SECTION 3

SPECIALIZED BROADCAST RADIO ENGINEERING

GENERAL DISCUSSION

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GENERAL DISCUSSION

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GENERAL DISCUSSION

SCOPE OF ASSIGNMENT

The primary object of this assignment is to introduce the student to the general problems of broadcast transmission and the characteristics of radio equipment introduced by the problems peculiar to broadcasting. The broadcast engineer must be familiar with the characteristics of modern broadcast transmitters and also with the older types so that he may be able to formulate ideas on the trend of things to come. He must be familiar with audio frequency equipment, amplifiers, attenuators, characteristics of telephone lines and audio control equipment of all kinds. He must have a good understanding of studio and auditorium acoustics and the acoustical problems which must be solved in order to deliver to the transmitter sound programs of high quality. In order to get satisfactory results from an expensive highly efficient transmitter he must have a good understanding of antennas, ground conductivity problems and directional antenna arrays. The characteristics and uses of the various types of microphones, as well as the proper use of remote pickup equipment will be important in his daily life. Also of very great importance are the rules and regulations of the Federal Communications Commission and the standards of good engineering practice as outlined by that Commission. All of these matters and many others too numerous to mention at this point will be discussed in the following series of assignments.

FUNDAMENTAL CONCEPTS

STANDARD BROADCAST.—The standard broadcast band of frequencies is 550 to 1600 kc/s. This band of the frequency spectrum is divided into channels each 10 kc/s wide. The channels are arranged in groups, each of which is reserved for some specific purpose, such as clear channels for high power stations serving a large area; regional channels for medium power stations serving fairly large areas but having, due to wide distance separation, more than one station on a channel; local channels in which low power stations serve individual communities and on which a number of stations may use a single channel on a shared time basis; and channels reserved for stations in Canada and Central America. These channels are allotted by the Federal Commission in accordance with international treaties and will not be tabulated here. They will be found in the rules and regulations of the Commission.

DEVELOPMENT OF FREQUENCY MODULATION.—One of the most significant contributions to radio broadcasting in recent years was the development of frequency modulation and the opening up of a new section of the radio frequency spectrum to this broadcast system. Broadcasting by frequency modulation is practical only at the ultra-high frequencies because of the required channel width. The frequency band made available to this system is from 88-108 mc/s which will provide one hundred frequency modulation channels each 200 kc/s wide (including those assigned to non-commercial educational stations). In view of the transmission properties at the ultra-high frequencies and the peculiarities of frequency modulation reception, the distance between FM stations using the same channel need not be as great as that required between broadcast stations using the same frequency in the broadcast band and hence a large number of FM stations can be allocated throughout the United States within the scope of these one hundred channels.

Frequency modulation makes more practical the broadcasting of really high-fidelity noise-free programs and therefore increases the importance of the proper design of all components in the audio and acoustical system having to do with the development of true high-fidelity transmission. This refers primarily to the microphone, audio amplifiers and telephone lines by means of which the sound program is caused to modulate the transmitter. The problems in connection with the development of high-fidelity receivers is entirely separate and will not be discussed at this point. Ultra-high frequency broadcasting including frequency modulation will be taken up in considerable detail in subsequent assignments.

HIGH FIDELITY OUTPUT.—The outstanding characteristic of the well-designed modern broadcast transmitter is high quality of reproduction. The modern transmitter when properly adjusted is far ahead of the modern receiver in this respect. Where the good broadcast receiver will reproduce with fair fidelity a frequency band of from about 50 to about 5,000 cycles and the inexpensive receiver probably from about 150 to 3500 cycles, the modern broadcast transmitter is usually designed for an almost flat frequency response of from 30 to 10,000 or even 15,000 c.p.s.

It is a well known fact that as the audio-frequency response of a receiver is broadened the noise pickup is considerably increased, which means the usable receiver sensitivity is reduced. The program received on a high-fidelity receiver will always contain a much greater noise component than if the receiver audio selectivity were greater. For satisfactory high fidelity reception a high signal level must be maintained to overcome the increased noise pickup. Also the high fidelity receiver is more subject to interference from "monkey chatter" on adjacent bands. Therefore, in the standard broadcast bands high fidelity receivers do not appear to be entirely satisfactory except for the reception from nearby stations from which the signal intensity is high.

Whether, in view of present broadcast conditions, a wide frequency response characteristic for receivers would or would not be desirable will not be considered here. The point is the well-designed transmitter must be able to meet the most exacting requirements in this direction. It is true that at present frequencies above 5,000 cycles are not carried over most telephone program lines owing to cost considerations. However, program circuits equalized to 8,000 cycles are available between certain points and such circuits are being increased in number. As a large number of frequency modulation stations went on the air many high quality receivers were designed to receive either frequency modulation or standard broadcasting. To take advantage of frequency modulation quality the audio and acoustical system of the receiver had to be excellent.

The modern broadcast transmitter must be so designed that its radio frequency can be held to within ±20 cycles of its assigned frequency. (This frequency tolerance applied to all stations built after January 1, 1940. For all broadcast stations prior to January 1, 1940 a tolerance of ±50 cycles was allowed until January 1, 1942 after which the tolerance for all these broadcast stations had to be also ±20 cycles.) At 1000 KC/s this is only 20 parts in one million. When it is remembered that the frequency of an "X" cut quartz crystal varies about 25 parts in a million per degree of temperature change (the variation is even greater with "Y" cut crystals) and that slight variations in the circuit constants, voltages, etc., also affect the frequency to some extent even with crystal control, it will be seen that this modern standard is extremely high. However, standard apparatus that will hold well within this frequency tolerance is available commercially and most broadcast transmitters can be rebuilt to incorporate such equipment so as to comply with the regulations of the Federal Communications Commission.

In approving a broadcast transmitter design the FCC makes the following interpretation of good engineering practice as relating to crystal control: The crystal chamber, together with the conductor to the oscillator circuit, must be totally shielded. The crystal chamber must be so constructed, insulated and temperature controlled that the maximum temperature variation at the crystal shall not be greater than ± .1 degree Centigrade when an X- or Y-cut crystal is used and ±1 degree Centigrade when a low temperature coefficient crystal (for example AT-cut or V-cut) is employed. A thermometer must be installed in such a manner that the temperature at the crystal can be accurately measured within 0.05° C for X- or Y-cut crystals or 0.5° C for low-temperature-coefficient crystal. It is preferable that the tank circuit of the oscillator tube be installed in the temperature controlled chamber. In case an excessive shift in frequency is found during warm-up periods the crystal oscillator must be operated continuously. The Federal Communications Commission will take special precaution to ascertain that composite crystal chambers and oscillator units meet the requirements of good engineering practice before the station is considered as having satisfactorily complied with rule 3.59.

The Federal Communications Commission requires (Section 3.60) that the licensee of each standard broadcast station have in operation at the transmitter a frequency monitor which shall be approved by the Commission and shall have a stability and accuracy at least five parts per million. The general specifications that frequency monitors shall meet before they will be approved by the Commission are as follows:

1. The unit shall have an accuracy of at least five parts per million under ordinary conditions (temperature, humidity, power supply and other conditions which may affect its accuracy) encountered in standard broadcast stations throughout the United States.

2. The range of the indicating

device shall be at least from 50 cycles below to 50 cycles above the assigned frequency (when used by stations required by section 3.59 to maintain an operating frequency within 20 cycles of the assigned frequency, the range may be less than from 50 cycles above to 50 cycles below zero deviation but in no event shall the scale be less than from 20 cycles above to 20 cycles below zero deviation).

3. The scale of the indicating device shall be so calibrated as to be accurately read within at least one cycle.

4. The unit shall be equipped with an automatic temperature control chamber (preferably enclosing the tank circuits of the oscillator) such that the maximum temperature variation of the crystal from the normal operating temperature shall not be greater than (a) ±0.05° Centigrade when an X- or Y-cut crystal is employed or (b) ±.5° Centigrade when a low temperature coefficient crystal is employed.

5. Unless otherwise specially authorized the instrument shall be equipped with a thermometer such that the temperature can be accurately measured within 0.25° C. for X- or Y-cut crystals or .25° C. for low-temperature-coefficient crystals.

6. The monitor circuit shall be such that it may be continuously operated and the emitted carrier of the station is not heterodyned thereby.

7. Means shall be provided for adjustment of the temperature or other means for correction of the indications of the monitor to agree with the external standard. Fig. 1 shows a front panel view of the RCA type WF-48A AM frequency monitor which is FCC approved for use in standard broadcast stations. It indicates continuously, and directly in cycles-per-second, the magnitude and direction of any departure of the carrier from its assigned channel frequency.

Fig. 1.—Front panel view of the WF-48A Frequency Monitor.

The indicating element of the frequency meter is calibrated to read zero when the audio beat is exactly 1000 cycles per second. Any deviations from 1000 cycles are indicated directly as frequency deviation of the transmitter in cycles per second.

The monitor is a-c operated and is mounted on a single relay rack panel. A short length of wire is attached to the input terminals to act as an antenna coupling the monitor to the transmitter. Its stability is better than one part in a million, and a warning lamp system indicates the failure of either transmitter carrier or monitor crystal oscillator, the oscillator being of the controlled piezo-electric type.

MODULATION

PERCENTAGE OF MODULATION. — A broadcast transmitter must be designed for high percentage modulation. This is necessary in order that the maximum signal for a given power output will be obtained within the service area. The power for which a station is licensed is determined to a large extent by the population to be served and a transmitter is required to be so designed, installed and located that it can adequately serve the greatest number of listeners within that area. Everything else being the same the higher the percentage of modulation (up to 100 per cent) the greater the signal strength for a given carrier power, and consequently the greater the effective service range. (By signal strength here is meant the demodulated output of the receiver.) Up to the limit of 100 per cent the percentage of modulation is more important than the carrier power in determining the audio output of the receiver. By FCC order a broadcast transmitter must be capable of at least 85 to 95 per cent modulation with the combination of all audio frequency harmonics not in excess of 7.5 per cent.

The operating percentage of modulation of all stations must be maintained as high as possible consistent with good quality of transmission and broadcast practice and in no case less than 85 per cent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration. The maintenance of high percentage modulation without over-modulation on signal peaks requires skill on the part of the monitoring engineer and adequate monitoring and measuring equipment.

As a means of assuring that broadcasting stations are satisfactorily modulated the FCC requires all such stations to have in operation an approved type of modulation monitor. The specifications that the modulation monitor must meet before it will be approved by the Commission are as follows:

1. A d-c meter for setting the average rectified carrier at a specific value and to indicate changes in carrier intensity during modulation.

2. A peak indicating light or similar device that can be set at any predetermined value from 50 to 120 per cent modulation to indicate on positive peaks and/or from 50 to 100 per cent negative modulation.

3. A semi-peak indicator with a meter having the characteristics given below shall be used with a circuit such that peaks of modulation of duration between 40 and 90 milliseconds are indicated to 90 per cent of full value and the discharge rate adjusted so that the pointer returns from full reading to 10 per cent of zero within 500 to 800 milliseconds. A switch shall be provided so that the meter will read either positive or negative modulation and, if desired, in the center position it may read both in a full wave circuit.

4. The frequency characteristic curve shall not depart from a straight line more than ± .5 db from 30 to 10,000 cycles. The amplitude distortion or generation of audio harmonics shall be kept at a minimum.

5. The modulation meter shall be equipped with appropriate termi-

nals so that an external peak counter can be readily connected.

6. Modulation will be tested at 115 volts ±5 per cent and 60 cycles and the above accuracies shall be applicable under these conditions.

7. All specifications not already covered above and the general design, construction and operation of these units must be in accordance with good engineering practice.

The characteristics of the indicating meter are as follows: Speed—the time for one complete oscillation of the pointer—shall be 290 to 350 milliseconds. The damping factor shall be between 16 and 200. The useful scale length shall be at least 2.3 inches. The meter shall be calibrated for modulation from 0 to 110 per cent and in decibels below 100 per cent with 100 per cent being 0 db.

The accuracy of the reading on percentage of modulation shall be ±2 per cent for 100 per cent modulation and ±4 per cent of full scale reading at any other percentage of modulation.

It is important in the adjustment of the audio amplifying system between the output of the studio amplifier, across which the studio volume indicator is connected, and the modulation input terminals of the transmitter that the gain be exactly correct to give 100 per cent modulation when the peak indication at the studio volume indicator is obtained. Thus where the path of the program is from the studio control position to a supervisory control position to a telephone line and finally to the transmitter building, it is necessary that at each of these points variable gain amplifiers, attenuators and volume indicators be provided. In any but the most simple installation the program, in getting from the microphone to the modulator of the transmitter, follows a quite complex path consisting of many stages of amplification, several attenuating pads and one or more telephone lines which must be properly equalized for flat frequency response. Each part of this path introduces the possibility of distortion and the greater the number of component parts of the path the greater the possibility of serious distortion over the circuit. For this reason particular care must be exercised in the design and construction of broadcast equipment so that negligible distortion will be introduced by each component in order that the total distortion introduced by transmission over the entire circuit can be kept within the necessary small limits.

