ESSENTIAL CIRCUITS AND ANTENNA SYSTEMS USED IN A.M. BROADCASTING

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For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

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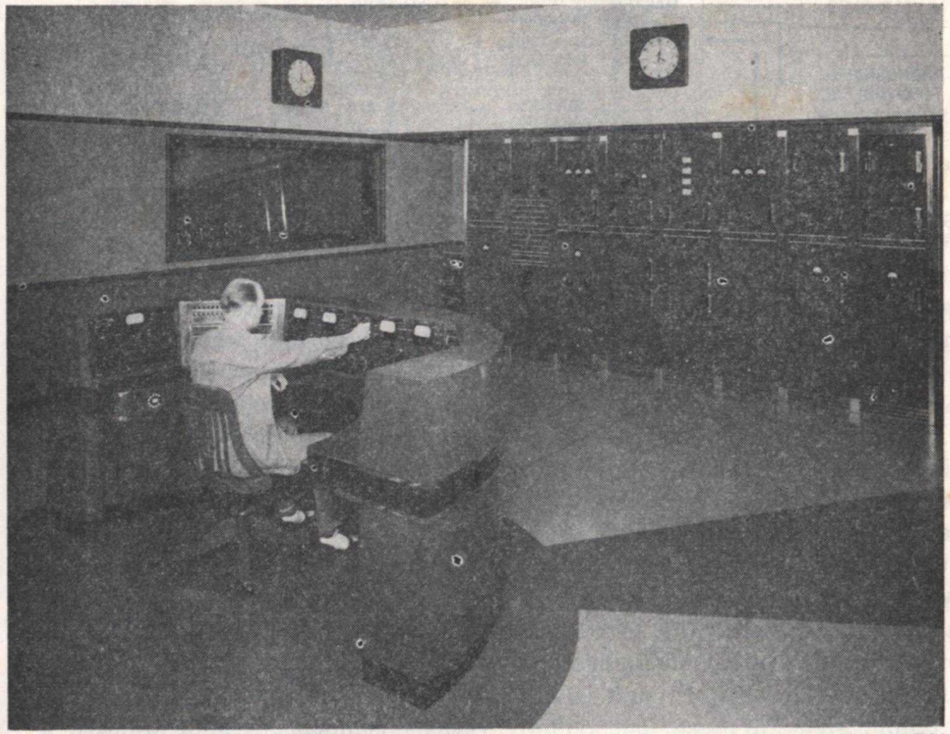
ESSENTIAL CIRCUITS AND ANTENNA SYSTEMS USED IN A. M. BROADCASTING

Standard A. M. Broadcast Systems

STANDARD broadcast transmitters are licensed by the FCC for radiotelephone transmissions in the public interest—that is, intended primarily for the entertainment or education of the general public. These stations operate on carrier frequencies 10 kc. apart in the 540 to 1650-kc. band, are amplitude modulated, and generally have carrier powers of 250 watts, 1 kw., 5 kw., 10 kw., or 50 kw.

Standard broadcast stations generally consist of two units. One is the "studios," where the programs originate and from which the operator controls the signals to be broadcast. The



Courtesy RCA

This is a view of the master control room of WFBR in Baltimore, Maryland. At this U-shaped desk the master control operator is able to combine programs from the several studios and other program sources in any manner desired, and to apply the output to the program line. The racks at the back of the room hold the audio line amplifiers, limiting amplifiers, patch panels, and auxiliary equipment used by the control operator in performing his duties. Although this set up may seem complex at first, you will soon see how it is all arranged to aid the operator in his job of providing a consistent radio program of high technical quality.

room in which the operator sits is called the "control room." The studios are generally located in the city to be served. The second unit is the "transmitter," a term that includes the transmitter proper, the antenna system, and their associated equipment. The transmitter is generally located outside the town to obtain an efficient antenna system. Telephone lines are used to send the program from the studios to the transmitter and to provide communication between them.

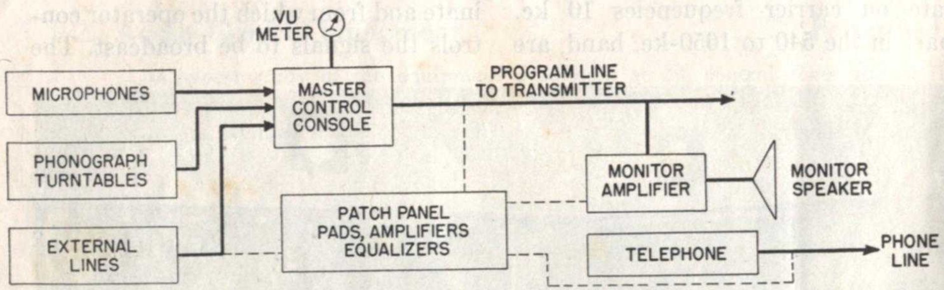


FIG. 1. Block diagram of the basic equipment used in the studios and control room of a broadcast station.

Let us start our study of broadcasting systems with a general view of the complete over-all system.

STUDIO EQUIPMENT

In Fig. 1 is shown the block diagram of the major equipment that the studio operator in a broadcast transmitter uses and must be familiar with. This equipment is physically arranged to give the operator maximum ease in his duties and to permit him to resume normal operation easily and quickly in case of breakdown of any unit in the system.

All program signals—whether they come from microphones or phonograph turntables in the studio or are "piped in" from outside the studios over special leased telephone lines—are applied to the master control console. Faders, mixers, and amplifier circuits in this console are used by the operator to switch in and out, mix, and control the volume levels of the signals to be broadcast. ("Riding the gain," as this activity is called, is a very important part of the control room operator's job. We will study it in more detail later in this Lesson and in other Lessons.) A VU meter at the console gives a visual indication of the program volume level.

The signal is then applied to a line amplifier (which may be contained in the control console), where it is amplified and applied to the program line that runs to the transmitter itself. A part of the output is also applied to the monitor amplifier and loudspeaker to provide aural monitoring of the program.

It is important in commercial operation to have as few and as brief interruptions to programs as possible. To aid the operator to minimize "off-air" time despite inevitable breakdowns of various components and to have a flexible system that can be adapted to many situations, supplementary equipment is provided in the control room. This includes spare amplifiers, equalizers, pads, and a patch panel to interconnect these units as may be desired.

The patch panel, which is so named because it is used to "patch together" various pieces of equipment on a temporary basis, performs many services. It can be used, for example, to switch spare amplifiers quickly in place of defective line or monitor amplifiers. Or, if the line being used to carry a remote broadcast needs equalizing, the patch panel can be used to connect equalizers into the circuit. The patch panel is also the terminus of all remote lines. Even a small station may have ten to twenty remote lines to various sports arenas, churches, and other places where broadcasts may originate. All these lines cannot be permanently connected to the console. Instead, they are brought to the patch panel, from which any desired line can be quickly connected to the console.

The control room generally has a direct telephone line to the transmitter. This phone is very useful, especially in emergencies.

TRANSMITTER EQUIPMENT

The general equipment at the transmitter itself is shown in Fig. 2. The usual path for the incoming program signal is from the program line through an equalizer and a line amplifier to the transmitter, where it modulates the r.f. carrier. The modulated r.f. signal is then applied through an r.f. transmission line and an antenna coupler to the antenna.

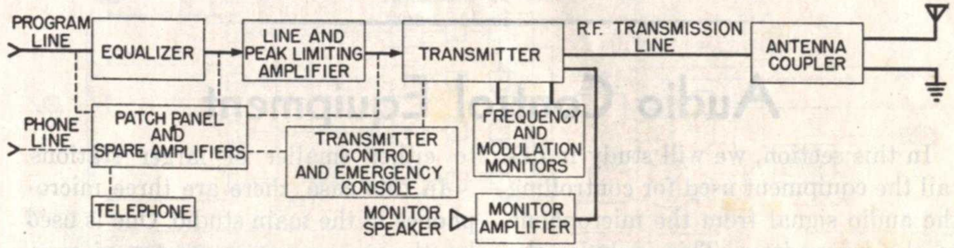


FIG. 2. Block diagram of the transmitter and basic associated equipment of a standard broadcast station.

The other equipment shown is used to monitor the program, to make necessary repairs and adjustments, and to aid in restoring operation quickly in emergencies. The FCC requires that the frequency monitor and modulation monitor be used at all times to indicate the operation of the transmitter itself. In addition, a VU meter is used to give a visual check on the program level, and a monitor system is used with a loudspeaker to give an aural check on operation. Generally, part of the r.f. output signal is detected to provide this aural monitor signal; doing so gives the operator a chance to check the operation of the whole system, since he then hears the program as it sounds to someone listening to a home receiver.

A patch panel, spare amplifiers, equalizers, and pads are also used at the transmitter. This equipment makes it possible to "patch out" defective amplifiers and "patch in" spare units, and to switch a spare line in case of failure or unsatisfactory operation of the program line. This spare line may be either an emergency line used for nothing else, or the line normally used as a direct telephone link between the transmitter and the control room operator.

So that a program can be improvised in case of failure of all lines between the control room and the transmitter, a spare microphone and turntable are generally located at the transmitter. They can easily be patched to the transmitter.

A noise analyzer and an audio oscillator are included as part of the test equipment. These are used to make periodic checks on the frequency response of the audio lines, the amplifiers, or the transmitter, and to check on the signal-to-noise ratio of the various components of the system.

Other test equipment, such as multimeters and oscilloscopes, is also included as part of the equipment at all broadcast stations to facilitate maintenance. Spare tubes and other components, and sometimes a spare transmitter and an emergency primary power source, are also a part of the station equipment.

Audio Control Equipment

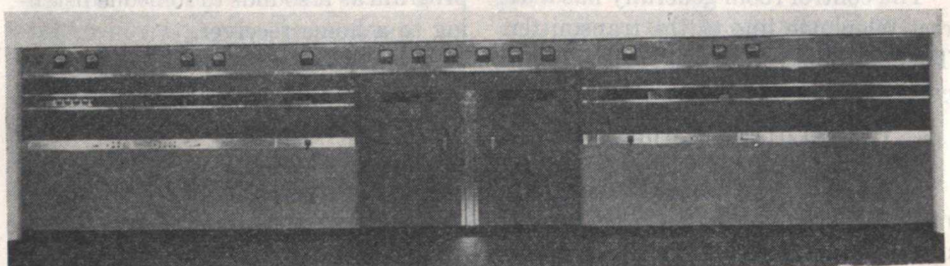
In this section, we will study in detail the equipment used for controlling the audio signal from the microphone to the transmitter. This includes the studio equipment, the control room equipment, the program lines, and the audio equipment at the transmitter.

STUDIO EQUIPMENT

Let us take as an example a station having only two studios, an announcer's booth, and two phonograph turntables. This set-up is typical of many stations. The basic principles given here can, of course, be applied to either smaller or larger stations.

In this case, there are three microphones in the main studio. One is used by the announcer or master of ceremonies, the second is used for general pickups of singing groups or small instrumental groups, and the third is used for spot pickups—say of a soloist or an actor. These microphones are connected through shielded cables to the master control console in the control room.

Both studios and the announcer's booth have monitor speakers. These loudspeakers monitor the program be-



Courtesy RCA

A general view of the front of an RCA 50-kw. standard a.m. broadcast transmitter. The large meters on the top row can be read at great distances, and are used for routine monitoring and checking of the transmitter. Windows in each section permit reading other meters and observation of the tubes and other equipment.

ing broadcast and are used for providing cues to the announcers and performers. The speaker in a studio is automatically switched off when any microphone in that studio is turned on.

A part of the auxiliary equipment used in studio controlling is the studio warning system. When any mike in a studio is "alive," warning lights are turned on. These are generally over the studio door, both inside and outside the studio.

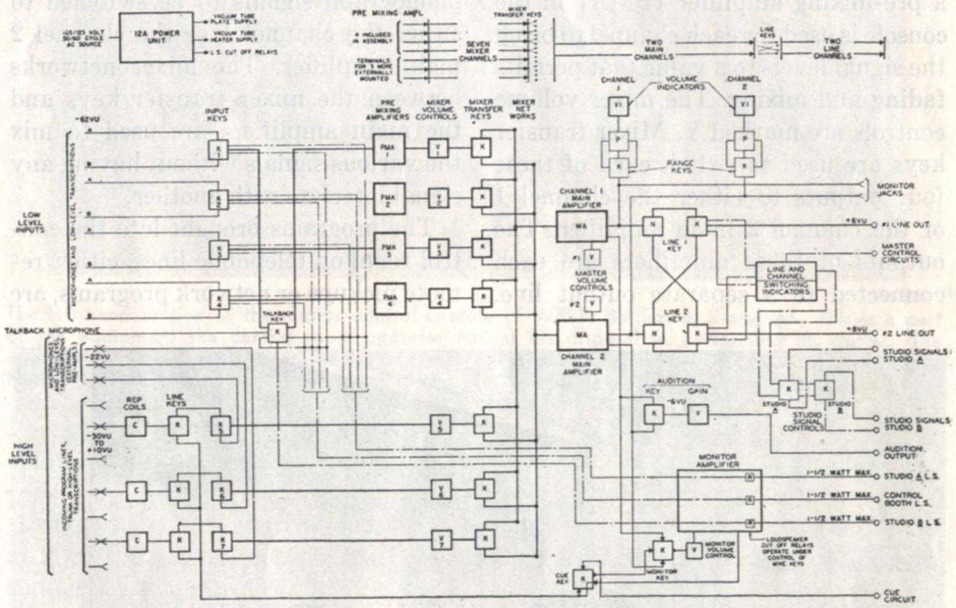


FIG. 3. Functional schematic diagram of the Western Electric 25B Speech Input Equipment.

