1.3	19	10	20	......	1,250	20,000	1,250	43	45	100,000	60	31	32,000	500	15,000	17
.....	......	......	..	3	14	......	.....	20,000	1,000	32								
.....	......	......	..	3.5	21	......	.....	20,000	1,000	29								
.....	......	......	..	4	26	......	.....	300	1,000	26								
550	0.4	......	..	−10	25													
1,000	0.4	......	..	−10	20													
500	0.5	3	..	1 (25°C)	23													
1,250	0.5	3	..	1 (25°C)	23													
2,500	0.5	3	..	1 (25°C)	23													
1,250	0.5	≦8	..	1 (25°C)	23													
.....	......	......	..	50 (25°C)	..	......	.....	10,000	500	39								
.....	......	......	..	−10														
300	0.16	0.8	..	−10	20	......	.....	1,000	500	30								
300	0.125	0.8	..	−10	20	......	.....	1,000	500	26								
300	0.125	0.8	.	−20	20	......	.....	1,000	500	26								
1,000	0.5	0.5	..	−10	10	......	.....	20,000	1,000	36								
1,000	2.0	0.5	..	−10	20	......	.....	20,000	1,000	36								
600	0.5	0.5	..	−10	20	......	.....	600	1,000	26								
50	2.0	......	..	−15														
500	1.0	......	..	−10														
600	1.0	......	..	−10	20	......	.....	30,000	1,000	40								
700	1.0	......	..	−10	20	......	.....	30,000	1,000	40								
500	1.0	......	..	−15	22	......	.....	30,000	1,000	36								
250	1.0	......	..	−25	24	......	.....	30,000	1,000	32								
500	1.0	......	..	−15	20	......	.....	30,000	1,000	40								
300	1.0	......	..	−15	22	......	.....	30,000	1,000	37								
250	1.0	......	..	−15	22	......	.....	30,000	1,000	33								
350	2.0	......	..	−10	25	......	.....	30,000	1,000	38								
700	2.0	......	..	−10	22	......	.....	30,000	1,000	39								
1,500	2.0	......	..	−10	20	......	.....	30,000	1,000	41								
900	1.5	0.9	..	−9	14	−0.006	.....	30,000	1,000	33								
1,400	2.0	0.9	..	−8	18	−1.5	.....	300	.....	24								
1,200	2.0	0.7	..	−10	18	−0.006	.....	30,000	1,000	35								
650	1.3	0.5	..	−14	21	−0.006	.....	30,000	1,000	27								
600	1.2	0.7	..	−10	18	−0.006	.....	30,000	1,000	40								
700	2.0	2	17	10	30													
1,000	1.0	0.95	25	10	30													
400	1.0	0.5	..	−6	..	......	700	50,000	700	39.5	125	300,000	125	31	35,000	1,000	35,000	15
400	1.0	0.5	..	−6	..	......	550	67,000	550	39	125	300,000	125	31	27,000	1,000	27,000	13
400	1.0	0.5	..	−6	..	......	450	85,000	450	37	125	300,000	125	31	20,000	1,000	20,000	11

Characteristics measured at 25°C unless otherwise noted.
[e] Characteristics measured at 30°C.
[f] Characteristics measured at 27°C.
[g] Temperature not given.

Table 9-8. High-

Manufacturer	Type No.	Type	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max ambient temp, °C	Storage temp, °C	Typical small-signal			
								Bias			
								V_c, volts	I_e, ma	β	r_e, ohms
General Electric	2N78	n-p-n rate grown	50 (30°C)	15	20	100	100 max	5	−1	27.5	...
	2N123	p-n-p fused	150 (25°C)	−15	150	...	85	−5	1	30–150	...
	2N135	p-n-p alloyed	100 (25°C)	−20	−50	...	85	−5	1	20	...
	2N136	p-n-p alloyed	100 (25°C)	−20	−50	...	85	−5	1	40	...
	2N137	p-n-p alloyed	100 (25°C)	−10	−50	...	85	−5	1	60	...
Germanium Prod.	RD2523A (2N99)	n-p-n grown	50 (25°C)	40	10	75	....	5	−1	40	25
	RD2525A (2N100)	n-p-n grown	25 (25°C)	25	5	50	....	5	−1	100	25
	RD2521A (2N98)	n-p-n grown	50 (25°C)	40	10	75	....	5	−1	40	25
	RD2517A	n-p-n grown	50 (25°C)	30	10	75	....	5	−1	13	25
Hydro-Aire	HF-1	p-n-p fused	35 (25°C)	−15	−5	55	....	−4.5	1	25	30
	IF-1	p-n-p fused	35 (25°C)	−15	−5	55	....	−4.5	1	20	30
Philco	SB-100	surface barrier [a]	10 (40°C)	−4.5	−5	...	−55 to 85	−3	0.5	19	50
Raytheon	CK-760	p-n-p fused	....	−6 [c]	−5	...	−55 to 85	−6	1	45	22
	CK-761	p-n-p fused	....	−6 [c]	−5	...	−55 to 85	−6	1	50	22
	CK-762	p-n-p fused	....	−6 [c]	−5	...	−55 to 85	−6	1	60	22
Sylvania	2N94	n-p-n alloyed	50 (25°C)	20	10	...	−55 to 85	6	−0.5	30	52
	2N94A	n-p-n alloyed	50 (25°C)	20	10	...	−55 to 85	6	−0.5	30	52
Texas Inst.	220	n-p-n grown [a]	50 (25°C)	30	5	50	....	22.5	...	...	...
	221	n-p-n grown [a]	50 (25°C)	30	5	50	....	22.5	...	...	...
	222	n-p-n grown [a]	50 (25°C)	30	5	50	....	22.5	...	...	...
	223	n-p-n grown [a]	50 (25°C)	30	5	50	....	22.5	...	...	...
	904A	n-p-n grown	150 (25°C)	30	10	150	....	5	−1	≥19	150
	224–1	....	....	...	...	...	....	...	...	...	...
	2	....	....	...	...	...	....	...	...	...	...
	3	....	....	...	...	...	....	...	...	...	...
	4	....	....	...	...	...	....	...	...	...	...
	5	....	....	...	...	...	....	...	...	...	...
	225–1	....	....	...	...	...	....	...	...	...	...
	2	....	....	...	...	...	....	...	...	...	...
	3	....	....	...	...	...	....	...	...	...	...
	4	....	....	...	...	...	....	...	...	...	...
	5	....	....	...	...	...	....	...	...	...	...
	226–1	....	....	...	...	...	....	...	...	...	...
	2	....	....	...	...	...	....	...	...	...	...
	3	....	....	...	...	...	....	...	...	...	...
	4	....	....	...	...	...	....	...	...	...	...
	5	....	....	...	...	...	....	...	...	...	...
	227–1	....	....	...	...	...	....	...	...	...	...
	2	....	....	...	...	...	....	...	...	...	...
	3	....	....	...	...	...	....	...	...	...	...
	4	....	....	...	...	...	....	...	...	...	...
	5	....	....	...	...	...	....	...	...	...	...
Tung-Sol	DR-155	p-n-p fused [b]	50 (25°C)	−10	...	85	−55 to 85	−1.5	0.5	32	...
	2N112	p-n-p fused	50 (25°C)	−10	−8	85	−55 to 85	−6	1	32	31
	2N113	p-n-p fused	50 (25°C)	−10	−8	85	−55 to 85	−6	1	32	31
Western Electric	2N27	n-p-n grown	50 (60°C)	30	5	85	....	4.5	−1	20–198	50

Socket types A to H unless otherwise noted.
[a] Socket type A only.
[b] Socket types A and J.