HIGH AND LOW LEVEL MODULATION.— With respect to modulation systems, broadcast transmitters may be divided into two principal classifications, "high level" and "low level." In low level systems modulation is effected in a low power stage or in the grid of the last stage (power amplifier) of Class C amplification by a modulator operating Class A or Class B in push-pull. (Both plate- and grid-bias modulation are extensively used.) The output of the modulated amplifier is then amplified to the required power level by successive stages of linear (Class B) amplification. The principal advantage of such a system is the low audio power required for modulation. This simplifies and reduces the cost of the audio circuit of the transmitter. The two principal disadvantages are: First, the over-all power efficiency of the transmitter is relatively low when conventional Class B radio frequency amplifiers are used. Second, there is a certain amount of distortion introduced by each succeeding stage of radio frequency amplification even though the adjustments are carefully made.

Within the past several years radio-frequency amplifiers have been developed in which the operating efficiency is approximately double that of the conventional linear amplifier. This has made it possible to design a low level modulated system comparable in efficiency to that of the high level system. The first of these high efficiency circuits was developed by Doherty of Bell Telephone Laboratories and is explained in detail in another assignment. This circuit is now used in Western Electric transmitters from 1 to kw to 50 kw and, of course can be used with even greater saving in transmitters of higher power. In a circuit of this type the higher the power output the greater the saving due to increased efficiency.

RCA has developed a high efficiency power amplifier which employs what they call a Class B-C circuit. Two r-f amplifier tubes are furnished with separate output circuits feeding the common antenna load and separate bias rectifiers. One tube is adjusted so that it operates essentially Class B and provides a normal carrier output. The other operates Class C and comes into operation only on positive modulation peaks. This circuit also operates at approximately twice the efficiency of the conventional Class B amplifier.

A second development which makes it possible to cancel out the distortion introduced by r-f power amplifiers is that of the inverse feedback circuit. In the inverse feedback circuit a part of the output of the final radio-frequency power amplifier is rectified to obtain an audio component which is then fed back in the proper proportion and in inverse phase to the input of the audio system. In other words, the signal, together with the distortion and noise developed in the radio-frequency power amplifier, is introduced into the input of the audio amplifier in inverse phase so that when these components are passed through the modulator and amplified up to the final radio-frequency stage they counteract the desired proportion of the inherent distortion and noise normally present in the final amplifier output and reduce the undesirable components accordingly. The amplitude of the inverse feedback is usually made such that the distortion and noise voltage in the output are reduced to about 10 per cent or less of their original amplitude. This circuit is also explained in considerable detail in another assignment.

High-level high-percentage modulation was made practical by the development of the high-fidelity high-power Class B audio amplifiers, which make the overall efficiency of the high-level system high. The final radio-frequency amplifier is operated Class C with an efficiency of approximately 60 per cent. (For purposes of calculating power output by the indirect method of high-level modulated transmitters the Federal Communications Commission specifies the following efficiency factor, F: Rated carrier power 100 watts, F = .5; 250 - 1000 watts, F = .6; 2500 - 50,000 watts, F = .65. This may be contrasted with the efficiency factor F = .33 specified for conventional low-level modulation systems.) In the high level system the modulator, while it must deliver large peak power, is not required to deliver large average power output because the peaks occur for only a small percentage of the total time and, due to Class B operation, comparatively small tubes operated at quite high efficiency can deliver the required peak power. In such a transmitter the entire system of radio-frequency amplifiers up to and including the final stage operates Class C, the efficiency is high, and the adjustments are not particularly difficult because there is no audio frequency component to be distorted except in the final stage. The modulated output of the final amplifier is transferred directly to the antenna.

An extreme example of such a high level modulated system was the 500 kw transmitter of WLW in which eight 100-kw tubes operated Class B fully modulated twelve similar tubes operating Class C. In contrast to this was the early high level modulated transmitter of WEAF in which twelve 20-kw tubes operated Class A were required to modulate eight 20-KW tubes to a maximum of about 60 per cent. In one RCA-1-kw transmitter the final radio frequency power amplifier consists of two Type 833-A tubes modulated by two Type 833 tubes operating Class B.

TRANSMITTER LOCATION

POWER CONSIDERATIONS.—The trend in broadcast transmitters is toward higher power. The higher the power, everything else being equal, the greater the noise-free service area of the transmitter. A broadcast transmitter is a commercial proposition; it is supported by sponsored programs and an advertiser will pay for station time in proportion to the population coverage obtained. While the actual cost of a high-power transmitter both in original cost and power consumption is much greater than that of a low-power transmitter, the same studio facilities, program talent, operating force and general overhead are required for both if identical program quality is to be obtained. The large station usually can charge enough for its time to provide high quality program material; small stations, unless in a thickly populated area where the coverage per watt is unusually high, often cannot afford to originate or carry really high-grade programs; which in turn operates to reduce the number of listeners and further decreases the station's revenue when satisfactory results are not obtained by the advertisers. Thus the Federal Communications Commission is continually receiving applications from station owners for license to use higher power and a large number of such applications are granted.

With modern receivers the 50-kw transmitter, except in its immediate vicinity, causes little more interference on adjacent channels than does a 1-kw transmitter and serves a much greater number of listeners. The field intensity at a given point with a given antenna system varies as the square root of the increase in power output. Thus the signal intensity at a given point from a 50-kw transmitter, everything else being equal, is about seven times greater than from a 1-kw transmitter at the same location.

TABLE I

Power of Station	Population of city or metropolitan area.	Miles Approximate radius of blanket area 250 mv/m.*	Miles Distance of Transmitter site from center of city.
100 watts	5000 - 50,000	.15	.5 - 1
100 watts	50,000 or more	.15	—
250-500 watts	50,000 - 150,000	.3 - .5	1 - 3
250-500 watts	150,000 or more	.3 - .5	—
1 kw	5000 - 200,000	.6 - .9	2 - 5
1 kw	200,000 or more	.6 - .9	—
5-10 kw	All	1.5 - 2.5	4 - 10
25-50 kw	All	3 - 4.5	10 - 15

The power a station may use without creating serious interference in its immediate vicinity is determined largely by the location of the transmitter. In the immediate vicinity of any broadcast transmitter there exists a so-called "blanket area." The blanket area of a broadcast station is defined as that area adjacent to the transmitter in which the usual broadcast receiver would be subject to some type of interference to the reception of other stations due to the strong signals from the station under consideration. The normal blanket area of a broadcast station is that area living within the 250 mv/m contour line. The average radii of the blanket areas for broadcast stations of several powers are given in Table I.

The Federal Communications Commission has established certain requirements for the location of broadcast transmitters. One of these requirements is that the maximum percentage of the total population in the blanket area be not greater than 1 per cent of the total population in the primary service area of the station. There are several exceptions to this as will be explained. Table I shows the approximate radius of the blanket area of 250 mv/m for transmitters of various power ratings. These radii are only approximate and the actual blanket area (area within the 250 mv/m contour) may be materially different depending on the antenna employed and other factors. Table I also shows the approximate distance the transmitter should be located from the center of the city (either business or geographical) in order to minimize the number of receivers within the blanket area and still provide the most satisfactory signal throughout the desired service area. It will be noted that in several cases no distance in miles is tabulated. This is due to the fact that in the cases of fairly large cities the area of the city may be quite large and if a low or medium power transmitter is located outside the city it probably would be difficult to get sufficient signal intensity to override noises in the business area. In these cases it usually is necessary to locate the station within the

*mv/m = millivolt per meter.

city in order to render satisfactory service. Such sites shall be in or near the center of the business district and under no circumstances will the FCC authorize the site in a residential section.

It should be noted that in the case of transmitters of 5 KW or over the approximate radius of the blanket area extends for several miles and hence transmitters of such power ratings should not be located within a city. For example, suppose the residential outskirts of a city extend seven miles from the center of the business district. The approximate radius of the blanket area will be in the order of four or five miles. In this case a site five or six miles beyond the outskirts of the residential section and twelve or thirteen miles from the center of the city should provide excellent signal with no blanket interference except possibly in the case of a few obsolete receivers.

INTERFERENCE.—Another factor which must be taken into consideration in the location of a broadcast transmitter is cross-modulation. It has been found unsatisfactory to locate broadcast stations so that high signal intensities occur in areas with overhead electric power or telephone distribution systems and sections where the wiring and plumbing are old or improperly installed. These areas are usually found in the older or poorer sections of the city. These conditions give rise to cross-modulation interference due to the non-linear conductivity characteristics of contacts between wiring, plumbing or other conductors. This type of interference is independent of the selectivity characteristics of the receiver and normally can be eliminated only by correction of the condition causing the interference. Cross-modulation tends to increase with frequency and in some areas it has been found impossible to eliminate all the possible sources. This results in unsatisfactory reception to the listener and a great many complaints to the broadcast station.

If the city under consideration is of irregular shape, the station is of high power, a directional antenna system is employed, or if other unusual conditions obtain, the data in Table I may not apply and special consideration will be necessary. However, the general principles as outlined above will still apply. In a later assignment on broadcast antennas the many considerations involved in the selection of a transmitter site will be discussed in greater detail.

The ground wave field intensity required to give satisfactory noise-free reception in the primary service area of a broadcast station is a function of the prevalent noise signal intensity which, of course, varies widely in different locations. In city business or factory areas the noise field intensity is always high due to electrical machinery, sign flashers, streetcars, etc. To counteract this a strong broadcast field intensity is required so as to maintain a high signal/noise ratio. The automatic gain control will then reduce the receiver sensitivity to the point where the noise intensity is negligible and the desired signal is of a reasonable level. On the other hand, in rural areas the "man-made" noises will be (usually) negligible and noise interference which must be considered is natural static which will vary with the difference in the location and with the season of the year, but normally will be of much lower intensity than "man-made" noise interference in urban localities. Thus for the same quality of service, the broadcast station must produce a much greater field intensity in the city than in the rural areas. Table II lists the ranges of signal field intensities necessary for satisfactory service in different locations.

TABLE II
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.	.1 to .5 mv/m
Rural—southern areas during summer	.25 to 1 mv/m

A broadcast transmitter must be so designed that it supplies very little harmonic energy to the antenna. Many older types of transmitters radiated very strong second and third harmonics and in some cases caused considerable interference on high frequency communication channels. The modern transmitter is carefully shielded and provided with harmonic filters ahead of the antenna circuit so that the transfer of harmonic energy to the antenna is reduced to a minimum. In modern high power transmitters the suppression of radiated harmonics to at least 70 db below the fundamental is typical.

RADIATING SYSTEMS

LOCATION AND RADIATION EFFICIENCY. — The subject of radiating systems is to be covered in considerable detail in two later assignments. At this point only the general conclusions and trends will be discussed. The radiating system is equally as important as the transmitter itself. In fact, improvements in radiating systems have probably accounted for as much of the increased signal intensity delivered by modern broadcast transmitter as have the general power increases in the transmitters themselves.

The radiating system of a broadcast station differs considerably, because of the type of service, from those used in most other branches of radio. Some of the peculiarities of the broadcast radiator and the steps taken in the solution of the problem of broadcast radiation will be briefly mentioned at this point and studied in detail later.

In order that the greatest possible percentage of power supplied to the antenna may be actually radiated, the radiator must be as far as possible from absorbing objects, buildings, trees, etc. If the antenna lead-in is taken up through a building or up the side of a building the absorption may be very high and the losses in the induction field so great that the actual radiated energy is a small proportion of the total.

Whenever possible the antenna should be located at a considerable distance from all absorbing objects and the power from the transmitter carried to the antenna over an untuned non-radiating transmission line. In the case of many high power stations the transmitter will be located anywhere from 10 to 20 miles out of the city in open country. The antenna system is often located five or six hundred feet from the transmitter house and the power transferred over a transmission line.

In the case of low power stations such an arrangement usually is not practical for various reasons. Where the antenna must be located on the roof of a large building a transmission line can be used to take the power from the transmitter room up to a small coupling house located on the roof adjacent to the radiator. With this arrangement very little power is expended between the transmitter and the radiator and, considering the other difficulties involved in such an installation, the maximum radiation can be obtained.

Just as the percentage of modulation is a more important factor than carrier power, so are the location of the antenna and its radiation efficiency more important than either power or percentage of modulation. According to engineering surveys by the Federal Communications Commission and independent engineers the efficiency of radiating systems varies all the way from approximately 5.7 per cent to 57 per cent, the location of the transmitter and the type of antenna being largely responsible for this wide variation.

