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RCA REVIEW

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THE BIRTH OF AN INDUSTRY*

BY

DAVID SARNOFF

President, Radio Corporation of America

THE successful planning of this building and the exhibits it contains are due in the largest measure to the skill and the experience of Major Lenox Lohr, whom I had placed in charge of this task. He came to it well equipped by his record of success as general manager of a previous Fair known as the Chicago Century of Progress. In fact the record he made there so commended itself to us here that we invited him three years ago to become President of the National Broadcasting Company, the position he occupies today.

When one views the wonderful social and industrial developments embodied in the exhibits at the New York World's Fair, he has reason to be proud of the ingenuity of his fellow men. All about us here today, in scores of great buildings, are exhibits which testify to the unwillingness of man to remain satisfied with the marvels of our present civilization. They prove his ability to bring to practical use and service today and tomorrow the dreams of past generations.

This RCA Exhibit Building, which we are dedicating here, houses only a small part of all the scientific advances displayed on these grounds. But the services to mankind shown here represent one of the outstanding advances that has been made in this century to overcome limitations imposed by nature and to bring the peoples of the world into closer contact.

Today we are on the eve of launching a new industry, based on imagination, on scientific research, and accomplishment. We are now ready to fulfill the promise made to the public last October when, after years of research, laboratory experiments and tests in the field costing millions of dollars, the Radio Corporation of America announced that television program service and commercial television receivers would be made available to the public with the opening of the New York World's Fair.

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* An address at the dedication of the RCA Exhibit Building, New York World's Fair, April 20, 1939.

Ten days from now, this will be an accomplished fact. The long years of patient experimenting and ingenious invention which the scientists of the RCA Research Laboratories have put into television development, have been crowned with success. I salute their accomplishments and those of other scientists both here and abroad whose efforts have contributed to the progress of this new art.

On April 30th, the National Broadcasting Company will begin the first regular public television program service in the history of our country; and television receiving sets will be in the hands of merchants in the New York area for public purchase. A new art and a new industry, which eventually will provide entertainment and information for millions, and new employment for large numbers of men and women, is here.

There is something tremendously inspiring to all of us in the RCA Family in launching a new service whose purpose is constructive, into a world where destruction is rampant. We have all been impressed of late by the ease with which things can be destroyed, compared with the skill and the labor that go into their making.

Human aspiration and intelligence are at constant war with the forces of reaction and destruction. When a major victory is won, civilization is able to make a giant stride forward. The coming of radio was one of those victories. After ages in which nature had maintained the barriers of time and distance between men and nations, radio eliminated them, and enabled man to send a whisper around the earth.

And now we add radio sight to sound. It is with a feeling of humbleness that I come to this moment of announcing the birth in this country of a new art so important in its implications that it is bound to affect all society. It is an art which shines like a torch of hope in a troubled world. It is a creative force which we must learn to utilize for the benefit of all mankind.

This miracle of engineering skill which one day will bring the world to the home, also brings a new American industry to serve man's material welfare. In less than two decades, sound broadcasting provided new work for hundreds of thousands of men and women, added work in mines and forests and factories for thousands more, and aided the country and its citizens economically by causing the flow of hundreds of millions of dollars annually. Television again bids fair to follow in its youthful parent's footsteps, and to inherit its vigor and initiative. When it does, it will become an important factor in American economic life. Also, as an entertainment adjunct, television will supplement sound broadcasting by bringing into the home the visual images of scenes and events which up to now have come there as mind-pictures conjured up by the human voice.

Time does not permit me to describe the many other exhibits in this building. They demonstrate important radio services and instrumentalities such as facsimile, which transmits printed words and pictures through the air; the automatic emergency alarm, which is adding immeasurably to the safety of those who travel by sea; and the significant services for message communications by land and sea and in the air.

In dedicating this RCA Building as the birthplace of a new American art and industry, we have in mind the conception of a great service which will benefit our social and economic life, and the national ideals of our people. The television receiving sets about us today, and millions of their like to follow, will serve to bring about these practical results and to foster these ideals. They represent radio's "World of Tomorrow."

A TELEVISION-DEMONSTRATION SYSTEM FOR THE NEW YORK WORLD'S FAIR

BY

DONALD H. CASTLE

Video Facilities Section, Engineering Department, National Broadcasting Company

Summary—*A brief description is given of the television demonstration system now in use in the RCA Building at the New York World's Fair. A few of the many problems encountered in such an installation are mentioned and their practical solutions indicated. The various program sources arranged for are described, together with the facilities provided for distribution of the television signals to the viewing receivers.*

THE formal presentation of television by RCA at the New York World's Fair required that ample facilities be provided for the general public to see a television picture and to inspect modern home television receiving equipment.

The viewing room arrangement shown in Figure 1 was decided upon as being the one which would accommodate the largest audience groups and provide good traffic control. It also makes it possible to demonstrate the large-screen projector equipment, to provide a complete show under good viewing conditions, and to schedule the shows at definite intervals. Both the viewing room and adjacent equipment room are located within the main RCA Exhibit Building at the Fair grounds. Additional receivers, including the "flask" receivers and a transparent receiver, are located in the main exhibit hall in the front portion of the building, where visitors can see them. The television receivers are arranged in rows so that the audience may file into the viewing hall from the entrance doors, form groups around each receiver and, when the show is completed, leave by the rear building doors.

The problem of suitable program sources gave some concern since, in addition to reliable service, a variety of program types seemed desirable. The signal-to-noise ratio with all the Fair exhibits in full operation could not be estimated in advance, the general opinion being that it would be an adverse factor. The final arrangement provided for reception of the programs broadcast from the television transmitter in the Empire State Building, for a film program from a local film scanner, and a live-talent or "Vox-Pop" pickup at the Fair using either the mobile-unit equipment or a direct-connected camera system.

To assure a good signal and reduce noise a directive receiving-antenna system was located atop the 250-foot steel tower on the RCA grounds. This was connected to two master receivers, the video outputs of which were used to supply video signals to the various receivers on the premises. The video distributing system thus set up can also be supplied from the local film scanner, the local camera equipment, or the mobile-unit video outputs. In the latter case, it should be pointed out that in the normal operation of the mobile units, the unit transmitter supplies a radio signal on 177 megacycles to the Empire State transmitter which then re-transmits it on the television band, 44—50 megacycles.

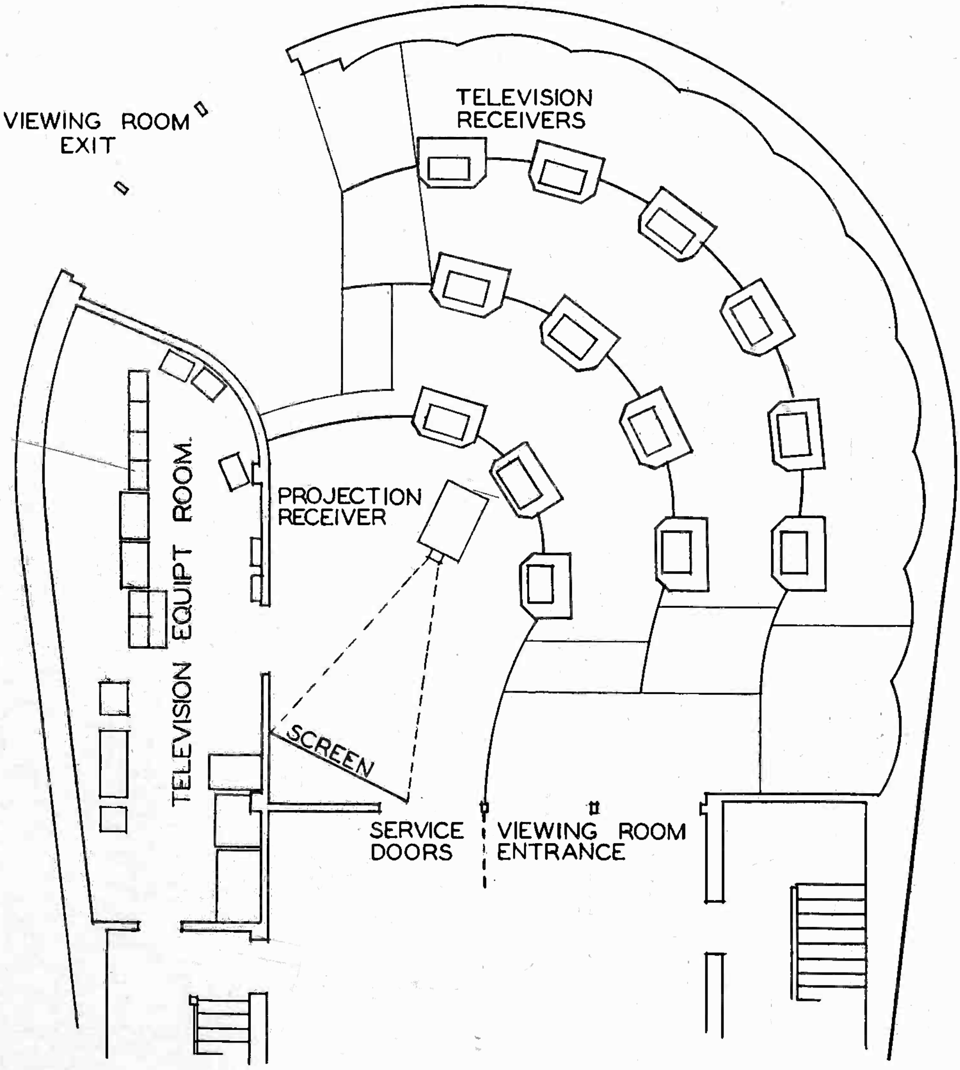
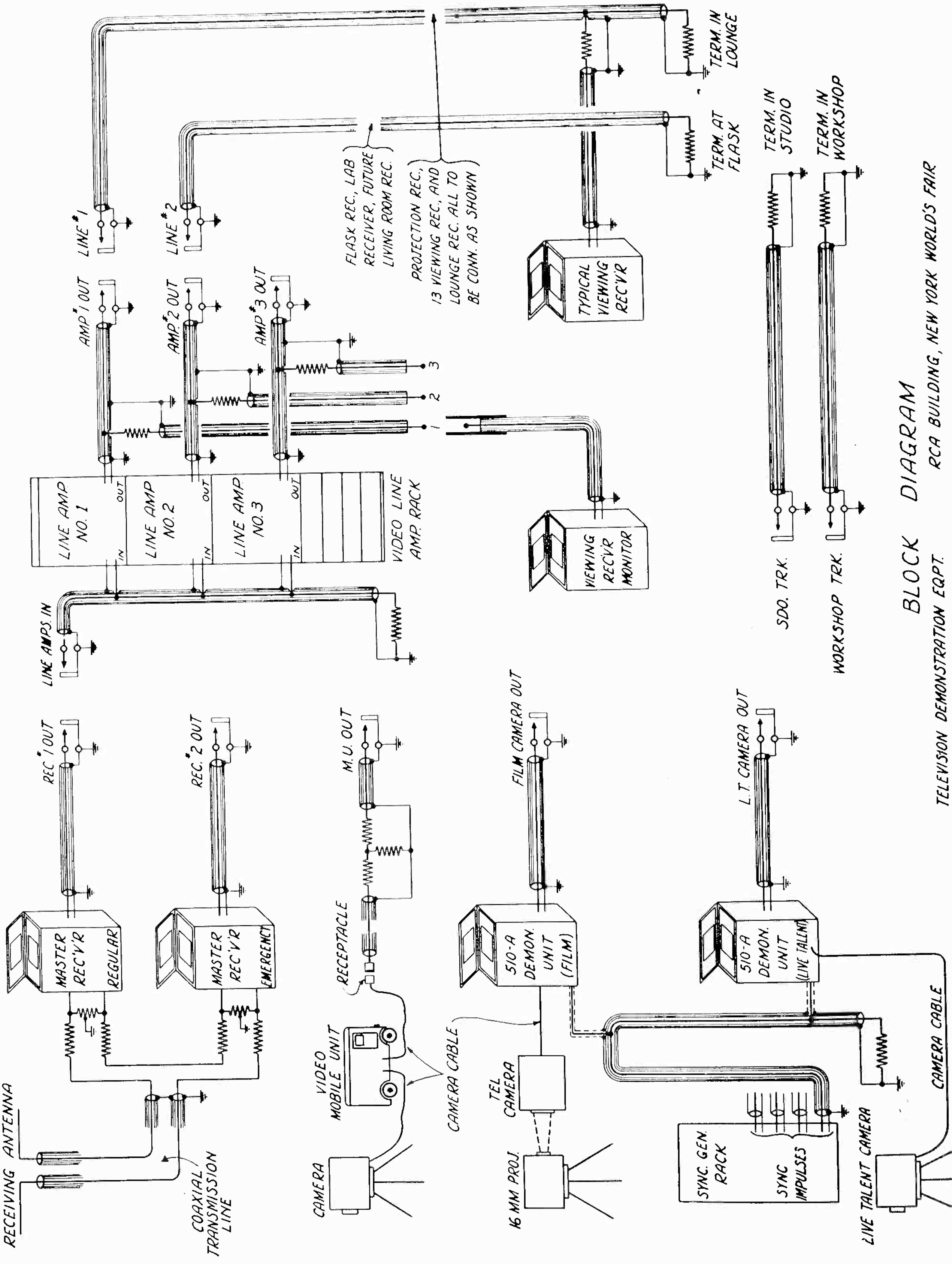


Fig. 1—Plan of television viewing and equipment room.

Figure 2 shows a block diagram of the equipment and connections. The two master receivers are connected through suitable isolation resistances to the antenna transmission line, the latter consisting of



BLOCK DIAGRAM

TELEVISION DEMONSTRATION EQPT. RCA BUILDING, NEW YORK WORLD'S FAIR two coaxial cables connected as a balanced line. These receivers are standard models of home television receivers which were modified by the addition of video-output amplifiers to enable them to transmit the complete standard video signal to each output-transmission line. Each master receiver remains equipped with its regular kinescope, thus providing for monitoring of its picture output without connection to other equipment. The video-output signal from these receivers is routed through coaxial transmission lines to the video-jack field, at which point all video switching is carried out.

The video outputs from the mobile unit and the film-camera system are also available at this video-jack field. An attenuator is inserted in the video-output circuit from the mobile unit in order to match its signal level with that produced by the film-camera system and the master receivers. Both the mobile-unit and the master-receiver outputs provide complete video signals including deflection, blanking, and timing impulses.

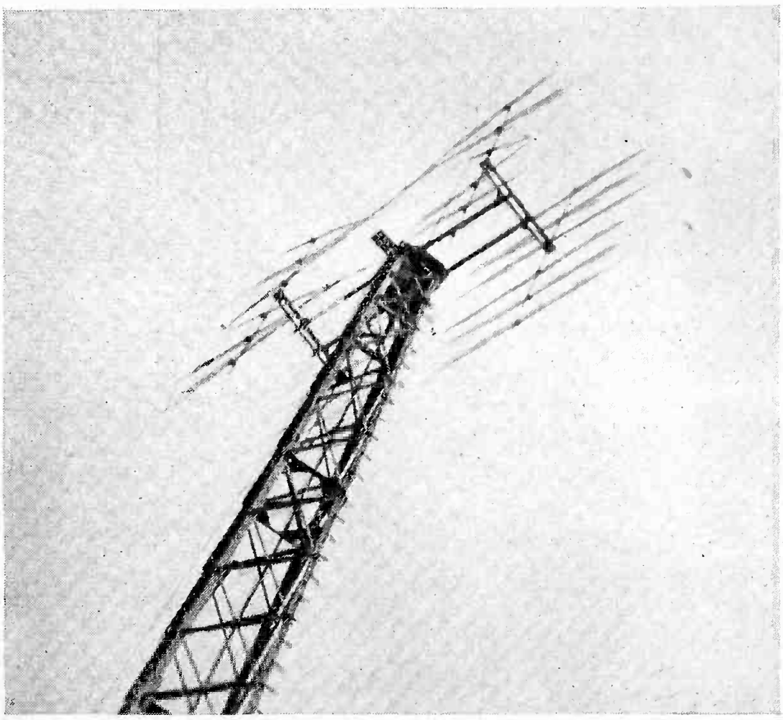


Fig. 3—Directive antenna system for master television receivers. Steel tower 250 feet high.

At the video-jack field, any one of the three program sources may be connected to the inputs of the three video-line amplifiers. The outputs of the video-line amplifiers lead to the video-jack field and may, at this point, be connected to the various video-transmission lines as desired.

Two main-transmission lines supply video signals to all the receivers in the exhibit. Additional transmission lines lead to various working points on grounds of the RCA exhibit and are used for receiver servicing or for special monitoring purposes. One of the two main-transmission lines supplies signals to the thirteen receivers, the projection receiver, and is terminated at a position on the second-floor lounge where a single receiver is connected. The other main-transmission line connects to the miscellaneous receivers on display in the main-exhibit hall in the front portion of the building. These include the "flask" receiver, a special home receiver designed for the "living room of tomorrow," and a "bread-board" type laboratory receiver.

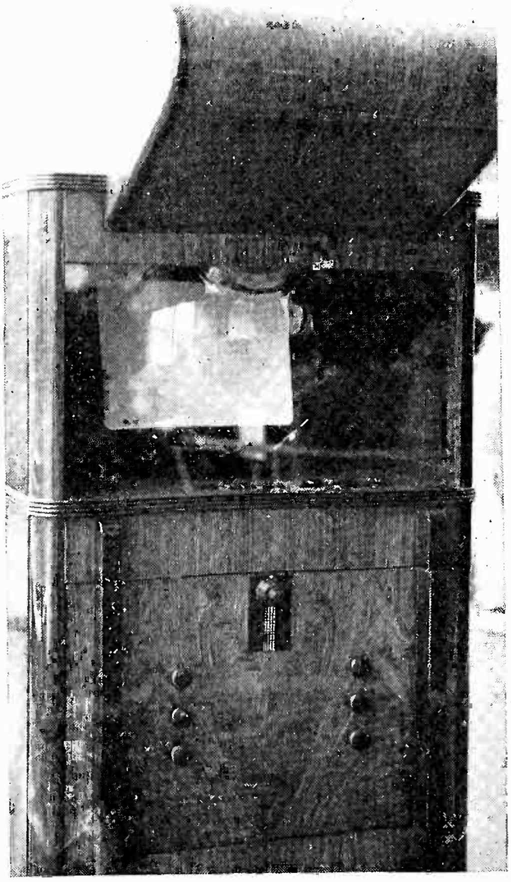


Fig. 4—An experimental model "Flask" receiver, containing front excited fluorescent screen. Provides sufficient illumination for daylight viewing.

Connections to all receivers are made by cutting the coaxial transmission line at each receiver location and inserting special splicing sleeves. The outer splice sleeve is cut out to accommodate a 500-ohm isolation resistance, connected directly to the center conductor of the transmission line. The other side of the isolation resistance is connected, through flexible low-capacity coaxial cable, to the input terminals on the receiver.

Each viewing receiver, except for the few special-display receivers, is a standard model TRK-12 RCA home-television receiver to which a video amplifier has been added for line coupling. The input impedance of this amplifier is high or "bridging" to prevent an objectionable degree of loading of the transmission line at the monitor points. The output of this amplifier is connected directly to the control grid of the kinescope, thus by-passing all normal video amplifier stages in the standard receiver. The separating circuits and deflection circuits in the receiver are not changed, being connected directly to the added video amplifier.

The projection receiver produces a picture on a screen approximately 4½ ft. x 6 ft. in size. It utilizes a 25,000-volt, small-screen kinescope of the projection type, giving a picture of sufficient brilliance for projection by means of an optical system. The screen for this receiver is placed in such a position that the audience may view either the projected image or the image on the television receiver which is directly before them.

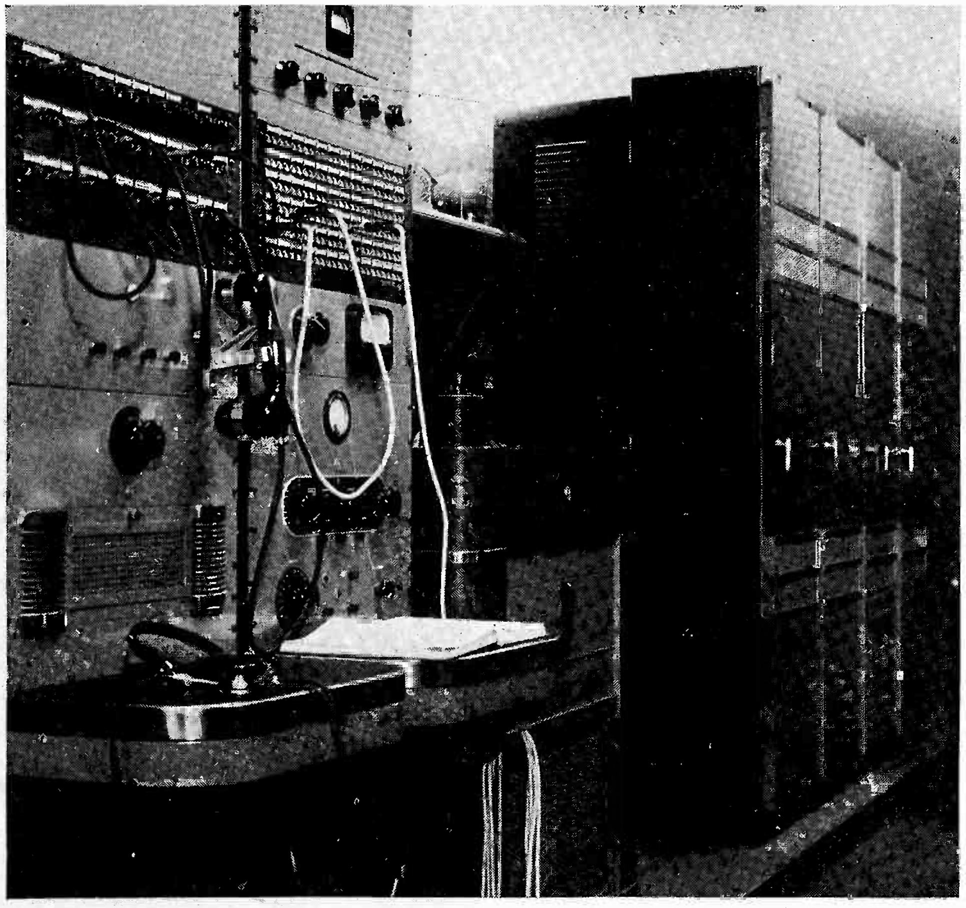


Fig. 5—Equipment room, showing left to right, audio racks with co-axial and audio jack fields, 510-A demonstration cabinet, and synchronizing generator and line-amplifier cabinet racks.

The "flask" receiver on display in the front exhibition hall consists of a standard receiver equipped to operate a special laboratory type of kinescope. In this kinescope the fluorescent screen is not transparent, but is viewed from the side on which the electron stream impinges. This results in a bright image, making it possible to view the picture in an illuminated room. The screen and the necessary electron gun is assembled within a large laboratory flask, hence the name "flask" receiver.