frequency Transistors

low-frequency parameters							HF parameters	High-frequency circuit conditions					High-speed switching characteristics			
r_b, ohms	r_c, megohms	$f_{\alpha co}$, Mc	C_c, μμf	I_{co}, μa	I_{eo}, μa	NF, db	r_bC_c, μμ sec	Application	R_i, ohms	R_o, ohms	Power gain, db	Circuit	Rise time, μsec	Fall time, μsec	Reverse emitter voltage, volts	Circuit
...	...	5.5	6	1	...	14	....	RF amp	1,000	6,000	20					
								IF amp	1,500	10,000	30					
...	...	7.5	14	−2	5	10	1,000	Switching	...	......	..	..	0.1	0.2	5	
...	...	4.5	14	5	...	..	....	RF/IF amp	...	......	29					
...	...	6.5	14	5	...	..	....	RF/IF amp	...	......	31					
...	...	10	14	5	...	..	....	RF/IF amp	...	......	33					
150	5.0	3.5	10	2	...	15	....	IF amp unneut	500	10,000	22	..	<0.2	<0.3		
400	5.0	5.0	14	2	...	20	....	IF amp unneut	750	10,000	23	..	<0.2	<0.3		
150	5.0	2.0	14	2	...	20	....	IF amp unneut	500	10,000	22	..	<0.2	<0.3		
100	3.0	1.0	19	2	...	20	....	IF amp unneut	350	10,000	20	..	<0.2	<0.3		
500	1.0	5.0	10	−10												
500	1.0	2.0	10	−10												
...	0.4	30 (osc)	2.2	−0.5	0.5	..	800									
70	1.0	5	14	−2	2	25	1,000									
70	1.0	10	14	−2	2	25	1,000									
70	1.0	20	14	−2	2	25	1,000									
500	2.0	3.5	10	3	−3	15	1,000	IF (g-b)	80	100,000	25 [d]	*C*	0.15	0.15	≥0	*F*
								IF (g-e)	500	25,000	32 [d]	*D*				
500	2.0	6.0	10	3	−3	15	1,200	IF (g-b)	80	100,000	25 [d]	*C*	0.1	0.1	≥0	
								IF (g-e)	800	25,000	35 [d]	*D*				
								RF (g-b)	80	15,000	20 [e]	*E*				
...	...	...	...	50	...	..	....	262-kc (g-e) IF	750	70,000	31	*A*				
...	...	...	...	50	...	..	....	262-kc (g-e) IF	750	70,000	33	*A*				
...	...	...	...	50	...	..	....	262-kc (g-e) IF	750	70,000	35	*A*				
...	...	...	...	50	...	..	....	262-kc conv	300	60,000	20	*B*				
1,250	0.5	≥8	...	1												
...	...	...	...	...	...	..	....	Neut 262-kc	600	70,000	26	*H*				
...	...	...	...	...	...	..	....	g-e IF	...	......	28					
...	...	...	...	...	...	..	....	....	...	......	30					
...	...	...	...	...	...	..	....	....	...	......	32					
...	...	...	...	...	...	..	....	....	...	......	34					
...	...	...	...	...	...	..	....	Neut 455-kc	500	50,000	24	*H*				
...	...	...	...	...	...	..	....	g-e IF	...	......	26					
...	...	...	...	...	...	..	....	....	...	......	28					
...	...	...	...	...	...	..	....	....	...	......	30					
...	...	...	...	...	...	..	....	....	...	......	32					
...	...	...	...	...	...	..	....	Neut 262-kc	65	120,000	18	*I*				
...	...	...	...	...	...	..	....	g-b IF	...	......	20					
...	...	...	...	...	...	..	....	....	...	......	22					
...	...	...	...	...	...	..	....	....	...	......	24					
...	...	...	...	...	...	..	....	....	...	......	26					
...	...	...	...	...	...	..	....	Neut 455-kc	65	150,000	18	*I*				
...	...	...	...	...	...	..	....	g-b IF	...	......	20					
...	...	...	...	...	...	..	....	....	...	......	22					
...	...	...	...	...	...	..	....	....	...	......	24					
...	...	...	...	...	...	..	....	....	...	......	26					
...	1.0	1.4	...	−15	...	28										
110	1.2	5	...	−10	...	28	....	IF	600	25,000	32	*G*				
110	1.2	10	...	−10	...	28	....	IF	600	25,000	33	*G*				
700	2.0	2	17	10												

Characteristics measured at 25°C unless otherwise noted.
[c] Characteristics measured at 27°C.
[d] Bandwidth 12 kc.
[e] Bandwidth 25 kc.

Table 9-9. Grown *n-p-n*

Manufacturer	Type No.	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max base-to-base current, ma	Application
Germanium Prod.	RDX-302/3N23	50 (25°C)	30	5	5	Video amp, switching 10-Mc osc
	RDX-301/3N23A	50 (25°C)	30	5	5	Video amp, switching 20-Mc osc
	RDX-300/3N23B	50 (25°C)	30	5	5	Video amp, switching 35-Mc osc 20-Mc IF
	RDX-300A/3N23C	50 (25°C)	30	5	5	Video amp, switching 50-Mc osc 20- to 30-Mc IF
Texas Inst.	700	50 (25°C)	30	5	5	Low-level, low-freq agc
Western Electric	3N22	30 (25°C)	12	5	5	Video amp, R-F

All sockets A, F, G, H, and M.

Table 9-10.

Manufacturer	Type No.	Type	Max power output, watts: Class A	Class B (push-pull)	D-C switch	Max coll power, watts	Max coll voltage, volts: Circuit g-e	g-b	Max coll current, amp	Small signal: $f_{\alpha ce}$, kc	Bias: V_c, volts	I_e, ma
Amperex	2N115	*p-n-p* fused *	1.5	2.5	. . .	2 (45°C)	−12(B) −6(A)	. . .	−1	300	. . .	. . .
	2-OC72	*p-n-p* fused *	. . .	. . .	. . .	0.045 (45°C)	13(B)	. . .	0.045	10	. . .	. . .
CBS-Hytron	HD-197	*p-n-p* fused *	. . .	. . .	. . .	0.5 (25°C)	−40	. . .	. . .	150	−10	50
Hydro-Aire	JP-1	*p-n-p* fused *	0.45	0.9	1.5	0.5 (25°C)	. . .	−45	−0.1	50	−22.5	20
Minneapolis-Honeywell	H-1	*p-n-p* fused *	5	10	40	20 (21°C)	−30	−60	−0.8	20	−2	. . .
Regulator Co. 2753 4th Ave. S	2N57	*p-n-p* fused *	6	12	48	20 (21°C)	−30	−60	−1	20	−2	. . .
Minneapolis, Minn.	H-2	*p-n-p* fused *	8.5	18	68	20 (21°C)	−30	−60	−1.4	20	−2	. . .
	H-3	*p-n-p* fused *	2	4	16	5 (21°C)	−30	−60	−0.35	20	−2	. . .
	H-4	*p-n-p* fused †	2	6	16	5 (21°C)	−30	−60	−0.5	20	−2	. . .
Sylvania	2N68	*p-n-p* alloyed †	0.75	10	. . .	4 (25°C)	. . .	−25	−1.5	. . .	−6	50
	2N95	*n-p-n* alloyed †	0.75	10	. . .	4 (25°C)	. . .	25	1.5	. . .	6	−50
	2N101	*p-n-p* alloyed		Electrically identical	to 2N68							
	2N102	*n-p-n* alloyed		Electrically identical	to 2N95							
Texas Inst.	X-2	*n-p-n* grown	. . .	. . .	. . .	. . .	. . .	35	0.075	225	5	−1
	951	*n-p-n* grown Silicon	. . .	0.45 (25°C)	. . .	1 (25°C)	50	. . .	0.06	. . .	. . .	. . .
			. . .	0.3 (100°C)	. . .	0.5 (100°C)	. . .	. . .	. . .	. . .	. . .	. . .
				0.15 (150°C)	. . .	0.15 (150°C)						
	952	*n-p-n* grown Silicon	. . .	0.6 (25°C)	. . .	1 (25°C)	80	. . .	0.05	. . .	. . .	. . .
			. . .	0.4 (100°C)	. . .	0.5 (100°C)	. . .	. . .	. . .	. . .	. . .	. . .
				0.15 (150°C)	. . .	0.15 (150°C)						
	953	*n-p-n* grown Silicon	. . .	1 (25°C)	. . .	1 (25°C)	120	. . .	0.04	. . .	. . .	. . .
			. . .	0.5 (100°C)	. . .	0.5 (100°C)	. . .	. . .	. . .	. . .	. . .	. . .
				0.15 (150°C)	. . .	0.14 (150°C)						
Transistor Products 241-251 Crescent Ave. Waltham, Mass.	X-107	*p-n-p* fused *	1	. . .	. . .	2 (25°C)	−30	−60	−1	. . .	−24	80
	X-120	*p-n-p* fused *	7.5	. . .	. . .	15 (25°C)	−30	−60	−4	. . .	−28	360
Transitron	2N83	*p-n-p* fused ‡	5	15	40	10 (25°C)	−30	−45	−1	200	−20	100
	2N84	*p-n-p* fused ‡	5	10	30	10 (25°C)	−22	−30	−1	200	−20	100
Tung-Sol	DR-150	*p-n-p* fused	. . .	1	3.5	5 (25°C)	. . .	−25	−1	250	−15	10
Western Electric	2N66	*p-n-p* fused *	. . .	. . .	. . .	5 (25°C)	−40	−60	−0.8	500	−4.5	100
											−40	0

* Type A sockets.
† Socket types A to H.

