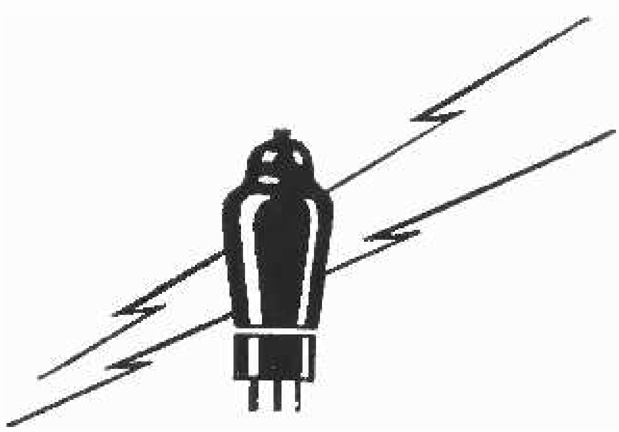
MODERN RADIO

by Kingdon S. Tyler

ILLUSTRATED WITH DRAWINGS BY JAMES MAC DONALD

AND WITH PHOTOGRAPHS



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KINGDON S. TYLER

New York City
May, 1944

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MODERN RADIO

I The Studio

THIRTY million families listen to radio programs every day, but few people listening in have any idea how modern radio stations, networks, and receivers operate. Even people who visit broadcasting studios usually come away more mystified than they were before.

It is true that radio is a complicated science and a science that is constantly developing and changing. It is also true that some of the scientific problems involved cannot be fully explained even by scientists. But much of the mystery of radio can be cleared up if each operation, from the original broadcast to its reception in your home, is explained separately. Starting with the studio where the program originates, we shall follow the program to the control room, to master control, then out along the telephone lines to the transmitter, to the transmitting antenna or radiator, to your receiving antenna, through your radio set to the loud-speaker in your home.

Radio has made tremendous strides in the last few years.

Studios have been designed where the quality or tone of a program may be changed by merely pressing a button. Echo chambers and echo machines have been invented that make a voice sound as if it were coming from a cave or from the bottom of a well. Sound effect machines can reproduce the sounds of soldiers marching, thunder, subway trains, a man being stabbed, and hundreds of other sounds. New types of microphones have been developed. New master control switching facilities have been designed to handle the ever-increasing number of programs coming from studios all over the country and by short wave radio from Europe and South America. New types of antenna systems have been invented.

The studio itself, the quality of the radio equipment, the skill of the technicians, the directing and timing, and many other things affect the production of any program. The variety of programs affects the design of the studio and the radio facilities that go into it, and the type and number of studios that a large broadcasting company must have.

If you have ever been to a radio broadcast, you probably have noticed that each actor or actress reads the lines from a script. This might leave you with the false impression that very little rehearsing is necessary to produce a radio show. Reading the script does save the time that would be required for each actor or actress to memorize the lines, but a great deal of time is still spent rehearsing. Some of the actors do memorize most of their lines, but they must always be prepared for changes which may be made in their script right up to the time they go on the air.

Half-hour shows can require ten hours or more of rehearsal. This means that each large station must have a dozen or more studios.

The studios are usually located in office buildings in the center of large cities. This makes it easier for actors, musicians, engineers, and all the other people employed by the broadcasting company to get to them.

Most large broadcasting companies have a transmitting station near each principal city in the United States, and they also have a number of studios associated with each transmitting station. The studios are in the city itself. The transmitting station and its antenna system are generally located out of town. The radio tower or towers and ground system require a considerable amount of space, so it is not practical to locate them in the heart of a city. The program, originating in the studios, is sent over telephone wires to the transmitting stations.

In order to see how active these various studios are in a large broadcasting company we will select the Columbia Broadcasting System (C.B.S.) Studio #22 in New York City and check what is going on in this studio for one typical day. Al Ward and Stoopnagle are rehearsing from nine o'clock in the morning until one. Broadway Matinee comes into the studio at one-fifteen and rehearses until four o'clock; at four they go on the air until four-twenty-five. At four-thirty Fun With Dunn comes into the studio for their rehearsal until five when they go on the air. Jeri Sullivan rehearses at five-forty-five and is on the air from six-thirty until six-forty-five. The Joan Brooks program comes into the studio at nine-forty-five for rehearsal and goes on the air at eleven-fifteen to eleven-thirty. In this particular case the studio is used almost continuously from nine o'clock in the morning until eleven-thirty at night and still was only on the air for eighty-five minutes.

This is typical of all active broadcasting studios, whether they are the studios of C.B.S., N.B.C. (National Broadcasting Company), the Blue Network, Mutual, or any other large broadcasting company.

Studios vary in size, depending upon the type of program and whether it is an audience show or not. Only the large programs have audiences—most of the smaller daytime programs do not. The studio is a sound-proof room which has been designed especially for broadcasting purposes. The studio also has other rooms that are used in conjunction with it. One of these rooms is the control room and it is usually located near the acting area where the microphones are set up. The control room is also sound proof, so you cannot hear what is going on in the studio except over the control room loud-speaker which is reproducing the program that is being picked up by the various microphones. In one wall of the control room is a large plate glass window through which the control man and the director can see what is going on in the studio. Quite often, near the control room or in some other part of the studio is another sound-proof room which is also equipped with a loud-speaker and a window. This room is used for the sponsors, so that they can hear the program exactly as it sounds in the control room.

There is usually still another room near the studio where the various equipment is stored for each broadcast. A band usually requires music stands, a raised platform, electric organ, three or four microphones, a xylophone, etc. A play would not require a raised stage or any musical equipment but would need sound effect equipment. The platforms, electric organs, pianos, sound effect equipment, microphone stands, etc., are stored in the equipment room.

There are usually two large electric clocks in each studio, one over the control room window and one opposite the control room. These clocks have to be extremely accurate and they are constantly checked, since timing in radio is very important. A clock which is a few minutes or seconds off can cause a program to be cut off before it is over; or it may mean the opening lines of the next program are not heard because the program in the next studio has already started before the switch is thrown to pick it up. The clocks are so situated that the director, engineer, and actors can see them at all times.

During rehearsals the program is timed by the director or assistant director. He uses a stopwatch or a special electric clock which operates like a stopwatch to check the timing of the various parts of the program. In this way he can determine to the second just how long each part of the program is going to take. The program must be arranged to take exactly fifteen, thirty, sixty minutes, or whatever time is allowed for it. After the timing has been checked, a program log is made up, showing to the second when each part of the program should be complete. At the top of the log is the time when the show is to go on the air. If the commercial is to end at two minutes and fifty seconds after air-time, that exact time is shown. The log covers the entire show, and the director keeps checking the timing. During a program, he signals the various actors from the control room, indicating with his hands whether they are on time, behind time, or ahead of time.

If they are on time, the director points to his nose with his index finger—this means "on the nose." If the actors are behind time, the director swings his index finger rapidly in a circle or pretends to turn a crank handle with his hand. This means "crank it up; you're behind time." Then the artists speak their lines a little faster to make up for lost time. If they are ahead of time, the director makes a motion with his hands as if he were stretching something. This indicates they are speaking their lines too rapidly and he is telling them to "stretch it out—slow down." In this way the show is speeded up or slowed down to keep pace with the timing on the log, and the program is completed exactly on schedule.

Another sign that is used when everything is progressing properly is to hold up the right hand and form a circle with the thumb and index finger. This means everything is "okay."

The program log also shows what musical instruments are to be used on the program, and the personnel involved.

Large programs require a large personnel. One or two technicians operate the radio equipment in the control room. A director and assistant director take care of the log sheet and timing. They usually operate from the control room. The announcer, orchestra conductor, sound technicians (sound effects men), and artists are in the studio.

On certain shows four men are required to produce the various sound effects. Some of these effects are produced mechanically while others are produced from recordings.

During rehearsals the writer of the play is on hand to make changes in the lines if they are necessary. Script changes can and do occur right up to the time the program is put on the air.

As the various actors and actresses rehearse before the microphone, the director and engineer stay in the control room and listen to the program as it is reproduced there by the loud-speaker. This enables them to hear exactly what is picked up by the microphones.

The reproduction by the control room loud-speaker may be quite different from the original sound. One of the reasons for this is the variation caused by the distance of the sound source from the microphone. The effect when the sound source is close to the microphone is quite different from the effect when the sound source is far away from the microphone.

As the director listens, he signals the artists on the program when they are too far away from the mike or too close to it. The director beckons when he wants the artists to move closer to the mike. If the artist is too close, the director moves his hands as if he were pushing someone away, indicating that the person should back away from the microphone.

If the director wants the musicians or artists to increase or decrease their volume of sound, he uses another set of signals. He holds the palms of his hands upward or downward—palms upward mean increase the volume, and palms downward mean decrease it.

During rehearsals the director tells the various actors how he wants them to speak their lines. He tells them whether they should speak faster or slower or with more punch. He also tells the sound effects man just what type of effect he wants, such as a horse galloping, a horse pulling a heavily loaded wagon, or a tired man climbing a long flight of stairs. The director will spend hours of rehearsal to create just the right atmosphere for a play.

The engineer sits at his control desk in the control room. Indicating lights on the desk show what microphones are in use. This is important since several microphones are used at the same time in large productions. These indicating lights go on as the engineer throws the various switches which turn on the microphones. When a microphone is not in use, it is switched off so it will not pick up extraneous sounds. Above each indicating light on the control desk is a small writing tab where the engineer can record what each microphone position is being used for—announcer, sound effects, orchestra, and so on.

Right outside of the studio door is a sign indicating whether a studio is rehearsing or is on the air. This is done so that people working around the studio know when it is safe to enter. The on-air sign is controlled by a switch on the engineer's control desk. When this switch is thrown, it not only operates the on-air sign but it also connects the studio to a telephone line which indirectly goes to the transmitting station. This line first passes through a master control room where all studios are connected to various outgoing lines. Some of these lines go to transmitting stations in other cities.

The on-air switch on the engineer's control desk has three positions: cue, rehearsal, and on-air. During rehearsals he leaves it on the rehearsal position. Just before it is time to go on the air he switches to the cue position. He can then listen by means of a special line coming from the master control room (called a cue line) to the tail-end of the program preceding his. This is originating from some other studio, and the cue line is connected to the outgoing line of that particular studio. The engineer hears the other program sign off the air and so checks on the sign-off time. If the other program signs off a few seconds late, the engineer can start his own program a few seconds late, and the director can speed it up to make up the difference in time.

As the engineer hears the other program sign off, he throws his switch to the on-air position and signals the artists that they are on the air. The director then takes over, coaching the various actors as to the timing and when they are to come in with their various parts.

Let's look in at Studio #22 and see what's going on now. The studio is set up for a rehearsal of Broadway Matinee.

There is a seventeen-piece orchestra practicing before the microphones. This orchestra consists of 4 violins, 1 viola, 1 cello, 1 base, 1 percussion, 4 saxophones, 3 trumpets, and 2 trombones. Four microphones are being used to pick up the music. The orchestra is divided into two groups—the string instruments on one side of the studio and the wind instruments on the other. Two microphones are used in front of these two groups and these mikes cover the entire orchestra. Another microphone is placed directly in front of the violins and the fourth in front of the trumpets.

The engineer in the control room can control the volume on these various microphones. He increases or decreases the volume on the different mikes according to the requirements of each musical number. He would, for example, increase the volume on the trumpet mike when a trumpet solo happened to be a feature of the music.

The musicians in the back part of the orchestra are seated on a platform so they will be visible to the audience. A girl who is a soloist is in front of the orchestra on a small raised platform, and she sings into a separate microphone. When she sings, the engineer reduces the volume on the orchestra microphones and increases the volume on the vocalist's microphone to balance her voice with the orchestra.

In the control room overlooking this scene are the engineer, the director, and assistant director, seated at their desks. The engineer notices that the vocalist's voice is varying in volume at certain times, and he calls this to the attention of the director, who sees that she is turning her head away from the mike as she sings. He presses a button and talks into a microphone on his desk which is connected to a loud-speaker in the studio. In this way he instructs the vocalist to move in closer to the microphone and to be sure not to turn her head as she reads the music. When she completes the number, the director checks his assistant on how many minutes and how many seconds that particular number took. After checking the time on all the various parts of the show, the director discovers he is going to run fifteen seconds over his time. To take care of this he cuts out part of the script and calls the author to rewrite a few of the lines.

A half-hour before air-time the rehearsals are completed and the audience is permitted to enter the studio and take their seats.

Just before air-time the engineer throws one of the switches on his desk from rehearsal position to the cue position. As he listens to the program preceding his, he adjusts the volume on his loud-speaker by means of a volume control located on his desk. He keeps his eyes glued on the sweep-second hand of the clock on the studio wall. As it approaches four o'clock he hears the preceding program sign off. When the second hand indicates it is exactly four o'clock, he throws the switch to the on-air position and signals the director to start the opening number.

Broadway Matinee is on the air.

II Studio Design

MODERN broadcasting studios today are quite different from what they were a few years ago. They are designed and constructed for the particular purpose for which they are used, whereas in the early days of radio almost any room served as a studio. Studios have gone through many changes to keep pace with the other technical improvements in radio. They are not just modern, dramatic rooms designed to create the proper atmosphere for radio shows. They are rooms which the engineers have developed after years of research and experimental work. Practically everything in the modern studio, including the floors, walls, and ceilings, is designed to improve the quality of reproduction of sound.

As radio improved its technical equipment so that more accurate reproduction of sound could be achieved, it was necessary also to improve the studio, since it plays an important part in sound reproduction.

A person talking or playing a musical instrument can sound entirely different in different rooms. You may have observed that in a certain room you have to raise your voice in order to be heard, while in another room if you whisper you can be heard all over the room. The reason for this is that part of the sound reaches your ear directly from its source and the rest of it reaches you after it has been reflected from the walls, ceilings, and other objects. Sounds, which are really air-borne vibrations, are reflected by certain objects and almost completely absorbed by others. So if you are in a room where there is a lot of sound-absorbing material, such as rugs, drapes, upholstered furniture, your voice does not seem to have power; but if you are in such a place as an indoor tile swimming-pool, your voice is reinforced by the sound that is reflected from the floor, walls, and ceiling, and the volume seems to be increased.

When sound is reflected by hard walls, floors, and ceilings it bounces around the room for a short period of time. This is called reverberation. However, when sound waves strike soft materials, such as rugs, drapes, and clothes, most of the sound is absorbed and there is little reverberation. As we live indoors a good part of the time and usually hear music and other forms of entertainment indoors, our ears have become accustomed to a certain amount of reverberation. But it becomes annoying when there is too little or too much.

Engineers and scientists have made a study of sound and its behavior under different conditions, a branch of science called acoustics. Today, by applying the knowledge that the scientists have gained by research, many of the early difficulties with studios have been eliminated.

In the early days of radio, when almost any room was used as a studio, great difficulties were encountered. Noises originating outside of the room penetrated the walls and spoiled the program. Orchestras did not sound right—certain musical instruments were too loud in comparison with others. Certain sounds would build up and linger annoyingly when the microphone was placed in certain positions in the room. Today we not only know what causes these difficulties; we also know how to overcome them.

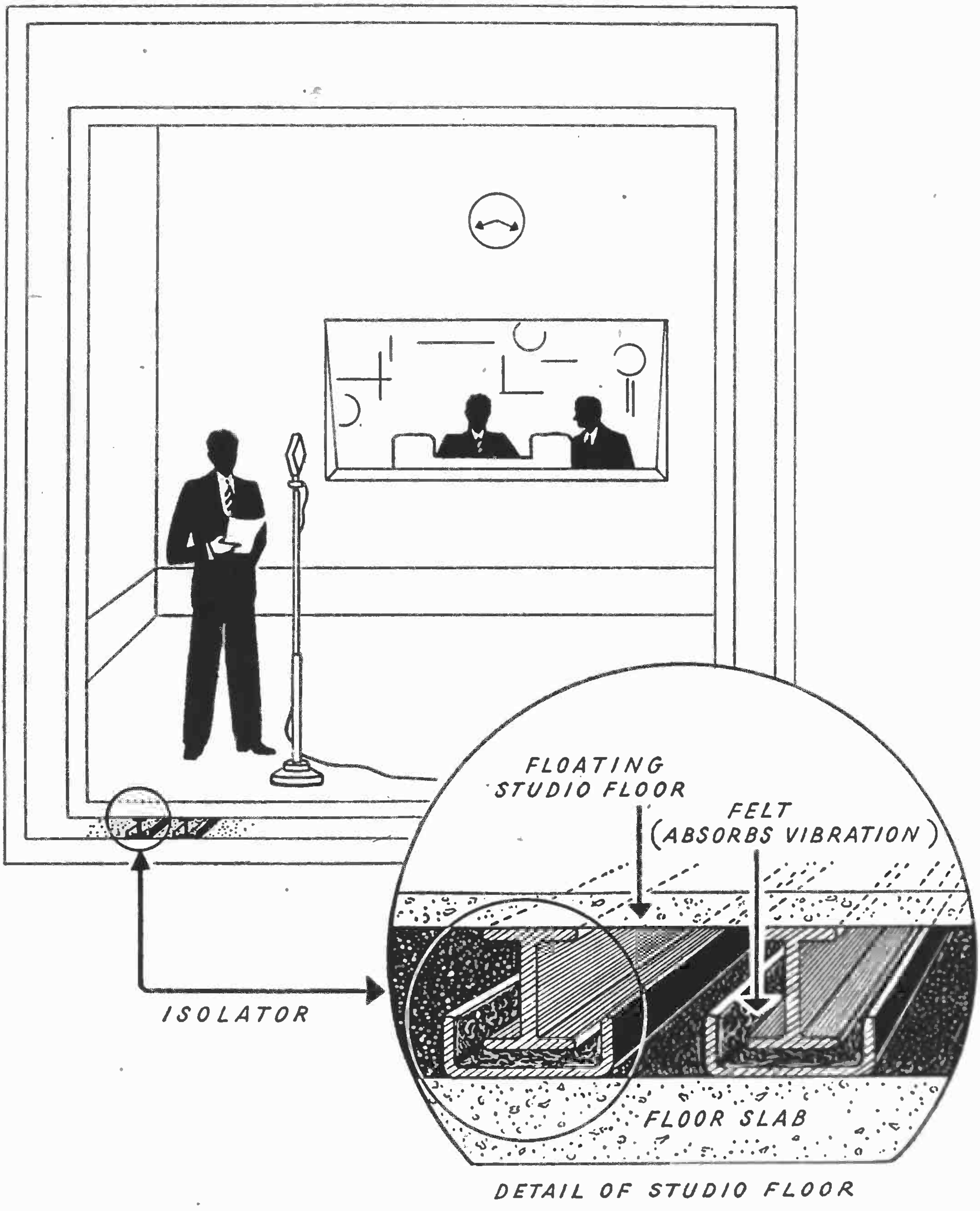
Sounds are created chiefly by mechanical vibrations. These vibrations may originate, for example, in the vocal cords in your throat or in the strings of a piano. They may be caused by the reed in a wind instrument or by an insect rubbing his legs against his wings. Sound travels in the form of waves. Therefore we call the vibrations sound waves.

Sound can enter a studio from the outside in many different ways. If the walls are porous, the sound can penetrate the walls or cause them to vibrate. The vibration of the wall will develop sound waves inside the room. Mechanical vibrations caused by motors or machinery can travel along beams and cause a wall to vibrate or cause some other object in the room to vibrate, thus producing sound waves.

Microphones are very sensitive, and if the least noise or vibration leaks into the room it is picked up by the microphone. Even sounds or vibrations which you cannot hear or feel register on the microphone and so must be eliminated. Whatever the microphone picks up is amplified or magnified many, many times before it reaches your home. Therefore any foreign noise becomes quite objectionable on the receiving end. Great care must be taken to isolate the studio from all outside noise or vibration.

As most studios are located in office buildings in the heart of large cities, where there is considerable vibration and noise, special precautions have to be taken against this. So the better studios have double walls, floors, and ceilings. The studio is really a room within a room—in other words, a floor is built on top of a floor with an air space in between. Separators are used to keep the two floors apart and these separators are supported by hair-felt pads. The hair-felt pads consist of a mixture of hair and felt which absorbs a considerable amount of vibration when properly compressed. Hair felt of a certain density under compression will absorb certain frequencies of vibration, the frequency being the rate per second of the vibration.

The floor of a modern radio studio is a floor floating on hair-felt pads. The walls and ceiling are constructed in a similar fashion. These separators and hair-felt pads are called isolators, because they isolate or absorb certain vibrations which otherwise would be carried into the studio. As an example, we will imagine there is a motor mounted on the floor of the room next to the studio. The vibration from this motor could be transmitted to the studio by the beam supporting the floor, but these felt isolators absorb the vibration and prevent it from reaching the floating floor in the studio. The springs on a car work on a similar principle, except that they are designed to absorb shock or vibrations of greater intensity and lower frequency.



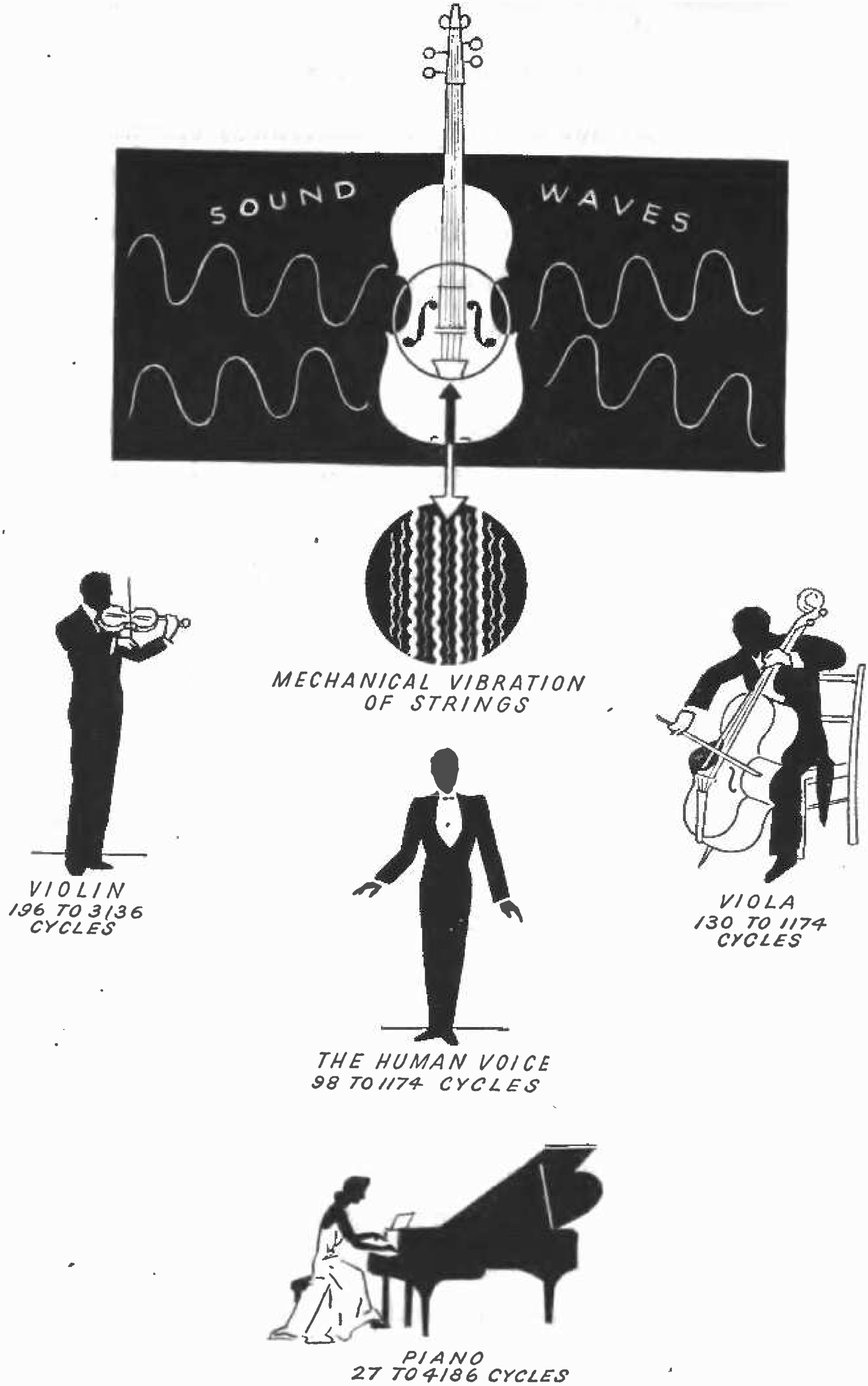
STUDIO CONSTRUCTION

The frequency and intensity of the mechanical vibration determine whether or not it will produce sound waves which we can hear—that is, audible sounds. Audible sounds are sounds which we are capable of hearing. There are a great many sounds which the human ear cannot hear. When we think of sound, we should think in terms of frequency. When a violinist draws his bow across one of the strings of his violin, he causes that string and sound-board to vibrate; this in turn causes vibrations in the air, thus generating sound waves. The number of times per second at which the string vibrates is called the frequency. The middle C string on the piano when struck will vibrate two hundred and fifty-six times per second, or at a frequency of two hundred and fifty-six cycles. This generates a sound wave of the same frequency.

As each note is struck on the piano, a different frequency is generated by the vibration of the strings. As a person plays the piano, sounds of various frequencies are produced. These airborne vibrations of various frequencies combine to produce other frequencies. Generally speaking, sounds are a combination of frequencies. The piano can produce sounds varying in range from 70 cycles per second to 6,500 cycles.

It is possible for the human ear to detect sounds as high as 20,000 cycles per second, though a good many people cannot hear above 15,000 cycles. The reason for this is that some peoples' ears are more sensitive than others'—just as eyesight varies with the individual.

The normal male speaking voice covers a range of about 100



FREQUENCIES PRODUCED BY VARIOUS MUSICAL INSTRUMENTS to 8,500 cycles per second; the female voice, from about 150 to 10,000 cycles per second. Musical instruments cover a range from 40 to 15,000 cycles per second.

Interior rooms are usually used for studios, since this helps to eliminate noises coming from the street. In order to ventilate these studios, an air-conditioning system is used. Even the metal ducts which supply air to the studios have to be isolated so they will not transmit vibration or sound to the studio. This is done in two ways. First, the ducts are lined with sound-absorbing material; this eliminates air noise caused by the fans. Second, the parts of the ducts where they connect to the fan on one end and the studio on the other are made in the form of a canvas sleeve for a space of a few inches. This absorbs any vibration that might travel along the ducts and reach the studio.

Sound waves bounce around a room like a rubber ball. If you clap your hands together in a large room with plaster walls, the sound seems to linger for a second or two. This is caused by the sound rebounding off the walls again and again. This reverberation plays a very important part in studio design. You might think of it as a series of echoes of short duration. Reverberation tends to increase the volume of an orchestra and to blend the different musical instruments together. But if the reverberation time is too long, it causes a hashing effect, which spoils the quality. Therefore a studio must be designed for a definite reverberation time. This is done by the use of acoustical materials or, in other words, sound-absorbing materials. There are a great number of these materials on the market.

Reverberation time (the length of time it takes for a given sound to die out in a studio) can be pre-determined fairly accurately by acoustical engineers before the studio is even built. This involves complicated calculations, however, because various audible frequencies behave differently. For instance, a certain material will absorb more sound at 100 cycles than it will at 1,500 or 5,000 cycles per second. The acoustical engineer first determines how much reverberation he wants at various frequencies; then he sets about designing the studio to produce this effect. Everything in the studio, including the air, has to be taken into consideration. Also all the dimensions of the studio play an important part in reverberation. It can readily be seen that in a very small studio the sound may strike several wall, ceiling, and floor surfaces before it has traveled very far. In large studios certain sound waves may travel the entire length of the studio before striking a wall surface to be partially absorbed or reflected.

The acoustical engineer must also consider the types of shows to be broadcast from the studio. Bands or concerts require different acoustical treatment from plays. However, studios have been designed where the acoustics can be varied for different types of shows. In fact, an invention has been made which makes it possible to change the reverberation time in a studio by merely pressing a button. This invention, the acoustivane, will be described later in this chapter.

By laboratory experiments the acoustical engineer knows just how much sound will be absorbed at the various audible frequencies by all the materials used in the studio—floor covering, glass, plaster, wood, metal, etc. He also knows just how much sound absorption is provided by the various acoustical materials that he is going to use in the studio. By knowing just how many square feet of each material are going to be used and by applying the various absorption factors that have been established by tests, he can plot a curve. This curve shows what the reverberation time will be at various audible frequencies. The materials used and the size of the studio can vary this anywhere from one-fifth of a second to well over a second. This may seem like a very small difference but it makes a tremendous difference in the quality of the sound in a studio.

Some of the acoustical materials are in the form of perforated metal squares; others are perforated asbestos board or fiber board. There are acoustical plaster and rock-wool blankets, and various other materials are also used for acoustically treating rooms. Restaurants often use these materials on the ceiling to reduce noise. The perforated materials have an advantage, as other materials can be placed behind them to change the absorption at various frequencies. A good deal of sound passes through the holes in the perforated materials and is trapped behind the walls or ceiling. By placing different materials behind the perforations the acoustical characteristics can be changed.

We have already mentioned that certain sounds picked up by the microphone seem louder when the microphone is placed in certain locations in the studio. The cause of this is what is known as a standing wave. A standing wave is produced by the sound beating back and forth between two parallel surfaces, such as walls, or ceiling and floor. When this happens two or more sound waves of the same frequency are often super-imposed upon each other. This causes them to build up in intensity. If you think of these sound waves as being ripples on water, you can visualize what occurs. As these waves beat back and forth between two surfaces, the crest of one wave at a certain point matches the crest of another, and the sound wave builds up in intensity at that particular location in the studio. This is called a standing wave. It usually occurs when sounds of the same frequency pass one another, traveling in opposite directions. Naturally, this may occur when the sound is reflected by two parallel surfaces so that it travels back and forth in the same plane.

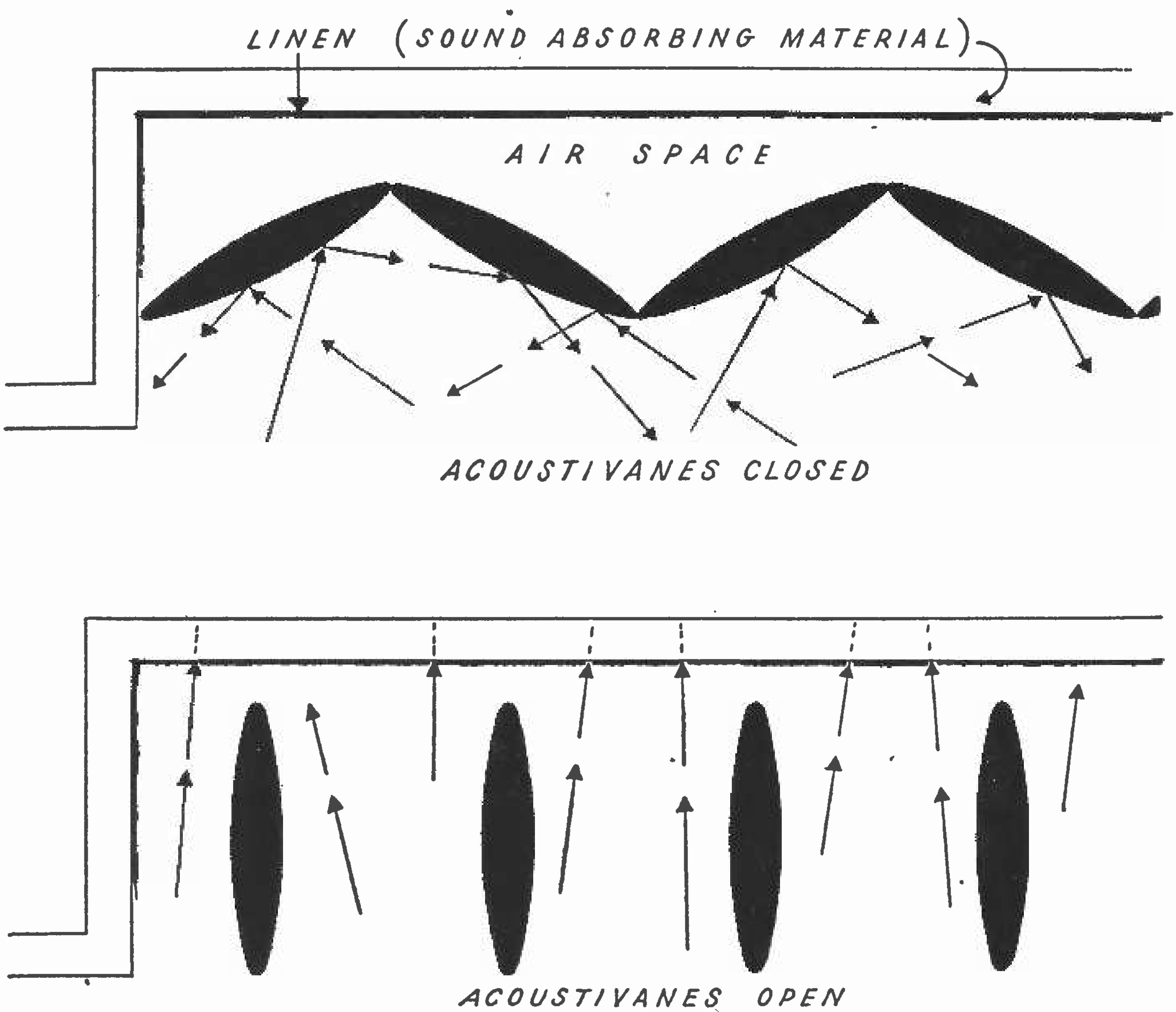
Some of the newer studios have eliminated this difficulty by designing the studio with no parallel surfaces. This is done in any one of several ways: by setting two walls and the ceiling at an angle; by making the walls and ceiling curve; or by making certain walls and the ceiling in the form of a saw-tooth. Some studios use several different treatments to break up parallel surfaces. If this is properly done, it eliminates practically all the difficulty caused by standing waves.

Plywood panels can improve the acoustical quality in a studio. They tend to make the sound in the studio more brilliant. These panels vibrate, when sound waves strike them, in somewhat the same way as the body of a violin vibrates when it is being played. This causes each sound to linger slightly, smoothing out the sound. Plywood panels (especially when they are in certain shapes) reverberate and improve the acoustical quality of a studio, particularly for music. The panels not only liven the music but seem to add a mellowness. If you place your fingers against the wood surface of the panels while an orchestra is playing, you can feel it vibrate.

Studios have been built with large wall areas consisting of half-round plywood strips. As they are mounted lengthwise, this makes part of the studio have an appearance similar to the inside of a log cabin. These long half-round hollow plywood strips add a pleasing reverberant quality to the sound.

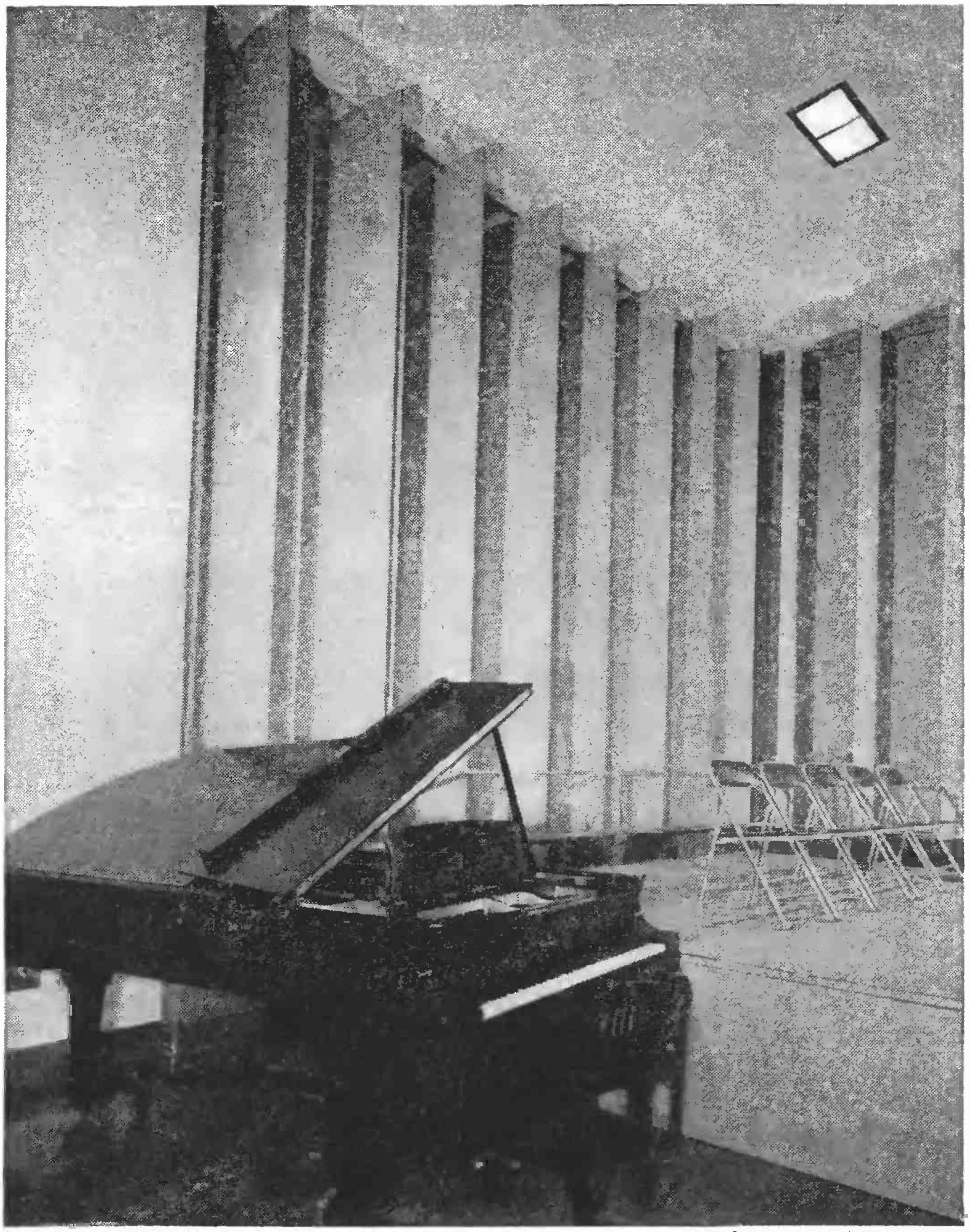
Being able to vary the acoustics in a studio has definite advantages. While a live reverberant room may be good for music, it does not work out so well for plays. For instance, if the scene was supposed to be an outdoor one and there was considerable reverberation, you would immediately get the effect that the scene was in a large room of some kind and this would spoil the illusion. Even in the case of musicals, some conductors want more reverberation, others want less. This is probably due to the type of music, the musical instruments used, and the conductor's interpretation. How to be able to vary the acoustics at any time in a studio to suit a particular set of conditions has been a difficult problem for the acoustical engineers.

Mr. C. R. Jacobs, acoustical engineer, invented acoustivanes to solve this problem. These vanes are used in C.B.S. Studios 21 and 22. The engineer can automatically vary the acoustics of the room by merely pressing a button on his control desk. These are the only two studios in the United States equipped with acoustivanes. Beside being very practical, they are the most modern and dramatic thing in the studio. Silently an entire wood-paneled wall opens or closes automatically. When the blades are closed, these wooden vanes form a reverberating wall. When the blades



HOW ACOUSTIVANES ABSORB OR REFLECT SOUND

are open, they expose sound-absorbing material which reduces the reverberation time. By varying the amount you open the acoustivanes you can increase or decrease the reverberation time to the desired effect. At five different locations in the studio there are groups of these acoustivanes—large hollow plywood veneered



Courtesy of C.B.S.

STUDIO 22, ACOUSTIVANES OPEN

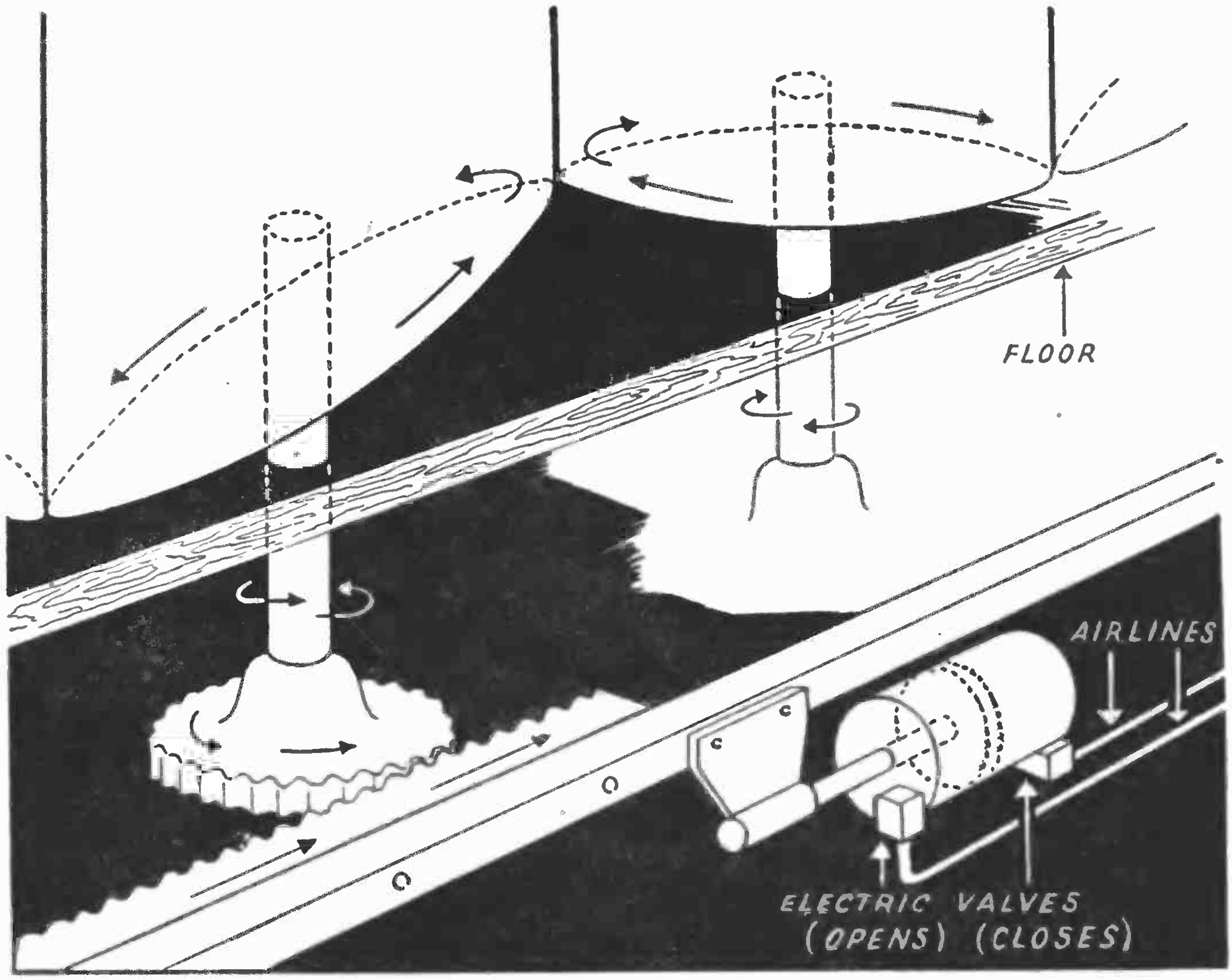
panels shaped something like airplane wings. Two of these groups form part of the walls for the stage or the end of the room where the microphones are set and the actors perform.

These wood panels are 2 feet 5 inches wide, 4 inches thick, and 12 feet tall. They pivot at the top and bottom. When they are closed they form a saw-tooth wall, and when they are open they expose the sound-absorbing material behind them. If they are only partly opened, they expose only part of the acoustical material.

These plywood vanes not only regulate the reverberation but improve the quality of the music in the studio. The three shorter sets of wood vanes at the audience end of the studio are used to compensate for the audience. Since clothes absorb a great deal of sound, a few hundred yards of sound-absorbing material are added to the studio when an audience is present. The vanes are left open during rehearsals when no audience is present, and the sound-absorbing material behind them is exposed. When on-air time arrives and the audience is present, the acoustivanes are closed to compensate for the audience.

The large vanes in the acting area start about 3 feet from the floor and extend to the ceiling. The 3-foot space beneath the vanes encloses the mechanical device which automatically controls them. Each vane has a drive shaft on the bottom that extends into the enclosure. Gears are mounted on this shaft and a long rack gear engages them. This rack gear is driven by a vacuum cylinder. The vacuum cylinder is similar to the piston and cylinder on a steam engine, except that a vacuum is used instead of steam.