The other studio in our typical example has two or three microphones and the same loudspeaker monitoring and warning light system. The announcer's booth has only one microphone, a monitor speaker, and warning lights.

The phonograph turntables may be placed either in the announcer's booth or in the control room. If they are in the booth, they are usually operated by the announcer; the control room operator runs them if they are in the control room.

CONTROL ROOM

All of these microphones and turntables are connected to the master control console. Here the proper input signals are switched in, mixed, amplified, and fed to the program line.

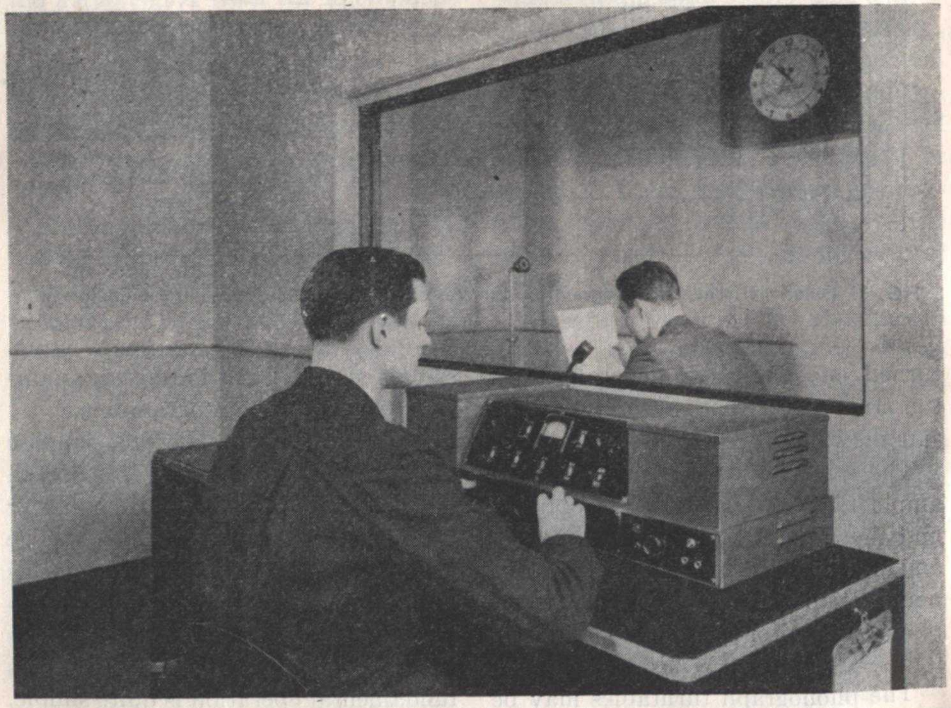
Master Console. Let us suppose that the Western Electric 25B Speech Input Equipment is used as the master console in our typical station. The functional schematic diagram of this unit is shown in Fig. 3. Do not be disturbed by its apparent complexity; as we study it, you will soon see that its fundamental operation is quite simple.

The microphones are connected to the low-level input terminals. Input switches K_1, K_2, K_3, and K_4—called "keys"—are used to switch the desired microphones in and out. Each key controls two microphones (one in each studio), but only one can be "on the air" at one time. If only three microphones are used in the studios, the fourth low-level input line can be used for the announcer's booth.

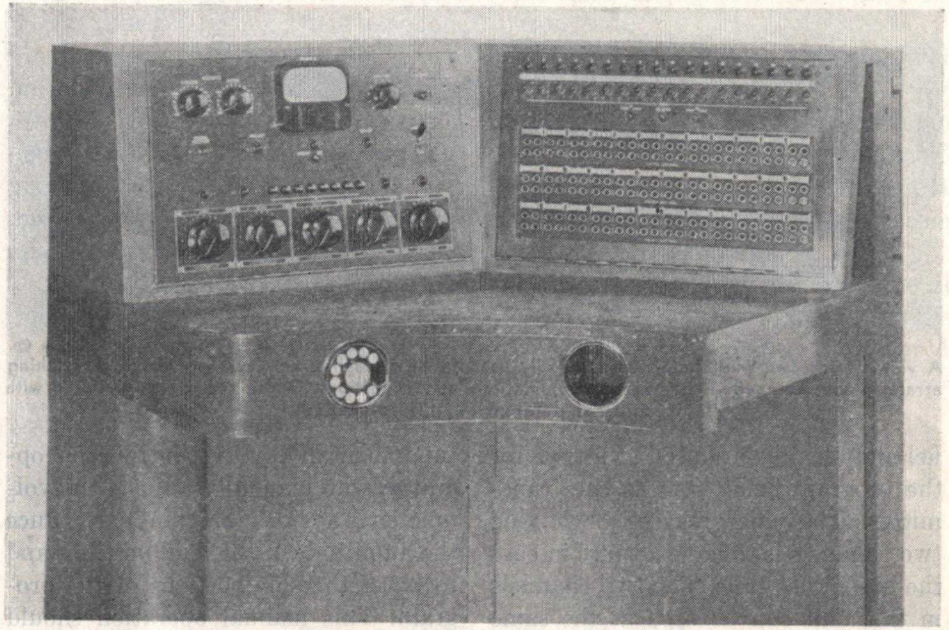
Since the microphones are low-level, a pre-mixing amplifier (PMA) in the console is used for each channel to bring the signal levels to a value that permits fading and mixing. The mixer volume controls are marked V. Mixer transfer keys are used to switch each of these four outputs to either the channel 1 or the channel 2 main amplifier. The outputs of these amplifiers are each connected to a separate output line. Two line keys are used to switch amplifiers from one line to another if necessary.

The phonograph turntables have built-in preamplifiers. Their outputs are connected to the —22 VU lines of the high-level inputs and are switched in or out by keys K_5 and K_6. Their levels are controlled by V_5 and V_6. Two mixer transfer keys permit the phonograph signals to be switched to either the channel 1 or the channel 2 main amplifier. The mixer networks between the mixer transfer keys and the main amplifiers are used to mix the various signals without having any signal interfere with another.

The programs brought into the control room on telephone lines, either remote pickups or network programs, are



For the smaller broadcasting station, or for semi-permanent "remotes" in large systems, the Western Electric type 23 equipment shown here provides a single compact unit containing program production facilities for one or two studios.



Courtesy RCA

The left-hand section of the master control console of WFBR, Baltimore, Maryland. This is a part of the equipment the control room operator has at his disposal in performing his duties. The operator can control, monitor, and check most of the audio system without leaving his desk. Note the small console, the patch panels, and the dial for the private telephone used for direct contact with other parts of the broadcast station.

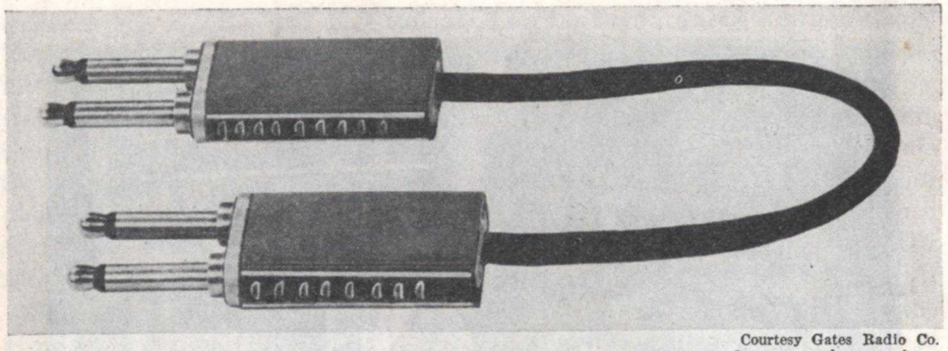
connected to the three lines marked —30 VU to +10 VU. Repeating coils (transformers) are used to couple the lines to the control console. All three channels are controlled by line keys that permit them to be connected to K_5, K_6, and K_7, and thus to the main amplifiers. These line keys also permit signals to be sent out on the remote lines, making it possible for the remote operator to be given instructions over the cue circuit or to hear the program being broadcast. The cue key and monitor key also permit the outside lines to be monitored before being put on the air.

The output of each main amplifier is connected to volume indicators to give a visual indication of the program level.

The monitor key allows the output of either channel to be connected through the monitor volume control to the monitor amplifier to operate the loudspeakers in the studio and in the control booth itself. The broken lines indicate the action of switching any of the microphone input keys to either studio will mute the speakers in that studio. Switching in the talkback microphone, which can be used in the control room to talk to any studio through PMA_1 and the channel amplifier not in use for program broadcasting, disables the microphones in the studio being "talked to."

This speech input equipment also has an audition key, the use of which permits a program being auditioned to be on either channel while the program being broadcast is on the other channel.

Normally, of course, only one chan-



Courtesy Gates Radio Co.

A view of the two plug patch cords widely used in broadcasting services for versatile switching arrangements as needed for varying applications and conditions. These plugs are available with cords of different lengths as needed.

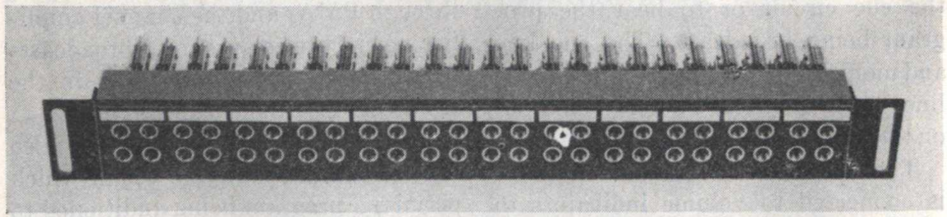
nel and one line are used at a time for the program being sent to the transmitter. The chief reason for having two channels is to have a spare in case the one in use fails. The two channels in this unit can be used at the same time, however. As an example of dual use, an a.m. and an f.m. station operating from the same studio equipment may be fed separate announcements or programs if desired.

Riding Gain. The volume level of a broadcast program may vary as much as 70 db. If the maximum volume level modulates the transmitter 100%, the low volume signals will be lost in the noise level of the received signal. It is necessary, therefore, to provide a means for adjusting the volume level of the program so that these weak passages will not be lost. This is done fundamentally by the control room operator, who manually adjusts the volume level ("rides the gain") to reduce the amplitude of the loud portions and to boost the soft portions of the program. This manual operation should effectively compress the variations in volume level to 25-30 db.

At the master console, the gain can be controlled by adjusting either the mixer volume controls or the master volume control. Generally, however, it is preferable to leave the master gain at some fixed position and adjust the individual volume controls (V_1 through V_7 in Fig. 3).

Patch Panel. As we said earlier, the patch panel in the control room of a broadcast transmitter has many uses.

The first use for this panel is as



Courtesy Gates Radio Co.

Patch panel as used in broadcasting systems. The inputs and outputs of various lines, amplifiers, equalizers, microphones, and other audio equipment are brought out to the pairs of terminals in this panel. Patch cords plugged into this panel cause the switches at each terminal to connect and disconnect circuits and circuit elements as needed.

a terminus for the telephone lines used at a broadcast station. These telephone lines are used to connect the transmitter with remote pickup points and network programs, to send programs from the control room to the transmitter, and to furnish a means of communication between the control room and the transmitter.

A broadcast station may have numerous lines for remote broadcasts. As we pointed out earlier, the master console may not have enough circuits to permit each of these remote lines to be connected permanently. For this reason, all the remote lines, and one or two of the remote line inputs to the master console, are connected to separate positions on the patch panel. Connections are then made by plugging a patch cord into the desired line and into the input line.

Another important use of a patch panel is in switching out a defective amplifier and replacing it with a spare amplifier. The basic method of doing this is illustrated in Fig. 4. The two switches on the input jacks (1-2 and 3-4) are normally closed, connecting the input line to the input of amplifier A. Likewise, the output is normally connected through 5-6 and 7-8 to the output line.

When it is desired to have amplifier B connected as a spare, one end of the patch cord C is plugged into the input jacks of B, and one end of patch cord D is plugged into the output jacks of B. Plugging in these cords opens switches 9-10, 11-12, 13-14, and 15-16.