The equation to be used in calculating antenna efficiency will be discussed later. The advantage of having high radiation efficiency is obvious. A 1000-watt transmitter with antenna efficiency of 57 per cent is the equivalent of a 10,000 watt transmitter with antenna efficiency of 5.7 per cent, other conditions being equal. This, of course, is an extreme comparison, but very often the station can, by simply installing a more modern radiator or by moving the radiator to a better site, increase the signal intensity at any given point by an amount equivalent to a power increase of several times.

No fixed rules can be given for the selection of a transmitter location because a number of factors must be taken into consideration. So far as radiation efficiency is concerned the ideal antenna location is a low area of marshy soil or an area which is damp the greater proportion of the time and from which a straight line view over the entire center of population may be had. The top of a hill is almost universally a poor location because the moisture drains away leaving low ground conductivity. Unless the surrounding hills are too high and too numerous a low location where the ground conductivity is high is usually preferable to a hill top even allowing for the added absorption of the hills between the transmitter and the area to be served. Sandy soil is considered the poorest for an antenna location. Salt water marsh is the best. To serve a city located on a general sloping area it is usually better to select a site below the city rather than above it.

In selecting a site for a broadcast transmitter where several are available it is always advisable to take extensive field strength measurements from a portable low power transmitter installed at each site to verify the judgement of the responsible engineer. That is the only way in which it is possible to determine in advance of construction exactly what may be expected in the way of coverage in the area in question. *The field strength measurements and the plotting of the curves should always be done by a competent engineer with adequate equipment.* Methods of making such measurements and plotting the curves will be discussed in detail in a later assignment.

In broadcasting the necessity for developing the greatest possible field intensity within a limited service area has lead to extensive research and experimentation to determine the most suitable types of radiating systems. With respect to service area the broadcasting station differs widely from practically every other type of radio service.

Point-to-point radiotelephone and telegraph stations endeavor, by the use of high power and directive antennas, to get the maximum signal to points hundreds or thousands of miles distant. Other stations wish to radiate equally well in all directions for the dissemination of press dispatches and other communications to ships stationed hundreds of miles away. In the case of the broadcast station, thousands of watts of power are used with the primary object of developing the strongest possible signal within the primary service area, the radius of which may be only a few miles—in almost all cases less than 100 miles.

The primary service radius ends at night at the point where the combination of ground and sky wave causes objectionable fading. This point may be from 40 to 120 miles from the transmitter depending largely upon the dimensions and shape of the radiating system; it is not a function of the transmitter power output.

Thus to obtain the greatest primary service radius with a given amount of power in the antenna, the radiating system should be so designed as to give the maximum field intensity at low angles above the earth and a minimum of high-angle radiation. With such a system the point where the field of the sky wave approximates that of the ground wave will be a maximum distance from the transmitter. At the same time a concentration of most of the energy within a restricted vertical angle will produce a more intense field at every point along the ground than would be possible if the same total energy were radiated over a wider vertical angle.

For low power stations where the primary service radius is well within the distance at which fading becomes objectionable with any type of antenna, the primary consideration is maximum field intensity within a radius of a very few miles. In the case of high power stations both the maximum field strength and the maximum distance to the fading point are important. The type of antenna which concentrates the radiated energy within a low vertical angle tends to accomplish both objects.

For the purpose of comparing the radiation efficiencies of broadcast antennas the engineering department of the FCC has set up a standard based on measurements of the field intensity one mile from the transmitter. This standard is defined as follows: "The antenna efficiency equals 100 per cent if the effective field intensity of the station at one mile per 1-kw antenna input power is equal to 265 millivolts per meter."

$$\text{Antenna Efficiency} = \frac{F^2 \times 100}{(265)^2 \times P}$$

F = Effective Field intensity at 1 mile in millivolts/meter.
P = Antenna input power in kw.

The root mean square value of all the "inverse field intensities" at one mile from the antenna in a horizontal plane is termed the "effective field intensity." The inverse field intensity is the unattenuated field at one mile. The determination of this figure involves the use of both field intensity measurements and ground conductivity and inductivity curves, the use of which will be discussed in detail in a later assignment.

ANTENNAS.—The early types of broadcasting antennas were mostly inverted L or T types supported between two steel towers. On the basis of results obtained with modern broadcasting antennas these older antennas were extremely inefficient. The first improvement was to increase the height of the vertical section leaving only a very short horizontal section so that the height approached as nearly as possible .25λ after allowing the required length for lumped tuning and coupling inductance. This type of antenna has two principal disadvantages: First, the proportion of the total energy radiated in the form of sky wave is excessive, this effectively reducing the useful field due to the energy radiated at lower angles; second, the losses in the towers cannot be eliminated.

It has long been known that a vertical half-wave radiator tends to radiate the greater proportion of the total field at a lower angle than does the quarter-wave radiator. The relation is somewhat as shown in Fig. 2 where the dotted line shows the distribution of radiation in the vertical plane for a .25λ antenna and the full line shows the distribution for the .5λ antenna.

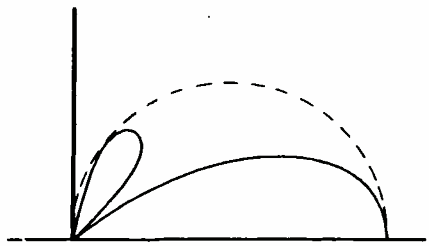


Fig. 2.—Radiation in the vertical plane for a .25λ and .5λ antenna.

Calculations by Ballantine show that for broadcasting optimum performance is obtained when the ratio of operating wave length to fundamental wavelength is .39 and that this condition should exist when the antenna is .625λ high. These calculations were based on the following assumptions: Velocity of propagation in the antenna equal to the velocity in space; equal velocity in all parts of the antenna; sinusoidal standing wave of current in the antenna. This condition actually cannot be obtained but can be approached by the use of an antenna consisting of a small vertical wire. Thus the optimum radiator would place the current peak and hence the center of radiation .375λ above ground.

In practice such ideal conditions do not exist. It is somewhat impractical to suspend a small wire to a height of 700 or 800 feet. In a tower the velocity of propagation is somewhat less than in free space and is not the same in all parts of the antenna; also in most tower shapes the current distribution is far from sinusoidal. Thus in a typical non-uniform-cross-section guyed fabricated steel tower having a ratio of operating wavelength to fundamental wavelength of .39, the actual height will be about .58λ and the point of maximum current will be close to .25λ above ground. With such a system measurements do not show the small loop of high angle radiation shown in Fig. 2. It would seem that the important factor in broadcast antenna design is to get the center of radiation (current maximum) from .25λ to .37λ above ground.

In Fig. 3 is shown the theoretical optimum current distribution in a vertical wire and the typical current distribution in a guyed tower radiator of varying cross section.

Several years ago in an attempt to take advantage of the known advantages of the high vertical radiator for broadcast purposes the Columbia Broadcasting System installed vertical guyed radiators in the form of fabricated steel towers at two of its stations (Boston and New York) the towers themselves being the radiators. The towers were designed to have a height of .58λ, the difference between the electrical length and .75λ consisting of the tuning and coupling circuit and allowing the antenna to be conveniently fed at low impedance just as any .75λ Marconi antenna. The very marked improvement in the radiation field obtained by the use of such

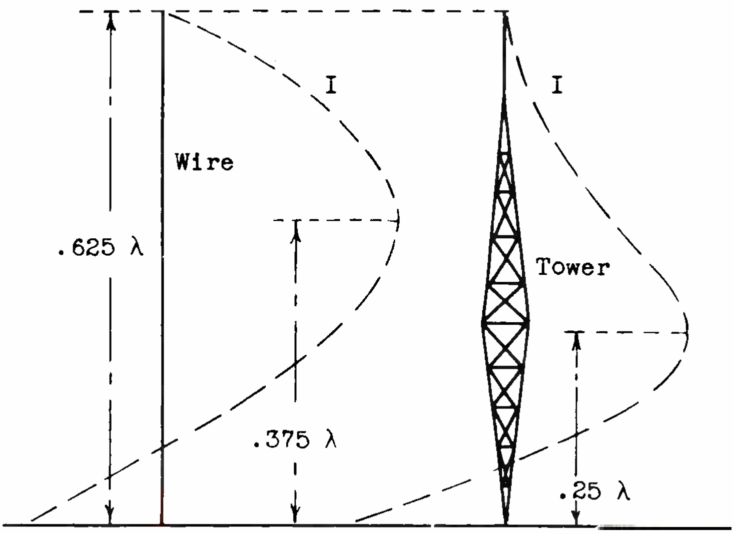
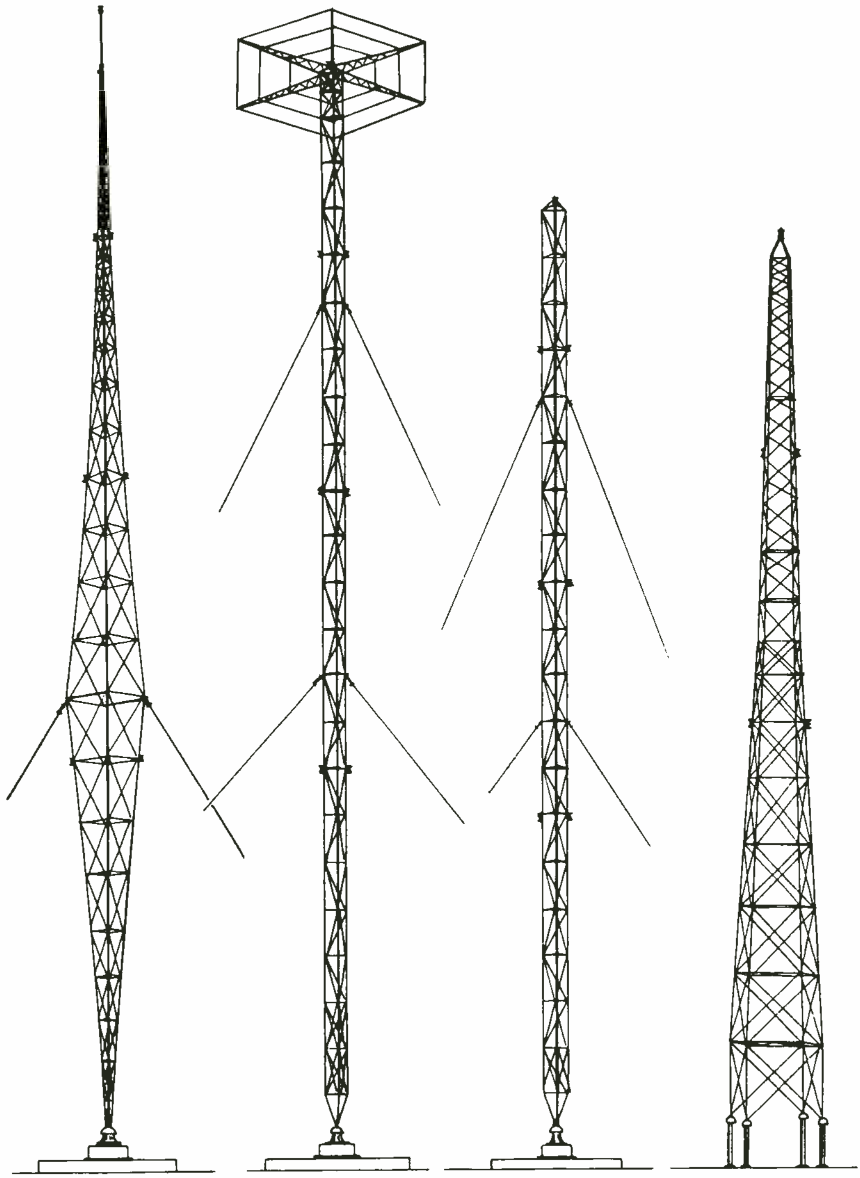


Fig. 3.—Comparison of the theoretical current distribution for a vertical wire and that experimentally determined for a guyed tower radiator.



Guyed Cantilever Tower.

Tower with top-loading capacity frame.

Uniform cross-section tower.

Broad—base self-supporting Tower.

Fig. 4.—Different types of Broadcasting antennas in use.

tower antennas has led to their almost universal adoption by broadcast stations.

Fig. 4 illustrates a number of different types of broadcast tower antennas in common use. One type of fabricated steel tower is pointed at each end and broad in the middle with the base resting on a porcelain pedestal. The tower is well guyed from the broad section usually with eight well-insulated guy wires. The top is quite often extended in the form of a steel pole which may be raised or lowered over a limited range to permit some variation in height where a small change in the vertical angle of radiation may be desired. Such towers of more than 800 feet in height are being used. More recent is the development of fabricated steel towers of uniform cross section, one example being the 640 foot tower of WJZ. This type of tower allows more nearly sinusoidal current distribution and hence operates more nearly in accordance with fundamental theory.