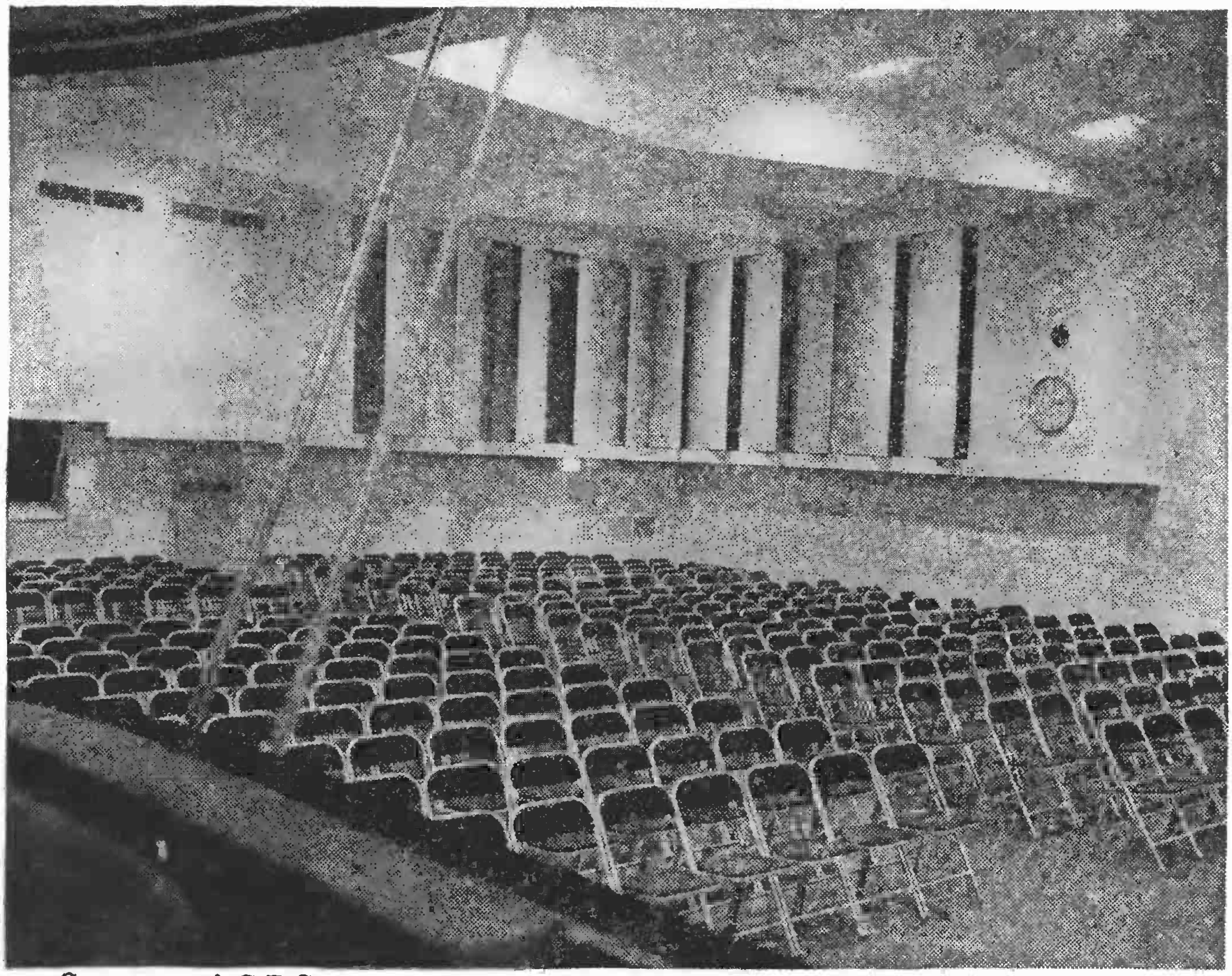
These vacuum cylinder pistons which control the various groups of vanes move back and forth, opening and closing the vanes smoothly and silently. Electric valves control the operation



MECHANICAL DEVICE WHICH CONTROLS ACOUSTIVANES

of the cylinder pistons, the various control buttons being mounted on the engineer's control desk. There is also an indicating meter for each group of blades which gives the engineer the position of all the acoustivanes in the studio. These indicating meters are controlled by an electrical device, a rheostat, on the vacuum cylinders.

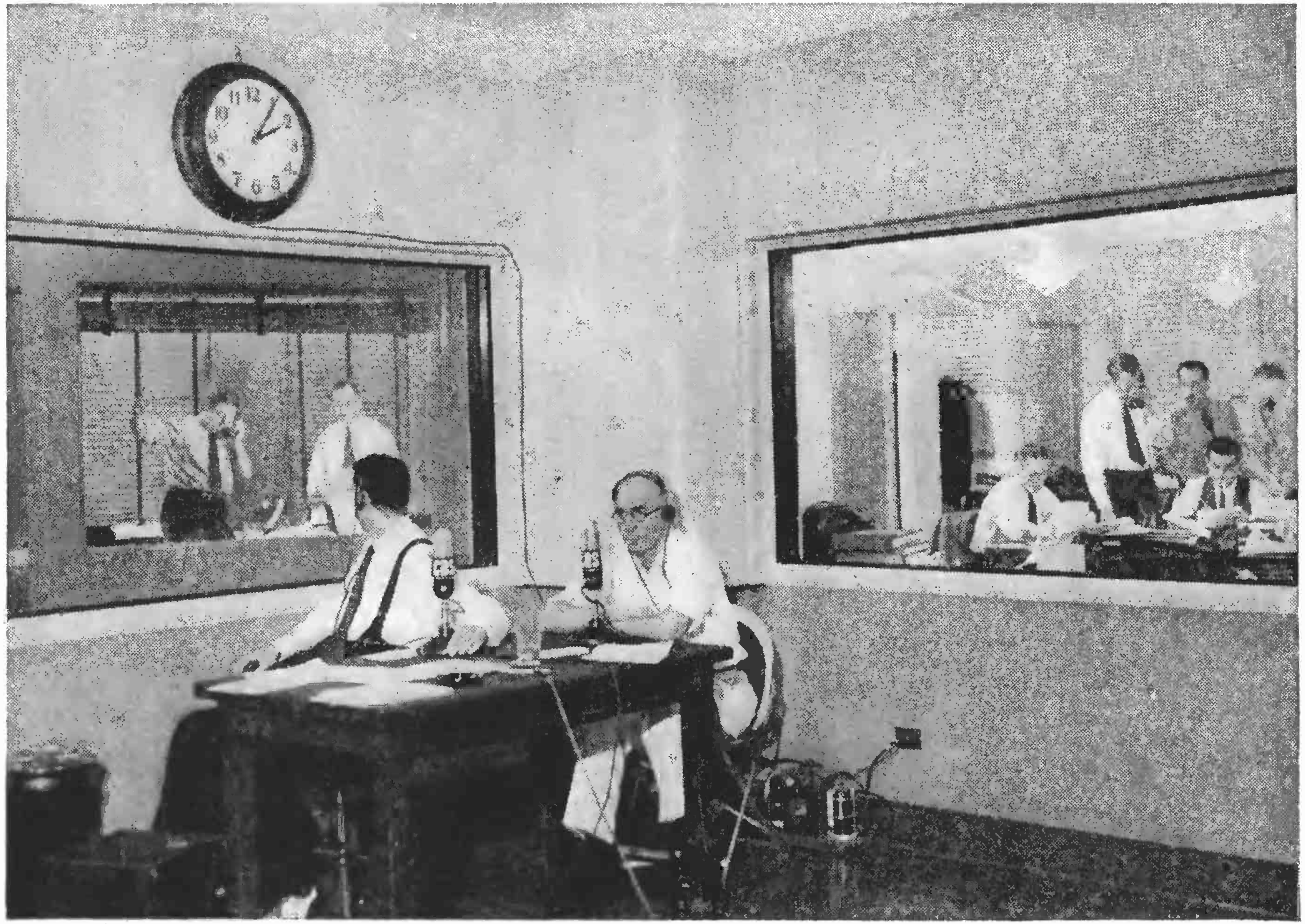
These acoustivanes are set differently for almost every program, depending on the type of show and the number of microphones used. When large orchestras use these studios, the large vanes are partially or completely closed to add as much brilliance



Courtesy of C.B.S.

STUDIO 22, ACOUSTIVANES, AUDIENCE END

as possible. Usually a single microphone is used to pick up a large orchestra. Smaller orchestras quite often use more than one microphone. This is done to accent certain groups of instruments, often producing the effect of a larger orchestra. In other words, one microphone may be used to pick up the entire orchestra, while another mike is placed in front of the string instruments to in-



Courtesy of C.B.S.

NEWS STUDIO

crease the volume of this section of the orchestra.

When this is done, it adds to the reverberation. Both microphones are picking up reverberant sound. To compensate for this, either one or both sets of the large vanes are partially or fully opened.

The studios with acoustivanes are designed so they have no parallel walls or surfaces. The wall sections between the acoustivanes are set at an angle and curved. The ceiling is of a saw-tooth type. A perforated asbestos board is used on the walls and ceiling, with various acoustical treatment behind it, to get the proper absorption at various frequencies.

In the early days, studio acoustics were checked mainly by listening. Today there is a recording machine for measuring the reverberation time at various frequencies. This is the way it operates: The machine is set up in the control room and several microphones are placed in various parts of the studio. What each microphone picks up is amplified and fed into the machine. A large loud-speaker is set in the studio and individual sounds of various frequencies are fed to the speaker system by a machine called an oscillator. The oscillator supplies pure sounds of various frequencies, such as 100 cycle tone, 500 cycle tone, 1,000 cycle tone, and so on. As each tone is produced by the speaker, the microphones in the studios pick it up. The machine records what each microphone is picking up. The various tones are only applied to the speaker system for a short time and then they are cut off abruptly. This machine records on tape the exact time it takes for the sound to die out in the studio or, in other words, the time it takes for the sound reverberating around the room to be absorbed. You can also tell from this tape if there are standing waves in the studio. Machines of this type have enabled the engineers to improve the acoustic quality of programs to the high standards existing today.

III Sound Effects

REALISTIC sound effects play an important part in radio. The director relies on these effects to produce the proper realistic atmosphere and background for a play.

Almost every play requires certain sound effects. They may be quite ordinary sounds such as the closing of a door; they may be farmyard noises like the cackling of chickens, the grunt of a pig, the neighing of a horse; they may be night noises—the sound of a katydid or the far-away whistle of a train. Properly handled sound effects and timing add immensely to the reality of a scene.

Orson Welles directed a show in which the effects were so realistic that it threw a great many people into a state of panic. Men from Mars were supposed to be invading New York City. The description and the effects were produced so well that a number of people thought an invasion was actually occurring. Some people packed their belongings in their cars and drove to the transmitting station, asking which way they should go to escape the invaders. Policemen were stopped in the street and questioned by panicky drivers who had been listening to the program in their cars. Other people ran from their homes.

Sound effects are so important that the large broadcasting companies have entire departments which do nothing else but invent, record, and produce various effects. No matter how many sound effect machines and sound recordings a company may have, new effects are always being called for. The sound effects men build machines and experiment for days to reproduce certain sounds accurately. They travel great distances to make sound recordings of steel mills in operation, mining operations, the engine room noise in a ship, or any other sounds or combination of sounds which may be reproduced more accurately by recording them than by attempting to imitate them.

The broadcasting companies maintain huge record libraries containing thousands of records of different types of noises: airplane sounds, songs, boat whistles, bird songs, cheers, battle noises, animal noises, etc.

It takes a good deal of practice, a trained ear, and split-second timing to produce good sound effects. The gadgets and machines help, but much ingenuity is required to reproduce effects accurately. The sound effects men who do this work are really artists. Each sound effects man has to go through a training period to learn how to use the various gadgets and machines.

A great many of these sound effect gadgets are quite simple. The one for horses walking, trotting, or galloping is made of two suction cups about 4 inches in diameter, or a cocoanut shell, cut in half, with straps fastened to the outside so that you can slide your fingers underneath the straps. By putting these down on a wood surface with the proper motion all sorts of horses' gaits can be produced. A skilled operator can make the horse sound tired,

Courtesy of C.B.S.

DEVICE FOR PRODUCING SOUND OF HORSES' HOQFS

frisky, or as if he were pulling a heavy load. By using sand on the wood surface, the effect of a horse traveling on a gravel road can be produced.

How hard or how easy it is to produce a desired effect is difficult to determine unless you have had experience in this field.

Offhand, you might think it difficult to reproduce the sound of a crackling fire. Actually this is quite easy to do by crushing a sheet of cellophane in your hands. You might imagine that the opening, closing, or slamming of a door would be simple to reproduce. There is no easy method that we know of for reproducing these sounds accurately. One of the best-known methods is actually to build a small door approximately 2 feet by 3 feet, set in a wooden frame, with standard door-catches, locks, and bolts. Screen doors and windows are handled in a similar fashion. As an automobile door sounds different from an ordinary door, the sound effects department actually purchases an automobile door and mounts it in a frame. These various doors and door frames are mounted on platforms equipped with wheels, so they can be moved from studio to studio as the doors are needed.

On horror programs the eerie squeaking of a door is often used and the sound effects department of C.B.S. found this one of the most difficult sounds to reproduce. They first thought all they would have to do would be to obtain a set of squeaky hinges and mount them on one of their sound effects doors. So they set out and tried various doors all over the city, and when they found one that squeaked properly they bought the hinges from the owner and gave him new ones. After collecting quite a few hinges with various squeaks, they mounted these hinges on the sound effects doors, only to find they would not squeak. They added weights on the doors and made the doors bind and did various other tricks to produce a squeak. Finally they succeeded. The door they had fixed up squeaked beautifully during re-

Courtesy of C.B.S.

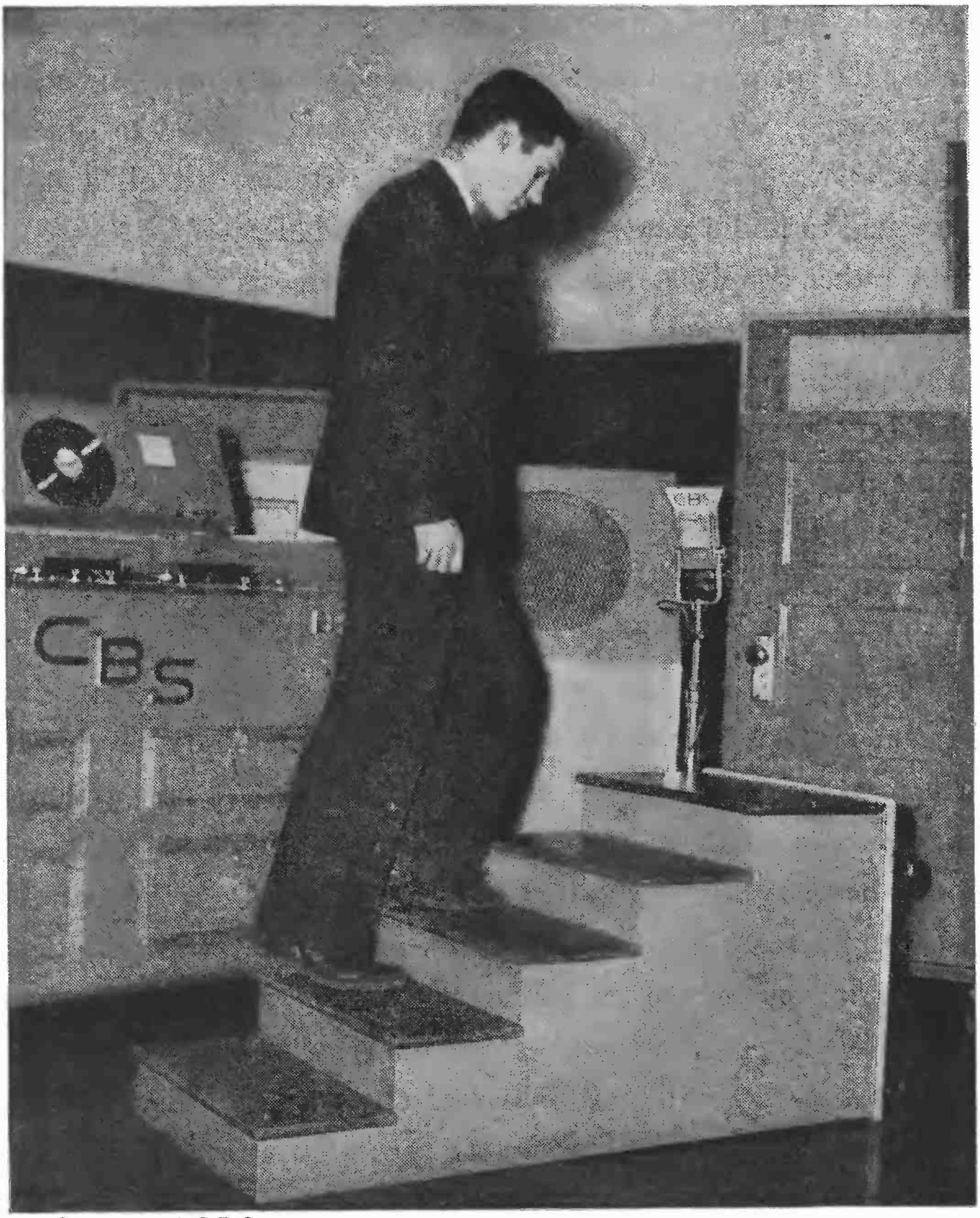
DEVICE FOR PRODUCING WINDOW NOISES

hearsals, but failed when they were on the air. They then decided to use the springs and mechanism from a squeaky revolving chair. This worked well for a while, then one day it failed to squeak. Some energetic maintenance man in the studio had oiled it, so they had to find a new squeaky revolving chair.

A rather simply constructed but odd device is the gadget used to produce the sound of marching men. It consists of a wooden frame about a yard square with wires stretched across it, approximately 2 inches apart in both directions. At each point where the wires cross, a wooden dowel or peg about 4 inches long is fastened by the end, so the pegs hang down below the frame. By holding this frame slightly above a table top and lowering it with a rocking motion, so the ends of the pegs do not all strike the table at the same time, you can produce the effect of soldiers marching. A sound effects man can produce numerous marching effects with this machine—marching as in a parade—men drilling—prisoners marching in single file on pavement, dirt, or cement roads.

To imitate people running up and down stairs a small portable wooden staircase is used, usually consisting of three or four steps. It's rather odd to see the sound effects man run up these steps, reach over, open the sound effects door, and slam it. But when you hear it on the air, it sounds perfectly natural. If a heavy person is supposed to be climbing the stairs, he walks up slowly in flat-footed fashion. If the script calls for a girl running upstairs, the sound effects man puts a pair of girl's shoes on his hands and makes his hands climb up or down stairs.

For scenes requiring a wagon, the sound effects department has



Courtesy of C.B.S.

SOUND EFFECTS DEVICES

constructed a device which is a platform with two uprights to support an old-fashioned wooden wagon wheel. A crank handle is attached to the wheel axle, so it may be turned. The wheel rests on rollers which are covered with sandpaper. This produces the sound of a wagon going over a dirt road. The horse effect is added by another sound effects man manipulating the suction cups. Certain scenes require three or four sound effects men. This might be necessary, for instance, if you added fog horns and boat whistles to create the illusion that the wagon was traveling along the water front.

So far no machine has been developed which can satisfactorily produce the sound of running water; that is, not unless running water is actually used to produce the effect. C.B.S. has developed a machine which uses water and it can produce many different types of water sound effects. This machine is a self-contained unit with its own water circulating system. It contains a water storage tank, a water pump, and an electric motor for operating the pump. It is so arranged that various attachments can be made to the machine for producing different effects. This machine has a sink, a drain, and a pipe over the sink where the various plumbing fixtures can be attached. Faucets can be attached to produce the sound of water running in the sink. Various types of showerheads may be used to produce different shower effects. It is also possible to produce very realistic rain effects with this machine.

Chain noises are produced on a machine which is operated by a crank. The chain is made in the form of a loop which passes over a drum on the crank shaft and several wooden rollers. Various types of chains can be used on this machine.

The ingenuity of the sound effects men, when last minute demands are made, is uncanny. For instance, just before air-time the director may decide he wants one of the actors to milk a cow for a barnyard scene. If the sound effects man doesn't have time to get back to his department to pick up a couple of syringes full of water and a pail, so he can squirt the water into the empty pail to produce the necessary effect, he may take a pail away from one of the charwomen, fill his mouth with water, and squirt it into the pail.

On one of the radio shows just before air-time they had to produce the sound of a man drowning. One of the sound effects men took off his coat, submerged his head in a bucket of water, gasped for air, and called for help with his head half under water.

Usually the sound effects man takes extra equipment with him to the studio, hoping to anticipate last minute requests. If the play is centered around a railroad station, he would take enough gadgets and records to produce almost any kind of a noise that might occur in a station. As a precaution he usually takes a couple of doors and windows too, because they might shift the scene at the last moment.

A great many of the effects do not require elaborate machines. To give the effect of a person being stabbed, the sound effects man merely plunges a knife into a head of cabbage. To produce thunder, he shakes a long sheet of tin. Buck-shot shaken inside a football bladder can be used for surf pounding on a beach. The crushing of a melon with your fist produces the sound of a skull

Courtesy of C.B.S.

SOUND EFFECTS TECHNICIANS AT WORK

being crushed.

As the recorded sound effects are used over and over again, the sound effects department usually is equipped with several portable dual electrical reproducers. This reproducer consists of two electrical phonographs with volume controls and loud-speakers housed in a cabinet that can be wheeled from studio to studio, wherever it is needed. The sound effects man can use one turntable for background music and the other for sound effects or any other combination he desires.

These records often contain many different effects of the same type; one record may include twenty different types of boat whistles; another will have all sorts of train noises. One broadcasting company has recorded steam engine noises and has a complete set, starting with the oldest type of railroad engine and winding up with the latest streamline model. They have also recorded the latest planes in all kinds of action—taking off, landing, power dives, barrel rolls, and loops. For war scenes they have dog fights and bomber squadrons flying in formation. Some sound effects departments have records actually made during battles.

If the sound effects men cannot find a record with the proper effect and if none of their gadgets will produce it, they take portable equipment and record the actual sound. This portable equipment usually consists of a microphone, amplifier, and sound-recording machine. If the request were for the sound of a lion yawning, they would take the equipment to the zoo and sometimes wait for days to get the recording.

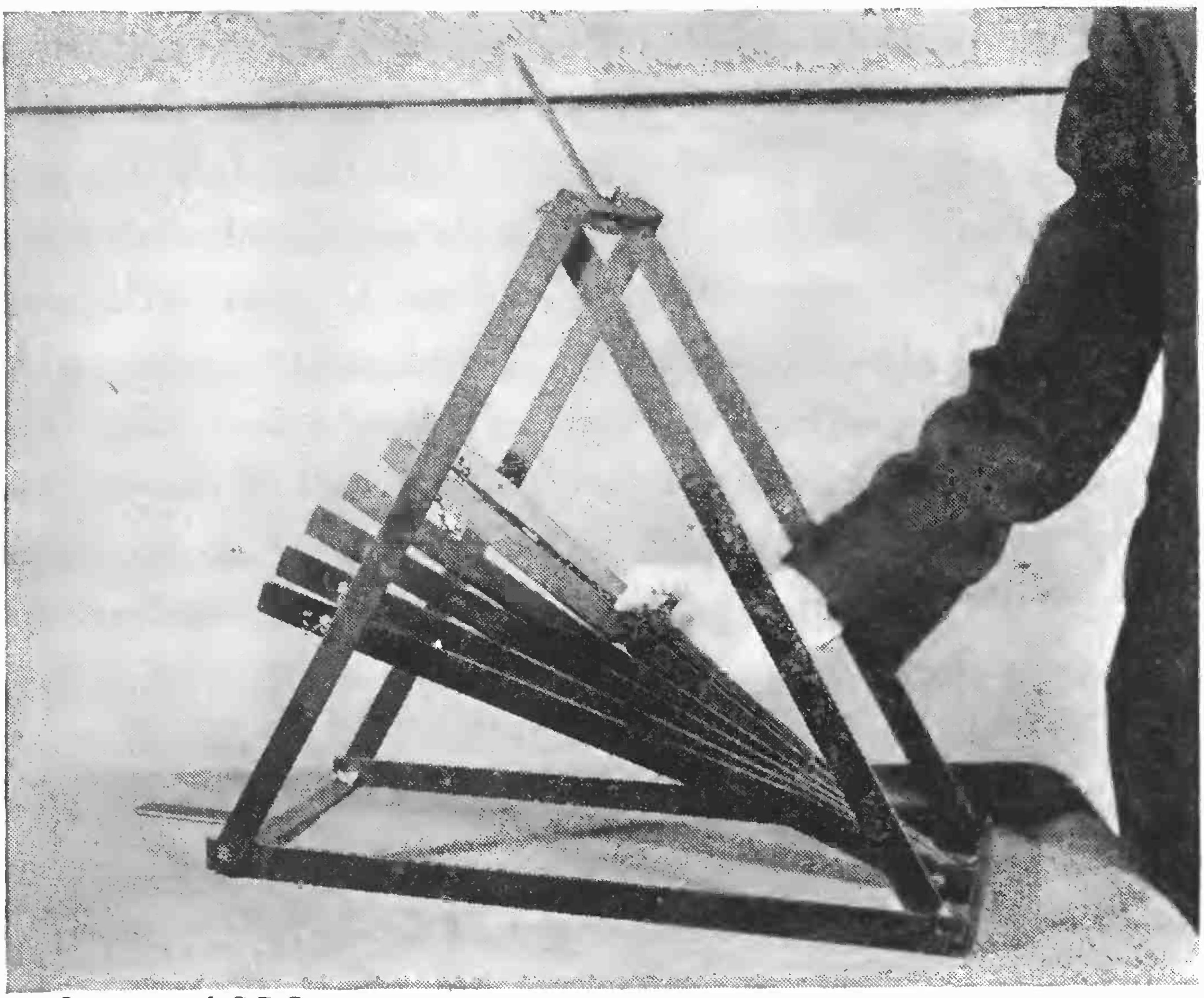
After checking the script, different records are selected from the sound effects library. Then they are played and the proper effects are selected. The point where a particular effect starts may be in the middle of the record, and this point is marked on the record with a grease pencil. During the show the operator starts the turntable revolving but keeps the record from turning by holding it until the sound effect is needed. He then places the pick-up needle on the mark he has previously made, and when he receives his cue he releases the record. Thus the record obtains its proper speed almost immediately. There is a key switch on the machine so the effect can be cut off at the right time. Since there are two reproducers, another switch is provided to change from one to the other. This allows the operator to set up two sound effects at the same time; he may use one for the background music and the other for special effects.

Quite often records and manually operated sound effects are used together. If the script calls for an airplane crash, the noise of the flying plane may be selected from a record and the crash produced by crushing a small wooden box.

It is easy to see how an entire scene may be built up by using several sound effects. For example, the background noise of a ship's engines and the sound of the anchor chain being hauled can be produced simultaneously with different records. At the same time another sound effects man provides the lapping of water against the side of the ship with a bucket of water equipped with paddles. To this you add a half-submerged man calling for help and a fog horn, and you have a completely realistic scene.

This can be done so well that you would never realize it was coming from a studio.

Quite often an electrical filter is used to change or improve the



Courtesy of C.B.S.

IRON GATE SOUND EFFECTS DEVICE

quality of an effect. This filter operates in a similar manner to the tone-control on a receiving set. The filter is connected into the microphone circuit, and it can be used to reduce or cut out sounds of high or low pitch (high audio frequencies or low audio frequencies.) This filter is plugged into the microphone circuit by the control room technicians whenever it is needed. If a certain effect does not sound quite natural because part of the sound contains noises of a high pitch, then the filter can be added to eliminate them. The filter is often used to create the effect of a person talking on the telephone. Your voice sounds different over a telephone because the telephone does not reproduce high frequencies, so the high frequencies in the voice are eliminated. This filter accomplishes the same thing. When the sound is reproduced by your receiving set loud-speaker, you have the effect of a person talking on the 'phone because the filter has eliminated the high frequencies.

When you walk through a sound effects department, it reminds you of a museum. On shelves and in cabinets you see all types of bells and gongs, pistols, telephones, New Year's Eve noisemakers, coconut shells, balloons, shoes, horns, whistles, castanets, windows, doors, and all the various machines for making weird noises. Next to this department is an experimental shop where they build and try out various gadgets. Another room is used to repair the various machines.

As you look around, you hear all sorts of noises, from horror chamber sounds to a babbling brook and the call of wild geese. Then you realize you are not in a museum but in a sound effects department.

IV Microphones

RADIO, like all other branches of engineering, is always striving to improve the quality and design of its equipment. A new and improved design for one piece of equipment usually requires the re-designing of all other equipment associated with it. As an example, if a new radio set were designed with better reproduction than any other equipment developed so far, it would be of little use until microphones, amplifiers, and transmitters were brought up to the new standard. The radio receiver cannot reproduce electrical waves that the microphones, amplifiers, and transmitters are not capable of reproducing. However, inexpensive receivers are the weak point in broadcasting today. The old saying, "A chain is only as strong as its weakest link," is particularly applicable to radio apparatus.

So the microphone has had to be improved in design to keep pace with other developments in radio.

Before we discuss the latest types of high fidelity microphones, it is necessary to know how they operate.

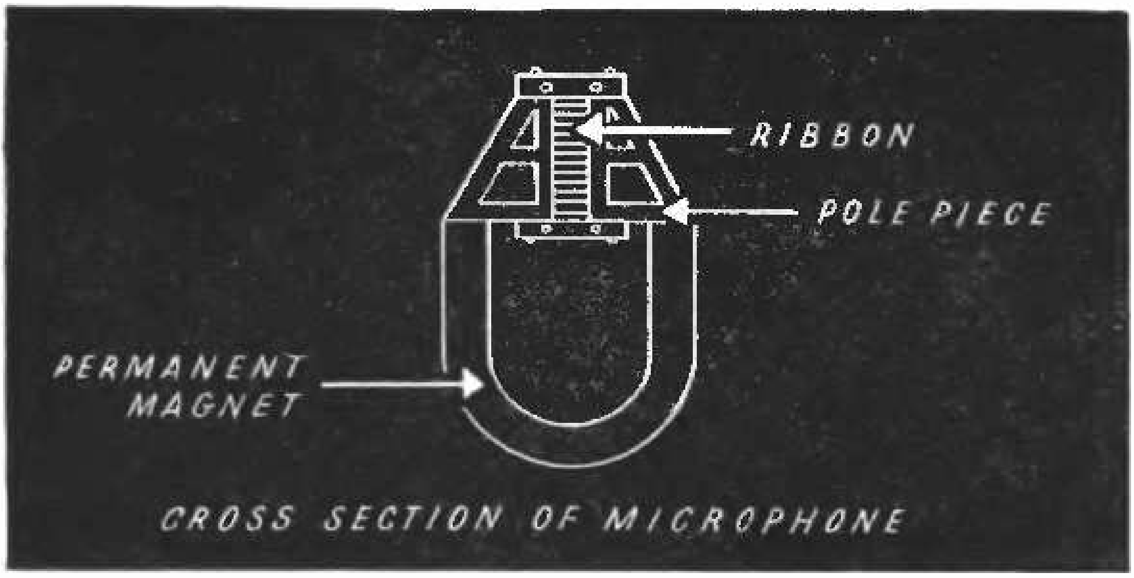
The microphone is an electrical instrument which converts the energy of air-borne sound waves into electrical waves. These electrical waves have the same frequency characteristics as the sound waves. If, for example, one string on the piano sends out a sound wave of 256 cycles, the microphone converts this into an electrical wave of the same frequency.

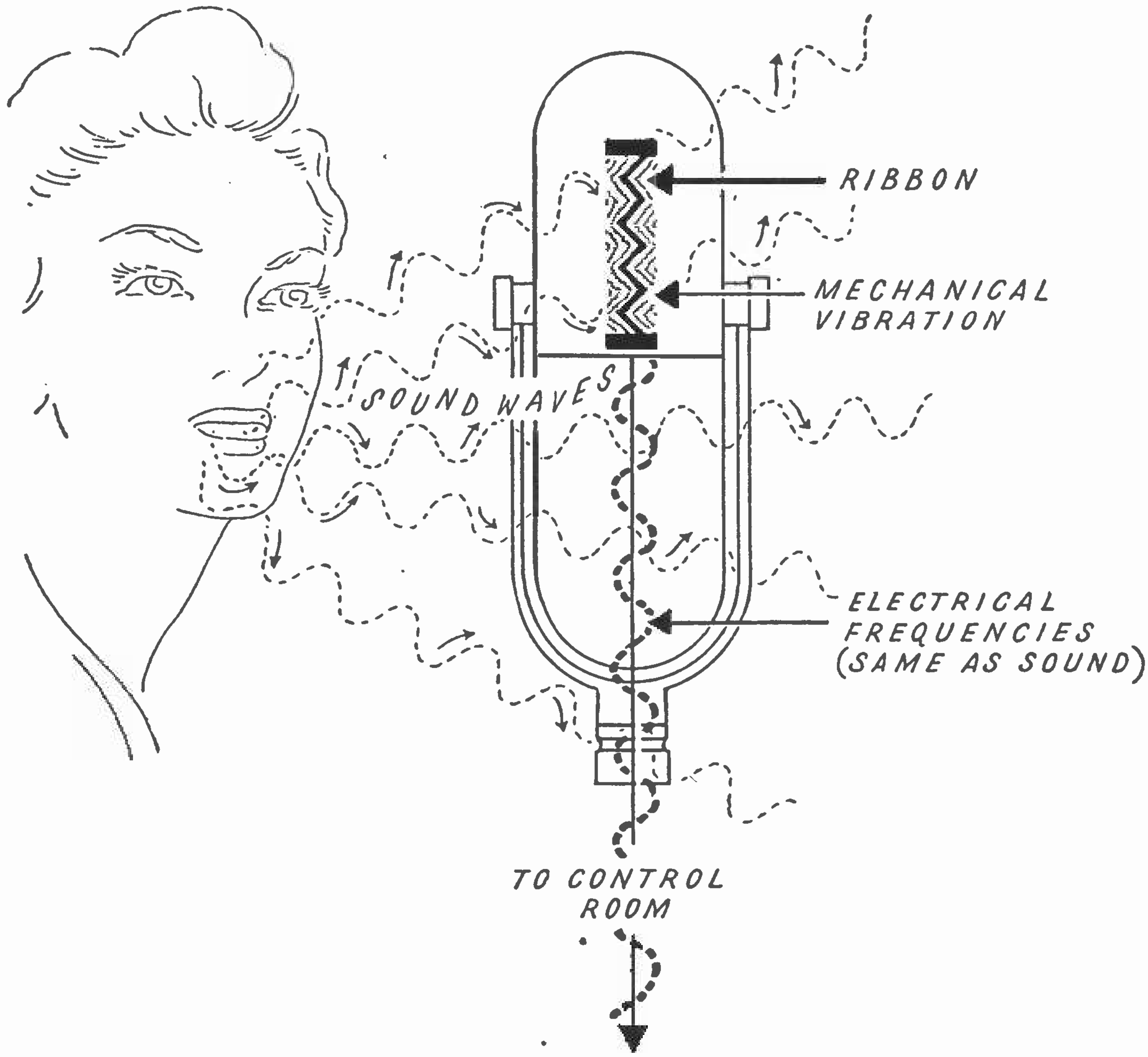
One thing is common to all types of microphones—the sound waves go through an intermediate stage before they become electrical waves. This intermediate stage is mechanical. The sound waves strike a surface or diaphragm in the microphone and cause it to vibrate at their own frequency. This is quite similar to the way in which your ears function. Sound waves strike your ear drums and cause them to vibrate. The ear drums then send these impulses via your nerves to your brain.

While there are a great many types of microphones, the most widely used types are the ribbon or velocity, carbon, condenser, moving coil, and crystal microphones.

The ribbon or velocity type is a high quality sensitive microphone which is used to a great extent in the broadcasting field. This microphone utilizes a thin metallic ribbon which vibrates as the sound waves act upon it. This ribbon is mounted between two permanent magnet pole pieces, and as it vibrates in this magnetic field it generates a voltage. This voltage or current is generated at the same frequency as the frequency of the vibrating ribbon. The ribbon, in turn, vibrates at the same frequency as the sound wave acting upon it.

The other types of microphones—carbon, condenser, crystal,





HOW AIR-BORNE SOUND WAVES ARE CONVERTED INTO ELECTRICAL WAVES BY MICROPHONE and moving-coil—are operated by varying pressure created by sound waves on a diaphragm; so these types are called pressure microphones. The diaphragms of these microphones are mechanically connected to a condenser, crystal, or moving-coil.

When these elements are agitated by the varying pressure of the sound wave on the diaphragm, the current in the microphone circuit fluctuates at the same frequency as the sound wave. Although carbon, condenser, moving-coil, and crystal microphones are operated by the varying pressure caused by the sound wave, the net results from them are quite similar to those produced by the ribbon microphone which is operated by the varying velocity of the sound wave.

High quality microphones have a flat frequency response from about 40 to about 10,000 cycles. A flat frequency response means that the volume level reproduced by the microphone will not increase or decrease over a certain frequency range. This means the microphone will respond equally well for all frequencies between 40 and 10,000 cycles; therefore, this microphone is capable of reproducing electrical waves corresponding to most sound waves produced by an orchestra.

In early days of radio, microphones were not capable of doing this, and when they were used for orchestra pick-up they could not reproduce certain musical notes or frequencies. This was one of the reasons for poor reception in those early days.

This is also true today of less expensive types of microphones used primarily for inter-communicating systems where good reproduction is not important. These microphones only respond well between 200 and 2,500 cycles, but they are used because they are small, rugged, and inexpensive. This type of microphone is used in the studio control room to talk back to the studio during rehearsals. Microphones of this type are also used in other places where quality of reproduction is not important, but where space requirements, cost, or durability are the primary factors.

Most microphones are directional, though there are types which will pick up sound coming from any direction in a horizontal plane. The ribbon or velocity microphone usually picks up sound from the front and rear, covering a figure-eight pattern. This microphone is used to a great extent in studios, as it not only picks up the original sound source but a great deal of reverberant sound as well. Of course, in studios that are over-reverberant it is better to use a microphone that is sensitive in only one direction, such as most types of pressure microphones. Pressure types are also often used for a public speaker before a large audience, when the crowd noise might become objectionable.

One of the latest types of microphones is a combination—non-directional, bi-directional, or uni-directional. This microphone can be used for a great many purposes for it is really two microphones built into one unit. It is a ribbon type; the ribbon is fixed at the center with one half acting as a velocity microphone and the other half as a pressure microphone. The directional characteristics of the microphone are varied by a switch which cuts in the velocity half of the ribbon, the pressure half of the ribbon, or both.

If the switch is set to cut in the pressure half of the ribbon,

DIRECTIONAL CHARACTERISTICS OF VARIOUS MICROPHONES it is sensitive in one direction only, covering an area of about 180 degrees in front of the microphone. If the switch is set so the velocity half of the ribbon is connected in the circuit, then the microphone is sensitive front and rear, covering an area approximately 90 degrees in each direction. If the switch is set in the third position, so both the pressure and velocity parts are utilized, then the microphone is sensitive in all directions.

The amount of current the average microphone delivers is very small indeed—less than one ten-millionth part of one watt. If you think of a small electric light bulb as consuming twenty-five watts of current, you will realize what a small amount of current this is.

Microphone amplifiers are used to step up the output of the microphone. These units are quite small, containing one radio tube and two small transformers. They are capable of raising the level of the microphone approximately 30 volume units, a volume unit being one-hundredth part of one watt.

The parabolic reflector is not a microphone, but it is used with microphones to pick up sound that is originating some distance away. This type of reflector is used to a considerable extent at football games. It picks up a band, for instance, that may be playing on the opposite side of the field from where the microphone and radio equipment are located. The reflector is shaped like a searchlight reflector, and it is approximately three feet in diameter. The microphone used with this reflector is usually a unidirectional type. The microphone is mounted on a bracket facing the reflector. The sound waves strike the curved surface of the reflector and are directed at the microphone. This makes the microphone and reflector operate in the opposite way from the way a searchlight reflector works. The reflector is quite directional, so it eliminates noises coming from other directions, including a good percentage of the crowd noise.

This type of reflector is used principally for outdoor sports.

V Studio Control Room

STUDIO #22, previously described, has a very modern control room.

At the side of the studio, in the acting area, is a large sound-proof double glass window. Through this window you can see the engineer's control room. The window is set at a vertical angle to eliminate reflections from overhead lights and this makes it easier for actors to see the engineer and production man in the control room.

The control room is a small isolated sound-proof room which contains the engineer's control desk and the director's desk. The floor of this room is raised about three feet above the studio floor, enabling the engineer and director seated at their desks to see everyone in the studio.

The engineer's control desk is made in the form of a U. As he faces the studio, the equipment is mounted in front and on both sides of the desk. The front part of the desk is quite low so it does not interfere with his vision. This part of the desk houses

Courtesy of C.B.S.

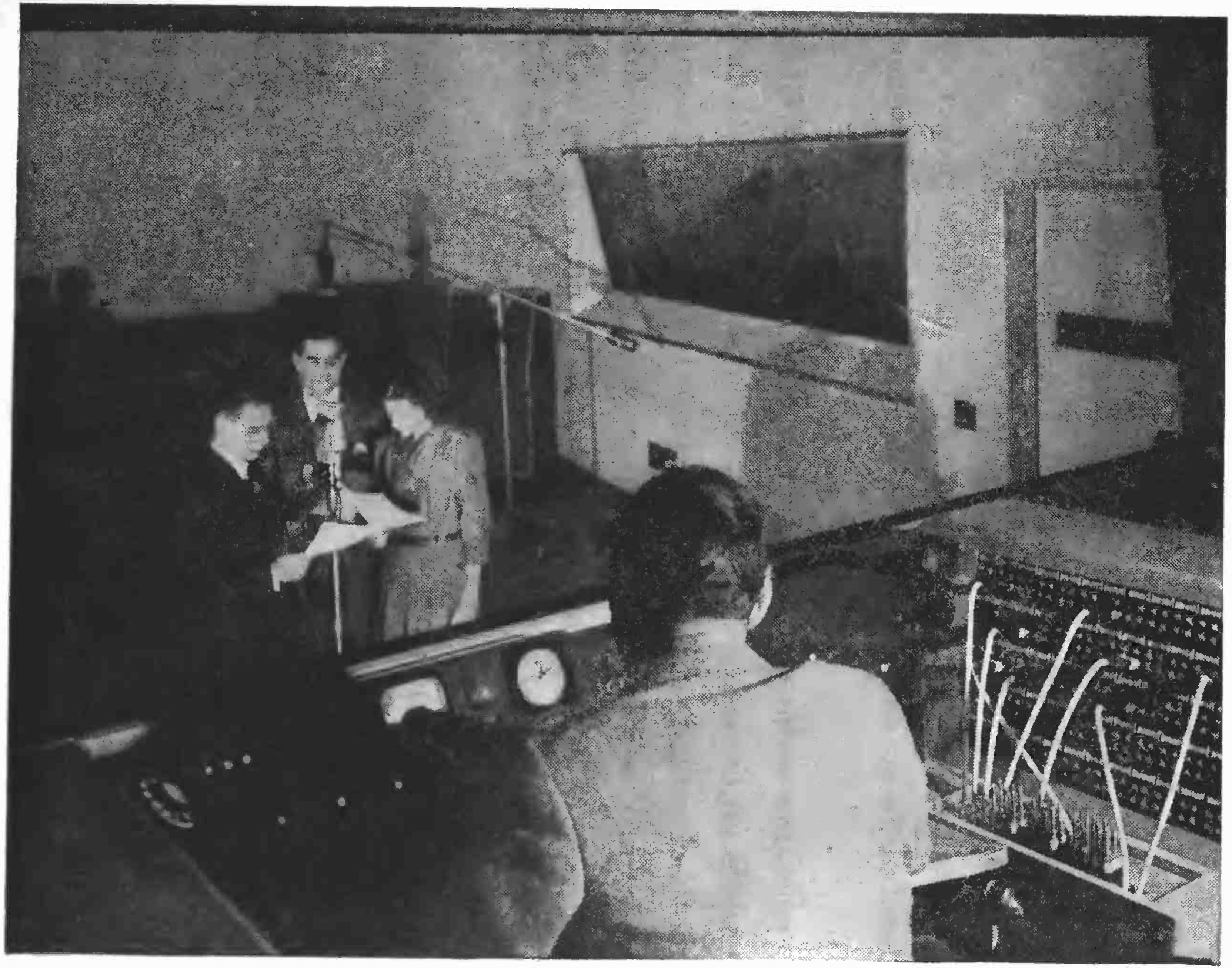
STUDIO 21, CONTROL ROOM WINDOW AT RIGHT

the volume controls, indicating lights, microphone switches, talk-back microphone, and sound effects filter. Thus all the equipment that he uses during the show is at his finger tips. Each side of the desk is slightly higher than the front panel and houses equipment which is pre-set before the program.

Mounted above the engineer's control desk is a monitor loudspeaker. Through this speaker he hears what is being picked up by all the various microphones in the studio, so that he will hear the program as you hear it in your home. This can be quite different from the way you hear it in the studio because of the different microphone locations and the sound effects added after the studio microphones pick up the production.

For large radio shows from three to six microphones are used. There may be two or more for the actors, one for the orchestra, and one for the announcer. Each of these microphones is connected by means of a cable to a special microphone outlet located in the studio wall. These microphone outlets are wired individually to the engineer's control desk.

The electrical sound waves which the microphone sends out are called audio signals because they are of the same frequency as audible sounds. As these audio signals coming from the microphone are at a very low volume level, a microphone amplifier is used in each incoming microphone line to raise the volume level. Then the audio signal goes to individual volume controls located on a sloping panel at the front of the control desk. These volume controls are adjusted by a series of knobs which have indicating dials marked off in volume units. By means of the



Courtesy of C.B.S.