To connect amplifier B in place of A, the other end of patch cord C is plugged into the input of amplifier A

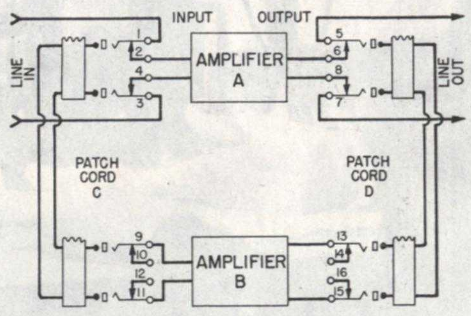


FIG. 4. How patch cords can be used to "patch in" a spare amplifier (B) in place of a defective unit (A).

and the other end of patch cord D is plugged into the output of A. This causes switches 1-2, 3-4, 5-6, and 7-8 to open. The input line is now connected to the input of amplifier B, the output line is connected to the output of B, and amplifier A is out of the circuit. This same basic principle can be used to connect various equalizers in a line, to "patch in" pads, and to perform many other similar operations.

Of course, the basic switching action just described could have been done with ordinary switches. However, when a number of lines, microphones, amplifiers, and pads are to be used in various combinations, the patch panel method permits a more flexible and versatile arrangement than switches would.

Courtesy Western Electric Co.

When broadcasts are made from auditoriums, night clubs, ball parks, or other remote points, a radio operator must go along with the announcer and set up portable speech input equipment like this. During a broadcast, this operator watches the meter, and adjusts the volume control so that the meter pointer stays within a limited range of movement; this prevents overloading of the transmitter by excessively strong sound signals.

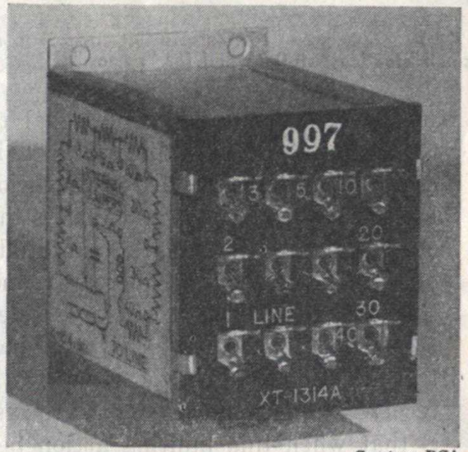
TRANSMITTER EQUIPMENT

The audio control units (patch panel, amplifier, pads, equalizers, and console) at the transmitter are generally quite similar to those already studied. The console used for emergency operation is not usually as elaborate as that used at the control room; some stations, however, use identical units at both places.

A very important part of the transmitter control equipment is the peak-limiting amplifier, which automatically governs the audio level and thus supplements the "gain riding" of the control room operator.

We know that in a.m., the power in the side bands is proportional to the square of the modulation. This side-band power basically determines the amplitude of the audio signal output from the listener's radio. It is, therefore, desirable to keep the average percentage modulation of a broadcast transmitter as high as possible. A 250-watt station with an average modulation of 50% is just as effective, as far as the listener is concerned, as a 1-kw. station with a 25% average modulation.

It is the control room operator's duty to maintain the volume level at as nearly a constant level as possible. This signal is then used to modulate the carrier at a high modulation percentage. This system, however, is generally not sufficient to produce a satisfactory output signal. First, even if the average signal modulates the carrier only 60-70%, a speech wave form has a number of sharp peaks capable of overmodulating the transmitter, producing "splatter," distortion, and undue interference with other stations. It has been found that reducing the amplitude of these peaks does not detract much from the quality of the signal, yet permits the average modulation level to be high without objectionable overmodulation.



Courtesy RCA

An example of a fixed line equalizer as used generally at broadcast transmitters for equalizing unloaded program lines. This unit can be used as either a series or a parallel resonant a.f. circuit and various values of resistances available at the terminals can be wired in to provide a wide variety of corrections. Once an equalizer of this type is set up it is generally not changed.

Since it is not physically possible for the control room operator to act quickly enough to reduce the amplitude of these peaks, electronic amplifiers with variable gain have been devised for this purpose. On normal amplitude signals, these peak-limiting amplifiers act as normal line amplifiers. However, when the amplitude increases above a certain pre-set value, the gain of the amplifier is quickly decreased electronically to limit the peaks.

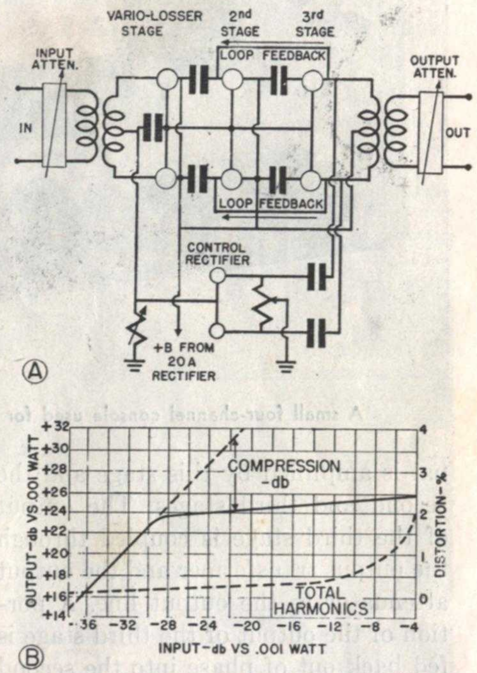
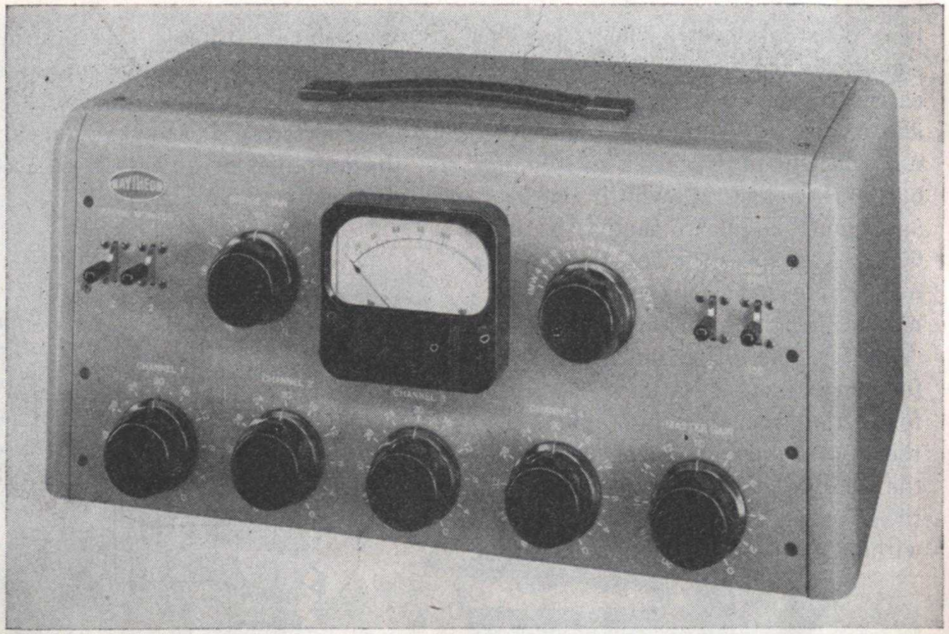


FIG. 5. A: Functional schematic of the Western Electric 1126C program-operated level-governing amplifier. The circles represent tubes and associated parts. B: The gain of this amplifier; the broken line indicates normal amplifier action, the solid line shows the peak-limiting operation. Note that as the compression increases the harmonic distortion increases.

Let us study the operation of a typical unit of this type to see how this limiting is done.

Western Electric 1126C. A simplified diagram of the Western Electric 1126C program-operated level-governing amplifier is shown in Fig. 5A.

The input audio signal is applied through the variable input attenuator to the push-pull first stage, which is called the "vario-losser" stage. The sig-



Courtesy Raytheon

A small four-channel console used for small broadcast stations and for "nemos."

nal is amplified by this stage and the second and third stages. The output of the third stage is coupled through the output transformer and the output attenuator to the output line. A portion of the output of the third stage is fed back out of phase into the second stage to reduce hum noise and to broaden the frequency response.

The action so far is the same as that of any isolation amplifier. To obtain the variable gain characteristic, the output of the third stage is rectified by the control rectifiers to produce a negative d.c. voltage proportional to the amplitude of the output signal. This d.c. voltage is then applied to the vario-losser stage to control its gain. As the output signal increases, the amplitude of the rectified voltage increases, and the gain of the vario-losser stage is decreased. (As you can see, this is similar to the action of an a.v.c. circuit in a receiver.) The result, as Fig. 5B shows, is that when this limiting action begins, large variations in the amplitude of the input signal cause only small changes in the amplitude of the output.

Standard A. M. Broadcast Transmitters

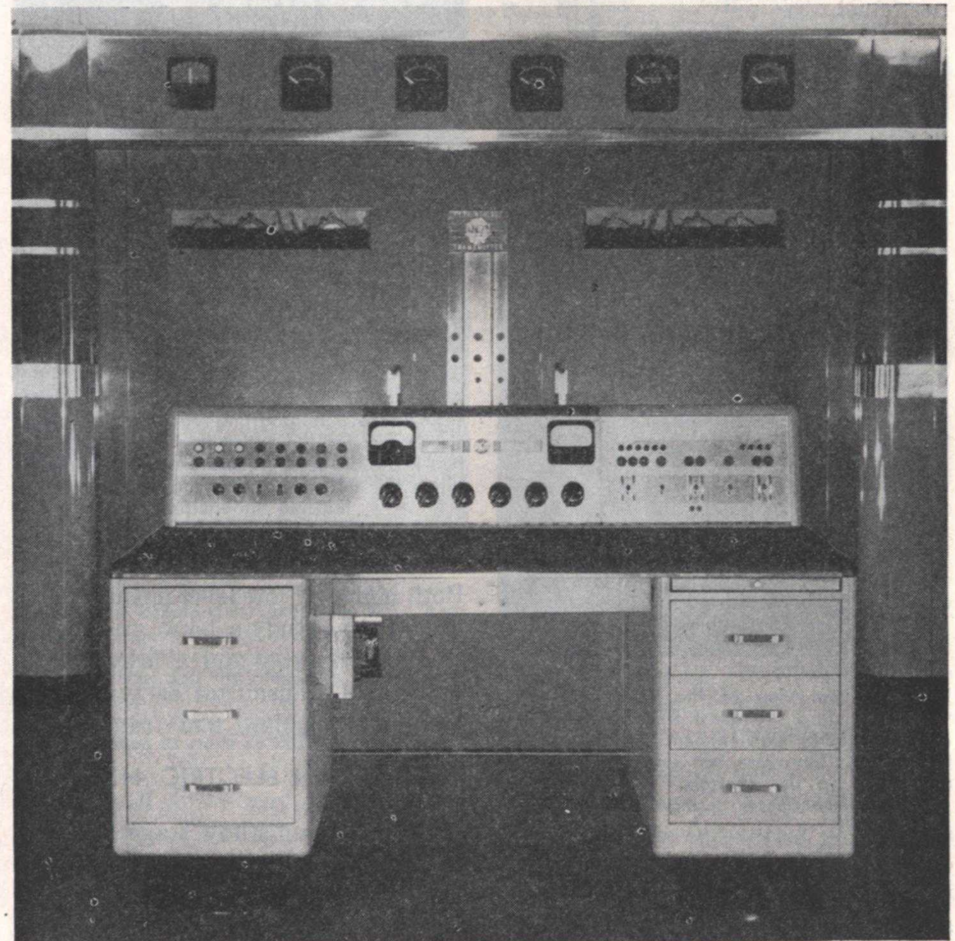
Before we make a detailed study of broadcast transmitters, let us see what standards have been set by the FCC for this equipment. Briefly, these standards are:

1. *Carrier power and frequency stability.* The carrier frequency must be within a maximum allowable deviation of 20 cycles per second. The output power must be kept within +5% and —10% of the assigned value.

2. *Minimum carrier noise level.* The carrier hum and extraneous noise (exclusive of microphone and studio noises) must be at least 50 db below 100% modulation.

3. *Reliability of service.* The transmitter must remain in continuous operation during normal operating times at rated carrier power output with a minimum of interruptions.

4. *Distortion.* The over-all signal dis-

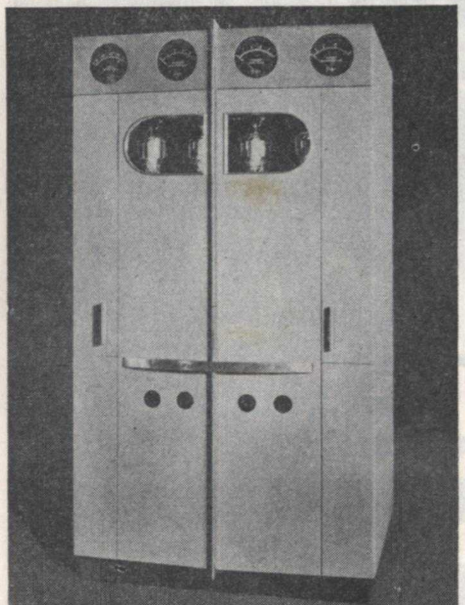


Courtesy RCA

The transmitter control console of the RCA 50-kw. a.m. broadcast transmitter. Similar consoles can be used in lower powered stations.

tortion from the microphone terminals (including microphone amplifiers) to the antenna output must be low. The output must not contain more than 5% harmonics (voltage measurements of arithmetical sum or r.m.s.) when the carrier is modulated 0 to 84%, and not over 7.5% harmonics when it is modulated 85 to 95%. The frequency response between 100 and 5000 cycles must not be more than 2 db from that at 1000 cycles.