Junction-tetrode Transistors

Small-signal low-frequency Parameters								Typical operation	
Bias									
V_c, volts	I_e, ma	I_{b2}, ma	α	r_e, ohms	r_b, ohms	r_c, megohms	I_{co}, μa	Freq. Mc Circuit J	Power-gain at 5 Mc Circuit K
4.5	1	0	0.95	30	70	2	10	10–20	12
4.5	1	0	0.97	30	100	2	10	20–35	14
4.5	1	0	0.98	30	200	2	10	35–50	15
4.5	1	0	0.99	30	300	2	10	50–80	17
5	−1	0	0.95	30	1,000	1	10		
9	−2	−4.5	0.90	25	100	1	10	15	
9	−2	0	0.975	25	1,000	1			

Characteristics measured at 25°C.

Power Transistors

low-frequency parameters							Typical operating conditions										
β	r_e, ohms	r_b, ohms	r_c, ohms	C_c, $\mu\mu$f	Rise time, μsec	I_{co}, μa	Class and circuit	Supply voltage, volts	Coll current, ma	Base current, ma	Zero signal current, ma	Power output, watts	Power gain, db	Driving power, mw	R_c, ohms	R_L, ohms	R_g, ohms
..	...	...	...	...	..	...	B(g-e)	−6	−1,280	...	−5	5 ¶	27				
..	...	...	...	...	..	...	B(g-e)	−6	...	...	...	0.2 ¶	27				
10	...	70	5,000	...	..	...	A	...	−50	...	...	...	30	...	...	5,000	100
9	2	150	100,000	...	..	−500	B(g-b)	−22.5	−40	...	...	0.7 ¶	20				
..	...	...	...	...	1.5	−8,000	A(g-e)	−28	400	50	...	5	15	158	20	70	4
							B(g-e)	−28	510	...	4	10 ¶	12	630	100	140	4
..	...	...	...	...	1.2	−8,000	A(g-e)	−28	500	45	...	6.25	16	156	35	56	4
							B(g-e)	−28	640	...	4	12.5 ¶	13	625	140	128	4
..	...	...	...	...	0.5	−8,000	A(g-e)	−28	600	30	...	7.5	20	75	40	47	4
							B(g-e)	−28	890	...	4	17.5 ¶	16	440	100	80	4
..	...	...	...	...	1.2	−1,000	A(g-e)	−28	150	15	...	1.9	16	48	100	187	4
							B(g-e	−28	220	...	0.5	4.4 ¶	12	278	240	320	4
..	...	...	...	...	0.6	−1,000	A(g-e)	−28	150	10	...	1.9	21	15	60	187	4
							B(g-e)	−28	318	...	0.5	6.25 ¶	14	250	200	224	4
40	1	30	100,000	300	..	−100	A(g-b)	−12	−150	...	...	0.6	23	...	75	100	50
							B(g-e)	−12	−550	...	−1	5 ¶	15	...	50	12	50
							B(g-c)	−12	−550	...	−1	5 ¶	10	...	250	12	100
							B(g-b	−24	−950	...	−1	10 ¶	10	...	2	24	2
40	1	30	100,000	300	..	100	A(g-b)	12	150	...	...	0.6	23	...	75	100	
							B(g-e)	12	550	...	1	5 ¶	15	...	50	12	
							B(g-c)	12	550	...	1	5 ¶	10	...	250	12	
							B(g-b)	24	950	...	1	10 ¶	10	...	2	24	
9	25	0.75	200,000	...	..	25	B(g-b)	22.5	40	...	...	0.5 ¶	9.5	...	...	1,000	
							B(g-b)	22.5	40	...	...	0.5	22.7	...	...	1,000	
..	...	...	...	...	..	5	B(g-e)	28	30	...	...	0.45 (25°C) ¶	20	...	...	1,500	1,000
..	...	...	...	...	..	...	...	...	...	...	...	0.15 (150°C)					
..	...	...	...	...	..	6	B(g-e)	45	25	...	...	0.6 (25°C) ¶	21	...	...	4,000	1,000
..	...	...	...	...	..	...	...	...	...	...	...	0.15 (150°C)					
..	...	...	...	...	..	8	B(g-e)	67.5	20	...	...	1 (25°C) ¶	23	...	...	8,000	1,000
..	...	...	...	...	..	...	...	...	...	...	...	0.15 (150°C)					
22	0.85	12	50,000	...	..	−120	A(g-b)	−28	−80	...	...	1	24	1	1.5	375	
20	0.65	1	10,000	...	..	−200	A(g-b)	−28	−360	...	...	5	20	50	0.8	100	
8	0.3	15	20,000	400	1.5	−100	B(g-e)	−30	−160	...	...	2.5 ¶	24	...	...	600	100
12	0.3	15	20,000	400	1.5	−100	B(g-e)	−20	−160	...	...	2.0 ¶	22	...	...	400	100
33	...	...	30,000														
45	...	...	...	400	..	75											
..	...	...	...	...	..	300											

‡ Socket types A and K.
¶ Push-pull connection.

Table 9-11. Point-

Manufacturer	Type No.	Application	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max reverse emitter voltage, volts	Max emitter current, ma	Max emitter power, mw
Hydro-Aire	A-0	Amp, osc	0 (25°C)	−20	−8	. . .	. . .	. . .
	A-1	Amp, osc	50 (25°C)	−20	−8	. . .	. . .	. . .
	A-2	Amp, osc	50 (25°C)	−20	−8	. . .	. . .	. . .
	A-3	Amp, osc	50 (25°C)	−20	−8	. . .	. . .	. . .
	S-0	Switching	50 (25°C)	−40	−8	−30	. . .	. . .
	S-1	Switching	50 (25°C)	−40	−8	−30	. . .	. . .
	S-2	Switching	50 (25°C)	−30	−8	−30	. . .	. . .
Sprague Electric Transistor Prod.	5A	Switching	80 (25°C)	−50	−10	−50	. . .	. . .
	2A	Amp, osc, sw	120 (25°C)	−50	−8	−50		
	2C	Switching [a]	100 (25°C)	−50	−8	−50		
	2D	Amp, osc [a]	100 (25°C)	−50	−8	−50		
	2E	Amplifier [a]	100 (25°C)	−50	−8	−50		
	2G	Switching [a]	120 (25°C)	−50	−8	−50		
	2H	Amplifier [a]	100 (25°C)	−50	−8	−50		
	2L	Switching [a]	50 (25°C)	−50	−8	−50		
	2N32	Switching [a]	50 (25°C)	−40	−8	−40		
	2N33	Switching [a]	30 (25°C)	−8.5	−7			
	2N50	Switching [a]	50 (25°C)	−15	−1	−15		
	2N51	Sw, osc [a]	100 (25°C)	−50	−8	−50		
	2N52	Amp, osc [a]	120 (25°C)	−50	−8	−50		
	2N53	Switching [a]	120 (25°C)	−50	−8	−50		
Western Electric	2N21	Switching	120 (25°C)	−100	−60	−100	60	80 (25°C) [b]
	2N21A	Amp, osc, sw	120 (25°C)	−100	−60	−100	60	80 (25°C) [b]
	2N110	Switching	200 (25°C)	−100	−75	−100	75	100 (25°C) [b]
	2N67	High-speed sw	100 (25°C)	−100	−60	−100	60	60 (25°C) [b]

Socket types A to H unless otherwise noted.
[a] Socket types A and L
Maximum ambient temperature 50°C unless otherwise noted.
[b] Maximum ambient temperature 85°C.
Characteristics of A-0, A-1, A-2, A-3, 2N21, 2N21A, 2N110 and 2N67 measured at 25°C.