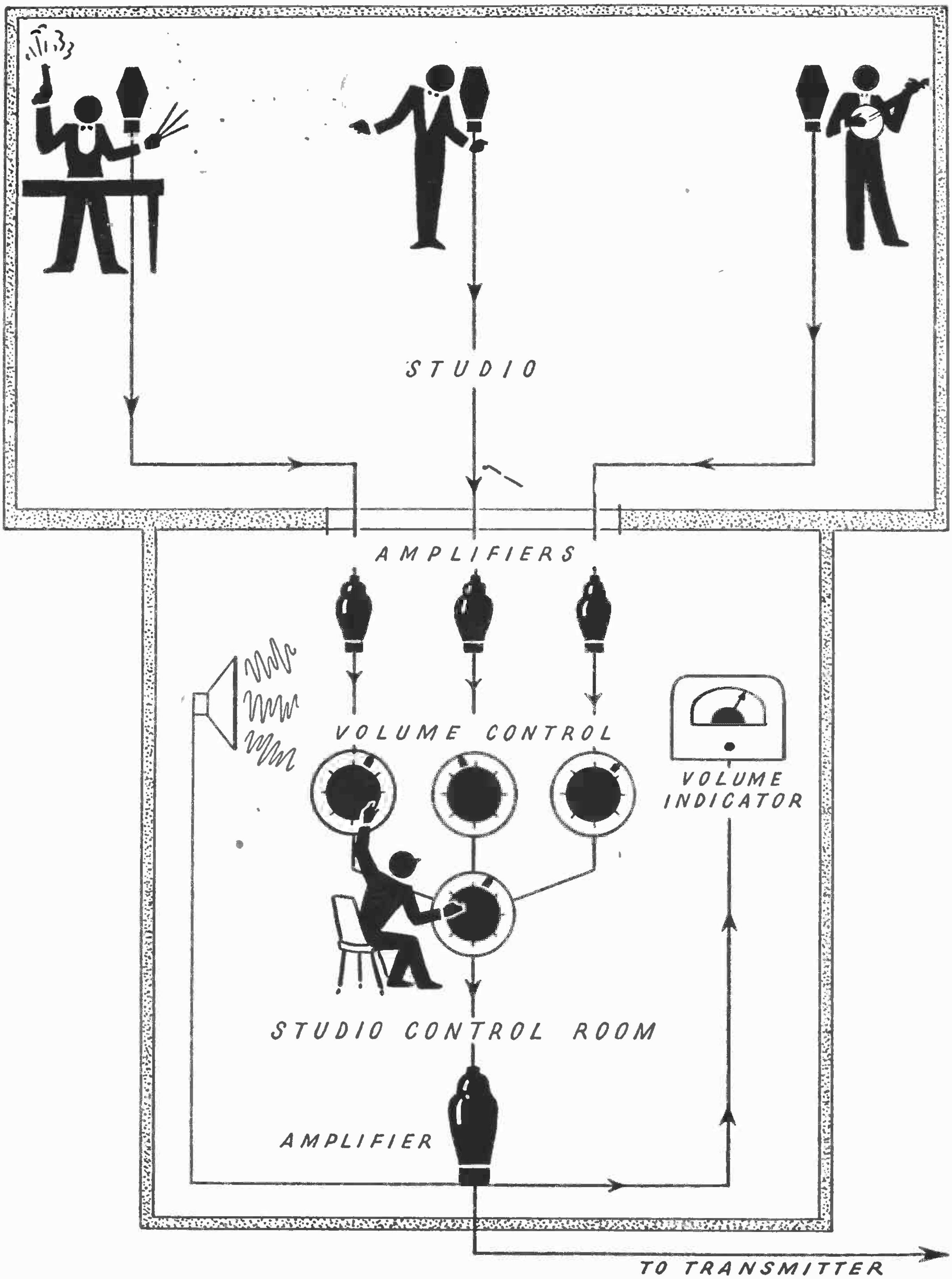
ENGINEER AT CONTROL DESK DURING PROGRAM

volume controls the engineer can increase or decrease the volume coming from any studio microphone. The volume controls are really variable resistors especially designed for this purpose. A resistor is a unit which resists the flow of current in an electrical circuit. By increasing and decreasing the resistance in the line they increase and decrease the volume. These units are also called attenuators.

These controls enable the engineer to maintain the proper volume level of the studio microphones, beside producing other sound effects.

On your own radio you have probably heard an announcement made while an orchestra is playing; the orchestra seems to fade into the background while the announcer is speaking. The engineer accomplishes this by slowly turning the volume control down on the orchestra microphone while increasing the volume on the announcer's microphone. There are many other fading effects he can produce by manipulating these controls.

Beside the individual controls, he also has a master volume control and this enables him to raise or lower volume on all the microphones at the same time. This is used primarily for maintaining the proper volume of the entire program. This is quite important, for if he allows volume to get too high, he will overload the various amplifiers that the program passes through before it reaches the transmitter. Overloading is feeding an amplifier more power than it can handle and this causes distortion of the audio signal or poor reproduction. The engineer must also be careful that the volume does not fall below a certain level, for if



HOW ENGINEER CONTROLS VOLUME ON STUDIO MICROPHONES it does you may not hear certain passages on the receiving end.

He does not maintain the proper volume level by listening to his loud-speaker, as you might imagine. It is done visually. There is a large illuminated meter located directly in front of the engineer on the control desk. This meter is known as a volume indicator and it is marked off in volume units and percentage of modulation. Every sound that is picked up by the microphones causes the needle on the meter to indicate the intensity of the audio signal. During a program this needle is constantly moving with every syllable of a word or note of a musical instrument. The engineer watches this constantly and makes the necessary adjustments with his master volume control.

Between the front and the left wing of the control desk is a sound effects filter. This filter is an electrical circuit containing condensers and coils. When it is cut in on the line, it filters out the high or low frequencies, thus producing odd effects. There are two dials on this unit—one for eliminating high frequencies, the other for low frequencies. They can be adjusted to produce any effect desired by the engineer. This filter is often used to produce special voice effects for dramatic plays and comedies.

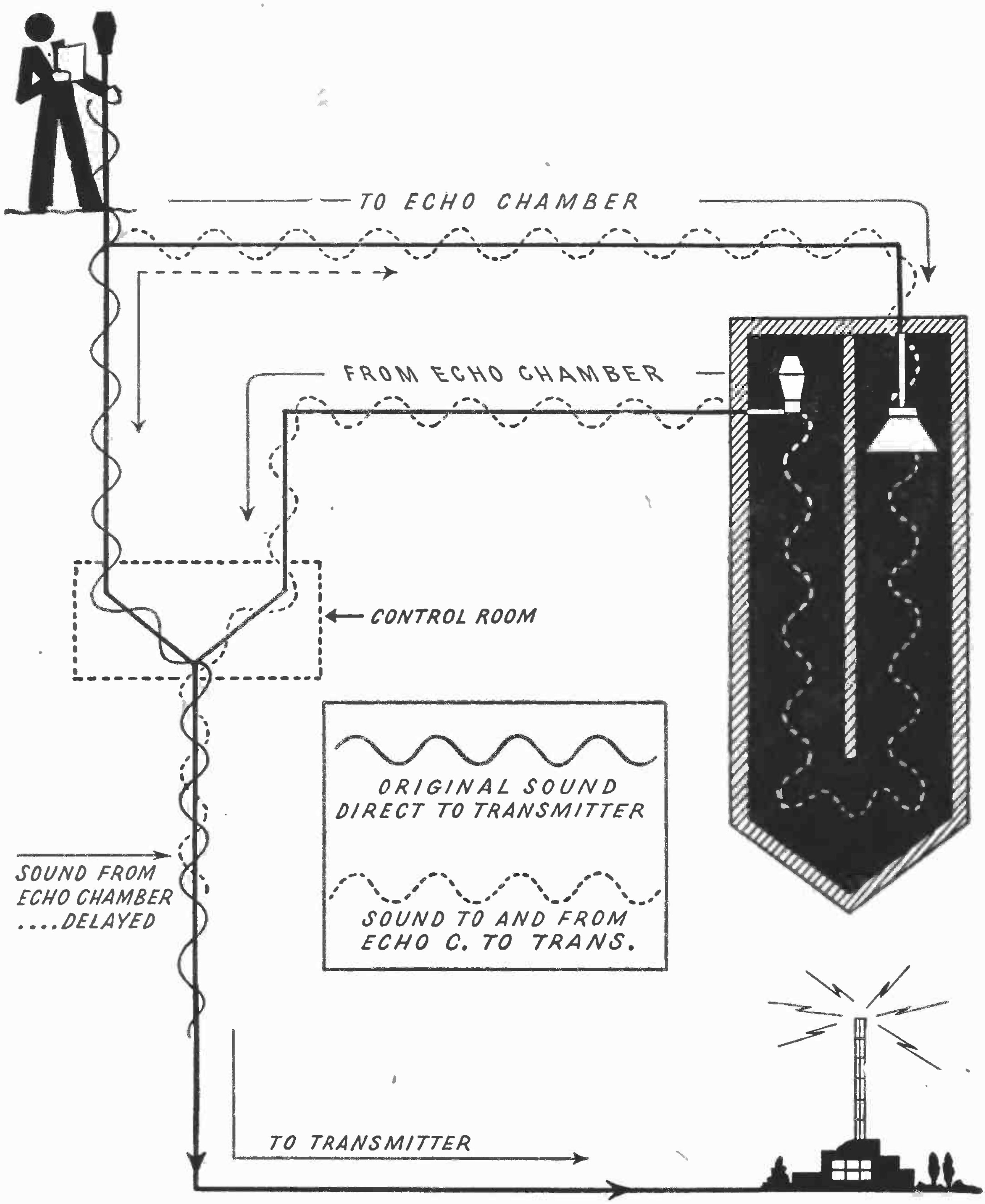
A jack field is located on both the left and right wings of the control console. These jack fields are similar to those used by telephone operators for making their telephone connections. Each row of jacks consists of a bakelite strip containing holes behind which are mounted electrical receptacles—these are called telephone jacks. These receptacles are connected to the different amplifiers, sound effects filter, coils, outgoing-lines, etc. By using wire cords with a plug on each end (known as patch-cords) these different pieces of apparatus can be connected together in any desired combination. This gives the control man great flexibility in selecting the necessary equipment for any particular show.

One of the outgoing lines that appears on this jack field runs to an echo chamber, located in another part of the building. There is also a jack for the return line from this echo chamber. The echo chamber is used to produce the effect of people talking when they are in a cave or calling from the bottom of a well, or any other effect that calls for an echo.

The echo chamber is a long, narrow, U-shaped room, approximately 3 feet wide, 6 feet 6 inches high and 30 feet long, closed at both ends. The room is isolated from all outside noise and the interior walls are plastered to reflect sound. At one end is located a loud-speaker, and a microphone is usually located near the other end. By using the jack field, the engineer can connect lines leading to and from the echo chamber.

When this is done, the sound that is being picked up by the studio microphone is amplified and sent to the loud-speaker in the echo chamber. The sound coming from the loud-speaker reverberates off the walls, floor, and ceiling as it travels down this long narrow room to the microphone. Then it is picked up by the microphone and travels back to the engineer's control desk.

The echo chamber really only adds reverberation to the sound. The echo effect is accomplished by mixing the audio signal coming from the echo chamber with the original audio signal. As an example, we will imagine that we strike a note on the studio



● HOW MICROPHONE SIGNAL IS DELAYED BY ECHO CHAMBER TO PRODUCE ECHO EFFECT

Courtesy of C.B.S.

STUDIO CONTROL ROOM DESK

piano and it is picked up by the studio microphone. The electrical impulses coming from the microphone are separated when they reach the control desk. Part of the signal goes to the echo chamber and the rest passes through this control room equipment on its way to the master control room. The impulse going to the echo chamber is transferred back to a sound wave by a loud-speaker and the sound wave travels at approximately 1,130 feet a second. So we will say it takes about one thirty-fifth of a second to travel the length of the echo chamber and be picked up again by the echo chamber microphone. It then goes back to the control room to join the original signal, but is approximately a thirty-fifth of a second late. This produces two signals about a thirty-fifth of a second apart and when they are reproduced the result is a sound like an echo.

At the top of one side of the control desk are located the control buttons for the acoustivanes. Above the acoustivanes' push buttons are meters which indicate the position of the acoustivanes.

During rehearsals the acoustivanes are adjusted until the director is satisfied with the reverberation in the studio. As there is usually a lapse of time between rehearsals and air-time, the engineer can keep a record of the acoustivanes' settings by jotting down the meter readings.

In large audience studios, beside the regular control desk there is a small control desk used for the public address system. This is handled by another engineer. It is used to feed the program back to the audience loud-speakers. It is connected to outgoing program lines. It has four volume controls and a volume indicator. Great care must be taken not to feed too much volume to the audience loud-speakers, as this causes considerable trouble if it is picked up by the studio microphones. Should this occur, it creates a howling sound as the sound keeps traveling from the microphones through equipment back to the studio where it is picked up again by the microphones. This is called feed-back.

This public address system enables the audience to hear the program after the special effects have been added.

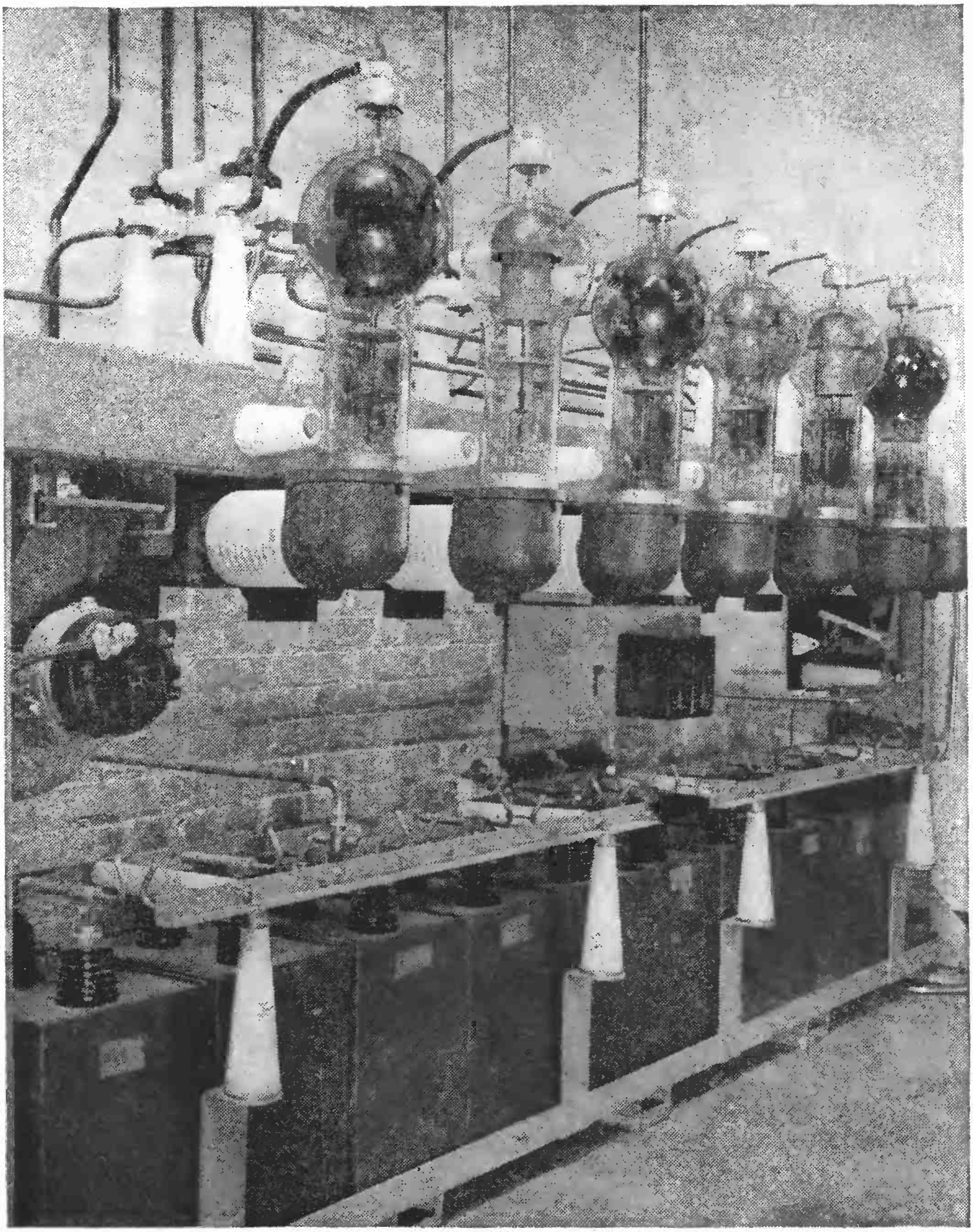
During rehearsals it is quite important for the engineer and the director to be able to talk to the actors. As the control room is sound-proof and isolated from the studio, audio facilities are provided to take care of this. Small microphones are built into the engineer's and production man's consoles and are connected through an amplifier to loud-speakers in the studio. Switches are mounted on the control desks to cut in this equipment whenever the engineer or production man desires to talk to anyone in the studio. Beside the hand-operated switches, a foot-controlled switch is provided for the engineer, as his hands are usually busy with the other controls. These switches are electrically interlocked with the on-air switch, so if anyone should throw the switch by mistake while a program is on the air it would fail to operate.

The microphone amplifiers are located under the front part of the control desk. The larger amplifiers are mounted in each side of the desk. They are reached by opening doors on the side of the unit. These amplifiers are mounted on tracks so they slide out of the unit like a file drawer. This simplifies the replacement of parts and the repairing of the equipment.

VI How Radio Tubes Operate

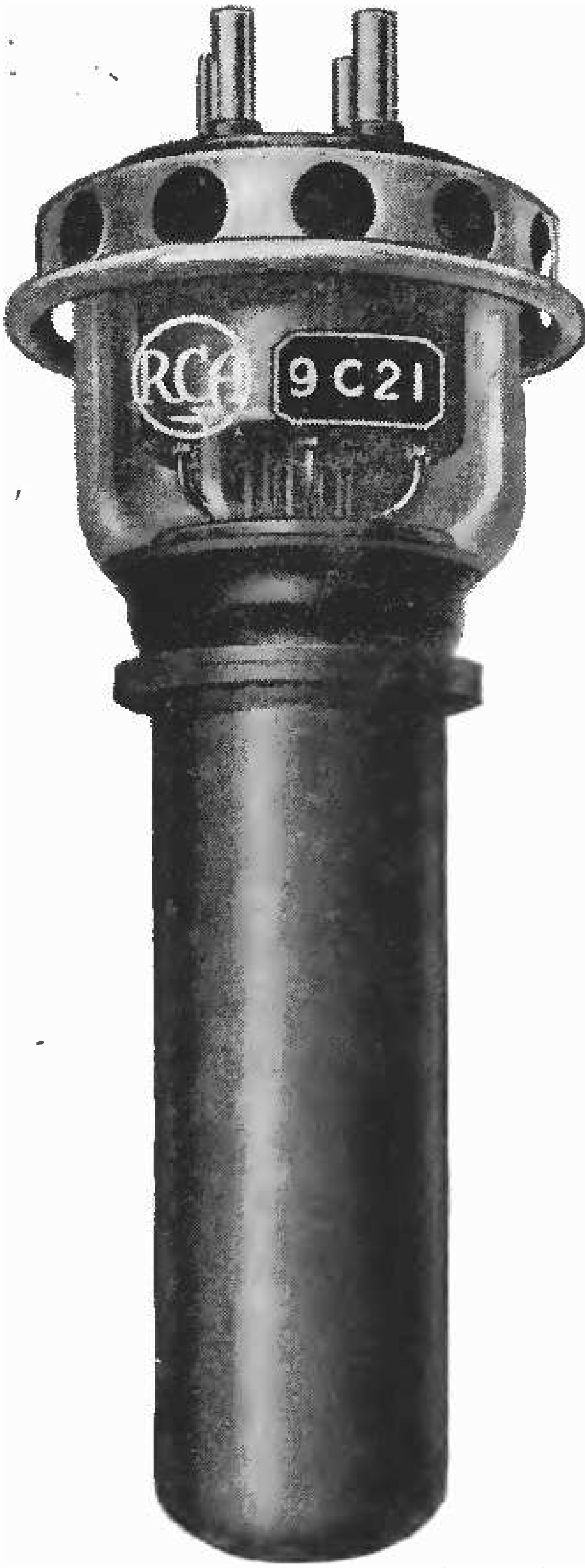
THE VACUUM tube (radio tube) is really the heart of radio. It is the invention which has made possible the tremendous advancement of all branches of radio. Radio broadcasting, international broadcasting, television, frequency modulation, radar, submarine detectors, and many other radio devices would have been dreams or crude experiments today if the vacuum tube had not been invented. Certain types of these tubes are used in every radio set, and without them we probably would still be using headphones as they did in the early days of radio. The vacuum tube is responsible for increasing the volume so that loud-speakers can be used and headphones are not necessary.

Today thousands of different types of radio tubes are manufactured for different purposes. They range in size from the huge water-cooled or air-cooled types used in large broadcasting transmitters to the small types used in portable radio equipment. All of them are used mainly for one of two purposes—either to amplify an electrical signal, or to rectify alternating current,



Courtesy of C.B.S.

HIGH VOLTAGE RECTIFIER TUBES USED IN 50,000 WATT TRANSMITTER that is, to change alternating current to direct current. Direct current is an electrical current flowing in a single direction. The source can be a battery or a direct current generator. Batteries always supply direct current, whereas some generators are designed to supply direct current and others, alternating current. When you turn on the current in a battery-operated flashlight, it flows from one terminal of the battery through the filament to the other terminal. There is a continuous flow of current from one terminal to the other. This is called direct current (D.C.) as it flows in a single direction. Alternating current (A.C.) does not flow in a single direction as direct current does, but changes the direction of flow intermittently. That is, an alternating current generator causes the electrical current to reverse its direction. It starts to flow in one direction, then stops and starts to flow in the opposite direction. In other words, an alternating current generator does not generate a current continuously. The current starts at zero and gradually builds up as it flows in one direction through the circuit. It reaches a peak and then returns to zero. The next time the current starts to flow, it flows in the opposite direction, building up to a peak and then returning to zero. The peak voltage to which the current builds up depends on what voltage the generator is capable of delivering. A cycle is completed when the current has flowed once in each direction. The time that it takes for this to occur is called the frequency. Alternating current, A.C., is used to a great extent in homes today. It is usually of a frequency of 50 or 60 cycles per second. This means it takes either one-fiftieth or one-sixtieth of a second for the current to



Courtesy of R.C.A.

WATER-COOLED POWER AMPLIFIER TUBE USED IN RADIO TRANSMITTERS make one complete cycle.

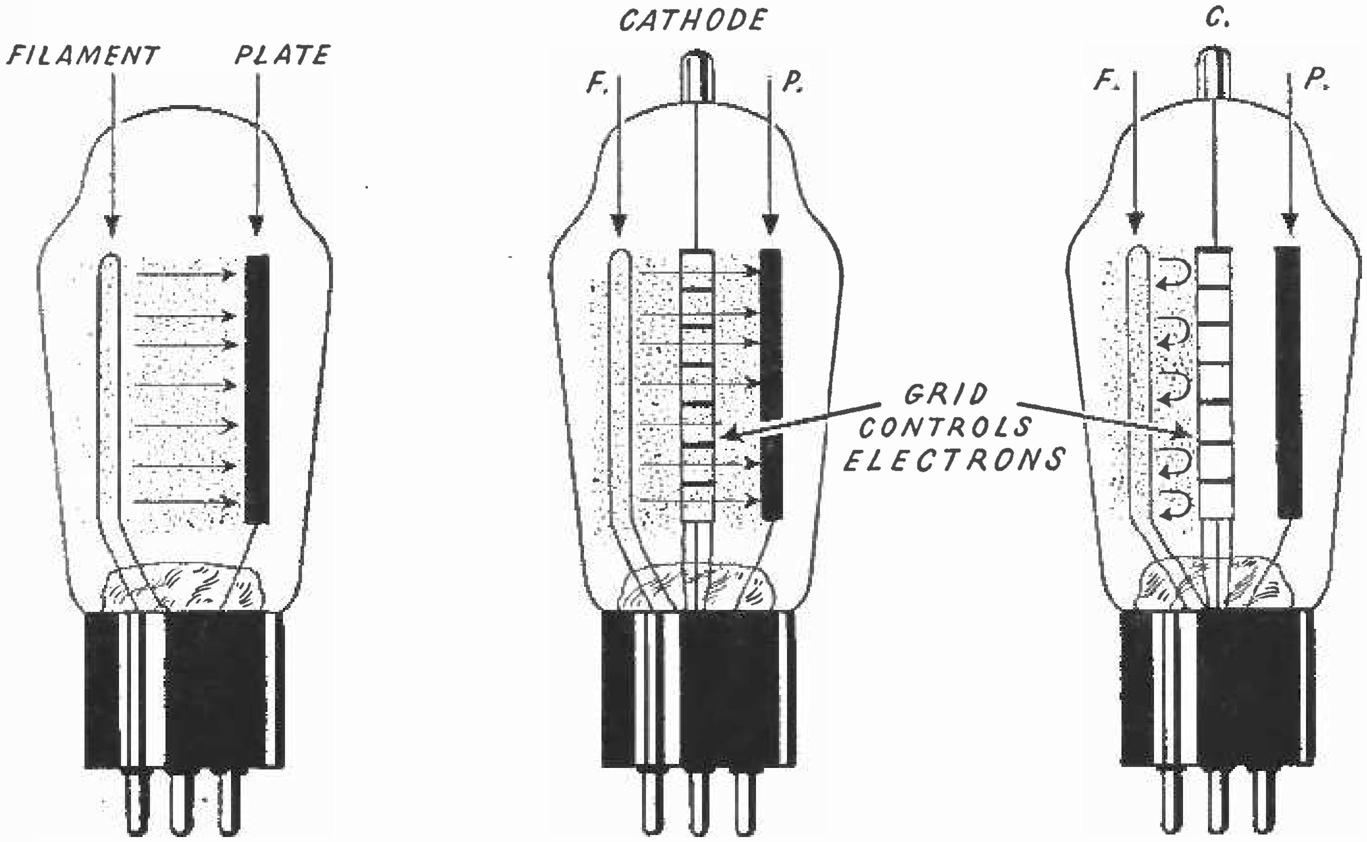
In radio circuits, the frequency of these oscillations can be anywhere from a few cycles per second to millions of cycles per second. You will learn more about these higher frequencies in the chapter about the different types of transmitters.

When an ion, which consists of positive and negative electrons, loses one or more of its negative electrons, it is considered to be a positive electron. The negative electron is a minute charged particle, much smaller than the positive electron, and it travels at a much greater velocity. These negative electrons are used to control the flow of current through a vacuum tube. The negative electrons tend to move toward a positive electrode, particularly when they are allowed to move through a space which has a high degree of vacuum. This is the reason that radio tubes contain a high degree of vacuum.

The vacuum tube can be used to change an alternating current into a direct current. When it is used this way it is called a rectifier tube. Your radio set contains one of these tubes if it is an A.C. operated set. This tube is used to change the A.C. house current to direct current because some of the elements in the other tubes in your set require direct current.

The rectifier tube is a simple type of vacuum tube containing two elements. One of these elements is a filament which in some respects is similar to the filament in an electric light bulb. The second element, which usually surrounds the filament, is called the plate (anode). The filament is usually called a cathode and it will emit large numbers of negative electrons when heated to the proper temperature by an electrical current. These electrons are attracted to the plate when the plate current is positive.

An alternating current is constantly changing from positive to negative as it changes its direction of flow. If this alternating cur-



SCHEMATIC DIAGRAM SHOWING HOW ELECTRONS TRAVEL AND ARE CONTROLLED IN THE TWO OR THREE ELEMENT VACUUM TUBE

rent is applied to the plate of a rectifier tube the current will only be allowed to flow in one direction. The reason for this is that the plate current only becomes positive when the current is flowing in one direction. When it reverses its direction it becomes negative. During the time that the plate is positive it attracts the electrons that are given off by the cathode. The current only flows through this tube when the electrons pass from the cathode to the plate. This causes the current to flow in the plate circuit of the tube. When the current starts to flow in the opposite direction so the plate becomes negative it repels the electrons so no current is allowed to flow in the plate circuit. Hence the current is only allowed to flow in one direction, which produces D.C. In other words, this tube acts like a check-valve in a water line and only allows the current to flow in one direction. There are many other applications and uses for this type and other types of rectifier tubes, but the fundamental operating principles of the tube remain the same.

The cathode can be one of two types, either a filament which is heated by passing current through it, or a small cylinder which is heated by an internal filament. These two types are known as the filament and heater-type cathodes respectively.

Even in more complicated tubes where additional elements are added, their operation depends on the plate attracting the electrons given off by the cathode. This is true of the small amplifier tubes in your radio set and the powerful amplifier tubes used in large commercial transmitters. It is also true of the television tubes which produce the picture in the television receiver.

The amplifier tube is used to increase the power of a radio signal. This may be a weak audio signal coming from a microphone or a weak radio signal picked up by the receiving antenna on your radio set.

The two-element tube just described is known as a diode. If the tube contains three, four, five, or more electrodes, it is called a triode, tetrode, pentode, etc.

Courtesy of R.C.A.

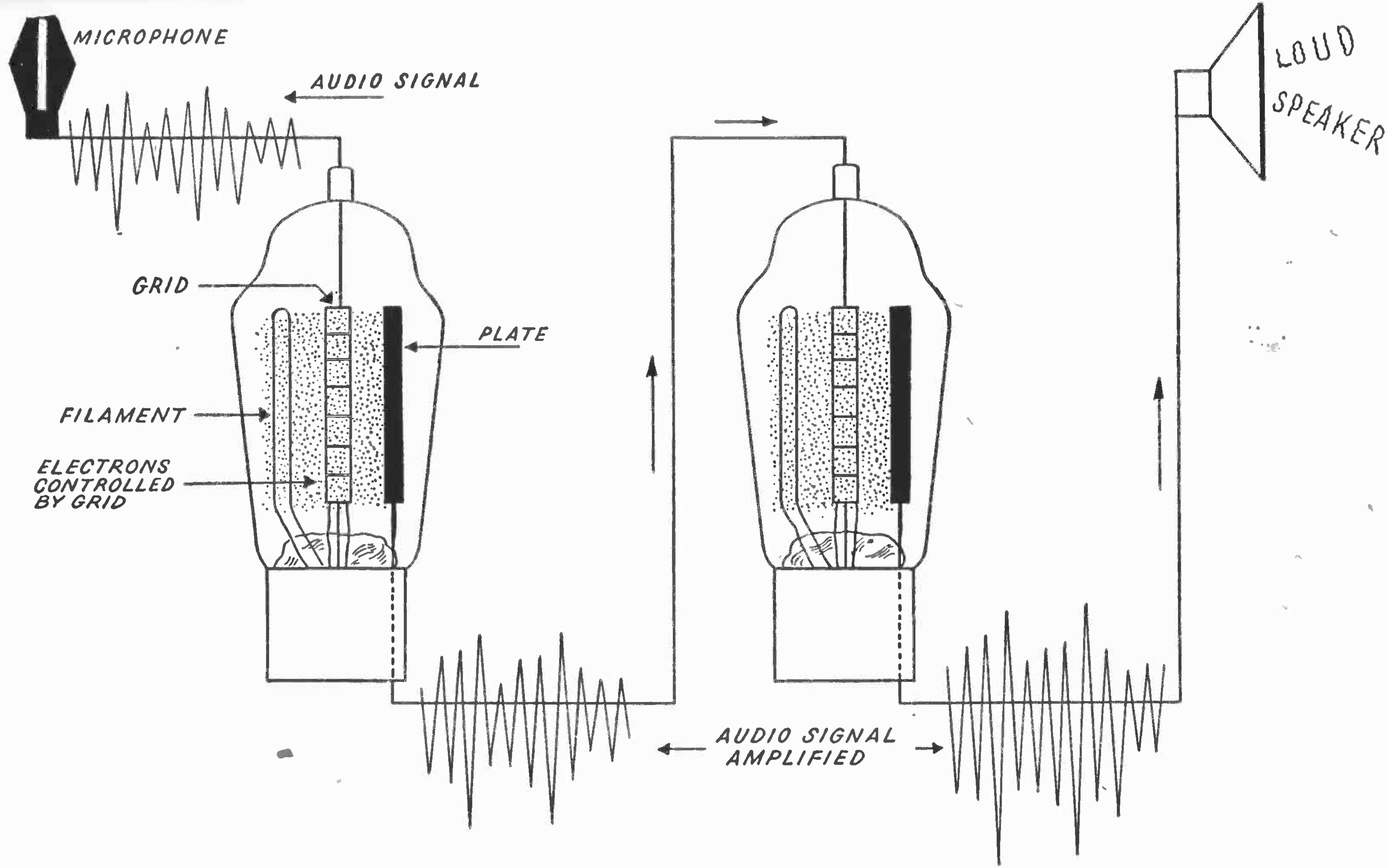
AIR-COOLED POWER AMPLIFIER TUBE USED IN RADIO TRANSMITTERS

Most amplifier tubes contain at least three or four electrodes, that is, one or two in addition to the cathode and plate. These additional elements are used to control the flow of electrons between the cathode and plate and influence the characteristics of the tube.

The three-electrode tube is used to a great extent in radio amplifiers, transmitters, television amplifiers, and many other places where amplification is needed. The third electrode is called a grid and is located between the cathode and the plate (anode). It usually consists of an open spiral or mesh of fine wire. When this grid is made negative with respect to the cathode, it repels the electrons given off by the cathode so that no electrons are allowed to pass through the grid to the plate. However, if the grid is made less negative (more positive) with respect to the cathode, the electrons will pass through the grid to the plate. In this way the grid controls the number of electrons that can be attracted to the plate, thus controlling the current that flows in the plate circuit.

A small amount of current applied to the grid can control a rather large amount of current in the plate circuit.

Now let's see what occurs if a microphone is connected to the grid circuit of a tube. We will imagine a 500 cycle tone is being picked up by the microphone. The microphone is producing a very weak 500 cycle electrical signal. This causes the current in the grid circuit of the tube to fluctuate at 500 cycles a second. In other words the grid current is changing from negative toward positive and back to negative at the rate of 500 cycles a second.



SCHEMATIC DIAGRAM SHOWING HOW VACUUM TUBE IS USED TO AMPLIFY MICROPHONE SIGNAL

This causes the quantity of electrons passing from the cathode through the grid to the plate to vary at the rate of 500 cycles a second.

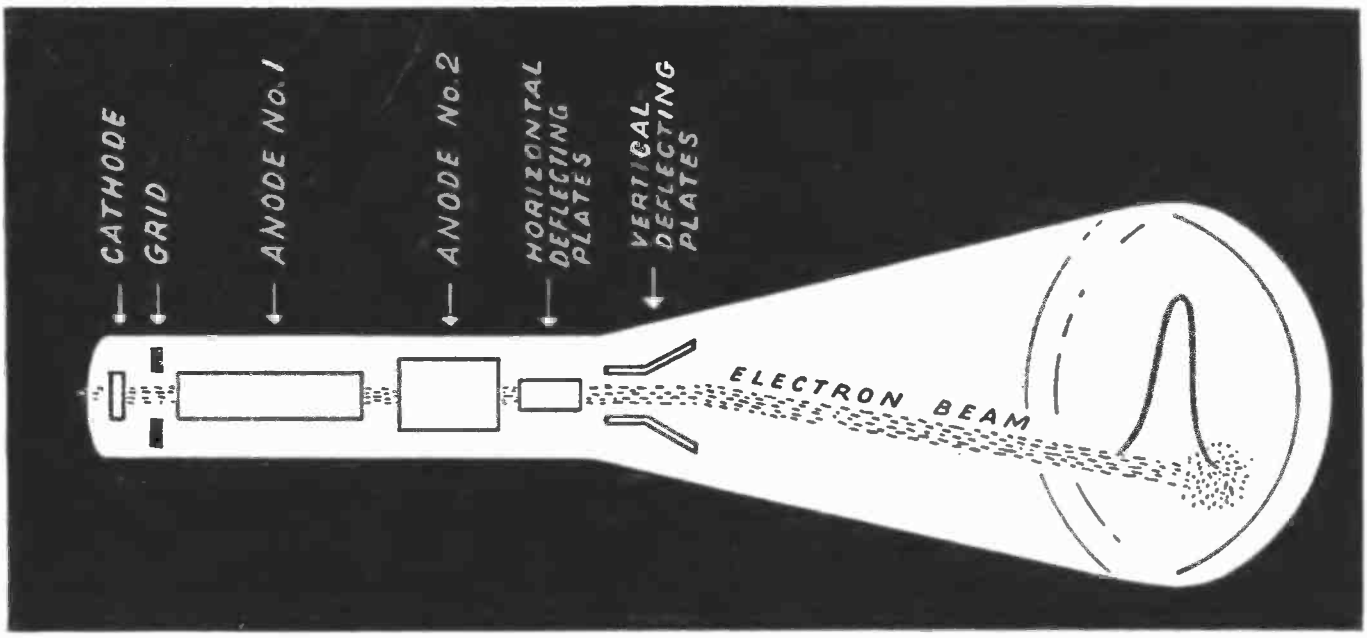
As these electrons cause a rather large plate current to vary at this frequency, the electrical signal has been stepped up in power. When a vacuum tube is used in this manner it is called an amplifier. This signal can be amplified again by another vacuum tube operating in the same manner. This would be called a two-stage amplifier because the original signal has gone through two stages of amplification. An amplifier may contain from one to several stages of amplification.

The output of one of these amplifiers can be coupled to a loudspeaker and the audio signal transferred back to a sound wave. These amplifiers vary in size from the small units used to amplify the audio signals in the studio to the large powerful amplifiers used in transmitters. The large amplifiers used in broadcasting transmitters can increase this signal until it represents 50,000 watts of power.

Cathode-Ray Tubes

This type of tube is used in an oscilloscope which is an electrical machine for the visual checking of the amplitude and wave form of an audio signal. This type of tube is also used for producing the picture in a television receiver. It is described in the chapter on television receivers and transmitters.

The cathode-ray tube is a vacuum tube which accelerates the electrons given off by a cathode and transforms them into a beam which is directed at a special translucent, fluorescent screen. The tube is a funnel-shaped glass container, the narrow part of the tube containing the electrodes which form the beam and control it. The screen consists of a coating of special fluorescent material on the inside of the large end of the tube. When the beam of elec-



ELEMENTS IN CATHODE-RAY TUBE

trons strikes the screen, a spot of colored light is produced—usually green, white, yellow, or blue, depending upon the ingredients in the screen material.

The electrodes in the narrow end of this tube form an electron gun. It consists of a cathode, grid, and two anodes. The cathode supplies the electrons and the grid controls the intensity of the electron beam. The first anode accelerates and narrows the beam; the second anode further increases the velocity of the electrons in the beam. At the point where the tube widens there are two sets of deflecting plates. One set is used for deflecting the electron beam horizontally and the other for deflecting it vertically. In larger tubes, coils are usually used instead of plates for deflecting and controlling the electron beam. When coils are used, they are mounted externally, close to the glass container.

Normally when the electrons strike the screen they create a small bright spot in the center of it.

When varying voltages are applied to either the horizontal or vertical plates, the bright spot moves back and forth in either a horizontal or vertical plane. When this motion is sufficiently rapid, the path of the moving spot appears to be a continuous line.

When a varying voltage is applied to the horizontal plate, the spot travels rapidly across the screen from left to right and then returns to the left side. This is called a horizontal sweep voltage. The time the spot takes to return to the left side of the screen is called the fly-back time.

When varying voltages are applied to both sets of the deflecting plates and the frequency remains the same, the wave form is traced over and over again as long as the amplitude of the signal and other conditions remain the same.

Now the wave shape is visible to the eye, and if the return sweep (fly-back time) is short enough, the return trace will be invisible. Many patterns of wave forms can be produced with this tube and it is used by engineers for studying alternating currents.

When this tube is connected into an audio circuit coming from the studio microphones, you can see the various frequencies of the sound waves being picked up by the microphone. If an orchestra is playing, you can see the various frequencies produced by the different musical instruments. These frequencies seem to dance along the screen at a very rapid pace and are fascinating to watch.

VII Master Control Room

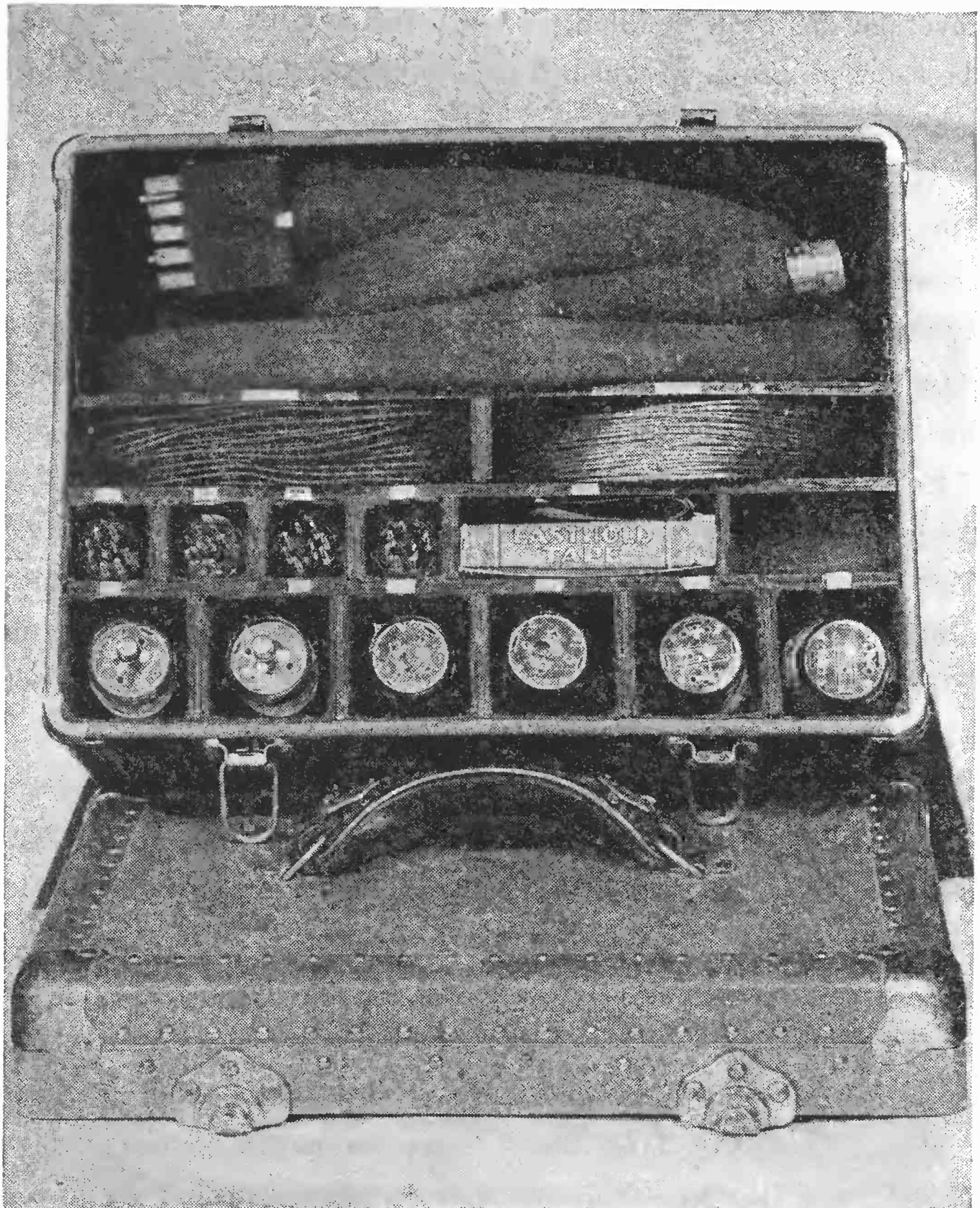
IN THE early days of radio, transmitters operated more or less independently—that is, each station had one or two studios and the programs consisted only of what they produced in their own studios. This method was not very practical, as the cost of producing a program was quite high considering the number of people it reached. Advertising firms would not pay a high price for time because the programs only had local coverage.

As the income of any company controls the quality of material they produce, radio programs in those days were not very interesting or entertaining. This difficulty was overcome when local stations became affiliated with out-of-town stations and could exchange programs by sending them over telephone lines. In this way the same program could be broadcast from two transmitters located in different cities. The cost of producing the programs was then cut in half, as one program would do for two transmitters. Of course, you have the additional cost of the telephone line and an additional amount of overhead. But at the same time the coverage has been doubled, so twice the number of people hear the same program. Because of this, advertisers are willing to pay a higher price.

The system worked out advantageously all the way around. The broadcasting company could afford to produce better programs and install better equipment. The advertisers were pleased because of this and because of the fact that they were reaching a larger audience. The public was pleased, for they received better entertainment from local and distant points.

So this system grew and grew until stations all over the country were connected by telephone lines to form a chain of stations. This is called a broadcasting network and today there are many different networks. Some cover the east coast, some cover the middle west, others the west coast, and there are national networks that cover the entire country.

Of course, these various hookups are not permanent. A local station may be connected in on a national hook-up for fifteen minutes; then for the next fifteen minutes it may operate independently, producing the program in its own studios; during the following fifteen minutes the program may come by short wave from Europe. In large broadcasting companies this becomes quite complicated, with program changes occurring almost every fifteen minutes. Most of the large broadcasting companies, such as C.B.S., N.B.C., and the Blue Network, have transmitters and studios in New York, Los Angeles, San Francisco, Chicago, Washington, Boston, and other cities. These companies also have what are known as basic networks, consisting of from twenty to fifty trans-



Courtesy of C.B.S.

FIELD EQUIPMENT ACCESSORIES

mitting stations spreading over certain areas. The larger stations have agreements with the smaller companies in these areas to transmit their programs at certain times. The larger companies can arrange national networks consisting of well over a hundred stations.

One of the large broadcasting companies in New York has twelve or more regular studios; among them are two large audience studios, four theaters used as audience studios, two short wave studios for foreign broadcast, and a special studio for news broadcast. The same company has many different types of transmitters: a large 50 kilowatt transmitter for regular broadcast; a frequency modulation transmitter; a television transmitter; and a number of 50 kilowatt international transmitters. This is just their setup for New York City. They also have additional studios and transmitters in Chicago, St. Louis, Washington, Charlotte, and Hollywood.

All the lines that carry the various local programs from each studio terminate in the master control room; so do all the outgoing lines to the various transmitters, both local and out of town. This room is where all the lines are connected for the various setups, and as these setups change about every fifteen minutes you can imagine what a busy place it is.