5. *Safety*. Suitable safety devices must be included to protect operating personnel.



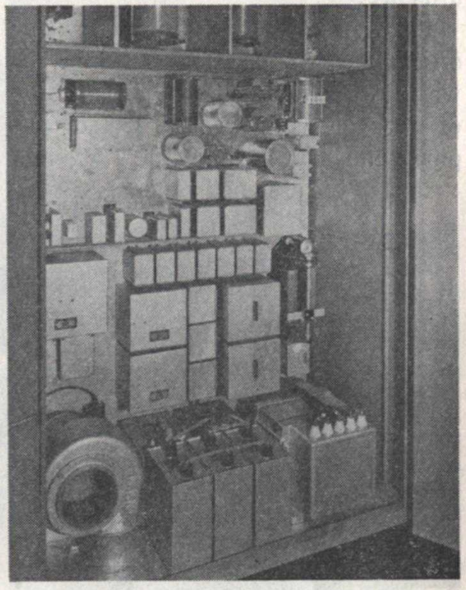
Courtesy Western Electric

FIG. 6. Front view of the Western Electric 443A-1 standard broadcast transmitter. This is a 1-kw. Doherty high efficiency grid-modulated transmitter. There are two side doors to permit access to the controls. These doors are normally closed during operation.

6. *Metering*. Approved electrical metering facilities for proper adjustment and operation of the equipment must be included.

In addition, station owners generally demand that a transmitter be highly efficient, be reasonably small (to minimize installation and housing costs), and have a pleasing appearance.

Standard a.m. transmitters are generally made with output powers of 250



Courtesy Western Electric

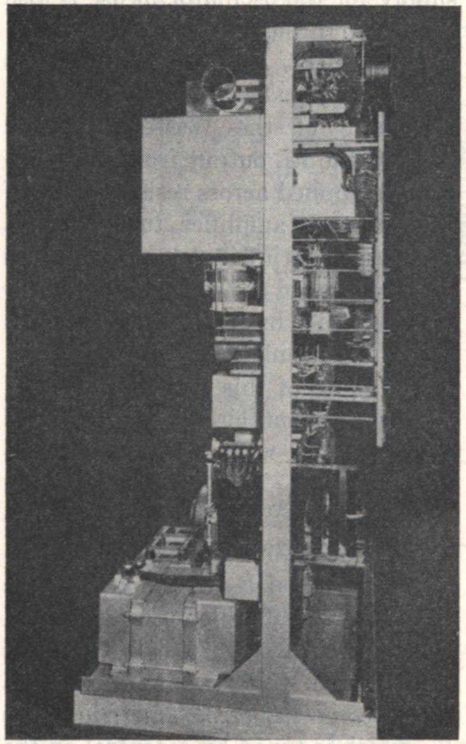
A blower in the rear of the Western Electric 443A-1 radio transmitting equipment provides air cooling for the entire transmitter. This system is designed to provide a slight air pressure within the unit, thus preventing dust from filtering into the equipment.

watts, 1 kw., 5 kw., 10 kw., or 50 kw. Both high and low level modulation is used. Let us study a 1-kw. grid-modulated transmitter and a 5-kw. plate-modulated transmitter as typical examples of standard a.m. transmitters.

WESTERN ELECTRIC 443A-1

We will first study stage by stage the Western Electric 443A-1, 1-kw. Doherty high-efficiency grid-modulated transmitter. A front view of this transmitter is shown in Fig. 6.

702A Crystal Oscillator. Since the congestion of assigned frequencies in the broadcast band makes it necessary for the frequency of the oscillator circuit to be controlled very accurately, broadcast transmitters must be crystal-controlled, and the crystal must be maintained at a constant temperature



Courtesy Western Electric

To provide long trouble-free life in the Western Electric 443A-1 radio transmitting equipment, all electrical components except the three door switches are mounted on a central structure. The heavy plate power equipment and blower are on the base plate, and the remaining apparatus is mounted on the vertical plate. This arrangement facilitates any repairs that the radio operator may need to make on this equipment.

that is well above any possible room temperature. This is done by mounting the crystal in a special housing with automatic control circuits to operate the heater units that maintain the temperature at a constant level.

Fig. 7 shows the oscillator circuits of the WE-443A-1, consisting of two type 702A crystal oscillators, either one of which may be selected by the switch D_{14}. Only one is used at a time —the other is a spare for use in case the first one becomes defective.

As is the general practice, the crystal

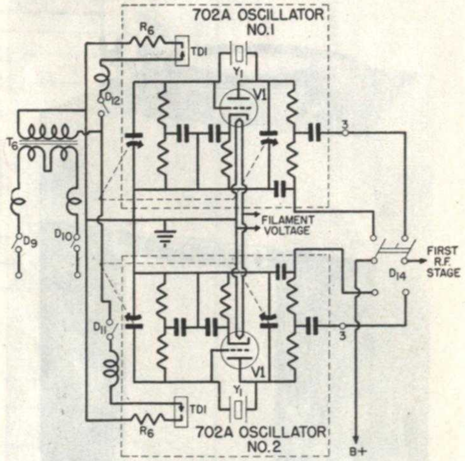


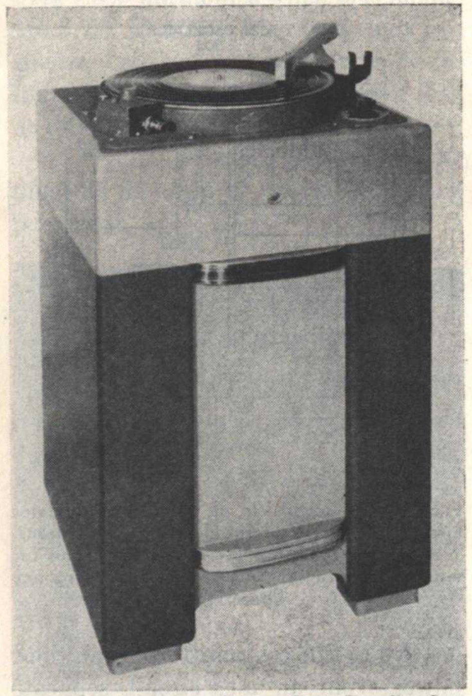
FIG. 7. The schematic of the crystal-oscillator circuits of the Western Electric 443A-1 transmitter. Two 702A oscillators are used; one for regular operation, the other for emergency operation.

heaters in this transmitter obtain their power from an a.c. circuit separate from the rest of the transmitter. The main ON-OFF switch, which (as we will see shortly) controls the other a.c. circuits, does not turn the crystal ovens off. They remain on all the time.

The primary of the transformer T_6 is tapped so that either a 115- or a 230-volt supply line can be used.

The switches D_9 and D_{10} in the line to transformer T_6, and switches D_{11} and D_{12} in the individual power lines to the oscillators, also serve as magnetic overload circuit breakers. All four of these switches should be closed after the oscillators are in position, and the oscillators should be allowed to reach the normal operating temperature of 60° Centigrade (140° Fahrenheit) before transmitter-tuning adjustments are made.

As shown in Fig. 7, each oscillator circuit consists of a quartz crystal Y_1 and a Western Electric 247A vacuum



Courtesy Presto Recording Corp.

The Presto 62 transcription turntable which is typical of the high quality turntables used in reproducing recorded and transcribed programs at many broadcast stations.

tube (V_1) with its associated circuits. The temperature control circuit consists of the heater resistance R_6 and the thermostat TD_1. When the temperature in the crystal enclosure falls very slightly below 60°C, the thermostat TD_1 closes the heater circuit so that current flowing through the resistance R_6 heats the crystal. When 60°C is reached, the thermostat opens the circuit so that no current flows through the resistance. In this way, the crystal is maintained at the proper operating temperature at all times.

The r.f. output from each oscillator is fed from terminal 3 to switch D_{14}, so either oscillator can be connected to the grid circuit of the first r.f. amplifier tube by operating this switch. The plate supply for the oscillator in use is also connected through D_{14}.

First R.F. Amplifier Stage. As shown in Fig. 8, which is a general schematic of the Western Electric 443A-1, the r.f. output from the oscillator is applied across resistance R_3 of the first r.f. amplifier tube VT_2 (a Western Electric 349-A tube). The bias voltage applied to the grid of this tube may be varied by R_1 to adjust the power of the transmitter.

The plate of this tube is connected to the resonant circuit consisting of L_1 in parallel with the variable condenser C_7.

Second R.F. Amplifier Stage. The output of the first r.f. stage is coupled through C_6 and R_8 to the grid of the second r.f. stage, which uses a Western Electric 350-A tube (VT_3). The plate of the tube works into the resonant circuit composed of C_{13} and inductance L_2, which is tuned by a control on the front panel of the transmitter cabinet. The output is coupled to the third stage through C_{12} and R_{16}.

Third R.F. Amplifier Stage. Since a triode (VT_4) Western Electric type 331A is used in the third r.f. stage, the stage must be neutralized. This is done by taking from L_2 a voltage 180° out of phase with the grid voltage and feeding this voltage through C_{22}. Since C_{22} is a fixed condenser, the amount of neutralizing voltage is varied by changing taps on L_2.

The plate of VT_4 works into the

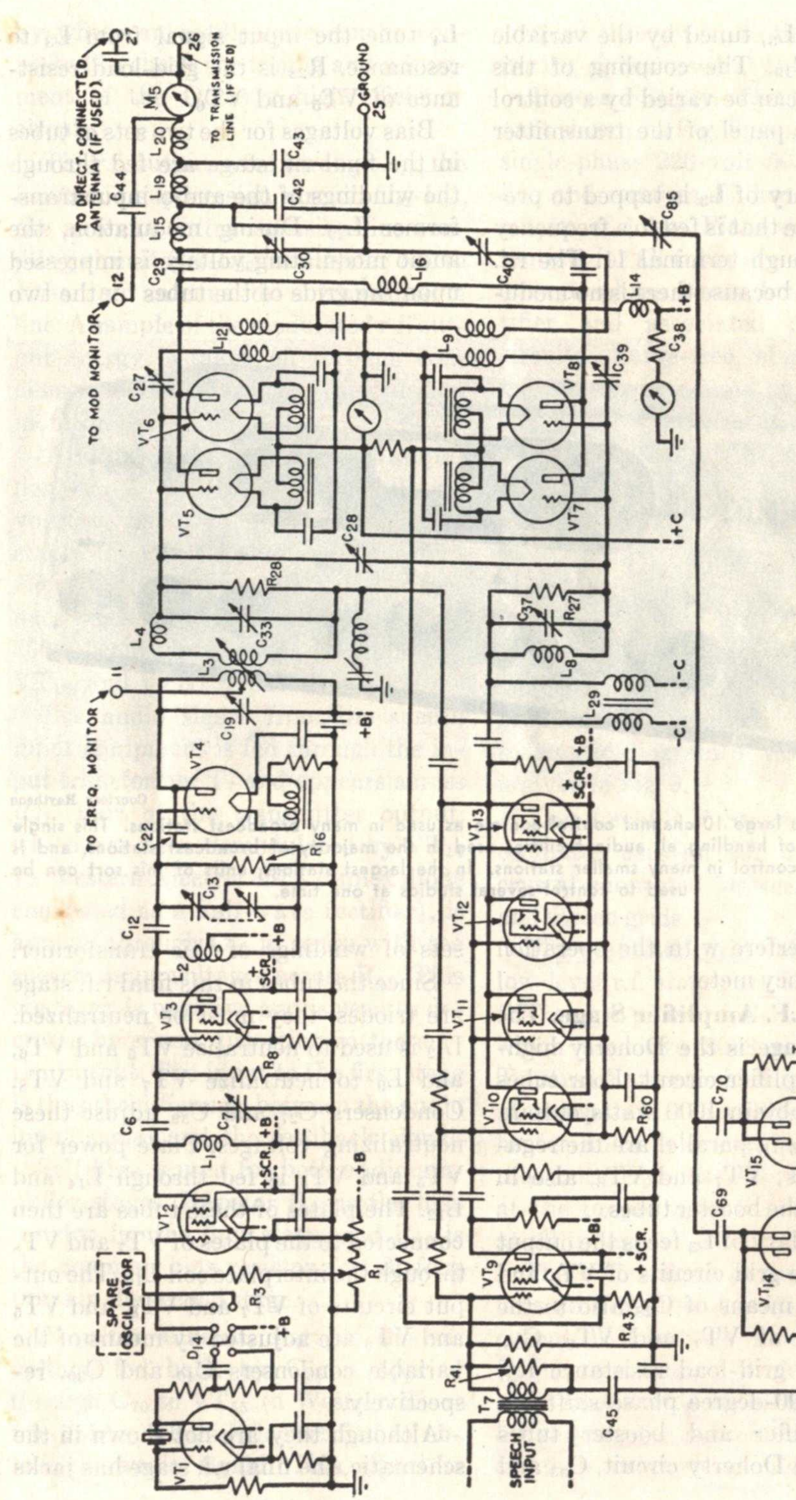


FIG. 8. Schematic diagram of the Western Electric 443A-1 standard a.m. broadcast transmitter using grid modulation and Doherty high efficiency amplification.

transformer L_3, tuned by the variable condenser C_{19}. The coupling of this transformer can be varied by a control on the front panel of the transmitter cabinet.