Self-supporting broad-base vertical radiators also have attained some popularity in the broadcast field. This type of antenna has the disadvantage of a quite high base capacity to ground which limits the height of the tower for a given operating frequency. The lumped capacity to ground tends to produce high dielectric losses in the ground at the base. This can be satisfactorily counteracted by constructing a well-grounded copper mat or ground screen beneath the tower to screen the earth beneath the tower from the strong electric field. Another plan is to insert the base insulators twenty or thirty feet above ground, the lower portion forming simply a base for the antenna proper. Most broadcast antennas of this type vary in height from about .25 λ to .42 λ.

It should be emphasized at this point that all heights referred to in this discussion are in terms of a free wavelength in space and do not take into consideration correction factors and the actual electrical length of the circuit. Thus a vertical antenna .58 λ high has an actual electrical length of more than .58 λ. A .25 λ radiator for an operating wavelength of 300 meters (1000 kc/s) would have an actual physical height of 300/4 or 75 meters. A self-supporting steel tower .42 λ high may have electrical length similar to that of a .58 λ guyed mast due to the lumped capacity at the base of the former.

The same antenna efficiency can be obtained with practically all types of vertical radiators of equal height provided they are well designed and have adequate ground systems. In fact, it can be shown there is little advantage in using antenna heights between .25λ and .4 λ. Calculations and measurements further show that with a properly designed ground system the radiated energy from a tower .125 λ high is only a few per cent less than from a tower .25 λ high. In the case of the lower towers the excellence of the ground system is considerably more important than the height of the tower itself.

The ground system with high vertical antennas is particularly important because of the fact that it is attempted to direct the radiation at a low angle above ground and because the point of maximum current in the ground system from an antenna

.5λ high or higher is at quite a distance from the base of the antenna. Hence if a sufficiently large amount of copper is not used most of the ground current will have to flow through the earth, the conductivity of which is much less than that of copper.

In order to keep the ground losses—resistance, dielectric and absorption—to an absolute minimum, the radial ground system should have a radius of at least .25 λ and preferably at least .5 λ and it should contain a large amount of copper. There should be as many radials as practical and in no case less than 90. (120 radials .5 λ long should form an excellent ground system). Judging from measurements taken at a large number of stations with all types of antennas it appears that the higher the radiator the greater is the improvement when the radius of the ground system is increased. It is particularly essential that an extensive ground system be used when the station is located in a region of poor ground conductivity.

Since theoretical antenna calculations usually assume a ground of high conductivity, the better the ground system is made the more nearly the actual results will approach the calculated characteristics. The ground conductors should be buried only deep enough to provide mechanical protection and not greater than twelve inches. They should not be allowed to rest on the surface of the earth. A counter-poise may be employed where a good ground cannot be obtained.

Some of the older types of broadcasting antennas produced at one mile a field intensity of 100 mv/m or less per 1 kw input; an average of fourteen good conventional antennas (tower supported T types) produced a measured field intensity of 169 mv/m at one mile; measurements of eight .58 λ guyed tower antennas showed an average field intensity of 247 mv/m at one mile. These figures show that by changing from the older type of antenna to a .58 λ guyed tower, leaving the transmitter unchanged, the average broadcasting station can secure an increased field intensity equivalent to practically doubling the transmitter power. If the station is at present using a very poor type of antenna, that is, one having a large horizontal section and a short vertical section, the effective improvement by changing over to the vertical radiator would be even more startling; in some cases the effect might be the equivalent to a four-fold increase in power.

It should be emphasized however, that in the case of a low-power station where the service area is limited by inadequate signal and not by fading due to the combination of sky and ground waves, the cost of a .58 λ tower would not be justified by the increased field intensity over that of a well-designed .25 λ radiator. The particular advantage of radiators .5 λ high or higher lies in the reduction of fading which is a problem that does not concern the low-power local stations. However, a low-power station should gain a marked increase in signal intensity in changing from an L- or T-type to a .25 λ tower.

The increasing demand of broadcasting stations for increased power has necessitated the use in many cases of directional antenna arrays in order to prevent interference with other stations on the same frequency or with nearby stations on adjacent channels. In some cases it is necessary to consider interference in one direction only so that a simple directional array can be used. In other cases the service areas of stations in two or more directions must be protected and more complex arrays are required.

Another reason for the use of the directional array is where the station is located, for example, near a sea coast, and it is desired to concentrate the radiated energy into the useful service area with a minimum of radiation toward the sea. For these two principal purposes directional arrays are used for all types of stations from the lowest to the highest power. Directional antennas, their design, their calculation and the types of patterns obtained will be discussed in considerable detail in a later assignment and will not be further considered at this point.

TRANSMITTERS

CIRCUIT ARRANGEMENTS.—During the past several years there have been extensive changes in broadcast transmitter design both in the circuit arrangements and in the mechanical layout and general appearance of the installations. For many years the general arrangement and appearance of a broadcast transmitter followed the lines of the conventional electrical switchboard. Apparatus was mounted on shelves back of steel or bakelite panels and component parts on which adjustments had to be made, such as tuning capacitors and coupling devices, were so mounted that the shafts could project directly through the front of the panel.

The modern transmitter looks like anything but a switchboard; the external appearance is that of a smartly styled cabinet, the finish and decoration in many ways resembling that of a modern high-grade automobile. Internally and electrically the changes are equally marked. Component parts are mounted for easy access and replacement. Components of the radio-frequency circuit are mounted in the best place electrically and where panel adjustments are necessary the shafts are brought out to a symmetrical panel arrangement by means of flexible control cables and shafts.

Several years ago it was considered out of the question to heat the tube filaments of a broadcast transmitter with alternating current due to the impossibility of keeping hum out of the carrier. The development of tube types has gone ahead so rapidly, together with such circuit innovations as inverse feedback, that today direct-current filament generators are entirely outmoded and replaced by small filament transformers mounted within the transmitter cabinet.

Some of the greatest advances have been made in the actual audio- and radio-frequency circuits which, operating at two to three times the efficiency of the audio- and radio-frequency circuits of only a few years ago making possible the use of tubes having a power dissipation rating of only a fraction of that previously required.

In the medium-power transmitter field and in the medium-power stages of high-power transmitters an important development has been the air cooling of transmitter tubes having ratings in excess of 1 kw. By the use of heat dissipating fins and air blowers it is now possible in transmitters up to 5- or 10-kw output rating to dispense with the necessity for water cooling equipment. This results in a reduction of cost and increased simplicity of installation and operation.

Another development in broadcast economy which takes into consideration the trend of broadcasting toward higher and higher output is the construction of transmitters in unit form. A broadcast station licensed for an output of 250 watts may purchase a 250-watt unit transmitter. If a power increase to 1 kw is subsequently authorized the station may later purchase a unit of symmetrical and similar appearance, which by using the 250-watt transmitter as a driver can be converted into a one-kilowatt transmitter.

Or, by the purchase of another unit, the 250-watt transmitter can be converted into a 5 kw job with no duplication of equipment. If the station subsequently obtains a license for 50 kw the 5-kw transmitter can be used as a driver to be followed by a 50-kw radio-frequency power amplifier built up in similar unit form so that the entire installation has a planned and finished look.

It is believed that the best way to bring these points out is to discuss the tube, circuit and unit arrangement of several high-grade modern broadcast transmitters. For this purpose typical transmitters of RCA, Western Electric, General Electric AM and Collins FM have been selected for description. The technical operation of circuits will be discussed in later assignments, at this point the discussion will be limited to a general consideration of the tube and circuit arrangement and the general characteristics of the transmitters.

RCA BTA-1L BROADCAST TRANSMITTER.—Fig. 5 illustrates the type BTA-1L transmitter of RCA. The schematic circuit diagram is shown in Fig. 6.

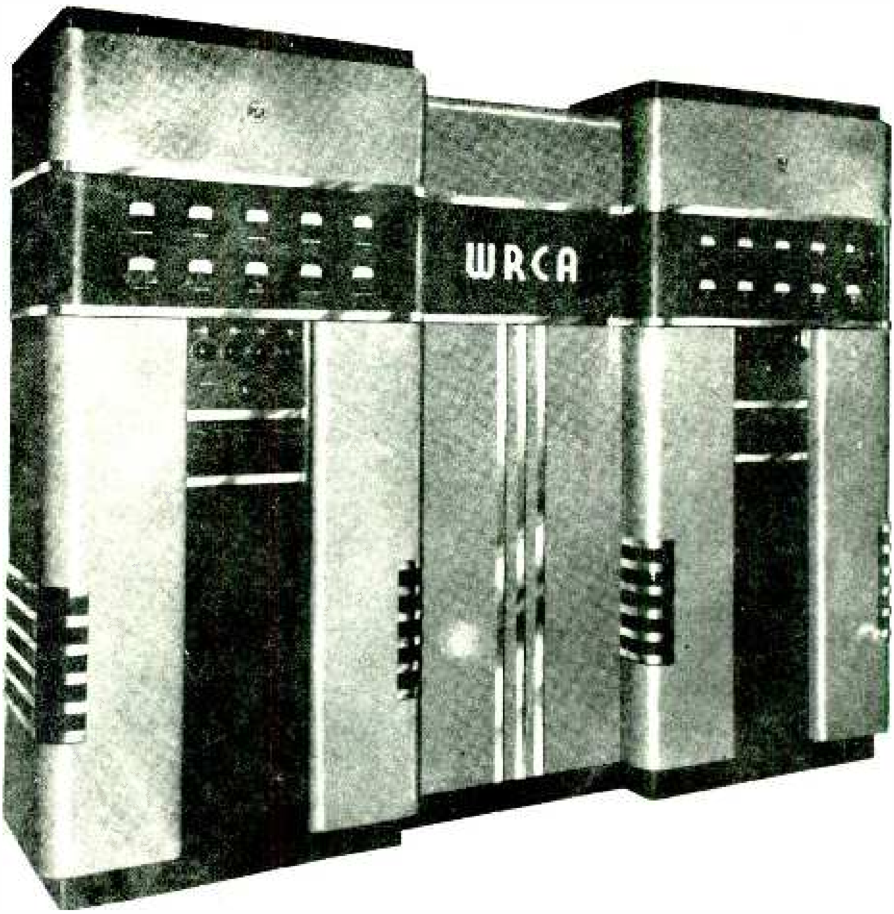
This is a 1-kilowatt transmitter designed to meet the most exacting demands of the modern broadcasting station. Essentially, the BTA-1L is composed of an RCA BTA-250L Transmitter, (250 watt output) serving as an exciter section to drive the 1-kw amplifier section. The complete transmitter is housed in an attractive cabinet assembly consisting of the BTA-250L cabinet, a matching amplifier cabinet, and a center section which contains the heavy power equipment.

The equipment is mounted in such a manner that every item can be easily removed by one man. Controls for each of the two units are grouped on indirectly illuminated panels conveniently placed on each of the two cabinets. The tuning elements are continuously variable inductors which are connected to the control knobs by means of bevel gears and extension shafts. The tuning controls are provided with indicators so that their positions may be accurately logged.

This transmitter provides reliable, high-fidelity operation at any frequency between 50 and 1600 kc. Efficient high-level modulation is employed.

Two RCA low-temperature-coefficient quartz V-Cut crystals mounted in RCA type TMV-129-B temperature-controlled holders are provided. The oscillator stage has an extra crystal socket in which the spare crystal may be continuously maintained at the correct temperature. The crystals provide excellent frequency stability with no greater deviation than ±10 cycles from the assigned frequency. A control is provided in the oscillator circuit for precise adjustment of the crystal frequency.

It employs a tube line-up as follows; type 807 crystal oscillator; type 828 buffer; type 810 intermediate amplifier; and two type 833A as r-f power amplifiers. The audio frequency circuit employs two type 6J7 tubes driving two type 828 tubes which in turn drive two 833A power tubes as modulators. High-level modulation is employed with the r-f power amplifiers operating class C push-pull and plate modulated by two similar tubes operating class B



(Courtesy of RCA)

Fig. 5.—RCA type BTA-1L kw Broadcast transmitter.

push-pull.

The type BTA-1L will deliver rated power into a 20- to 250-ohm transmission line or into any type of antenna normally used by broadcast stations. A matching network is provided between the output tank circuit and the output terminals of the transmitter which includes series inductors and shunt capacitors, resulting in excellent radio-frequency harmonic attenuation.

Output terminals are provided at the top of the cabinet for connection to an unbalanced open-wire transmission line or antenna leadin. A concentric transmission line may be connected through either the top or the base of the transmitter. Should this type of transmitter be coupled into a concentric line or to a single ended line, the RCA type BTA-1 (MI-28901) Antenna tuner may be used.