At eight o'clock the program coming from Studio #21 and going to the local transmitter must be replaced by a program coming from Theater #3 which is to go out on a national hook-up. At the same time the foreign broadcast originating in short wave Studio #31, which is being sent to the European transmitters,

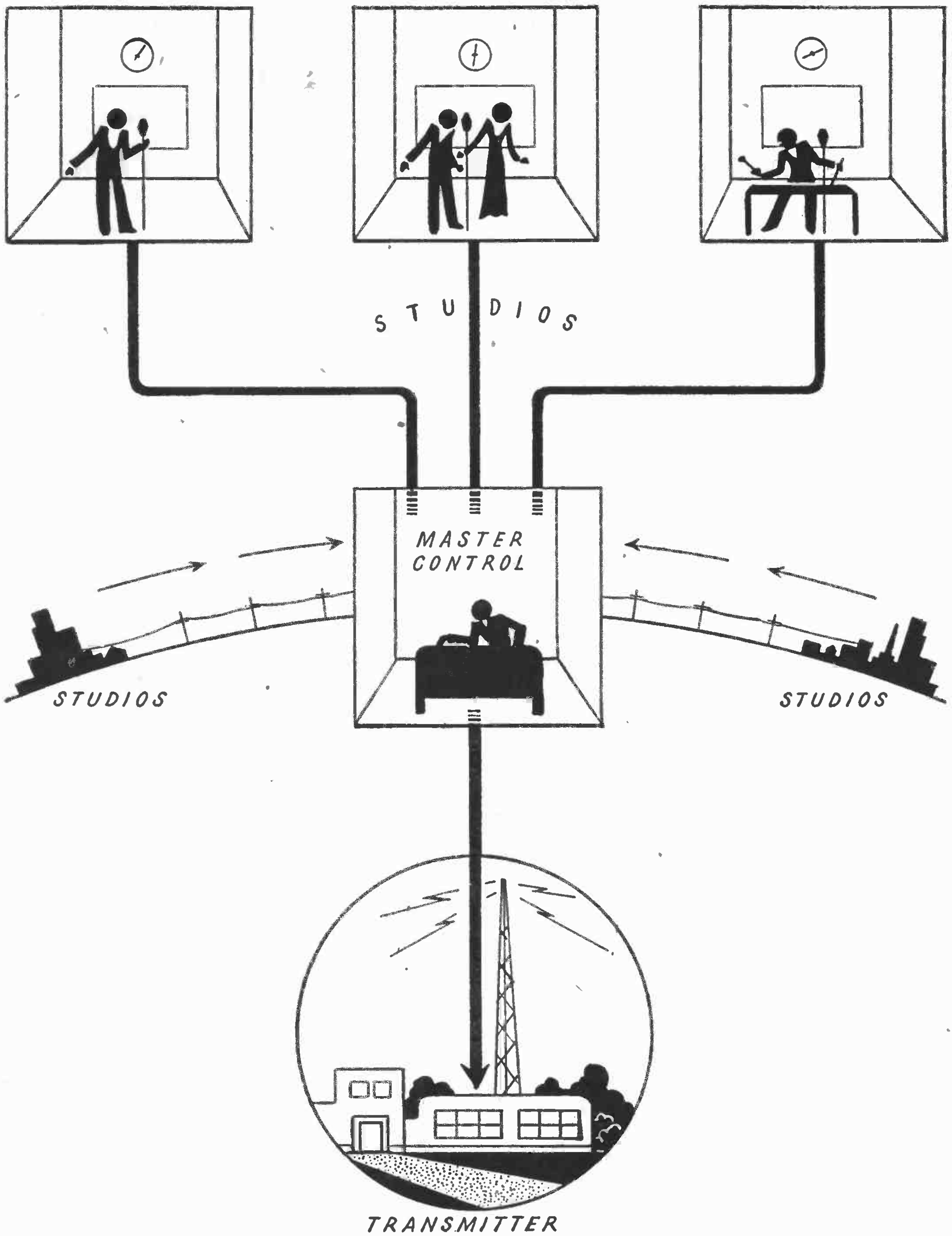


DIAGRAM SHOWING HOW ALL PROGRAMS PASS THROUGH MASTER CONTROL ROOM must be switched so the program originating in short wave Studio #32 takes its place. At the same time, a program in Studio #28 must be sent to another locality in the city so that it may be recorded and used the following day. There is also a program coming in by short wave from Europe that one of the executives wants to hear in another studio. This is an imaginary setup, but actually the changes that occur every fifteen minutes are often much more complicated than this.

The master control room not only takes care of all of these changes but handles them almost instantaneously. This sounds like an impossibility, but radio engineers have worked out several different methods to accomplish it. We will describe one of the latest methods for master control switching.

In the middle of a room there is a large control desk shaped like a horseshoe. This desk consists of a series of sixteen narrow panels set side by side around the curve of the horseshoe. These panels extend twenty-four inches above the writing shelf which also extends around the curve of the horseshoe. At the bottom of each panel are a large dial and an indicator. As you turn the dial, a number appears on the indicator. This is the number of one of the studios. Above this indicator are several rows of keys; these are really small switches and above them are indicator lights representing the various outgoing lines that go to the different transmitters and networks.

The dial at the bottom of each panel is really a rotating switch which cuts in the various studios by an electrically operated switch or relay. There are also two buttons on this panel—one marked

"Pre-set" and one marked "On the air."

This is how the engineer operates. First he presses the pre-set button on panel #1 and turns the studio-indicating dial to the desired studio. The studio number will show up green in the indicating slot above the dial. He then presses down one of the key switches on top of the panel, and an indicating light goes on, showing which outgoing line he is connected to. Actually he has not made connections at this time but has pre-set the panel, so that when he presses the on-air button, the switching will actually take place. He then repeats the operation on panel #2, pre-setting it for the next program, and he continues to do this until at least four programs are set up. Now when the time comes for program #1 to go on the air, all he has to do is press the on-air button. This on-air button turns on electrical energy for the various electrically operated switches (relays). The pre-setting has already determined which switches will operate, and the proper studio is automatically connected to the proper outgoing line. Now when the time comes for the next program, the engineer presses the on-air button on panel #2. This cuts out panel #1 and substitutes the setup on panel #2. Panel #1 is now set up for another program. When another program is going out at the same time, another group of panels is used in a similar fashion.

The engineers who operate this equipment have more to do than just to pre-set these panels and switch them at the proper time. For each outgoing program they have a monitor loud-speaker so they can listen to the program. It is quite confusing to the layman when he stands in the master control room and hears four or more

Courtesy of C.B.S.

FIELD EQUIPMENT IN OPERATION

programs at the same time, but the engineer has trained his ears so that he can detect the slightest trouble on any one of the programs and can tell on which program it is occurring. Also he can usually tell whether it is tube trouble, a condenser going bad, a faulty line, a bad switch, etc. If the trouble is in some of the amplifier equipment in the master control room, it can usually be located and corrected in less than a minute.

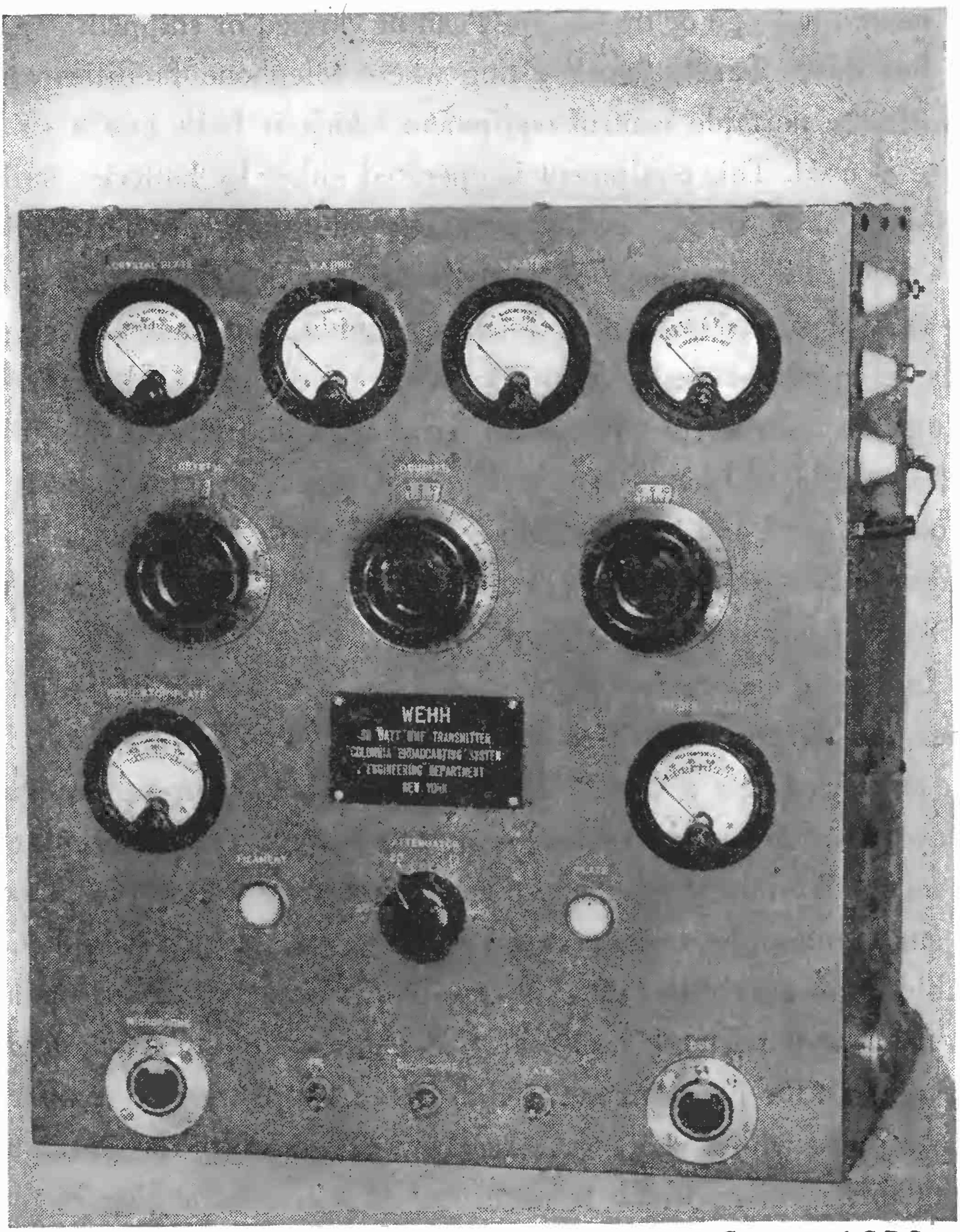
The master control room always contains spare equipment to replace any parts that may become defective. All this equipment is checked periodically and a running log is kept of everything that happens in the master control room.

The volume level of each incoming and outgoing line is checked in the master control room with volume indicators. The room is also equipped with a private line telephone system so that it can communicate with all studios, transmitters, and other points of importance without relying on the public telephone system.

Even programs originating outside of studios are sent over telephone wires to the master control point. A good many programs do not originate in the studios—broadcasts from nightclubs, boxing bouts and horse races, addresses by government officials, on-the-scene descriptions of notable events, and so on.

To pick up these programs and send them over telephone lines to master control requires special portable equipment. This type of pickup, when it originates outside of the studio, is called a remote pickup.

The equipment used for it varies considerably, depending upon the circumstances. This radio equipment is especially designed



Courtesy of C.B.S.

FIELD TRANSMITTER

to fit into luggage or trunks, so it can be carried or shipped.

For dance bands, broadcasting where telephone facilities are available, portable control equipment which is built into a suit-case is used. This equipment is operated either by batteries built into the unit or by local power. The amplifiers are built into the same unit or into a separate portable unit. These units are usually designed to handle four or eight microphone positions. The microphones are equipped with long rubber cables which plug into the control equipment. Another cable connects the unit to a telephone line. The control panel has a volume indicator mounted on it and a receptacle for plugging in headphones. The engineer can stand the panel on a table and listen to the program with the headphones.

In a good many cases no telephone facilities are available, and then the pickup requires additional equipment. For instance, if we are covering a golf match, the sports commentator follows the players around on a tractor. A portable short wave transmitter is mounted on the tractor, and the commentator carries in his hand a small microphone connected by means of a long microphone cable to an amplifier unit. The amplifier unit supplies the signal to the 5 watt portable transmitter. A short wave antenna is used to transmit the program to the club house where another engineer is stationed with a short wave receiver. He picks up the program with this receiver which is connected to a telephone line in the club house. This receiving unit is equipped with a volume control and volume indicator, and the program is monitored with head-phones. The telephone line carries the program to the master control room where it is connected to the line going to the main transmitter or to out-of-town stations.

Usually a second transmitter is used for this type of pickup.

Courtesy of C.B.S.

BROADCASTING FROM A PLANE

This is used so that the engineer at the club house can communicate with the engineer in the field, who is equipped with a receiver as well as his transmitter.

Descriptions of large planes on their maiden voyages have been broadcast. In cases of this type the program must be sent quite a distance before it is picked up and re-broadcast. This requires a much larger short wave transmitter. One hundred watt transmitters have been used for this purpose.

The department in a broadcasting station that handles remote pickups is known as the field department, and it must have a considerable amount of portable equipment. There may be as many as ten portable short wave transmitters, ranging in size from a three watt transmitter to a hundred watt unit, and twenty or more short wave receivers.

VIII The Broadcasting Transmitter

We have already discussed the way in which sound waves are changed by the microphone into electrical waves of the same frequency, how they are amplified and sent over telephone lines to the transmitter. We will now find out what the transmitter does to these signals and how they are radiated by an antenna system.

The main function of a transmitter is to generate a powerful carrier wave which brings the sound wave frequencies to your receiver. This carrier wave has a frequency of its own which is generated by the transmitter. The frequency of the carrier wave is much higher than the audio frequencies generated by the microphone. The frequencies used for the carrier wave for commercial broadcasting may be anywhere between 550,000 cycles and 1,600,000 cycles per second. Usually each transmitter, in any one locality, broadcasts on a different carrier wave frequency. This prevents stations from interfering with one another.

The method that is used for coupling the microphone signals to the carrier wave determines the type of transmission. Amplitude modulation (A.M.) is the method most widely used today and is the type we will discuss in this chapter. The newer type,

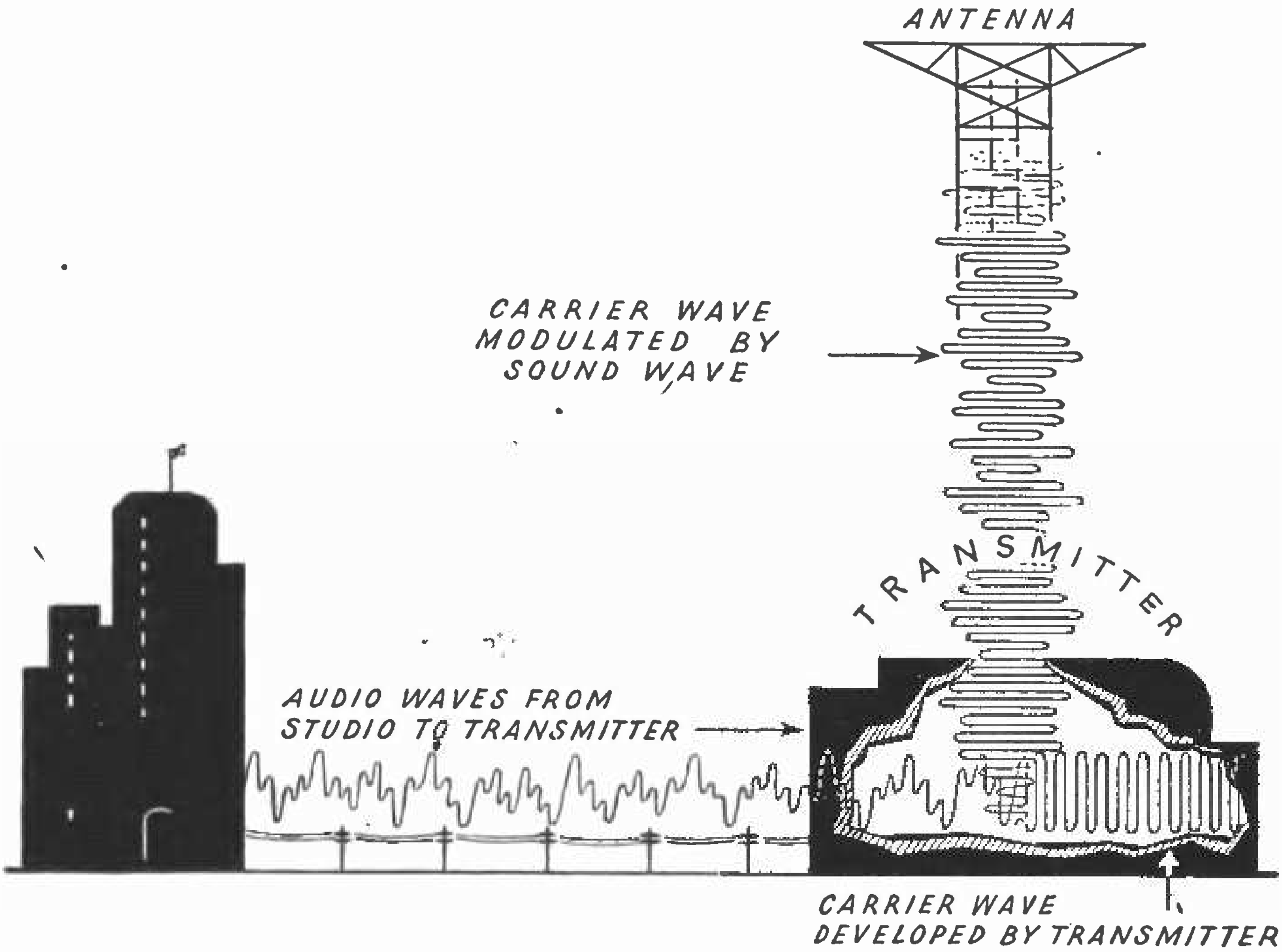


DIAGRAM SHOWING HOW MICROPHONE SIGNAL AFFECTS CARRIER WAVE

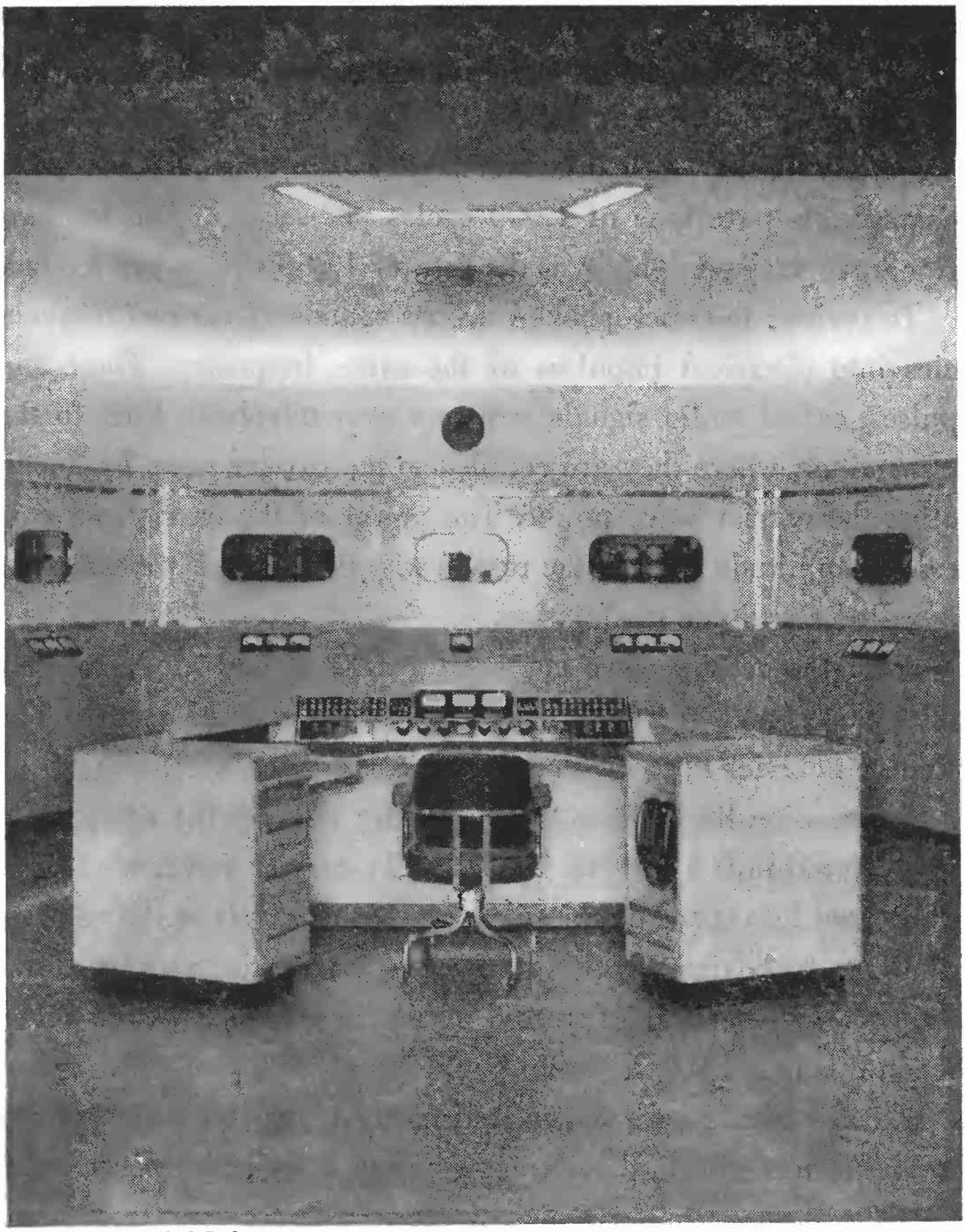
frequency modulation (F.M.), often called staticless radio, will be discussed later on.

The transmitter generates a powerful carrier wave and also amplifies the microphone signal (audio signal) coming from the studio. The transmitter then combines the carrier wave and the audio signal by a method known as amplitude modulation. The electrical circuits in the transmitter are designed so the audio signal varies the carrier wave power. This is called modulation. In other words, the power of the carrier wave is fluctuated at the frequency of the original sound wave. If the original sound, for example, is pure tone of 1,000 cycles per second, then the carrier wave varies in power at the rate of 1,000 cycles per second.

To review: the microphone converts sounds of various frequencies into electrical impulses of the same frequency. These impulses, called audio signals, are sent over telephone lines to the transmitter, where they are coupled to the carrier wave by fluctuating the carrier wave power. The power of the carrier wave is called amplitude. This is the reason why this type of transmission is called amplitude modulation.

After the carrier wave has been generated and modulated by the audio signal, it travels over wires to the antenna system. The line that carries this carrier wave to the antenna system is called a transmission line. The antenna actually radiates the energy that is delivered to it by the transmitter. The carrier wave, when it is dissipated into space by an antenna system, travels at the velocity of light, approximately 186,000 miles a second. In radio work, the velocity is usually expressed in meters per second—the velocity in this case being 300,000,000.

The electrical power that a transmitter is capable of supplying to an antenna system determines how far away your receiver can be from the transmitter and still produce satisfactory reception. Small broadcasting transmitters may only supply the antenna system with a few hundred watts of power; large transmitters are



Courtesy of C.B.S.

WABC, NEW YORK, TRANSMITTER CONTROL DESK capable of supplying from 10,000 to 50,000 watts of power. Though the electrical circuits and types of tubes in various transmitters may be different, the fundamental operating principles remain the same for all amplitude modulation transmitters.

The transmitter not only must generate an alternating current of the proper frequency for the carrier wave but it must also maintain the frequency within narrow limits. Naturally, if the frequency should vary, it might interfere with other transmitters. Varying frequency would also cause poor reception at the receiving end.

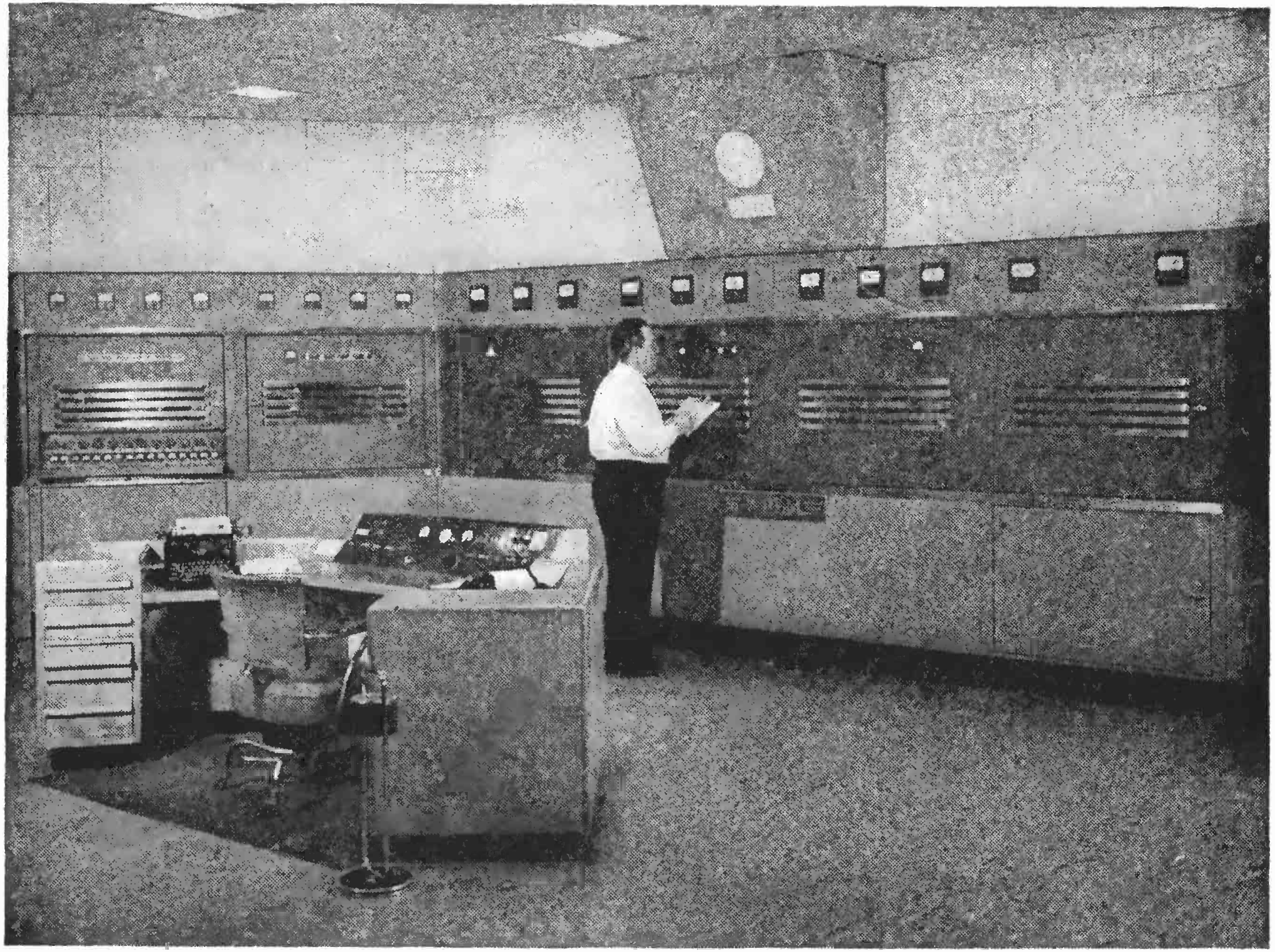
The circuit also used for creating these frequencies is called an oscillator circuit. There are many different types of oscillator circuits, but the type used in broadcast transmitters for producing the carrier wave is called a crystal oscillator. Actually the carrier wave frequencies are created by a vacuum tube and the crystal is used for controlling the frequency.

You have read how radio tubes can be used to change alternating current to direct current. A three-element tube can be arranged in an electrical circuit so that it will produce alternating currents of various frequencies from direct current.

The plate of a vacuum tube is usually called the "output"—the grid of the tube being the "input." By connecting the output and the input of an amplifier tube in an electrical circuit containing other elements, the current in the circuit is made to oscillate—that is, the current will keep fluctuating between the input and output at a certain frequency, depending on the other elements in the circuit. This unit is called an oscillator, and when a crystal is used in the circuit to control the frequency of the oscillations it is called a crystal oscillator.

The crystal that is used to control this oscillator is a quartz crystal. If an alternating current is applied, the crystal will vibrate mechanically with considerable amplitude at a certain frequency determined by the thickness of the crystal. The frequency at which the crystal vibrates determines the frequency at which the oscillator operates. Thus by selecting properly cut crystals of the right thickness the frequency can be controlled within very narrow limits, provided the temperature of the crystal is kept constant. The crystal is enclosed in a metal container and an electrical heater element and a thermostat are used to keep the temperature constant.

The carrier wave produced by the transmitter is at a single frequency though this varies slightly when it is coupled with the microphone signals. The Federal Communications Commission assigns the frequency at which each transmitter is allowed to broadcast, so that there will be no interference between transmitters. The same Commission also assigns bands of frequencies that may be used for each type of broadcasting. The frequency band assigned to commercial A.M. broadcasting is between the frequencies of 550,000 cycles and 1,600,000 cycles per second. The word kilocycles is usually used for these frequencies, so you would say 550 kilocycles and 1,600 kilocycles. These are the numbers generally used on receiving set dials, though the last zero is usually left off for convenience. So 88 on your receiving set dial would mean 880 kilocycles. These frequencies may seem

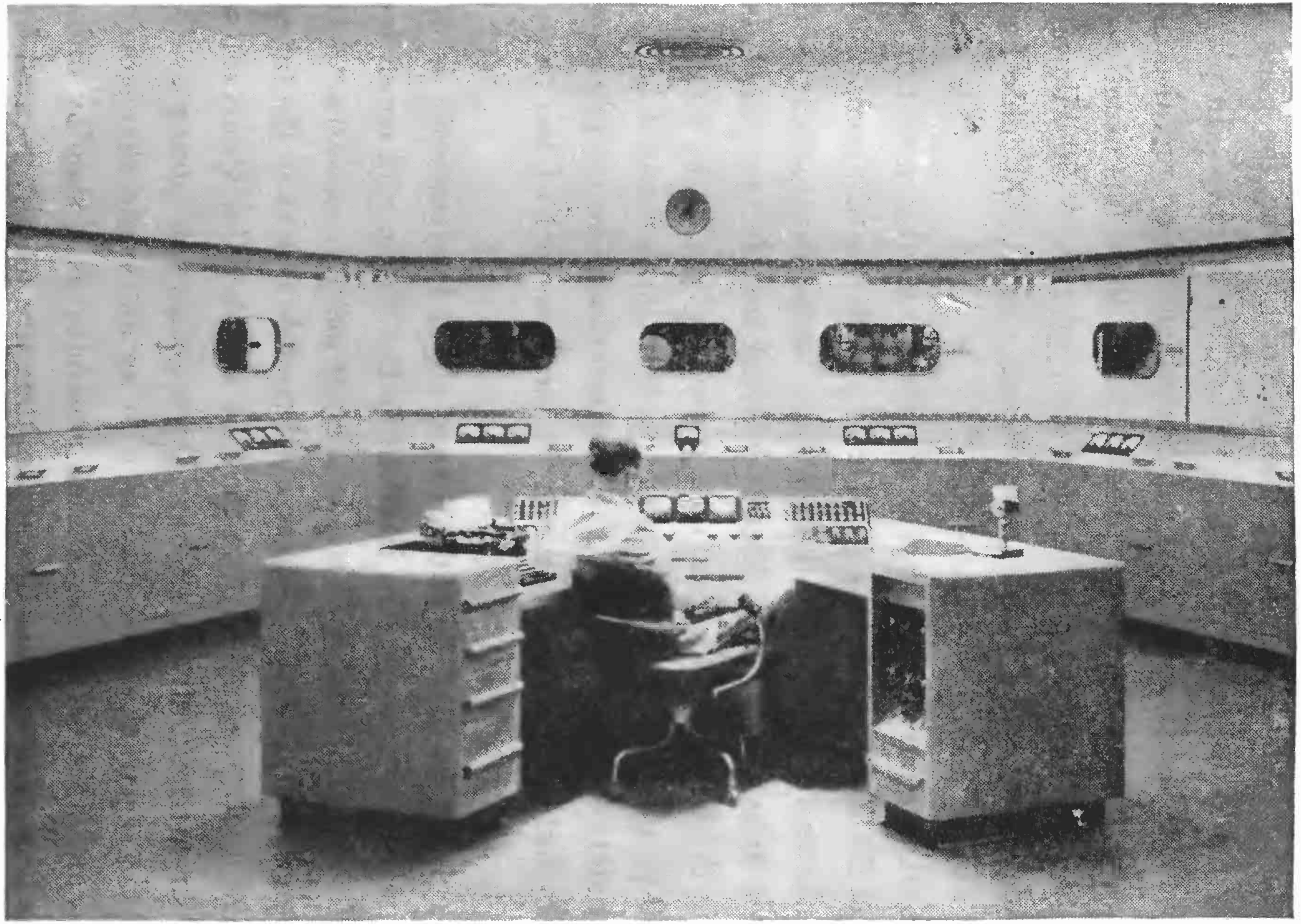


Courtesy of C.B.S.

WBBM, CHICAGO, 50,000 WATT AIR-COOLED TRANSMITTER high, but actually they are low in comparison with the frequencies assigned to international broadcasting, frequency modulation, and television.

In order to cover a large area with a transmitter, the modulated carrier wave must be quite powerful. Large broadcasting transmitters can supply 50,000 watts (50 kilowatts) of modulated carrier wave to the antenna system. In producing a carrier wave of this power, both the wave and the microphone signal go through several stages of amplification. Large, powerful vacuum tubes are used throughout the transmitter to accomplish the necessary amplification.

The large amounts of electrical energy passing through the plate (anode) of the tubes would cause excessive temperatures if they were not controlled. Water or air is used to keep the plate at the proper operating temperatures. When a water cooling system is used, the plate is made in the form of a copper tube closed at one end. The other end is fastened to a glass bulb through which the filament, grid, and plate connections are made. The grid is also tubular in shape and fits inside of the plate with the filament fitting inside of the grid. When the tube is placed in the transmitter, the plate is set in a water jacket through which cool water constantly circulates. Pure or distilled water is a poor conductor of electricity; so if the column of water is long enough between the water jacket and the connection to copper water pipes in the circulating system, little or no current can be carried back to the water system. For this reason a coil of pipe made out of some non-conductive material is used to connect the water circu-



Courtesy of C.B.S.

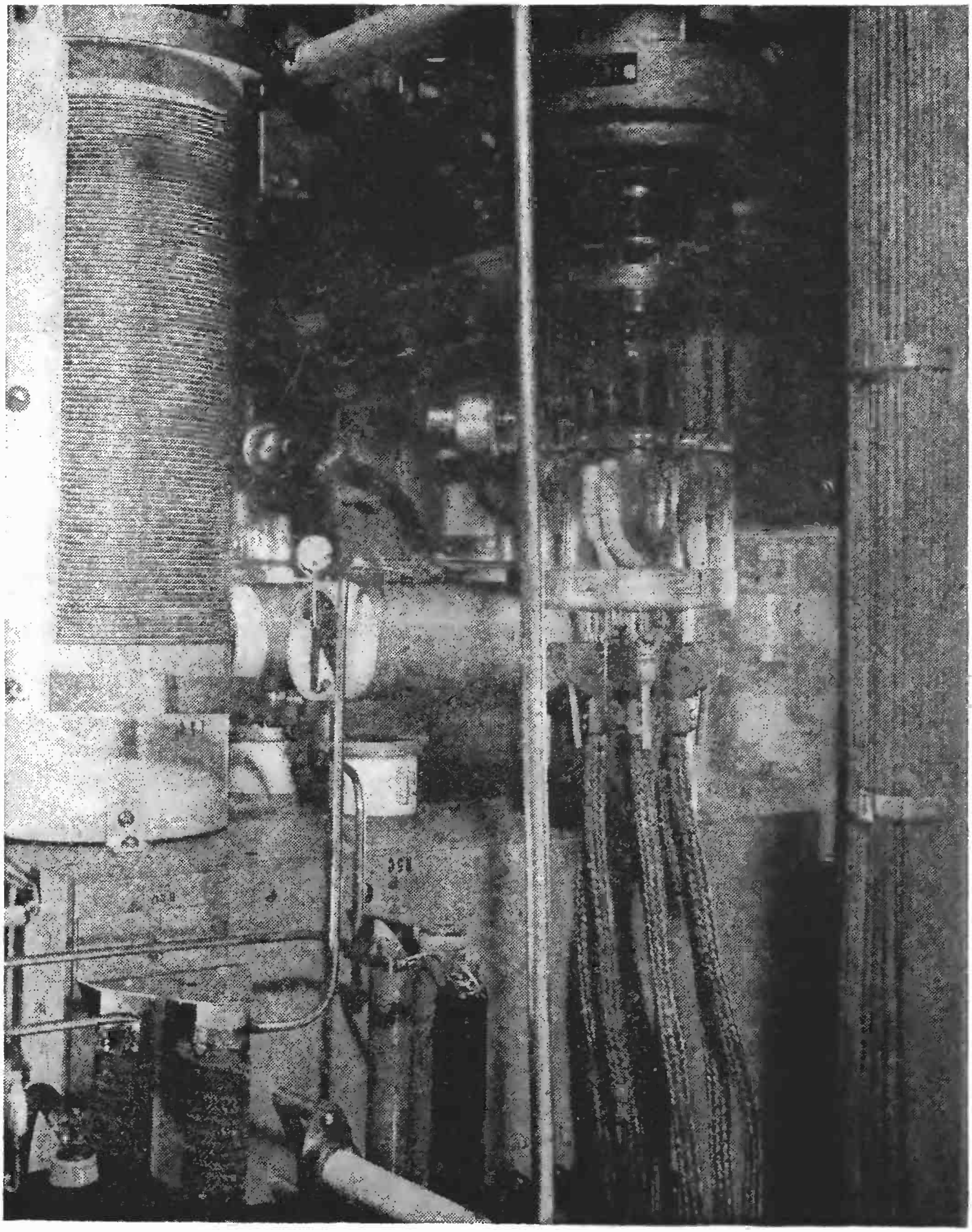
WABC, NEW YORK, 50,000 WATT TRANSMITTER

lating system to the tube water jacket.

When air is used for cooling the plate of the tube, the plate is usually made out of molybdenum, carbon, or tantalum. In place of the water jacket, a collar is substituted containing radial cooling fins. A stream of cool air passes through these fins usually at the rate of several hundred cubic feet a minute. A 50 kilowatt air-cooled transmitter may require as much as 10,000 cubic feet of air a minute for cooling the tubes.

The plate current necessary to operate these tubes may run as high as 20,000 volts D.C. In order to supply the different voltages necessary to operate these tubes, large transformers and rectifier units are needed. The modulation transformer which is used in the output of the modulating unit may weigh as much as 16,000 pounds. The dimensions of this transformer would be approximately 4 by 5 by 9 feet. These transformers are usually kept in a separate vault at the rear or in the basement of the transmitter building.

As continuous service, without even slight interruptions, is of vital importance, great care is taken in the design and construction of commercial transmitters. In a great many cases extra tubes are mounted in the various units, so if trouble occurs in the tubes that are operating, a new one may be switched in. Quite often these large transmitters also have three sources of power available—two separate power feeders with an automatic changeover switch, and a Diesel or gas engine generator as a standby unit. This is necessary because the transmitters are usually located in the country, where the power lines are carried on telegraph poles,



Courtesy of C.B.S.

INSIDE OF 50,000 WATT TRANSMITTER. NOTE WIRING AND WATER-COOLED TUBE and are, therefore, exposed to lightning, ice, and severe snowstorms which at times cause the service to be interrupted.

The transmitter engineer is usually equipped with a control desk which contains a volume indicator (for checking the volume of the incoming microphone signals), clock, indicating lights, transmitter controls, and a microphone for making local announcements. At certain intervals of time, he checks the meter readings on all of his equipment to see that everything is functioning properly.

Often transmitters are equipped with an automatic alarm system which rings a bell if the transmitter goes off the air, and automatically records the time of the interruption and how long it lasted. This equipment is made automatic, for the transmitter engineer is too busy locating and removing the trouble to keep a record of the "outage" time.

The fact that this equipment is supplied does not mean that transmitters go off the air very often; on the contrary, failures rarely occur. The engineer is a highly trained man and can usually spot the trouble before it becomes serious. He listens to his monitor loud-speaker, and if you asked him what the program was about he probably would answer that he was not listening to the program. This might seem peculiar, but he has trained his ear to listen for defects only. He can detect trouble when the average person would think everything was functioning perfectly. He not only can detect trouble but also can usually tell what part (among the hundreds of parts) in the transmitter is causing it.

IX Broadcast Antennas

TRANSMITTERS are next to the last step in the transmission of radio waves. After the transmitter has generated and modulated the powerful carrier waves, they are coupled to the proper antenna system and are dissipated into space. They will then travel to the receiving sets within range.

As you probably realize, the proper antenna system does not mean any wire that is strung between two poles. An efficient antenna system must be designed first for the frequency it is going to dissipate and then for mechanical strength and economy. Also it is sometimes necessary to make the antenna system directional —that is, to make it cover a great territory in certain directions. These are the fundamental problems behind designing an antenna system.

You may have seen the tall broadcast transmitting antennas (radiators) stretching 500 feet, 600 feet, or more into the air, so thin in comparison with their height that you wonder what holds them up. Perhaps you have also noticed that the heights of the antenna systems vary for different transmitter stations; also that some transmitters use one tower, some two towers, and others three. The number of radiators used determines whether the system is directional or not. The height determines the frequency at which it operates. If you knew the exact height of an antenna system, you probably could estimate the frequency at which the station is operating.

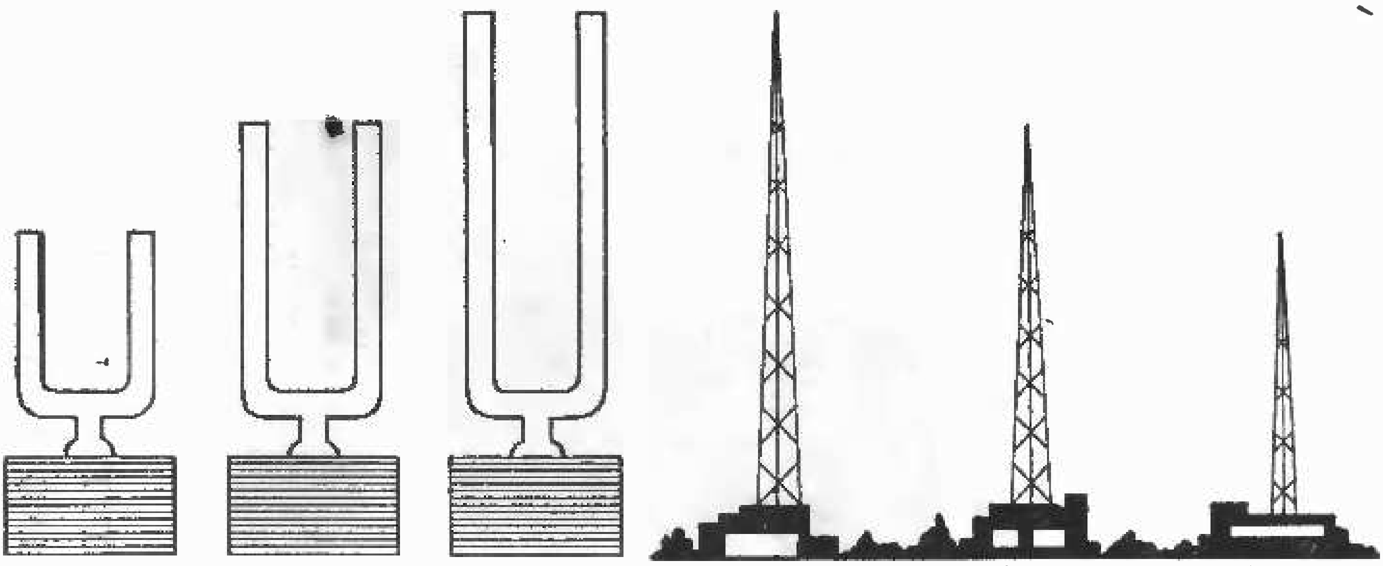
In order to understand how antenna systems operate, it is necessary to know more about the carrier wave. The carrier wave, after it has been dissipated into space by an antenna system, is usually thought of as a radio wave. The length of this wave plays an important part in the design of the antenna system. The length of the wave depends entirely upon the length of time it takes to generate a single wave. As the frequency of the wave determines the time it takes to generate a single wave it also determines the wave length. As an example, if a single wave is dissipated by an antenna system, the first part of the wave travels a certain distance before the wave is completed. The time that it takes to generate a single wave determines the distance it travels before the wave is completed. In other words, the length of the wave is the distance a single wave travels in space while it is being formed. As radio waves travel at the rate of 300,000,000 meters per second in space, you only need to know the frequency of the wave to determine the distance it travels before a single wave is completed. This is the wave length.

As an example, we will select a 1,000 kilocycle carrier wave. This means that the frequency of the carrier wave is 1,000,000

Courtesy of C.B.S.

WEEI, BOSTON, TRANSMITTER BUILDING AND SELF-SUPPORTING TOWER cycles per second. Now if we divide 300,000,000 meters by the carrier wave frequency, we get the length of a single wave. In this case the answer would be 300 meters—which is the wave length at this frequency.