The primary of L_3 is tapped to provide a voltage that is fed to a frequency monitor through terminal 11. The r.f. is taken here because there is no modulation to interfere with the operation of the frequency meter.

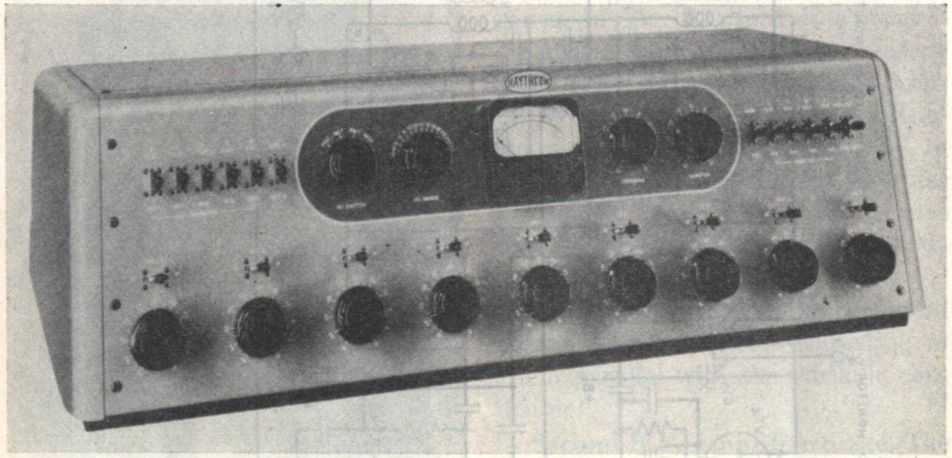
Fourth R.F. Amplifier Stage. The fourth r.f. stage is the Doherty high-efficiency amplifier circuit. Four tubes are used to obtain 1000 watts output. VT_5 and VT_6 in parallel are the regular amplifiers; VT_7 and VT_8, also in parallel, are the booster tubes.

The secondary of L_3 feeds the output of VT_4 to the grid circuits of VT_5 and VT_6 and by means of C_{28} also to the grid circuits of VT_7 and VT_8. C_{28}, L_8, C_{37}, and grid-load resistance R_{27} provide the 90-degree phase shift between amplifier and booster tubes needed in the Doherty circuit. C_{33} and L_4 tune the input signal from L_3 to resonance. R_{28} is the grid-load resistance of VT_5 and VT_6.

Bias voltages for the two sets of tubes in the final r.f. stage are fed through the windings of the audio-input transformer L_{29}. During modulation, the audio modulating voltage is impressed upon the grids of the tubes by the two sets of windings of this transformer.

Since the tubes in this final r.f. stage are triodes, they must be neutralized. L_{12} is used to neutralize VT_5 and VT_6, and L_9 to neutralize VT_7 and VT_8. Condensers C_{27} and C_{39} adjust these neutralizing voltages. Plate power for VT_5 and VT_6 is fed through L_{14} and L_{12}. The plates of these tubes are then connected to the plates of VT_7 and VT_8 through the interplate coil L_{16}. The output circuits of VT_7 and VT_8, and VT_5 and VT_6 are adjusted by means of the variable condensers C_{40} and C_{30}, respectively.

Although they are not shown in the schematic, the final r.f. stage has jacks



Courtesy Raytheon

An example of a large 10 channel control console as used in many broadcast stations. This single unit is capable of handling all audio facilities used in the majority of broadcast stations, and is used as master control in many smaller stations. In the largest stations, units of this sort can be used to control several studios at one time.

by which an oscilloscope can be connected to check the tuning and adjustment of the Doherty high efficiency circuit.

The r.f. output is fed through L_{15}, the harmonic suppression circuit C_{42}-L_{19}, the antenna or transmission-line coupling circuit C_{43}-L_{20}, and meter M_5 to either an antenna or a transmission line. A sample of the modulated r.f. output energy is taken off through condenser C_{44} to feed the modulation monitor.

Audio Amplifier. The audio amplifier, which provides the modulating voltage, has two resistance-coupled stages. The first stage uses a Western Electric 349A pentode (VT_9). The second stage uses four Western Electric 350A beam power tubes (VT_{10}, VT_{11}, VT_{12}, and VT_{13}) in parallel.

The audio signal from the speech input equipment is fed through the input transformer T_7 and appears across R_{41}. Part of the transmitter output, which has been demodulated by VT_{14} (a Western Electric 351A duplex diode connected as a half-wave rectifier), is applied through C_{45} in series with the speech input voltages across R_{41}. This feedback is negative and is used to decrease hum and distortion in the carrier output. The input to the first stage is thus the difference between the audio input signal and the feedback signal.

Self bias is used for both audio amplifier stages. Resistor R_{43} is the bias resistor for the first stage, and R_{60} is the common bias resistor for all four tubes in the second stage.

Monitor Circuit. Part of the r.f. voltage fed back by C_{85} is applied through C_{70} to VT_{15} (a Western Electric 351A), where it is rectified to obtain an audio signal. This signal is coupled through T_8 to the aural monitoring circuit used at the transmitter.

Power Supply. The power supply (not shown in Fig. 8) operates from a single-phase 220-volt 50- or 60-cycle line and requires 4.3 kw. for a carrier output of 1 kw. Plate and screen potentials for all tubes are obtained from a single-phase 4-tube bridge-type rectifier and associated potentiometer circuits. Surge-free starting of the transmitter is secured by using a two-step starting system for the rectifier. The bias potential for the final stage is obtained from a single-phase full-wave rectifier. All other r.f. and a.f. stages are self-biased.

RCA 5-F TRANSMITTER

The RCA 5-F transmitter is an example of a 5-kw. high-level-modulated, broadcast transmitter. A simplified schematic diagram of this transmitter is given in Fig. 9.

Low-Level R.F. Stages. The crystal oscillator uses an 802 tube with the crystal connected between the control and screen grids.

The plate and grid voltages for the low-level r.f. stages are obtained from the single-phase full-wave rectifier, which uses two 8008 rectifier tubes. Terminals are provided for connection of a separate 115-volt supply to the heater units in the crystal holders so that both crystals will be maintained at the proper operating temperatures at all times.

The buffer stage in this transmitter uses an 828 tube. A portion of the r.f. output of this stage is coupled to the frequency monitor through R_1. The plate tank circuit in this stage is tuned by varying the inductance L_1. This is common practice in high-power r.f.

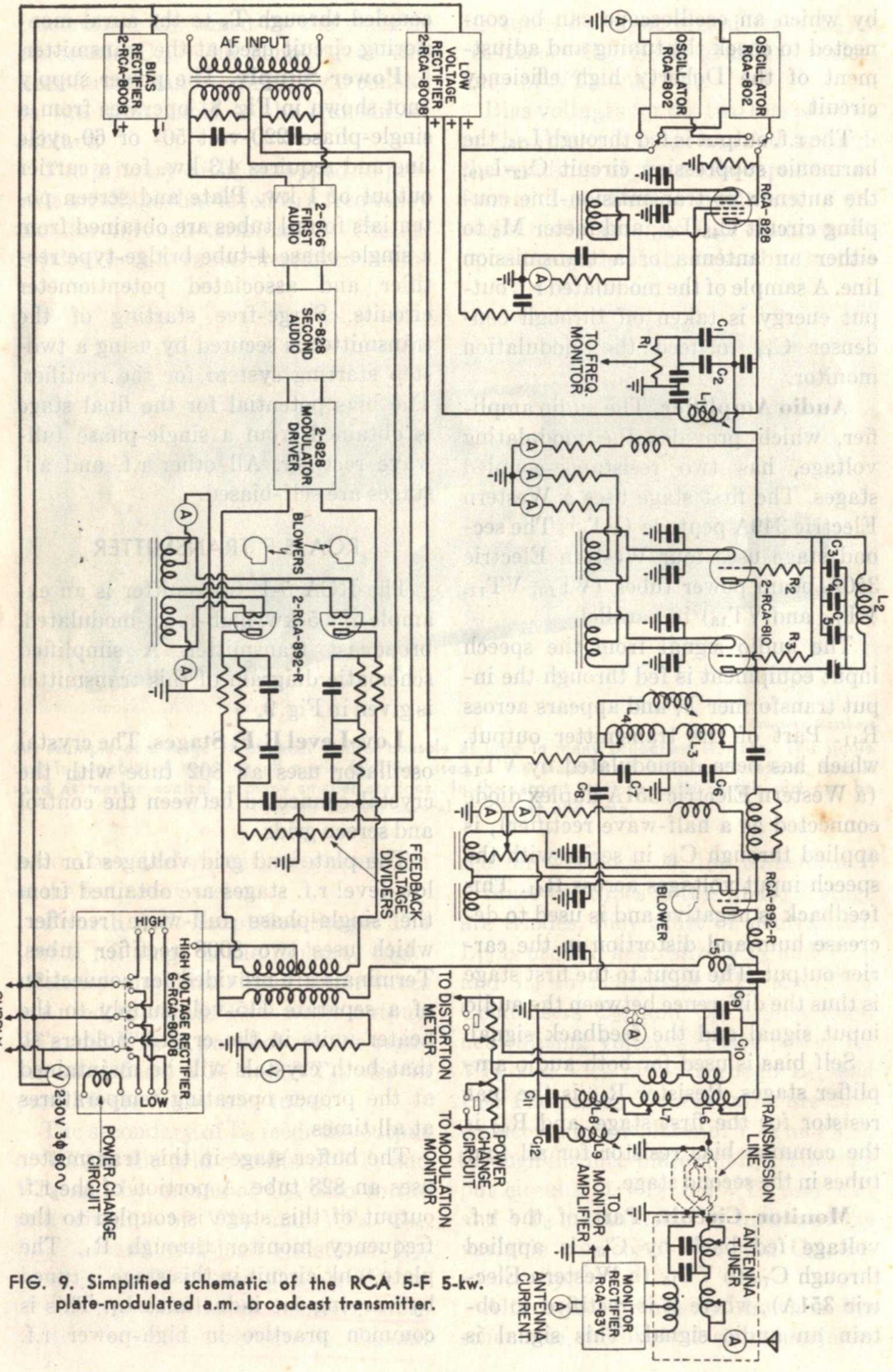


FIG. 9. Simplified schematic of the RCA 5-F 5-kw. plate-modulated a.m. broadcast transmitter.

amplifiers, because the size and cost of variable condensers capable of handling the high circulating currents and peak voltages encountered is excessive.

The r.f. driver stage consists of two 810 tubes in parallel. R_2 and R_3 are used as parasitic suppressors. This stage is neutralized by the parallel resonant circuit L_2, C_3, C_4, and C_5.

High Power R.F. Amplifier. The modulated r.f. amplifier stage uses an 892-R tube, air cooled by a blower motor. Notice that plate neutralizing is used, with L_3, L_4, and C_6 and C_7 balanced to provide the out-of-phase neutralizing voltage fed through C_8 to the output tank circuit. The tank circuit consists of fixed tuning condensers C_9 and C_{10}, and main tank coil L_5. This tank circuit is also a part of the coupling network L_6, L_7, L_8, C_{11} and C_{12}, and L_9, and is tuned by variable inductance L_8. Variable inductance L_9 in series with the output provides fine control of the power output and loading. Condensers C_{11} and C_{12} are selected to provide impedance matching for any transmission line loading between 70 and 500 ohms.

The antenna tuner (located in the "doghouse" at the end of the transmission line) is a T network that provides a proper termination for the transmission line. It also includes a monitoring rectifier using an 83-V tube inductively coupled to the antenna network. The rectifier current is fed back to the transmitter to operate an antenna circuit indicator located on the exciter unit or control desk. Since the rectified current is directly proportional to the current flowing in the antenna circuit, this meter, when properly calibrated, provides a true indication of the transmitter output. The audio envelope of the rectified carrier is also fed back to the input of the station's aural monitoring amplifier.

Audio System. An audio speech input of approximately +4.5 VU is delivered from the line amplifier to the input transformer. The secondary of this transformer is split into two sections, which are connected in series with the feedback voltage dividers in the output of the 892-R modulator stages. The grids of the first stage audio tubes (two 6C6's) are, therefore, excited by a voltage that is the vector sum of the input and feedback voltages.

The first stage is resistance-coupled to the second stage (two 828's), which, in turn, is resistance-coupled to the third audio amplifier (also two 828's). This stage is coupled to the 892-R modulators through a driver transformer.

D.C. power for the modulators and the modulated amplifier is furnished by a three-phase full-wave rectifier using six 8008 mercury-vapor tubes.