The film-scanning equipment includes a 16-mm projector and a "demonstration" type of film-camera system in which the entire camera chain, with exception of the camera itself is contained in a cabinet similar, in general, to a receiver cabinet. Although this demonstration-unit system generates special synchronizing impulses, a standard type of synchronizing generator was connected to this equipment in order to provide complete standard video signals at its output, the same as received from the other program inputs. The projector equipment for the film scanner comprises a standard 16-mm projector and a standard RCA 70-B turntable for sound source, both suitably modified for television use. Since all other synchronization is obtained from the 60-cycle alternating current source, the film projector synchronization is also obtained from that source. Thus the main 60-cycle a-c supply drives the synchronous motor in the projector as well as the television-synchronizing generator supplying the deflection and timing impulses to the film camera and associated circuits. The film projector in turn drives the turntable by means of a Selsyn motor system. A relay system is provided which automatically supplies power to the Selsyn motors and the main synchronous motor in the proper time

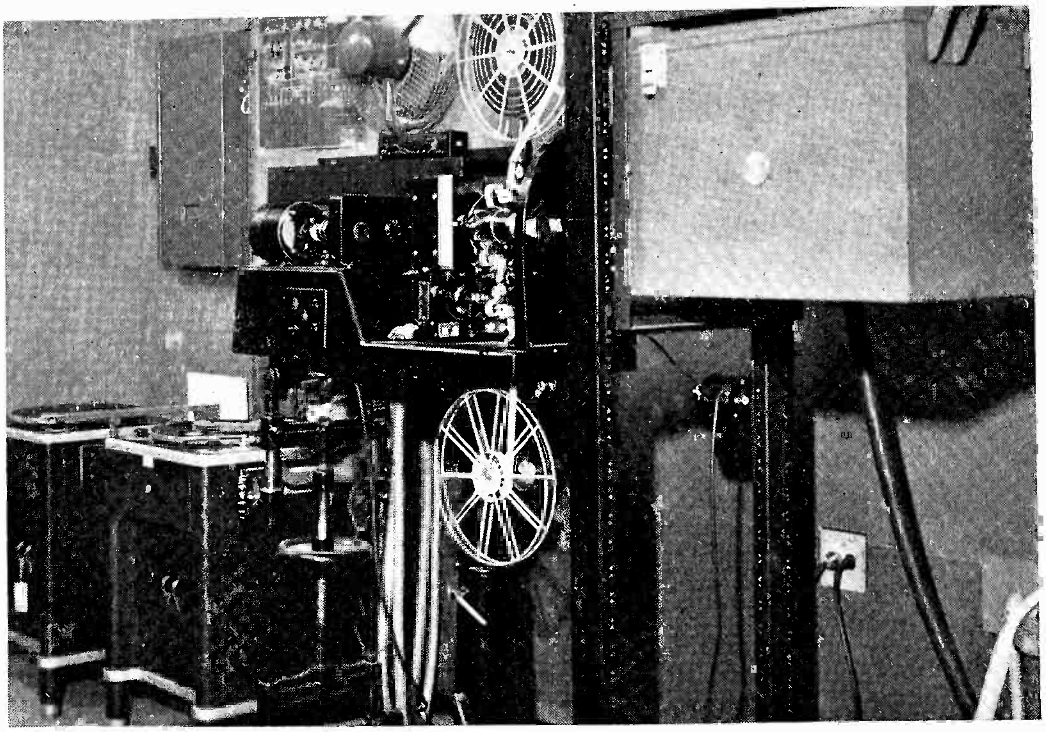


Fig. 6—Film scanner, 16-mm projector and camera (in box on rack). Turntables driven from projector by Selsyn motors.

sequence when the machine is started. Since the synchronous motor driving the film projector can operate either in phase or 180° out of phase with the main television-synchronizing impulses, control relays are arranged to interrupt automatically the main power supply to the motor during the proper interval of time so that it will "slip" 180° in phase by operating a "framing key" on the control panel.

A parking station is provided on the RCA grounds near the building to accommodate the television-mobile pickup unit which constitutes one of the program-supply sources heretofore mentioned. Outlet receptacles located at this point provide connection with cables leading into the building. These cables carry the video-output signal and intercommunicating circuits and supply the three-phase 60-cycle alternating current required for operation of the mobile-unit equipment. Since "Vox-Pop" programs may be held at night, a lighting system is installed under one of the parking canopies assuring a light intensity of 1500-foot candles over the necessary area.

The audio equipment setup is not unique, but parallels as closely as possible the arrangement of the television equipment. All equipment used is of the standard R.C.A. broadcast type, and the circuit arrangements are according to usual practice.

The equipment room, which adjoins the theater, contains all the operating and control equipment for this system. At this point all switching is carried out, viewing-room lights controlled, master receivers adjusted, etc. A standard receiver, of the type used in the viewing room is provided in the equipment room, and connected in the same manner as all the viewing-room receivers. This provides for accurate monitoring by the control-operator on picture conditions as seen on the theater receivers.

The installation described above was completed April 30th for the opening of the New York World's Fair. It has been in successful daily operation since that time and as many as 22,800 persons have witnessed the demonstrations in a single day. Thus it has provided a large number of people with an opportunity to see their first home-television program, but even more important, it has provided an educational demonstration to many who reside outside the range of the Empire State transmitter and who would otherwise not have a similar opportunity until local television transmission becomes available to them.

A MODERN RADIOTELEGRAPH CONTROL CENTER

By

D. S. Rau and V. H. Brown

R.C.A. Communications, Inc.

Summary—*High-powered transoceanic and medium-powered inter-city radio stations located at points on Long Island, in New Jersey and in New York City, representing 51 transmitters using 79 frequencies and a corresponding number of receivers, are operated by remote control from a central point at Sixty-six Broad Street, New York City. Audio-frequency circuits over both land lines and ultra-high-frequency radio channels are utilized as the medium for the remote control functions. The special apparatus provided for handling these channels, their arrangement, and operation, are described in this paper.*

DURING the early days of long-wave radio communication it was the practice to concentrate operating personnel at the radio stations. Messages received over the radio circuit were copied at the receiving station, and retransmitted over land telegraph lines to the city office, where they were again copied for delivery to the addressees. Similarly, messages for transmission were telegraphed to the radio station for retransmission over the radio circuit.

When transocean radio business increased so that additional facilities had to be provided it was realized that the old method of telegraph relaying was too slow and therefore commercially unsound. It was then that concentration of operating personnel at central control offices was inaugurated.[1] A central office directly keys the transmitters at the distant transmitting station, and receives signals directly from the receiving station for recording and distribution to the addressees.

The central office handling that part of the world-wide network of R. C. A. Communications, Inc., which centers in New York City is located at 66 Broad Street. This office now controls:—

36 Transmitters on 60 frequencies at Rocky Point.
10 Transmitters on 14 frequencies at New Brunswick.
2 Transmitters on 2 frequencies at Tuckerton.
3 Transmitters on 3 ultra-high frequencies at 30 Broad Street.
39 Combination telephone and telegraph short-wave receivers mostly used in diversity groups of 3, and

126 telegraph short-wave receivers mostly used in groups of 3, all at the short-wave center at Riverhead.
16 long-wave receivers at the long-wave receiving center at Riverhead.
1 Ultra-high-frequency receiver at Exchange Place.

Control of the radio equipment is intimately associated with the broad subject of traffic handling. The latter includes, among other items: contact with customers through an elaborate private telephone exchange supplemented with branch printer telegraph lines, pneumatic tubes, and messenger service; distribution of messages among operating positions by an extensive system of high-speed conveyor belts; conversion of printed text into telegraph signals by expert operators; and even the handling of addressed program material to and from foreign stations for local rebroadcast. This article, however, will be concerned only with that part of the system which ties in the traffic handling processes to the radio stations. The tie or nerve center of the system is the main control room.

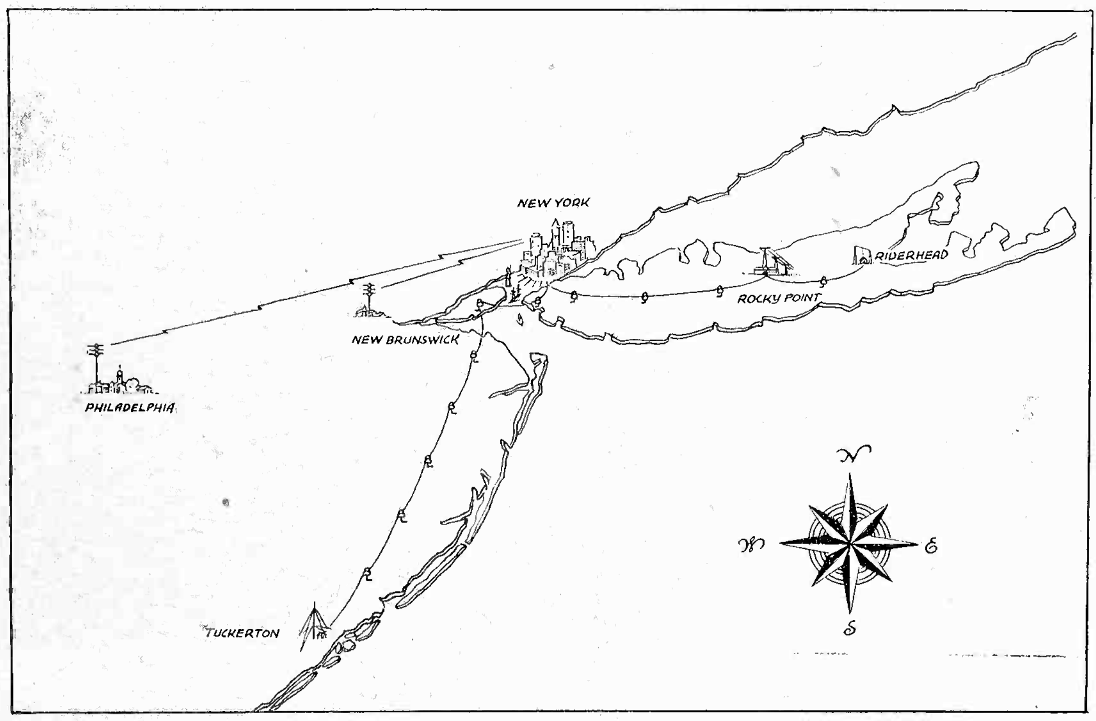


Fig. 1—Chart showing location of stations.

In detail the functions performed in the control room are as follows:—

Transmitting:
- Switching facilities for tape transmitters.
- Converting d-c keying impulses to tone signals.
- Monitoring signals to check their formation.

Switching facilities for distribution of tone signals to the proper transmitters.

Receiving:

Switching facilities for incoming lines.
Amplifying and rectifying incoming tone signals to d.c.
Monitoring of incoming signals.
Adjustment of signals for best operation of recorders.
Switching facilities to recorder positions.

Intercommunication:

By telegraph to each station.

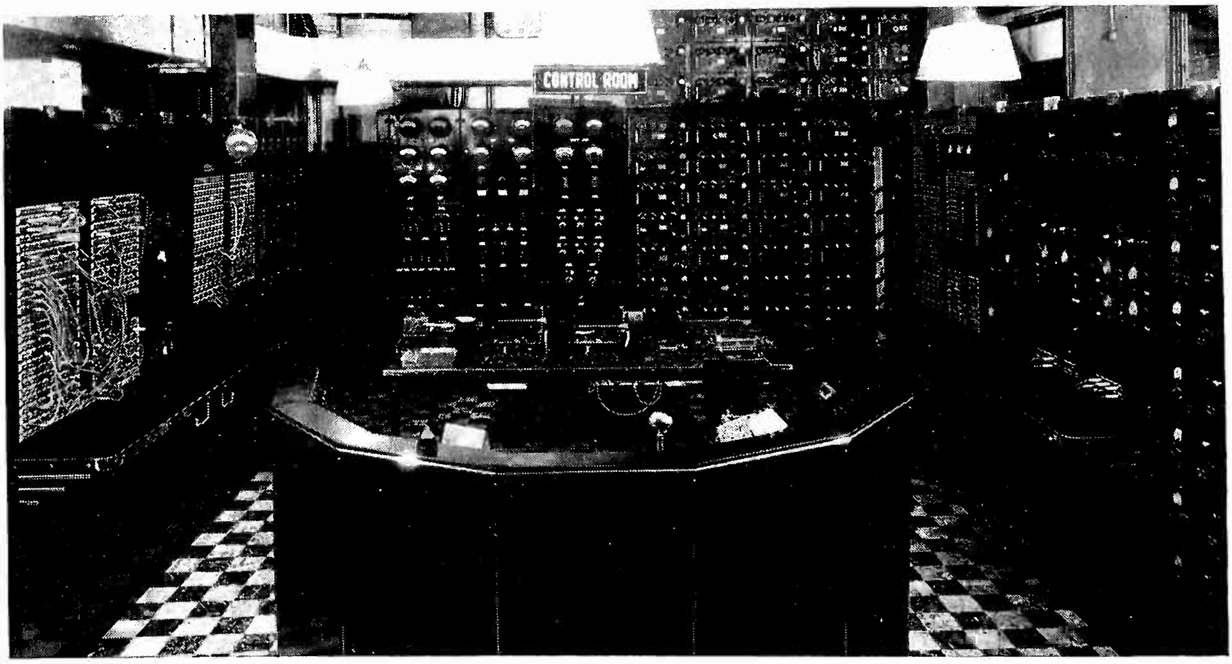


Fig. 2—Main control room.

By printer to Rocky Point and Riverhead.
By microphone and loudspeaker to operating centers.

Testing:

Lines.
Equipment.

Ultra-high-frequency transmitter control:

u-h-f link to New Brunswick.
u-h-f relay to Philadelphia.

The equipment with which these functions are performed is laid out in a systematic arrangement designed to save steps on the part of the operating staff. The heart of the entire system is the control console which is in constant touch with all parts of the system, including the operating centers, the apparatus rooms, and all the stations. Surrounding the console are the control racks where switching of lines, operating positions, and accessory apparatus is performed. Next in order and in some cases on other floors are located units of equipment that require little attention or else special attention which can be given by a separate group of attendants from those who man the main control room.

THE CONTROL CONSOLE

The console provides for the major part of the manual control functions necessary to keep traffic moving through the control center.

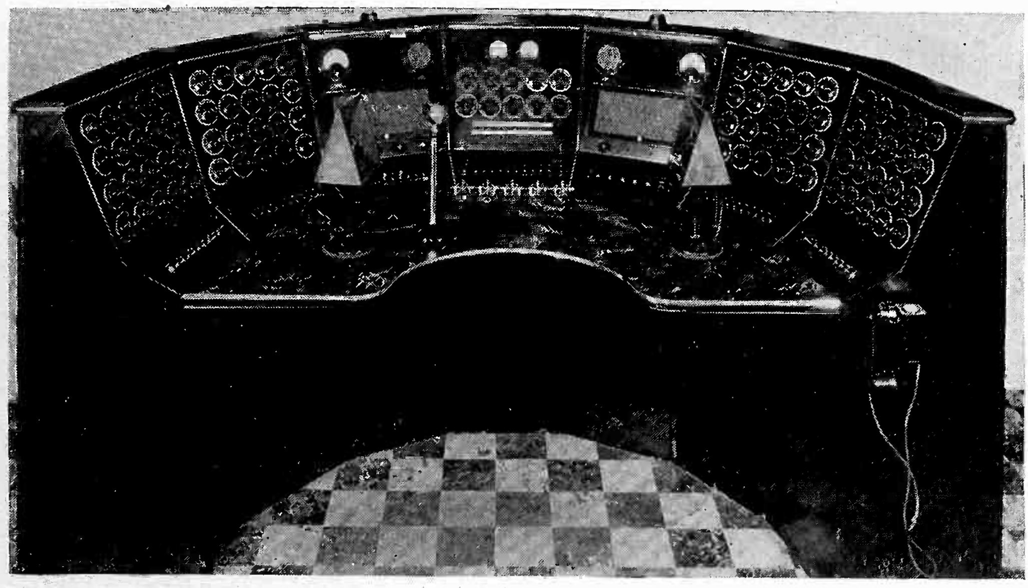


Fig. 3—Control console.

These functions include the following:—

1. Monitoring all signals, received and transmitted.
2. Communications to the stations.
3. Communications to the operating centers, and
4. Adjustment of the received signals.

The photograph of the console shows the arrangement of its panels, all within easy reach of the operating technician seated before it. On the upper panels are mounted attenuators for adjustment of the received signals, meters for observation of signal levels, loudspeakers for aural monitoring of signals and for the receiving end of the voice-intercommunication system, telegraph sounders, and other items. On the lower panels are mounted the key switches for cutting in any desired signal for monitoring, and others for control of the communicating systems. Telegraph keys, sounders, and intercommunicating microphone are located directly on the operator's shelf.

To monitor an incoming signal the key switch identified by the call letters marked on its label is thrown into its operating position. This switch connects a loudspeaker so that the signal may be heard, and a milliammeter into the rectified output of the associated amplifier-rectifier so that the amount of current going to the recorder at the operating position may be observed. The level of the signal and the corresponding direct current to the recorder may be adjusted by variation of the setting of the attenuator located on the panel above the key switch. A total of 80 attenuators and key-switch positions are provided on the console at the present time, and space for many more may be made available by extending the console beyond its present semicircular limits. If the speed of the monitored signal is too great for aural reception, connections are available for transferring it to the adjoining test table for reception on a tape recorder.

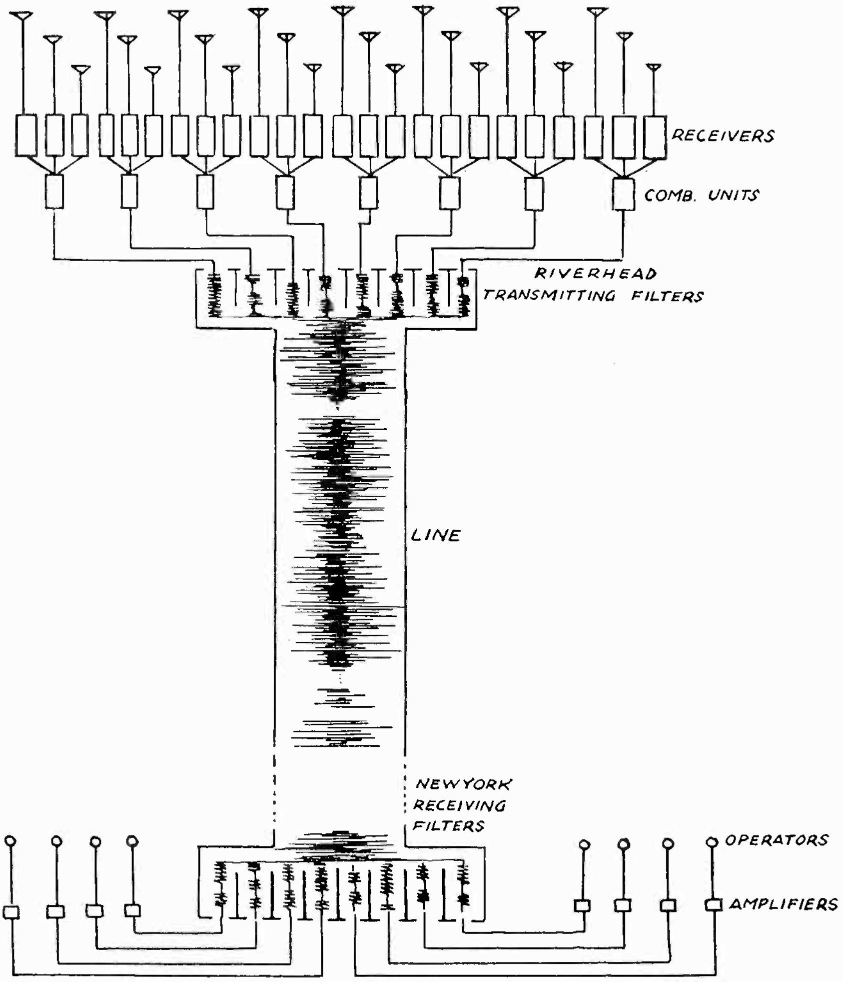


Fig. 4—Grouping of signals on common line.

Outgoing signals are monitored somewhat differently. Since outgoing signals are adjusted at their source to a definite level, further individual adjustment is not required and no necessity exists for bringing the individual signal channels to the console. To permit monitoring, however, the outgoing lines, on each of which a number of individual signals are grouped, are routed via the console. Means are provided for selecting an individual signal by switching a group of monitor filters on to the line involved and observing the output of the filter corresponding to the tone frequency of the desired signal. The group of monitor filters is coupled to the line through a bridging amplifier so that signal levels on the line are not disturbed.

Although individual outgoing signals need not be adjusted, it is necessary when a number of them are grouped on a single line to keep the resulting amplitude peaks within definite limits in order to prevent cross-talk into adjacent lines.[2] Attenuators are provided on the console for this purpose and a standard procedure has been formulated for their operation. Since the peak level on the line depends on the number of tone signals on that line and also on their phasing, these conditions must be considered in setting the combined signal level. With each keyer-output tone adjusted to zero level of 1.92 volts (6 milliwatts at 600 ohms) and a line limitation of 1.92 volts rms, the line attenuators must be set as follows to keep within this limit:—

Number of Tones	*Fixed Phase*	*Random Phase*
6	12 db	16 db
8	14	18
10	15	20
12	17	22

Communications to the stations consist in most part of orders to start-up or shut-down transmitters and receivers; to change frequencies on transmitters; and to retune receivers and to check quality of signals at the stations. "Order Wires" for this purpose are available from the console to Rocky Point, Riverhead, New Brunswick, and Tuckerton. In addition a communication circuit is provided to Philadelphia for communications concerning the operation of the ultra-high-frequency relay to that city. The sounders for the most used circuits, Rocky Point and Riverhead, are mounted on resonators located on the main shelf, while the other sounders are installed on shelves hidden behind grille panels.

Communications to the operating centers and other parts of the building are handled over an intercommunicating-voice system. A dynamic microphone on the console shelf can be connected to various lines by key switches. Standard public-address-type amplifiers and permanent-magnet-type dynamic loudspeakers strategically located throughout the operating floors complete the outbound system. Similar equipment is provided for the inbound circuits. The loudspeakers in this case are mounted behind the telegraph-sounder shelves and are thus hidden by the same grille panels.