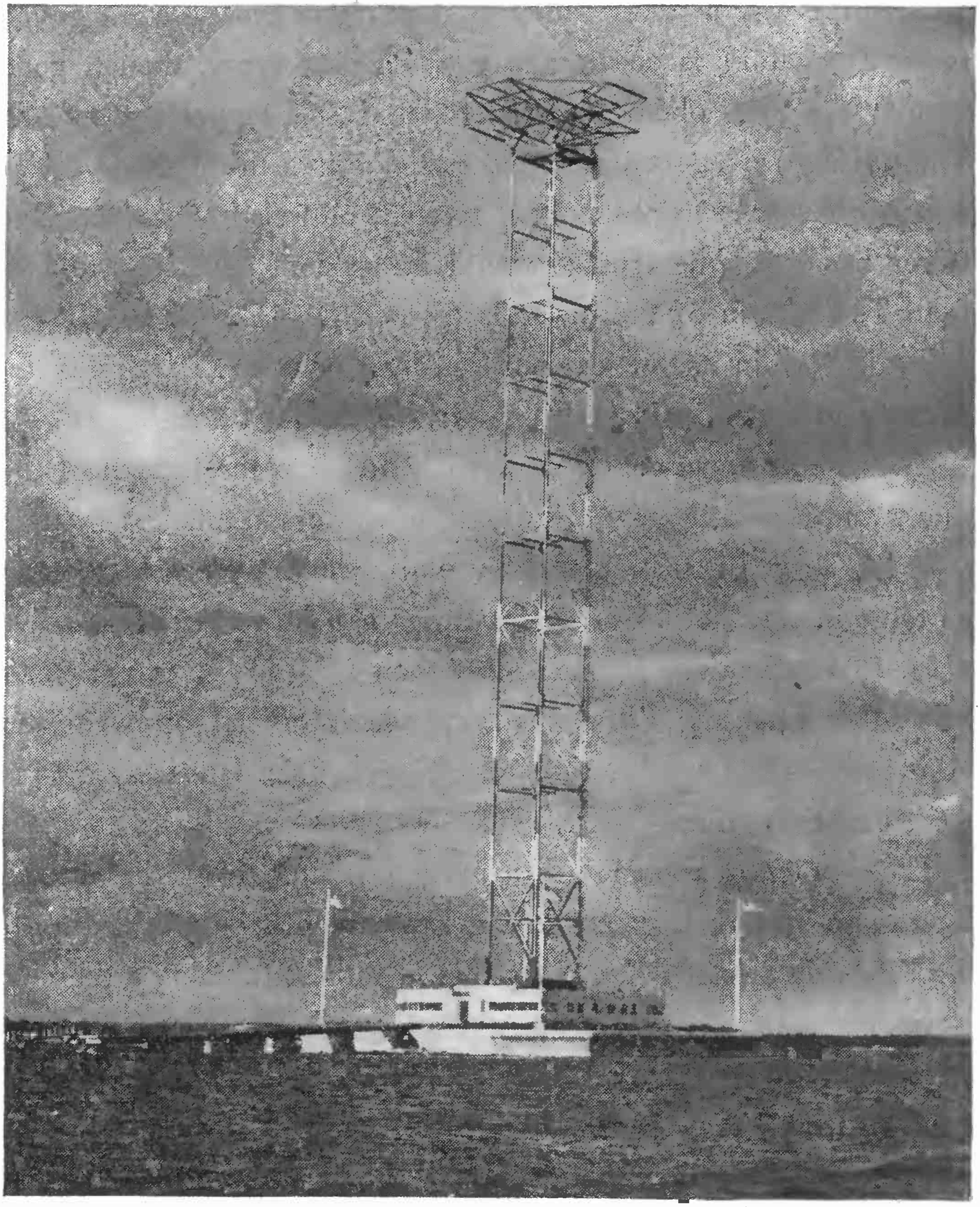
The length of a piano string is one of the primary factors determining the frequency at which the string will vibrate and the



HOW LENGTHS OF TUNING FORK AND HEIGHT OF RADIO TOWERS BOTH GOVERN THE RADIATED FREQUENCIES

frequency of the sound wave it generates. Radio towers work on a similar principle—their length determining the frequency at which they will radiate efficiently. For this reason, broadcast towers are made ½, ¼, or ⅛ of the length of the carrier wave they will broadcast. This means that a station operating on a wave length of 300 meters (983.4 feet) probably would have a tower approximately 496 feet high, or about one-half the wave length of the carrier wave.

The shape and dimensions of the tower also play an important



Courtesy of C.B.S.

WABC, NEW YORK, TRANSMITTER BUILDING AND TOP HAT ANTENNA part in the way a tower radiates. A uniform cross-section guyed tower (radiator) is one of the most efficient types, though good results are also obtained from tapered self-supporting towers. The uniform cross-section guyed radiator is a tower made up of reinforced steel sections bolted, riveted, or welded together. The tower has the same cross-sectional dimensions from top to bottom. The bottom of the tower is pivoted on a single point. The tower is kept in its vertical position by guy wires. Large guy insulators are used to insulate the guys from the tower.

The carrier wave energy is usually fed into the bottom of the tower and the entire tower radiates or acts as an antenna system.

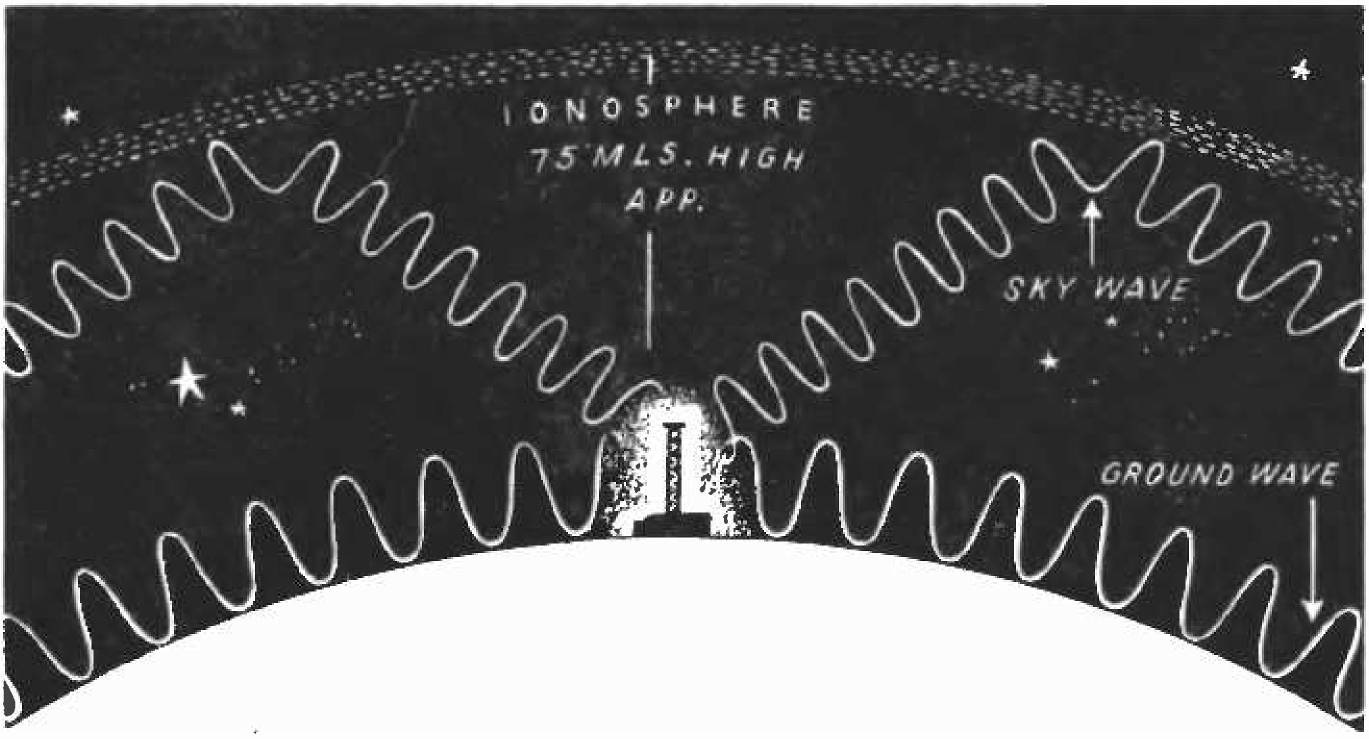
It has been discovered that by adding a flat piece to the top of the antenna the height of the tower can be reduced. In other words, the tower can be made less than a ½ or ¼ wave length by adding a flat top to it. Antennas to which this flat top have been added are called top hat radiators. Some of the latest towers are built in this fashion.

These antenna systems are usually insulated from the ground by a huge insulator, and lightning gaps are provided to drain off the lightning or static electricity that is gathered during a thunder storm.

If the static electricity is not drained off, the charge may build up until it flashes across the base insulator or at some other point where equipment may be damaged. Quite often just before a thunder storm, you can hear the static electricity flash across the insulators in the guys. The charge is often so heavy that it can be heard blocks away.

The antennas usually have a ground system consisting of 90 to 120 radials made of copper wires buried around the antenna. Each is approximately the length of a half wave.

The type of ground on which a radiator is located plays an important part in its operation. Wet soil is a better conductor



HOW TRANSMITTING ANTENNA RADIATES GROUND AND SKY WAVE

of electricity than dry soil. This is the reason you often see transmitters placed in low, wet soil or swamp land.

The waves radiated from an antenna system of this kind are divided into two types—ground waves and sky waves. Ground waves travel over the surface of the earth, and sky waves travel at an angle toward the sky. The sky wave travels upward until it strikes the ionosphere which bends it back toward the earth again. The ionosphere is an ionized region, the lower part of which is approximately 70 miles from the earth's surface. The ionosphere consists of several layers of ionization and these layers vary in height, depending upon the time of day and season of the year. Their height is affected by solar radiation.

During the day the ground wave signals are the ones usually picked up by a receiver, as the sky wave signals are quite weak. This is because the ionosphere region which affects the carrier waves used for commercial broadcasting is highly ionized by the sun radiation during the daytime. When this region is highly ionized, it absorbs most of the carrier wave energy, so very little of it is returned to the earth. During the night, when the sun's rays are not acting upon the ionosphere, the ionization is less and the waves are returned to the earth.

The ground waves which we pick up in the daytime do not travel a great distance before their intensity becomes too weak for good reception. During the night the sky waves become stronger and cover a greater distance as they return from the ionosphere. This is the reason why you get better long distance reception at night and can hear stations you cannot pick up during the day.

The frequency of the radio wave plays an important part in sky wave transmission as you will learn in the chapter on short wave international transmitters. These use the sky waves exclusively.

The amount of energy dissipated into space by 50 kilowatt transmitters is considerable. If a radio tower is being constructed near another tower which is operating, great difficulties are en-

Courtesy of C.B.S. and RENI Newsphoto Service

WTOP, WASHINGTON, TRANSMITTER STATION AND THREE TOWER DIRECTIONAL ANTENNA SYSTEM countered, even though there is no electrical connection between the tower under construction and the one operating. Large steel cables which are used for hoisting materials may be burned through by the electrical energy that they pick-up. The steel hoisting cables act as a receiving antenna, picking up the energy radiated by the other tower. This is particularly true when the cable is a half or quarter wave length long.

The men handling the cables often receive burns. The current at these frequencies burns rather than shocks. If a steel cable hanging from the tower under construction is allowed to rest against a piece of metal on the ground, you can actually hear the program from the other tower as the sparks arc across between the two pieces of metal.

When a small transmitter wants to increase its power, the Federal Communications Commission often requires it to use a directional antenna system, in order to eliminate the possibility of interference with another near-by station operating on approximately the same frequency. Without a directional antenna, the two stations would interfere with each other, but if one of them uses a directional antenna system this difficulty is eliminated.

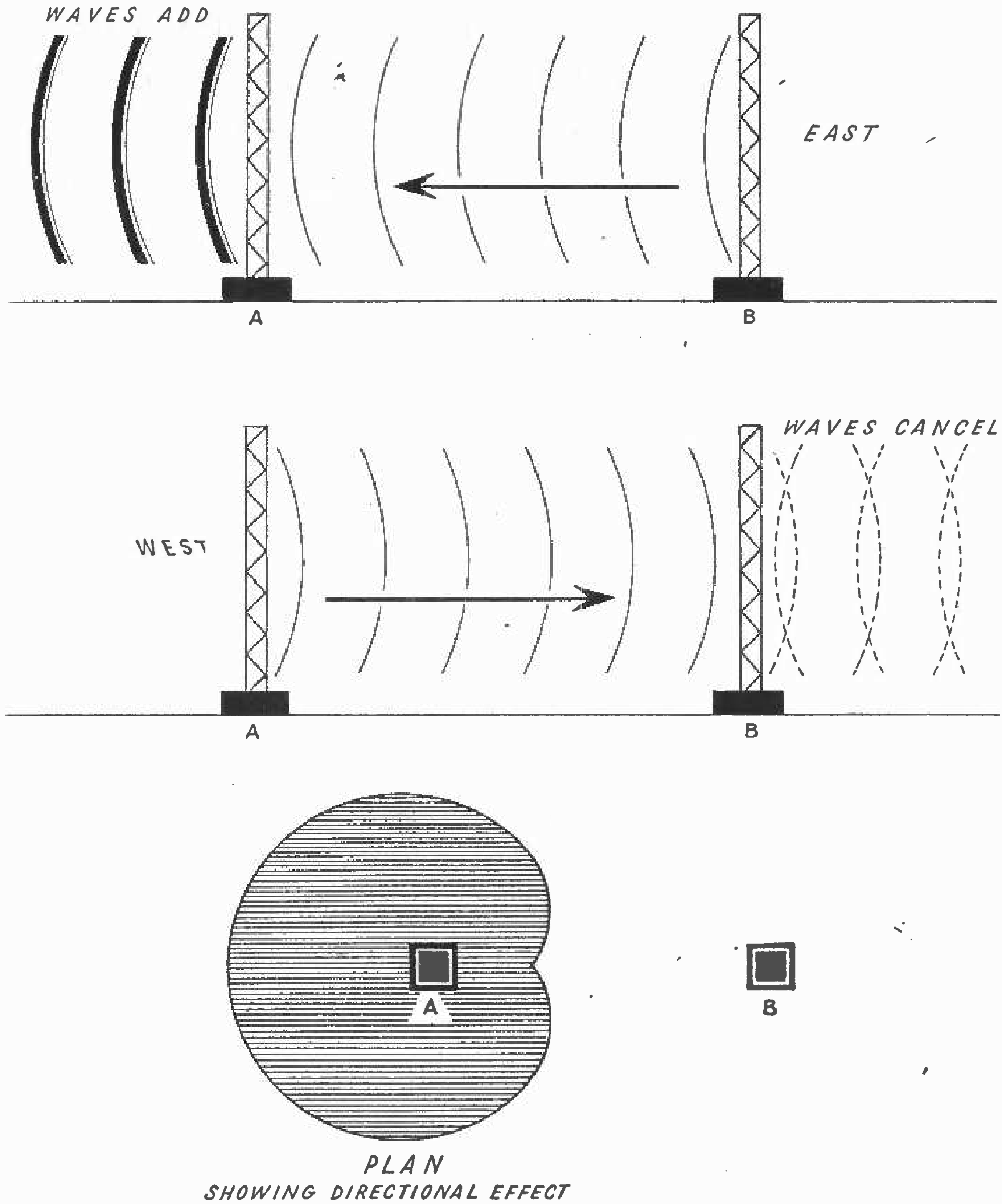
There are numerous types of directional antennas and they vary a great deal in construction, depending on what frequency band they are designed for and the purpose for which they are to be used. Here we will only discuss the directional antennas used for commercial broadcasting.

The directional effect of this type of antenna is accomplished by using two or more properly spaced radiators. By varying the spacing between the towers, the energy that is radiated by the antenna system can be controlled; it can be made to cover just the desired areas. Beside eliminating the coverage in certain areas, directional antennas can also extend the coverage in other areas.

Naturally it is a great advantage to be able to make the energy radiate in certain directions. This is particularly true when the station is located near the sea coast. The antennas are usually arranged so the carrier wave is radiated inland and up and down the coast line.

The directional effect is accomplished by using two or three towers that are properly spaced. The way the carrier wave is fed to the towers also affects the directional characteristics.

Let us look at a two-tower directional antenna system and analyze what occurs. Going back to the 1,000 kilocycle carrier wave which has a wave length of 983.4 feet, let us work out the spacing on the towers. We first want to space them ¼ wave length apart; ¼ of 983.4 feet is 245.85 feet. Therefore we will set tower A 245.85 feet from tower B. If the carrier wave reaches tower B ¼ of a cycle after it has reached tower A, it is said to be ninety degrees out of phase. If there is a half cycle difference it is one hundred and eighty degrees out of phase. If the carrier wave starts from tower A ¼ of a cycle late, by the time it travels ¼ of a wave length to reach tower B, it is a half cycle late. Then the waves are one hundred and eighty degrees out of phase. This causes the waves to cancel one another, so little or no energy is dissipated in this direction. Now the wave leaving tower B and traveling toward A starts ¼ of a cycle ahead of the wave leaving



HOW DIRECTIONAL ANTENNA SYSTEM FUNCTIONS

A. By the time it reaches A it has lost its ¼ cycle lead, so the waves are now in step (phase). This adds energy to the wave leaving tower A and the carrier wave is strong in this direction.

By varying the spacing or changing the phasing or both, various directional affects can be produced. Of course, mountains, large bodies of water, and other geographical conditions affect the radiation, and they must be taken into account when designing an antenna system. Nevertheless, radio engineers who specialize in this field can calculate the radiation of a given antenna system and predict within fairly close limits just how strong the signal will be in any locality within range of the transmitter.

X Broadcast Receivers

YEARS ago when people purchased their first radio receivers, they marveled at them and racked their brains wondering how they worked. Today most of these people still have no idea how a radio receiver functions and have long since given up thinking about it. Today they accept their radio as a machine that brings high quality reception to their homes, but this machine is actually one of the greatest and most fascinating developments of our time.

Any radio receiver contains many electrical circuits, and the radio wave goes through several changes before it reproduces the sound wave again.

You have already learned how the electrical sound wave (audio signal) modulates the carrier wave and how this modulated carrier wave is dissipated into space by an antenna system. Practically all of the transmitters in any one locality use a different frequency for their carrier wave. So the space around us is filled with carrier waves, each carrying a different program. These various carrier waves are picked up by your receiving antenna and fed into your receiver.

Now the job your radio receiver has is to select the proper carrier wave when you turn the dial, to adjust the variations in the intensity of the different signals, and to separate the audio signal from the carrier wave. There are several stages, or circuits, containing vacuum tubes which the signal must pass through before it can supply your loud-speaker with the proper audio signal.

The first step is to select the desired carrier wave from the various carrier waves that your antenna system picks up. It has been discovered that a circuit containing a coil of wire and a condenser connected in series will cause the current flow to be greater at a certain frequency. This is called the resonant frequency of this circuit. By varying the values of one or more elements in this circuit, you can change the frequency that it is tuned to. Broadcast receivers have a variable condenser for tuning this circuit to the desired frequency. This condenser is mechanically connected to the tuning dial on your receiver.

If you have ever looked at the inside of your radio set, you have probably noticed that the tuning dial is mechanically connected to a device which consists of a stack of semi-circular metal plates. As you turn the dial, you will notice that every other plate rotates, so that the moving plates pass between the stationary plates. This unit is a variable condenser, and as you rotate the plates you vary its capacity. This affects the electrical characteristics of the circuit. So, as you turn the dial on your receiver, you change the value of the condenser and tune the circuit to various frequencies. When the dial on your receiver reads 80, you have tuned your set to 800 kilocycles, which is the fre-

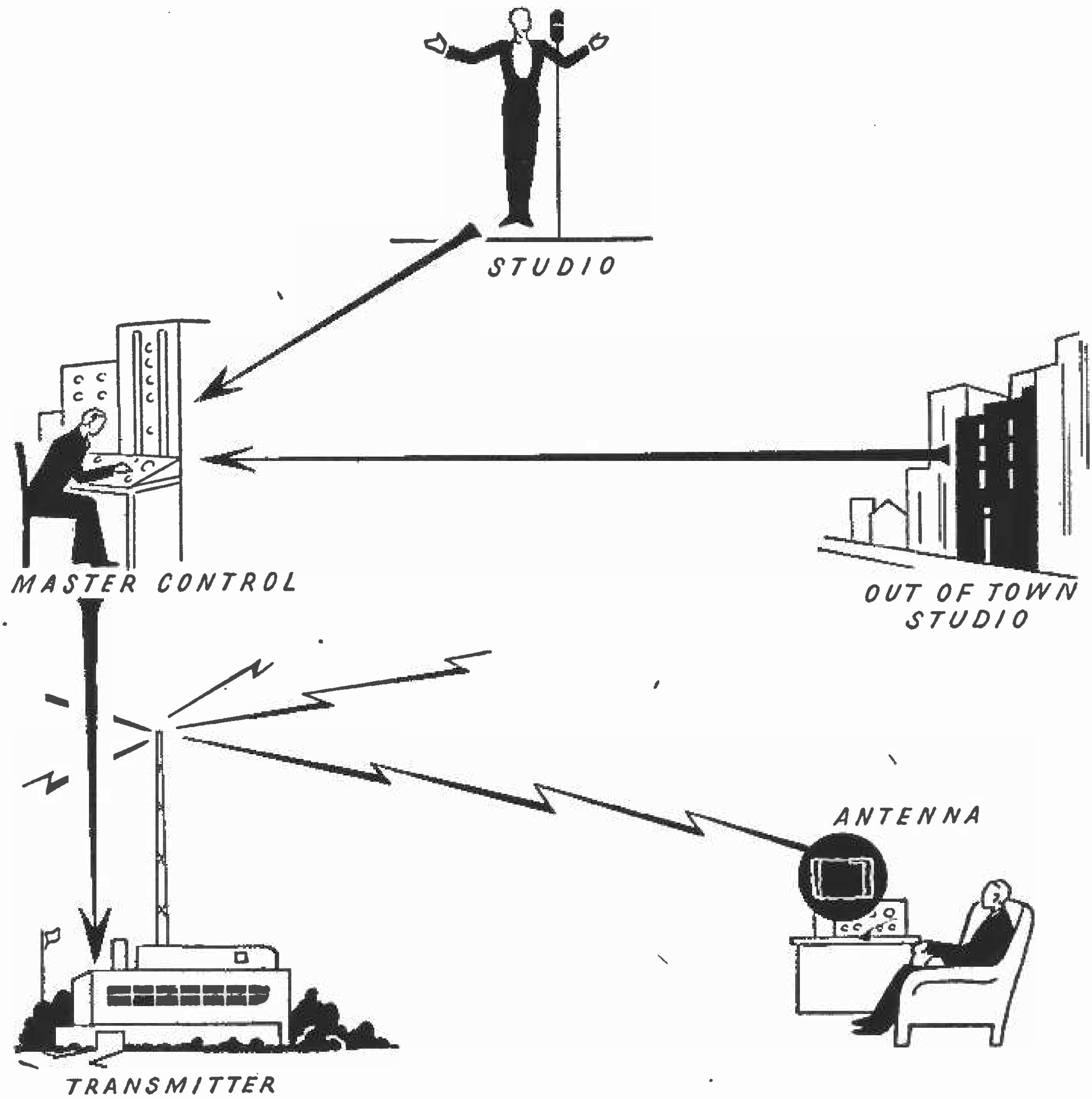


DIAGRAM SHOWING HOW PROGRAM TRAVELS FROM STUDIO TO RADIO RECEIVER

quency of the station you desire. This first stage is called the radio frequency section of the receiver.

After you have selected the carrier wave you desire by tuning, it is necessary to amplify the signal, as it is too weak at this stage for the audio signal to be extracted from the carrier wave. This presents a problem, as it is quite difficult to design an amplifier that will increase the volume equally well at the various broadcast frequencies. It is, however, quite simple to design amplifiers to operate at a single frequency. Because of this, your receiver set has an electrical circuit containing a vacuum tube which changes any selected carrier wave into a single pre-determined frequency. This new frequency is still modulated so the audio signal has not been lost.

This is the way your receiver functions in order to change the frequency of the carrier wave: A vacuum tube circuit in the receiver oscillates and generates an alternating current. The frequency of the current generated by this circuit is also controlled by a variable condenser. This variable condenser is usually on the same shaft with the tuning condenser, so as you tune to select the station you desire, you are also tuning the circuit that produces currents of various frequencies.

When two frequencies join in a circuit, an odd thing happens—a third frequency is produced. This third frequency is the difference between the two frequencies. If an alternating current of 300 kilocycles is superimposed on a 200 kilocycle wave, it produces a third frequency of 100 kilocycles. The second stage in your receiver does just this—it takes the frequency produced by the oscillator just described and superimposes it on the carrier wave selected to produce a third frequency.

This third frequency is called the beat frequency, and it is used in your receiver because it is more readily amplified. As an example, we will tune a radio, using arbitrary figures, and see what happens. We turn the dial to 80 and we have tuned in 800 kilocycles. At the same time the oscillator has automatically been tuned to 700 kilocycles, as both tuning condensers are on the same shaft. The difference between these two frequencies is 100, so our beat frequency is 100 kilocycles. If we tuned to 600 kilocycles, the oscillator is tuned at 500 kilocycles, and our beat frequency is still 100 kilocycles. Regardless of what frequency we select, the beat frequency will always remain the same. Most sets manufactured today operate on this principle.

The beat frequency contains the same modulation as the original carrier wave and may now be amplified by the use of an amplifier tube, which is called the intermediate frequency section of your receiver.

Now that the beat frequency has been amplified, it has served its purpose so it may be canceled, leaving the audio modulation which will later become a sound wave. A tube, acting as a rectifier, changes the alternating current of the beat frequency to direct current, and leaves only the audio modulation. This rectifier tube is called the second detector and the first audio stage of your receiver. The audio modulation is now your audio signal and, when amplified again, it can be made to drive a loud-speaker which produces the sound wave.

A loud-speaker and a microphone accomplish the opposite results. The loud-speaker produces sound waves from the electrical

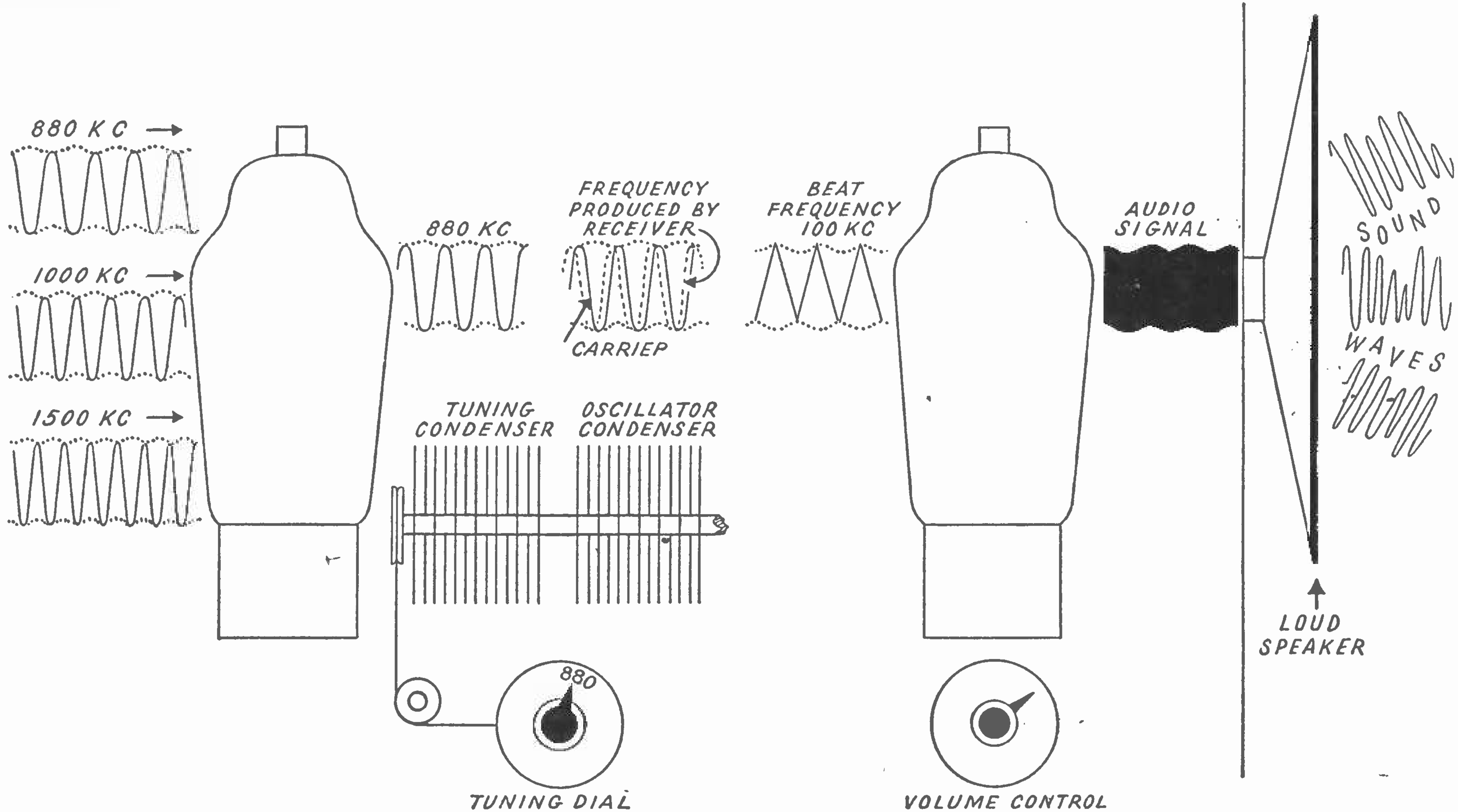


DIAGRAM SHOWING HOW RADIO RECEIVER SELECTS CARRIER WAVE AND CONVERTS THE SIGNAL INTO AUDIBLE SOUNDS impulses that are supplied to it. The microphone changes sound waves into electrical impulses.

While there are a great many variations in receiving sets, if you understand these fundamentals you really know how a receiving set operates.

The carrier waves reaching your receiver naturally vary in strength. The variation depends upon how powerful the station is and how far it is removed from the receiver. The strength of each signal is usually checked by the engineers of that particular station. They use a field-car equipped with a special antenna and measuring equipment. They measure the strength of their carrier wave for miles around the transmitter and plot field intensity charts. These field intensity charts look a great deal like contour maps, with irregular lines drawn around the transmitter to indicate the intensity of the carrier wave at each location.

There are also many other circuits and gadgets added to the modern radio set, such as automatic volume control circuits which maintain a constant volume level even though the incoming signal may vary or fade in volume. A great many sets today also include an automatic tuning device, either electrical or mechanical. Many sets have tuning indicators. Sometimes this is a small cathode-ray tube, in which the luminous area varies as you tune in different stations.

When sets are designed for both commercial broadcasting and short wave, they contain an extra set of tuning coils which are usually connected in the tuning circuit by means of a switch. This allows you to tune your set to a higher band of frequencies called short wave. These shorter wave bands are used for international broadcasting, frequency modulation, television, police calls, and other types of communication.

Of course, you can purchase receivers today which are combination sets covering commercial broadcasting, frequency modulation, and television. They are really two or more sets built into one, and some of the tubes are used for more than one purpose. The radio and phonograph combinations feed the phonograph pickup into the audio amplifier section of the set and cut out the radio frequency section by means of a switch. This audio section in your set can be used for many purposes. A microphone can be connected in the circuit at this point, for example, and you can have a public address system. It is also possible in some sets to utilize the audio section for recording your own records, providing you have a recording-head on the pickup arm of your phonograph. If you would like to make some of these additions to your set, your radio dealer will probably help you. If you give him the make and model number of the set, he will tell you where to make the necessary connections.

XI Frequency Modulation

EVERY day more people hear about frequency modulation (F.M.) and every day its popularity is increasing. The radio stores in most of the large cities have sold a great many F.M. receivers. As you learn more about F.M. you will find that not only a new type of receiver has been developed but a new type of transmitter is required for its use. This transmitter generates a carrier wave which is quite different from the carrier wave we have previously discussed. Probably the easiest way to break the ice on this new development in radio is to discuss the reasons for its development.

For years the radio field realized that present day commercial broadcasting was not all that it could be. One of the main difficulties with it is that static resulting from storms, elevator machinery, street cars, power plants, etc., distorts the program considerably on the receiving end. At times this distortion of the signal becomes so objectionable that it is necessary to turn the receiver off. While certain static suppressors have been developed for standard receivers they have not been too successful. F.M. does eliminate practically all static.

The second weak spot in present day broadcasting is the audio frequency range. The best A.M. (Amplitude Modulation) transmitters operating on the frequency band allowed them by the F.C.C. can only cover an audio range of approximately 50 to 10,000 cycles. While this is a wider range than most inexpensive receiving sets can reproduce there is still room for improvement. By going up to 15,000 cycles in the audio frequency range both on the transmitting and receiving end, excellent reproduction can be accomplished. A good F.M. transmitter and receiver can accomplish this. Many public F.M. demonstrations have been given to show what this improvement means to the listener. Sawing wood, planing wood, juggling keys are very difficult sounds to reproduce because a great deal of the sound is in the high frequency range. At these demonstrations such sounds have been so realistically reproduced that you feel as if you were in the room where the sound originates. There are crispness and good definition in the sounds reproduced, whereas in systems that do not have good frequency response the sound is muffled in comparison. When you hear an orchestra reproduced by F.M., you can pick out the various instruments and each is most distinct. Once you hear good reproduction you realize what a great difference it can make. For this reason F.M. is invaluable to music lovers. However, this greater frequency range does not make a great deal of difference as far as soap operas and comedies are concerned. The reason for this is that voice frequencies are well below 10,000 cycles; therefore, nothing is gained by the high frequency range. Of course, sound effects and background music will sound better, so there is a slight advantage even for these types of shows.

While F.M. has definite advantages, it also has some limitations, one of which is that for F.M. the receiver must be closer to the transmitter. This limitation occurs because of the ultra-high frequencies that are used for the F.M. carrier wave. The frequency of the signal determines its characteristics; that is, a 500,000 cycle carrier wave behaves differently from a 80,000,000 cycle wave. Light has a frequency of about 500,000,000 megacycles, and as the carrier wave gets closer to this frequency its behavior becomes quite similar to that of light waves. These waves travel in a straight line and they can be reflected or refracted in somewhat the same way that light is. As these ultra-high frequencies (short waves) travel in a straight line, they do not follow the curvature of the earth the way the lower frequency ground wave does in A.M. broadcasting. For this reason it is necessary to have the receiving antenna within the line of sight of the transmitting antenna. This limits the distance between the transmitter and the receiver because of the curvature of the earth. The higher the transmitting antenna and the receiving antenna are, the greater the range of the transmitter. For this reason F.M. transmitters and antennas are usually located on the top of the tallest building in a city. In some localities where there are mountains near by, they are used for the transmitting point.

The antennas that are used for these short waves look entirely different from the A.M. broadcasting radiators. There are many different types of short wave antennas and they are usually mounted on a pole even when they are on top of a building. One of the simplest types consists of two short rods about ¼ wave length long (at these frequencies this may be 3 or 4 feet long) mounted in a horizontal plane. This type is also used to a great extent as a receiving antenna.

There are other types that are made up in various forms. The elements on some form a square; others form a circular arrangement. When two sets of radiators are used one above the other, it is called a two bay antenna system. Four bays or more are quite common today. When a directional effect is desired, additional elements reflect the signal that would otherwise travel in the wrong direction. This reflected signal also increases the power of the directed wave.

With a 10 kilowatt or 50 kilowatt transmitter and a good antenna system located on top of a 40 or 50 story building, good F.M. reception can be had within a 50 or 60 mile radius of the transmitter. The type of antenna systems just discussed are not only used for F.M. but can be used for any system which operates at ultra-high frequencies.

What is the difference between amplitude modulation (the type of broadcasting transmitter previously discussed) and frequency modulation? The major difference is that the carrier wave in frequency modulation actually varies in frequency while the amplitude remains constant. A 50 kilowatt F.M. transmitter is always pumping out a 50 kilowatt carrier wave, but the carrier wave is constantly varying in frequency. While in A.M. transmission the carrier wave frequency remains constant but the power is constantly varying at the rate of the audio frequency. The F.M. transmitter which operates on a frequency of 67 M.C. (67 million cycles) may be varying this frequency by as much as 75

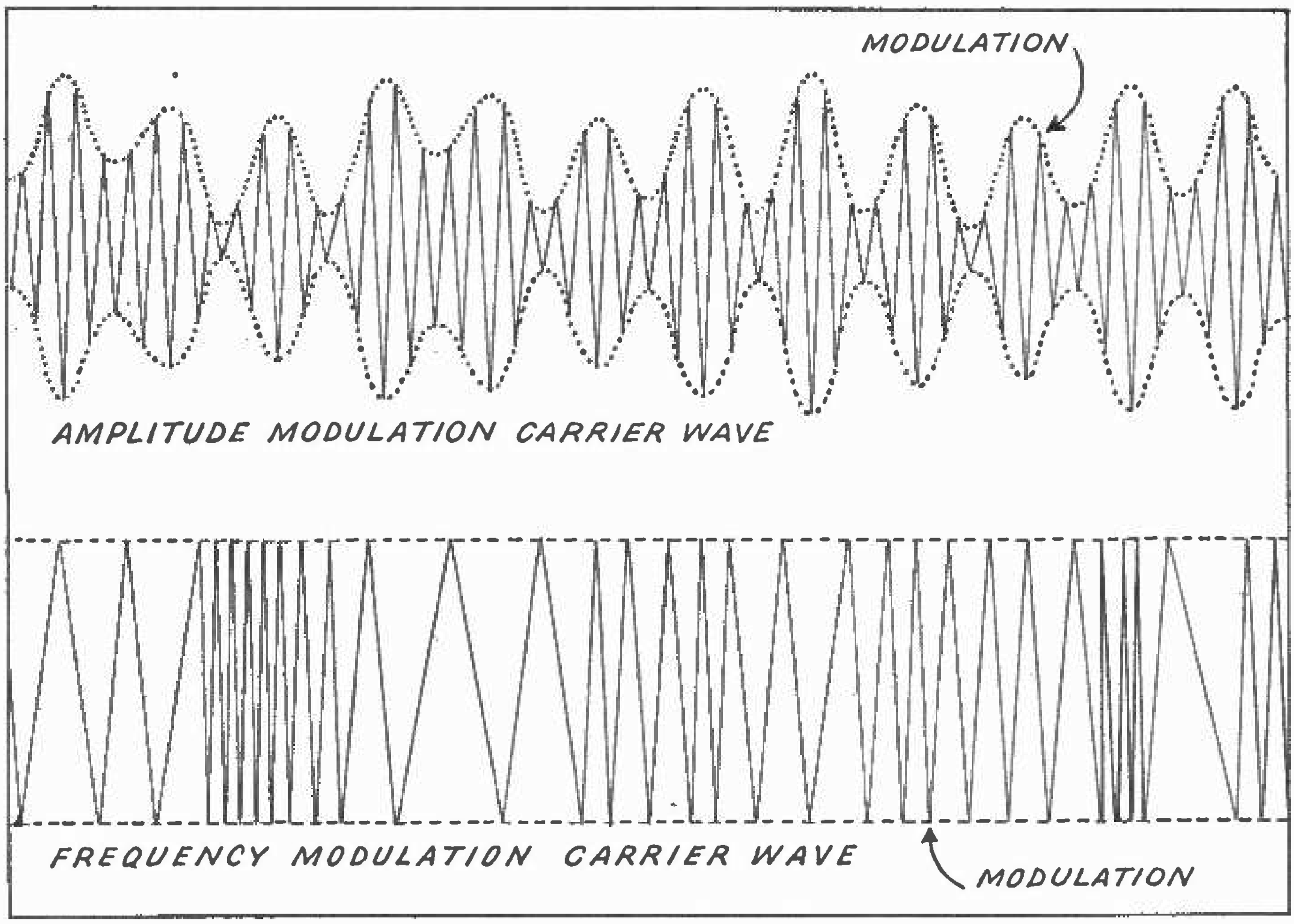


DIAGRAM SHOWING DIFFERENCE BETWEEN AMPLITUDE AND FREQUENCY MODULATED CARRIER WAVE

K.C. (75,000 cycles) plus or minus. That is, this carrier wave increases a certain number of cycles then decreases a certain number of cycles and this occurs at a very rapid rate. The number of cycles by which the carrier wave varies depends on the loudness (amplitude) of the audio signal.

In order to see what the audio signal does to the carrier wave in F.M. we will forget about various amplifiers for the moment and see what occurs to the carrier wave as you talk into the microphone. Let us see what the loudness of your voice does to the carrier wave. We first assume the transmitter is operating on a carrier wave frequency of 67,000,000 cycles (67 M.C.). If the microphone is not picking up any sound waves, then the transmitter is producing a carrier wave of 67 M.C. Now if we whisper into the microphone or whistle very softly into the microphone, the frequency of the carrier wave will start to vary. It will increase and decrease its frequency rather rapidly. As the sound we are producing is of a low intensity, the carrier wave may only increase and decrease by 10,000 cycles—that is, it will change back and forth from 67,010,000 cycles to 66,990,000 cycles at a rapid rate and it will keep swinging back and forth as long as we produce any sound. Now if we speak into the microphone in a normal tone of voice, the frequency may vary as much as 50,000 cycles each side of its normal operating frequency. If you speak in quite a loud voice, it may vary as much as 75,000 cycles plus and minus. So it is plain that the intensity (amplitude) of the original sound wave determines how much the carrier wave varies in frequency.

You probably recall from the discussion on audible sounds that every sound has its own particular frequency, and as we talk or create a sound we are transmitting air-borne sound waves of various frequencies. These sound waves are transformed into an electrical signal (audio signal), of the same frequency by the microphone and then go to the F.M. transmitter in this form. Now the F.M. carrier wave must also carry these various frequencies to your F.M. receiver even though a different method from A.M. is used for transporting them. By picking out sounds of various frequencies we will be able to see quite clearly how the carrier wave is affected. To keep it in round numbers, we will select an audible frequency of 5,000 cycles and assume it is of such an intensity that it causes the carrier wave to fluctuate 40,000 cycles each side of its normal operating frequency. So this carrier wave is now changing back and forth from 67,040,000 cycles to 66,960,000 cycles at certain rates of speed. The speed of these changes is determined by the audio frequency. The audio frequency is 5,000 cycles per second, so it causes the carrier wave to vary its frequency at the rate of 5,000 per second. If the original sound was 256 cycles then the carrier wave would vary at the rate of 256 times a second and so forth.

As we have previously stated, one of the benefits gained by using frequency modulation to transport audio frequencies is that it eliminates static on the receiving end.

The reason static causes distortion is because it varies the intensity of the various carrier waves picked up by your receiving antenna. As A.M. transmitters rely on varying the power of the carrier wave to transport the various audio frequencies, anything that interferes with the amplitude of the signal will cause distortion. So if static affects the amplitude of the incoming signal, which it does, it will distort any carrier wave which relies on amplitude variation to carry its message. While static will vary the amplitude of incoming signals, it has little or no effect on the frequency of the carrier wave. F.M. actually uses the variation in frequency of the carrier wave to carry its message. It does not depend on the variations in amplitude to carry the audio signal. So static has little or no effect on it.

It is also possible to transmit audio frequencies up to 15,000 cycles using this type of carrier wave and still stay within the limits allowed by the Federal Communications Commission. This gives you an audio frequency range approximately 5,000 cycles greater than that which A.M. transmitters can handle. The same type of audio signals is used between the microphone and transmitter. This means the same audio signal can be sent over the telephone lines to both F.M. and A.M. transmitters. For F.M. transmitters, however, the audio signals have a greater frequency range. The various audio amplifiers used must be capable of reproducing audio frequencies up to 15,000 cycles. The amplifiers that are generally used for A.M. broadcasting are only good up to 10,000 cycles, so when the same program is sent to F.M. transmitters as well as A.M. transmitters the amplifiers have to be re-designed or replaced by amplifiers capable of this higher frequency range. This is also true of studio microphones. If this is done, the same program can be sent out to both types of transmitters.

You might wonder why F.M. has not already replaced A.M. broadcasting. The reason is that people living 100 miles or more from the transmitter would not be able to get satisfactory reception from F.M. but they can get good A.M. reception. While F.M. transmitters could be installed all over the country, unless the population is fairly thick where they are installed the revenue received from advertisers would not be sufficient to pay for their operation. Of course this does not mean that F.M. may not replace A.M. in years to come, but that is probably a long way off. F.M. transmitters have been installed in a good many large cities today and they will also be installed in some of the smaller cities in the near future, but this still leaves considerable ground to be covered by A.M. broadcasting. Moreover, in mountainous regions the A.M. carrier wave is not affected as much as an F.M. carrier would be. F.M., traveling in a straight line similar to light, will not climb over mountains or hills the way an A.M. ground wave will. While A.M. is affected to a certain extent by the terrain, it is not affected as much as F.M. Therefore, A.M. has certain advantages as far as transmission is concerned.

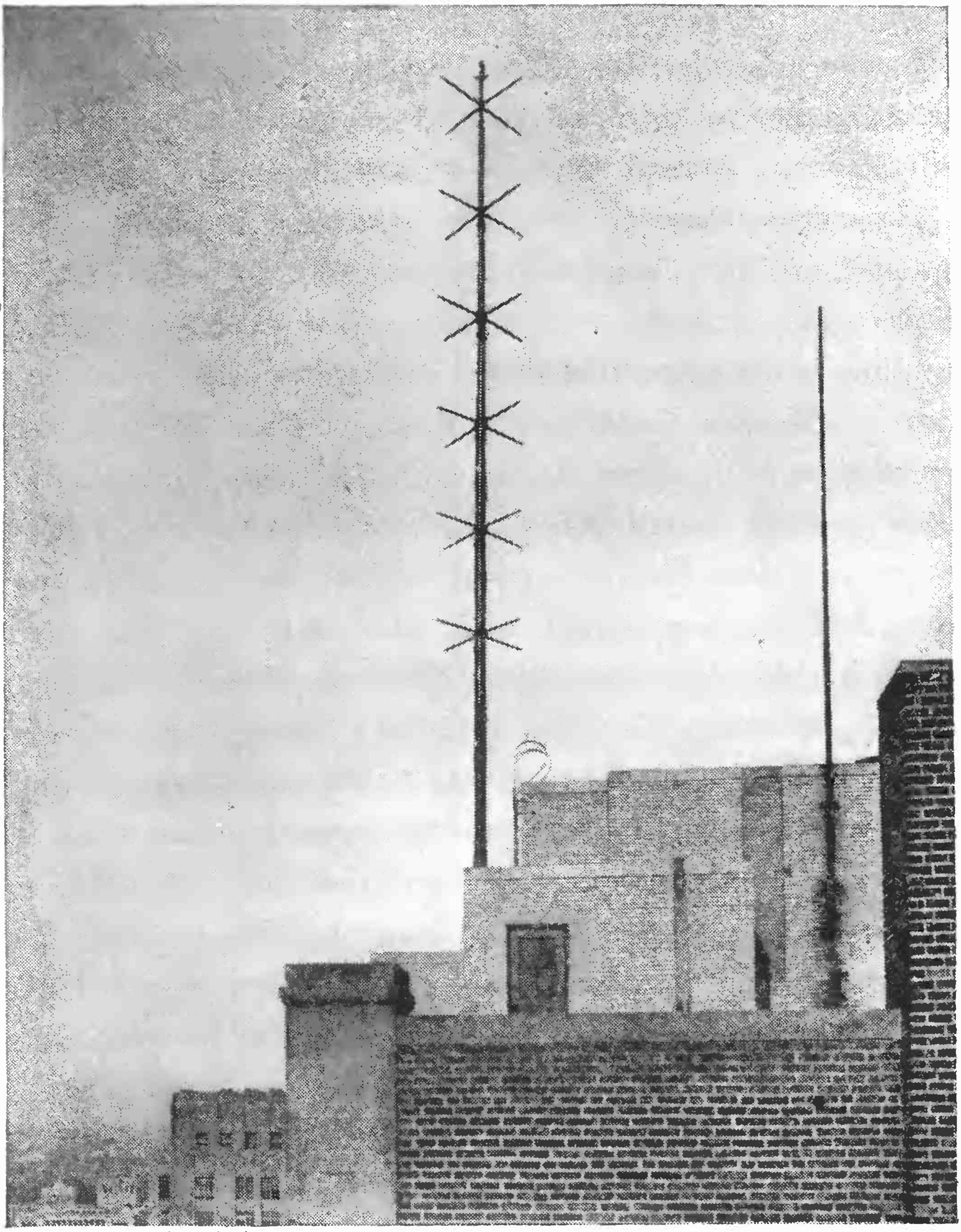
F.M. is also used today in conjunction with television. In television two carrier waves are used—one for the picture and one for the sound. The sound carrier wave is F.M. and it functions in the same way as any F.M. transmitter. The picture carrier wave we will discuss when we cover television.