Parameter Conversion Formulas

$$H_{21} = \frac{R_{21}}{R_{22}} = -\alpha$$

$$H_{11} = R_{11} - \frac{R_{21}R_{12}}{R_{22}}$$

$$\doteq r_e + (1 - \alpha)r_b$$

$$H_{12} = \frac{R_{12}}{R_{22}} \doteq \frac{r_b}{r_c}$$

$$H_{22} = \frac{1}{R_{22}} \doteq \frac{1}{r_c}$$

$$r_c = \frac{1}{H_{22}}$$

$$r_b = r_c H_{12}$$

$$|\alpha| = |H_{21}|$$

$$r_e = H_{11} - r_b(1 - \alpha)$$

Transistor Sockets

Code	Manufacturer	Type
A	Solder connections	. . . . . .
B	Elco Corp.	3-pin polarized 3-pin printed-circuit
C	Cinch Mfg. Corp.	3-pin polarized
D	Super-Ear Prod. Co.	3-pin polarized
E	Mycalex Tube Socket Corp.	3-pin polarized
F	Elco Corp.	4-pin polarized 4-pin printed-circuit
G	Super-Ear Prod. Co.	5-pin
H	Elco Corp.	5-pin 5-pin printed-circuit
I	Super-Ear Prod. Co.	3-pin equal spacing
J	Cinch Mfg. Corp.	5-pin
K	Amphenol Co.	. . . . . .
L	Cinch Mfg. Corp.	. . . . . .
M	Cinch Mfg. Corp.	4-pin polarized

contact Transistors

Small-signal low-frequency parameters										Large-signal parameters					
Bias															
V_c, volts	I_e, ma	$-\alpha$	r_e, ohms	r_b, ohms	r_c, ohms	$f_{\alpha co}$, Mc	C_c, $\mu\mu f$	NF, db	I_{co}, μa	Rise time, μsec	Turnoff time μsec	Off I_c, ma	On V_c, volts	Emitter rev resist., ohms	α (at max rise time)
−8	0.3	2	425	200	13,000	3	....	......	−1,200						
−8	0.3	2	425	200	13,000	2	....	......	−1,500						
−8	0.3	2	375	175	13,000	1	....	......	−2,000						
−8	0.3	2	350	150	13,000	0.3	....	......	−2,000						
....	...	....	...	...	......	....	....	......	...	0.2 [c]	...	−1	−2	50,000	
....	...	....	...	...	......	....	....	......	...	0.5 [d]	...	−1	−2	50,000	
....	...	....	...	...	......	....	....	......	...	1 [e]	...	−1	−2	50,000	
−10	1	3	...	...	......	5	....	43	...	0.12	0.5				
−10	1	2.5 [f]	200	90	10,000	2	....	45	−1.1	0.2	1.3	−1.1	−1	200,000	5
−10	1	2.5 [f]	200	90	10,000	2	....	45	−1.1	0.2	1.3	−1.1	−1	200,000	5
−10	1	2.5 [f]	200	90	15,000	1.5	....	......	−0.9	0.3	1.3	−0.9	−1	200,000	4
−10	1	3	900	500	20,000	20	....	......	−0.9	0.02	0.9	−0.9	−0.8	2,000,000	7

[c] Fall time = 1 μsec.
[d] Fall time = 2 μsec.
[e] Fall time = 6 μsec.
[f] Large-signal α = 2.4.

Table 9-12. Phototransistors

Manufacturer	Type No.	Type	Max coll voltage, volts	Max coll current, ma	Max coll power, mw	Max dark current, μa	Max ambient temp., °C	Cut-off freq., kc	Noise, ft-c	Sensitivity, μa/ft-c
General Transistor	GT-66	Fused, 3 lead *	12	20	50 (25°C)	15	..	750	6×10^{-5}	25
Texas Inst. Transistor Prod.	800	Grown, 2 lead †	20	20	50 (25°C)	250	40	20	....	35
	1N188	Grown, 2 lead	100	..	40 (25°C)	....	50	...	3–10 μv	10 μa/millilumen
	1N189	Nonrect, 2 lead	...	..	30 (25°C)	20	50	...	....	0.08%/ft-c
	10A	Grown, 2 lead	15	..	100 (25°C)	500	50	...	15–100 μv	4 ma for 300 ft-c
	10B	Grown, 2 lead	15	..	100 (25°C)	50	50	...	15–100 μv	50% for 10 ft-c
	5B	Grown, 2 lead	50	..	100 (25°C)	20	50	...	3–10 μv	1 ma for 300 ft-c
	5C	Grown, 2 lead	50	..	100 (25°C)	5	50	...	3–10 μv	50% for 40 ft-c
	11A	Nonrect, 2 lead	15	..	50 (25°C)	4,000 ohms	50	...	....	2,000 ohms for 300 ft-c
	11B	Nonrect, 2 lead	15	..	50 (25°C)	4,000 ohms	50	...	....	3,000 ohms for 300 ft-c
	17A	Grown, 2 lead	..	..	....	...	..	...	Below 1 μv	
Western Electric	1N85	Grown, 2 lead *	90	1	50	20	85	25	2×10^{-6} μa	0.35 μa/μw

* Socket type A.
† Socket type A to H.

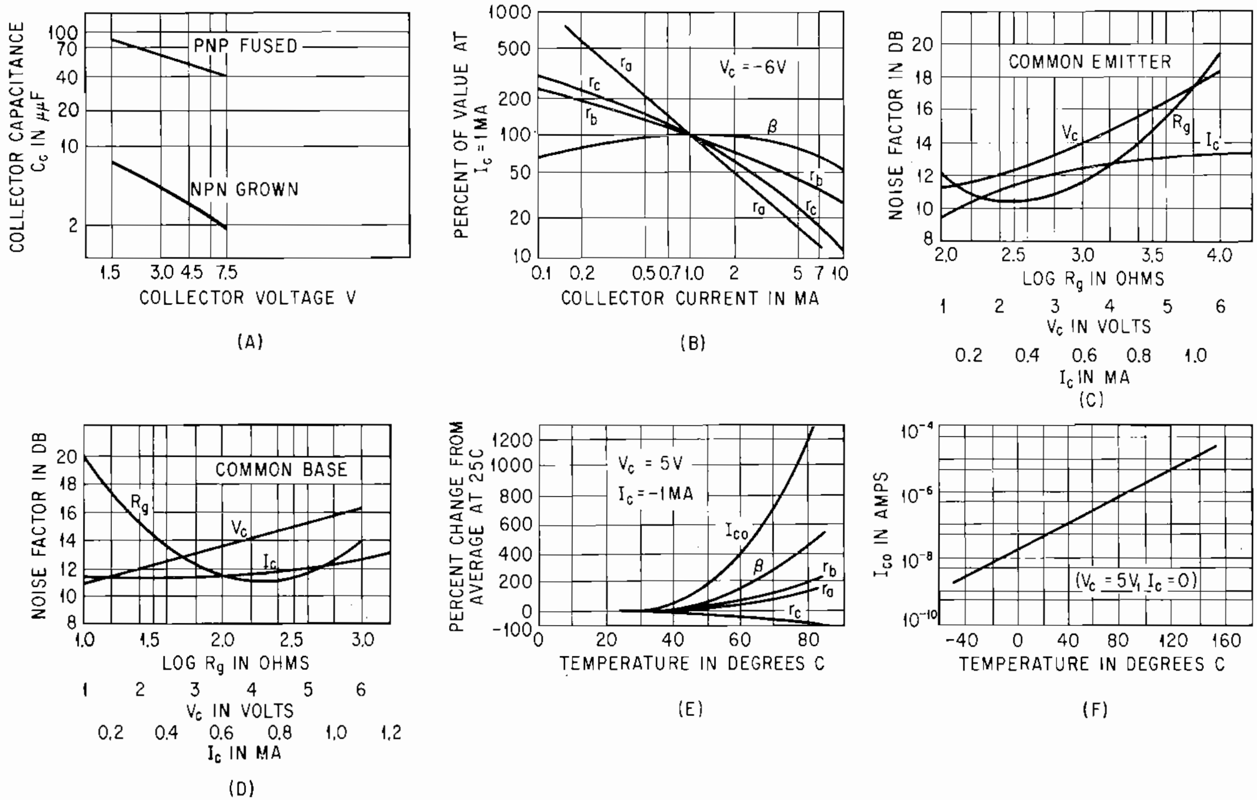


FIG. 9-26. Variation of transistor parameters with operating point (*A* to *D*) and ambient temperature (*E*, *F*).