LINE CONTROL AND TEST RACKS

Arranged on the left side of the console is a group of seven racks, five of which are assigned for control and testing of the lines connecting 66 Broad Street to the transmitting and receiving stations. Figure 5 shows the general arrangement of apparatus mounted on these racks. Numbered from right to left, since future growth will continue to the left, racks No. 1 and No. 2 contain miscellaneous apparatus directly associated with the lines, such as repeat coils, equalizers, hybrid coils, and associated networks. On racks No. 3 and No. 4 are mounted all jacks directly concerned with the lines. A typical lineup of jacks is shown in Figure 6. Although this actually illustrates a receiving-line circuit, the circuit is the same for a transmitting line except that for the latter no equalizer is provided at Broad Street. Ample jacks are provided to permit tests to be made at several important points in the lineup as well as to permit cross-patching to idle

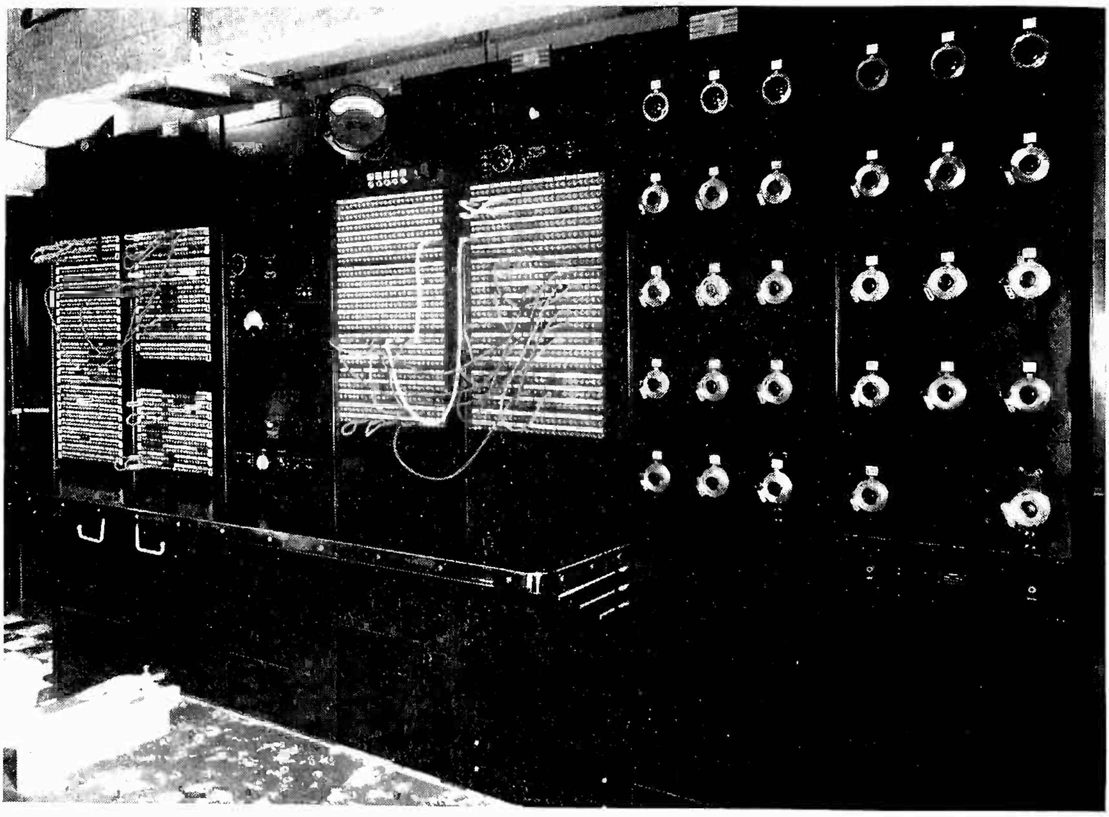


Fig. 5—Line and receiving rack.

lines or equipment in case of failure of any single part. Single-circuit jacks have been used for the line circuits, separate jacks being provided for each side of the pair of conductors comprising the line. The main reason for this measure is that in patching into these circuits the tips only of the patch-cord plugs are utilized and the pressure of the jack-contact springs on the tips of the plugs assures perfect contact, an assurance which cannot be realized with two-circuit jacks requiring contact to be made between the jack and plug sleeves. Since in most cases the lines carry a number of signals due to frequency channelling by means of wave filters, the importance of reliable connections to avoid interruption to as many as twelve traffic channels on a line justifies the method described.

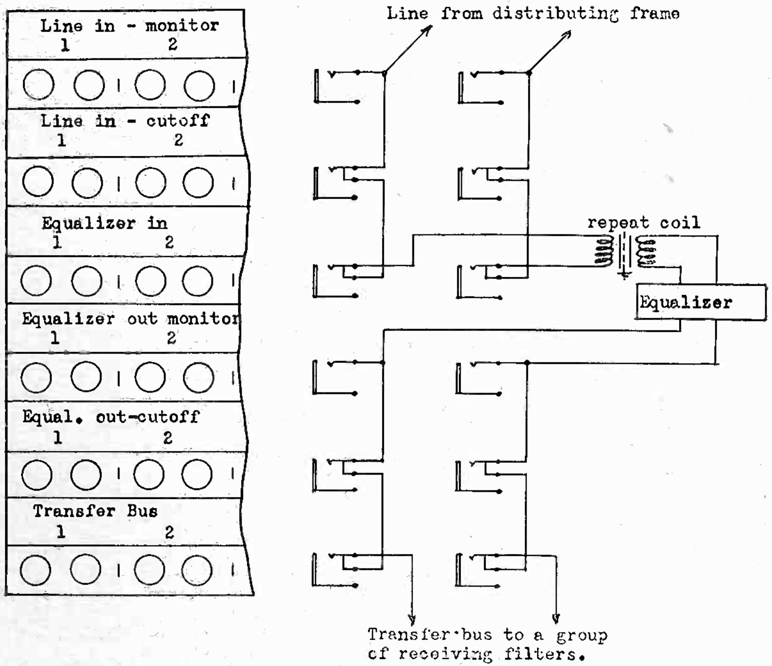


Fig. 6—Line jack layout and diagram of connection.

The line facilities provided on these racks are as follows:—

To Rocky Point—	2 lines, usable frequency band up to 5000 cps.
	4 lines, usable band up to 2500 cps.
To Riverhead—	2 lines, usable band up to 5000 cps.
	20 lines, usable band up to 2500 cps.
To New Brunswick—	2 u-h-f radio links, usable band up to 17,500 cps.
To Philadelphia—	1 u-h-f radio link, usable band up to 30,000 cps.
To Tuckerton—	2 single lines for d-c controls.

In addition, high-quality, program-material service lines are provided to Rocky Point and Riverhead, but these do not terminate on the racks being described, but lead directly to the special program-material service racks on the fourth floor.

Until recently, simplex circuits using ground return had been provided on several of the Riverhead and Rocky Point lines for use as interstation direct-current telegraph circuits. These circuits required critical relay adjustments as additional terminal loops were added, and occasionally became usable only with difficulty or not at all when leaky lines were experienced, although the audio-frequency tone circuits were little disturbed by the line conditions. Emergency tone circuits were set up as a rule to permit necessary communications to be passed on to the stations at such times. Steps have now been taken to abandon the d-c telegraph circuits and substitute tone-communication circuits, although retaining the d-c closed-circuit loops at the terminals for their advantage in respect to local-branch circuits. Three tone-communication channels are provided for Riverhead and three for Rocky Point. The three channels to Rocky Point include one printer channel for the more lengthy communications, a telegraph "order wire", and a channel with a d-c extension loop from Rocky Point to Riverhead assigned exclusively for facsimile service communications. The three to Riverhead are similar except that the third channel with a d-c extension loop from Riverhead to Rocky Point is assigned to the program-material service.

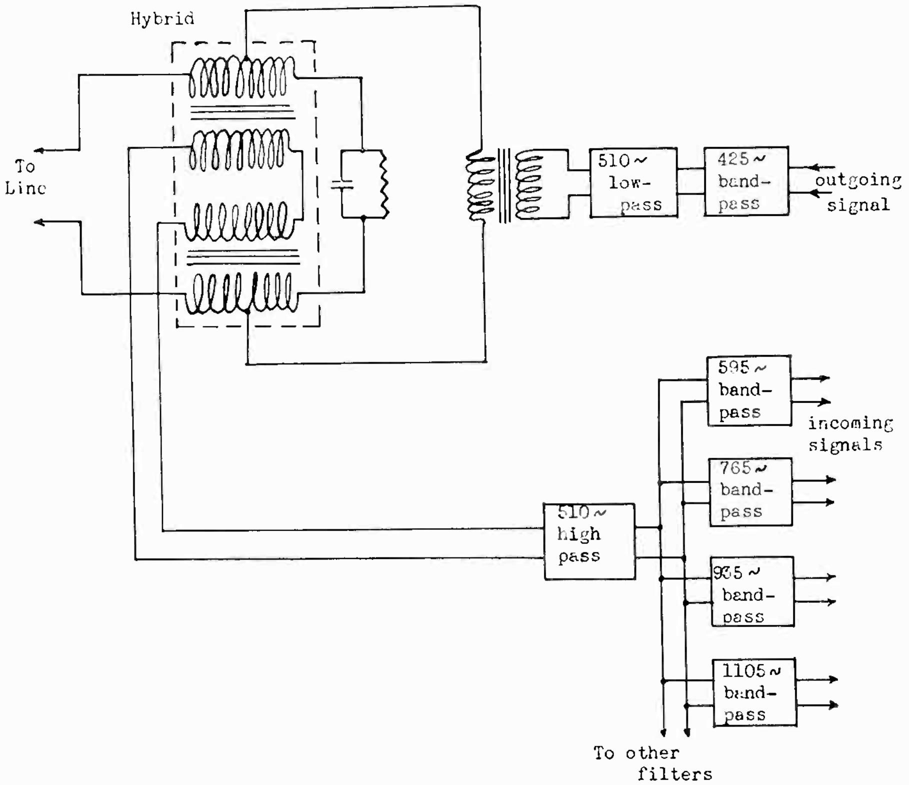


Fig. 7—Hybrid coil and filter arrangement.

The cable lines from 66 Broad Street are normally one-way circuits, that is, all lines to Riverhead are set up for transferring signals from Riverhead to the Central Office, and all lines to Rocky Point for transferring signals from the Central Office to the transmitters. To provide the tone channels in the reverse direction necessary for intercommunication circuits several of the lines to each station have, therefore, been equipped with hybrid coils. To reduce possibility of cross-talk to a minimum even under most unfavorable line conditions, the hybrid circuits have been reinforced with additional channel filtering to provide a high degree of protection to the very important traffic channels. In Figure 7 the 425-cycle channel of the multiple group is assigned to the communication circuit carrying signals in the direction reversed to that of the remaining channels of the group. Any one of the channels of the main group may be assigned to the communication circuit in the normal direction.

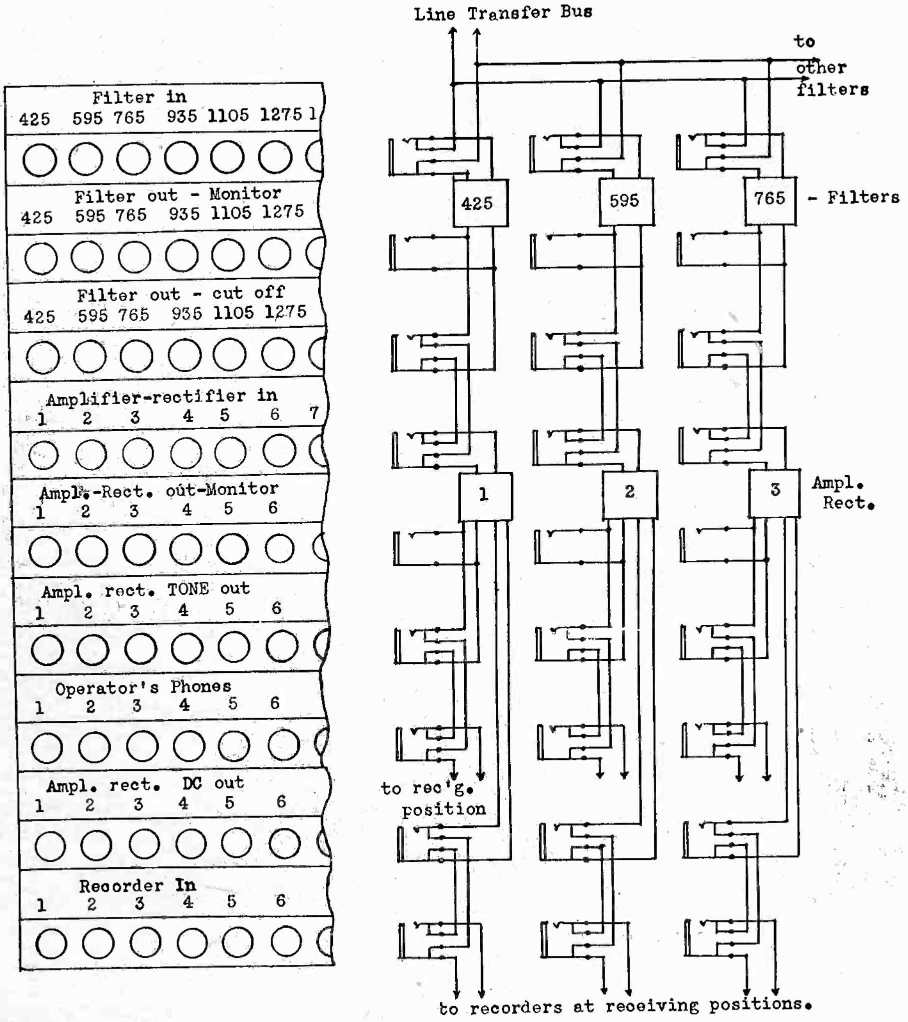


Fig. 8—Receiving jack layout and diagram of connections.

On line rack No. 5 are mounted several units of apparatus used for testing lines, signals, and equipment. These include a calibrated amplifier, volume indicator, and amplifier rectifiers to drive recorders on the associated test table located in the center of the room. A port-able cathode-ray oscilloscope forms part of the test equipment, and may be used to assist or replace the other test equipment. The patching jacks for the test equipment are located on line rack No. 4 for convenience in patching to the line jacks either directly or through the monitor filters. Any single signal or group of signals may thus be checked at this point.

RECEIVING CONTROL RACK

The last two racks, No. 6 and No. 7, of the group described above serve as switching and testing panels for the central office receiving equipment. On these panels transfer busses from the line rack connect the lines from the receiving station to the filter groups. The filters separate the individual channels from groups of as many as twelve channels on each line. Each filter connects to an amplifier-rectifier unit which in turn connects to a recorder at the receiving operating position. Jacks for all these connections are installed on the receiving panel since it is often necessary to divert channels to other positions than those regularly used. A typical group of jacks is illustrated in Figure 8.

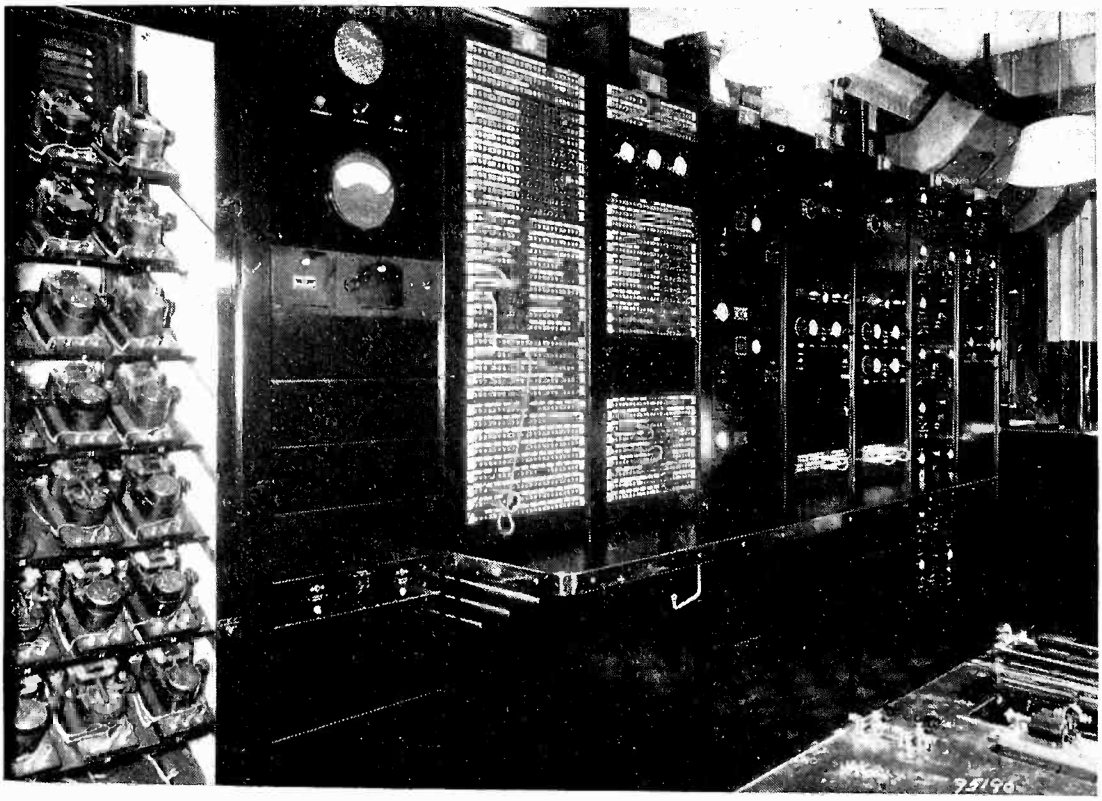


Fig. 9—Transmitting control rack.

To provide for present requirements the arrangement of lines from Riverhead is as follows:

6 lines each with a group of from 8 to 13 band-pass filters,
6 lines each with a set of 1200-cycle high- and low-pass filters,
2 lines each with a 510-cycle high-pass filter,
8 lines unequipped with filters.

The band-pass filter groups are subdivided into groups of narrow-band-pass and wide-pass filters. The narrow-band filters have their mid-band frequencies spaced at odd multiples of 85 cycles starting with the fifth multiple or 425 cycles. These filters are usable for keying speeds of 80 words per minute in Morse Code. The wide-band filters have their mid-band frequencies spaced at odd multiples of 425 cycles starting with the third multiple or 1275 cycles. These filters are usable for keying speeds up to 450 words per minute. The ability of the wide-band filters to handle this speed of transmission makes them suitable for use with the time-division multiplex equipment.

The 1200-cycle high-pass and low-pass filter combination provides two very wide bands on each line so equipped, and the resulting channels may be used for extremely high-speed telegraph keying. But even wider bands are necessary for facsimile transmission and the 5000-cycle lines equipped with 510-cycle high-pass filters to cut off low-frequency line noise, are available for this service.

Although the lines not equipped with filters may be used as spare lines to which any of the filter groups may be transferred, their more essential usage is for transfer of signals received at Riverhead with such poor quality as to be unsuitable for actuating the diversity-receiver tone keyers. Such signals must, therefore, be sent into the central office just as received, with varying amplitude and varying frequency, and an entire line must be turned over to each signal of this kind. Fortunately such signals are the exception and are decreasing in number as the foreign stations improve their transmitters.

TRANSMITTING CONTROL RACK

Similar in arrangement to the receiving control board just described is the transmitting control board taking up two racks, Nos. 3 and 4, of the group of racks to the right of the console. It differs only in the type of equipment to which the jacks connect, consisting in this case of tone keyers and their accessory apparatus, transmitting position equipment to control the keyers, tone sources to provide the audio-frequency signals to be keyed, and wave filters to pass the keyed tones, free from harmonics, into the multiple groups of signals on the lines to the transmitting stations.

The transmitting operating-position equipment may be either automatic, perforated-tape-controlled Wheatstone transmitters, teletype printers, or time-division multiplex equipment controlled in turn by either or both of the others.

The tone sources are either multiple-frequency generators or vacuum-tube oscillators. On rack No. 2 is mounted the remote control switching equipment for the tone generators which are installed in the basement generator room. Space is also provided on this rack for a group of recently designed vacuum-tube oscillators having a high degree of stability combined with economy of material and space. The new oscillators will generate tones suitable for the wide-band filters, whose mid-frequencies are separated by 850 cycles, and can be extended up to the limit of the 5000-cycle lines. The multiple-tone generators each provide twelve tones in steps of 170 cycles from 425 cycles to 2295 cycles. These correspond to the mid-frequencies of wide-band filters as well. Neither of these tone sources is required for certain special equipment such as multiplex and facsimile apparatus which include suitable oscillators as part of their own assembly.

The tone keyers associated with the transmitter-control board are of two types, mechanical relays and vacuum-tube locking-circuit type keyers. The latter are located elsewhere than on these racks and will be described later. The relays, however, are mounted on inclined shelves in rack No. 1 of the group being described in this section. A plate-glass door on this rack provides for constant visual observation of the relays, while access may be easily had in case re-adjustment of a relay is required at any time. The relays which are of the high-speed polarized type are extremely rugged and reliable.

Although the tone filters are not mounted on this group of racks, the separate rack on which they are mounted is located nearby and may properly be mentioned at this time. This rack with the filters in place is shown in Figure 10. A total of 191 individual filters are available at the present time, of which 88 are assigned to transmitting circuits, 84 to receiving circuits, and 19 for monitoring. All are not used simultaneously; depending on the type of signals being transmitted or received at any given time, wide-band or narrow-band filters in several possible combinations may be set up to suit.

To the right of the transmitter control panel, on rack No. 5 are mounted two 480-cycle frequency standards with their associated power units and switching panel. These standards are extremely stable fork-driven oscillators, whose outputs are fed to duplicate bus systems to which are connected all apparatus whose operation depends on synchronization with similar apparatus at the other end of the radio circuits. Included in this classification are multiplex terminals operating with similar terminals at Amsterdam, San Francisco, Chicago and Detroit,[3] and facsimile terminals working with similar units at Philadelphia.

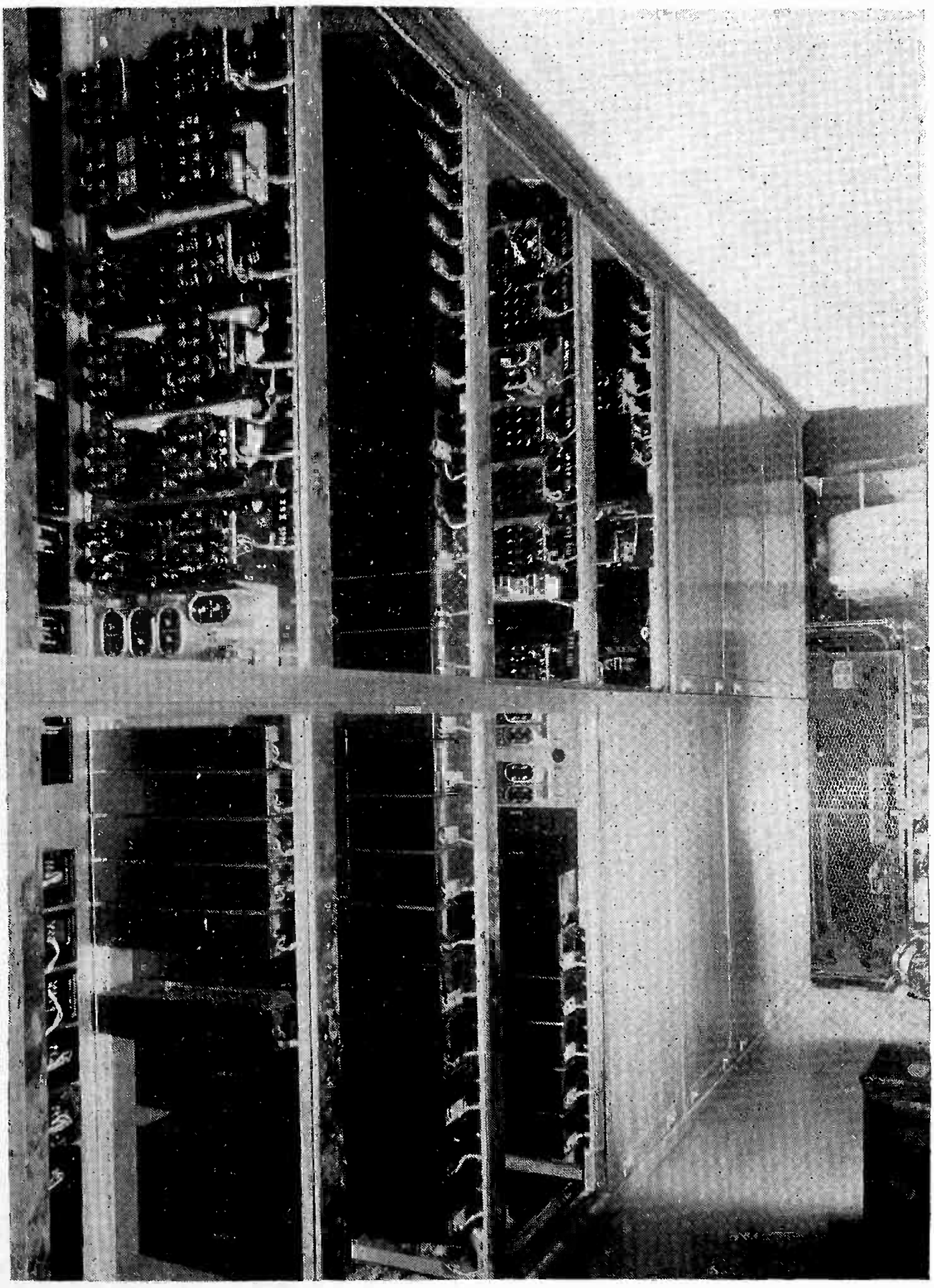


Fig. 10—Filter rack.