F.M. is also used for link transmitters. A link transmitter is a transmitter that is used for carrying messages between different points. If, for example, you wanted to send a program to a transmitter out of town and you did not want to use the telephone lines, you could use a low-powered F.M. transmitter with a special directional antenna. This type of directional antenna system works in a similar fashion to a flashlight. If you take a flashlight bulb and connect it to a battery without a reflector, the light will travel in all directions and it will be very weak in intensity at any point a few feet away. But if you take this same bulb and put a reflector behind it, so the light is collected and directed, it will produce a powerful beam in a given direction.

The antenna system used for link transmitters is usually equipped with a reflector which operates on the same principle as the flashlight reflector. The energy that would normally be traveling in the wrong direction is reflected to produce a concentrated radio beam in the desired direction. There are many different types of reflectors. In some cases two copper screens are set at an angle behind radiator rods to reflect the energy in the proper direction. Another type of reflector consists of a curved wire which has short copper wires attached to it at right angles so that it looks like a herringbone. This is set behind the radiators to reflect the energy. This type is called a herringbone reflector.

By using this type of an antenna system a low-powered transmitter can be used and it will produce a strong carrier wave in a single direction. This type of short wave directional antenna system can also be used for short wave A.M. transmitters. F.M. is used for a link transmitter because it eliminates static and other electrical interference and, as the program is to be rebroadcast, this is desirable.

One of these link transmitters has been used successfully between New York City and Long Island in conjunction with an international transmitter and this is how the system operates: The program is sent over wires from the studio in the usual fashion to the F.M. link transmitter located on top of one of the tall build-



Courtesy of R.C.A.

F. M. 6, BAY TURNSTILE ANTENNA SYSTEM

ings in New York City. This transmitter is only about three feet square and six feet tall and its output is only 25 watts. The output of this transmitter is connected to a directional antenna system which is aimed at the international transmitter located approximately 37 air miles away.

This international station has an F.M. receiver which is tuned to the frequency of the link transmitter, the signal being picked up by a short wave receiving antenna. This station picks up the carrier wave of the link transmitter and converts it into an audio signal with the F.M. receiver. They can then hear the program with their monitor speaker and at the same time use this signal to feed their 50,000 watt international transmitter which re-broadcasts the program to Europe or Asia.

While this link transmitter has been used successfully, it is really only used as a standby unit in case of failure of telephone lines. Telephone lines generally are used because they are more reliable and free from interference.

As far as the F.M. receiver is concerned, there are two major differences from an A.M. receiver. One is the "limiter" and the other is the "discriminator." The limiter circuit in an F.M. receiver removes any amplitude variation that might be present. While the F.M. carrier wave is free from variations in amplitude when the signal leaves the transmitter, static, amplifier circuits in the receiver, and various other things can cause the carrier wave to vary in amplitude. These variations in amplitude must be eliminated before the frequency variations are changed back to an audio signal in order to prevent distortion. This limiter circuit removes the variations in amplitude so the signal is constant and varies only in frequency.

The discriminator is the part of the receiver circuit which converts the variation in frequency back to the audio signal, which in turn is converted back to a sound wave by the loud-speaker. The tuning and the audio amplifier in the receiver are similar to those used in standard broadcast receivers.

XII International Transmitters

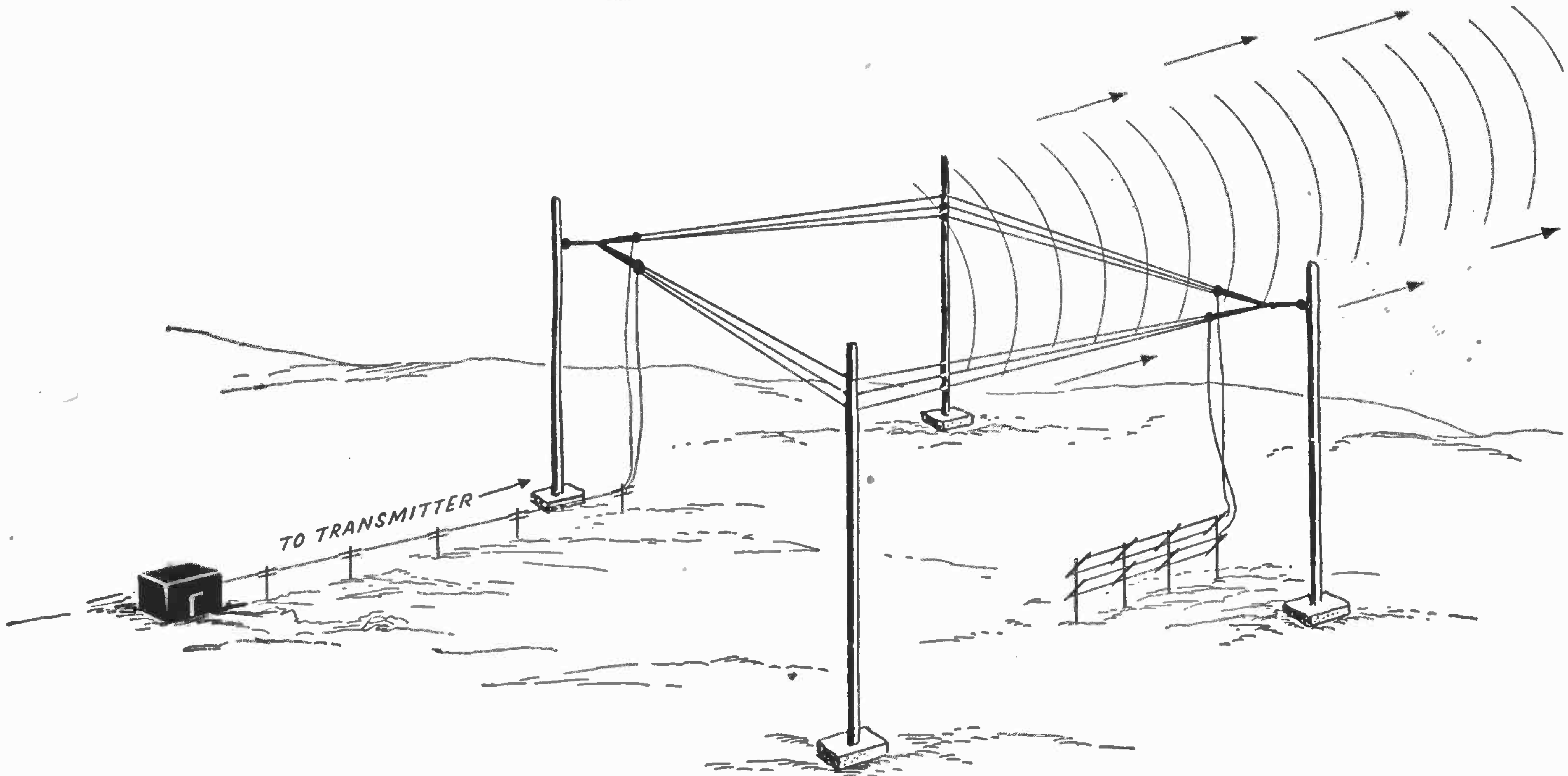
RADIO transmitters have been used between continents to carry messages for some time, but it was not until the Second World War that international broadcasting became such an important factor. The development of international broadcasting is playing an increasingly important part in our lives. Only a short time ago radio programs were completely local. All we heard were programs originating in our own town until network broadcasting was developed. Now, of course, we receive programs from all parts of our own country and from all over the world.

Faster boats and planes have brought us closer to the various foreign countries. It is important that we know more about peoples' lives in these countries and that they know more about us. International broadcasting brings the important events in other countries to our homes. We receive the music and various other forms of entertainment from them and they receive the same from us. The United States has a great number of international transmitters operating at the present time. They are sending different types of programs to every part of the world.

The international transmitters are quite similar to commercial broadcast transmitters except that they are designed to operate at higher carrier frequencies; in other words, most of them are short wave transmitters. However, short wave antenna systems are quite different from the commercial type. This is because of the frequency at which they operate and the problems involved in long range broadcasting.

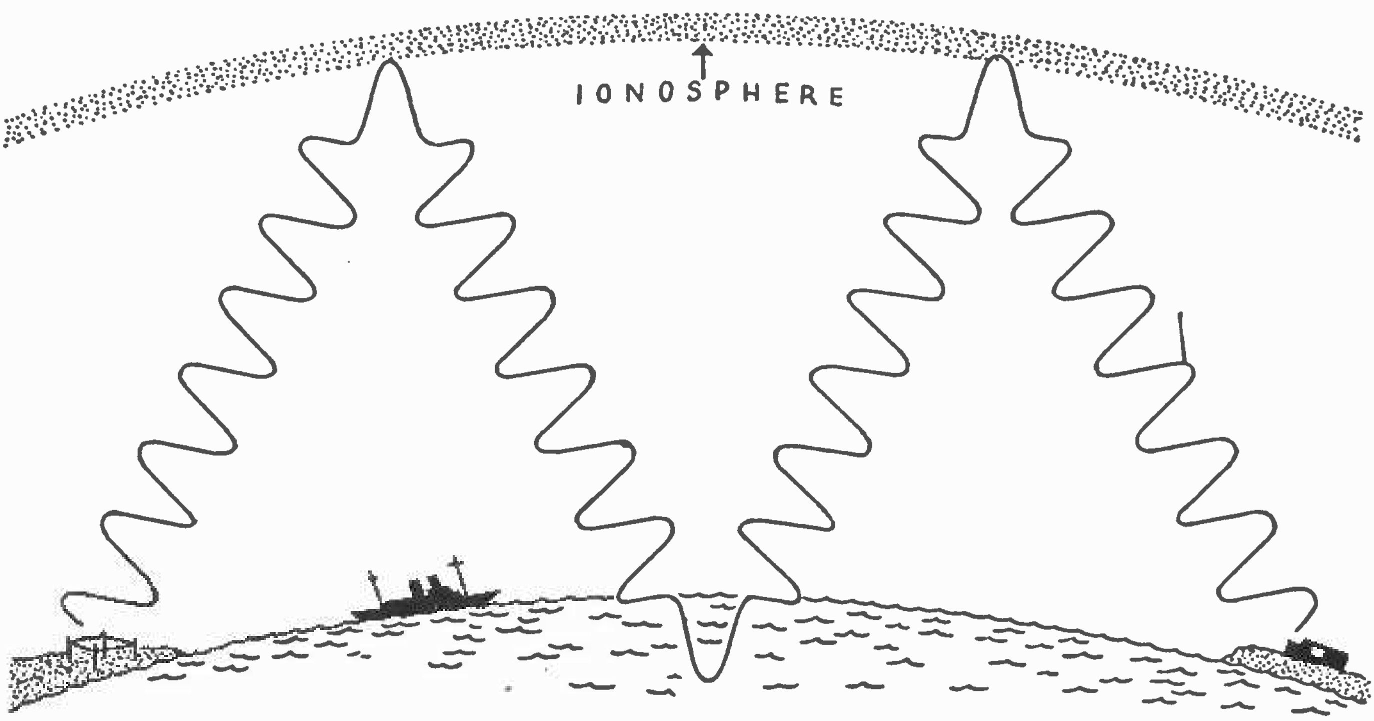
One of the major difficulties is that a tremendous amount of power would be required to send a ground wave as far as Europe. The ground wave that commercial broadcasting uses for transmission follows the curvature of the earth. As this wave travels along the surface of the earth, the part that is in contact with the earth's surface is rapidly absorbed by the ground. This dissipates the carrier wave rapidly and an immense amount of power is needed to transmit the wave any great distance.

A sky wave travels away from the earth and can travel much greater distances before it becomes too weak to be of any value. The only difficulty with the sky wave is that it does not follow the earth's curve but travels in a straight line toward the sky. Under certain conditions, the wave is bent back toward the earth by the ionosphere after it has traveled upward approximately one or two hundred miles. This refraction of the sky wave by the ionosphere makes its use possible for long range transmission between various countries. The causes of this phenomenon and the way in which the sky wave is utilized for long range broad-



HOW INTERNATIONAL BROADCASTING RHOMBIC ANTENNA RADIATES CARRIER WAVE casting are extremely interesting.

The ionosphere is an ionized region in the outer portion of the earth's atmosphere. It consists of a rarefied gas containing free electrons and ions or electrified particles. The sun's rays act on the particles in the upper air to cause ionization. So naturally the



HOW IONOSPHERE IS USED FOR INTERNATIONAL BROAD-CASTING

conditions in the ionosphere change considerably during the day, when the sun's rays act upon it, from the conditions at night when the sun's rays are not present. Sun spots also affect the ionosphere, and its behavior is quite different during the time when the spots are active.

The ionosphere really consists of three layers of ionization. These layers vary in height, depending on the time of the day and the season of the year. The lowest one is called the E layer and is approximately seventy miles from the earth. Above this is the F-1 layer about one hundred and forty miles up, and above that during the daytime is the F-2 layer, which is approximately two hundred miles from the earth.

At night the F-1 layer fades, and the F-2 layer moves down to the locality of the F-1 layer, so these two layers become one at night. The E layer stays in approximately the same location.

These layers refract radio waves of certain frequencies. Lower frequency waves are turned back toward the earth by the E layer. Waves of higher frequency pass through the E layer and are turned back toward the earth by the F layers. If the frequency is high enough, the carrier wave will pass through the entire region and will not be returned to the earth by these ionized layers. A frequency as high as this may be lost in space, though some scientists believe that there are other regions which might cause it to return. But when the proper frequencies are used, the ionized layers act similarly to a mirror, except that they refract the waves instead of reflecting them.

Light rays normally travel in a straight line. When their course is altered by fog, water, or some other substance, the rays are said to be refracted. This also applies to radio waves. They are only reflected when they rebound from an object as light rays do from a mirror.

If the radio sky wave strikes the ionosphere at an angle it will be bent back toward the earth at an angle. This means that the wave may return at some distance from the transmitter, depending on the angle of radiation of the antenna system.

You have often seen a stone skip across water when it is thrown in just the right way. Sometimes it skips several times. The same sort of thing happens to a carrier wave. The ground also acts as a refractor, and when the wave has been refracted downward by the ionosphere, it is bent back towards the ionosphere again by the earth. The ionized layer returns it to the earth again in the same manner as before. In this way a carrier wave skips across the country or ocean the way a properly cast stone skips across the water. This may occur a number of times until the signal becomes too weak to be of any value. So these waves bounce back and forth between the earth and the ionized layers of the upper air as they travel around the earth.

The angle of radiation determines how many times the wave may skip before it reaches its destination. Under normal conditions and a low angle of radiation, these waves may skip one, two, or three times between New York and England. Of course, the signals may be received at any point along the line where they return to the earth.

Engineers have perfected long range radio communication to a high degree. They know just what frequencies they must operate on during the day or night to accomplish certain results. They know just what kind of an antenna system will radiate the sky wave at the proper angle, so that it will return to the earth in the right locality. They know just what beam width the antenna system will have, so they can tell just what areas will be reached by the return wave.

For continent to continent transmission various frequencies are used, depending upon the time of day and the season of the year. By changing the carrier wave frequency, the vertical angle the antenna system radiates at can be changed. So it is possible to change the angle of radiation to compensate for the movement of the ionosphere.

The antenna systems used for international broadcasting do not look anything like a commercial broadcasting radiator. However, there is one thing common to all transmitter antennas—the length of the antenna system must be some multiple of a wave length, such as the ½ or ¼ wave length broadcast antennas. This limits the frequencies that can be used on a given antenna system to a narrow band of frequencies. In order to shift the frequency beyond this narrow band, it is necessary to have more than one antenna system. By using more than one antenna system the frequency can be changed to compensate for the movement of the ionosphere. As the frequency is changed, the vertical angle of radiation is changed, thus compensating for the ionosphere movement.

As a small scale example, you can imagine a large room with a mirrored ceiling. If you stood at one end of this room and aimed a flashlight beam at the ceiling in the center of the room, the mirrored ceiling would bend this beam back toward the floor. We will assume for the moment that this room is so proportioned that the beam reaches the floor at the far end of the room. Now if the mirrored ceiling were moved down a few feet and you kept the flashlight at the same angle, the beam would fall short of its former mark. But if you changed the angle of the flashlight, you could again place the beam at the end of the room.

So the antenna systems must change their vertical angle of radiation as the ionosphere moves, and this is done by changing frequencies. For instance, suppose a transmitter is operating in the morning and feeding an antenna system beamed at Europe. At the frequency they are using, the antenna vertical angle of radiation is fifteen degrees. The program is being received in France and other near-by localities. We will say the ionosphere is approximately two hundred miles from the earth at this time. As night falls, the F-2 layer which we are using moves down so it is only one hundred and forty miles from the earth. The carrier wave will now fall short of its mark. So the transmitter changes frequencies to lower its vertical angle of radiation, and this may also require changing to another antenna. This compensates for the movement in the ionosphere, and again the station will be covering France and other near-by localities.

These antennas are usually of the directional type; some operate in two directions, some in a single direction. There are types that are reversible so that they operate in one direction and by throwing a switch will operate in the other direction. This makes it possible to cover two different areas in different parts of the world with the same antenna system.

There are two widely used types of antenna arrays—the broadside array and the end-fire array. As in the case of your receiving antenna, a single wire is called an antenna. When more than one wire is used as a radiator, it is called an array. In antenna systems of this type, a number of wires are used as radiators and coupled together to produce certain directional effects. The antenna system operates on the same principle as the directional vertical radiators used in standard commercial broadcasting. That is, the wires are spaced so that the waves cancel each other in certain directions and add in other directions. The array is called a broadside when the greatest amount of energy is dissipated at right angles to the line of the array. The end-fire array is just the opposite, with the maximum radiation along the line of the array.

There are a number of different arrangements for antenna systems. The fishbone antenna array can be either a broadside or an end-fire array. This type of antenna system will operate over quite a broad band of frequencies. From an aerial view, it looks like the spine of a fish, the array being arranged in a horizontal plane.

The curtain array is another type which is used to a greater extent for this international broadcasting. The wires are arranged in a vertical plane spaced one-half wave length apart, to form a curtain. This typé of array is used as a broadside array, and when a single curtain is used it fires in both directions. When two curtains are used—one behind the other, spaced one-quarter wave length apart—they form a broadside array operating in a single direction, known as a uni-directional antenna system.

The V antenna system is neither broadside nor end-fire, but is also a popular type. The maximum radiation with this antenna system is toward the open end of the V. A considerable amount of energy is also radiated in the opposite direction and for this reason reflectors are often used back of the antenna. The reflector consists of another V antenna, spaced an odd number of quarter-lengths behind the main antenna, with the phasing arranged so the waves cancel in one direction and add in the desired direction. This type of antenna is mounted in a horizontal plane. The operating frequency determines the length of the wires and the height of the antenna above ground. These antennas are usually strung on telegraph poles. The energy is fed into the narrow part of the V; the widest part of the V is pointed in the direction toward which you wish the energy to be dissipated.

The rhombic antenna is another type. It operates similarly to the V antenna. The wires are strung to form a diamond or rhombus. This type of antenna system is directional in two planes—horizontal and vertical. The angle of radiation toward the ionosphere is not determined by tilting the antenna system but by the number of wave lengths used for each side and the angle at the side of the diamond. In a horizontal plane this antenna system is directional along the longest dimension of the diamond. The energy is fed into one end of the diamond and the antenna radiates toward the far end. As with the V antenna, the far end must be connected to some sort of a device for dissipating the energy which has not been radiated. Otherwise the antenna system will not function properly. This antenna does not require a reflector to increase its directional effect. It can be arranged so that it will radiate in the opposite direction by feeding the energy to the opposite end of the antenna. This is accomplished by switching the transmission line feeding the antenna from one end to the other. In this way a rhombic antenna that is beamed at Europe can be reversed to cover Mexico. When it is daytime in Europe it is nightime in Mexico, so this works out well from a program schedule point of view. You can broadcast to Europe from ten in the morning to ten at night, European time, then switch to Mexico where it is morning. So this antenna can be used for a dual purpose.

There are many problems involved in international broadcasting. In the first place, in order to cover the various countries you must broadcast in several languages. To see just what is required, we will follow an imaginary setup from studio to transmitter and to keep it as simple as possible we shall imagine we are broadcasting in just two languages. If we are going to broadcast to France and Italy, we must have announcers and actors who can speak French and Italian. If both broadcasts are to go out at the same time, we must have two studios and two announcers and two groups of actors. Scripts must be written and checked in both languages. There will also be two groups of operating personnel. Each studio is connected by a separate line to the master control room. Master control must make separate setups for both programs. These naturally require two outgoing lines to the transmitting station. At the transmitter station two complete transmitters will be used and two or more antenna systems, each one operating on a different frequency.

This is a very brief outline of what is involved in international broadcasting. To get a better picture of it, we will select one of the many international transmitters and discuss the equipment involved. This station is operated by Columbia Broadcasting System for the United States Government and is located at Brentwood, Long Island, N. Y. The antennas are spread over a large area. Some of the transmission lines connecting the transmitters to the antenna systems are over a half mile long. This station has three 50,000 watt transmitters which can be operated simultaneously. A transmitter switching arrangement makes it possible to switch any program to any transmitter. There is also an antenna switching arrangement so the engineers can switch any one of the three transmitters to any one of fourteen antennas.

As we have mentioned, a transmitter used for international broadcasting operates on different frequencies at different times, depending on what country the broadcast is being sent to and the conditions of the ionosphere at the time. The transmitter must be tuned for the particular frequency it is going to operate on. This is done by large adjustable coils and condensers. Even when these are power-operated, it takes a certain amount of time to change frequencies. This tuning takes place in the radio frequency end of the transmitter. By having complete flexibility in switching, rapid change-overs can be made. You can connect the radio frequency section of the transmitter to the antenna system you are going to use next, and tune it to the frequency you are going to operate on. You can then switch any program to this radio frequency unit, thus saving the time of tuning and switching antennas.

The antenna switching is quite complicated. You must be able to switch any one of fourteen antennas to any one of the three transmitters in order to have complete flexibility. This station has a switching system to make this possible, and it also has an inter-

Courtesy of C.B.S.

C.B.S. INTERNATIONAL TRANSMITTING STATION AT BRENTWOOD, L. I.

locking system so that two transmitters cannot be connected by mistake to the same antenna. Each set of switches is mounted behind a panel board; they are operated by a large hand wheel on the front of the panel. There are also indicating lights on these panels so the engineer can tell exactly what switching setup is in use.

The room where the transmitters are installed is very large and rectangular in shape. The various transmitter units are installed on each side of the room, leaving a long corridor down the middle. Each unit is completely enclosed with meters, indicating lights, and controls on the front panels. On one side of the room the audio equipment is mounted in racks. This consists of audio amplifiers and measuring equipment which is used to check frequency, modulation, and volume. This is where the telephone lines come in that carry the studio program. From here the program goes to the modulation units which are really nothing but powerful amplifiers for amplifying the audio signal. There are three of these units on the opposite side of the room. Alongside the modulators are three exciter units which generate the frequency for the carrier wave. These contain several crystals for producing the various frequencies needed for this type of broadcasting. They feed the carrier wave frequency to the radio frequency amplifiers or R.F. units, of which there are three. They are located across the room from the exciters. Each one is capable of producing 50,000 watt carrier waves. Just as in the broadcast transmitter already explained, the output of these R.F. units is controlled by the audio signal coming from the modulation unit. Amplitude modulation is used for this type of broadcasting.

So there are three complete transmitters, each transmitter consisting of three units—the modulator, the exciter, and the R.F. unit.

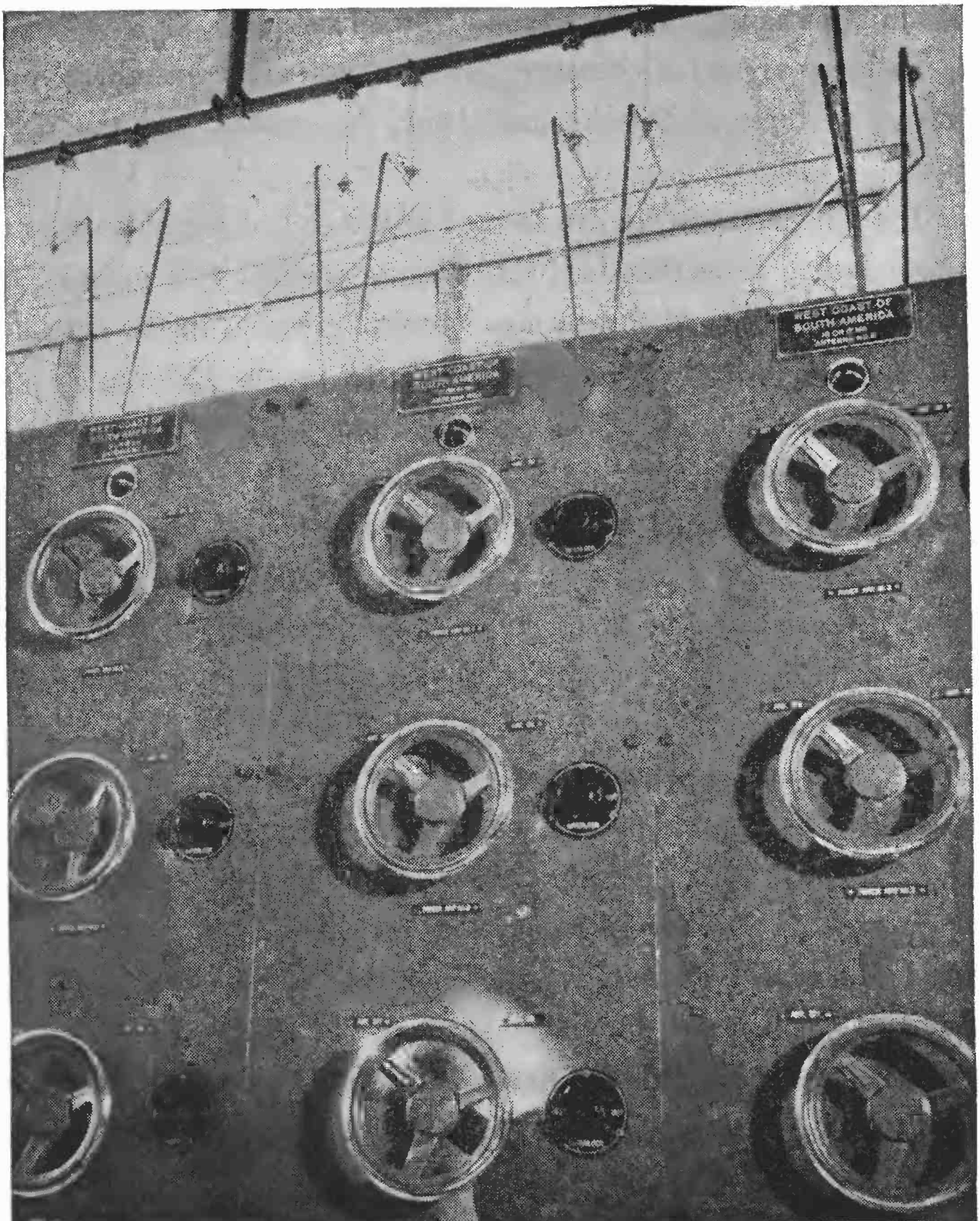
The antenna switches are located at the end of the room where the outgoing lines that feed the various antenna systems are located. The output of the various transmitters goes to the antenna switches at the end of the room. Here, by means of large rotary switches, any one of the three transmitters can be connected to any one of the fourteen antenna systems.

The reason for the large number of antennas is that each one operates only on a narrow band of frequencies. So in order to have a large band of frequencies available, more than one antenna is necessary for any given direction. Three antennas are beamed to Europe, for example, to provide various frequencies. Three are beamed to the east coast of South America, three to the west coast of South America, and three to Central America.

As we have stated before, the reason for changing frequencies is because of the movement of the ionosphere layers. By changing frequencies the antenna vertical angle of radiation is changed, and this compensates for the ionosphere movement.

These stations usually operate twenty-four hours a day because of the difference in time between various countries served. At least two engineers are on duty at all times, not counting the supervisor. This requires at least three shifts for the twenty-four hour period.

These engineers operate from a program schedule which tells



Courtesy of C.B.S.

ANTENNA SWITCHES USED FOR INTERNATIONAL BROADCASTING AT C.B.S. BRENTWOOD STATION them the time of the program, the country or countries to which the broadcast is to be made, and the carrier frequency that is to be used. They usually operate only two transmitters at a time. The third one is used as a standby unit. This permits them to maintain the equipment and make any necessary repairs or replacement of tubes without interrupting the programs. While transmitters #1 and #2 are on the air, #3 is checked. If any parts have to be replaced or any adjustments have to be made, the work can be done at this time.

An example will show the method by which programs are changed from one transmitter to another. The program on transmitter #1, which is now being broadcast to Europe, is to go to the east coast of South America. The #3 transmitter is connected by the antenna switching system to an antenna beamed in this direction. The transmitter is tuned to the proper frequency. The switch can then be made quite rapidly. This leaves the #1 transmitter off the air and it can now be overhauled and repaired, or tubes can be changed. As we mentioned previously, the individual units can also be switched, which adds to the flexibility of the transmitter.

On the Pacific Coast engineers are now constructing 200,000 watt (200 kilowatt) international transmitters to be used principally for Asia and Australia. Because of the greater distance to be covered more power is required. A great number of programs can even now be broadcast simultaneously from the United States to countries all over the world. These new powerful international transmitters will extend still more the areas to which programs can be sent.

These programs may be received directly by the people in the various countries on their short wave receivers. The programs can also be picked up by local stations in these countries and re-broadcast. This is the way in which most of our programs coming from other countries are received.

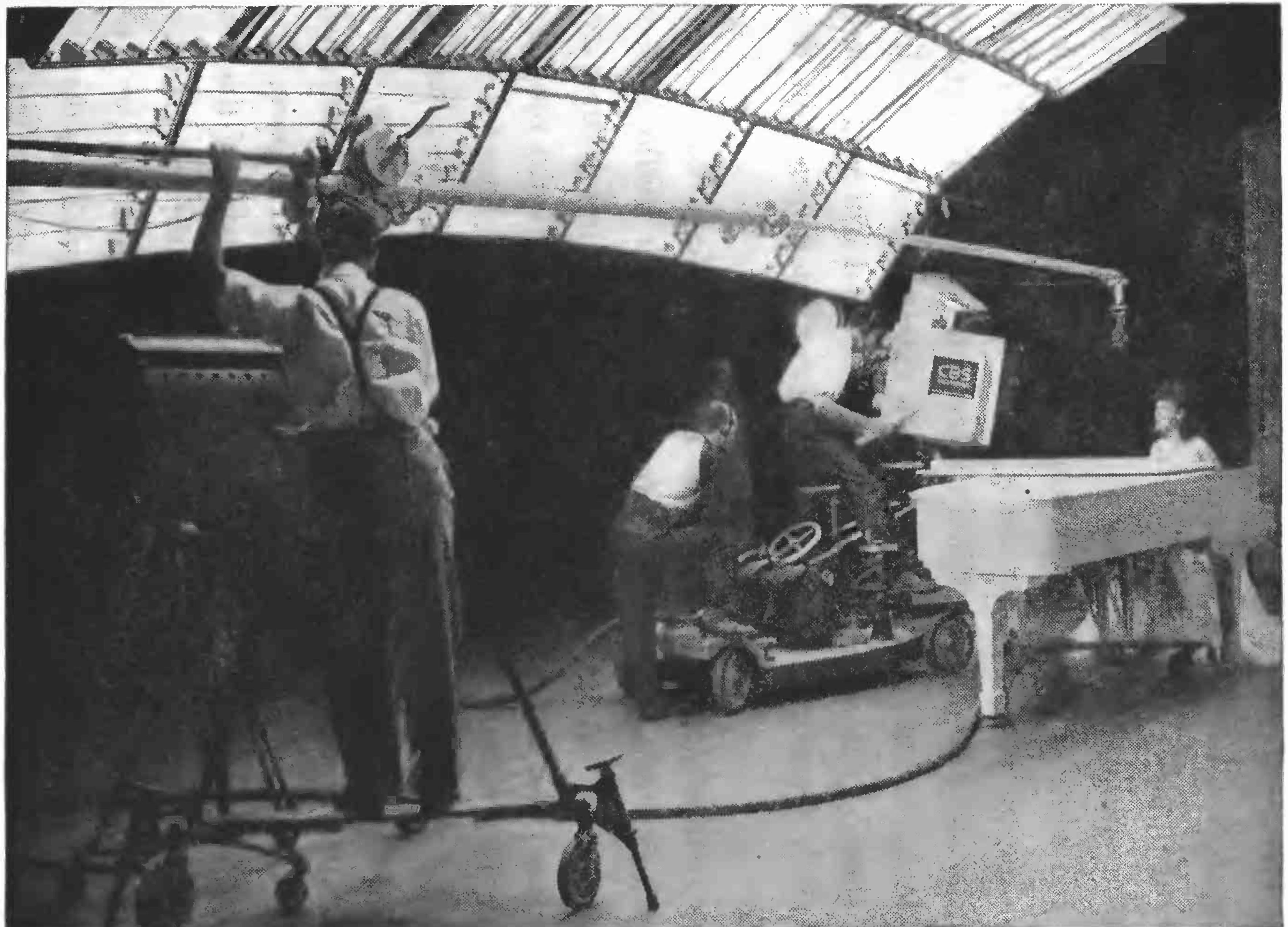
XIII Television Studio

Television, along with other electronic developments, has made great strides in the last ten years and is still moving ahead at a rapid pace. To the bystander its progress may seem slow. He does not see the many problems that are encountered and how difficult they are to overcome. The mechanical method of producing a picture used in a camera is quite different from the electrical method used in television, and years of research have already been spent on the development of this new science. Now scientists have perfected television receivers that can project the picture on a wall and a method for producing the pictures in color. The pictures produced today are sharper and contain more detail than they did a short time ago. In fact, one of the things that held television back was its rapid development. This may sound strange, but it is true. The manufacturers were afraid to put a receiver on the market, fearing that it would be obsolete before a year was out. The Federal Communications Commission didn't want to standardize too soon, as that would have retarded the development of television. So one of the reasons television was not marketed some time ago was its rapid development. Naturally, as more and more sets are sold the cost of producing them will decline, and more people will be able to purchase them. At the same time the entertainment value of the programs will be on the increase, and transmitters will be popping up all over the country.

The fundamental operating principles of a television tube are not difficult to understand, or the method of transmitting the picture, but the circuits and their function are rather difficult. For this reason we shall only discuss the basic operating principles of the cameras for black and white pictures and color; also the operating principles of the receiver tube for both.

Probably one of the most fascinating and colorful spots to visit in present day broadcasting is the television studio. It is a place where so many things are going on that it is difficult to tell just what is taking place. This is particularly true in large studios where it is possible to set up two or three sets at the same time. Television broadcasting requires considerably more equipment and personnel in the studio than the standard sound studio. The reason for this is obvious, as you have to consider the transmission of the picture as well as the sound.

The size of television studios varies, depending on the types of shows and the number of "live talent" shows being broadcast daily. Live talent shows are dramas, musicals, or any other type of performance where the television camera picks up the action directly from the stage and transmits it to your home. Shows where



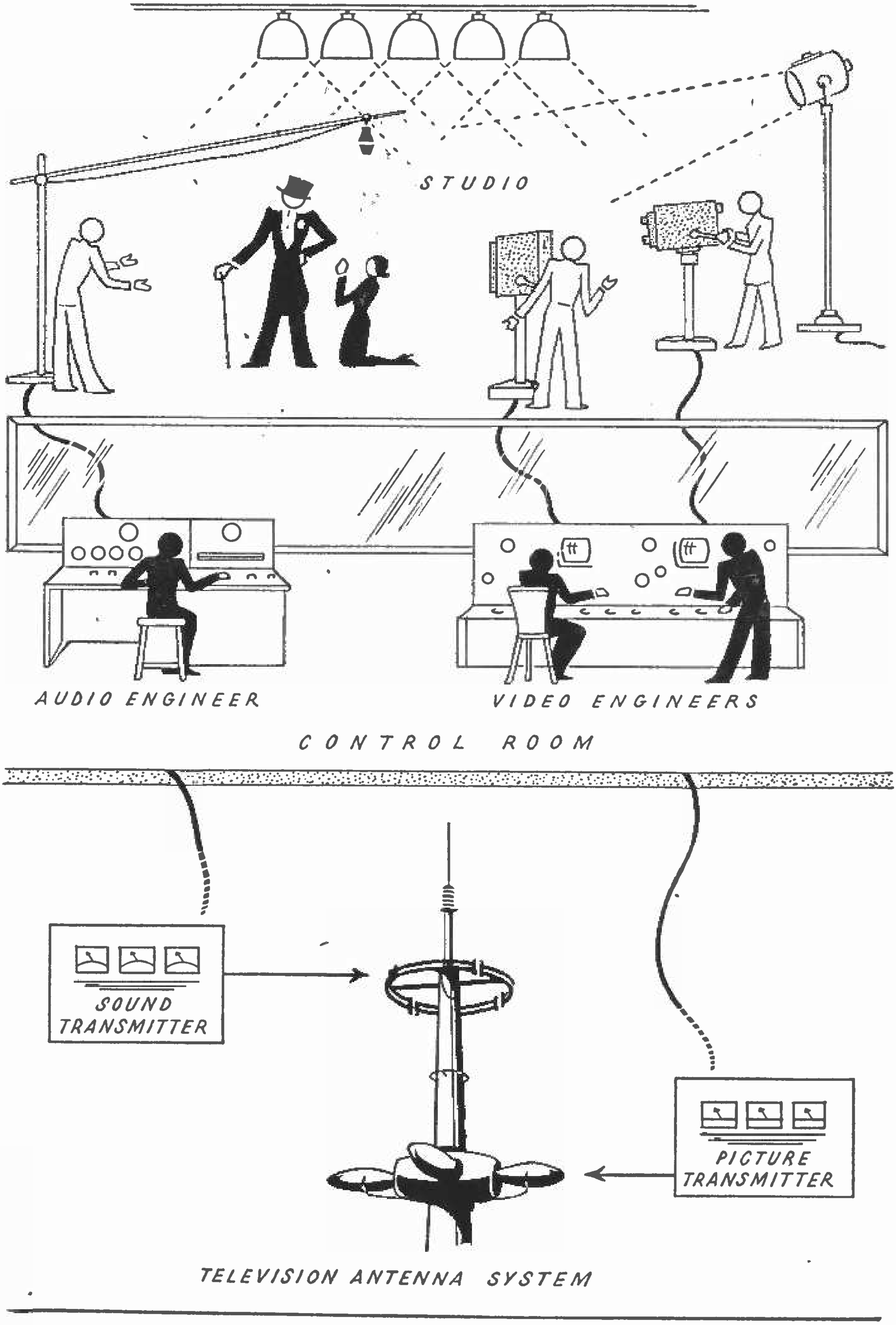
Courtesy of C.B.S.

TELEVISION STAGE

live talent is not used are produced from motion picture film or slides. The smaller television studios that are used for plays do not require the equipment or personnel needed in a large studio that is equipped to put on almost any type of show. The largest television studio in the country is equipped to broadcast either black and white or colored television pictures. At the present time the colored pictures are only being broadcast experimentally and cannot be received on the ordinary television receiver. This studio can televise several different types of entertainment from live talent shows. It is even possible to have several different scenes and switch from one to the other without interruption in this studio.

This studio itself is 56 feet wide by 83 feet long, but it is so designed that one wall can be removed, making a studio 56 feet by 220 feet; the space can also be divided into three studios approximately the size of the original one. At the present time the lighting is arranged for one large acting area and two smaller ones. The large area can be used for dance revues, boxing matches, or other types of entertainment requiring a large stage. The smaller areas can be used for plays, news events, comedies, or other kinds of shows that do not require as much space.

In television studios large areas are needed outside of the acting area for cameras, lights, and telescoping microphone booms. The microphone stand or boom is quite different from the type used in sound broadcasting studios. The reason for this is that the microphone must be kept out of the picture, and at the same time must be mobile in order to follow the actors as they move around



ARRANGEMENT OF TELEVISION EQUIPMENT

the stage. These telescoping microphone booms are designed to hold microphones over and in front of the actors' heads; at the same time they can be mechanically controlled to move the microphone up, down, sideways, back, or forward. The bases of the microphone stands are equipped with large rubber casters so they can be moved easily around the stage. The base is usually four or five feet high; it contains a vertical telescoping member which can be raised or lowered by means of a crank. At the top of this is a long horizontal arm which also telescopes.

The horizontal arm is controlled by pulleys and a floating counterweight which compensates for the microphone and the boom, when it is extended. The arm, which can reach out across the stage, is also controlled by a crank back at the base. The entire unit also pivots so the microphone boom can be swung from side to side. A lever rotates the microphone on the end of the boom. The man who operates the boom-stand is a sound engineer who has been trained for this particular work. He is known as the boom man. Standing at the base of the microphone he can move it to all parts of the stage by operating the cranks and levers at the base of the stand.

It is always necessary to have the microphone within a few feet of the actors because the microphone sensitivity at all audible frequencies depends upon the volume and the distance of the sound source. Furthermore, if the microphone is too far from the sound source, it requires more amplification; this tends also to amplify any foreign sounds caused by cameras being moved, the shifting of lights, or by the operating personnel as they move around the scene.

For this work a uni-directional microphone is usually used. In most cases it is tipped down at an angle of about 45 degrees when it is used over and in front of the actors' heads.

The microphone booms are operated from in front of the stage. This entire area in the form of a semi-circle in front of the stage is also used by the operating personnel who are responsible for the cameras, spotlights, general illumination, sound, and all other activities on the stage. They receive their instructions from the floor manager who in turn receives his instructions from the director. The director works from the control room which is at one end of the studio and so situated that it overlooks all three stages. The control room floor is about four feet above the stage floor. This permits the control room personnel to look down through the control room window at all stage operations. The director communicates with his floor manager over a microphone. The floor manager is equipped with headphones, so the instructions he receives from the director are not audible in the studio.

The control room is about 40 feet long. Both picture and sound are monitored here. The sound monitoring is handled in practically the same way as in sound broadcasting studios. The picture monitoring is much more difficult, as each camera is monitored separately. This requires two, three, or more men at the controls, depending on how many cameras are used in the production. For each camera there is a monitor picture tube in the control room. This picture tube is the same type of tube as those used in receiving sets. These tubes are set up just below the control room win-

Courtesy of C.B.S.

TELEVISION STUDIO CONTROL ROOM

dow, with the various picture controls on flat panels in front of the tubes. This enables the control men to see what each camera is picking up and to make any adjustments that may be necessary, such as brightness, shading, etc. These adjustments are made by the various electrical controls on the desk. The control room engineers also take care of camera switching. They operate under the supervision of the chief engineer, who is in charge of all technical operations occurring between the camera and the transmitter.

To explain camera switching we will start with the cameras on the stage and work back to the control room. As an example, we will describe an actual television show in which dancing lessons were given. One camera was set up for close-up work, to cover the introduction of the man taking the lessons and his dancing partner. The second camera was equipped with a wide angle lens to take in the entire stage while they were dancing.

The scenes picked up by these cameras are fed into the control room separately. The picture that each camera is taking appears on the picture tubes in the control room. So one picture is a close-up of the couple on the dance floor and the other is a long-shot taking in the entire stage. The engineer can switch either of the pictures to the outgoing line carrying the picture impulses to the transmitter, which in turn transmits the picture to your home.

After the introduction, the camera that is used for close-up shots is pivoted to follow the dancers around the stage; the wide angle camera is used at the same time to take in the entire action. By switching in the control room it is possible first to send out a close-up of the couple dancing and then a complete picture of the couple and the room they are dancing in. When viewed at the television receiver, the switching between cameras adds interest and gives both an overall picture and interesting details at the same time.

In a studio large enough to contain three sets at the same time quite large productions can be handled. They may require a number of changes in scene. Looking out from the control room, the largest set is opposite on the far side of the studio. This is used for dance-hall, street, or ice-skating scenes, or other types requiring a large area. On the right and left sides of the studio smaller scenes can be set up—a living room, the interior of a railroad train, the cockpit of a plane, or anything that may be required in the show. The cameras and other equipment are then set up in front of these various scenes. Now it is possible to switch action from one scene to another without interruption, by camera switching in the control room.

Beside the pictures taken on the stage, scenes can also be taken from previously prepared film. In fact, an entire show can be put on from film alone. Recording certain scenes on film naturally has great advantages, particularly when outdoor scenes are necessary in a play. The projection room, where the television pictures are taken from film by means of a special camera described in the next chapter, is located at the end of the control room. The lines that carry the picture impulses from these machines are also brought into the control desk and monitored. So it is possible to make up some of the scenes on film and switch to these at the proper time. This gives television as much flexibility in scene variation as motion pictures have.