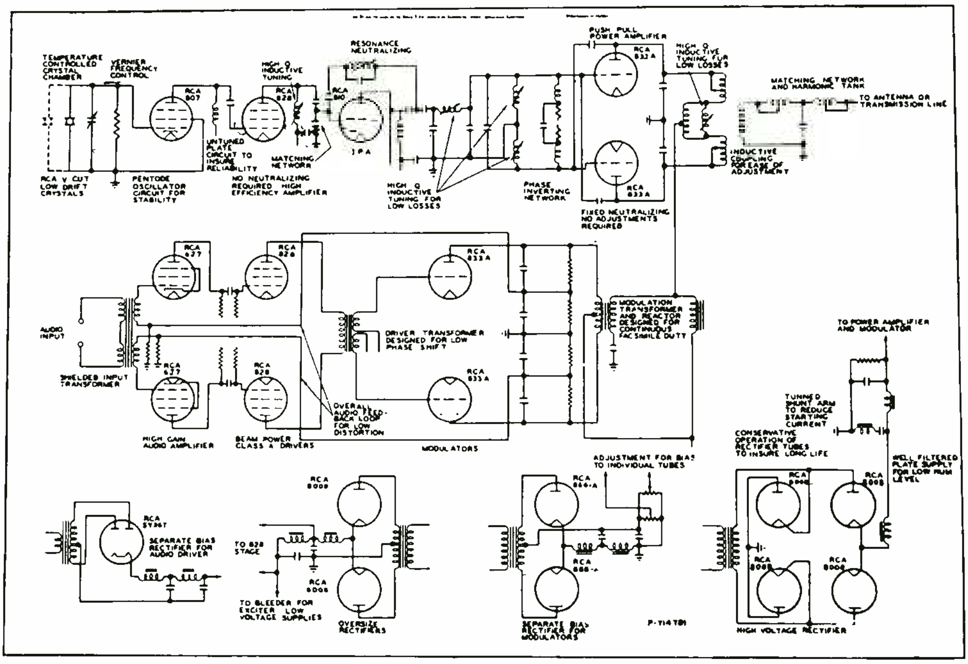


Fig. 6.—Schematic circuit diagram of the BTA-1L Broadcast Transmitter.

Terminals are provided on the BTA-1L for modulation indication by means of a pickup coil coupled to the tank coil of the output stage. Excitation for r-f frequency monitoring is taken off an r-f voltage divider across a capacitor in the ground side of the buffer stage. A-F monitoring is accomplished by means of a voltage developed across a resistor connected in series with the secondary of the modulation transformer at which point a level of approximately + 10 dbm is available at 100 per cent modulation.

Control circuits are simplified and offer maximum protection to the transmitter and operating personnel. A distinctive feature is a relay which eliminates the necessity of recycling of the time delay relay when momentary power failures or interruptions occur. Overload protection is provided by using magnetic circuit breakers that also serve as switches.

RCA BTA-50F1 BROADCAST TRANSMITTER. — In Fig. 7 is shown the RCA type BTA-50F1, all air-cooled AM transmitter operating in the range of 540 to 1600 kilocycles and providing up to 53 kilowatts of power. A simplified block diagram of this transmitter is shown in Fig. 8.

The low power r-f section contains duplicate crystal oscillators (type VL-4392) with a relay switching system which is push-button operated from the front panel. Hence, instantaneous switching between alternate oscillators is easily accomplished. The crystals have a low temperature coefficient that maintains the frequency stability well within FCC limits.

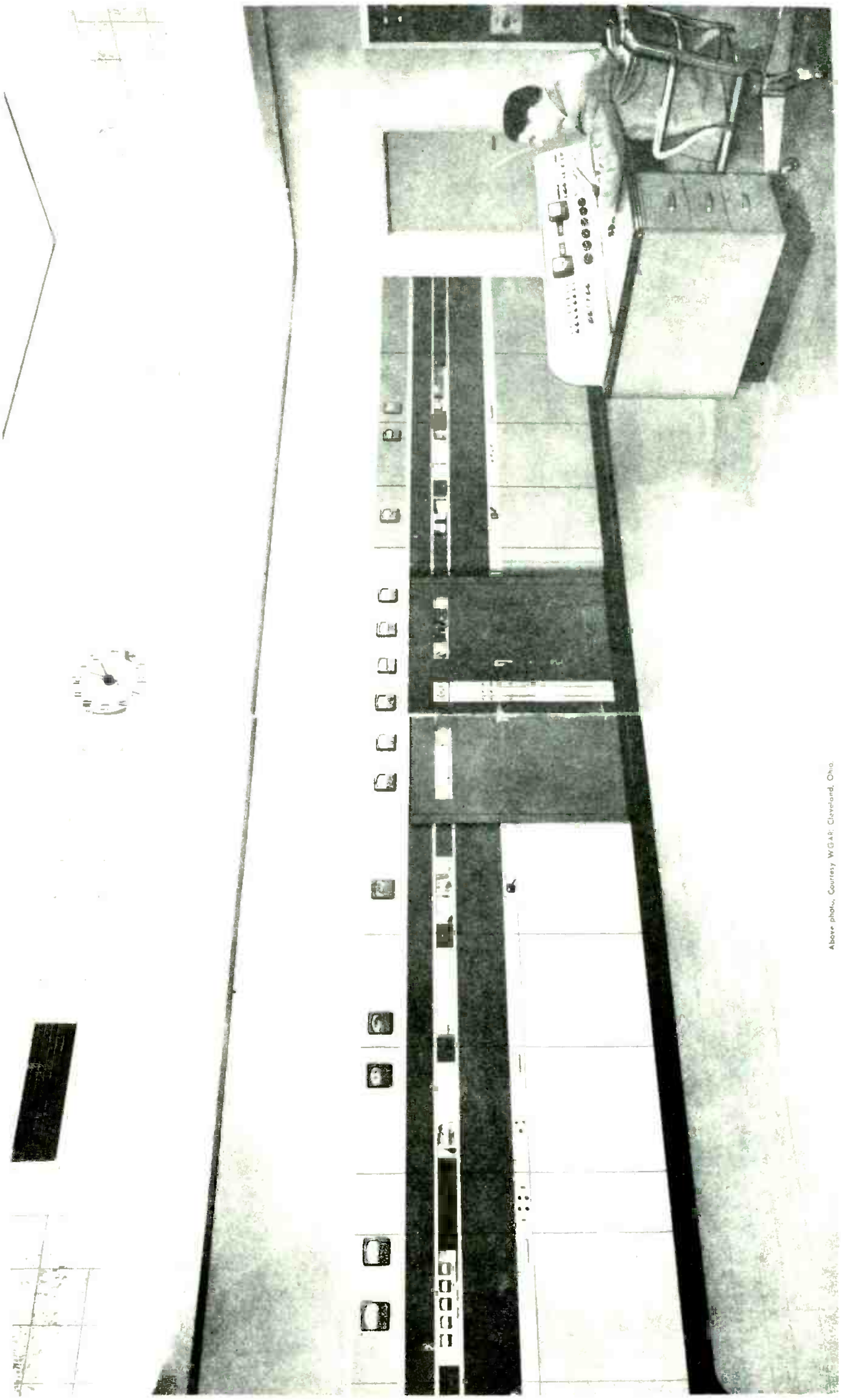
Type 807 beam-power tubes are used in the oscillators which are tuned by a tapped inductance (selected at the time of installation). A vernier-type capacitor is included in the oscillator for fine frequency adjustments. Thus precise, zero-beat adjustments are easily made during comparisons with a standard frequency. The crystal oscillator feeds a 828 beam-power buffer amplifier, and its power output provides excitation for two 810 triodes operating in parallel.

The 5-kilowatt I.P.A. or r-f driver employs one 892-R that receives ample excitation from the two 810's just mentioned. Power is fed from the 892-R tube through a concentric transmission line to the grid-tank circuit of the 5671 tubes in the power amplifier. The 5-kilowatt stage easily drives the final amplifier with plenty of excitation in reserve. Therefore it is possible to operate the 892-R driver below rated filament voltage resulting in long tube life and economical operation.

The first audio input stage consists of two 6C6 tubes which are used to drive two 828 beam-power tubes. This serves to furnish adequate voltage swing for four 828 tubes operating in a cathode-follower circuit. The design of the low-power audio section, using beam-power and low-filament power tubes plus the single fixed audio feedback loop, assures adequate driving power for the modulator and greatly reduces noise and distortion below that of ordinary circuits, without the use of r-f feedback.

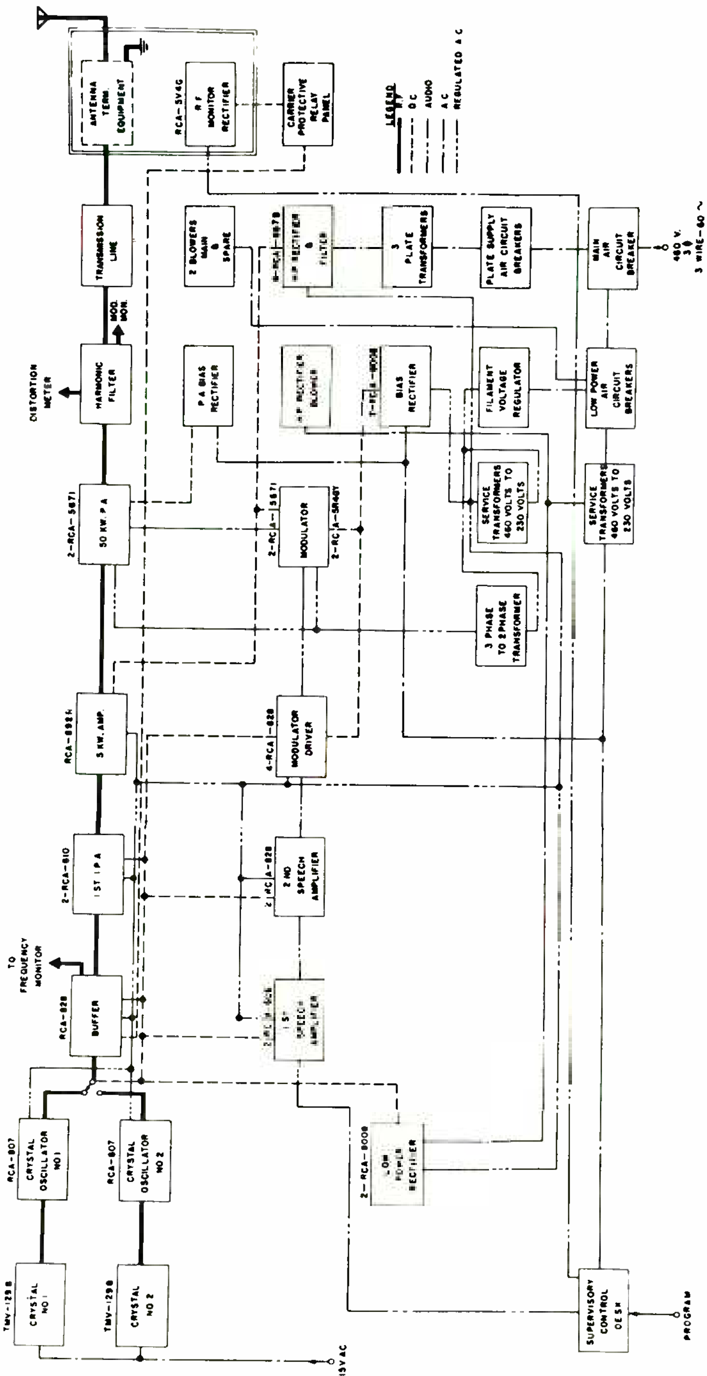
Two 5671 tubes, operating in a class-B circuit, plate modulate the two 5671 tubes of the final amplifier. An additional tube position is provided in the modulator compartment, thus permitting the spare tube to be readily connected to either side of the class-B circuit by simply moving flexible filament and grid leads.

The high-voltage rectifier is made up of seven 857-B type tubes, six of which operate in a three-phase circuit. The seventh is a spare and is so wired that it can be instantly switched into the circuit



(Courtesy of RCA and WGAR)

Fig. 7.— The RCA type BTA-50F1 broadcast transmitter.



(*Courtesy of RCA*)

Fig. 8.—A simplified block diagram of the RCA type BTA-50F1 broadcast transmitter.

and the defective tube disconnected by simply moving a switch.