The next two racks, Nos. 6 and 7, contain control equipment for the three transmitters of the u-h-f station at 30 Broad Street. In addition to switches for remote starting of the station at New York and the relay stations at New Brunswick and Arney's Mount, there are meters for indicating percentage of modulation on each transmitter, attenuators for adjusting the percentage of modulation, carrier-level indicators, and carrier-off alarms. Since the u-h-f transmitters are completely unattended, the equipment mounted on these two racks is necessary to carry on two important operations associated with transmitters, that is, the observation and control of the character of the transmitted signals. The controls are operated over two pairs of lines per transmitter. One pair carries the keyed-signal tones of the transmitter while its simplex connection with ground return provides a circuit for starting the transmitter. The second pair brings the transmitter-monitoring signals back to the control rack for operating a carrier-level meter, a carrier-off alarm, and a percentage-of-modulation indicator. Remote control of the distant relay transmitters is effected by means of one of the tones of the group transmitted over the radio circuit. The system has been described in detail in a previous paper.[4]

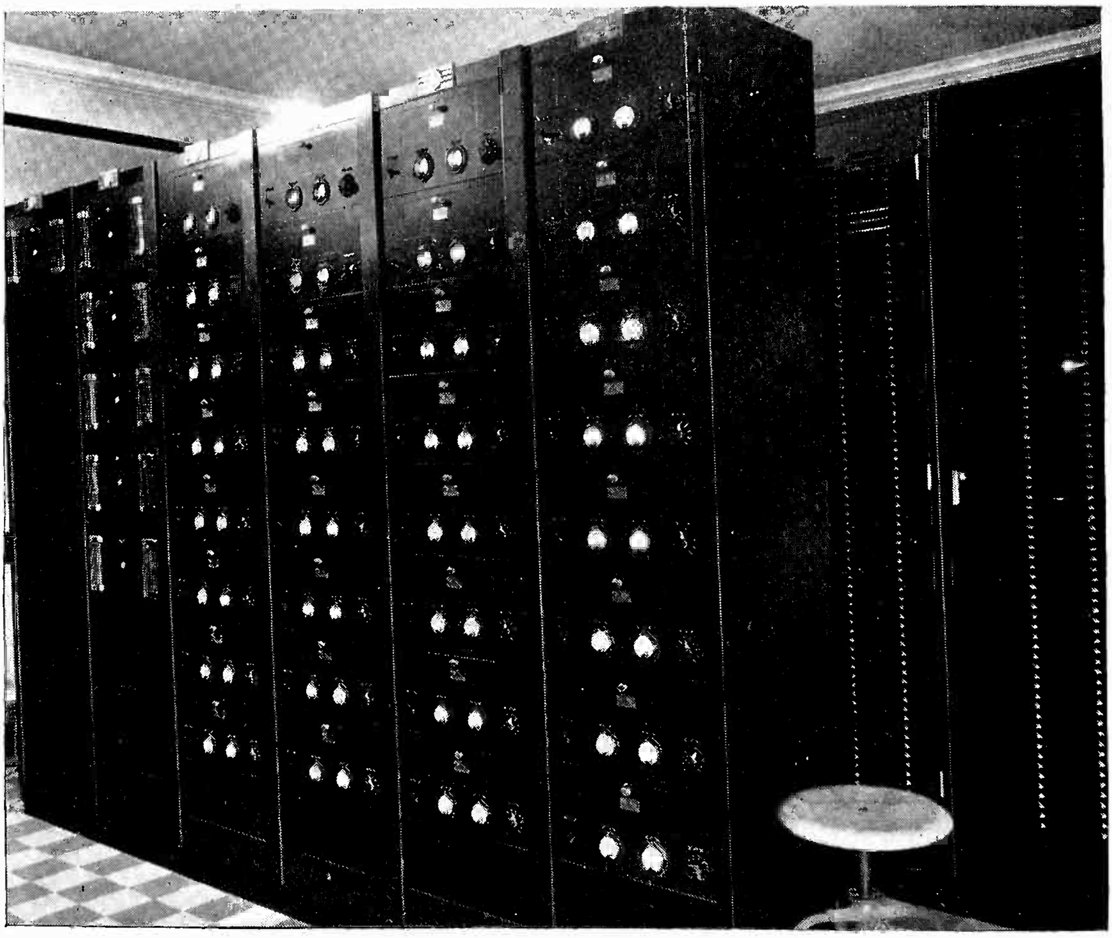


Fig. 11—Apparatus room—tone keyers.

Used in conjunction with the u-h-f relay to Philadelphia are the printer-control units mounted on the remaining two racks of this group, Nos. 8 and 9. The "outgoing units" are, in effect, tone keyers operated by the transmitting portion of standard teletype printers, while the "incoming units" are tone amplifier-rectifiers which convert the incoming tone signals to direct-current impulses for actuating the magnets of the teletype receiver mechanism. The jacks to which these units are connected are so arranged that the units may be operated either in simplex or duplex. Printer channels are provided by u-h-f relay to Philadelphia, and via land-line extensions from that point to Baltimore and Washington.

APPARATUS ROOM

Associated with the control center is the apparatus room located on the third floor, in which a number of racks are installed for mounting multiplex terminal apparatus, amplifier-rectifier units, vacuum-tube keyers, and miscellaneous amplifiers.

The amplifier-rectifier unit is designed to take an incoming tone signal from the receiving station at a level of 50 db or more below reference volume, amplify it, and rectify it to supply approximately 10 milliamperes into a 3000-ohm load, which in this case consists of the movable coil of an ink recorder. The unit also supplies a tone signal of 6 milliwatts into a 600-ohm load for aural monitoring. Those installed in the apparatus room are entirely self-contained units, each with its own rectifier for operation on 115 volts a-c power supply. Space is available for a number of additional units of this kind, some of which will eventually replace the bulky d-c operated amplifier-rectifiers still retained from the previous installation and which are temporarily located on the second floor against the rear wall of the control room.

The tone keyer is a unit designed to convert the positive and negative d-c impulses from the automatic transmitter at the operating position into tone signals suitable for transmission over a line to the transmitting station. Utilizing the locking-circuit principle the keyer regenerates the momentary pulses from the auto head, positive for "mark" and negative for "space", into full-length characters. Its action corresponds to that of the locking type of polar relay which, in fact, it replaces in this service.

Five complete groups of multiplex terminal apparatus of the RCAC time-division type are set up in this apparatus room for use on circuits operating with Amsterdam, Chicago, Detroit, and San Francisco. A multiplex terminal using the Higgett system and operating on a London circuit is also located here. The design of the RCAC multiplex terminals is such as to facilitate inspection and maintenance. The interior of each cabinet rack is painted white and all parts of the equipment are in their natural metal or cadmium-plated finish. Upon opening a cabinet door, lamps are automatically switched on, flooding the interior with shadowless light. Each unit of equipment is connected to the rack wiring forms by means of grouped link bars to permit ready removal of the unit from the rack when necessary. However parts are so mounted on the chassis of each unit that all

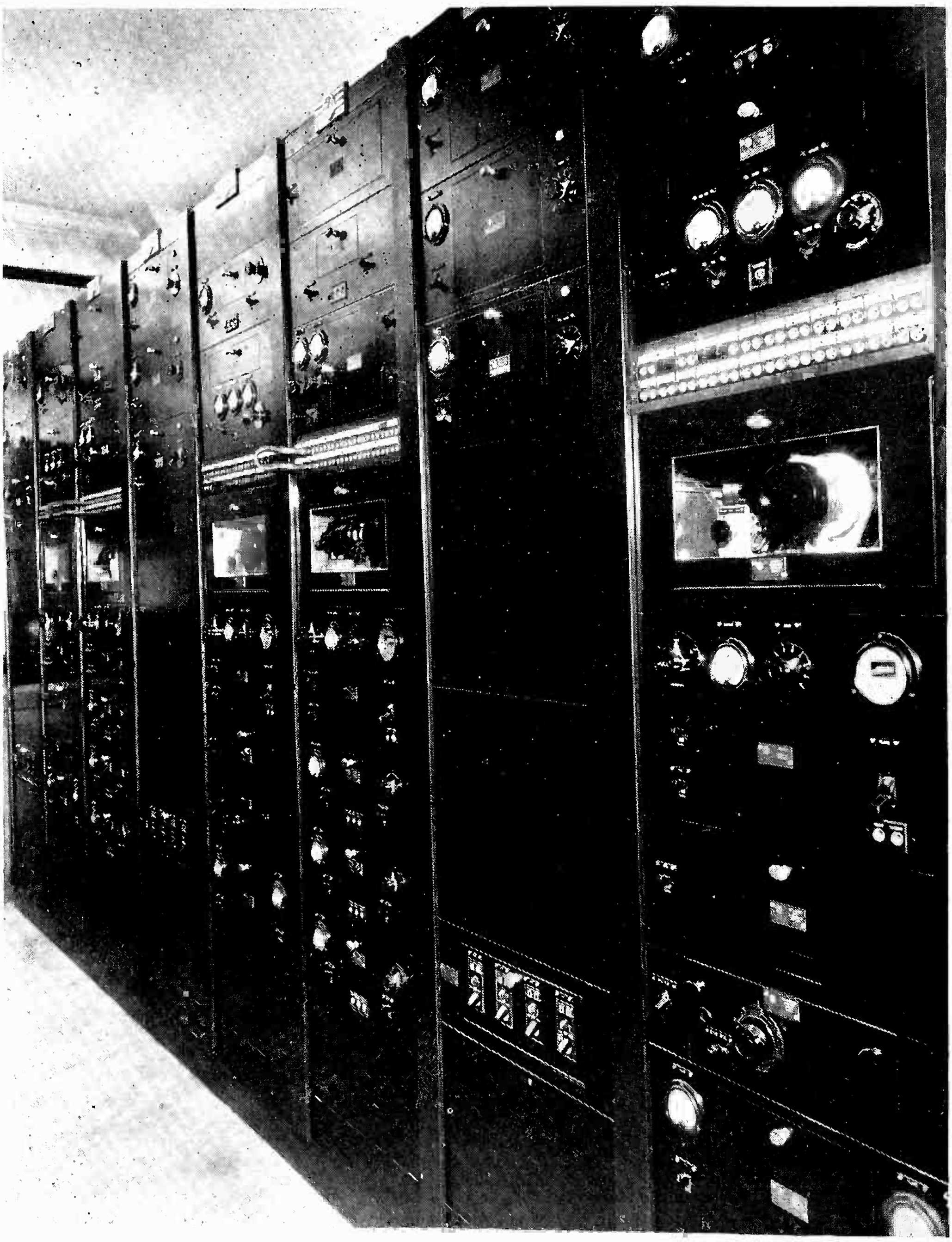


Fig. 12—Apparatus room—multiplex terminals.

may be seen or worked on without removing the unit from the rack, unless a replacement unit is to be installed.

Miscellaneous amplifiers, including those used for monitoring circuits and with the intercommunicating systems, all of which are either fixed-gain or remote-gain-controlled units, are installed in the apparatus room.

INSTALLATION DETAILS

As the photographs show, a uniform style of apparatus construction has been adopted in this installation. This style is characterized by flat front panels, hinged doors for access to tubes, and dull rubber-black finish. All units have standard 19-inch wide panels, and are mounted on cabinet-type racks.

Cabinet-rack shelves and floor are covered with a marbleized black and white linoleum to harmonize with the equipment. Chromium-plated trim has been used on the console, rack shelves, and rail. Because of the interest in the control room, shown by frequent visitors to 66 Broad Street, the appearance of this section of the establishment was considered an important feature in its design.

Each group of racks is mounted on a structural channel base which not only serves as a firm and level support for the group, but also becomes a very convenient trough for inter-rack connecting cables. Overhead ducts carry the connecting cables between groups of racks while an under-floor trench is provided for the cables to the console. All ducts and trenches are built for easy access so that need for pulling lines or cables through conduits has been entirely eliminated.

Interconnecting cables are of special design to provide maximum protection against cross-talk and pick-up of possible interfering currents. Twisted pairs of tinned enamel and silk-insulated conductors are individually shielded with copper-wire braid, and groups of 7, 11, or 26 of these shielded pairs are formed into cables for convenience in installation.

Close inspection of the installation would show that certain details have followed telephone-exchange and broadcast-studio practice. Because of the extensive use of audio frequencies in this service some of the problems are the same. For the most part, however, since the requirements of high-speed radio-telegraph control are peculiar to itself, no hesitation has been shown in departing from methods standardized in other services where it appeared advantageous to do so.

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GREAT LAKES RADIOTELEPHONE SERVICE

By

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Summary—*The radiotelephone communication systems now in use on the Great Lakes are similar in many respects to United States Coastal and Harbor services. Radiotelephone on the Great Lakes is used primarily for dispatching cargo vessels and for communication with pleasure craft.*

The Federal Communication Commission does not require radio equipment on Great Lakes vessels except those in the passenger-ship classification.

During the last three navigation seasons, the use of radiotelephone communication for business, pleasure, and safety purposes has shown considerable growth.

PRESENT-DAY radiotelephone communication on Lakes Erie, Huron, Michigan, Ontario, and Superior presents many problems which differ from established practices on the Atlantic and Pacific coasts of the United States.

Radiotelephone communication with vessels using coastal ports may be divided into two classes. In one class fall the trans-oceanic passenger liners which employ radiotelephone as an added service in conjunction with the regular radiotelegraph service carried for safety-of-life-at-sea and for public correspondence. Ships in this category utilize relatively expensive and complicated equipment which must of necessity be operated by skilled radio personnel. Multi-channel transmitters in the order of 400 and 600 watts output are commonly employed to enable reliable communication with high power coastal telephone stations over distances of several thousand miles.

The other class of vessels using radiotelephone on salt water and tidal rivers includes cargo vessels, yachts, tugboats, fishing vessels, and small craft. These vessels carry radiotelephone equipment designed to communicate over relatively short distances such as within harbors and along the coasts. A number of harbor-telephone stations have been established along the United States coastlines for this type of service. At the present time nine stations for harbor service are in operation and others are contemplated. Since communication is never intended over large distances, the allocated frequencies are in the 2100 to 2600 kilocycle band.

The Canadian-American agreement of 1933 allocated certain frequencies between 2100 and 2600 kilocycles for use on inland waterways, including the Great Lakes and the Gulf of St. Lawrence Waterway. Due to the geographical separation and the distance ranges of the frequencies involved, it is possible to duplicate frequency assignments. The following tabulation shows ship transmitting and receiving frequencies as contemplated for use on the Great Lakes and the Gulf of St. Lawrence:

Location of Ship	*Ship Frequency*	
	Transmitting	*Receiving*
On Lakes Superior and Erie	2158	2550
On Lakes Michigan and Ontario	2118	2514
On Lake Huron	2182	2582
On St. Lawrence Waterway	2190	2598

Special temporary rules, governing radiotelephone operation on the Great Lakes for the 1939 navigation season issued by the Federal Communications Commission effective March 31, 1939, change the above assignments. The frequency 2182 kc may be used by all Great Lakes shore and ship telephone stations for calling and for safety purposes. After communication has been established between the ship and shore stations, both stations will change to the traffic frequencies, either 2118 and 2514 kc or 2158 and 2550. Ships are not authorized to transmit on the traffic or working frequencies unless directed to do so by the shore station contacted. Such a system will prevent a ship from interfering with a conversation already in progress. In the case of ship-to-ship communication, both ships would change to 2738 kc after first having established communication on 2182 kc.

The U. S. Coast Guard will operate all of its approximately fifty radio stations on the five lakes to conform to this plan. These stations are being equipped to operate on 2182 kc so that ships requiring assistance or emergency information may call the nearest Coast Guard station directly and obtain assistance or information.

The rules also provide a special marine broadcast frequency of 2572 kc for periodical weather information.

New frequencies 4422.5 and 4282.5 ks for ship-shore communication are authorized for daytime use only. In addition, a new day-only intership frequency of 5532.5 kc has been allocated.

GENERAL REQUIREMENTS FOR RECEIVERS

Since frequencies adjacent to those used on the Great Lakes are used in other areas, the selectivity of ship receivers should be such that signals having a carrier frequency 8 kilocycles removed from the desired signal will be highly attenuated.

Equipment designed for the reception of voice only from the harbor stations must be capable of selectivity equal to or better than standard broadcast practice. Selectivity, such as required, is attained in practice only by the use of well-designed receivers of the superheterodyne type where high adjacent channel attenuation and optimum gain are possible with a minimum number of tuned circuits. It is well known that for random received noises, such as atmospherics, the voltage present in the receiver output, as a result of these noises, will vary as the square root of the effective band width of the receiver. The receiver radio-frequency oscillator must, of necessity, equal the stability of the shore station transmitters which are required by regulation to maintain frequency within ± 0.02 per cent. For example, a shore station operating on 2500 kc would have a tolerance of only ± 500 cycles. If the receiver intermediate amplifier (wherein the receiver derives most of its selectivity) is assumed to have a response essentially flat for transmitter side bands up to 2700 cycles, in order to give good voice reception and limit received noise, the receiver oscillator could be off frequency only a small amount without noticeable side-band attenuation. In order to maintain frequency stability as required, the receiver r-f oscillator must be quartz-crystal controlled.

To allow communication with weak signals the shipboard receivers must be capable of reasonable headphone or loudspeaker signals with inputs of 5 microvolts absolute or less. Electrical machinery and static will, in many cases, prevent usable sensitivities of this order since, assuming a receiving antenna of 5 meters effective height, it is more than likely that noise in excess of a signal of 1 microvolt per meter would be received.

Fading is usually present beyond the normal primary service area of the shore station which necessitates the use of automatic volume control in order to reduce the effects of fading. Automatic volume control is also desirable to prevent overloading and distortion when strong signals are received. It is well-known that delayed automatic volume control is desirable for weak signal reception in field strengths only a few microvolts above the noise level. The receiver "noise-equivalent", which is a figure-of-merit for modern receivers, must be low enough so that "carrier-hiss" is only a fraction of the audio output obtained when weak signals are received. The "noise-equivalent" effectively determines usable minimum signal reception since a signal which is present, but masked by noise is of no value for communication. Radio-frequency amplification ahead of the mixer or converter stage is always desirable so that receiver hiss may be reduced to values determined by "first-circuit" noise.

The audio output of marine telephone receivers must be sufficient to overcome room noise when the vessel is in rough weather. Audio fidelity should be purposely restricted to frequencies containing essentially all of the intelligence in a voice-modulated carrier.

TRANSMITTER AND WAVE PROPAGATION CONSIDERATIONS

The Federal Communications Commission licenses harbor telephone stations for an antenna power of 400 watts. Propagation conditions are variable depending on the frequency, power, transmitting site, antenna efficiency, time of day, and the season of the year. For frequencies in the order of 2500 kc it has been shown[2, 5] that attenuation is 6 to 12 db per mile of overland transmission. The attenuation is greatest adjacent to the transmitting site in the case of a station located inland. When 400 watts antenna power at 2500 kc and an antenna efficiency of 50 per cent is assumed, the radiated power would be reduced to approximately 100 watts at the shore if the station is one mile inland. This figure is based on the assumption that field strength is attenuated 6 db for the first mile of overland transmission. For this reason, in order to realize ground-wave field strengths as large as possible with relatively low power, land stations for communication with ships are always located as close to the shore as practicable.

The conditions for ground-wave propagation over sea water are considerably better[3, 4, 6]. The attenuation over sea water is less than 0.1 db per mile so that for 60 miles the signal would be reduced not more than 6 db below the inverse distance field, resulting in a field strength of approximately 300 microvolts. Attenuation over fresh water is somewhat more than over salt water so that the exclusively ground-wave or primary-service area of the average 2000 kc, 400-watt station may be only 25 to 50 miles over fresh water and intervening land. During daylight hours the reflected sky wave does not become appreciable under 50 miles. Since atmospherics are at a minimum near noontime, it is usually possible to communicate farther, by means of the ground wave, during the day than at night. For example, during August, 1938, tests were conducted between Harbor Station WAY (2514 kc), Lake Bluff, Illinois and low-power telephone equipment on boats up to 70 miles north of Lake Bluff along the western shore line of Lake Michigan. It was found that commercial signals were obtainable on both ends of the radio link at distances of 50 to 60 miles during the middle-daylight hours, but from late afternoon throughout the night, the increase in atmospherics limited communication to about 30 miles. Transmitters delivering 5,[8] 15,[7] and 50 watts were used for transmissions to WAY. During October, November, and until the close of Great Lakes navigation, it was generally possible to carry on commercial telephone calls with WAY up to distances of 450 miles at night.

GREAT LAKES TELEPHONE SHORE STATIONS

The Canadian Government has, for several navigation seasons been carrying on limited tests with Canadian boats equipped with Marconi radiotelephone apparatus. Following is a tabulation of Canadian shore stations:

VBA	Port Arthur, Ontario	(Northwestern Lake Superior)
VBB	Sault St. Marie, Ontario	(Junction Lakes Superior and Huron)
VBC	Midland, Ontario	(Georgian Bay, Lake Huron)
VBE	Sarnia, Ontario	(Lower Lake Huron)
VBF	Port Burwell, Ontario	(Lake Erie)
VBG	Toronto, Ontario	(Western Lake Ontario)
VBH	Kingston, Ontario	(Eastern Lake Ontario)

These stations were established primarily for radiotelegraph communications and the telephone apparatus has been located adjacent to the radiotelegraph equipment and is operated by the same personnel. VBB and VBG during the 1938 season transmitted on either 2550 or 1630 kc and maintained a watch on 1630 kc for 50 minutes then changed to the 2158 to 2550 channel for the remaining 10 minutes of each hour. The five other stations used only 1630 kc for both transmitting and receiving. It is expected that the Canadian radiotelephone stations will conform to the new plan. The Canadian ship stations use antenna power of approximately 25 watts and the shore stations of approximately 100 watts. Telephone communication to Canadian stations is on a "message" basis, it being necessary for the shore operator to write down the telephone message from the ship, convey it to its destination by land-line telephone or telegraph, receive the answer, if any, the same way, and read the message to the ship. Such a system is considerably slower in operation than the procedure employed by the United States stations now in operation where the ship is connected directly to the subscriber called just as in long-distance, land-line practice.

There are at present four United States Harbor or Coastal-Harbor telephone stations for Great Lakes service as follows:

WMI	Lorain, Ohio	500 watts	(near Cleveland)
WAY	Lake Bluff, Ill.	400 "	(near Chicago)
WAS	Duluth, Minnesota	400 "	
WAD	Port Washington, Wisc.	400 "	

It is estimated that 95 per cent of all Great Lakes cargo vessels are dispatched and directed from the Cleveland offices of the various shipping companies. Since reliable communication under adverse conditions is a matter of somewhat less than 100 miles in the vicinity of 2000 kc frequencies, additional frequencies normally allocated to ocean communication were assigned to WMI making that station a "Coastal-Harbor" service—the only one of its kind to date on the Great Lakes. The frequencies in use at WMI are as follows:

	For transmission	*For reception*
"Channel 30"	2550 kc	2158 kc
"Channel 20"	6470 kc	6660 kc
"Channel 10"	8585 kc	8820 kc

Channel 30 is used for all short distance communication in the western part of Lake Erie during the daytime and at night for any location in the lakes during low-static conditions, which normally occur only during early spring and late autumn.

Channel 20 is normally good for communication to any point in the lakes at night except for the gap between the ground wave and the beginning of the sky-wave reflection. The latter begins to be serviceable at about 100 miles from Lorain, Ohio whereas the ground wave is attenuated to non-commercial values only a few miles from the transmitting site.