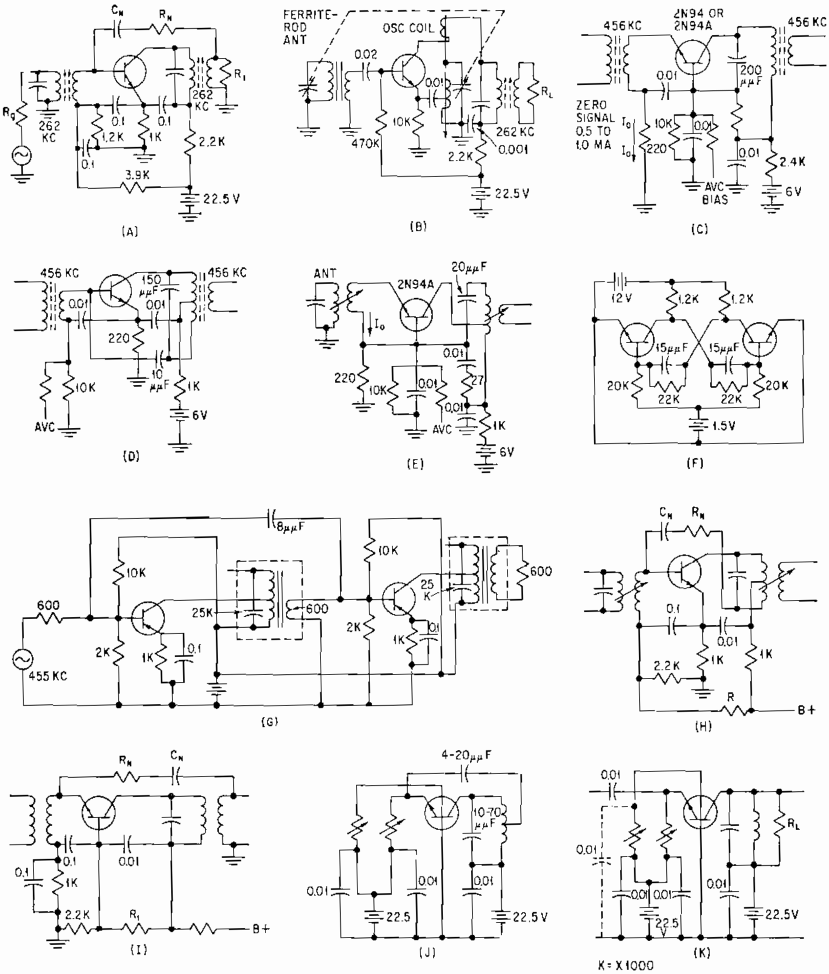


FIG. 9-27. Typical circuits for high-frequency transistors (*A* to *I*) and junction tetrode transistors (*J*, *K*) referred to in Tables 9-8 and 9-9.

Table 9-13. NAB Data Concerning Tower Failures

Information obtained from 298 television stations during 1958 indicated that 11 towers failed for various reasons. Briefly, 6 towers failed because of high winds, 2 fell during construction, and 3 failed because of structural weakness or faulty design. The following is a detailed breakdown of these 11 failures:

Height, ft	*Type*	*Weather conditions*	*Cause and comments*
826	SS	High wind	Broke in half during high wind
487	SS	97-mph wind	Failed at 125 ft above ground in wind
370	SS	Est. wind 190 knots	Due to gusty turbulence
570	SS	Hurricane "Carol"	Broke off TV tower at 200-ft level, Aug. 31, 1954
1250	G	50- to 60-mph winds	"Tower was completed to the 1,250 point. However, the top set of guys were not completely installed and in the process of tensioning these guys, high winds came up (50 to 60 m.p.h.), the unguyed portion of the tower began to oscillate, finally broke off at the 1150′ point and in falling, cut a permanent guy at the 1000′ level which in turn caused the entire structure to fail."
100	G	High winds	During process of erecting, 100 ft had been erected and temporary guy lines attached. Under high winds the temporary lines failed
450	SS	40-mile squall	Faulty design of tower
500	G	High level winds	Structural weakness
1262	G	. . . . . .	Fell during erection, Feb. 4, 1957
649	G	. . . . . .	Due to excessive strain during the process of attempting to lower a 12-bay antenna from it all at once. Actual cause of collapse not known, but it is not believed to have been caused by tower weakness
550	G	. . . . . .	Collapsed during construction. Cause not fully determined, but accident was during guy tensioning

Table 9-14. Decimal Equivalents

1/32	0.03125	17/32	0.53125
1/16	0.0625	9/16	0.5625
3/32	0.09375	19/32	0.59375
1/8	0.125	5/8	0.625
5/32	0.15625	21/32	0.65625
3/16	0.1875	11/16	0.6875
7/32	0.21875	23/32	0.71875
1/4	0.25	3/4	0.75
9/32	0.28125	25/32	0.78125
5/16	0.3125	13/16	0.8125
11/32	0.34375	27/32	0.84375
3/8	0.375	7/8	0.875
13/32	0.40625	29/32	0.90625
7/16	0.4375	15/16	0.9375
15/32	0.46875	31/32	0.96875
1/2	0.5	1.0	1.0

Table 9-15. Standard Metal Gauges

No.	*American or B & S* *	*U.S. Standard* †	*Birmingham or Stubs* ‡
1	0.2893	0.28125	0.300
2	0.2576	0.265625	0.284
3	0.2294	0.250	0.259
4	0.2043	0.234375	0.238
5	0.1819	0.21875	0.220
6	0.1620	0.203125	0.203
7	0.1443	0.1875	0.180
8	0.1285	0.171875	0.165
9	0.1144	0.15625	0.148
10	0.1019	0.140625	0.134
11	0.09074	0.1250	0.120
12	0.08081	0.109375	0.109
13	0.07196	0.09375	0.095
14	0.06408	0.078125	0.083
15	0.05707	0.0703125	0.072
16	0.05082	0.0625	0.065
17	0.04526	0.05625	0.058
18	0.04030	0.050	0.049
19	0.03589	0.04375	0.042
20	0.03196	0.0375	0.035
21	0.02846	0.034375	0.032
22	0.02535	0.03125	0.028
23	0.02257	0.028125	0.025
24	0.02010	0.025	0.022
25	0.01790	0.021875	0.020
26	0.01594	0.01875	0.018
27	0.01420	0.0171875	0.016
28	0.01264	0.015625	0.014
29	0.01126	0.0140625	0.013
30	0.01003	0.0125	0.012
31	0.008928	0.0109375	0.010
32	0.007950	0.01015625	0.009
33	0.007080	0.009375	0.008
34	0.006350	0.00859375	0.007
35	0.005615	0.0078125	0.005
36	0.005000	0.00703125	0.004
37	0.004453	0.006640626	
38	0.003965	0.00625	
39	0.003531		
40	0.003145		

* Used for copper, brass, aluminum, etc.; nonferrous alloy sheets, rods, and wire.
† Used for iron, steel, nickel, and ferrous alloy materials.
‡ Used for seamless tubes and by some manufacturers for brass and copper materials.

Table 9-16. Drill Sizes

Number	*Will clear screw*	*Brass, iron, steel tapping* *
1		
2	12–24	
3	.....	14–24
4	12–20	
5		
6		
7		
8		
9		
10	10–32	
11	10–24	
12		
13		
14		
15		
16	.....	12–24
17		
18	8–32	
19	.....	12–20
20		
21	.....	10–32
22		
23		
24		
25	.....	10–24
26		
27		
28	6–32	
29	.....	8–32
30		
31		
32		
33	4–36, 4–40	
34		
35	.....	6–32
36		
37		
38		
39	3–48	
40		
41		
42	.....	4–36, 4–40
43	2–56	
44		
45	.....	3–48
46		
47		
48		
49	.....	2–56
50		
51		
52		
53		
54		

* For tapping plastic, bakelite, lucite, hard rubber, micalex, etc., use one size larger drill.

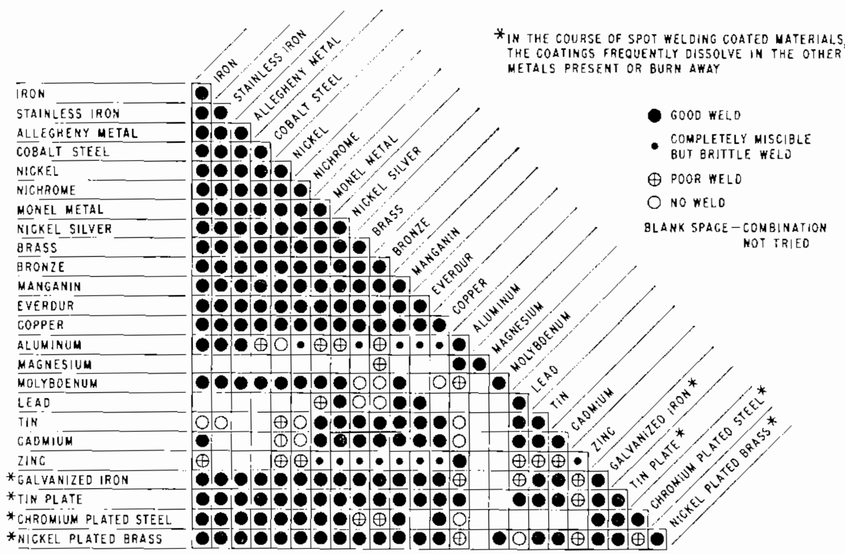


FIG. 9-28. The welding characteristics of some 250 combinations of metals.

STANDARD SYMBOLS FOR ELECTRONICS

The most-used schematic symbols for electronic components are collected here for convenient reference, as abstracted from the 54-page American Standards Association publication Y32.2-1954, "Graphical Symbols for Electrical Diagrams" and (for transistors) from MIL-STD-15A, "Military Standard Electrical and Electronic Symbols." (See Figs. 9-29*a*, 9-29*b*, and 9-29*c*.)