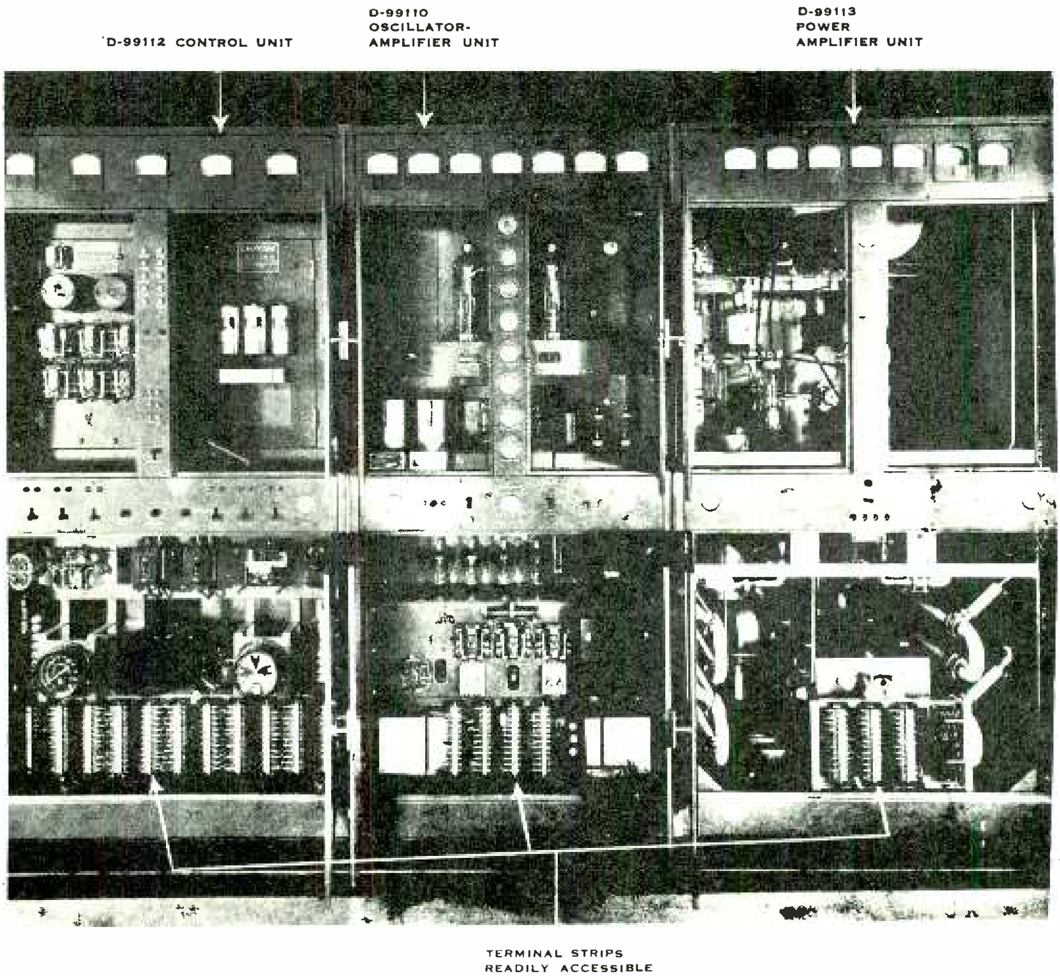
The control section provides automatic protection in the event of flashover or arc on the transmission line or terminating equipment. Such changes in power output cause the carrier to be removed momentarily to extinguish the arc. The transmitter is then automatically returned to the normal power output, should the fault persist, automatic operation further provides a recycling sequence which will remove the carrier after the third attempt to restore operation. A special hold-in circuit permits the transmitter to be returned to the air in the event of momentary power line failure.

It should be understood that the models of transmitters discussed here are only a part of the line of transmitters built by the manufacturer and were selected simply as being typical of good design.

WE 405A OR THE 405B-1 BROADCAST TRANSMITTERS.—This 5-kw transmitter which is to be briefly described is a not too recent model. It has been selected as typical of excellent design by this manufactor and also because a large number are at present in use. In Figs. 9 and 10 are shown a photograph and a schematic circuit diagram respectively. This size is available in either of two transmitters, the 405A or the 405B-1. These transmitters are essentially similar except for the type of tubes and method of cooling used in the 5-KW final power amplifier. The 405A transmitter employs in the final amplifier two Type 220C water-cooled tubes and associated water cooling system while the Type 405B-1 employs in the final amplifier two Type 343AA tubes which are metal anode types mounted in holders containing large cooling fins through which cooling air is forced by a motor-driven blower. There are other minor changes in the two transmitters which do not warrant discussion at this time. The three units of the 405A transmitter are arranged to form one side of an enclosure. The power apparatus consisting of distribution cabinet, regulators, transformers, and filters is installed in the enclosure behind these units. The high voltage rectifier may be installed immediately behind the control unit or elsewhere in the enclosure. For the standard arrangement steel and glass partitions are available for the protection of the personnel. They enclose the high-voltage power apparatus behind the transmitter unit and can be provided for standard layouts. When visibility such as is afforded by these partitions is not essential fire-proof wall construction may be utilized. The approximate overall dimensions of the transmitter including the enclosure are 10′ 9″ wide by 11′ 7″ deep by 6′ 6″ high.

Fig. 9 shows a front view of the transmitter with all front doors open. One of the water-cooled tubes can be seen in the upper section of the power amplifier units and sections of the water cooling system are immediately below. The water temperature and water pressure indicator are in the lower section of the control unit.

Fig. 10 shows a schematic circuit arrangement of the 5 KW transmitter. The crystal oscillator is followed by three stages of intermediate amplification, the first two employing pentode tubes and the third two triodes in parallel in a neutralized circuit. The third intermediate amplifier is grid-bias



(Courtesy of WE)

Fig. 9.—Radio Transmitter Units Assembly Front View with Doors Open, Type 405A 5 kw Radio Transmitting Equipment.

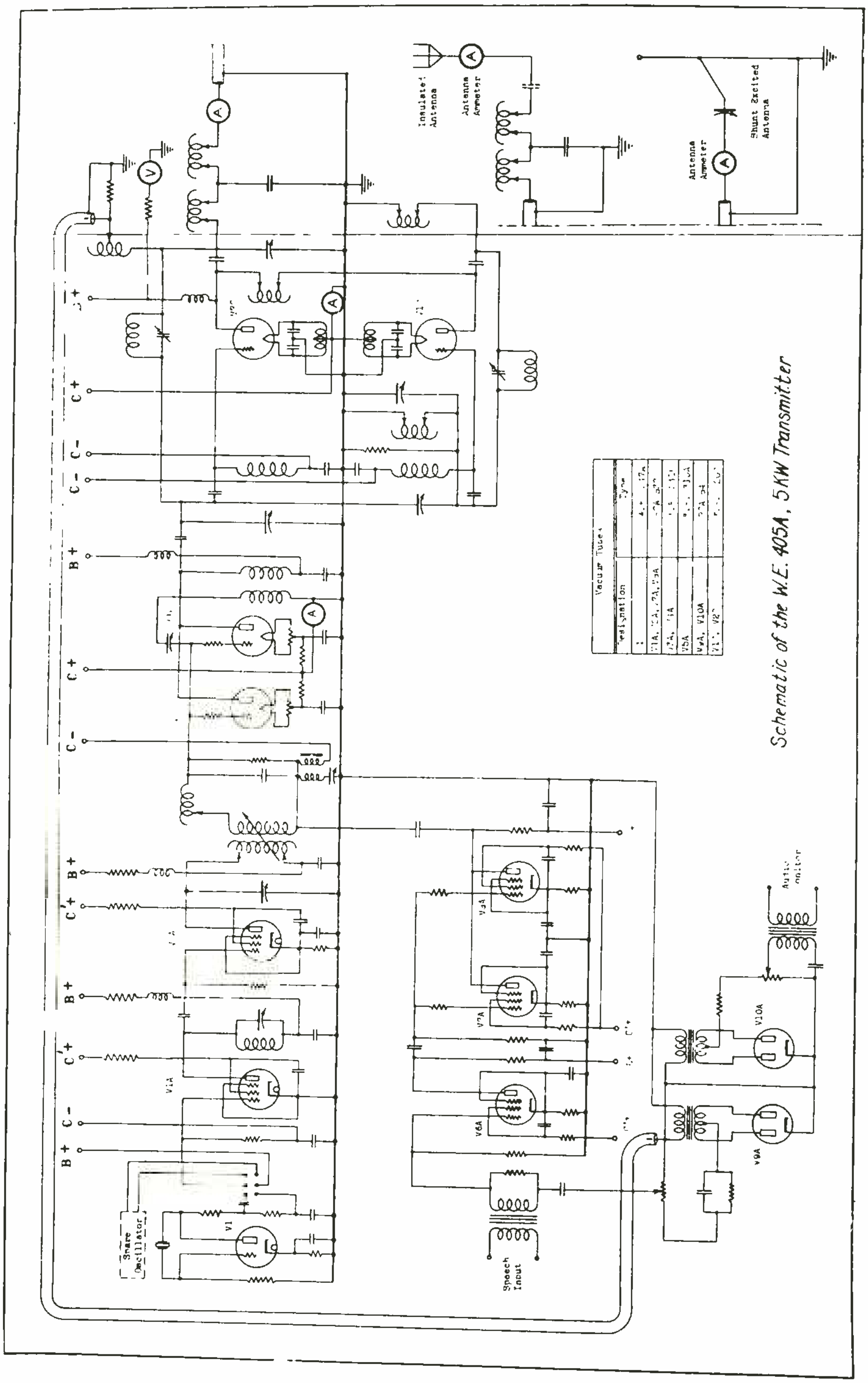


Fig. 10.—Schematic of the WE, 5 kw transmitter.

(Courtesy of WE)

modulated and drives the final 5-kw power amplifier which employs two tubes in a Doherty high-efficiency amplifier circuit. The audio system consists of a two-stage resistance-coupled amplifier similar to that used in the 1 kw transmitter, the difference in tube types being due to the different power output capacity required for the two transmitters. A similar inverse feedback circuit is also used, one rectifier feeding the audio monitor and the other feeding inverse audio voltage to the input of the first audio amplifier.

Among the features of this equipment are: An automatic circuit breaker and reclosing contactor in the power circuit to the rectifier; an automatic voltage regulator; omission of fuses in the transmitter with replacement by circuit-breakers; meters with concealed lighting flush-mounted in the front of the unit to provide visual indication of circuit conditions throughout the transmitter; provision for cathode ray oscilloscope connection in all important circuits; and key operated tuning control which permits easy control and accurate tuning. The transmitter is entirely a-c operated.

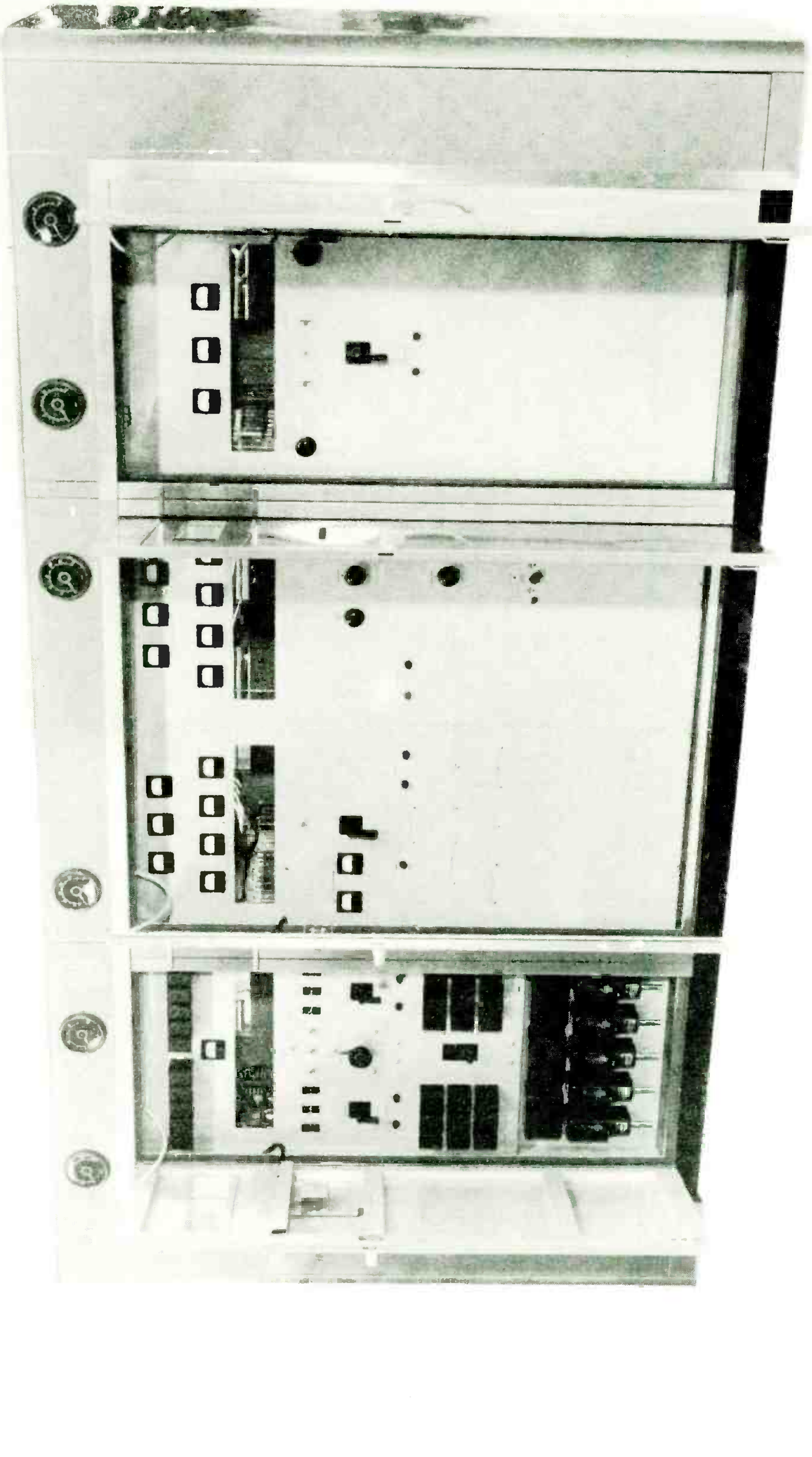
The performance figures, except for the greater power output, are essentially the same as those for the 1 kw transmitter. Typical power consumption is 15.3 kw for carrier only, 15.75 kw for average program and 19.5 kw for single frequency 100 per cent modulation. The frequency response is flat within ±1 db from 30 to 10,000 cycles. A typical value of audio frequency harmonic distortion in the range from 40 to 5,000 cycles is less than 2 per cent at 85 per cent modulation and less than 3 per cent at 100 per cent modulation.