Channel 10 is necessarily an exclusively daylight channel so far as Great Lakes communication is concerned since the minimum night time range of 8 to 9-megacycle transmission is about 1500 miles which is greater than the distance from Cleveland to any point on the Great Lakes. The minimum daylight range of this frequency is approximately 300 miles so that ships from lower Lake Huron to Duluth may normally use Channel 10 for communication with WMI during midday.

Station WAY is located at Lake Bluff, Illinois, and serves the lower part of Lake Michigan with Harbor Telephone service. WAY operates on 2514 kc with 400 watts power. Ships communicating with this station normally transmit on 2118 kc although the station is equipped to receive calls on any telephone frequency used on the Great Lakes.

Station WAS at Duluth, Minnesota operates on 2550 kc and is also rated at 400 watts power. It is expected that this station will improve communication facilities in the western part of Lake Superior inasmuch as the ore carriers, in order to receive docking and loading information, have previously depended on securing such orders from Cleveland via WMI. When it was necessary to converse with company agents in Duluth, or other harbors near the ore fields, a long radio link to Lorain, Ohio plus a long land-line connection was required.

Station WAD at Port Washington, Wisconsin operates on either 2550 kc or 2514 kc, the latter frequency being shared with station WAY. Port Washington is 70 miles north of Lake Bluff, Illinois.

SHIP EQUIPMENT

Ship equipment, operated by holders of "Third Class Telephone" licenses, must of necessity, due to government radio regulations and from a practical standpoint, be comparatively low power, simple to operate, and incapable of causing interference to services on other frequencies. Ship telephone transmitters (except the ocean-liner types) vary in power ratings up to 75 watts output. Normally the superior receiving conditions on shore and the additional power used by shore stations balances the generally unfavorable conditions for transmitting and receiving aboard ships.

The size and construction of the vessel usually limits the transmitting antenna so that it must be inductively loaded. This is true even on ore carriers whose length generally exceeds 500 feet. Ore boats are similar to tankers, the cargo holds being between the engine room and the pilot house. Any radio antenna must extend forward from the foremast in order to allow loading and unloading the forward holds without letting down or moving the antenna. The greatest length from the top of the mast to the pilot house or captain's office (two usual locations of the transmitting equipment) is not more than 60 feet. An antenna of this length loaded to 2000 kc has a total resistance of 5 to 10 ohms of which probably no more than 1 to 2 ohms are radiation resistance, the balance being distributed between dielectric losses, ohmic resistance, leakage, etc. If 75 watts transmitter output and an antenna efficiency of 20 per cent is assumed, the field strength at 50 miles, due to the ground wave only, would be approximately 200 microvolts per meter.[5] If the effective height of the ship receiving antenna is assumed to be 5 meters, the receiver r-f input would be 1000 microvolts. At 100 miles, and for the same assumed conditions, i.e. power, antenna efficiency, frequency, etc., the field strength would be approximately 80 microvolts per meter or 400 microvolts at the receiver input terminals.

In a great many cases, particularly on lakes, in harbors, and on inland waterways in general, the transmission path is along the coastline or over intervening land forming a large percentage of the propagation path. The attenuation of signals over fresh water is known to be greater than over salt water. In the case of predominant overland transmission, the attenuation would be such that at 50 miles, a 75-watt ship transmitter could be expected to produce a field strength of approximately 2 microvolts per meter. Obviously local ship interference caused by electrical machinery and static conditions may frequently be in excess of the received signal strength. Pertinent literature contains many statements relative to signal-to-noise ratios for telephone communication. While this is a debatable point, it is generally conceded that for the reception of news broadcasts and voice only, in cases where the listener has some special reason for wanting to listen and will tolerate annoyance, the signal must be 10 times stronger than the average noise level[1]. Measurements made during summer static conditions to indicate ratios of peak to average values show that during the day the ratio varies between 80 to 1 and 2 to 1, averaging a ratio of about 10 to 1. During the night, measurements showed the ratio to vary between 30 to 1 and 2 to 1, averaging 5 to 1. Apparently the night-time ratios of peak to average noise are more favorable for communication, since it is the peak crashes which obscure communication with weak signals.

It must be remembered, however, that average static levels at night may be 10 times the average day values so that in general and except in rare cases when there is little night static, the primary service range of a station is greater in the daytime than at night.

Actual observations made on the Great Lakes during November, 1938 and April, 1939 using transmitters of 75 watts power showed that daylight intership communication over water and intervening land on 2738 kc was practical up to 100 miles in the absence of static. Night-time intership communication was a variable factor. On occasion it was possible to carry on conversations up to 600 miles over lake water and intervening land. At other times difficulty was experienced in attaining a 50-mile range.

CALLING SYSTEMS

The use of loudspeakers for standing-by or monitoring shore station and ship transmitting frequencies is objectionable for several reasons. First, several channels must be monitored simultaneously in order that calls may be received from any shore station operating on any one of several channels. For example, WMI uses three transmitting channels any one of which may be used to call the desired ship, depending on the location of the ship and the time of day. This would require a minimum of three receivers for monitoring WMI or similar stations and one for intership incoming calls. Calls on all channels whose propagation characteristics permit reception at the ship location would be heard by all ships. The continual blaring of a loudspeaker located in the pilot house would be a source of annoyance to such an extent that the speaker volume would be reduced, causing incoming calls destined for the ship in question to be missed. Also, loudspeaker monitoring of all channels simulates a "party-line" where all conversations are heard by all subscribers whether they intentionally listen or not.

The majority of Great Lakes ships using radiotelephone utilize loudspeaker monitoring arranged so that the speaker has a response characteristic peaked at 300 cycles. The shore station normally communicating with these ships calls individual vessels by transmitting a 300-cycle tone broken up into characters to simulate the ship's whistle signal. Each lake carrier ship has a code signal different from other ships and, therefore, quickly recognized by the ship's bridge personnel. Ships use the same method to call each other, the "longs" and "shorts" comprising the whistle signal of the boat called being made by manipulating a telephone dial. The digit "8" is usually dialed to transmit a "long" or dash and the digit "2" is dialed to transmit a "short" or dot. Hence, to call the "Wm. H Wolf," another boat would dial 8222 222 on the intership frequency. The first group is the *fleet signal* of the Gartland Steamship Company and the second group is the identifying or *name signal.*

Stations WMI, WAS and WAD use the whistle-signal system to call ships. Combined shore station calls and intership calls during certain hours of the day tend to make a bedlam of sounds in the pilot house speaker and as a result the loudspeaker volume may be reduced so as to be less of an annoyance. This would increase the attendant likelihood of missing calls.

SELECTIVE SIGNALING SYSTEM

The two-tone audio-frequency, selective signaling system (when calling boats equipped with an automatic ringing device) has much to recommend it. This system has been developed particularly for marine telephone calling service and has been successfully used for a number of years by the Bell system harbor stations operating with harbor craft, yachts, fishing vessels, etc.

The selective signaling system has several distinct advantages over the loudspeaker method of attracting the attention of ship's personnel. The device is noiseless, faster and more accurate in its results. Except in exceptionally rare instances, a false alarm is practically impossible —the bell is rung *only* on the ship called and not on some potential 400 others. It is possible to put calls through when the shore station signals are only 2 db above the noise. Such a weak signal would be of little value for a commercial call, but would be usable in cases of distress. It is also possible to ring the bells on all ships at once in order to organize distress communication and establish control by shore stations or coast guard vessels.

The selective signaling device or automatic ringer, as it is sometimes called, consists fundamentally of a double filter network, two copper-oxide rectifiers, a polarized relay, and a stepping relay. The filters are fixed-tuned to 600 and 1500 cycles respectively. Each filter highly attenuates all frequencies except the one to which it is tuned. Separate copper-oxide rectifiers convert the filter outputs to direct current. The pulsating current is used to operate a polarized relay which is poled so that the reception of a 600-cycle audio tone in the radio receiver closes the relay in one direction where it stays until a 1500-cycle tone is received, which returns the relay armature to its opposite position. The reception of alternate 600- and 1500-cycle tones therefore causes the polarized relay armature to travel back and forth between fixed contacts. The function of the polarized relay is to charge and discharge a capacitor through the winding of a special stepping relay which must receive alternate impulses of capacitor charging and discharging current in order to operate the stepping and retaining mechanism. The stepping relay has a "code wheel" having movable pins which may be set in holes corresponding to any number desired so long as the sum of the digits in the number totals, for example, 23. The number of pins required depends on the number of digits. For example, a ship "telephone number" might be made up using three numbers such as 779, whose sum totals 23. The shore station impulsing telephone dial is specially constructed so that regardless of the number dialed the first digit of the next number will cause the opposite tone to be transmitted as A2 emission from the shore station. While it plays no part in the actual code, the digit "1" is always dialed as a prefix in order to reset the selector code wheel which might be resting on one of its pins and not at "zero," and in order to insure that all polarized relays are resting on either the 600- or 1500-cycle contacts. Actually, the *change* of tone from 600 to 1500 or vice versa, rather than the presence of either tone, causes the code wheel to advance.

Since the number of 3-digit codes whose sum equals 23 is limited, the use of a 5-digit code is recommended. For example, to call a certain ship, the shore station operator would dial 1 2 5 4 6 6. The prefix "1" moves the code wheel, but it returns to zero since no retaining pin is used in the number 1 position. Another ship might use the code 1 5 2 4 6 6, an arrangement which still totals 23 for the last five digits, but has the order of the 2 and 5 reversed. The code wheels of both ships, using the numbers as above, would step up to position 5 when the shore operator dialed "5," but only the second ship's code wheel would be retained at 5 and ready for the "2"; the code wheel on the first ship having fallen back to "zero" since no pin was in the 5 position. Using a five-digit code as above, over 2000 different ships could be dialed individually without the other ships being aware that a call or a conversation was in progress.

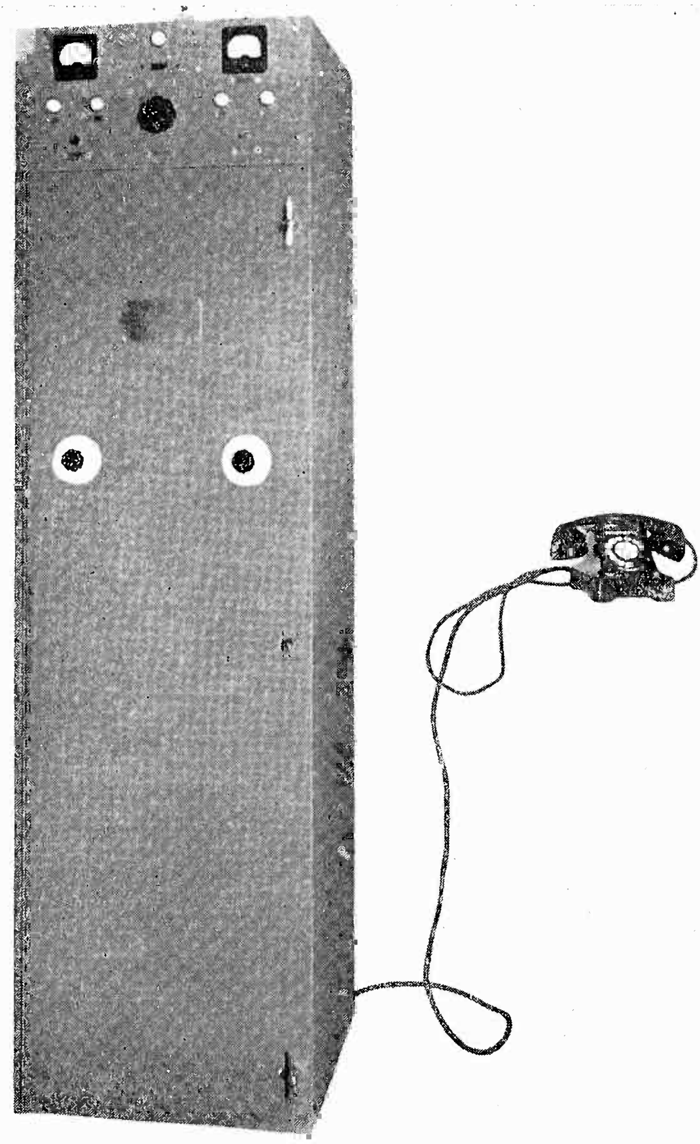

Fig. 1

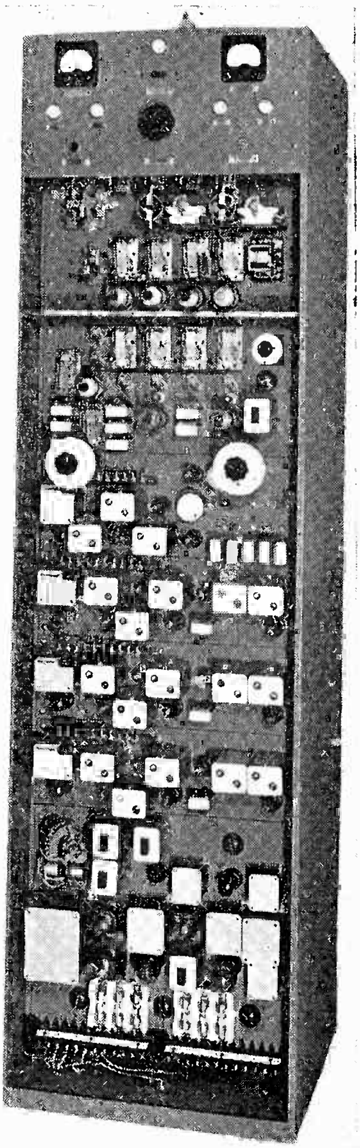

Fig. 2

Exterior and interior views of transmitting and receiving equipment used for four-channel operation.

Selective ringing can be applied to intership calling by somewhat complicating the ship transmitting equipment. Station WAY uses the selective ringing system for calling all ships so equipped.

SHIP RADIOTELEPHONE EQUIPMENT

Figure 1 shows a view of ship equipment installed in 1938 and 1939 on several ore carriers operating on Lakes Erie, Huron, Michigan, and Superior. This equipment was especially designed for telephone communication on the Great Lakes.

The complete installation consists of:

- Transmitter and receiver cabinet
- Local hand set

Remote hand set
Loudspeaker and bell box
Motor generator and starter
Transmitting and receiving antennas

The main cabinet is 20″ wide, 20″ deep, and 72″ high. The front is hinged and swings open for access to the tubes, for servicing, initial tuning during installation, etc. A lock is provided on the door. Figure 2 shows the front opened for inspection. The lower section of the apparatus panel includes a terminal board and fuse block arranged for easy access. The lower panel has three adjustable controls for obtaining the correct receiving tube and transmitting tube heater voltages and the high-voltage d.c. used for transmitting. These adjustments are made during the installation and need no attention thereafter since none of the voltages are especially critical.

The transmitter audio-frequency tubes and associated parts are on the lower panel. A carbon-button microphone such as is used in land-line telephone service swings the grid of a Class A microphone amplifier which in turn supplies grid voltage for the driver stage. The modulators are arranged in a high-level Class B circuit and modulate the plate and screen circuits of the r-f power amplifier. The complete audio circuit is designed so that a normal voice level at the microphone will produce 60 watts of undistorted a-f power output. This is sufficient to modulate completely a d-c input of 120 watts in the r-f power-amplifier stage. High-level, plate-circuit modulation of a Class C, r-f amplifier, as used in this transmitter, is considered better practice than grid or suppressor circuit modulations, which although requiring less audio power, are subject to more distortion, are more difficult to adjust, are critical as to output loading, and definitely have more distortion at high percentages of modulation. The latter is particularly true of suppressor modulation. The overall power efficiency of high-level and low-level modulation is approximately the same since to get the same antenna power, the high-level system uses highly efficient Class C r-f amplifiers at the expense of having to develop high audio power whereas the low-level system conserves on audio power, but requires inefficient Class B operation of the r-f modulating amplifier.

The equipment shown in Figures 1 and 2 is for four-channel operation, but has the advantage that one of the channels may be tuned to any one of five transmitting and receiving frequencies. The middle section of the equipment panel contains four separate, six-tube superheterodyne receivers with crystal-controlled oscillators. Each receiver consists of a 6L7 r-f amplifier, a 6K8 mixer-oscillator, 2 6L7 i-f amplifiers, a 6R7 detector and audio amplifier, and a 25A6 audio power tube.

The combined output of the receivers is fed to the loudspeaker, selective ringer, or handsets as will be described later.

The four channels are known as 10, 20, 30, and 40. A tabulation follows:

Channel	*Ship Transmits On*	*Ship Receives On*
10	8820 kc	8585 kc
20	6660 kc	6470 kc
40 (intership)	2738 kc	2738 kc
30	2118 kc	2514 kc
30	2158 kc	2550 kc
30 (coast guard)	2182 kc	2182 kc
30 (coast guard)	2670 kc	2670 kc
30	—	—

Any one of the four channels may be selected by means of a telephone dial located on the local or remote handset mountings. Since Channel 30 is normally a short-distance or local channel, the ship is expected to set Channel 30 for the shore-station serving their location. For example, a ship while in Lake Michigan would set the Channel 30 knobs, which protrude through the front cover, for operation with WAY or WAD. When in Lake Superior or Lake Erie, the Channel 30 knobs would be set for operation with WMI, Lorain, Ohio or WAS, Duluth, Minnesota or Canadian stations at Sault St. Marie or Toronto, Ontario. If communication is desired with various Coast Guard stations, the Channel 30 controls would be set for 2182 kc. An additional channel-30 pair of frequencies may be added at any time whenever a station begins to use them.

Channel 40 is used exclusively for intership communication except that the Coast Guard station at White Fish Point, Lake Superior, is set up to use 2738 as well as 2670 kc for the exchange of weather information with ships. This was done because very few of the Lakes vessels are equipped to use the Coast Guard calling and emergency frequency of 2670 kc or the new 2182 kc safety frequency. It is believed that the use of 2738 kc by Coast Guard stations and cutters is only a temporary expedient, pending the installation of a 2182 kc channel on existing and new Lakes telephone equipment.

Channels 10 and 20 are used exclusively for long distance communication with station WMI.

The r-f portions of the transmitter consist of three separate oscillator tubes and four power amplifier tubes operated in parallel. The tubes used are of the "beam" type and require very little excitation for full output. One oscillator tube serves the intership and five channel 30 frequencies. The other two oscillators operate on 6660 and 8820 kc respectively. Special crystal-oscillator circuits are utilized so that crystal currents are relatively low and also in order that the Channel 10 and 20 crystals may be one-half the output frequency to insure reliability, low heating, negligible feedback, and consequently high frequency stability.

The power output circuits of Channels 30 and 40 are tuned by a high-efficiency adjustable-inductance circuit. The Channel 40 (intership) antenna circuit is fixed tuned to 2738 kc, but the Channel 30 antenna circuit is resonated for any one of the five frequencies to which Channel 30 may be tuned. This is accomplished by the user after the proper crystal selector knobs are set for the local Channel 30 frequency.

The Channel 10 and 20 antenna circuits utilize an inductively coupled antenna tank circuit so that the antenna may be voltage fed.

Micalex and Isolantite insulation is used wherever necessary to obtain the high insulation required on marine transmitting equipment. The oscillator, power amplifier, and antenna circuits are switched by relays controlled from the telephone dial at the local or remote control points.

Since the receivers must operate 24 hours a day, the receiving tubes use the ship's line voltage (110 volts d.c.) for power to all elements. The use of ship's power directly for the receivers and selective ringer is desirable in that rotating parts are reduced to a minimum. The transmitter motor generator operates only during communication periods which are normally of short duration. The motor generator supplies 6.3 volts d.c. for transmitter tube heaters and for relay coils energized during communication and 500 volts for the transmitter plate and screen supply. A motor starter is used so that the motor generator may be conveniently started and stopped from a remote point and to minimize the starting load on the ship's line.

The loudspeaker box is normally installed in the pilot house where incoming calls will always be heard by the officers on duty. The loudspeaker box contains the bell which is actuated by the selective ringer. The speaker is equipped with a volume control and a filter network which attenuates high audio frequencies, but permits the 300-cycle intership or shore station calling tone to be clearly heard.

The local and remote handset and control units are similar to ordinary land-line apparatus using an automatic dial. A volume control and a pilot light are mounted in the handset cradle. The pilot light indicates when the motor generator is running.

MANIPULATION OF EQUIPMENT

Assuming the ship is in lower Lake Michigan, the Channel 30 transmitter and receiver crystal-selector knobs and the Channel 30 antenna tuning knob would be set for communication with station WAY and WAD. The equipment is now monitoring 2514 kc (WAY and WAD) 2738 kc (intership), 6470 kc (WMI) and 8585 (WMI). If the bell in the pilot house rings, or the ship's whistle signal is heard in the loudspeaker the captain, mate, or wheelsman lifts the handset from its cradle and replies on the channel indicated. The shore station normally identifies itself immediately by voice or by a tone and indicates by one, two, or three short tones which channel to use for the reply. When either the local or remote handset is removed from its cradle, the motor generator starts and the handset is connected to the output of all four channels. The loudspeaker is automatically disconnected from the circuit when either handset is in use.

If the call was from WAY, the ship operator would dial "3" which sets up the transmitting and receiving frequencies for Channel 30. The three receivers for Channels 10, 20, and 40 are automatically disconnected when "3" is dialed. The conversation is carried on much the same as in land-line communication except that it is not possible for either the ship or shore end to interrupt each other since when the ship is talking the ship receiver is deadened. Also, it is necessary to use voice-operated relays in the shore station to connect the incoming 2-wire land line to the 4-wire radio circuit leading to the transmitter and coming from the shore receiver. No trouble in carrying on a conversation is experienced by the conversationalists at either end of the circuit as soon as both realize that they must not talk at the same time. At the close of the conversation, the handset is replaced on its cradle, stopping the motor generator and returning the receivers to their monitoring condition as previously explained.

If the ship's crew hears their whistle signal on the loudspeaker, but no channel indication following the call, it means that another ship is calling on Channel 40. The handset is lifted from its cradle, the number "4" is dialed and the ship announces its name and asks who is calling.

If a ship desires to call another ship by the whistle signal system, the handset is lifted, and "4" is dialed. This sets up the transmitter for 2738 kc and disconnects receivers on Channels 10, 20, and 30, disconnects the loudspeaker and selector, and allows the dial to be used for making "longs" and "shorts" by dialing 8 and 2 as previously explained.

In any case, since recycling is automatic it is only necessary when transferring from one channel to another to "hang up" and dial the channel desired. The send-receive functions are automatic. The presence of voice in the microphone turns on the transmitter and deadens the receiver. After a cessation of voice, the transmitter is shut off and the receiver returns to full sensitivity. A small interval between words will not shut off the transmitter. This is done intentionally to allow a slight pause occasionally to avoid starting the transmitter carrier for each word since invariably a small part of the first syllable is lost.

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APPLICATION OF MOTION-PICTURE FILM TO TELEVISION*

BY

E. W. ENGSTROM, G. L. BEERS, AND A. V. BEDFORD

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Summary—*Motion-picture film will form an important source of programs for television broadcasting. Film projectors for this use are required to meet a number of conditions peculiar to television. Methods for projecting and utilizing motion-picture film are outlined. A specific film projector and associated television channel are described in some detail.*

In establishing a technique for producing films most suitable for television, equipment is needed to interpret the final results. Apparatus that will be used by broadcasting stations is described. A simpler system has been designed that may be useful for the specialized service of gaging the merit of films for television. This is described and its operation indicated.

Some very preliminary observations are included on the characteristics of films that have given good results in experimental work and in field tests.

THE production and utilization of motion-picture film for television programs introduces many new problems. It is the purpose of this paper to review these problems and to describe methods and apparatus for the use of film in television.