In order to control all the various stage and control room activities it is necessary to have quite a large staff of technically trained personnel, who operate under the director, the floor manager, the chief engineer, and the sound engineer. The director controls all stage activity, usually from the control room where he can check on the outgoing picture and sound, and communicate with the floor manager. The floor manager is stationed in the studio; he wears headphones to receive his instructions and directs the various operations with his hands. He motions with his hands when he wants a camera to back away or move into a scene. He signals the boom man to move the microphone closer to the actor or raise it when it is in danger of getting into the picture area. He is also in charge of the talent. The technical manager is in charge of scenes, props, and lights. The operators on the stage itself consist of the camera man or men, as the case may be, the dolly man, the boom man, and the technician who controls the lighting.

The camera man actually operates the camera in television work; this is not true in motion picture work. He must be an expert on photography and lighting, and must also have a good knowledge of the various types of lenses used in this work. He changes lenses, focuses, and sets the camera angle. His assistant is called the dolly man, and he must know the depth of focus of the various camera lenses and just what areas the various lenses take in.

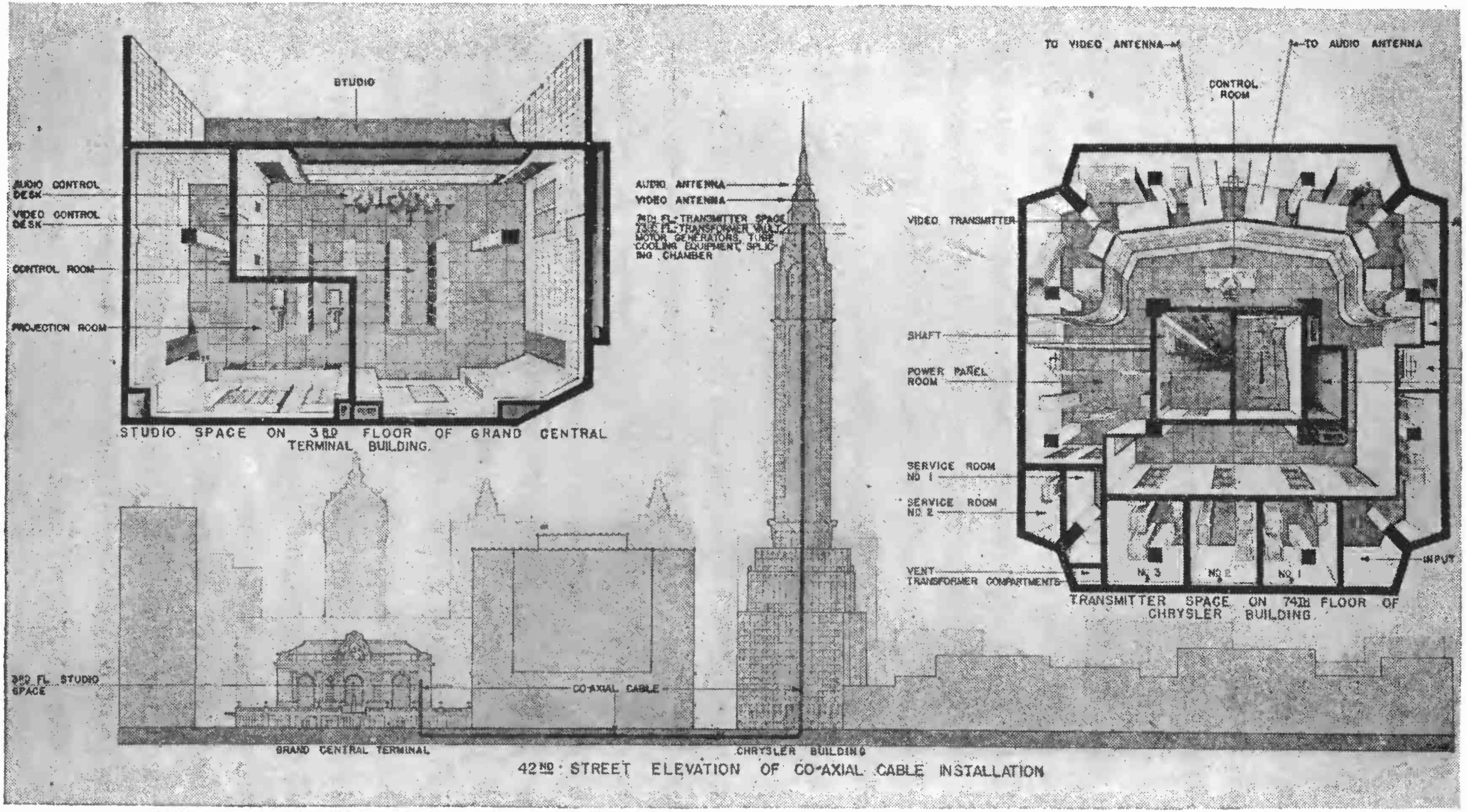
The camera dolly is a platform, on which the camera is mounted, equipped with large rubber casters. The platform can be moved quickly and silently while a picture is being taken, and this is often done to produce trick effects. Naturally, if the dolly man moves back too far, he may take in more than the stage area. If he moves in for a close-up, he may move in too close and cut out an important part of the picture. The stage area covered by each camera lens varies, depending upon the focal length of each particular camera. So considerable skill and knowledge are required to operate the camera dolly.

The technician or stage hand who controls the stage lighting handles quite a problem. Television work requires a considerable amount of general lighting beside the spotlights. Color television requires even more light than black and white, as the color filters used for this work absorb a great deal of light. For this reason, a television stage equipped to produce both black and white and colored pictures must have more general illumination than is required for most motion picture work.

This presents difficulties, since high intensity lights usually generate a great amount of heat. If ordinary incandescent lights were used for this work on a large stage, the heat generated by the bulbs would be so intense that it would be almost impossible for the actors to work under them.

Small television stages can use special incandescent lights without running into too much difficulty. But large stages that require five or ten times more light must have especially designed lights.

One of the large broadcasting companies in New York City



Courtesy of C.B.S.

TELEVISION TRANSMITTER AND STUDIO EQUIPMENT LAYOUT uses two different types of specially designed lights for their large television stage. They use twenty-one lighting units for general illumination and two high intensity units for special effects. Beside these, certain additional spotlights are used for some scenes.

They designed a fluorescent unit for general illumination, since this type of lighting gives more light for power consumed than most others. Each unit contains twelve 30 watt fluorescent tubes and six reflectors. Two tubes, one in front of the other, are used for each reflector. The units are hung on chains as close together as possible, and are arranged to form a huge arc slightly in front of and over the acting area. The reason for arcing these units is to concentrate the lights on the acting area. The lights supply 7,560 watts of general illumination for the stage.

Most fluorescent lights operate on alternating current, but when this is used the lights flicker at the frequency of the current. Normally this is not visible unless an object is moving quite rapidly. You can detect the flickering if you hold your fingers about a foot away from your face, in front of your eyes, and move your hand sideways very rapidly. Your fingers seem to have a jumpy motion. This is called a stroboscopic effect and it must, of course, be eliminated in television. So special fluorescent lights have been designed which operate on direct current and eliminate the stroboscopic effect completely.

This took care of the general lighting problem, but there was still a need for additional lighting in certain areas. Just where the extra light was needed depended on the particular scene. An entirely different type of light has been developed for this special use. It consists of a mercury vapor water-cooled light. This type of light has been used for other purposes and it is very efficient. In order to have lighting flexibility, a special unit was designed for television work. This unit supplies three thousand watts of high intensity light. The light is remote controlled, and can be directed at any area of the stage from the control position.

There are three 1,000 watt mercury vapor water-cooled lights in each unit. The 1,000 watt light itself is quite small—only about two inches long and smaller in diameter than a lead pencil. It is made in the form of a tube, sealed at both ends, and it contains a small quantity of mercury. The tube is made of quartz and has a brass fitting on each end for its electrical connection.

The mercury inside of this tube vaporizes when a high voltage current is passed through it. This produces a very brilliant light, so intense that you cannot look at it directly for any length of time without injuring your eyesight. To protect the actors' eyes, it is kept a good distance from them and high over their heads. It will produce a bad sunburn if you stand under it for any length of time. For this reason special glass is used in front of the lights to reduce the ultra-violet rays.

The heat generated by these little lights is so great that they have to be water-cooled or they will burn out or explode. So each light is placed inside a glass water jacket; the hose and electrical connections are made at each end. The glass water jacket is about three inches long and about one inch in diameter. It is designed so that it supports the light in the middle of the jacket. There is a water inlet on one end and an outlet at the other. The water constantly flows over the entire lighting tube, keeping it at the proper temperature. Distilled water is used because distilled water is a poor conductor of electricity; and the electrical contacts at each end are submerged in the water. Probably some current does pass through the water, but it is such a small amount it does no harm. To cool the water and re-circulate it, the water system is tied in with the control room air-conditioning system. This is done by using a water circulating pump and a heat exchanger. The heat exchanger consists of a small water tank inside of which is a copper coil of tubing. Chilled water is constantly passed through the tank from the air-conditioning system. The copper coil is connected to the water line returning from the lights. Since this coil is submerged in chilled water, the heat from the returning water is transferred to the chilled water system. This is why it is called a heat exchanger.

If the water-circulating system should fail, even for a fraction of a second, the lights would burn out immediately. A flow switch is installed in the water system to prevent this. The switch cuts the lights off if the water system fails even for an instant.

Each three thousand watt lighting unit contains a curved reflector about three feet long. The lights are mounted a few inches in front of the reflector and spaced about twelve inches apart. The reflector is completely enclosed, a glass panel being used over the open end to reduce the ultra-violet rays. The reflector unit is mounted on a large hollow shaft about three feet long, which houses the flexible water connection, power wiring, and control wiring.

Usually two or three of these units are mounted above the stage. Small electric motors are used to rotate the lights and tip them up or down, so they may be made to fall on any part of the stage that requires additional lighting. They can also be turned to produce strong shadows on a stage wall for certain dramatic effects.

The push button controls for these lights are located at the side of the stage. There are three sets of buttons for each light, one set for turning them on or off, one for twisting them clockwise or counter-clockwise, and one for tipping them up or down.

XIV The Television Camera

THE TELEVISION camera in some respects is quite similar to a still picture or motion picture camera; the lenses, for example, are quite similar to those used in all other cameras. Lenses of this type collect light and project a picture on a light-sensitive film. This film is later developed through a chemical process to produce a negative picture. You can check this by removing the back of any ordinary camera and placing a piece of ground glass where the film is normally located. Then if you open the shutter and place a piece of dark cloth over your head and the back of the camera, so you can see the ground glass in semi-darkness, you will see a picture of the object that is in focus. You probably have seen photographers do this to check a picture before they insert the film.

The lens system in a television camera does the same thing, except that it projects the picture on a mosaic screen or plate. This mosaic plate is made in layers. The side that the picture is projected on consists of thousands of small particles of a photosensitive material, which has been applied to a mica or insulating plate. The back side of this insulating plate is covered with metal. The photosensitive material forms thousands of small condensers.

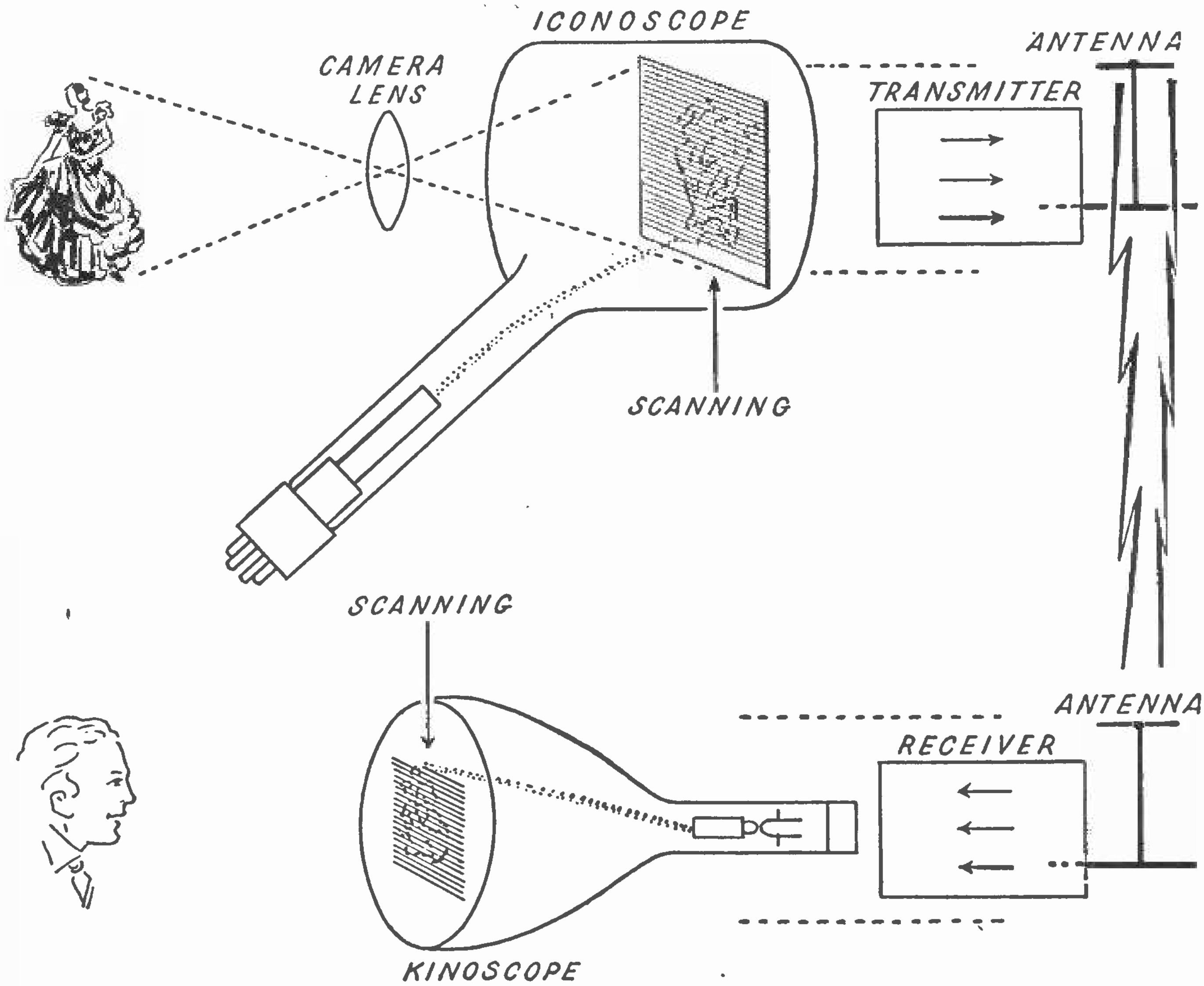


DIAGRAM SHOWING HOW PICTURE SCANNING IS ACCOMPLISHED IN TELEVISION CAMERA AND RECEIVER

(Probably if you thought of these as thousands of minute batteries it would be easier to visualize.) These condensers become positively charged when light falls upon them. The amount of the charge depends upon the intensity of the light that falls upon them. So you now have a picture made up of thousands of electrically charged particles, and if you could see them they would form a picture. Now we want to change this from a picture into a series of electrical impulses, so that the picture can be transmitted to another location. The iconoscope tube does this by playing a stream of electrons on the photosensitive surface of the plate that contains the picture in the form of electrical particles. This fine stream of electrons is played back and forth across the plate in the form of straight lines gradually traveling from top to bottom until the surface is covered. This operation is known as scanning. Two scanning operations, referred to as a frame, are accomplished in approximately 1/30th of a second. The first time the picture is scanned every other line is scanned and this is called a field. The second scanning covers the lines which were not scanned the first time. This type of scanning is called interlacing. Today five hundred and twenty-five lines are used to produce the picture. This is almost double the number of lines used in the earlier days of television, and is the reason why the pictures today are sharper and have more definition.

As the stream of electrons strikes each electrically charged particle forming the picture, it causes it to discharge, producing a rush of current through the wire which is attached to the back metal plate. This creates a series of small electrical impulses as each particle on the screen is discharged by the stream of electrons. These impulses can be amplified and transmitted to another location.

If you have ever looked closely at a picture in the newspaper you will find that it consists of thousands of small dots of black

Courtesy of R.C.A.

R.C.A. TELEVISION MOBILE EQUIPMENT

and white and various shades of gray. Now if each row of dots across the picture, starting from the top, were laid in a single line you would have a very long single line that mainly varied in degrees of gray. This line can be compared to the series of electrical impulses produced by the picture dissector tube we have just described. There is really a long line of electrical impulses passing along a wire and each one of the impulses is a part of a picture.

Going back to the long line of dots, if you were to break this line up and reassemble it in its proper order, you would naturally have your picture again.

The receiver tube does just this. To simplify the explanation, we are going to leave out for the moment, all intermediate steps between the camera tube and the television picture tube, and imagine that these impulses from the camera tube are fed directly into the receiver tube.

The tube that produces the picture in the receiver is really a cathode-ray tube, similar to the type described in one of the earlier chapters. This tube shoots a stream of electrons at a fluorescent screen which covers the large end of a funnel-shaped tube. This stream of electrons scans the screen in the end of the tube, in much the same fashion as the camera tube. The scanning is done line by line, from top to bottom. The electron strikes the screen and produces a bright spot and as the spot is moved rapidly across the screen it appears to be a white line. As scanning the entire screen only takes a fraction of a second, it would appear to the eye as a white screen if the intensity of the dot did not vary. The intensity of the dot is varied, however, by the impulses supplied by the camera tube. The varying intensity or brightness of the spot as each line is scanned produces the picture. In other words, the camera really breaks the picture up into little parts, and sends these parts out as electrical impulses. The receiver tube changes the impulses back into light and dark areas in the proper sequences, thus producing a picture. The fluorescent material used as a screen radiates light when the electrons act upon it, and it actually radiates light for a short time after the electron beam has been removed. This means that the first part of the picture has not died out completely when the last line is being scanned. One complete scanning operation—two fields—is called a frame. This is the equivalent of one frame of a motion picture.

Synchronizing the scanning with the impulses is naturally important. If this were not done the picture could not be produced. An electrical impulse is sent out at the end of each scanning line when the picture is being dissected by the camera. A different impulse is produced at the end of each frame. The receiver has an electrical circuit for selecting these impulses, and it uses them to keep the line scanning synchronized with the picture impulses and the framing.

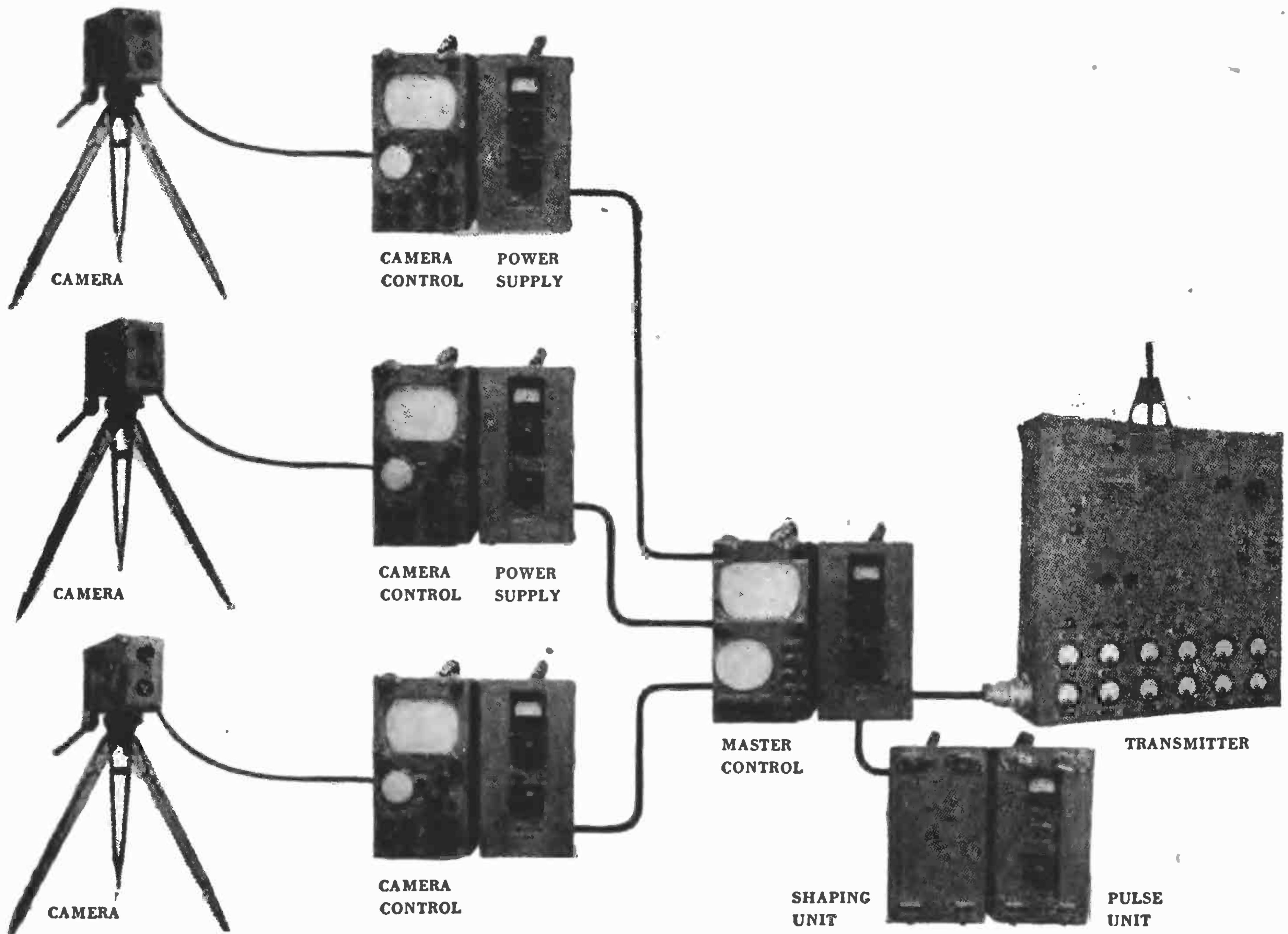
The camera tube and other associated electrical equipment are housed in a metal box or container. The lens system is mounted on the front of the camera and the light passes through it to the dissector tube. The front of the camera is designed so the lens may be removed and replaced with other lenses. This is done so that wide angle and other types of lenses may be used. The wide angle lens is used when it is desirable to have the camera quite close to the scene and the scene is quite broad. Telephoto lenses are also used at times for television work. These lenses are used principally for outdoor work. This type of lens is very useful for football and baseball games where the action is a long way off.

Some of the better television cameras use a double lens system. The second set of lenses projects the picture on ground glass in the back of the camera. This enables the camera man to see the picture just as you will see it and to be able to focus the camera visually.

When a camera is set up for studio use, it is usually mounted on a pedestal so it can be raised or lowered. Some cameras are raised and lowered by a hydraulic arrangement. The camera is tipped by means of a long handle fastened on one side of the camera, and this handle also takes care of the focusing of some cameras. In order to make the camera mobile, it is mounted on a large movable base equipped with large solid rubber or pneumatic casters. Many tricks effects can be produced when the camera is movable. For instance, if the scene is the observation platform of a railroad train, the effect of a train actually in motion can be produced by pulling the camera away while the scene is being taken.

The electrical connections are made by means of a long flexible cable which is plugged into the wall outlets around the studio.

Another type of television camera is used in connection with producing television pictures from motion picture film. In this case a motion picture projection machine projects the picture on



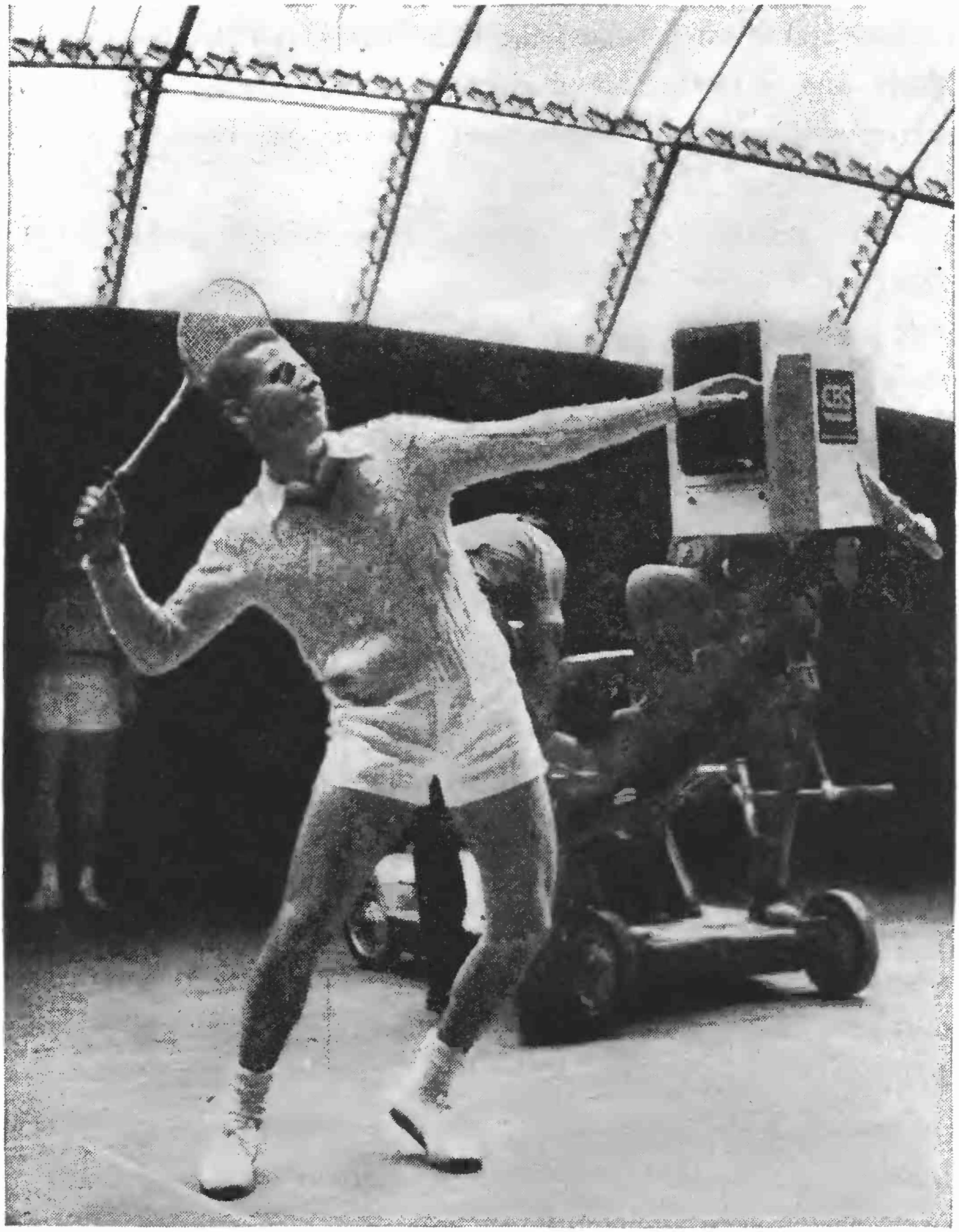
Courtesy of R.C.A.

TELEVISION FIELD EQUIPMENT

the mosaic plate of the television camera tube. The camera is mounted a few feet in front of the projection machine. The projection machine lens system is designed to focus a picture about the size of the dissecting tube plate directly on the plate of the tube. Except for this, the machine is the type that is used in most motion picture theaters. The camera tube operates on the same fundamental principles as the camera tube previously discussed.

The camera itself is nothing more than a box that houses the tube and other necessary electrical parts; the lens system is part of the projection machine. In some cases this camera is equipped with wheels which run on tracks. The tracks are mounted on the wall in front of the projection machines. Grooved wheels on the camera engage these tracks. This makes it possible to move the camera from one machine to the next one, and so one camera can be used for two projection machines. If two projection machines are used, one can be loaded with film while the other is operating. In this way there is little loss of time between reels. The operator can switch from one machine to the other quite rapidly. At the same time a technician can move the camera from one machine to the next.

The scanning is different for film television cameras, as the number of frames per second used in motion picture work does not correspond to the framing used in television. Motion pictures use twenty-four frames per second, whereas television uses thirty frames and scans each frame twice, producing sixty fields per second. In order to synchronize the scanning with the film, the scanning is alternated. The first frame is scanned twice and the



Courtesy of C.B.S.

TELEVISION CAMERA IN OPERATION

second frame three times; the third twice and the fourth three times, and so forth. This produces the same number of fields per second (60) as television normally uses, and synchronizes the scanning to the film frames.

There are twenty-four film frames per second; twelve of these frames are scanned twice to produce twenty-four fields; twelve are scanned three times, producing thirty-six fields; a total of sixty fields per second. In this way motion picture or television standards do not have to be changed in order to synchronize the projection machine operation with the television scanning. The film projector is slightly different from the type normally used and is equipped with a rotating shutter which cuts the lights while the film is being moved.

A studio equipped to produce pictures from film or an actual stage production can provide quite a variety of entertainment. The stage can handle musical shows, comedies, dramas, dance lessons, news broadcasts, etc. Film can be used for news events, animated cartoons, and various other forms of entertainment. This works out very well, as the film can be used to fill in when the stages are occupied with rehearsals or when the scenery is being changed. This reduces the number of stages required to produce continuous television shows.

Television also uses field equipment for remote pickups such as baseball games, tennis matches, boxing bouts, or news shots of fires, floods, ship launchings, etc.

Television requires so much more equipment than the broadcasting of sound that it is rather difficult to build it into small

Courtesy of R.C.A.

TELEVISION PROJECTION RECEIVER

units which can be carried by hand. Also the cameras are rather bulky and heavy and because of all this the equipment is usually built into a truck or bus. Part of this bus serves as a control room where the pictures may be monitored. A separate mobile unit is used for the transmitter.

The unit is built with large glass windows at the sides or the rear. This enables the engineer to view the action just as he does in a studio. Small and compact monitor units are used for this work. Receptacles are provided in different locations around the television mobile unit so camera cables can be plugged in from the outside. Tripods are usually used for the camera as they are light and easily portable. For baseball or football games, usually two or more cameras are used—one for an overall picture of the game and the other for closeups. In the case of baseball games, a long range or telescopic lens picks up the players in the outfield, since the camera cannot be located on the playing field. This camera follows the various plays so that you receive a closeup picture of any action that takes place in the outfield or at the bases. For this particular work, the television mobile unit can operate alongside the field so the control engineers can watch the action. The cameras can be located back of home-plate or along the baseline; they are connected to the truck by cables.

The picture impulses are sent to the main transmitter by a small mobile field transmitter. They are then picked up by a receiver near the main transmitter and re-transmitted to your home.

Power can be supplied locally to this mobile unit or its own mobile gasoline or Diesel generator can be used.

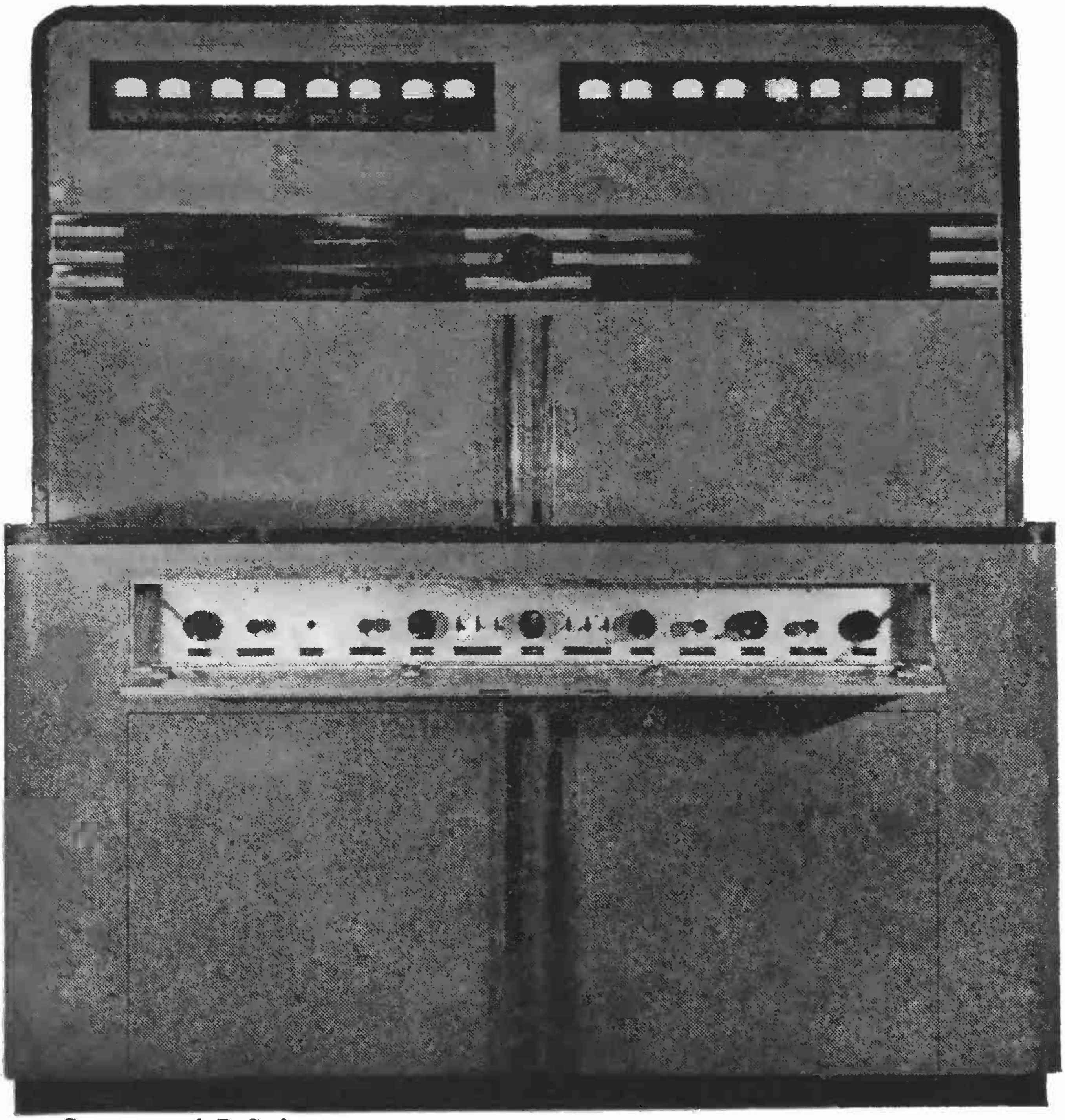
The mobile equipment designed by the Radio Corporation of America uses a separate truck for the field transmitter. This truck is equipped with a collapsible antenna system that folds down on top of it. The truck houses a 400 watt transmitter equipped with water-cooled tubes. The receiving antenna and the television receiver are located in the Empire State Building in New York City where the main transmitter is located.

XV The Television Transmitter

THE TELEVISION transmitter is in some respects quite similar to A.M. (amplitude modulation) broadcasting transmitters, though an entirely different type of antenna is required because of the ultra-high frequency used for the carrier wave. The carrier wave is also modulated at a much higher frequency.

The impulses that are produced by the camera are really a combination of frequencies varying with the picture variations. The frequencies that are produced by a picture cover a much larger range than the audio frequencies used for the transmission of speech and music.

Transmitting the picture presents a far greater problem than transmitting sound where the audio frequencies (even in F.M.) only go up to around 15,000 cycles. In order to be able to scan an entire picture in one-thirtieth of a second, each line must be scanned in slightly less than a 15,000th part of a second. This is based on the present standard of a 525-line picture. This terrific scanning speed determines the frequencies that are generated by each little dot in the picture, when they are transferred into an electrical impulse. As each line represents hundreds of impulses, the frequency of these impulses may exceed 4,000,000 per second. So the frequencies produced are up around 4,000,000 cycles per second. Frequencies as high as this are difficult to transmit, as the transmission losses are great. A special electrical conductor has been developed for transmitting these high frequencies and it is used whenever they have to be carried over a line for any distance over a few feet. When carrier waves are modulated they produce sideband frequencies; that is, they produce frequencies at each side of the carrier wave frequency. Other transmitters must be kept clear from these sideband frequencies or interference will be encountered. Because of this, the Federal Communications Commission set aside a certain band of frequencies to be used by each transmitter. This is called a channel. The frequencies covered by a carrier wave when it is modulated by a frequency of 4,000,000 cycles per second would be 8,000,000 cycles, as it modulates 4,000,000 cycles each side of the carrier wave frequency. This would more than blanket all the frequencies assigned to commercial broadcasting. This is the reason why much higher carrier wave frequencies are used for television. The F.C.C. has allowed a six megacycle (megacycle is one million cycles) band or channel for each television station. By using a filter which practically absorbs one of the sidebands produced by modulating the carrier wave, the frequency covered by the television picture can be kept down around 4.5 megacycles. This



Courtesy of R.C.A.

TELEVISION 4,000 WATT PICTURE TRANSMITTER leaves room for the sound carrier wave which is transmitted separately.

The television transmitter is really two transmitters, one for the picture and the other for sound. They are called video and audio transmitters. Separate antennas are used for the picture and sound. While television transmitters look similar to sound transmitters, they are more difficult to build because of the problems encountered in amplifying these extremely high frequencies produced in picture transmission. As we have said before, F.M. is used for transmitting the sound.

The carrier wave frequencies assigned for television are from 44 megacycles to 108 megacycles and from 156 to 294 megacycles. Carrier wave frequencies as high as this travel in a straight line and are rarely reflected by the ionosphere. This makes the transmission of these frequencies difficult; they do not follow the curvature of the earth and the ionosphere cannot be relied upon to reflect the waves back to the earth. As these waves travel in a straight line, they will only travel as far as the horizon before they start to depart from the earth. The distance to the horizon can be increased by elevating the transmitting point; this works the same way as increasing your own elevation to see a greater distance. In other words, the higher you go the farther away the horizon is.

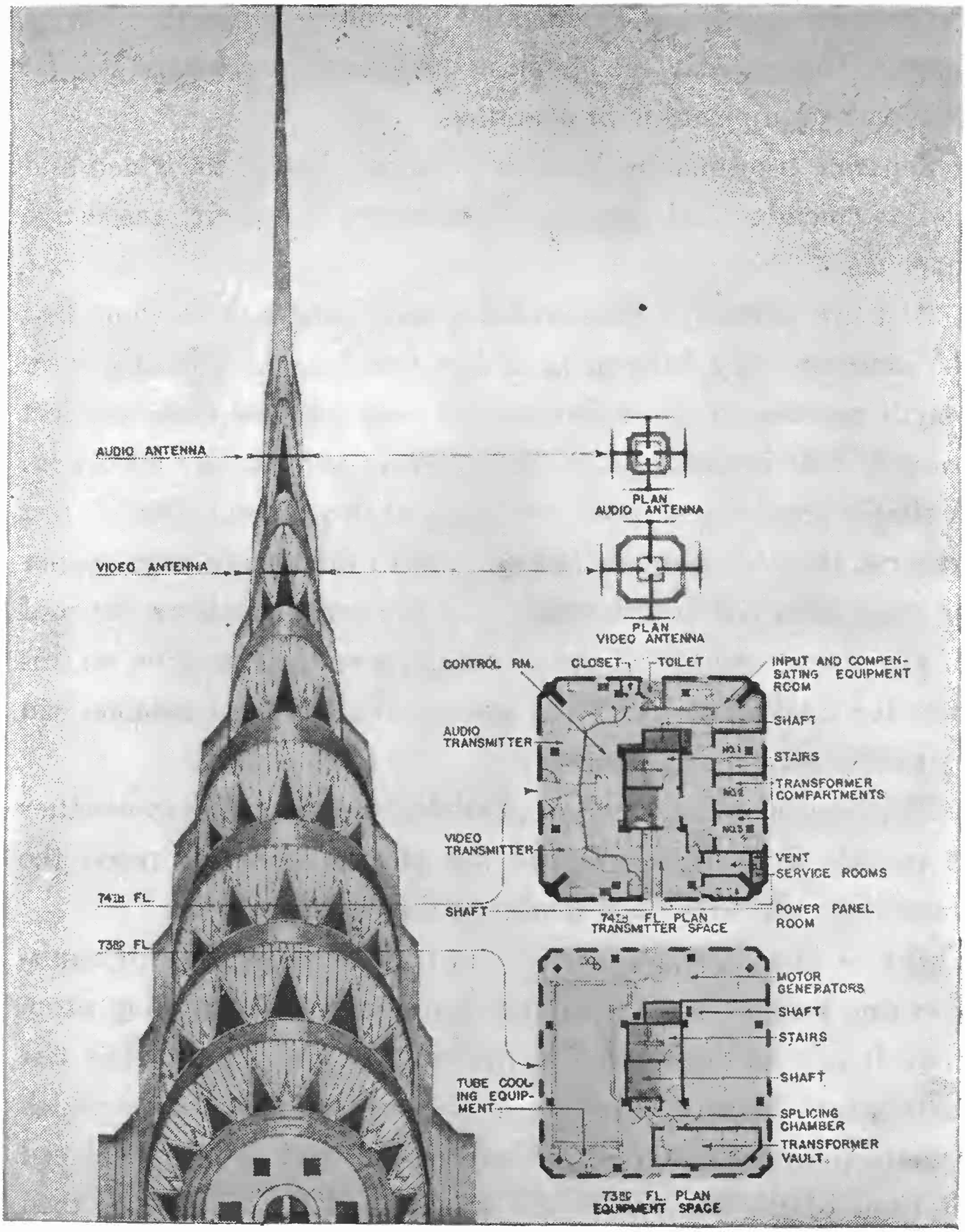
For this reason, television antennas are usually located on tall buildings. The elevation of the receiving antenna also helps to increase the distance the transmitter can be from the receiver. Distances up to 65 miles can be covered with a transmitting antenna elevated to about 1,500 feet and a receiving antenna elevated to 200 feet. So it is possible for a television transmitter to cover an area of about 13,000 square miles. This will cover the thickly populated suburban areas around almost any large city. Of course, where there are mountains and hills this area is considerably reduced.

The television transmitters are usually located close to the antenna system, as it is desirable to keep the lines connecting the antenna system to the transmitter as short as possible. For this reason the transmitters are usually on upper floors of the same building on which the antennas are located. As space on the upper floors of most buildings is limited, the transmitters are designed to be as compact as possible.

In most cases the front metal panels of the transmitter form one wall of the transmitter room. Meters are mounted on this panel for checking the voltage on the various transmitting tubes. All manual controls used for tuning and adjusting voltages and current are also mounted on the front panel, or they are easily reached by opening small hinged access doors.

In front of this panel is the transmitter control desk. Switches for turning on the various stages of the transmitter are located on this desk; so are pilot lights which indicate what part of the transmitter is in operation.

The transmitting tubes, transformers, filter condensers, and various other parts of the transmitter are located behind the front panel. The doors leading to this equipment have safety interlock switches which operate as soon as the door is opened. These



Courtesy of C.B.S.

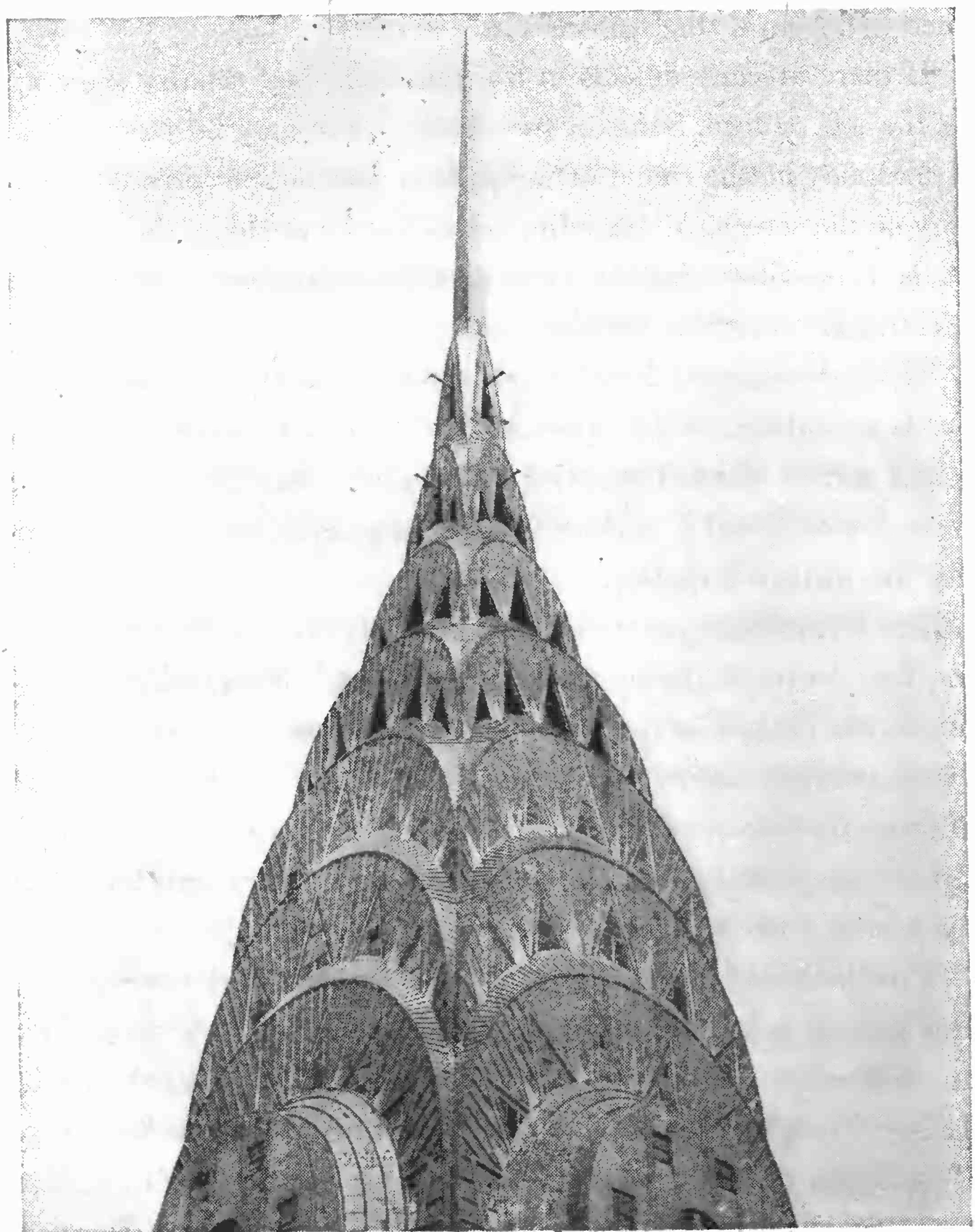
TELEVISION TRANSMITTER ROOM AND ANTENNA LAYOUT switches automatically cut off all high voltage when the door is opened. This prevents the operating personnel from entering when any of the equipment is in operation.