The power output of this transmitter can be reduced to 1 kw. if desired. During 1-kw. operation, the high-voltage rectifier functions simultaneously as a three-phase full-wave rectifier and three-phase half-wave rectifier through a specially designed power-change circuit. This permits the supply voltage for the modulated amplifier to be cut in half (through the three-phase half-wave unit) while the modulators continue to operate at full voltage. The half-wave section operates through a separate filter system.

Conversion to 10 Kw. A spare 892-R tube socket is provided in this transmitter. If 10-kw. operation is desired, this tube can be wired in parallel with the final r.f. amplifier. The conversion kit includes a blower, filament transformers, a 10-kw. modulation transformer, a modulation reactor, and all necessary accessories.

Protective And Control Devices

All broadcast transmitters have certain control and protective features designed to facilitate the operation of the transmitter, to protect the equipment from damage, and to protect personnel from the high voltages used in the equipment.

LINE VOLTAGE CONTROL

For maximum life and utility, large transmitting tubes must be operated with filament voltages that are held very close to the rated values. Furthermore, to maintain the power output within the tolerance set by the FCC, it is necessary that the plate voltage to a transmitter be maintained close to its proper value.

However, the a.c. input line voltage for most transmitters will vary as other loads are applied to or removed from the local power supply line. These variations can cause excessive variations in the filament and plate voltages of a broadcast transmitter, and must, therefore, be eliminated or minimized.

One method of compensating for variations in the line voltage is to use a variable auto-transformer in the a.c. power line. In the Western Electric 443A-1, for example, the input auto-transformer can maintain the input at 220 volts when the line voltage is anywhere between 187 and 250 volts.

Another method is to design the transmitter so that the filament and plate voltages are correct on low a.c. line voltages. The excessive voltages encountered when the line voltages rise are corrected by varying series rheostats in the filament and plate circuits.

The best method, however, is to use automatic voltage-regulating transformers. These transformers are generally the saturated core type you studied in an earlier Lesson. Their advantages are that they are quick-acting and fully automatic in their operation. Some transmitters have voltage regulators built in as original equipment; in other installations, the regulator is inserted between the a.c. power lines and the a.c. input to the transmitter.

CONTROL SWITCHING

Although it is possible to open and close plate and filament circuits directly with hand-operated switches, the control circuits in most broadcast transmitters are made or broken by relays controlled by hand-operated switches. This system is safer for the operator, since the relays operate on relatively low control voltages, and also, as we shall soon see, provides more flexibility of control.

Many control relays have "holding" contacts that keep the relay in its operated position once it has been actuated, regardless of whether the actuating switch is kept closed or not. This permits the relays to be controlled by push buttons, since the control switch need be closed only momentarily to operate the relay. Such holding relays are used in many types of control and protective devices, so let's take a moment to see how they work.

Holding Coils. One common use for holding coils (and one which shows the basic operation) is in conjunction with push-button on-off controls as shown in Fig. 10.

In this circuit, the Off and On buttons are connected in series with the relay operating voltage and the relay. The Off button is normally closed, the On button is normally open, and the "holding contacts" 1 and 2, in parallel with the On button, are also normally open.

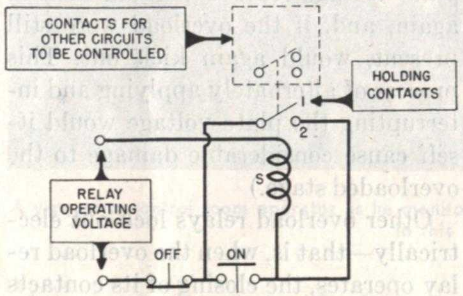


FIG. 10. Basic circuit showing the action of the holding coil circuit widely used in transmitter control systems.

To operate the relay, the On button is momentarily depressed to complete the circuit through the relay coil. Operation of the relay causes contacts 1 and 2 to close; since they are in parallel with the On button, they maintain a closed circuit through the relay coil, and thus keep the relay in its operated position, even when the On button is released.

These holding contacts are used only to keep the relay operated. Other contacts on the relay perform whatever function or functions the relay has—such as closing a filament or plate supply circuit.

The relay will remain operated until the circuit through its operating coil is broken. This is done by depressing the Off button. The relay then drops out, opening contacts 1 and 2. When the Off button is released, its contacts close again, but, since holding contacts 1 and 2 are now open, the relay will not operate until the On button is depressed again.

TIME DELAY PLATE SUPPLY CONTROLS

Transmitting tubes, either filament or cathode types, must have the filament or cathode hot and emitting the normal number of electrons before the plate voltage is applied to the tube. If the plate voltage is applied before full emission is reached, the tube may be damaged. Since about 30 seconds is required for a cold cathode (or filament) to reach full emission, the filament and plate supplies in broadcast transmitters generally operate from separate transformers with provision to turn on the plate supply only after the filaments have been on for 30 seconds.

This can be, and is sometimes, done simply by having separate switches for the plate and filament supplies and by waiting 30 seconds before turning the plate supply on.

Generally, however, automatic devices are used that will either turn on the plate supply or permit it to be turned on only after the filaments have been on for 30 seconds. Various types of time delay devices are used for this purpose. One is a small electric motor with a gear mechanism that closes a switch after 30 seconds. Another is a thermal element that expands when heated; filament voltage is applied to this thermal element, heating it until it expands enough to close switch contacts mechanically connected to it. Generally these contacts actuate a holding relay that applies the plate voltage and also by-passes the thermal element, permitting it to cool without breaking the plate supply circuit. If the plate circuit is turned off by some other means, the holding coil will drop out and will not be actuated again until the thermal element heats and again makes contact. This process is called "recycling."

A third type of time delay circuit uses an electrical time constant (generally a condenser charging or discharging through a resistor) to control the grid voltage on a tube. When this voltage reaches a certain critical value, the tube will conduct (if a gas tube, it will ionize), thereby operating a relay. This relay either turns on the plate supply voltage of the transmitter or permits it to be turned on. One of these types of electronic controls will be studied in detail shortly when we analyze the control and protective features of the Western Electric 443A-1.

OVERLOAD RELAYS

Since the high-level stages in radio transmitters (the final audio and r.f. stages) operate close to the maximum permissible power level, a current flow only slightly above normal will cause damage to the tubes or circuit components. If such an abnormal flow starts, the plate power to the affected stages must be quickly removed to prevent damage. All broadcast transmitters have automatic overload relays for this purpose.

In general, these relays are located in the B— lead of the final r.f. stage and are adjusted to "kick out" at a value of plate current that is slightly above the normal peak value. When this current value is exceeded, the relay operates and removes the plate voltage to the stage. One method of doing this is to have the plate supply leads connected through the relay contacts so that relay operation opens the circuit. The relay armature locks mechanically in this open position, and the power cannot be reapplied to the stage until the operator releases the relay arm. (If there were no mechanical locking, the relay would kick out, then, with the plate voltage removed, would kick in again, and, if the overload were still present, would again kick out. This process of alternately applying and interrupting the plate voltage would itself cause considerable damage to the overloaded stage.)

Other overload relays lock out electrically—that is, when the overload relay operates, the closing of its contacts operates a holding relay. One set of contacts on this relay then closes, operating the holding coil, and another set opens, cutting off the plate power. Of course, removal of the plate power will permit the overload relay contacts to open again, but the holding relay will remain operated and the plate power will remain cut off. The circuit can be put back in operation by momentarily opening the circuit of the coil of the holding relay.

Many of the transmitter overloads that occur last for only a short period of time. They may, for example, be caused by a sudden increase in line voltage, or by a particle of dust or an insect that may have caused a momentary arc in the r.f. tank circuit. In these cases, the d.c. power can safely be reapplied to the transmitter a fraction

Courtesy General Electric

A view of a control room operator as he monitors and "rides gain" on the three microphones used in this broadcast.

of a second after the overload has occurred. Some transmitters have automatic means for doing this in the temporary absence of the operator.

These means consist of mechanical or electro-mechanical devices that reapply the d.c. power a fraction of a second after the overload relay has kicked out. If the current flow at this time is normal, the program will be resumed without appreciable interruption. However, if the overload still exists, the relay will again kick out. To prevent the relay from oscillating if the overload continues, it is generally provided with stepping contacts so that, after a certain number of trials (perhaps three), the relay will lock out and will not again kick in until the operator has released it.

To prevent overloads when a transmitter is being tuned up, most broadcast transmitters have provisions for reducing the d.c. power applied to the high-level r.f. stages. This can be done by reducing the a.c. line voltage input to the plate supply transformer or by using a resistance in series with the d.c. plate voltage to reduce the voltage during tuning adjustments.

DOOR INTERLOCKS

Another very important protective feature in all broadcast transmitters is the door interlocks. These interlock switches open whenever any door of the transmitter through which it is possible to come into contact with any dangerously high voltages (above 300 volts) is opened. They cut off the high d.c. voltages by opening the a.c. line to the high-voltage rectifiers.

Where there are several doors, these switches are connected in series; thus, all doors must be closed before the high voltage can be applied to the transmitter.

In some broadcast transmitters, condensers with high-resistance leakage paths have such long time constants that dangerous potentials may be present long after the plate voltage has been removed. To furnish further protection in these cases, special means are provided to discharge these condensers when the transmitter doors are opened. Generally a low-resistance shorting bar is placed across the condenser terminals by the action of opening the transmitter door.

PROTECTIVE AND CONTROL CIRCUITS OF WE 443A-1

To illustrate many of the features just described, let us now examine the control and protective circuits of the Western Electric 443A-1 transmitter. These are shown in Fig. 11.

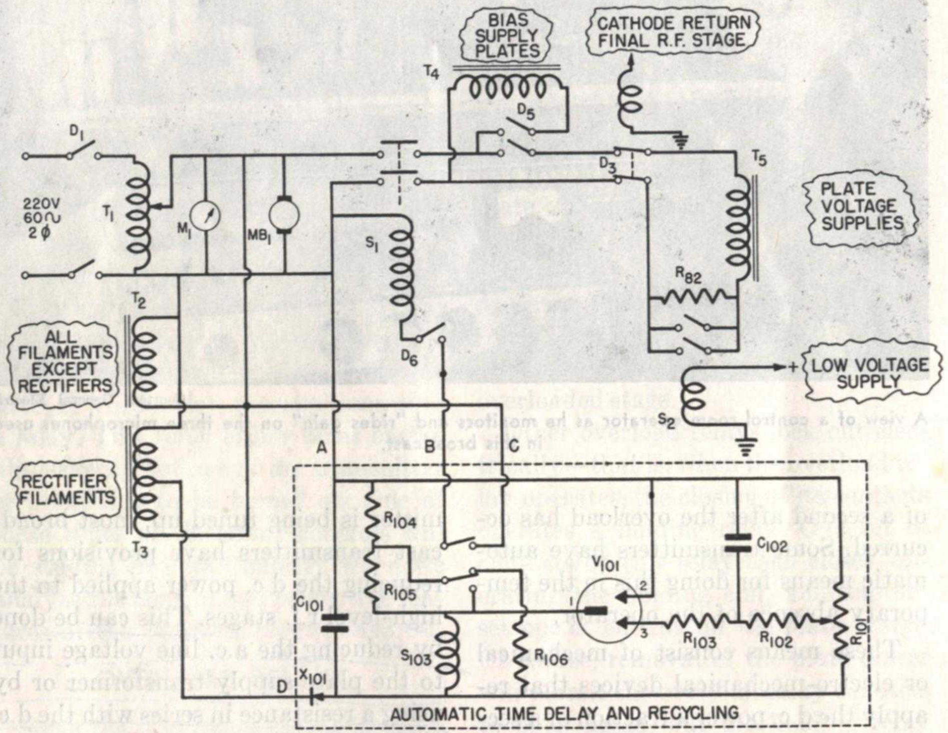


FIG. 11. The schematic of the control and protective circuits of the Western Electric 443A-1 transmitter. It illustrates many of the practices followed in transmitter control and protective systems.

The 220-volt, 60-cycle, single-phase a.c. is applied to the transmitter through main power switch D_1 and variable auto-transformer T_1. As you learned, this transformer can be adjusted to provide a 220-volt input when the power line voltage is anywhere between 187 and 250 volts. The a.c. voltage to the transmitter is measured by voltmeter M_1.

When D_1 is closed, power is applied

through T_2 to the filaments of all tubes except the rectifiers, and through T_3 to the rectifier filaments. The blower motor (MB_1) for air-cooling the final r.f. tubes also starts operating, and a portion of the a.c. line voltage, taken off through a tap on the primary of T_3, is applied to terminals A and D of the electronically controlled automatic time delay circuit. The contacts between B and C in this unit are open when the main power switch is first closed.

When the filament voltage has been on for about 30 seconds, the contacts between B and C in the time delay circuit close. (We will study the details of this circuit operation later.) If the door interlock switches D_6 (actually three switches in series) are closed, S_1 will now operate, closing its contacts; if D_5 is also closed, both T_4 (bias plate supply) and T_5 (plate voltage supplies) will be energized. D_5 is the plate-voltage on-off switch; as you can see, it has no effect until 30 seconds after the filament voltage is applied.