GENERAL DISCUSSION OF UTILIZATION METHODS

It is desirable first to review the general characteristics of two electronic television pickup systems, which are known to give practical results. In both systems the scene to be transmitted is projected upon a photo-emissive area or mosaic. The resulting "electrical image" is methodically explored by electronic means, one narrow strip or line at a time, in a process called scanning. The result of this scanning process is an electrical signal which varies in accordance with the scene brightness along the scanning lines. The information residing in this signal is used at the receiver to reconstruct the image—one element at a time—in a similar synchronized scanning process.

In one pickup system, exemplified by equipment using the Farnsworth dissector tube, only the light falling upon an element of the photo-emissive area at the instant that element is being scanned is effective in producing the signal. The other pickup system, exemplified by equipment using the Iconoscope, makes use of the principle of storage, whereby, when a particular photo-emissive element is scanned the light which has fallen upon that element since it was last scanned is effective in producing the signal.

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The characteristics of these pickup tubes determine the manner in which film can be used to provide television programs. In the system using the dissector tube which has no storage, for every instant that signal is transmitted, the film projector must supply a light image to the elemental area being scanned, though not necessarily from the entire frame. In the Iconoscope system utilizing storage, a charge image may be built up by a very brief projection of the image upon the photo-emissive mosaic, which is then scanned by an electron beam while the mosaic is dark to produce the signal. The film pull-down occurs during the relatively long interval while the mosaic is being scanned. The detailed discussion to follow will be based on the system utilizing the Iconoscope.

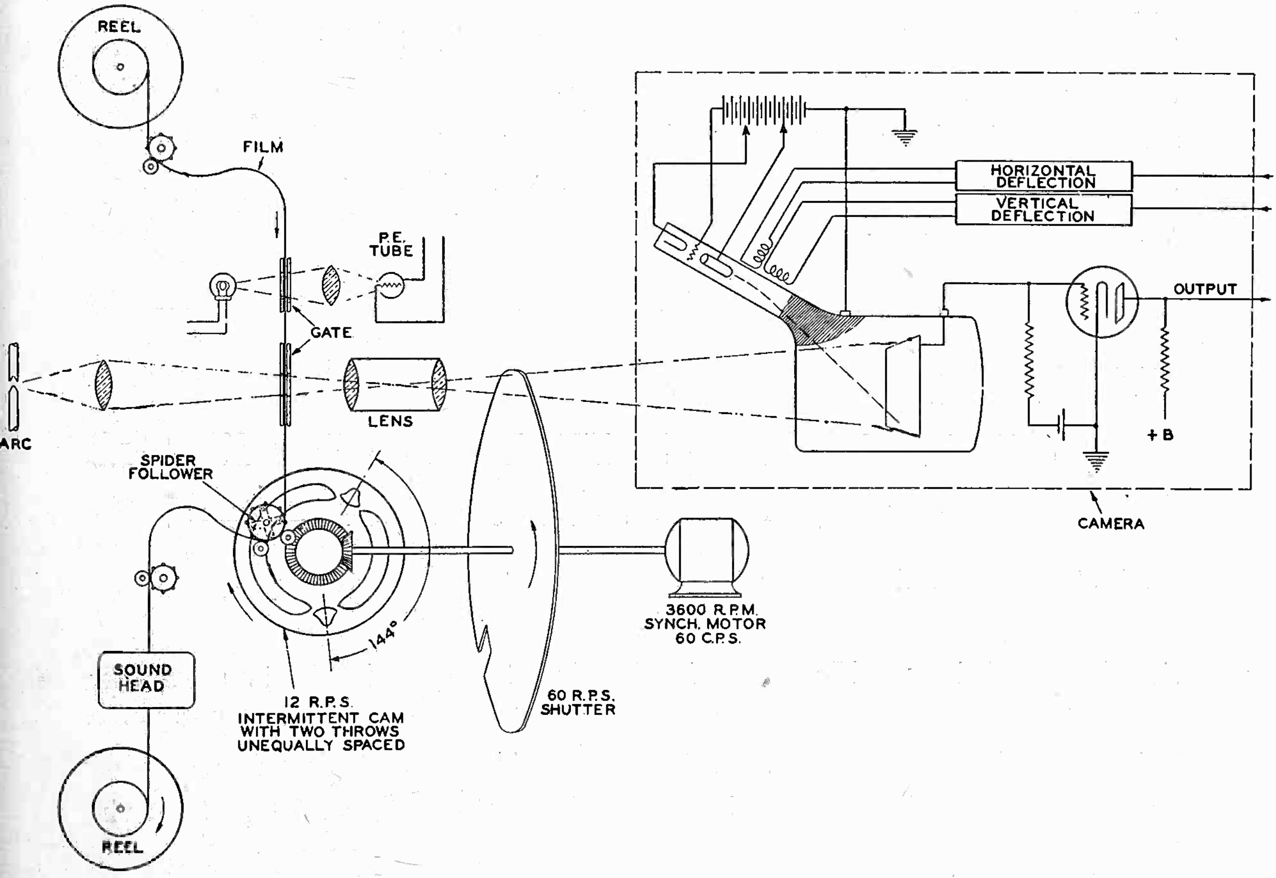

Fig. 1—Schematic of film projector for Iconoscope camera.

Discussion of Film Transmission System Utilizing an Iconoscope

Figure 1 shows schematically an Iconoscope camera and a special projector adapted to project standard 24-frame-per-second film upon the Iconoscope mosaic in such way as to generate television signals according to the Radio Manufacturers Association standards; namely, at 30 frames per second and 60 fields per second, interlaced.* The projector must flash a still picture upon the mosaic every 1/60 second with each flash lasting less than 1/600 second. Since the film must run at a mean speed of 24 frames per second for proper reproduction of sound and motion, it is evident that each frame must be projected more than once to provide the required sixty flashes per second. Since sixty divided by 24 is 2½, it would seem logical that each frame should be projected two and one-half times. This is impracticable, but a very satisfactory method is to project alternate frames of film two and three times each, respectively; for example, the even frames twice and the odd frames three times. Figure 2 shows the various steps of projection and scanning in proper relative time on a horizontal time scale. Since the light flashes are very brief, a relatively long (approximately 1/67 second) interval is available between flashes for the film pull-down. However, if the full time available is used, the alternate pull-downs must occur at non-uniform intervals of 2/60 and 3/60 seconds, respectively. Note from this figure that the scanning or transmission times occur *between* adjacent light flashes so that the television picture signal is actually produced and transmitted during periods when no optical image is present on the mosaic. However, during these periods an electrical image is present in the form of bound electrostatic charges on the tiny photo-sensitized silver globules comprising the mosaic. It is the act of neutralizing or rather equalizing these charges by the electrons of the scanning beam which causes the useful signal current to flow from the conducting back coating of the mosaic plate.

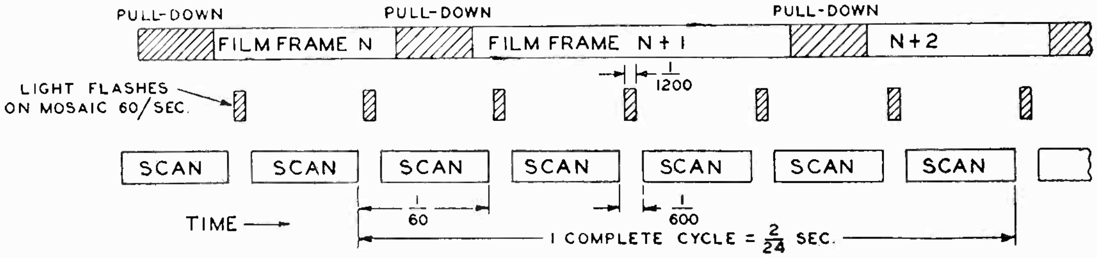

Fig. 2—Preferred sequence of events in film transmission by Iconoscope.

Referring again to Figure 1, the film is drawn through an illuminated gate by an intermittent sprocket which is driven by an intermittent cam and spider-follower of the early Powers type. The

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* G. L. Beers, E. W. Engstrom, and I. G. Maloff: "Some Television Problems from the Motion Picture Standpoint." *J. Soc. Mot. Pict. Eng.* XXXII (Feb., 1939), pp. 121-136.

3600-r.p.m. special synchronous motor drives the cam at 12 revolutions per second through a suitable gear, thus pulling the film down 24 times per second, since the cam has two "throws" instead of the customary one "throw." In order to pull the film at unequal intervals as required, the "throws" are located 144 degrees and 216 degrees apart, respectively. The film picture in the gate is projected upon the small photoemissive mosaic of the Iconoscope by a standard projection lens. The light is chopped 60 times per second by a large rotating shutter, located near the lens. The shutter is accurately timed relative to the intermittent cam so that the film is always stationary when the light flashes occur.

The generator of synchronizing signals for the television deflecting system is synchronously controlled by the same 60-cycle power supply which drives the projector synchronous motor. The phase of this signal generator is adjustable so that the operator can make the short duration light flashes fall safely within the 1/600-second intervals between the vertical scanning periods with some tolerance on each side for slight phase displacements such as are caused by small changes in the mechanical load on the projector or by voltage variations. This adjustment is very important, as any abrupt change in the illumination of the mosaic during the picture signal transmission time produces a spurious light streak across the received picture.

An ordinary 3600-r.p.m. synchronous motor has two identical pole structures which can assume either polarity and hence such a motor can lock into synchronism in either of two phase positions, depending fortuitously upon starting conditions. Two such lock-in positions are one-half of a cycle of the power-supply frequency apart in time, which for a 60-cycle power system is 1/120 second. Inspection of the diagram of Figure 2 shows that displacing the light flashes 1/120 second with respect to the scanning periods would cause them to occur during instead of between the scanning periods. The abrupt change in mosaic lighting caused by a flash during the scanning period would produce a serious streak across the middle of the picture as mentioned above. To prevent the frequent locking-in of the motor in the wrong position, a special synchronous motor is used which includes an additional d-c winding for fixing the polarity of the poles and thus determining the lock-in position with respect to the a-c power supply.

The sound head used is standard, since the mean speed of the film is 24 frames per second. It has been found that a suitable fly-wheel associated with the intermittent cam prevents any detectable deterioration of the reproduced sound due to the dissymmetry of the intermittent cam.

OTHER PROJECTING SEQUENCES AND MECHANISMS

There is some evidence that the television picture transmitted by a system depending completely upon the storage principle might not be as satisfactory as one transmitted by a system in which the film image is projected upon the photo-emissive mosaic either continuously or during the entire scanning period. It is natural, therefore, that investigations of the latter type of system should have been made. So far, the results obtained have not been wholly satisfactory and certainly have not been as excellent as those produced by the storage method described in the previous section. However, refinement of certain projection methods may at some time in the future make other systems of greater interest. It is, therefore, of value to digress and review some of the various schemes that have been investigated.

For obtaining a continuous and constant light image on the Iconoscope photo-emissive mosaic, a commercial type of theater projector was used, in which the film passed the picture gate at constant speed and a stationary projected image was obtained by means of an "optical intermittent." This projector employed several rocking mirrors on a rotating wheel. The lens system was properly proportioned for the projection of the small image required for the Iconoscope mosaic plate. In testing this system it was noted that the television performance was limited by various types of movement in the projected optical image and by low resolution. Motion of the optical image, in addition to causing objectionable motion in the received television picture, also contributed to loss of resolution in the picture. This is due to the storage action of the Iconoscope whereby the signal derived from each element of the mosaic in scanning is due to the summation of all the light which has fallen on that element since the preceding contact of the scanning beam. The effect is similar to that obtained when the optical image on a sensitized photographic plate moves during exposure.

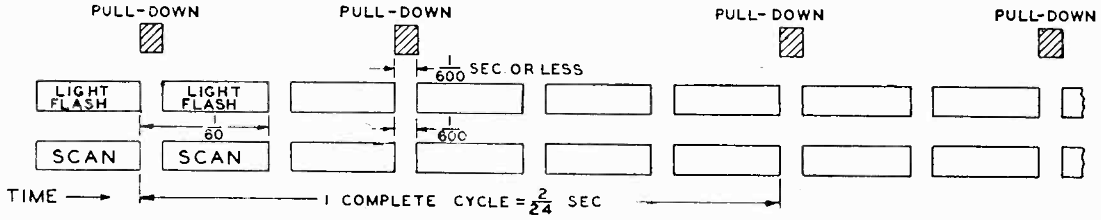

Fig. 3—Idealized sequence of events in film transmission by Iconoscope.

Figure 3 shows a projection sequence by which an intermittent type projector might project film on an Iconoscope for the entire scanning time provided the pull-down occurred in the almost prohibitively short time of 1/600 second or less. This would permit projection throughout the entire scanning period. There is no apparatus now available for meeting the 1/600 second pull-down requirement. If suitable equipment could be developed it is doubtful if the film would withstand the stresses imposed by the rapid motion.

An experimental projector using a continuously moving film, and a rocking mirror for producing a stationary image, was built and tested. A diagrammatic view of it is shown in Figure 4. The cam-driven mirror was arranged to neutralize accurately the film motion during the intervals marked "light flash" in Figure 3 and to return to receive light from the next consecutive film frame during the 1/600-second non-uniformly-spaced intervals marked "pull-down." Limitations were found due to slight non-uniform illumination of the approximately two and one-half frames of film always in the picture gate. This resulted in objectionable flicker in the television picture. Also, in spite of the very small amplitude of motion required for the rocking mirror, the cam and follower-roller created a very annoying noise and were subject to rapid wear.

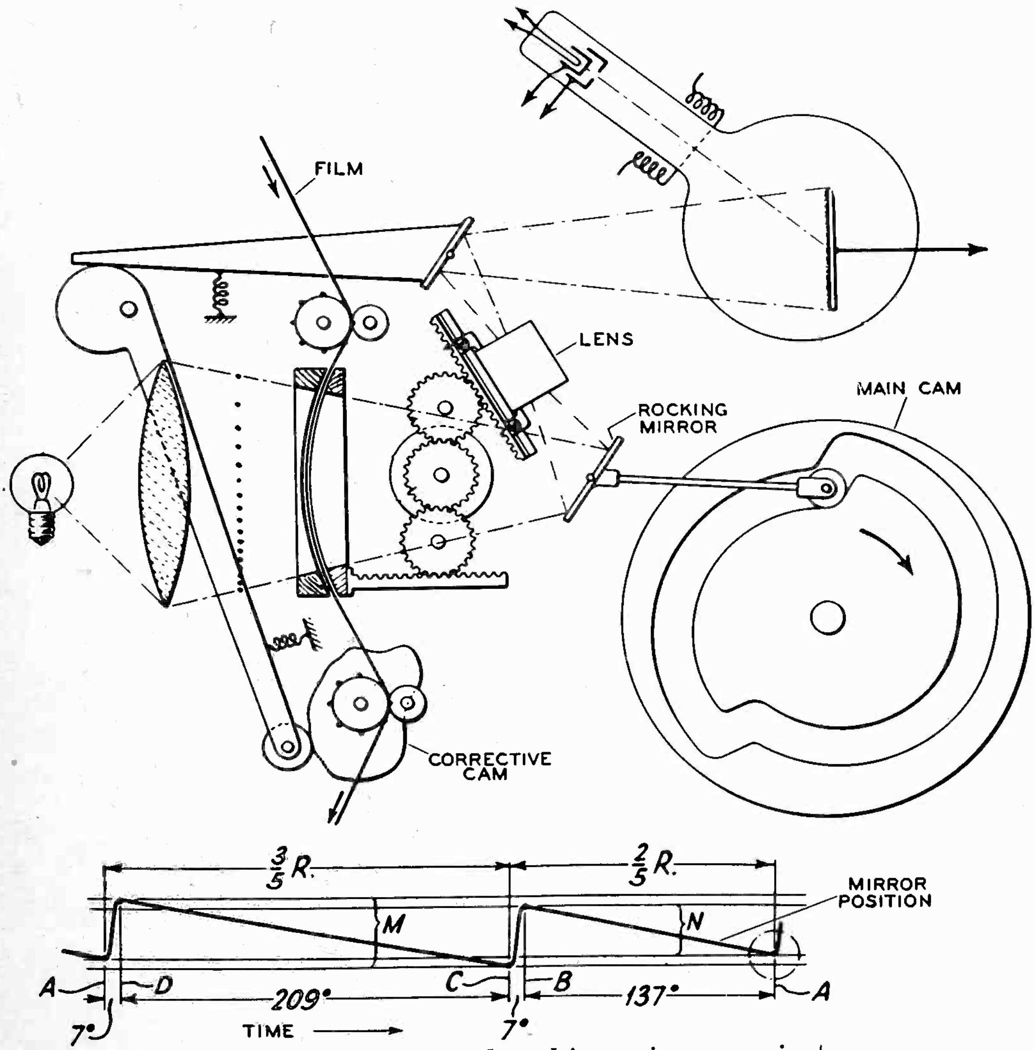

Fig. 4—Experimental rocking mirror projector.

DESCRIPTION OF FILM PROJECTOR

It is of interest to return now to the method for using film which is considered best at present, and review the apparatus in more detail.

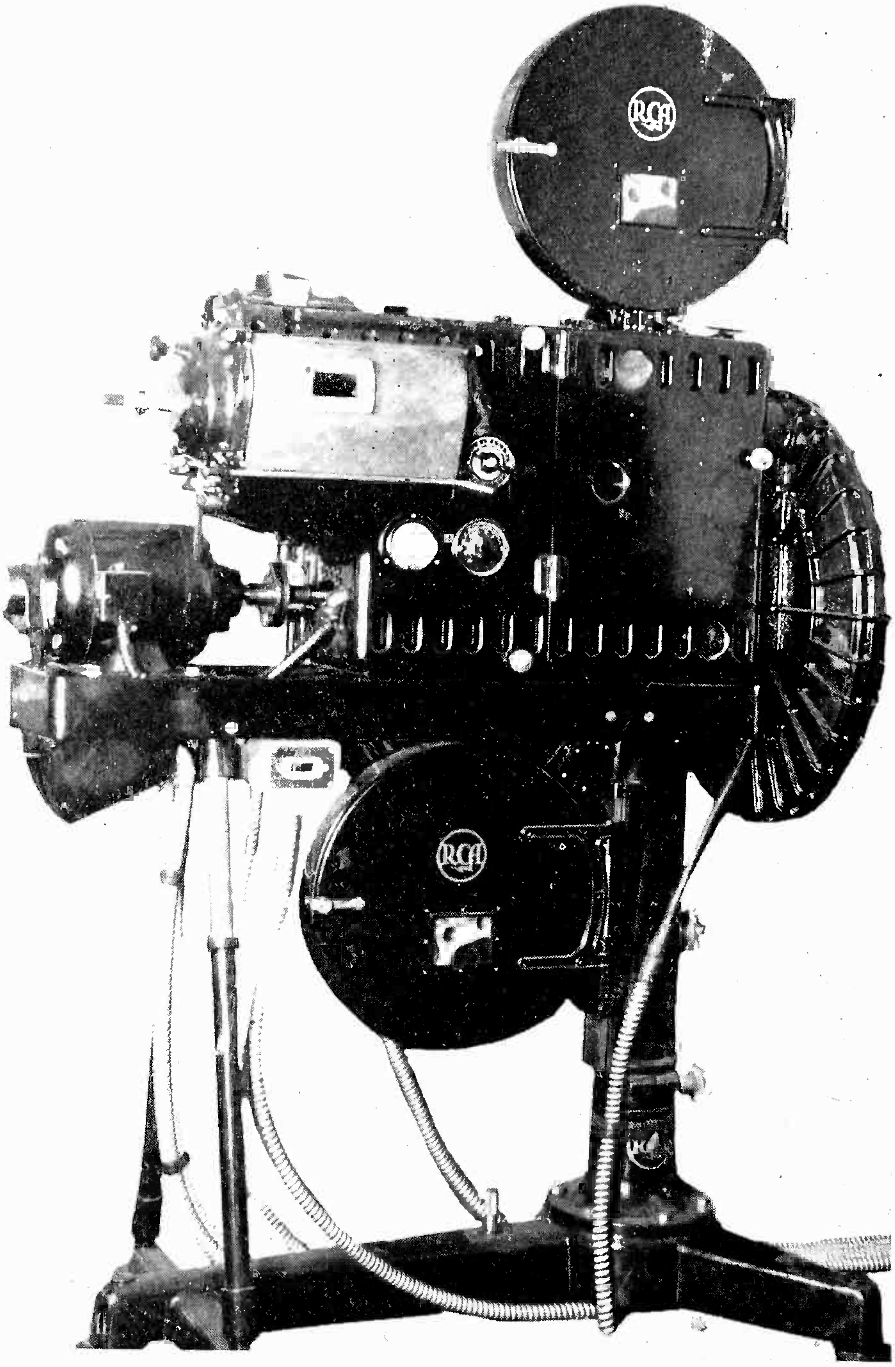

Fig. 5—RCA 35-mm sound motion-picture projector designed for 30-frame-per-second television with interlaced scanning.

Figure 5 is a general view of a 35-mm sound motion-picture projector* designed for 30-frame-per-second television with interlaced scanning.

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* This projector was built to RCA specifications by International Projector Corp.

This projector differs from standard theater projectors in the following major respects:

1. A special shutter is used to provide efficient light pulses of very short time duration for projecting, 60 times per second, images of the film pictures onto the photo-emissive mosaic of the Iconoscope.

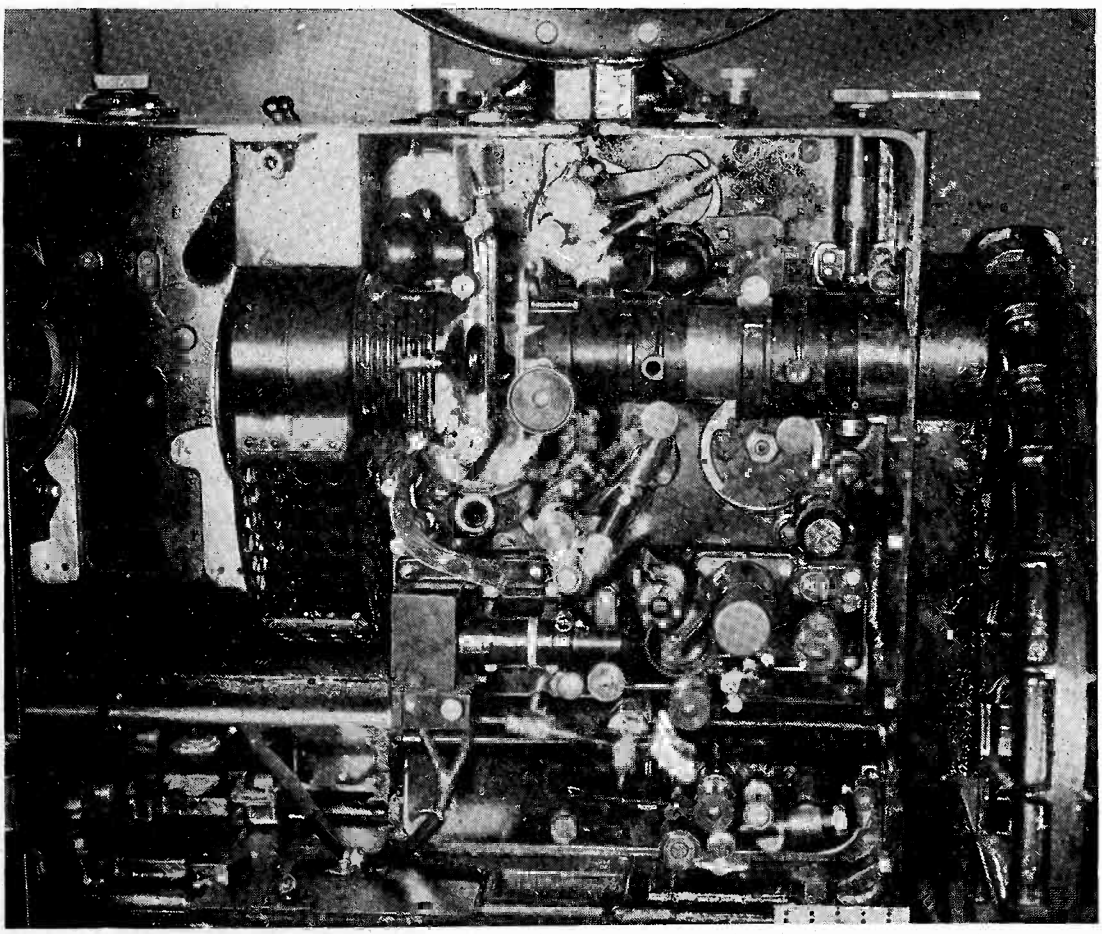

Fig. 6—Film projector for television with doors open.