GE BT-22-A BROADCAST TRANSMITTER.—The General Electric type BT-22-A transmitter and schematic shown in Figs. 11 and 12 respectively, furnishes 5 kw at the output. However, an instantaneous change from 5 kw to 1 kw output may be obtained by operation of a switch on the front panel or may be easily converted to 10 kw by a few changes. These changes are the addition of a second power amplifier tube in the space provided, and the installations of larger modulation and rectifier plate transformers; all other parts are identical in the 5-kw and 10-kw equipment.

Another very important feature is the arrangement whereby the high-power tubes may be simply and quickly switched in or out of the operating circuits in the event of tube failure. In the BT-22-A, spare tubes may be quickly switched into the circuit and normal operation continued. The defective tube may then be replaced during the maintenance period.

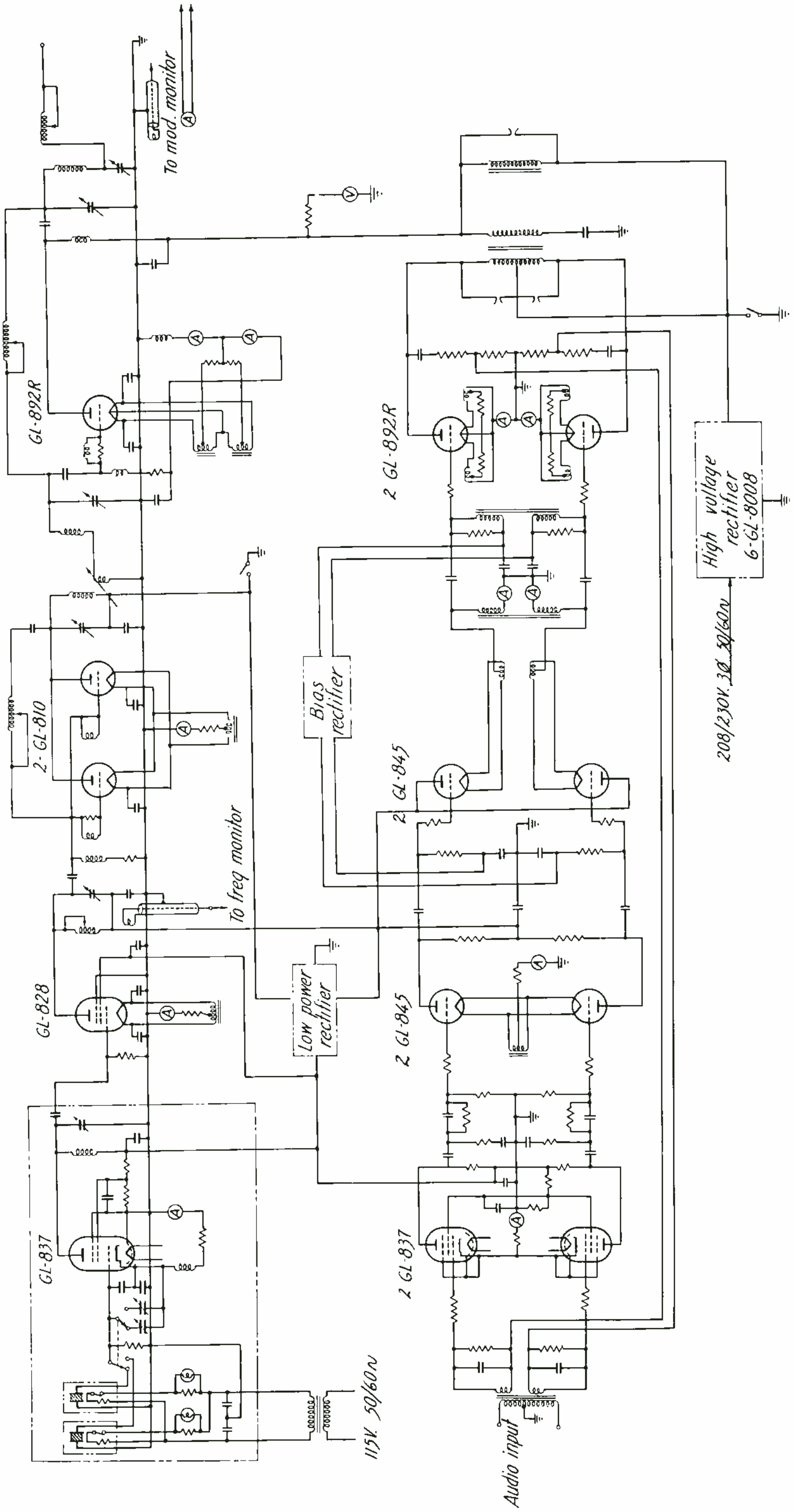
The crystal oscillator unit is a carefully shielded assembly, specially designed for good frequency stability. Duplicate crystal thermocells are provided. These are maintained at the operating temperature at all times, and either one may be quickly switched into operation. The oscillator employs a type GL-837 tube and a GE Type G30 crystal thermocell in an unusual circuit on which external conditions have negligible effect. A vernier adjustment of frequency is provided for each crystal.

The output of the crystal oscillator is amplified by the type GL-828 buffer amplifier which, in



(Courtesy of GE)

Fig. 11.—The GE Type BT-22-A broadcast transmitter.



(Courtesy of GE)

Fig. 12 — A simplified schematic diagram of the GE Type BT-22-A transmitter.

turn, feeds the driver stage. The driver stage, utilizing two GL-810 tubes in parallel, employs "coil" neutralization and is coupled inductively to the power amplifier grid tank. This coupling is continuously adjustable to permit any desired amount of excitation to be supplied to the power amplifier. The power amplifier utilizes one type GL-892-R air-cooled tube and by adding a second type GL-892-R in the mounting provided the power output may be converted to a 10-kw carrier output.

The audio circuits are balanced, double-ended in all stages. The input stage, using two GL-837 tubes, drives the second audio amplifier, consisting of two type GL-845 tubes, resistance-coupled to the audio driver stage. The audio driver employs two type GL-845 tubes in a cathode-coupled circuit to drive the push-pull modulator. The push-pull modulator operates as a class B amplifier with two type GL-892 R tubes, the same type as used in the r-f power amplifier. A spare tube may be kept in the mounting provided and may be quickly switched into either side of the modulator circuit.

COLLINS 733A-1 FM TRANSMITTER.— Shown in Fig. 13 is the Collins type 733A-1 3000-watt frequency-modulated transmitter. This transmitter meets the FCC specifications and operates on any specified channel between 88 mc and 108 mc. Other specifications are as follows; the stability is better than ±1000 c.p.s.; the frequency swing is from 0 to 120 per cent modulation, and the frequency response is flat within 1 db from 50 c.p.s. to 15000 c.p.s. with less than 1.5 per cent distortion for 100 per cent modulation. The noise level for frequency modulation is better than 65 db below 100 per cent modulation and for amplitude modulation is better than 50 db below a level representing 100 per cent amplitude modulation.

A simplified schematic of this transmitter is shown in Fig. 14. Note that the audio amplifier is simply two 6SJ7's in push-pull and that they frequency-modulate the r.f. right after the buffer. The output of the oscillator is at a low radio frequency and this r.f. after being passed through the buffer and modulated is multiplied and amplified by a series of multipliers until the desired fm channel has been obtained. The output of the multipliers is then fed through the necessary power amplifiers to obtain the desired power output or 3000 watts in this case. The FCC standards along with detailed description of FM equipment will be covered in a later assignment and hence will not warrant any further discussion here.

SPEECH CONTROL EQUIPMENT

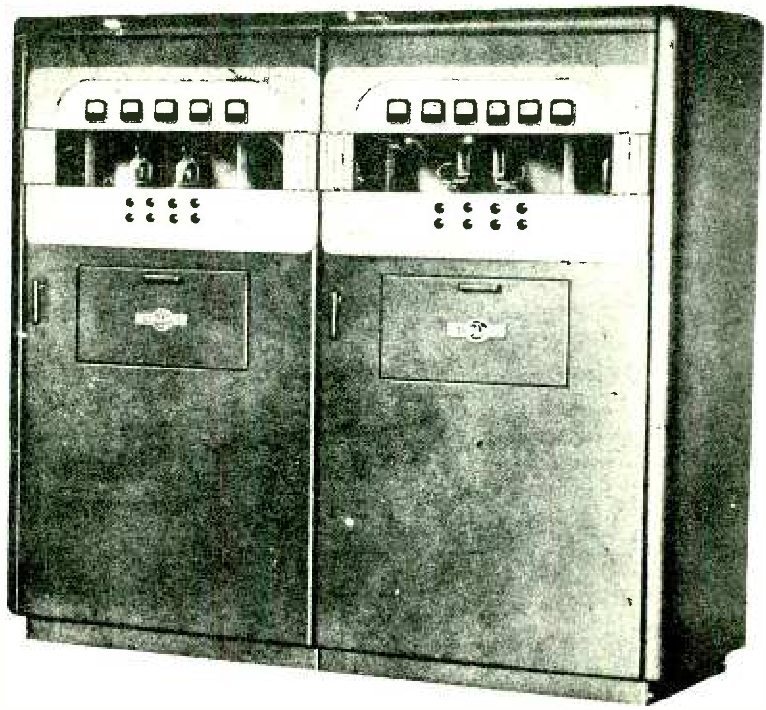
RCA TYPE MI-11621 CONSOLE.— Speech control equipment will be taken up in considerable detail in a later assignment. At this point two units typical of modern design will be briefly described.

Fig. 15 illustrates the MI-11621 control console designed for use with the RCA type BTA-50F1 broadcast transmitter. This console is equipped with a standard VU (volume unit) meter, extension modulation monitor and antenna current meters. Also provided are "time outage" and "duration outage" clocks which are controlled by relays located in the transmitter overload circuits. Thus an accurate station record of outage is made available in the event the carrier is interrupted.

Mechanical interlocking push-keys permit instant selection of the circuit to be monitored. Program operation, special tests, and appropriate transmitter control switches are all easily and quickly handled by the operator at the console. Important audio control-circuit keys such as "transmitter on" and studio and local switches are protected from accidental tripping by chromium-plated guards. Fig. 16 shows a partial rear view of control console showing turret cover removed. All the components and wiring can be seen and easily reached for ease of maintenance.