If the low-level stage of this transmitter is not operating, there is no r.f. excitation for the final r.f. stage, and the latter stage will be damaged if full plate voltage is connected to it under these conditions. To prevent such damage, relay S_2, which has normally open contacts, is connected to the low-voltage supply for the low-level stage. If the low-voltage supply is not operating (indicating that the low-level stage will not operate), S_2 will not be energized; resistor R_{82} will then be in series with the primary of T_5, reducing the current flow through this transformer and thereby reducing the voltage supplied to the plates of all tubes, including those of the final r.f. stage. If, on the other hand, the low-voltage supply is operating, S_2 will operate; its contacts will then close and short R_{82}, permitting full current to flow through the T_5 primary and thus permitting full plate voltage to be developed across the T_5 secondary.

The overload relay in this circuit is connected in the cathode return of the final r.f. stage. If it operates because of excessive current flow, contacts D_3 open, thus removing all plate voltages.

Operation of Electronic Time Delay. When the main power switch D_1 is closed, an a.c. voltage is applied to A and D of the time delay circuit. This a.c. is rectified by X_{101}, so there is a d.c. voltage across C_{101}. This d.c. voltage is applied through S_{103} to terminals 1 and 2 of gas tube V_{101}. This voltage is not enough to ionize the tube. However, terminal 3, which is initially at the same potential as terminal 2, slowly rises in potential as condenser C_{102} charges. When the potential on terminal 3 becomes high enough, the tube ionizes. The rate at which C_{102} charges (and therefore the delay time of the circuit) is determined by R_{101} and R_{102}. R_{101} can be adjusted to vary this time.

The current through S_{103} before V_{101} ionizes is limited by R_{104} and R_{105} and is not sufficient to cause the relay to operate. However, when V_{101} ionizes, there is an increase in current through S_{103} that causes it to operate and close the contacts between B and C. As you learned earlier, these contacts are one of the basic controls of the transmitter. Condenser C_{102} will discharge through V_{101} when it ionizes, but the tube will not de-ionize until the voltage across A and D is removed. When this voltage is removed, contacts B and C open and will not again close until the complete cycle has repeated. This gives automatic recycling.

Antennas and Station Locations

The effectiveness of broadcast service depends in large part on several factors: the operating power, the frequency of operation, the antenna system used, the ground conductivity, and the location of the transmitter site with respect to the area to be covered. Since the station frequency and operating power are fixed by the FCC, the choice of a transmitter site and the design of the antenna and ground system are the only factors directly under the control of the broadcast engineer.

Let us see what things we must take into account in choosing a site and designing a ground and antenna system.

TRANSMITTER LOCATION

Although the choice of a broadcast transmitter site is usually made by consulting engineers who are highly advanced specialists in the field, it is worth while for you to get a general picture of the factors affecting this choice.

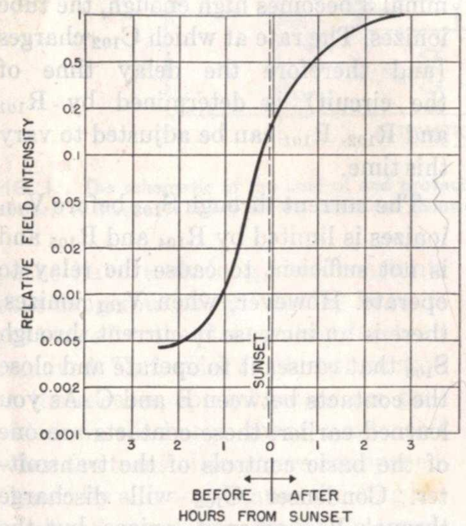


FIG. 12. How the relative field intensity skywave from a broadcast station varies. Note that the sky wave intensity increases sharply about sunset.

Basic Considerations. It is the primary objective of a broadcast station to deliver not just an "understandable" signal, but an interference-free and distortionless signal to the receiver. This kind of service is rendered by a station in what is defined as the primary coverage area of the transmitter. Primary service coverage is the result of the ground wave at the surface of the earth, which must have a carrier-to-noise ratio of at least 18 db, and a field strength of at least several times the strength of the sky wave. The area covered is dependent on the frequency of the transmitter; if two stations have the same amount of power and antenna system efficiency, the one with the lower frequency will have the greater ground wave strength, and consequently the greater coverage.

The so-called "secondary coverage" area of a broadcast transmitter is that area outside the primary service area reached by sky wave propagation, and therefore subject to selective fading and resultant distortion. Since the sky wave (at broadcast frequencies) is almost entirely absorbed during the daytime, the secondary service area is of appreciable importance only at night. Fig. 12 illustrates the attenuation curve of the sky wave through the sunset period.

The field strength required for satisfactory coverage depends on the interference level at the receiving point. Fig. 13 shows the approximate field strengths necessary for adequate coverage under various conditions. In general, the interference level is greatest in the business section of large cities, less in the residential areas, still less in small towns, and least of all in rural areas.

PRIMARY SERVICE

Area	Field Intensity Ground-Wave
City business or factory areas	10 to 50 mv/m
City residential areas	2 to 10 mv/m
Rural—all areas during winter or northern areas during summer	0.1 to 0.5 mv/m
Rural—southern areas during summer	0.25 to 1.0 mv/m

FIG. 13. Minimum ground wave field intensity necessary for primary coverage of different areas and for different seasons.

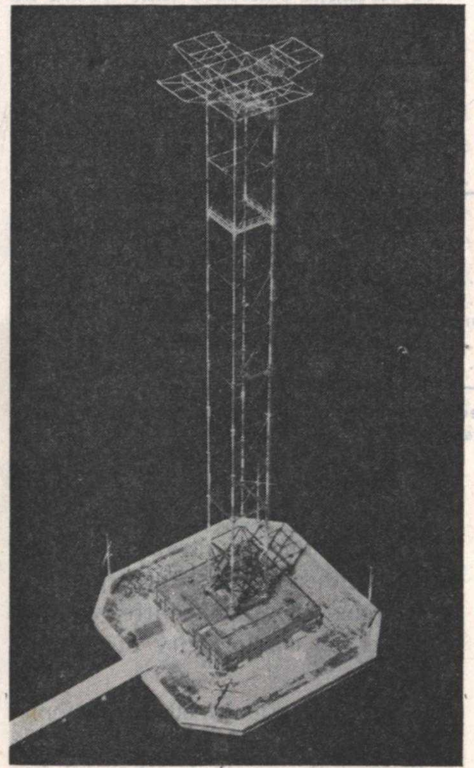
In locations where conditions are more favorable than average, primary coverage will be obtained with weaker ground field strengths than those indicated in Fig. 13.

When building or moving a broadcast station to a new location is contemplated, an application for approval of the transmitter site must be submitted to the Federal Communications Commission. There must be included with this report a map having a scale of not less than one inch to the mile, showing the 250, 25, and 5 mv/m contours and the population residing within the 250 mv/m contour. The FCC requires the station location be such that not more than 1% of the population to be served by the station be in this 250 mv/m area, where other signals will be interfered with. This map must also show by various symbols the proposed location, the character of each area (business, manufacturing, residential, etc.), the heights of tall buildings or other obstructions, the density and distribution of the population, and the locations of airports and airways.

The desirability of any particular site may be judged primarily by the field strength contours that would be produced by a transmitter at that location, considering the population within each contour and the areas where the signal might be subject to night-time fading and interference. The ground conductivity is usually, therefore, the most important single factor in determining the choice of a transmitter site, since, all other factors being equal, the field strength of a transmitter will depend on the conductivity of the antenna site.

In actual practice, in cities and populated areas, the effective conductivity that must be used in determining ground-wave propagation is less than the actual conductivity of the earth. This is true because there are energy losses in buildings with steel frameworks, such as those in business, industrial, and apartment-house districts. Setting up a test transmitter and plotting the contours of the resultant field strengths is the most reliable means of determining the effective conductivity. The next best method is to plot the contours of broadcast stations already existing in the area and convert the results for the frequency of the proposed new transmitter.

However, even though high antenna efficiency and low signal attenuation result from using a site where the ground conductivity is high, other factors may be more important than the



Courtesy WCBS

A view of the top-loaded vertical mast antenna used by WCBS, New York City, for its 50-kw. transmitter.

ground conductivity in certain localities. If, for example, a directional antenna system must be used to cut down on the signal west of the city to be served, then the transmitter should obviously not be located east of the city regardless of how high the ground conductivity may be there.

It is also inadvisable to locate the transmitter in old sections where there are many overhead power and telephone lines and where house wiring and plumbing are likely to be old and outmoded. High signal intensities in these localities cause cross modulation in the receiver because of the non-linear conductivity between contacts of wiring and other conductors such as plumbing systems. The FCC will not allow installation of a transmitter in a locality of this sort unless the station assumes full responsibility for adjusting all complaints. Since such interference is independent of receiver selectivity, it can usually be eliminated only by correcting the poor conditions causing the trouble. Consequently, an expense of several thousand dollars might be incurred by a licensee locating a transmitter in this type of locality.

Other considerations in the choice of a site are:

1. Location of airports and airways.
2. Availability of power sources.
3. Availability of telephone and program circuits.
4. Flood levels.
5. Accessibility of building.
6. Acreage and cost of land available.

ANTENNA REQUIREMENTS

Although it is of course evident that the best possible antenna and ground system should be installed for a given transmitter power, certain economic and engineering factors determine how closely it is practical to approach the ideal installation in designing the radiation system. Let's see what minimum requirements are specified by the FCC for various types of services.

Applicants for new or different broadcast facilities must specify on the application a radiating system that has an efficiency that meets the requirements of good engineering practice for the class and power of the stations concerned. Fig. 14 shows the minimum physical vertical heights that are considered necessary to meet field-strength requirements for powers and types of service indicated on the graph. These minimum heights apply for either ground or building-top location. If the antenna has its base on the ground, a ground system must be used that consists of at least 90 buried radial wires each at least ¼ wavelength long.

Any claim that the minimum field intensity may be secured with an antenna and ground system less than that stipulated above must be backed up by a field intensity survey made by an engineer who is qualified in the eyes of the FCC to make such surveys.

DESIGN APPLICATIONS

In the design of radiating systems, we are concerned with the factors that affect the inverse field intensity, which is defined as the unattenuated field intensity at a distance of one mile from the antenna for an input power (to the antenna) of one kilowatt. For a given power and location, the antenna height and the number and length of radial ground wires will affect the inverse field intensity.

The effect of increasing antenna height up to a certain optimum value is to increase the area in which there is no fading. This occurs because the increased directivity in the horizontal plane causes a stronger ground wave and also reduces the strength of the high-angle radiation that produces the sky wave that returns to earth close to the transmitter. The presence of a sky wave is what causes most fading, since the strength of the sky wave varies considerably from time to time. Actually, the strength of a ground wave at a distance is increased only a very few db by increasing the height from 0.125 wavelength to 0.5 wavelength, but the effective increase in usable,

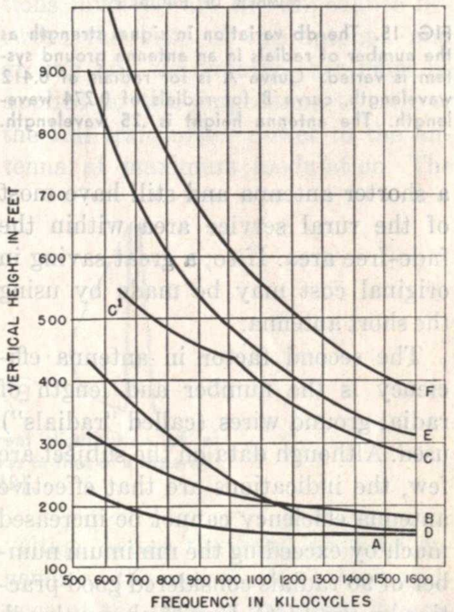


FIG. 14. Minimum antenna height requirements for standard a.m. broadcast stations. A refers to class IV stations which are local 100 or 250-watt stations rendering primary coverage to a city and its immediate area. B, for class II, clear channel .25 to 50 kw. and class III, 1-5 kw. regional stations. Curve C refers to class I, dominant clear channel 10 or 50-kw. stations for primary and secondary coverage of extended areas. Curve C¹ is used where CAA regulations do not permit higher antennas. For comparison curves D, E, and F show the heights for .25, .50, and .625 wavelengths respectively.

fade-free coverage is greater because the variations caused by a sky wave are eliminated. It has been found that an antenna length of approximately 0.53 wavelength is best if the comparative cost of such an antenna warrants the installation. However, for powers up to 5 kw., it is often possible to use

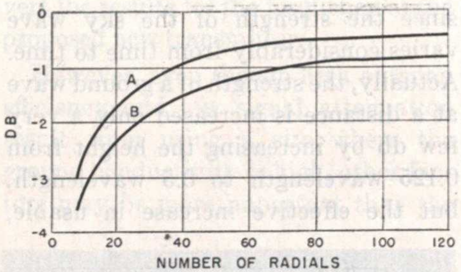


FIG. 15. The db variation in signal strength as the number of radials in an antenna ground system is varied. Curve A is for radials of 0.412 wavelength, curve B for radials of 0.274 wavelength. The antenna height is .25 wavelength.

a shorter antenna and still have most of the rural service area within the fade-free area. If so, a great saving in original cost may be made by using the short antenna.