Separate transmission lines are used to connect the video and audio (picture and sound) transmitters to their respective antennas.

At these ultra-high frequencies a wave length is so short that the antennas only have to be a few feet long. A one-half wave length antenna at these frequencies may be less than ten feet overall. This is also true of the receiving antenna for television. A simple receiving antenna consisting of two dipoles about 5 feet long can be used. A dipole is a stiff rod or tube made from copper or some other conductive metal. You can erect a pole on the roof of your home and mount the dipoles in a vertical position on this pole for a television receiving antenna. This type of antenna can be purchased quite reasonably.

Monitoring or checking the television picture at the transmitter is usually done twice—before the picture impulses reach the transmitter and after they modulate the carrier wave.

This is done at the transmitter to make sure that the transmission line between the studio and transmitter is functioning properly. It can be done visually by using a test pattern. The test pattern may be several circles of different sizes and lines which radiate from the center of the screen. This test pattern is placed in front of the camera in the studio, and the pattern is then checked at the picture monitor tube in the control room to make sure everything is functioning properly up to this point. It is



Courtesy of C.B.S.

TELEVISION AND SOUND ANTENNA SYSTEM

checked again at the transmitter.

If there are any defects in transmission, they usually show up on the test pattern. Some of the straight lines may be wavy or the circles may not be round or the pattern may not be centered properly on the screen. Minor adjustments can be made by the controls at the transmitter, such as increasing the brightness, centering the picture, or correcting the shading.

The video carrier wave which the television transmitter sends out is modulated in the same manner as an amplitude-modulated sound carrier wave. The major difference is that the video carrier wave is modulated at extremely high frequencies in order to transmit the picture impulses.

The test pattern previously described is also helpful in checking the picture at the receiving end. The call letters of the transmitter are flashed on the television screen before and after a television program starts. The name of the station and the call letters are usually incorporated in a test pattern. The pattern is a decorative design and serves a dual purpose, showing the call letters of the station and checking on the receiver operation.

This immediately tells whether the antenna and receiver are functioning properly. If a double image appears, it is usually an indication that the antenna is receiving a reflected signal. These ultra-high frequencies used for television are reflected by objects near the antenna system. This causes the antenna to receive two signals, one slightly delayed, causing two images. The second image is called a ghost image. This can be eliminated by moving or adjusting the antenna system.

The size of the receiver picture tube controls the dimensions of the picture. The three most popular sizes at the present time are 5-inch, 9-inch and 12-inch tubes. A 5-inch tube gives you a picture $3\frac{1}{8}$ by $4\frac{1}{8}$ inches; a 9-inch tube will produce a picture $5\frac{1}{2}$ by $7\frac{1}{4}$ inches; a 12-inch tube produces a picture $7\frac{3}{8}$ by $9\frac{3}{4}$ inches. Much larger tubes have been manufactured.

Television projector receivers have been developed by which the picture can be projected on a screen. This type of receiver has not been perfected but it may be at any time.

Most television receivers supply both picture and sound. There are receivers, however, which can be used in conjunction with your radio receiving set; that is, they are designed to use the audio amplifier and speaker in your present set. This reduces the cost of a television receiver somewhat.

The tuning dial on a television receiver usually tunes both picture and sound at the same time. The receiver is really two receivers, as separate amplifiers are generally used for sound and picture. Beside the tuning control, there are usually two additional controls for the picture adjustment. One operates in a similar manner to the volume control on a standard receiver, controlling the brightness of the picture, and the other is provided to adjust the contrasts of the picture.

The present day standards in television produce quite sharp pictures with good detail. There are very few people who have seen a present day television show who do not wish to buy a receiver. It will probably be only a short time before television receivers in homes will be quite common.

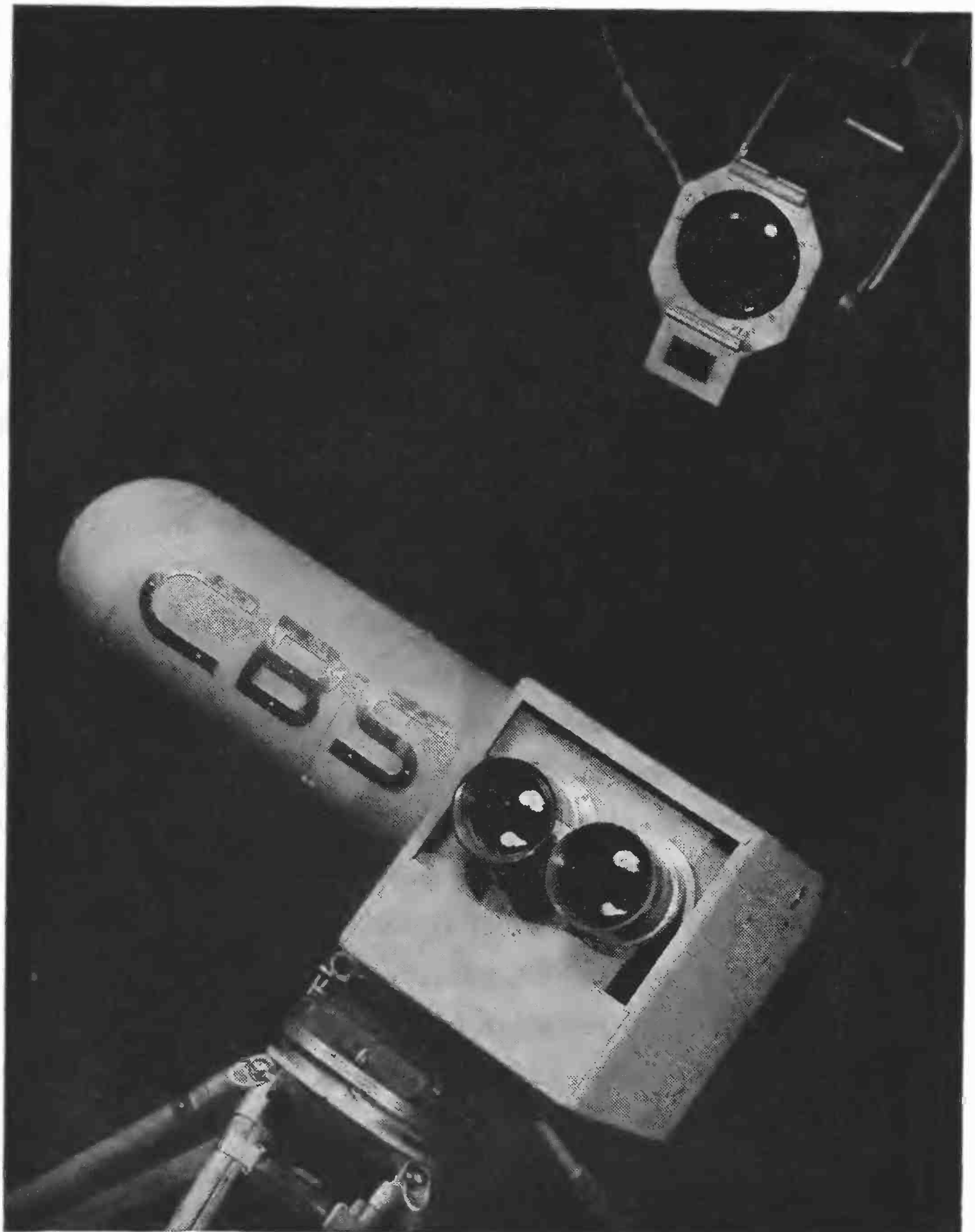
XVI Colored Television

BLACK and white television is now developed to such an extent that it is considered commercially sound, and colored television is not far behind. While engineers were working on black and white television other groups of engineers were working on colored television. As far back as July 1928 colored television pictures were being transmitted and received. The quality of the picture was not good at that time, but the feasibility of transmitting and receiving colored pictures was proved. Since then a good many technical men have been working on this development. The addition of color greatly improves the quality of the picture. Objects appear to have more roundness and their outline appears sharper. This adds depth to the picture, beside making it easier to define small objects. Generally speaking, this makes a more interesting and life-like reproduction of any scene.

There have been many different schools of thought on how colored pictures should be transmitted. Some engineers think it should be done by some electrical means; others prefer using some type of optical system; others are working on a mechanical system. Some of these systems use two primary colors; others work on three primary colors. The three-color systems have an advantage as they reproduce the colors more accurately. Each system has certain advantages and disadvantages as there are many difficulties to be overcome.

Most new developments pass through a number of stages before the public is even aware that the experimentation is going on. If you check the records on most great inventions you will find that the idea originated many years before the invention was perfected.

Colored television has passed through a good many of these stages in its development, and it is now rapidly approaching the place where it can be turned over to the public. This is not true of all these systems but there is at least one which has been demonstrated with very good results. This system has overcome many defects which some of the others have not overcome. This does not mean that some of these other systems may not become equally good or even better in the near future. However, this one system is at a point where the parts can be manufactured at a reasonable cost and assembled in a standard receiver, and it will produce good colored pictures. The system to which we are referring uses mechanical means to break the picture down into various primary colors. By considerable research certain standards have been established as to the number of lines and the method of scanning which produce the best results.



Courtesy of C.B.S.

TELEVISION COLOR CAMERA

This particular system is a three-color system, using colored filters to dissect the picture into its various color components. These filters are mounted on a disk or drum which can be rotated at a high speed. The filters are driven by an electric motor which is also electrically controlled.

The basic operating principles of the camera tube are the same as those for black and white television, but the electrical requirements are different. A special camera tube was developed by R.C.A. which had the proper electrical characteristics for color work. The scanning is accomplished just as it is in a standard camera tube except a different number of lines is used per frame and the interlacing is changed. The number of frames per colored picture also had to be changed to produce the best results. This was established after considerable research work and it will be explained later on in this chapter.

The picture is transmitted in the same way as a black and white picture—that is, by coupling various impulses or frequencies to the carrier wave that is generated by the television transmitter. Of course, the various control frequencies change because the number of lines per picture, the number of frames per second, and other details are changed when color is added. We will not go into all the various phases of the technical requirements to produce colored television, but we will explain the fundamental principles back of its operation.

We are discussing the C.B.S. system because it has been widely demonstrated and quite a few receivers have been built which produce good results. This system was developed by Dr. P. L.

Goldmark of the Columbia Broadcasting System and his television staff. They developed two different cameras—one direct pick-up camera and one for colored film or slides. They also developed two different receivers—one which uses a flat filter disk and another type which uses a drum filter to reproduce the color picture.

It is generally known that any picture can be broken down into three primary colors even though other colors are present; the other colors are then reproduced by combining two or more primary colors. This system uses transparent colored filters to break the picture down into the three primary colors. After this is done, each primary color is transmitted separately to the receiver which re-constructs the picture in color by using color filters.

The direct pick-up color camera filters, made of a transparent plastic material, are mounted on a drum which rotates at 1,200 R.P.M. The primary colors used were red, blue, and green. This differs from the colors normally used in art work, which are red, blue, and yellow. These colors were selected after much research and were found to be more suitable than the more commonly used primary colors—red, yellow, and blue.

The drum is approximately six inches in diameter and consists of a metal frame which holds the color filters. The color filters form the side of the drum. Six filters are used and they are so arranged that in one revolution of the drum they pass a given point in this order: red, blue, green, red, blue, green. The drum is so arranged that the light passes first through the lens system and then through the filters. The light rays are directed at the

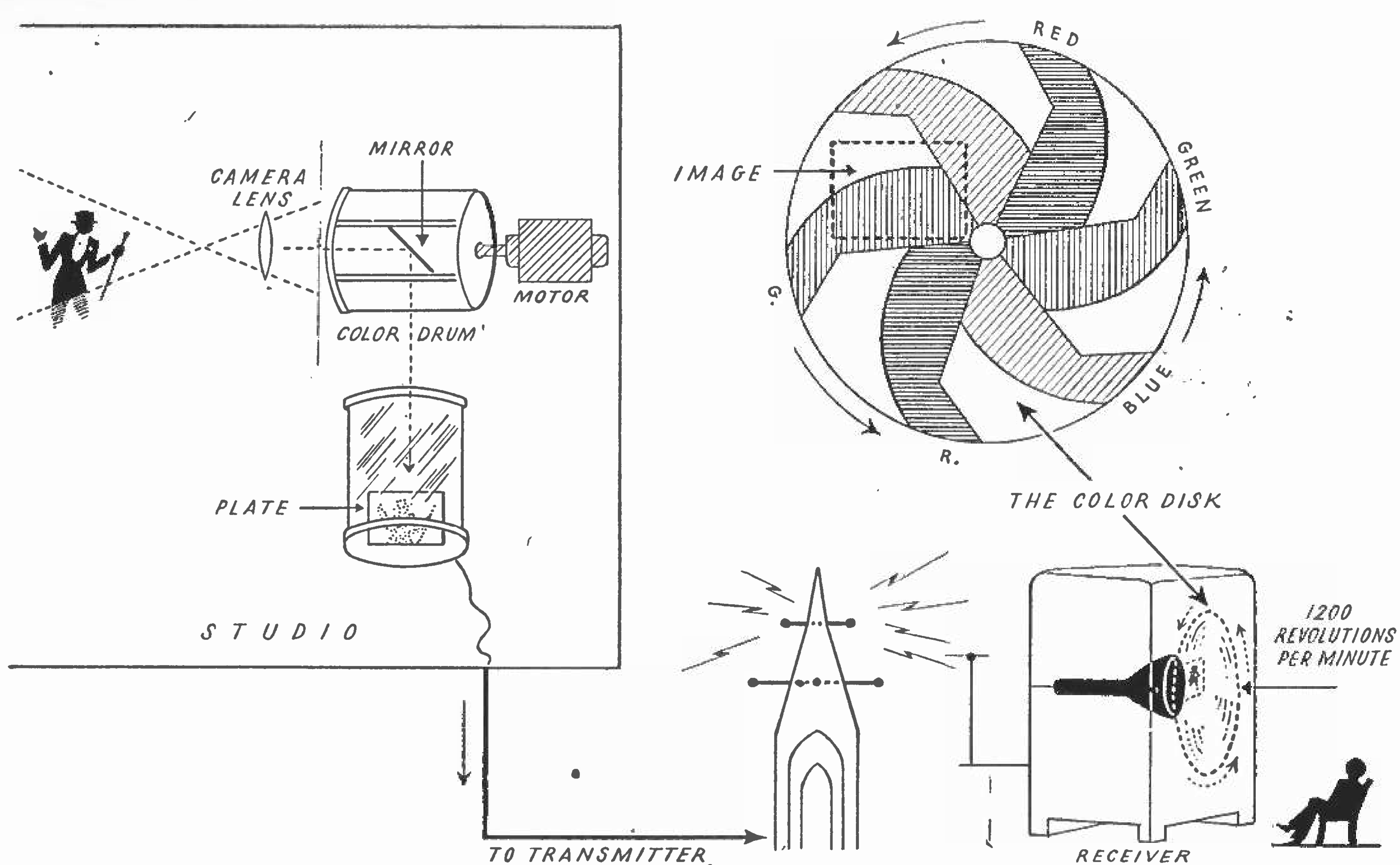


DIAGRAM SHOWING HOW COLOR IS ADDED TO TELEVISION PICTURE orthicon or camera pick-up tube by means of a mirror set inside the drum. This brings the light rays out at the side of the drum. The motor which drives the drum rotates at 1,200 R.P.M. or twenty times a second.

The filters are synchronized so that each time a filter passes the tube, one picture-scanning operation is completed. When the blue filter is in front of the tube, all the blue colors in the picture are registered; also any blue that is contained in any other color. Actually what the filter does is to allow more light to pass through where blue is present. So the greatest amount of light reaches the camera tube where the blue is most prominent. When the blue filter is in front of the camera tube, actually only the blue colors in the picture are being scanned.

The same thing also occurs when the red filter is in front of the dissector; in this case only the red colors are being dissected by the tube. This is also true of the green filter except that the green filter also takes care of the yellow in the picture, as yellow is contained in green.

As each filter passes in front of the tube, one scanning operation is completed and one color is transmitted by the tube. When the blue filter passes, all the blues in the picture are transmitted. The same thing occurs with red and green. Then the process is repeated. Actually the camera tube sends out electrical impulses just as it does with black and white pictures, but in this case the impulses represent colors. So the color camera breaks the picture down into various colors and transmits each color separately.

Now the receiving set also has a color wheel in front of the

Courtesy of C.B.S.

COLOR CAMERA IN OPERATION

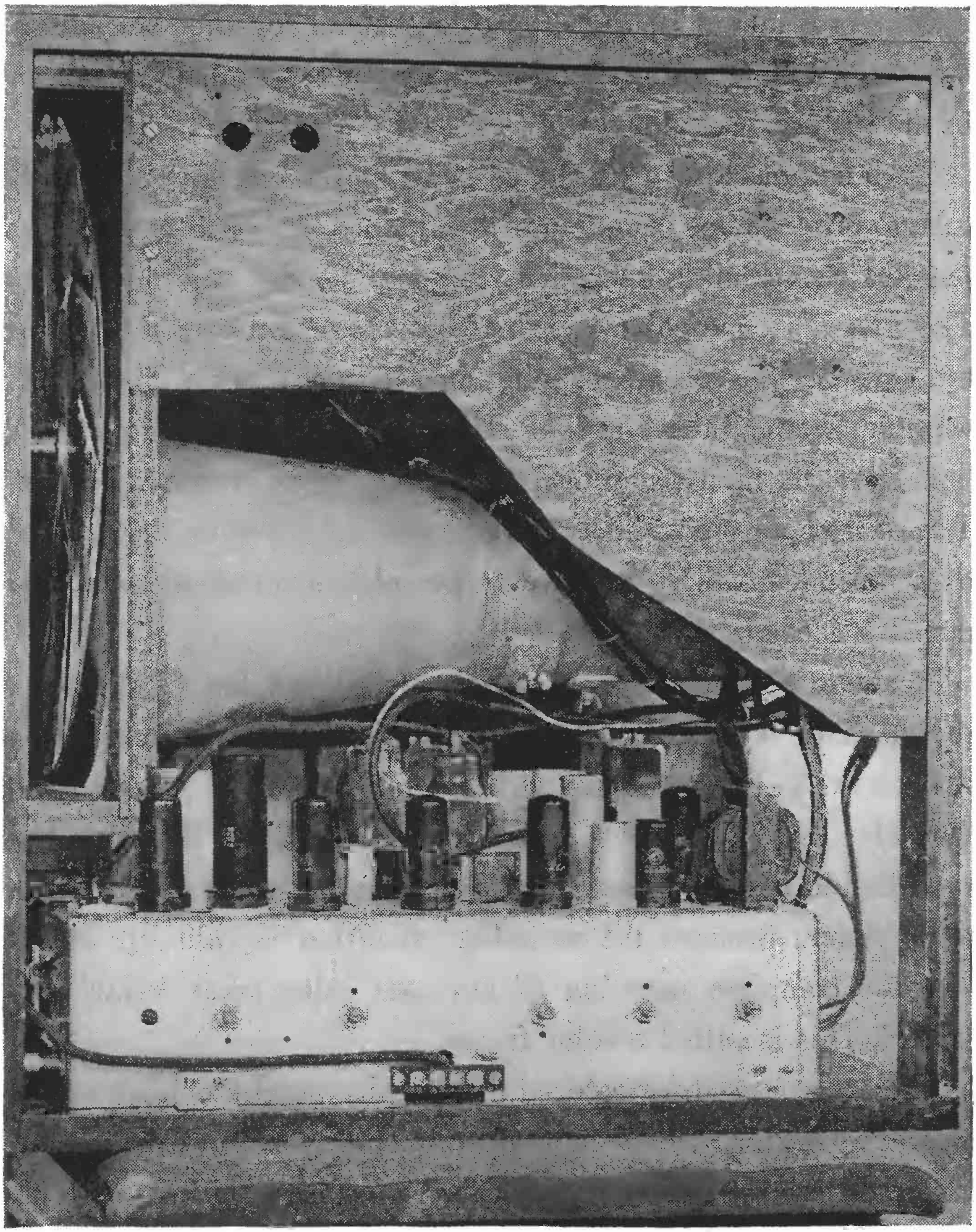
picture tube. This is rotated by an electric motor at the same speed as the camera motor. The same colors are used in this filter. The only difference is that the filters are mounted on a disk instead of a drum. The disk is flat and quite large in diameter, and it has six filters arranged in the same order as those in the camera. It is placed in such a manner in front of the tube that each filter passes the picture area as each picture is scanned. The filters are synchronized with the filters in the camera; that is, an electrical impulse controls the speed of the motor driving the color filter in the receiver. By this means, the camera filter and the receiving filters are kept in step with the picture scanning. When the blue parts of the picture are being reproduced by the receiving tube, the blue filter is passing the screen. The same is true of the red and green filters.

Now let's look at the entire operation and see what happens. The lens system on the camera is projecting a scene on the dissector tube. A blue filter is filtering out all the blues so only the blues in the picture reach the camera tube. These go to the transmitter and are sent out by a carrier to your receiver; that is, each part of the picture that contains blue is sent out in the form of impulses via the transmitter to your receiver. Your receiving tube converts these impulses back into a picture, but only the parts of the picture that contain blue. During the next operation the same thing occurs with the reds, and then the greens are transmitted in a similar manner. This occurs so rapidly your eye cannot detect it, the time being approximately $\frac{1}{20}$th of a second. So, as far as your vision is concerned, all the colors are present at all times. As a matter of fact, the colors blend together so you see browns, purples, oranges, and all the other colors that are present in the picture.

Each color is actually scanned twice by the camera and picture tube to produce one complete picture; since there are three colors, it takes six scanning operations to complete one colored picture. The first time one color is scanned alternate lines in the picture are covered; the second scanning operation covers the lines which were not scanned the first time. This interlaced scanning produces better results than scanning the entire picture in one operation. The entire operation which produces one color picture takes $1/20$th of a second. So there are twenty complete colored pictures produced a second.

A single scanning operation for one color takes $1/120$th of a second. This is called a color field. The complete scanning operation occurs in this order: first, alternate lines of red are scanned; then blue and green are scanned for the first time; then the lines are filled in by the second scanning operation which occurs in the same order. Because the scanning operation is split up in this way the complete scanning of any one color takes $1/40$th of a second. This is called a color frame.

The camera used for colored motion picture film or slides operates in a similar manner as the direct color pick-up camera. The major difference is that a small flat color filter disk is used instead of a drum. Light is supplied by a standard motion picture arc projector. The picture is projected on the dissector tube after it has passed through the filter. The light intensity used for this



Courtesy of C.B.S.

TELEVISION COLOR RECEIVER SHOWING COLOR DISC AT LEFT machine is so great that a water cell is used to protect the film or slide. The water cell consists of a glass vessel with a water inlet and outlet. This is placed in the beam of light between the projector and the film or slide. The light passes through the vessel and the water absorbs the heat before it reaches the film. There is a constant flow of cool water through the vessel, the water being circulated by a water pump. The heat is extracted from the water by a small cooling unit and the water is re-circulated.

Receivers have been designed to use either disk or drum for color reproduction. The disk type is simpler to construct and maintain and, therefore, has been used more than the drum type. The color disks have been made from metal with cutouts and frames to hold the filters. They have also been made out of transparent plastic such as lucite; then the filter is riveted on. For a nine-inch receiving tube, the filter disk would be about twenty inches in diameter. This color wheel has six filters arranged in the same order as those of the pick-up camera. The filters that are mounted on this wheel are peculiarly shaped. The shape is developed by rotating the disk slowly and drawing the scanning lines in their proper order. The disk is rotated at the same speed as the camera drum—1,200 R.P.M.

The filters pass by the receiving tube at the rate of 120 per second, which is much too fast for your eye to detect. All the viewer sees is a life-like full color picture.

The receiver which uses a color drum instead of a colored disk has one advantage—that is, it operates at 600 R.P.M. instead of 1,200 R.P.M. The reason for this is that the drum is quite large in diameter and it contains twelve color filters instead of six. It contains four red, four blue, and four green filters, twice as many as the number used in the disk. In one revolution, twelve filters pass by the tube instead of six, so the speed of the drum can be cut in half. When a drum is used in the receiver, a shorter picture tube is used. This tube actually fits inside of the rotating drum, the screen facing the side of the drum. The drum rotates in a vertical position so the filters pass the screen from top to bottom.

Adding color to television has been a great achievement. Color adds interest, definition, depth, feeling, and many other qualities to a picture. To be able to sit in your home and see musicals, dramas, baseball games, football games, and many other types of entertainment in full color would naturally appeal to almost anyone.

XVII *Radar*

When we think of radar we naturally think of a wartime detection device developed primarily for airplane detection. The war accelerated the development of radar and found new uses for it, but actually it was thought of and developed long before the war. Radar has many applications in many fields and its full usefulness is yet to be discovered. We are constantly hearing of new applications of it in various engineering activities.

While at the present time radar is not widely used in the radio broadcasting field, we believe it will affect the development of radio in general, and that is why we are discussing it here. Unfortunately we cannot release technical information regarding it, but we can cover its fundamental operation principles and new fields to which it may be applied within a short time.

Radar is radio equipment which is used for radio detection and ranging. Ra-(radio) d-(detection) a-(and) r-(ranging).

The discovery of the ionosphere and the measurements establishing its height were the beginning of radar. After this layer above the earth was discovered, and the fact that it reflected radio waves, scientists set about measuring its height. Knowing the speed of radio waves in space they could determine the height of the ionosphere by measuring the time it took for a wave to be reflected. By specially designed electronic equipment they were able to measure the time and establish the height. Later on it was discovered that a plane equipped with radio could measure its own height by measuring the time interval of a wave.

It had been discovered that certain radio waves, particularly short waves, behave similarly to light. These ultra-short waves were ideal for certain uses as they were invisible and would pierce fog. Experiments proved that these radio waves could be used to detect objects at some distance. R.C.A. saw a new use for this discovery in 1937 and designed a transmitter and receiver to be used on airplanes to prevent collisions. This equipment was capable of sending out radio waves and detecting the presence of mountains or other planes near by. The apparatus could detect these objects at night and supply the pilot with sufficient warning to enable him to avoid an accident.

The Army and Navy saw the possibilities of this discovery and set about developing this equipment as a range finder. They discovered many uses for it and developed it to a high degree. One of the first installations for the Navy was in 1938 when it was installed on a ship and tried out at sea.

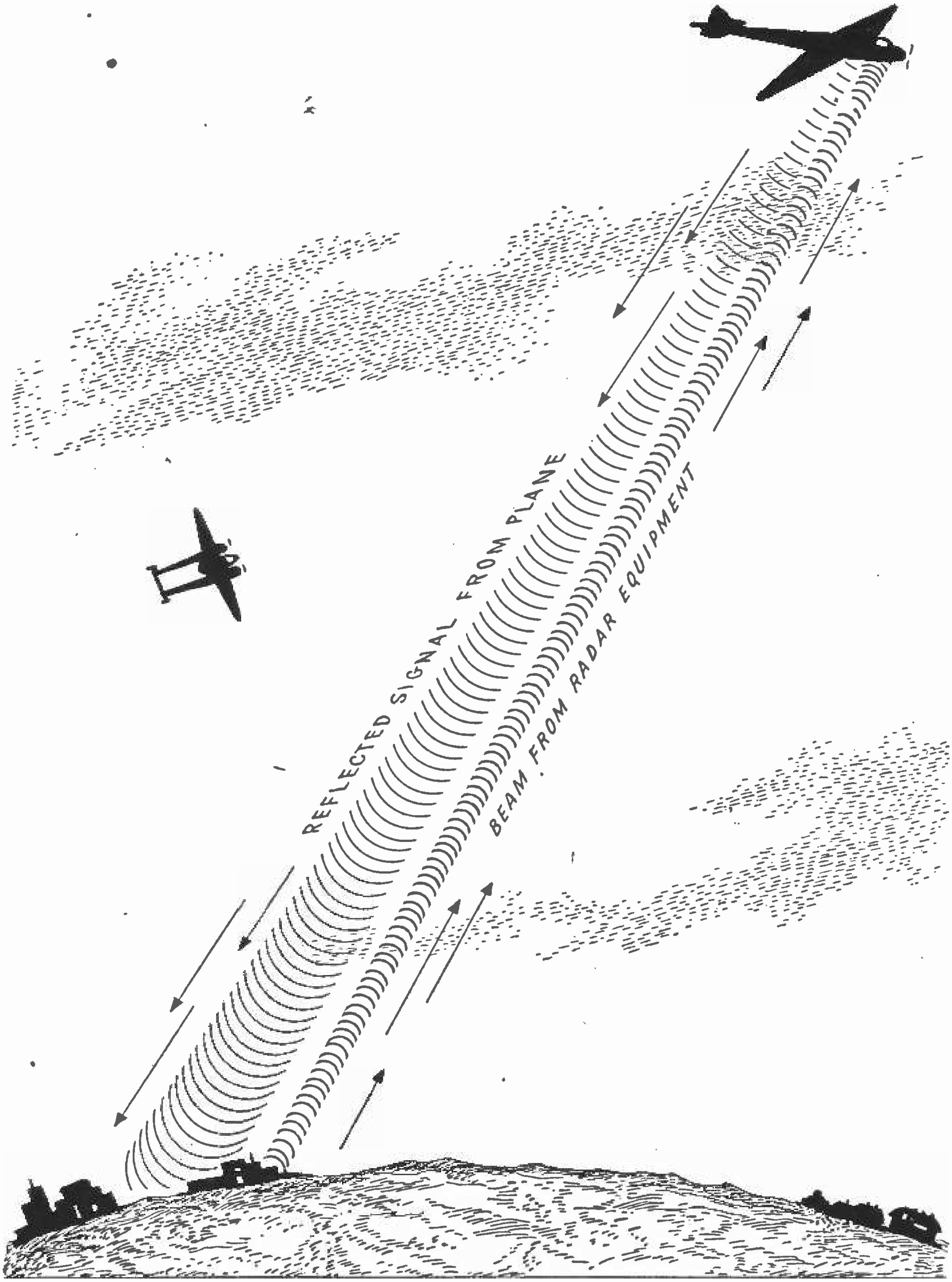
During 1940 and 1941 when England was fighting for her life during the aerial blitz, radar proved its value. There is probably nothing that contributes more to the protection of England than radar. The English called their apparatus a radio-locator and used it to detect attacking planes. It enabled them to get their fighters off the ground ready for attack before the German bombers arrived. This not only helped them to attack the invaders but it saved their planes from being attacked on the ground.

The United States found the value of radar in the very first engagement with the Japanese. At Pearl Harbor radar detected the attacking Japanese planes long before they reached the mainland. Unfortunately, the officers mistook these planes for their own which were due about that time. Radar certainly proved its detecting ability by discovering this Japanese air squadron more than seventy-five miles away.

Later on the United States Navy sank a Japanese battleship by radar. The Japanese ship was eight miles away, completely invisible because it was a dark night. Radar detected its exact location. Our naval vessel sank the Jap battleship with its second salvo. There are many such stories which show the value of radar.

The fundamental principle back of radar is not new and has been known for some time in the radio field. Using it for a detection means is a recent development. Probably no apparatus as competent as radar has ever been developed in such a short space of time. Today there are many different types of radar equipment; it is used on land, sea, and in the air.

The scientists of this country worked day and night to perfect this apparatus which sends out very small high-powered radio beams. This electronic machine scans the horizon or the sky to



HOW RADAR IS USED FOR AIRPLANE DETECTION detect and locate enemy ships or planes.

One of the most important parts of radar is the machine which receives the reflected waves and analyzes them. When you realize that the radio waves can travel 186 miles in a thousandth part of a second, it is difficult to see how a machine could be developed to measure the time elapsing between the transmitted and reflected wave. However, this has been accomplished and now the distance of the object reflecting the wave can be determined.

If you have ever checked the flash of light against the roll of thunder to determine how far away the lightning is, you have used a means similar to radar to check distance. This is quite easy to do. The light travels fast—at the same speed as radio waves—and so the time it takes to reach you is negligible. However, sound travels quite slowly. If you look at the second hand on your watch and note how many seconds pass before you hear the thunder, you can easily tell how far away the lightning is. Sound travels at the rate of 1,130 feet per second; so if it takes approximately 4.7 seconds between the flash of lightning and the time you hear the thunder, then the lightning is 1 mile away. You can do this with an echo too. This is a closer parallel to the way radar works. If there is a cliff near by which reflects sound waves to cause an echo, you can use the same method to determine how far away it is. You can shout and measure the time it takes for the echo to return. In this case if it took 4.7 seconds, which would be 1 mile, the object would be only ½ mile away since the sound has to travel ½ mile to the cliff and ½ mile back.

Going back to radar, if it took a 1,000th of a second to receive a reflected wave, then the wave has traveled 186 miles. The plane or ship reflecting the wave would then be 93 miles away.

It is valuable to know how far away the plane or ship is, but if you want to attack the object with guns or planes you must know its exact location. In the case of a plane you not only want to know its location but the altitude at which it is flying. Radar is capable of giving this information too.

If you visualize this radio beam as traveling in the form of a beam of light similar to a searchlight beam, it is quite simple to see how it works. You scan the sky with this beam until you receive a reflected signal; then you check the angle of the beam in a horizontal and vertical position. If the beam is at a vertical angle of thirty degrees when you receive the reflected wave, and you know the object is 93 miles away by timing difference, then you can easily calculate its height. Now you can do the same thing in a horizontal plane. At the time when you receive a reflected signal you can check the angle of the beam from true north. By knowing this and the previously determined height of the plane you can spot its exact location on a map. Radar equipment is so designed that you can take a direct reading that eliminates the calculation of the height or the location of the plane. You can tell this almost immediately and you can determine the direction in which the enemy plane is flying.

The fact that ships have been sunk and that planes have been shot down by radar is only the beginning of the important part this new scientific development will play in our lives. It has many applications; a good many of them are yet to be discovered but we do know several that are being considered at the present time.

Radar will be valuable to marine navigation in a number of ways. It is quite possible that a ship with this equipment could sail into a harbor or river during the night when there was a heavy fog, and anchor in its proper location without contacting radio stations for its bearing. This could be done by scanning the shore line with a radar beam. The contour of the shore line could then be established and the pilot would know exactly how far from shore the ship was. He could also tell if there were other ships in the harbor and their locations. In fact, he could pull right up alongside of another ship even though it was not physically possible to see it. Radar could eliminate many collisions and accidents both at sea and in harbors and rivers. It could be used to detect icebergs and floating wreckage. Accidents such as the sinking of the *Titanic* could be eliminated.

Even though the pilot's visibility was zero, he could locate buoys, lighthouses, and channel markers.

Railroads also will probably find a use for radar. The equipment could be mounted in the engine so that the radar beam would shoot out in front of the train. This would enable the engineer to detect trouble at a great distance ahead and would give him time to slow down or stop before he was on top of the object. Fog and snowstorms also handicap railroad lines and are often the cause of serious accidents because visibility is so poor. Radar might eliminate many grade-crossing accidents where automobiles are stalled on the tracks. The engineer would get an indication on a screen that something was on the tracks ahead of him; he would also have an indicator to tell him just how far ahead it was. He could then slow down long before the object became visible.

This might also eliminate accidents caused by stalled trains or rock slides. It is quite possible that this machine could even detect a bridge washed out. Of course, on curved sections of tracks it might not be practical, but it still might be used to warn the engineer that he was approaching a curve.

We have already mentioned the importance of radar to aviation. Without radar, even planes coming in on a radio beam can get off their course and run into mountains or other objects. Radar would give the aviator knowledge of all mountains near by and their altitude with respect to the plane. It would also enable him to know his exact height above the ground at all times. An altimeter only gives him his height above sea level, and this is not always accurate as it operates on air pressure which is varying at all times. Radar can send high-powered ultra-short waves at almost any angle. By shooting a wave directly beneath him the pilot can pick up the reflected wave and check his height above ground at that point. By sending the wave at a slight angle ahead of him towards the ground, he can tell what his height above the ground will be when he reaches a point five miles ahead.

Radar will also detect any high objects, such as radio towers, gas tanks, tall buildings, etc. If the plane is coming in for a landing, it will be quite easy for the pilot to steer clear of these objects even though they may not be visible.

If the plane were traveling at a relatively high altitude but still below mountain peaks, the radar beam could be set so it would scan the area ahead. Quite often ice or motor trouble will force the plane to fly at a lower altitude. In cases such as this, the pilot could locate the mountain peaks and go around them with safety. Some landing fields are located in valleys and are particularly hazardous in bad weather, when visibility is low. This machine would enable the plane to fly right down the valley without fear, as the pilot would know the exact location of the mountains on both sides.

In the early days of aviation it was rare for planes to collide in the air. There were relatively few planes then, and most of these only flew when the visibility was good. Later on radio communication was used at airports and this prevented accidents since the planes would receive word when they were to come for a landing. This gave the airport complete control over incoming and outgoing planes around the port. Not so long ago the radio beam was perfected which enables planes to land in a dense fog. As you probably know, the airport sends out a narrow radio beam which the pilot can pick up and fly in on.

As more and more planes are used, the danger of collision becomes greater. Around airports the problem will be difficult even though the planes can receive instructions from the field. It may become like a huge traffic jam around airports and if the visibility is poor, we may have a great many collisions in mid-air. Even away from the airports it will become dangerous to fly in bad weather.

Here radar can be used to great advantage. Planes equipped with radar could easily detect all planes around them whether they are above, below, to the side, or in front of them. This invisible beam will act like an eye, capable of seeing in the densest fog or on the darkest night. With this equipment it will be easier for the pilots to avoid accidents with other planes.

As time goes on you will hear more and more about the wonders of radar when all the details about it can be released.

XVIII Radio Tomorrow

When you stop to think of the accomplishments that have been achieved in radio, particularly in the last twenty years, you may begin to wonder if its scientific development has not reached a peak. When you realize that television is really here and that colored television is not far behind, you are apt to ask yourself what more can be done in radio broadcasting.

Radio engineers have a very different viewpoint, even though some of them felt that way when they were young engineers entering the field. But so many new developments are constantly being made that they realize that radio is only in its childhood.

Every day radio equipment is being improved. Every day engineers are discovering and gaining more knowledge about the behavior of electrons. Just what this all may lead to twenty years from now no one really knows.

In the early days of television a rotating disk with a series of holes in it was used to scan and reproduce the television picture.

This did not produce very good results, but it did prove that pictures could be transmitted electrically. Then the scientists discovered they could project a stream of electrons and control the stream by electrical means. This led to the development of present day television tubes.

There are new developments now that are in somewhat the same state that television was in when scientists were experimenting with mechanical scanning. Probably practical solutions will be achieved for these new developments by electronic discoveries.

Scientists are now working, for instance, to achieve a better method for sound reproduction. When we speak of better reproduction we mean reproducing the original sounds more accurately. If we had perfect reproduction, it would be impossible to tell the difference between the original sound and the reproduction. Great strides have been made in this direction, but we still have a long way to go. Frequency modulation has brought us one step closer to it but there is still a big step ahead. That is going from monaural to binaural reproduction, or what is called auditory perspective. Monaural reproduction is the type used at present. Monaural means hearing with one ear and binaural means hearing with two. If you put your hand over one ear and listen to any sound, it is difficult to determine the direction of the sound source. This is probably one of the reasons why we are equipped with two ears. The reason for this is that sound waves reach our right and left ears at slightly different times and with different intensity, unless the origin of the sound is directly in front of or behind us. Because our brains are capable of detecting this difference we can tell from what direction the sound is coming.

When we use a single loud-speaker to reproduce sound, all the sound comes from one location. We do not get the illusion of the various sounds coming from different locations as we should. If we hear two people talking and they are standing eight or ten feet apart, even if we could not see them we would know their approximate location. In the theater when we hear an orchestra playing, the various players with their instruments are in different locations on the stage and, therefore, the orchestra sounds quite different from the way it sounds when you hear it coming from a single loud-speaker. It is very natural to think that all you have to do to overcome this problem is to install more than one speaker. This spreads the sound out, which helps to some degree, but you still do not get the true effect because both speakers are producing the same sounds. You do not get the illusion of the piano being on one side of the stage, the drums in another location, the saxophone in another, etc. True binaural reproduction would do this—you would get the feeling of an entire orchestra playing on the stage and you could detect the location of the different instruments even though you did not see them.

This is not just a dream. Engineers have realized the difficulties in our present system and have been working on binaural reproduction for some time.

Demonstrations have been given in certain engineering societies and they have been quite successful. In one demonstration that was given, the audience sat in front of a large stage with the curtain drawn so you could not see what was going on behind the curtain. All you could do was listen to the various sounds being reproduced. Two people were talking behind the curtain—one on each side of the stage. Apparently they were stage-hands. One man called to the other and asked him for a hammer; the second man slid the hammer across the stage to him, and the first man picked it up and started to nail two boards together. Then the first man walked across the stage to talk to the second worker about sawing a piece of wood. You could actually follow his footsteps as he crossed the stage. Then the first man walked back to his side of the stage and the second man said he had found a golf ball and bounced it across the stage to him. The first stage-hand said, "Wait a second and I'll slide the hammer back to you." Just as he said this the curtain went up and there was nothing on the stage but two loud-speakers and then you heard the hammer slide back across the stage. The illusion of these men working and talking in various parts of the stage had been accomplished by the use of two loud-speakers in a special hookup. The sound and action that the audience heard occurred in another part of the building. This is how it was done: In another room in the building two microphones were set up and spaced a certain distance apart. These microphones were connected to individual amplifiers and then two separate lines were brought down from each amplifier to the two loud-speakers on the stage.

This means, if you forget about the amplifier system, that each loud-speaker was directly connected to one of the microphones in the other room. So if a person in the other room were talking closer to number one microphone, the number one speaker in the audience room would be louder than the number two speaker. If he were talking in front of the number one microphone and walked toward the number two microphone, then the volume on the number one speaker would gradually decrease as he walked, and the number two speaker would get louder as he approached the number two microphone. Naturally, as you listen to two loud-speakers, one on each side of the stage, and the volume gradually shifts from one to the other, you get an illusion of the sound traveling across the stage.

Of course, there is more to creating an illusion of auditory perspective than merely changing the volume levels on two speakers, but this demonstration was given to show what interesting and realistic effects could be accomplished. You can naturally imagine what an improvement it would make in radio if you could sit in your home and hear the various actors' voices coming from different parts of the room and could tell when they moved across the stage. If you listened to an orchestra, it would seem as if an entire orchestra were stretched out across the room and you could detect the locations of the various instruments.

Other demonstrations of this have been given. In one case it was used in conjunction with a motion picture. Several microphones were used to pick up the orchestra and a separate recording was made of each pick-up. When the recordings were reproduced, several loud-speakers were used, and each speaker was supplied from one of the separate recordings that were previously made. The loud-speakers were placed in approximately the same positions as the microphones were with respect to the orchestra. This demonstration was quite successful. You really had the effect of a huge orchestra being on the stage.

This method, while it served its purpose to demonstrate the possibilities of auditory perspective, is entirely too costly to be used commercially. The same thing could be done in radio, but it would require two or three transmitters operating on different frequencies and a great deal of other equipment.

As this would be quite costly and would eliminate quite a few stations, because the frequency band allowed broadcasting is already crowded, it is not practical.

The methods described here for reproducing this effect are not necessarily the only ways of accomplishing auditory perspective. The engineers are working on other methods at the present time, but we do not know how close they are to a practical solution. Some new discovery or development may make it practical at any time.

For some time scientists have also been working on the reproduction of three-dimensional pictures. The third dimension gives depth to a picture, so the objects in the picture appear to have roundness or depth instead of appearing flat. Quite some studies have been made along these lines in the motion picture field. In fact, present day colored motion pictures give you the feeling of a certain amount of depth. As the same fundamental principles could be applied to television we will describe a demonstration that was given of three-dimensional motion pictures.

If you have ever experimented by closing one eye, then opening it and closing the other while you concentrated on a single object, you probably have discovered that the object seemed to shift its position. This illusion is caused by the fact that the right eye sees the object from a slightly different angle than the left eye. This enables us to judge distances and adds depth to our vision.

If you photograph a scene using two cameras spaced eye distance apart, you are accomplishing the same thing that your eyes do. Now if you could reproduce these two pictures so your left eye would see one of the pictures and your right eye the other, then you would have a three-dimensional picture. Here is one way it has been done: Two projection machines were used, spaced the same distance apart that the cameras were, and both pictures were projected on a single screen. This makes the pictures overlap, one on top of the other. Each of these projection machines was equipped with polaroid filters. When this is done it produces light which is said to be polarized. The light coming from one projection machine is polarized in one direction and the light coming from the other machine is polarized by these filters in the opposite direction. By wearing glasses in which the left eyeglass is polarized in one direction and the right glass polarized in the opposite direction, you can see a three-dimensional motion picture. The reason for this is that each glass filters out one of the pictures, so your right eye sees one picture and your left eye sees the other. When you look at the picture with these glasses on, you get the feeling of great depth. A train coming toward you gives the feeling that it is coming right out into the audience.

This principle could be applied to television if two projection receivers were used. Of course, this would be very expensive, so it would not be considered practical. Various engineers have been considering methods for producing three-dimensional television, but up to this time they have not discovered any practical solution.

We have only mentioned two ideas which could be developed. There are many other possibilities.

The radio field is constantly developing new apparatus, making new discoveries, and finding additional uses for radio. Just what it all may lead to only time will tell.

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