2. The intermittent mechanism is designed for the three-to-two ratio of pull-down periods required in using 24-frame film for 30-frame television.
3. A special synchronous driving motor is used to assure that the projector mechanism always "locks-in" in proper time relation with the synchronizing pulses.
4. An additional film gate with light source and photo-electric cell is included near the picture gate for deriving a control potential which varies with the average density of the film.

In the projector shown in Figure 5, it was impracticable to locate the shutter between the light source and the film. The shutter was, therefore, mounted just beyond the projection lens. Sufficient clearance between the shutter and lens was provided to permit a limited movement of the lens for focusing. The time during which the image may be projected onto the photo-emissive mosaic of the Iconoscope is limited to the vertical return time of the scanning beam. With present television standards this is not more than 10 per cent of 1/60 second or 1/600 second.

In order to make efficient use of the projection lens, it is necessary for the aperture in the shutter to be at least as wide as the diameter of the lens. A large diameter shutter (23″) is necessary to meet this requirement. This shutter rotates at 3600 r.p.m. and has a peripheral speed of approximately 4¼ miles per minute. The shutter is enclosed in the circular housing which is shown at the extreme right-hand side of Figure 5. In the shutter housing opposite the projection lens is a window through which the picture is projected. The shutter disc is made of two overlapping sections of thin metal. These two sections can be rotated with respect to each other through a small angle in order to vary the width of the aperture. Figure 6 is a photograph showing the film side of the projector with the cover removed.

A second gate is located four frames of film above the picture gate. To the left of this gate, as shown in Figure 6, is a lamp housing. To the right of this gate is a photocell housing which also includes an optical system for forming an image of the lamp filament on the photocell. The output voltage from this photocell is rectified, and after being passed through a suitable filter is used to control the return-line blanking signals. The resultant variation in the blanking signals is used to control the average brightness of the reproduced picture. Figure 7 shows a view of the film side of the projector with a film threaded ready for projection.

Although the projector just described is equipped with a small 30-ampere arc, either an incandescent lamp or an arc may be used.

EQUIPMENT FOR BROADCASTING TELEVISION FILM PROGRAMS

In considering the production of motion-picture films for television, it is important to review the apparatus that will be used in the broadcasting station. The essential elements of a system for television transmission from motion-picture film are shown in Figure 8. These include: Film Projector; Iconoscope Film Camera; Camera Amplifier Equipment; Control Equipment; Monitor Equipment; Synchronizing Generator.

The Iconoscope camera used with the film projector includes deflecting circuits and a pre-amplifier for the video signals. This pre-amplifier provides a signal level suitable for transmission over a coaxial cable to the camera amplifier equipment. The camera is usually mounted on one side of a wall, with the film projector located on the other side. The picture is projected through a window in the wall into the camera onto the photo-emissive mosaic of the Iconoscope.

The camera amplifier equipment includes apparatus for amplifying further the video signals from the camera and a line amplifier to prepare these signals for transmission over coaxial cable to any desired location. Amplifiers providing suitable wave shapes for horizontal and vertical deflection of the Iconoscope beam are included as well as the power supplies for the several parts of the system. This equipment is usually rack-mounted in some convenient location.

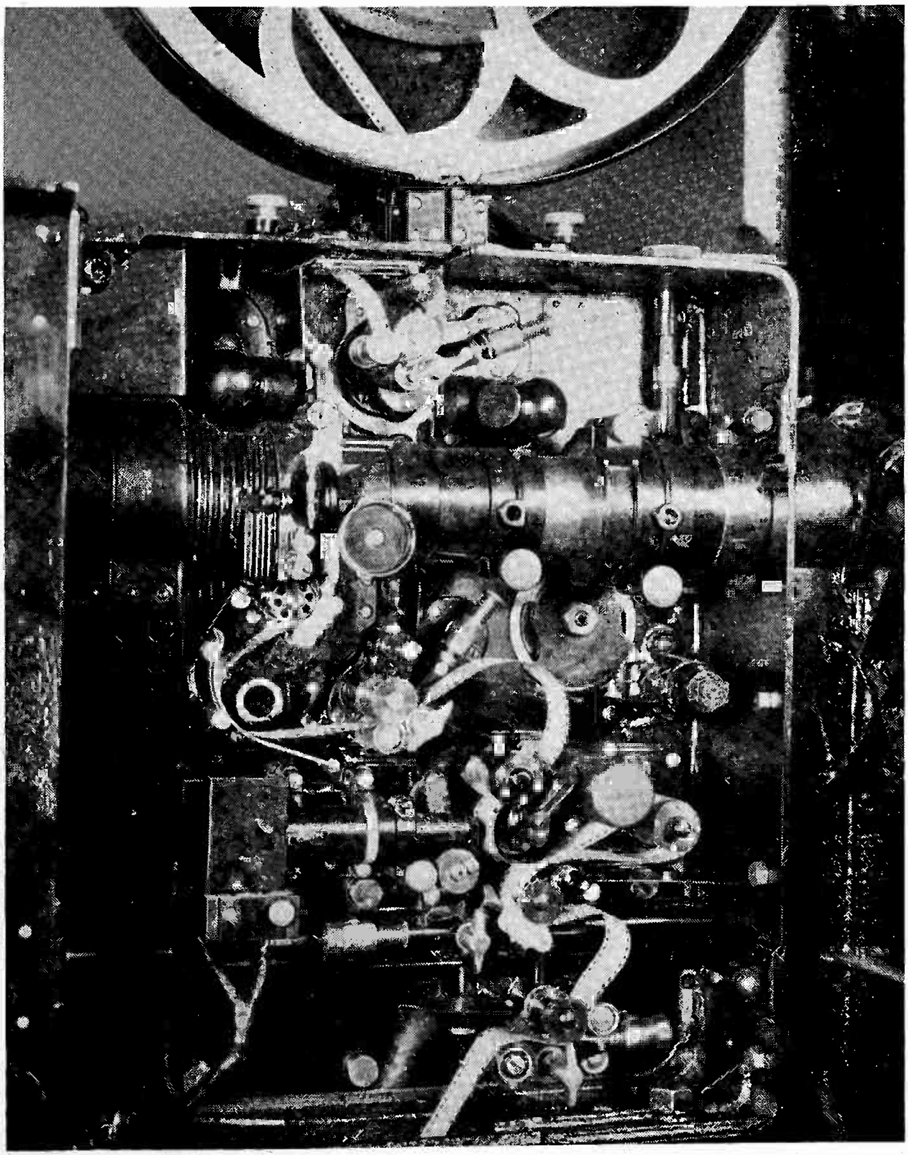

Fig. 7—View of film projector for television showing film path.

The control equipment provides means for varying the video signal gain, the picture brightness, and the uniformity of the picture-background illumination (shading), and for starting and stopping the

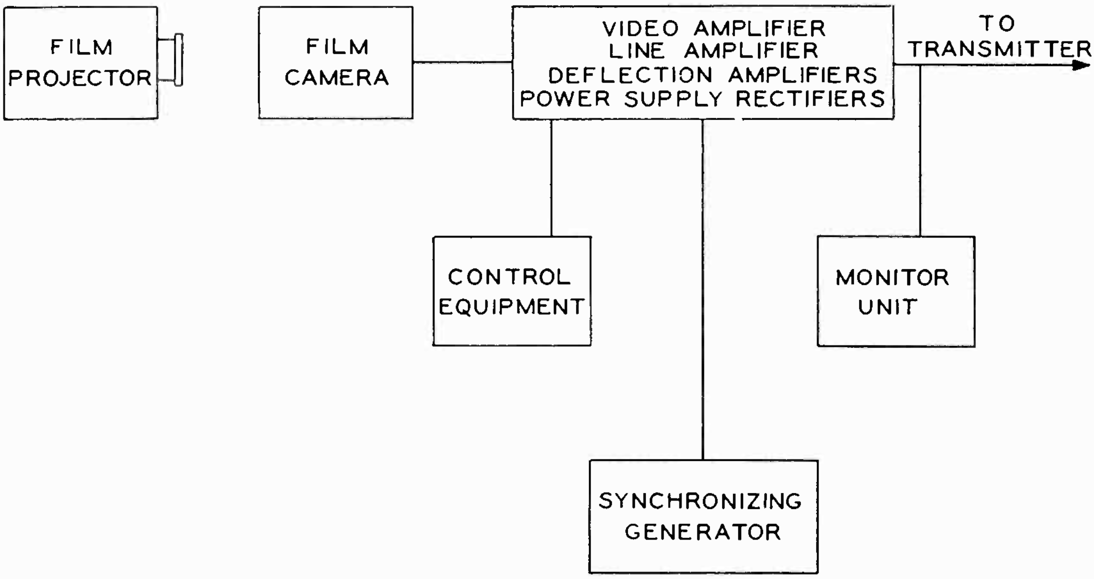

Fig. 8—System for television transmission from motion-picture film.

film projector. In an installation designed to provide a continuous program from motion picture film, where two or more film projectors and television channels are included, controls are also provided for switching from one channel to another.

The monitor equipment includes a 12″ Kinescope by means of which television images obtained from the film can be viewed. It also includes a cathode-ray oscilloscope for observing the wave shapes

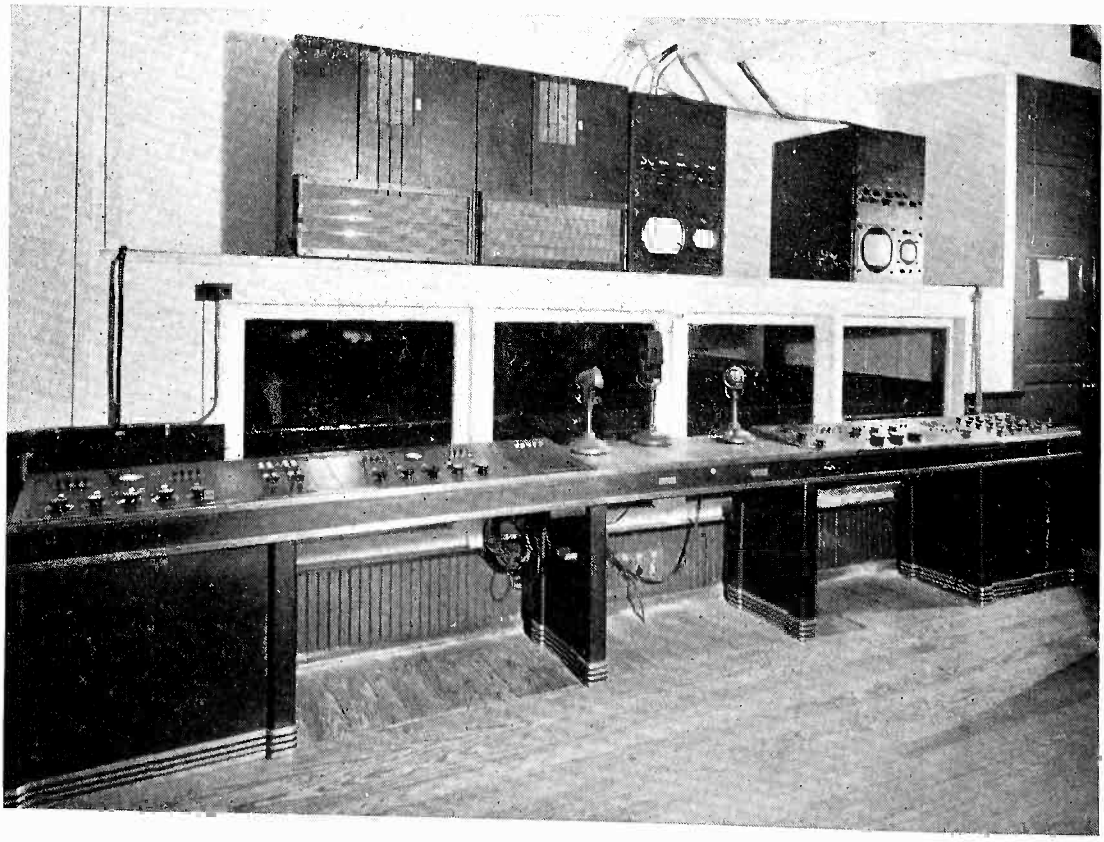

Fig. 9—Television control equipment for studio and film-type cameras.

and amplitudes of the television signals. This monitor equipment is usually located so that it may be observed conveniently by the operator manipulating the control apparatus.

The synchronizing generator supplies the several complex waveforms which are required to determine the timing of scanning processes in the transmitting equipment and to synchronize the reconstruction of the images at the receivers. The wave shapes of the synchronizing signals have been standardized by the Radio Manufacturers Association.

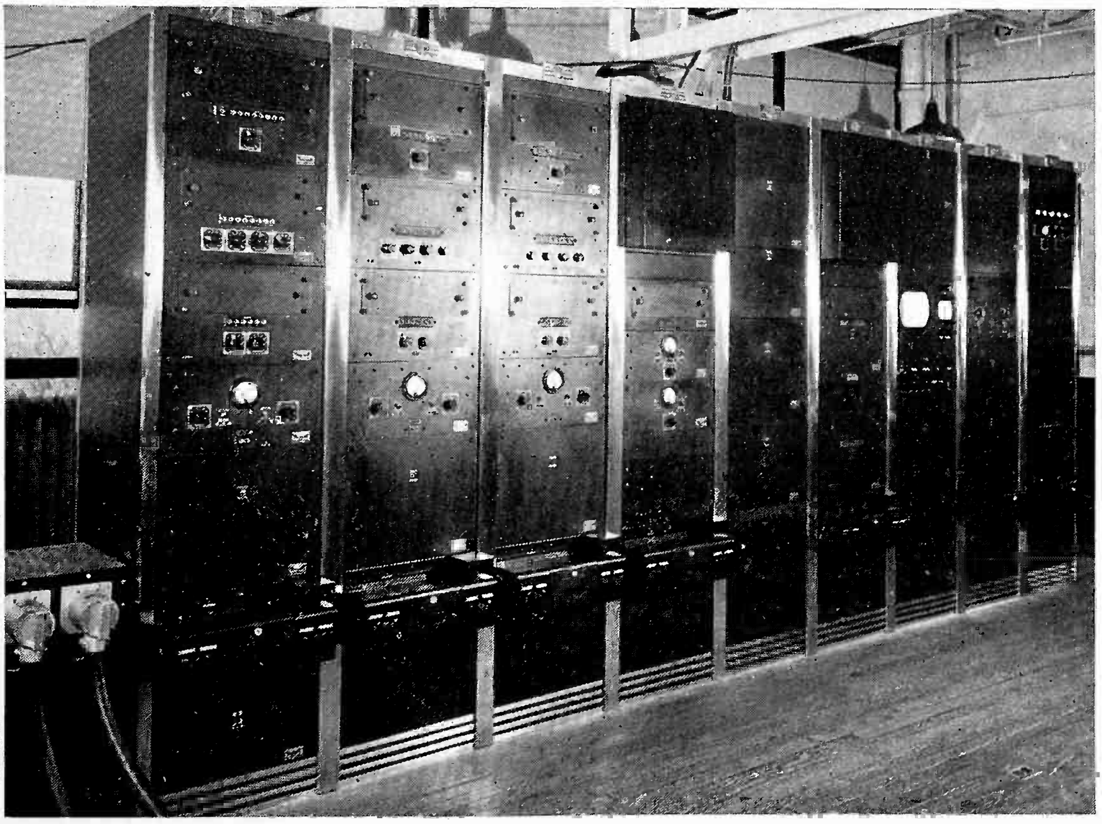

Fig. 10—Television terminal equipment suitable for television broadcasting stations.

Views of television equipment of a type suitable for television broadcasting stations are shown in Figures 9 and 10. Figure 9 shows an installation of control equipment for studio and film type cameras. This equipment is grouped on a common control console with the monitors mounted in a recess in the wall above the console. In this installation, the control engineer may look directly into the studio. Figure 10 shows a typical installation of racks of television-terminal equipment.

SIMPLIFIED TELEVISION APPARATUS

For specialized services, more simple and compact television equipment is desirable. Apparatus of this sort has been developed both for direct studio pickup and for film applications. The simplified equipment suitable for producing television signals and television images from motion-picture film includes all of the elements previously described, but in far more compact form. The equipment less the Iconoscope camera and the projector is included in one cabinet approximately 44 inches high, 34 inches wide, and 21 inches deep. This equipment produces a television signal which is suitable for transmission to remote viewing positions or for other uses.

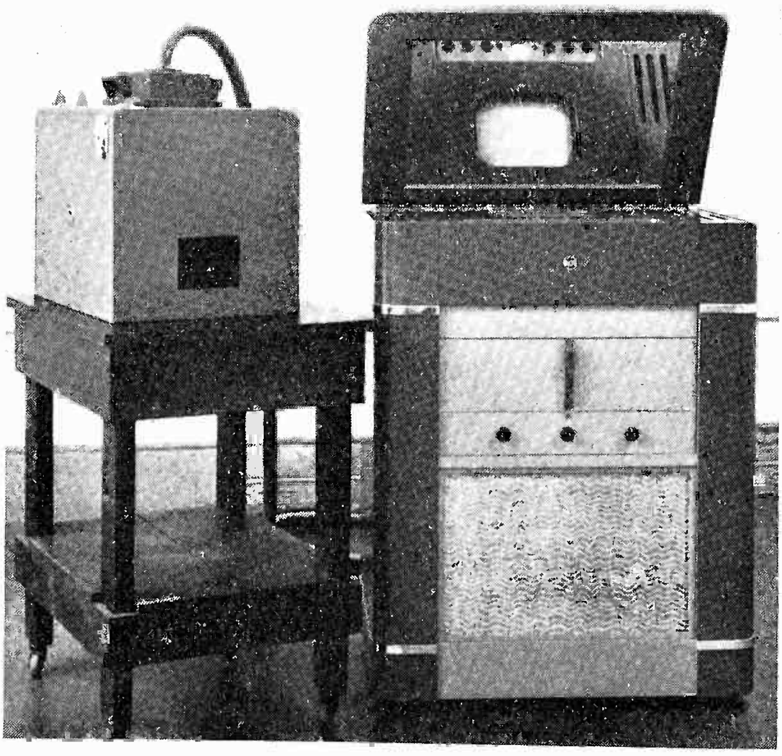

Fig. 11—Simplified television apparatus suitable for judging the merits of motion-picture film.

This simplified equipment is not as flexible in some respects as the broadcasting type of equipment, nor does it lend itself well to large complex systems. However, it does provide the facilities necessary for judging the merits of film for television use. In this simplification of apparatus and circuits, the synchronizing wave shapes do not conform entirely to the Radio Manufacturers Association standards. The synchronizing signals are, however, satisfactory for the self-contained monitor and for other receivers or reproducing devices, but the adjustments may be a little more critical than would be the case with standard synchronizing signals. Figure 11 shows a view of the equipment with the Iconoscope camera mounted on a simple wooden dolly.

APPARATUS FOR JUDGING THE MERITS OF MOTION PICTURE FILM FOR TELEVISION

An earlier paper* reviewed some of the limitations inherent in present-day television and compared these with similar limitations in motion-picture film and apparatus. Experience has indicated that the production of television pictures from a particular film is the only practical method for judging the merits of that film as television program material. It is, therefore, suggested that this method be used for checking and studying motion-picture films produced for television programs and for determining the usefulness of film available from other sources. Apparatus of the type used at the television-broadcasting station or apparatus of the simplified type just described will be satisfactory for this service.

FILM BEST SUITED FOR TELEVISION

Laboratory work and field-test experience permits some preliminary generalizations on film that has given good results for television. Comment is here directed to the technical characteristics of film and not to the entertainment qualities. It appears that film having characteristics best suited for theater projection is also generally best for television. Studio sets having all dark backgrounds should be avoided. A goodly number of close-ups should be used, but these should be generously interspersed with long shots. Some experience may be necessary to take into account the resolution limits* of present-day television. Special processing of film does not seem to be necessary.

Film photographed in color directly from real life or nature appears satisfactory for television. Some cartoons in color have not given particularly satisfactory results. Thus, it appears that there may be no really serious technical problems in the production of motion-picture films suitable for television-program material.

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* Loc. cit.

A PUSH-PULL ULTRA-HIGH-FREQUENCY BEAM TETRODE

By

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Summary—*The design of a vacuum tube capable of delivering 10 watts useful power output at frequencies of the order of 250 megacycles and with a d-c plate voltage of 400 volts and good economy of space and cathode power, is discussed. In order to keep the physical dimensions of the tube small and to make it adaptable to straightforward circuit arrangements, the tube was designed as a push-pull beam tetrode. Unusual constructional features include the use of short, heavy leads sealed directly into the moulded glass bulb.*

Characteristics of the tube are given. Tests show that the tube will operate as a stable Class C amplifier at frequencies up to 250 megacycles. At that frequency a power output of the order of 13 watts with an efficiency of 45 per cent has been obtained. Satisfactory operation as a frequency multiplier is possible in the same frequency range. Oscillator operation has been obtained at considerably higher frequencies. The variation of output and efficiency with frequency is shown.

THE frequency spectrum above 100 megacycles has proved itself valuable for communication over line-of-sight ranges. Since relatively small amounts of power are satisfactory and it is relatively easy to build efficient antennas for communication at these frequencies, the frequency band above 100 megacycles seems to be eminently suited for aircraft communication from plane to plane or from plane to ground over short distances. It was for such an application that the development of a tube suitable for use in the output stage of transmitters was undertaken.

Consideration of some of the necessary points in the design of a satisfactory ultra-high-frequency transmitter indicates a number of limitations and qualifications which a suitable tube should meet. In order to make the equipment simple and operable at all times its filament and plate power should be obtainable from the regular storage battery, and should be kept at a minimum. To have frequency stability, the transmitter should consist of an amplifier stage driven either by a crystal-controlled oscillator through a frequency multiplier, or by a stable high-frequency oscillator. The transmitter should preferably be capable of operating at several frequencies and the final amplifier stage should operate stably at frequencies up to approximately 250 megacycles. A useful output of the order of 10 watts was chosen as sufficient for requirements.

There are several limitations on the proposed tube which are determined by these considerations. In the first place, the tube must be economical in filament and plate power. Second, because of the difficulty of insulating high voltages at the reduced pressures encountered at high altitudes, the operating plate voltage must be as low as possible. Therefore, a value of 400 volts for unmodulated service was decided upon. Third, the tube must function as a stable amplifier. The necessity for neutralization would render a triode unsatisfactory for operation over a band of frequencies and, consequently, a tetrode or pentode design was indicated. Because it is possible to develop a greater plate voltage swing in a pentode or beam power amplifier than in a tetrode for the same direct plate voltage, and thus to obtain higher plate-circuit efficiency, the beam power-amplifier design was chosen for this tube. The reasons for choosing the beam power amplifier in preference to the pentode will be discussed below. The use of a low plate-supply voltage makes it especially desirable to have the peak plate-voltage swing as high as possible. And last, the tube must be sufficiently rugged to withstand vibration and physical shock without an elaborate mounting. Simplicity in tube and circuit is important to insure satisfactory performance and ease of maintenance.