Symbols may have any orientation, size, and line weight. The open-circle terminal symbol can be added to leads if desired. Arrowheads can be either filled or open unless otherwise noted. Electrically actuated devices are normally shown in the power-off position. One-line symbolism has been adopted for waveguide diagrams, as indicated for microwave symbols.

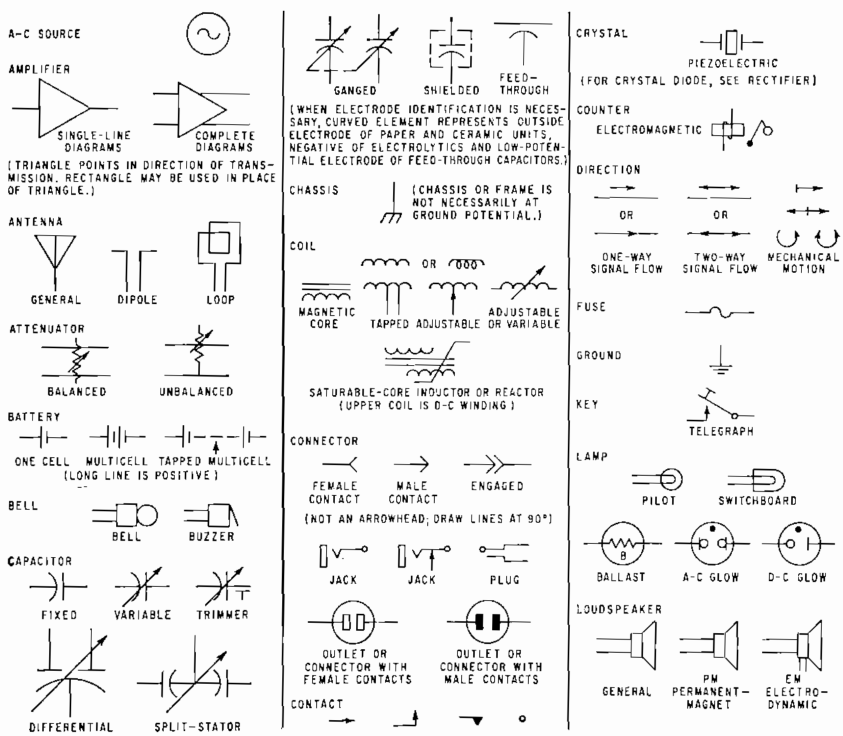


FIG. 9-29*a*

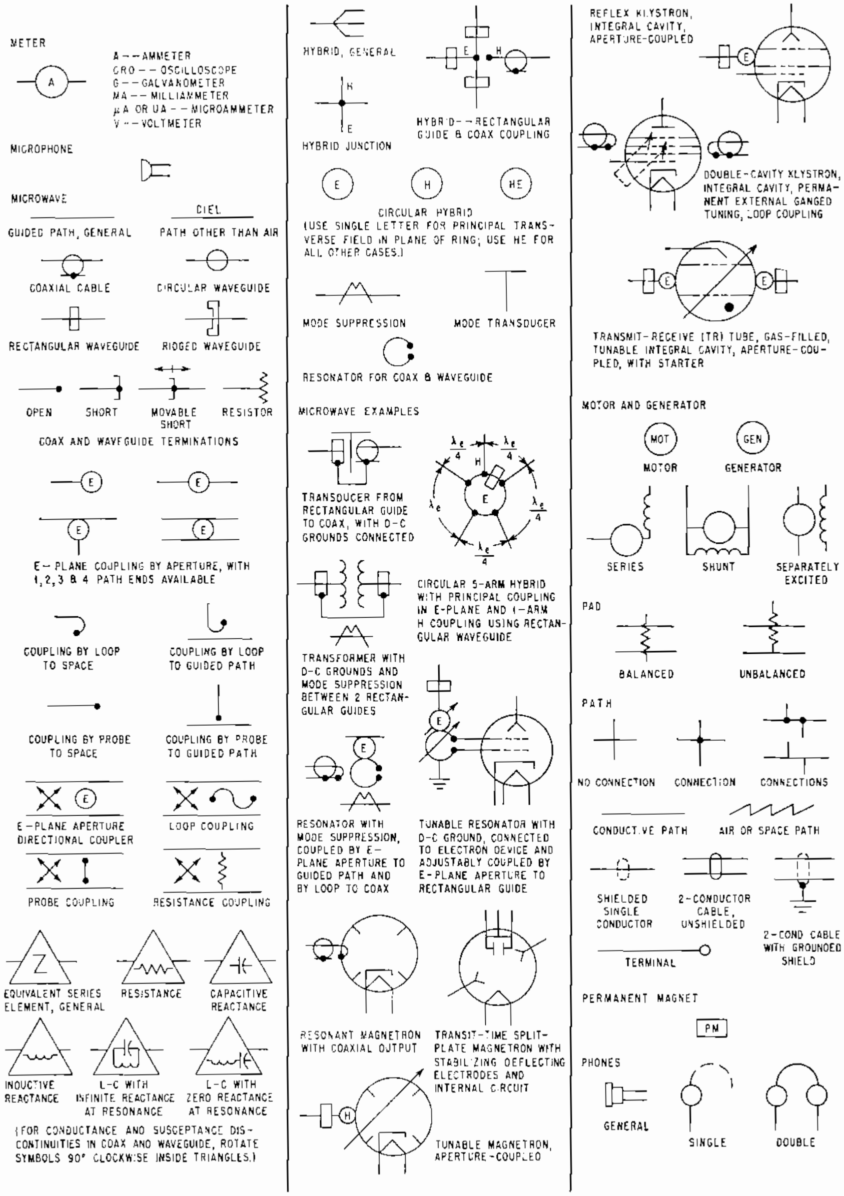

METER
A
A -- AMMETER
CRO -- OSCILLOSCOPE
G -- GALVANOMETER
MA -- MILLIAMMETER
μA OR UA -- MICROAMMETER
V -- VOLTMETER
MICROPHONE
MICROWAVE
GUIDED PATH, GENERAL
DIEL
PATH OTHER THAN AIR
COAXIAL CABLE
CIRCULAR WAVEGUIDE
RECTANGULAR WAVEGUIDE
RIDGED WAVEGUIDE
OPEN
SHORT
MOVABLE SHORT
RESISTOR
COAX AND WAVEGUIDE TERMINATIONS
E
E-PLANE COUPLING BY APERTURE, WITH 1, 2, 3 & 4 PATH ENDS AVAILABLE
COUPLING BY LOOP TO SPACE
COUPLING BY LOOP TO GUIDED PATH
COUPLING BY PROBE TO SPACE
COUPLING BY PROBE TO GUIDED PATH
E-PLANE APERTURE DIRECTIONAL COUPLER
LOOP COUPLING
PROBE COUPLING
RESISTANCE COUPLING
Z
EQUIVALENT SERIES ELEMENT, GENERAL
RESISTANCE
CAPACITIVE REACTANCE
INDUCTIVE REACTANCE
L-C WITH INFINITE REACTANCE AT RESONANCE
L-C WITH ZERO REACTANCE AT RESONANCE
(FOR CONDUCTANCE AND SUSCEPTANCE DISCONTINUITIES IN COAX AND WAVEGUIDE, ROTATE SYMBOLS 90° CLOCKWISE INSIDE TRIANGLES.)
HYBRID, GENERAL
H
E
HYBRID JUNCTION
HYBRID--RECTANGULAR GUIDE & COAX COUPLING
H
HE
CIRCULAR HYBRID
(USE SINGLE LETTER FOR PRINCIPAL TRANSVERSE FIELD IN PLANE OF RING; USE HE FOR ALL OTHER CASES.)
MODE SUPPRESSION
MODE TRANSDUCER
RESONATOR FOR COAX & WAVEGUIDE
MICROWAVE EXAMPLES
TRANSDUCER FROM RECTANGULAR GUIDE TO COAX, WITH D-C GROUNDS CONNECTED
λe/4
CIRCULAR 5-ARM HYBRID WITH PRINCIPAL COUPLING IN E-PLANE AND 1-ARM H COUPLING USING RECTANGULAR WAVEGUIDE
TRANSFORMER WITH D-C GROUNDS AND MODE SUPPRESSION BETWEEN 2 RECTANGULAR GUIDES
RESONATOR WITH MODE SUPPRESSION, COUPLED BY E-PLANE APERTURE TO GUIDED PATH AND BY LOOP TO COAX
TUNABLE RESONATOR WITH D-C GROUND, CONNECTED TO ELECTRON DEVICE AND ADJUSTABLY COUPLED BY E-PLANE APERTURE TO RECTANGULAR GUIDE
RESONANT MAGNETRON WITH COAXIAL OUTPUT
TRANSIT-TIME SPLIT-PLATE MAGNETRON WITH STABILIZING DEFLECTING ELECTRODES AND INTERNAL CIRCUIT
TUNABLE MAGNETRON, APERTURE-COUPLED
REFLEX KLYSTRON, INTEGRAL CAVITY, APERTURE-COUPLED
DOUBLE-CAVITY KLYSTRON, INTEGRAL CAVITY, PERMANENT EXTERNAL GANGED TUNING, LOOP COUPLING
TRANSMIT-RECEIVE (TR) TUBE, GAS-FILLED, TUNABLE INTEGRAL CAVITY, APERTURE-COUPLED, WITH STARTER
MOTOR AND GENERATOR
MOT
GEN
MOTOR
GENERATOR
SERIES
SHUNT
SEPARATELY EXCITED
PAD
BALANCED
UNBALANCED
PATH
NO CONNECTION
CONNECTION
CONNECTIONS
CONDUCTIVE PATH
AIR OR SPACE PATH
SHIELDED SINGLE CONDUCTOR
2-CONDUCTOR CABLE, UNSHIELDED
2-COND CABLE WITH GROUNDED SHIELD
TERMINAL
PERMANENT MAGNET
PM
PHONES
GENERAL
SINGLE
DOUBLE