The second factor in antenna efficiency is the number and length of radial ground wires (called "radials") used. Although data on the subject are few, the indications are that effective antenna efficiency cannot be increased much by exceeding the minimum number of 90 radials considered good practice by the FCC. Fig. 15 shows the db change in signal level caused by using various numbers and two different lengths of radials. As you can see, using more than 30 radials causes only a negligible increase in db.

The effect of the length of the radials on the db change in signal level is illustrated in Fig. 16. From this, you can see that 0.5 wave radials may not be

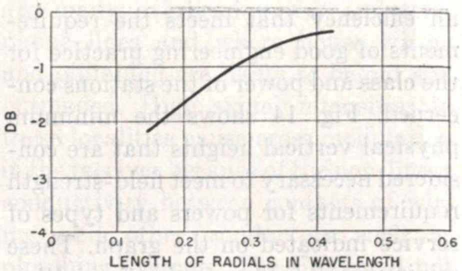


FIG. 16. The effect of varying the length of the radials on the field intensity of a broadcast station.

justified on grounds of economy over 0.35 wave radials. The latter length would require about half the ground area necessary for 0.5 wave radials.

To decrease earth losses caused by the large current through the capacity from the base of a vertical radiator to ground, a copper ground screen is usually used in the area immediately surrounding the antenna base.

TRANSMITTING ANTENNAS

The broadcast transmitting antenna consists of a steel tower of various sizes and shapes that functions as a vertical radiator. When, for some reason such as prevailing commercial airlanes, it is not feasible to use a vertical radiator of the required height, "top loading" is used. Top loading consists of placing a steel ring or some similar arrangement on top of the tower to provide a lumped capacity that raises the *effective* height of the antenna.

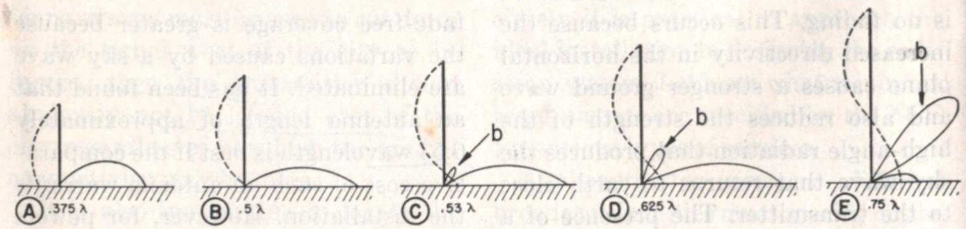


FIG. 17. The characteristic current distributions of various length of vertical antennas.

Fig. 17 illustrates several types of vertical radiators in terms of their characteristic current distributions. They may be either of uniform cross-section or tapered cross-section, the former usually being guyed and the latter self-supporting.

A tower having a uniform cross-section (same width from bottom to top) has a substantially sinusoidal current distribution as shown in Fig. 18A. Both the equivalent electrical height and the impedance to be expected between the feed point of the tower and ground can be predicted accurately for such an antenna. A tower having a tapered cross-section (wide at the base and narrowing toward the top) has a current distribution somewhat like that shown in Fig. 18B. This current distribution differs somewhat from that of a tower with a uniform cross-section radiator, with the result that the effective electrical height is less than the actual physical height would indicate. The electrical height of tapered towers is not accurately predictable.

When guy wires are used to support the tower, they are broken up at intervals of about 0.1 wavelength with insulators. This prevents resonance along the wires that might seriously detune the tower and absorb considerable energy.

Series-Fed Tower Antennas. In series excitation, the tower antenna is insulated from ground and fed by applying the carrier voltage between the lower end of the tower (just above the insulators) and ground. In this type of excitation, the important considerations involved are the impedance between the base of the antenna and ground and the voltage that must be applied to this impedance to deliver the full transmitter power to the antenna at maximum modulation. The

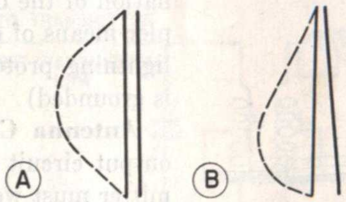


FIG. 18. How the current distribution of a straight tower (A) compares to that of a tapered tower (B).

voltage across the base insulator depends on the magnitude of the impedance at the base of the tower (determined primarily by the antenna height) and the amount of power delivered to the antenna. You recall that quarter-wave antennas, when fed at the base, are fed at a point of maximum current (Fig. 17A). The base impedance in this case is a resistance of approximately 37 ohms, and the base insulator voltage is comparatively small (about 545 peak volts for 1 kw. of carrier power modulated 100%). This base voltage increases rapidly as the height of the tower is raised, becoming a maximum when the equivalent electrical height is a half-wavelength (Fig. 17C). This antenna, when fed at the base, is excited at a current minimum and voltage maximum (in fact, it is said to be "voltage-fed"), and the base impedance is a resistance of the order of 200 to 400 ohms. The peak voltage across the insulator in this case is between 1200 and 1800 volts during maximum modulation for 1 kw. of carrier power. Towers that are tapered and have wide bases generally have less than 1200 volts developed across the base insulators under the same conditions.

Shunt-Fed Tower Antennas. When a tower antenna is shunt-fed, the tower

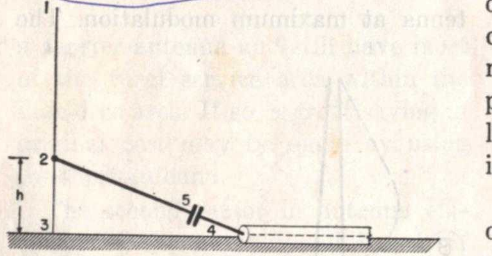


FIG. 19. The method of connecting to a shunt-fed tower.

is grounded and the carrier excitation is applied across a section of the tower as shown in Fig. 19. The shunt-fed method of excitation lends itself particularly well to concentric-conductor transmission line arrangements.

The inclined wire is connected to the tower at a point where the resistance component of the system impedance, as viewed from point 4 looking toward 2-3 (Fig. 19), has a resistance value equal to the characteristic impedance of the concentric line. The reactive component of the impedance at point 4 is always inductive, and is resonated out by the series capacity 5. The point 2 where the wire is connected to the tower depends upon a number of factors, including the height and shape of the tower, and in practice must be determined by cut and try methods. This point is usually about one-fifth of the total tower height. The slope of the wire connecting the tower to the line is roughly 45°.

From Fig. 19, you can see that this system consists essentially of a tower 1-2 where the exciting voltage between the lower end 2 and ground is developed across the section 2-3 of a small equivalent inductance 2-3-4-5 formed by the inclined wire 2-5-4, the antenna section 2-3, and the ground return 3-4.

Advantages of the shunt-fed tower over the series-fed tower are: 1, lower construction costs resulting from elimination of the base insulator; 2, a simpler means of coupling; and 3, greater lightning protection (since the tower is grounded).

Antenna Coupling Circuits. The output circuit of the broadcast transmitter must work into the proper load impedance to achieve maximum transfer of power. For this reason, both transmission-line and antenna impedance must be properly matched. The antenna-ground system constitutes the radiating system for the broadcast transmitter, and this system receives the power from the transmitter through the transmission line and coupling circuits. The transmission line is simply a link circuit by which the transmitter is connected to the antenna-coupling unit.

In most broadcast stations, it is advisable to have the antenna system at some distance from the transmitter itself. Keeping the transmitter building away from the antenna has two advantages: 1, it improves the field pattern, which would otherwise be distorted by the presence of the building; and 2, it greatly reduces the possibility of instability caused by r.f. feedback from the antenna to the transmitter proper.

Fig. 20 is a schematic diagram of a typical method of using a coupling transformer to match a two-wire transmission line to the antenna. The primary of the transformer is tuned to the operating frequency by condenser C_1. The secondary circuit is tuned by L_2 and the capacitive reactance of the antenna-ground system. Proper matching impedance for the line is obtained by adjusting the position of the secondary of the transformer L_2, thus changing the mutual inductance and therefore

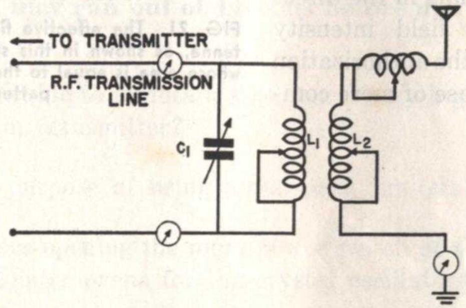


FIG. 20. Schematic of a typical coupling transformer to match a two-wire transmission line to an antenna.

the amount of resistance reflected to the primary circuit.

In the case of concentric lines, or open wire lines with one side of the system grounded, the coupling network takes the form of a T or Pi network like that shown in Fig. 9. Such a network can be used to match any antenna to any transmission line.

DIRECTIONAL ARRAYS

There has been and will continue to be a tremendous increase in the use of directional transmitting arrays. With large scale expansion of all types of radio services, and with the increase of the number of standard broadcast stations, the directional array is becoming more commonplace than the single radiator.

Directional patterns are used for three reasons: 1, energy is directed into a desired direction with a resultant gain in relative field strength; 2, radiation of more than a specified field strength in the direction of another station on the same channel is prevented; and 3, the power may be increased (if the pattern is properly directed) without effectively increasing the amount of interference with other stations on the same or adjacent channels.

Before regular operation of a broadcast transmitter with a directive antenna is allowed, proof of performance of the directional antenna system must be submitted to the FCC. These tests are made during the experimental period following completion of installation and they must show that the resultant pattern is the same as predicted and required by the terms of the authorization.

The methods of establishing this proof of performance are quite detailed. Briefly, however, field intensity measurements are made beginning just outside the induction field of the array (not less than 10 times the spacing between the elements of the system) along a sufficient number of radials to establish the effective field. A curve is plotted on polar co-ordinate paper from the fields obtained that gives the inverse distance field pattern at one mile.

Fig. 21 shows that the radius of a circle whose area is equal to the area bounded by the pattern indicates the effective field. In the case of the relatively simple directional pattern in Fig. 21, measurements along 8 radials in addition to the radials in the directions for which the field intensity values are specified in the authorization are sufficient. In the case of more complicated patterns, containing several sharp lobes or nulls, measurements are taken along as many additional radials as necessary to define the pattern exactly.

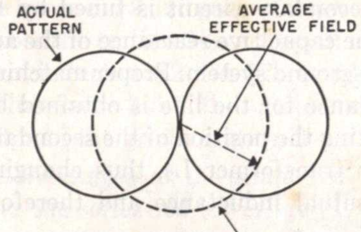


FIG. 21. The effective field of a directive antenna, as shown in this simple case, is a circle whose area is equal to the area of the directive pattern.

Lesson Questions

Be sure to number your Answer Sheet 41RC-1.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. Why is it desirable to maintain a comparatively high percentage of modulation in an a.m. transmitter?

2. What is the purpose of using audio peak limiters?

3. In general, does opening the main power switch of a broadcast transmitter turn off the heater ovens for the crystal oscillators?

4. Why is the r.f. signal for the frequency monitor generally taken from an r.f. stage preceding the modulated stage?

5. Why is inductance tuning generally used in high-power high-voltage stages of broadcast transmitters?

6. Draw a simple circuit diagram showing the use of a holding relay.

7. Why is it necessary to wait 30 seconds after the filaments are turned on before applying the plate voltage in a broadcast transmitter?

8. When a tower transmitting antenna is shunt fed, is a base insulator used between the antenna tower and the ground?

9. For the same amount of power and antenna system efficiency will the ground wave strength from a station on 1500 kc. be: (1) *less than;* (2) *the same as;* or (3) *more than;* the ground wave from a station on 600 kc.?

10. Why does increasing antenna height up to a certain optimum value increase the area in which there is no fading?

DOING THE IMPOSSIBLE

To a vast number of human beings, the term "impossible" is like a closed gate, barring the path that leads to a more satisfying life. They turn away from the "impossible" without the slightest attempt to find out just *why* a particular accomplishment has this awful word attached to it.

"Impossible" is applied in the majority of cases simply because *nobody has done that particular thing before.* The history of science is full of thrilling examples of men doing the "impossible"—the steamboat, the airplane, the radio, and many, many more. Naturally, brilliant men were responsible for doing these things, but more important is the fact that they refused to believe in the "impossible." They were determined to find out *really* why it had not been done and *how* it might be done. They kept banging away at it until they found a way to do it.

This is the approach to the "impossible" that works not only in science and invention, but in bringing to all of us the satisfactions we seek in life. When you believe the "impossible" is not a closed gate but a challenge to you to achieve and move forward into new fields, then you are a man marked for success and happiness.

J. E. SMITH