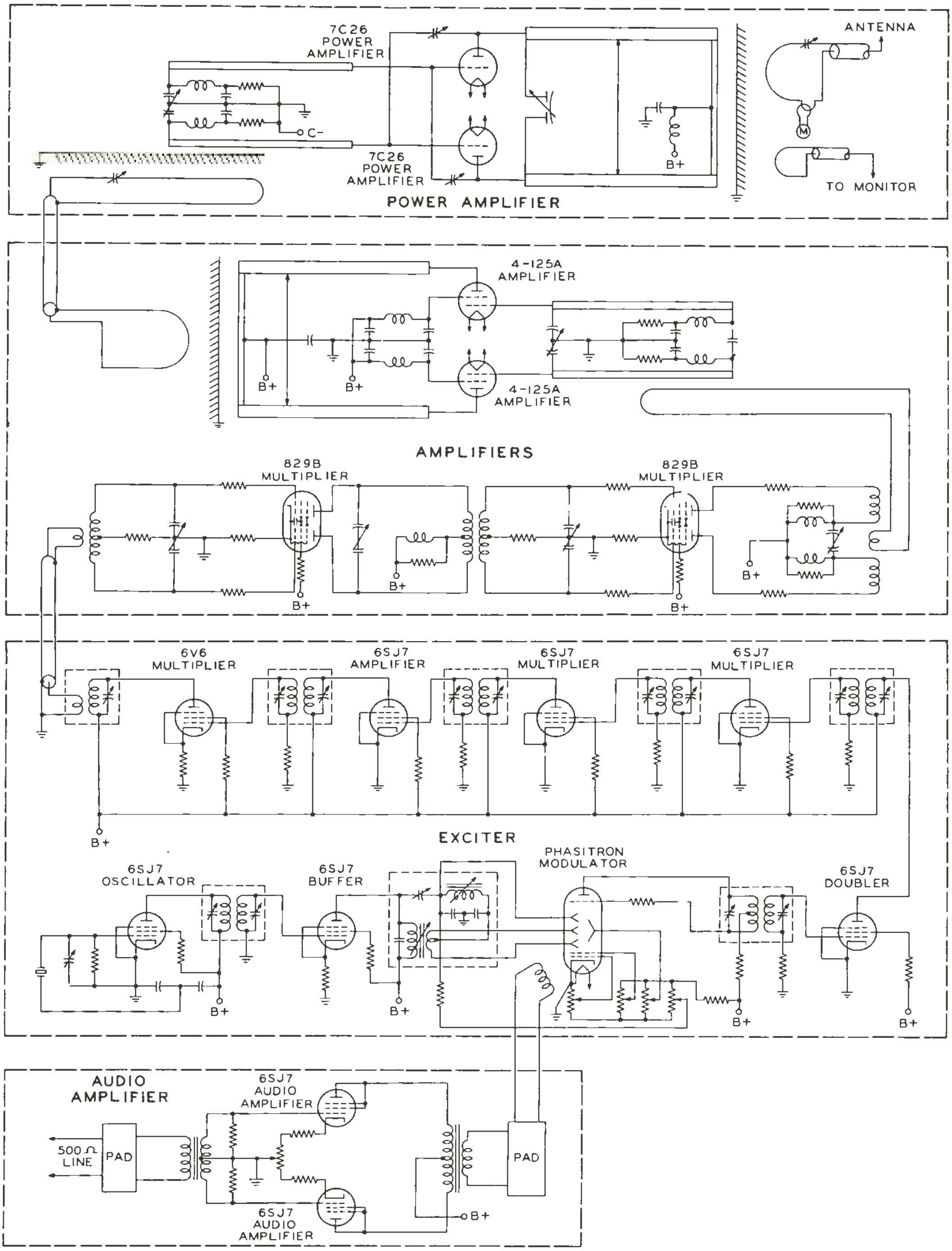
In Fig. 17 is shown a Gates SA-40 desk-type studio speech input console with the two turn-tables. Here in a single unit is complete studio-control equipment including preamplifiers, volume controls, volume indicator and everything necessary for control of a program between the microphone and the line to the transmitter. On top of the desk on either side are turntables for playing transcriptions so that the equipment may be used for either live talent or recorded programs.

Fig. 18 shows the bottom view of the Gate SA-40 console with the tilt-



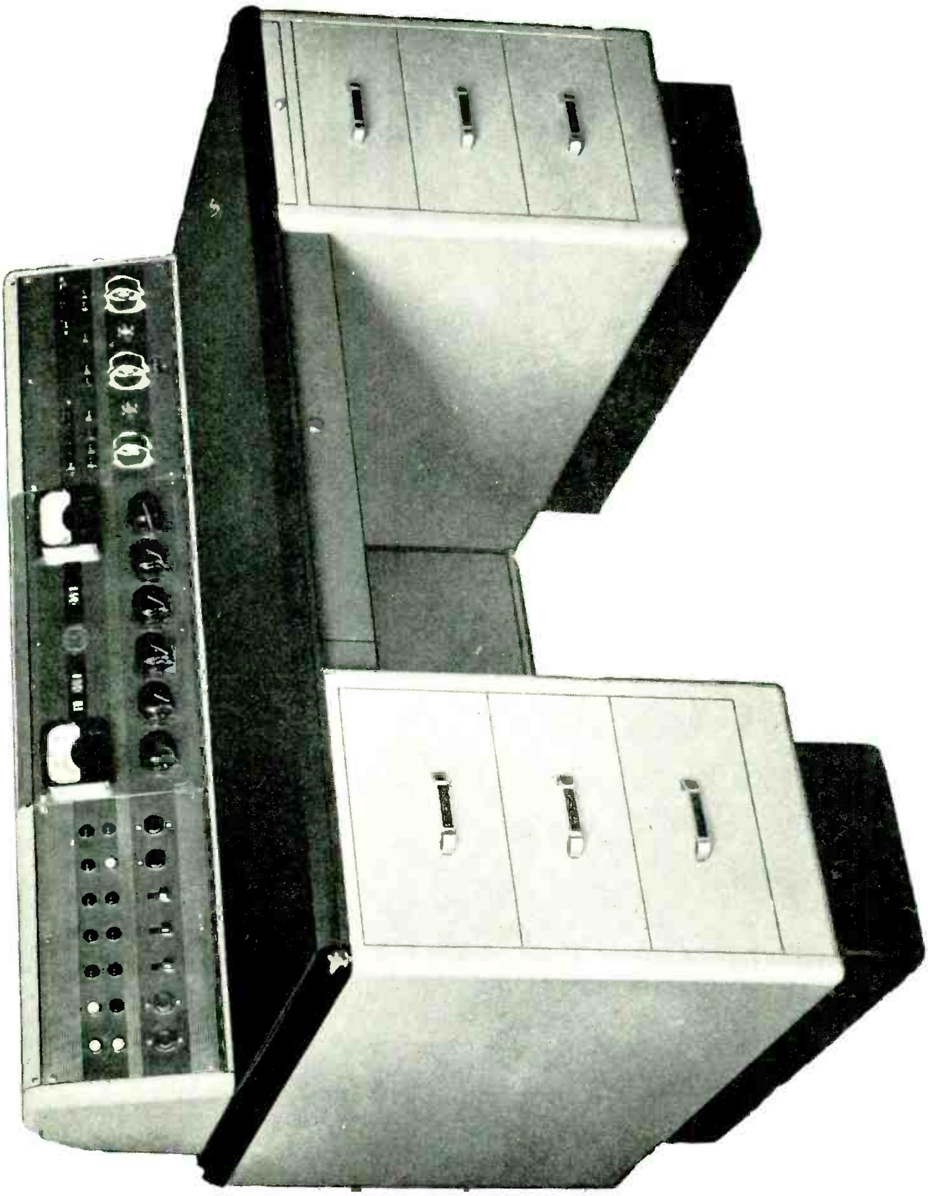
(Courtesy of Collins)

Fig. 13.—Collins type 733A-1 3000 watt fm Transmitter.



(Courtesy of Collins)

Fig. 14.—A simplified schematic diagram of the Collins Type 733A-1 3000-watt fm transmitter.



(Courtesy of RCA)

Fig. 15.—Front view of RCA type MI-11621 Console for use with RCA type BTA-50F1 transmitter.

back-to-service feature. The complete accessibility of all the components and terminal connections is one of the outstanding features of

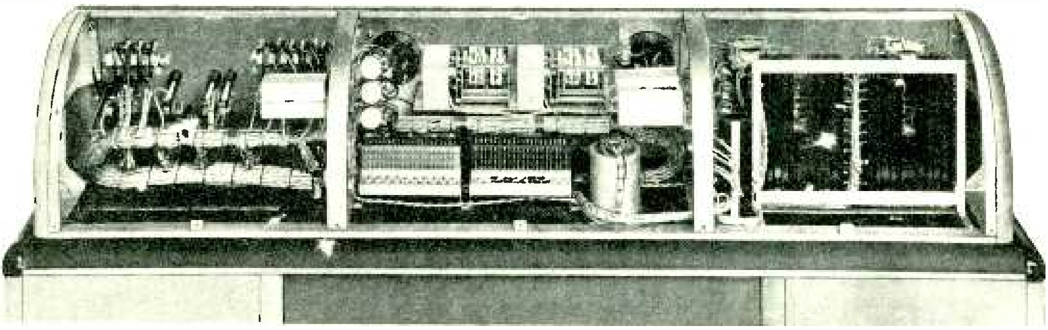
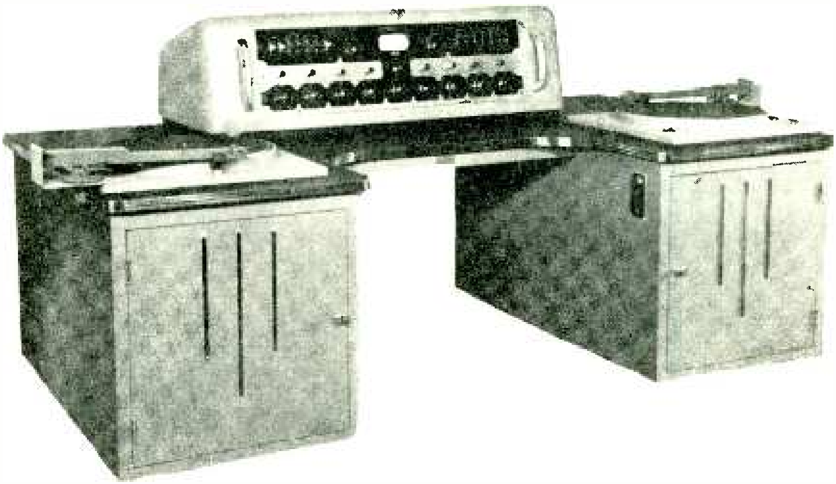


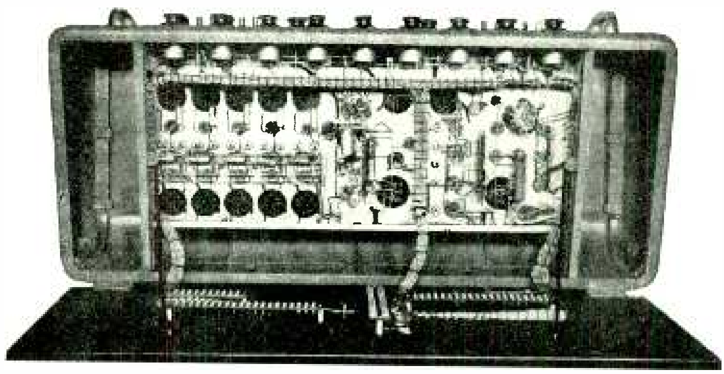
Fig. 16.—Rear view of the RCA type MI-11621 console.



(Courtesy of Gates Radio Co.)

Fig. 17.—Illustration of the Gates SA-40 console mounted on CB-4 horseshoe desk with CB-11 transcription turntables.

this console.



(Courtesy of Gates Radio Co.)
Fig. 18.—A bottom view of Gates SA-40 speech input console.

RESUME'

This assignment should give the student who is in broadcasting or contemplating entering the broadcast field a good idea of the development and trends in broadcast transmission engineering. Subsequent assignments will discuss in great detail broadcasting apparatus, circuits, antennas, studio amplifiers and other factors involved in delivering high-quality program material from the artist to the listener in the home.

GENERAL DISCUSSION

EXAMINATION

1. (A) Explain two objections to the use of really high-fidelity receivers for conventional broadcast reception.

(B) Under what conditions can such receivers be used satisfactorily? Explain.

2. (A) Explain why the FCC has adopted such rigid requirements for frequency stability and percentage of modulation for broadcast transmitters.

2. (B) What provisions must be made by the broadcast station to assure that these standards are maintained? Explain.

3. Explain the advantages and disadvantages of high-level and low-level modulation. To what extent are those factors modified by the use of the Doherty high-efficiency amplifier? Explain.

4. (A) If two broadcast transmitter locations are available, one on top of a hill overlooking the desired service area and the other below the area to be served, and other conditions are equally satisfactory, which location would you favor? Why?

4. (B) Why is a greater field intensity required for satisfactory summer reception in the South than in the North?

5. (A) What is the principal reason for the use of a high vertical radiator (in excess of $.5\lambda$) for a 50 kw broadcast transmitter? Explain.

(B) Would the reason in 5(A) be true in the case of a 250 watt transmitter? Explain.

6. How important is an elaborate ground system for a broadcast transmitter? If you had a .25λ antenna with a .5 kw transmitter and a poor ground system, and a limited amount of money was available for improving the antenna system, would you recommend increased antenna height or an improved ground system? Why?

7. What is the function of a frequency monitor, and basically how does it operate?

8. (A) Explain the manner in which modulation is produced in Fig. 6.

EXAMINATION, Page 5

8. (B) What type of modulation is this? What are the advantages? Disadvantages?

9. (A) Explain the manner in which modulation is produced in Fig. 10.

(B) What type of modulation is this? What are the advantages? Disadvantages?

EXAMINATION, Page 6.

10. Why is it necessary for the oscillator to be followed by a series of multipliers as shown in Fig. 14, instead of operating at the final assigned frequency?