FIG. 9-29*b*

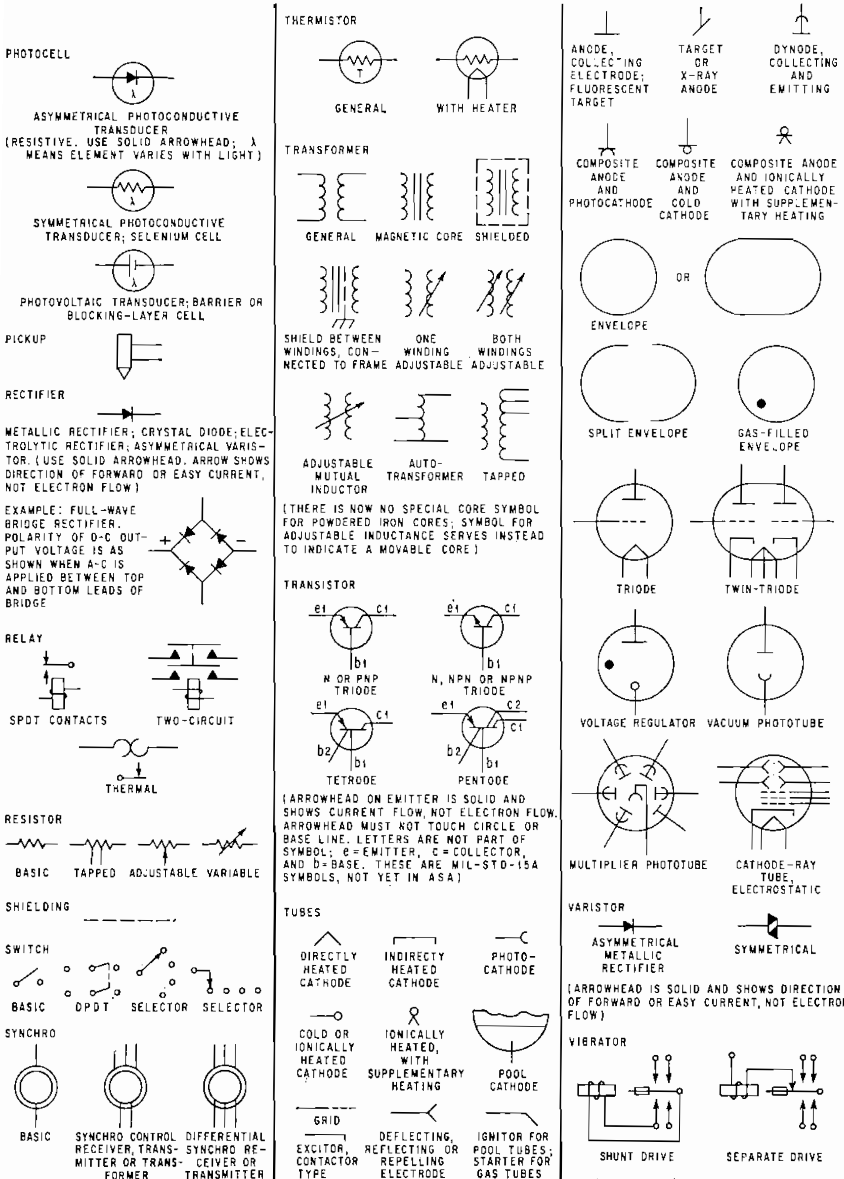

PHOTOCELL
ASYMMETRICAL PHOTOCONDUCTIVE TRANSDUCER (RESISTIVE. USE SOLID ARROWHEAD; λ MEANS ELEMENT VARIES WITH LIGHT)
SYMMETRICAL PHOTOCONDUCTIVE TRANSDUCER; SELENIUM CELL
PHOTOVOLTAIC TRANSDUCER; BARRIER OR BLOCKING-LAYER CELL
PICKUP
RECTIFIER
METALLIC RECTIFIER; CRYSTAL DIODE; ELECTROLYTIC RECTIFIER; ASYMMETRICAL VARISTOR. (USE SOLID ARROWHEAD. ARROW SHOWS DIRECTION OF FORWARD OR EASY CURRENT, NOT ELECTRON FLOW)
EXAMPLE: FULL-WAVE BRIDGE RECTIFIER. POLARITY OF D-C OUTPUT VOLTAGE IS AS SHOWN WHEN A-C IS APPLIED BETWEEN TOP AND BOTTOM LEADS OF BRIDGE
RELAY
SPDT CONTACTS
TWO-CIRCUIT
THERMAL
RESISTOR
BASIC
TAPPED
ADJUSTABLE
VARIABLE
SHIELDING
SWITCH
BASIC
DPDT
SELECTOR
SELECTOR
SYNCHRO
BASIC
SYNCHRO CONTROL RECEIVER, TRANSMITTER OR TRANSFORMER
DIFFERENTIAL SYNCHRO RECEIVER OR TRANSMITTER
THERMISTOR
GENERAL
WITH HEATER
TRANSFORMER
GENERAL
MAGNETIC CORE
SHIELDED
SHIELD BETWEEN WINDINGS, CONNECTED TO FRAME
ONE WINDING ADJUSTABLE
BOTH WINDINGS ADJUSTABLE
ADJUSTABLE MUTUAL INDUCTOR
AUTO-TRANSFORMER
TAPPED
(THERE IS NOW NO SPECIAL CORE SYMBOL FOR POWDERED IRON CORES; SYMBOL FOR ADJUSTABLE INDUCTANCE SERVES INSTEAD TO INDICATE A MOVABLE CORE)
TRANSISTOR
N OR PNP TRIODE
N, NPN OR NPNP TRIODE
TETRODE
PENTODE
(ARROWHEAD ON EMITTER IS SOLID AND SHOWS CURRENT FLOW, NOT ELECTRON FLOW. ARROWHEAD MUST NOT TOUCH CIRCLE OR BASE LINE. LETTERS ARE NOT PART OF SYMBOL; e = EMITTER, c = COLLECTOR, AND b = BASE. THESE ARE MIL-STD-15A SYMBOLS, NOT YET IN ASA)
TUBES
DIRECTLY HEATED CATHODE
INDIRECTY HEATED CATHODE
PHOTO-CATHODE
COLD OR IONICALLY HEATED CATHODE
IONICALLY HEATED, WITH SUPPLEMENTARY HEATING
POOL CATHODE
GRID
EXCITOR, CONTACTOR TYPE
DEFLECTING, REFLECTING OR REPELLING ELECTRODE
IGNITOR FOR POOL TUBES; STARTER FOR GAS TUBES
ANODE, COLLECTING ELECTRODE; FLUORESCENT TARGET
TARGET OR X-RAY ANODE
DYNODE, COLLECTING AND EMITTING
COMPOSITE ANODE AND PHOTOCATHODE
COMPOSITE ANODE AND COLD CATHODE
COMPOSITE ANODE AND IONICALLY HEATED CATHODE WITH SUPPLEMENTARY HEATING
OR
ENVELOPE
SPLIT ENVELOPE
GAS-FILLED ENVELOPE
TRIODE
TWIN-TRIODE
VOLTAGE REGULATOR
VACUUM PHOTOTUBE
MULTIPLIER PHOTOTUBE
CATHODE-RAY TUBE, ELECTROSTATIC
VARISTOR
ASYMMETRICAL METALLIC RECTIFIER
SYMMETRICAL
(ARROWHEAD IS SOLID AND SHOWS DIRECTION OF FORWARD OR EASY CURRENT, NOT ELECTRON FLOW)
VIBRATOR
SHUNT DRIVE
SEPARATE DRIVE
(SHOWING OF TERMINALS IS OPTIONAL)

Fig. 9-29*c*

Table 9-17. Standard Telephone-cable Color Code

Pair No.	*Color*	*Mate*	*Pair No.*	*Color*	*Mate*
1	Blue	White	26	Blue White	Red
2	Orange	White	27	Blue Orange	Red
3	Green	White	28	Blue Green	Red
4	Brown	White	29	Blue Brown	Red
5	Slate	White	30	Blue Slate	Red
6	Blue White	White	31	Orange White	Red
7	Blue Orange	White	32	Orange Green	Red
8	Blue Green	White	33	Orange Brown	Red
9	Blue Brown	White	34	Orange Slate	Red
10	Blue Slate	White	35	Green White	Red
11	Orange White	White	36	Green Brown	Red
12	Orange Green	White	37	Green Slate	Red
13	Orange Brown	White	38	Brown White	Red
14	Orange Slate	White	39	Brown Slate	Red
15	Green White	White	40	Slate White	Red
16	Green Brown	White	41	Blue	Black
17	Green Slate	White	42	Orange	Black
18	Brown White	White	43	Green	Black
19	Brown Slate	White	44	Brown	Black
20	Slate White	White	45	Slate	Black
21	Blue	Red	46	Blue White	Black
22	Orange	Red	47	Blue Orange	Black
23	Green	Red	48	Blue Green	Black
24	Brown	Red	49	Blue Brown	Black
25	Slate	Red	50	Blue Slate	Black

NOTE: The last pair in all cables is a red with white mate, viz.,

6-pair cable	6th pair	Red	White
11-pair cable	11th pair	Red	White
16-pair cable	16th pair	Red	White
26-pair cable	26th pair	Red	White
51-pair cable	51st pair	Red	White

RESISTOR COLOR CODE

The chart shown in Fig. 9-30*a* indicates the appropriate significant figure of resistance and the multiplier. The fourth colored band, if any, indicates the tolerance. If none is shown, the tolerance is 20 per cent, with other tolerances as follows: gold, 5 per cent; silver, 10 per cent.

CAPACITOR COLOR CODE

The value of capacitors is similarly shown by colored bands or dots as indicated in Figs. 9-30*a* and 9-30*b*. Note that the bands and dots (for disc ceramics) apply for the ceramic-type capacitors, while the various dot systems are applicable to mica- and paper-type condensers. The various systems that have been used in recent years are included, even though some of them are obsolete. The tolerances are indicated by the appropriate colored dot, and the voltage rating is obtained by multiplying the value of the appropriate dot by 100.

STANDARD COLOR CODE — RESISTORS AND CAPACITORS

INSULATED UNINSULATED COLOR	FIRST RING BODY COLOR FIRST FIGURE	SECOND RING END COLOR SECOND FIGURE	THIRD RING DOT COLOR MULTIPLIER
BLACK	0	0	NONE
BROWN	1	1	0
RED	2	2	00
ORANGE	3	3	,000
YELLOW	4	4	0,000
GREEN	5	5	00,000
BLUE	6	6	,000,000
VIOLET	7	7	0,000,000
GRAY	8	8	00,000,000
WHITE	9	9	000,000,000

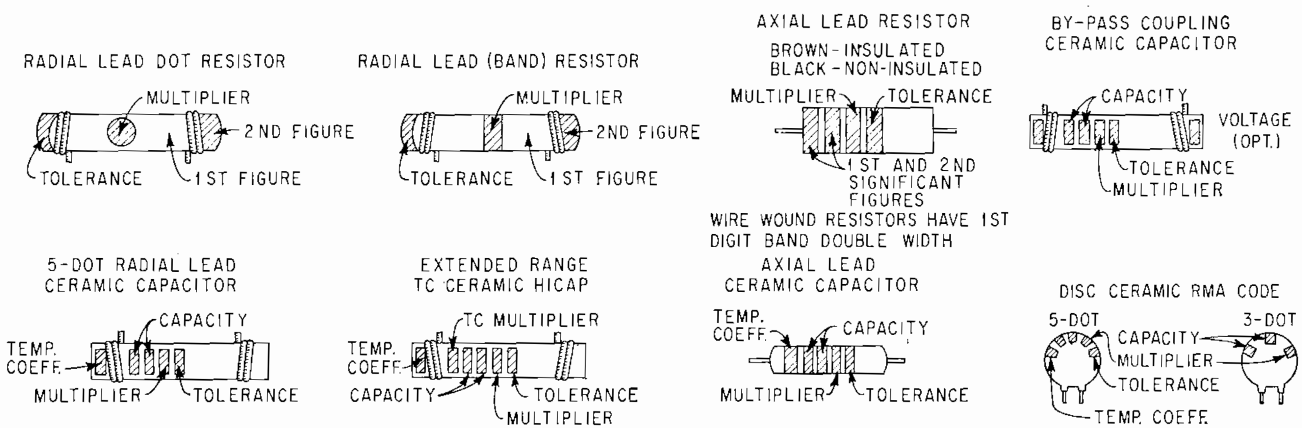


FIG. 9-30*a*. Standard color code—resistors and capacitors.

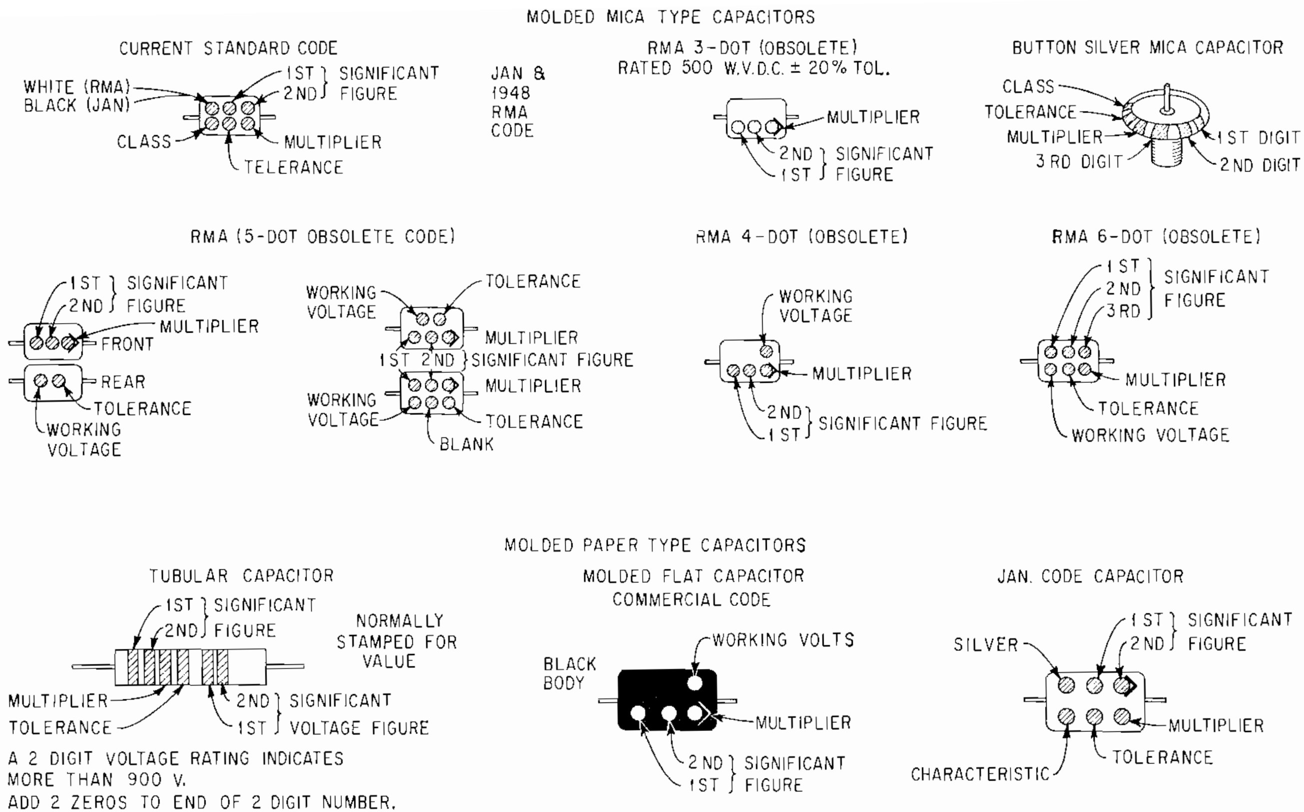


FIG. 9-30*b*. Standard color code.

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