Besides these requirements, there should be noted those requirements which are imposed by the frequencies at which the tube is intended to operate. The various qualifications which a tube should possess for successful operation at high frequencies have been covered rather completely in the literature.[1 2 3] The important considerations which entered into the design of this tube are summarized below:

1. The tube must lend itself to satisfactory circuit design. The greatest possible amount of circuit must exist outside the tube at any given frequency. In order to meet this requirement, the input and output capacitances and the lead inductances must be kept at a minimum, and the tube must be small in size. For the higher frequencies, the use of transmission lines as circuit elements has the advantage of allowing greater physical size of circuit than when lumped circuits are used. The tube leads should preferably be so arranged that the tube is adaptable to operation in either type of circuit.

2. The leads to the tube electrodes must be of such a size as to carry safely the high-frequency currents to the electrodes and to avoid losses which would reduce the output.

3. In order to minimize the limiting effect of electron transit time, the spacings between electrodes must be kept small. In particular, the cathode-to-grid distance must be small since it is in this space that the electron must be accelerated from a low velocity at the cathode

surface to a considerable velocity at the plane of the grid. The effect of an appreciable transit time in this region is to increase the input conductance of the tube. The result of the finite time of transit from cathode to plate in reducing the plate-circuit efficiency has been pointed out by Haeff.[4]

4. Because of the small spacings, the grids are subjected to severe conditions of temperature. The grids, however, must not emit primary or secondary electrons to any appreciable extent. To avoid such emission requires that the grid temperature be kept low and, consequently, adequate provision for cooling the grids.

5. The insulation provided must be sufficient to prevent breakdown at the operating frequencies and voltages. Also, it must not introduce excessive losses at these frequencies.

On the basis of these requirements, consideration was given to the use of a push-pull circuit. Such a circuit offers advantages in design and ease of operation over a single-ended circuit which at ultra-high frequencies is not so straightforward. Because of the symmetrical character of the push-pull circuit, an effective ground plane exists in the circuit which materially simplifies the problem of by-passing and connecting low potential leads. The connection between screens and cathodes in the two units allows the fundamental frequency and odd-harmonic components to cancel out, and leaves only even harmonics to be by-passed. In addition, push-pull operation is well-suited to the use of parallel-line circuits, since the conductors are symmetrical in arrangement. For these reasons, it was decided to design the tube for push-pull operation. In order to keep the space required at a minimum, both units of the push-pull combination were placed in a single envelope. A similar arrangement has been described by Samuel.[5] The spacing between the two units may be made smaller than where separate envelopes are used, and considerable improvement may be obtained from the point of view of length of connecting leads. Those electrodes which are connected together in the push-pull circuit, the screen grids and the cathodes, may be connected inside the tube by a lower inductance path than is possible for two separate tubes. A low-impedance connection between the screen grids becomes an important factor in attaining stable operation at the high frequencies. To obtain maximum shielding between input and output circuits, it is essential that the screen grid be at r-f ground potential, a condition which is easily met at low frequencies with external by-passing. At high frequencies, however, the connection from screen to ground through the external by-pass condenser will present considerable impedance, and result in an appreciable r-f voltage on the screen. When the screens are connected within the tube, the impedance of the lead to the effective ground point may be decreased very appreciably. In a similar manner, the short connection between the two cathodes results in a smaller impedance between the cathodes and the effective ground point, and reduces the effects of degeneration. The smaller spacing between units and the smaller total assembly aid in fulfilling the circuit requirements.

The structure of each unit of the tube has been made that of a beam power amplifier[6] in which directed electron beams are obtained by electrical focusing with properly chosen grid wires, grid side rods, beam confining plates, and electrode shapes and in which it has been found practical to suppress secondary emission effects by space charge rather than by a suppressor grid. Both the space charge in this beam tube and the suppressor grid in the conventional pentode act to form a potential minimum which prevents the relatively low-velocity secondary electrons from passing to the screen from the plate. The use of the beam structure makes the construction simpler and considerably more rugged, and at the same time allows use to be made of aligned screen and control grids with the attendant decrease in screen current. The lowering of the screen current and the consequent decrease in screen dissipation is of importance in transmitting pentodes where screen dissipation is a serious limitation. Economy of high-voltage power is achieved at the same time.

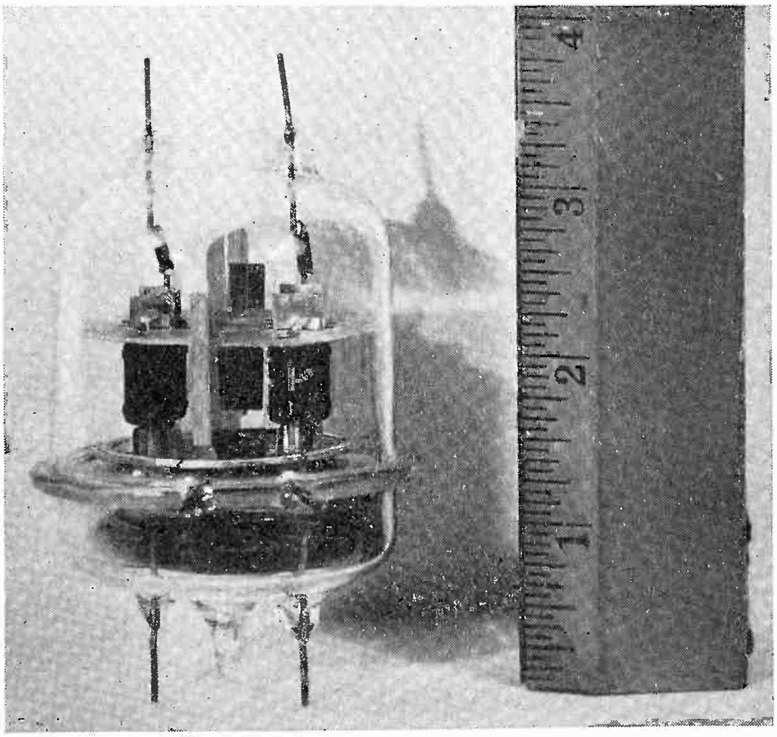

Fig. 1—Early developmental type of ultra-high-frequency amplifier tube.

A photograph of one of the early developmental tubes of this type is shown in Figure 1. The construction will be seen to be somewhat similar to an enlarged Acorn-type tube with its low potential leads extending radially through the main seal. The cathode and screen leads may be seen at the front of the tube. The plate and grid leads from the two units extend symmetrically from the top and bottom of the tube, respectively. The input and output sides of the tube are shielded from each other by the flat disc shield which extends horizontally across the tube below the plates. This shield connects to the two cathodes and serves as connection between them. The low plate voltage allows the use of oxide-coated cathodes and mica insulation, both of which increase the ruggedness of the assembly and improve its resistance to vibration. The screen grids are joined together by a low-impedance connection, and from this a common lead is brought out.

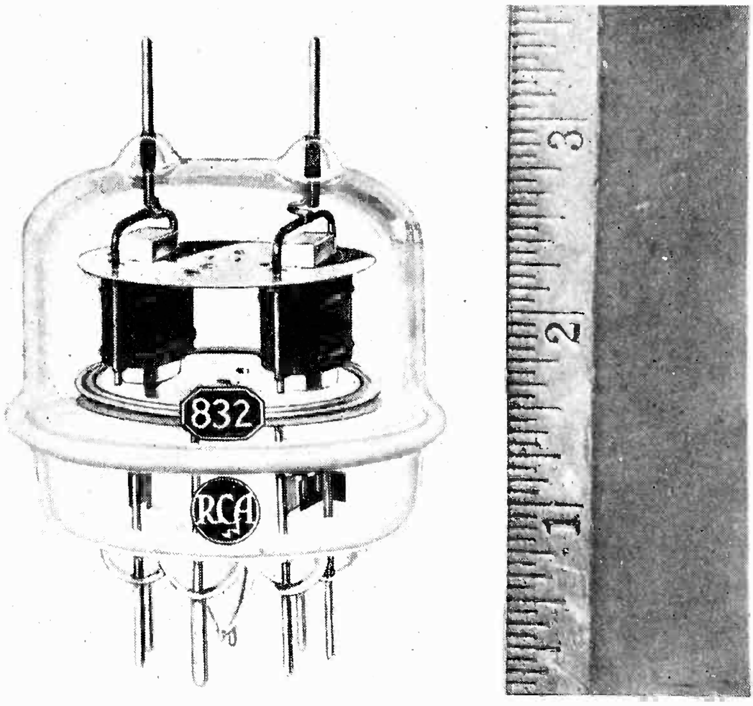

Fig. 2—The RCA-832 ultra-high-frequency beam tetrode.

The structure shown proved satisfactory in operation, but for three reasons it was thought wise to modify the design. In the first place, the tube occupied considerable space, largely because the radial leads increased the mounting area appreciably over that required for the envelope alone. Second, the radial leads were required to withstand severe strains when the tube was inserted in or removed from a socket. And last, the radial construction did not permit easy fabrication. Accordingly, a redesign was undertaken which ultimately resulted in the tube shown in Figure 2. This tube is identified as the

RCA-832. The leads which formerly extended radially from the bulb were placed parallel to the grid leads, and were made heavier. This structure gives greater strength and provides increased current-carrying capacity. The tube can be placed in a socket without danger to the seals from strain on the leads. The bulb has been made short and the space required for the mounting has been decreased approximately 50 per cent.

The arrangement of the electrodes was changed only slightly. The plate leads were shortened inside the envelope and a double lead was used to lower the resistance and inductance of the connection. The center shield between the two units was found to contribute nothing to the tube's performance and was eliminated. The ends of each unit were shielded to decrease the number of stray electrons which ordinarily leave the active section and bombard the insulators or the bulb. Such bombardment tends to release secondary electrons which return to the plate by a long transit-time path and, lagging behind the normal plate current pulse, increase the plate loss. Bombardment of the insulators and bulb also tends to release gas which gradually impairs

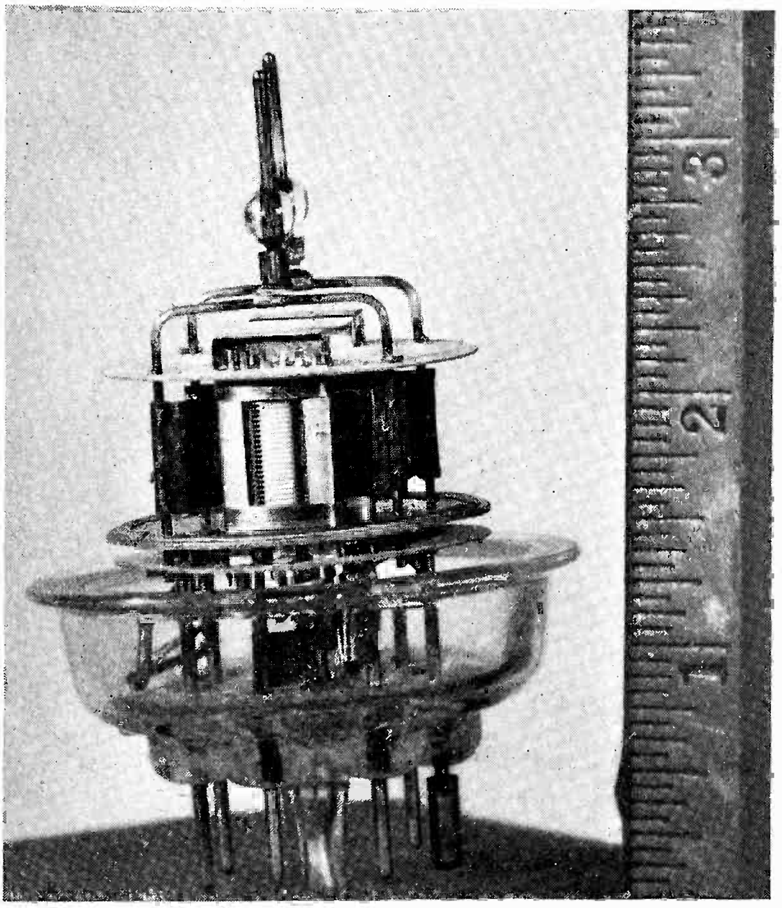

Fig. 3—A view of the mount structure of the RCA-832.

the vacuum and eventually ruins the cathode emission. The screen grids of the two units were joined together by a short connector which forms one plate of a by-pass condenser. The other plate of the condenser was connected directly to the cathode. The combination of the low-impedance connector and the direct high-frequency by-pass maintains the screens very close to ground potential and materially improves the stability of the tube as an amplifier at the higher frequencies.

A photograph of the mount structure with one of its plates cut away to show the arrangement of the electrodes, is presented in Figure 3. The shields at the ends of the unit are shown, as are the beam-confining plates.[6] These plates or channels extend longitudinally through the structure around the grid side rods and, as their name implies, confine the active area of the tube to the section between the grid side rods in order to improve the uniformity of the electron stream throughout the active area. The arrangement of the electrodes may be seen in the line drawings of Figure 4, where the left-hand diagram shows the cross-section of one unit in a plane perpendicular to the cathode and the right-hand diagram shows a section taken in the plane through the cathode axis. The two grids are aligned so that the turns of the screen grid are directly behind the turns of the control grid as viewed from the cathode. The control grids are cooled by the use of large-diameter side rods which are connected to a short wide strap having a blackened surface to improve its radiating characteristics. The strap is in turn connected directly to the external grid terminal. This construction serves to conduct a fairly large amount of heat from

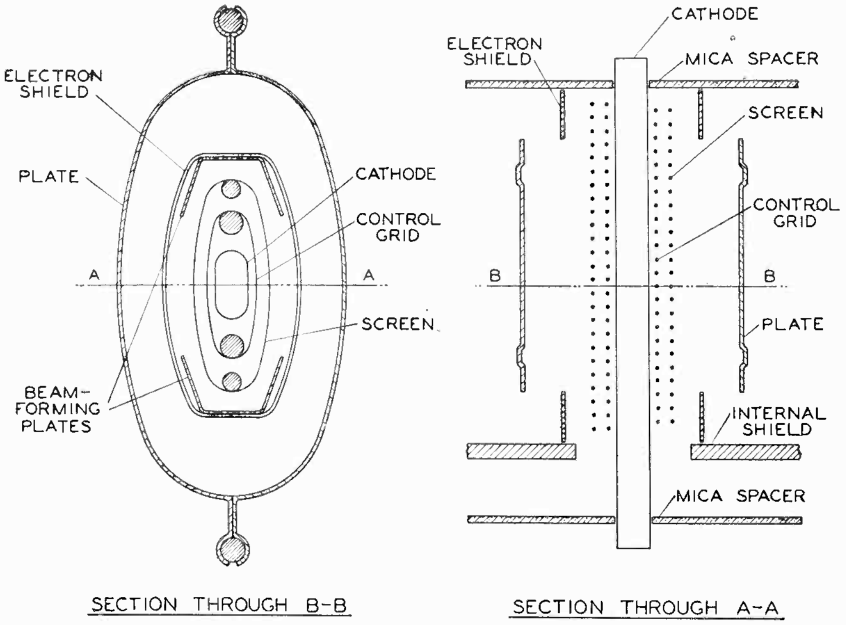

Fig. 4—Arrangement of the electrodes in the RCA-832.

the grid to the outside of the tube envelope, and at the same time results in a low-resistance, low-inductance grid connection. The screens are cooled in a similar manner. The strap welded to the screen side rods is, however, not blackened and forms one plate of the internal by-pass condenser.

The use of a large cathode surface and a small grid-cathode spacing results in high perveance for the tube. The grid-cathode spacing is of the order of ten thousandths of an inch. The heaters have been designed to operate at 12.6 volts to facilitate operation directly from a 12-volt storage-battery supply. The heaters for the two units are connected in series and the mid-point is brought out to a terminal so that 6.3-volt operation may also be obtained.

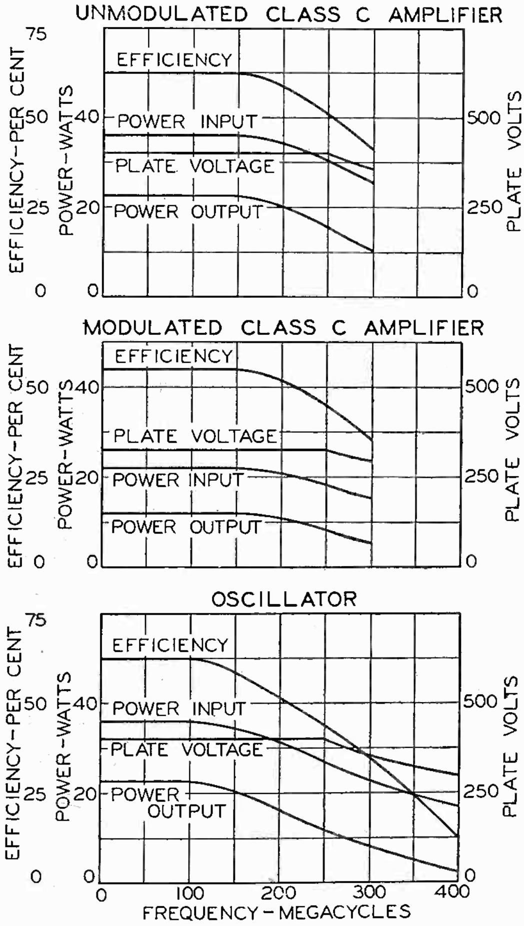

Fig. 5—Variations of efficiency and power output with frequency.

The fact that the finite electron transit time from cathode to plate results in a decrease in plate-circuit efficiency from the value obtained at low frequencies where the transit time is negligible has already been mentioned.[4] As the frequency is increased, the transit time becomes a larger fraction of a high-frequency cycle, and its effect, therefore, becomes greater. The variation of efficiency with frequency is plotted in Figure 5 for various classes of service. The efficiency decreases less rapidly with frequency for amplifier than for oscillator service because of the difference in phase relation between the instantaneous plate and grid voltages in the two classes of operation. In the usual oscillator circuit, the plate and grid voltages are almost 180° out of phase. Because of the time of transit, electrons leaving the cathode under the action of the grid voltage arrive at the plate lagging behind the grid voltage and, consequently, after the plate voltage has passed its minimum. The energy of these electrons is thus higher because of the higher plate voltage than it would be with negligible transit time. As a result, the plate loss is higher and the efficiency is reduced. In an amplifier, on the other hand, the grid voltage is independent of the plate voltage. The plate circuit is tuned so that the plate-current pulse and the plate-voltage swing bear the optimum phase relationship to each other, with the result that the efficiency is higher than for the oscillator case. The efficiency is not so high as at low frequencies, however, because the appreciable transit time causes spreading and distortion of the plate-current pulse and because the electrons are acted upon for a longer time by the plate voltage. The effect is the same as if the angle of plate-current flow were made larger at ordinary frequencies. Increased losses in the leads and electrodes also tend to lower the efficiency obtainable at high frequencies. Because the efficiency falls off, the input must be dropped at the higher frequencies in order that the plate dissipation will not be exceeded. Since the loss in the glass and in the internal insulation increases with frequency and with the voltage applied to the insulation, the voltage on the tube must also be decreased at the higher frequencies. Figure 5 shows how the input power and plate voltage are reduced. This same plot shows also the approximate values of output which may be obtained at various frequencies. These curves are based on results obtained in operating the tube at various frequencies.

One of the requirements specified for the tube was that it lend itself to satisfactory circuit design. The RCA-832 has shown itself to be well-adapted for use with parallel-line circuits at the highest frequencies at which it is capable of operation. For instance, when the tube is used as an oscillator at 200 megacycles with grid and plate lines having approximately 150 ohms surge impedance, the length of plate line from tube terminals to shorting bar is 7 inches while the grid line measures 5 inches. At 300 megacycles, there is still 1½ inches of grid line external to the tube and the plate line measures 3½ inches. At 400 megacycles, the grid line must be ¾ wavelength long since the first voltage node is inside the tube.

A photograph showing the use of the RCA-832 with parallel-line circuits is shown in Figure 6. This is a master-oscillator power amplifier combination which was made up for test purposes. A brass cylinder supports the various parts of the circuit and at the same time serves as shield between the input and output circuits of the RCA-832 power amplifier. The driving oscillator unit is shown at the left and in front of the cylindrical shield. It consists of two RCA-955 tubes in a push-pull circuit in which each grid is excited by capacitance coupling to that conductor of the plate transmission line which is connected to the plate of the other tube. The unit shown at the right is the mounting for the amplifier tube and the tuned grid line. These two transmission lines are supported inside the cylindrical shield in the relative position shown, and the oscillator unit may be rotated about the axis of the shield to vary the coupling between the lines and with it, the amplifier excitation. The plate circuit is entirely external to the shield and is clearly shown in the photograph. As pictured, the circuit is tuned to operate at a frequency of 240 megacycles.

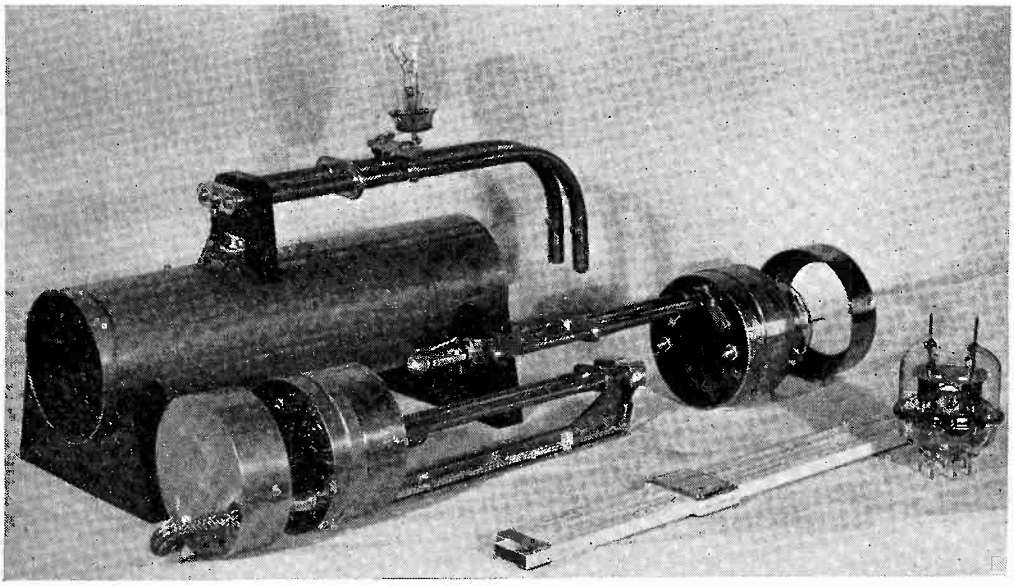

Fig. 6—The RCA-832 used as an amplifier with parallel-line circuits.

The RCA-832 presents advantages for operation in mobile installations as well as other types of service when outputs of the order of 10 watts are required at frequencies up to 250 megacycles. At these frequencies the tube will operate as a stable amplifier without the necessity for neutralization. It is compact, rugged, easily adapted to circuit design, and economical in power consumption.

ACKNOWLEDGMENT

The author wishes to express his appreciation for the many contributions of those who have assisted in the development of the

RCA-832, in particular those of Mr. J. C. Hapgood and Mr. C. F. Nesslage who have solved many of the problems connected with the fabrication of the tube, and of Mr. W. Happe, Jr., to whom the author is indebted for much of the necessary circuit design.

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THE APPLICATION OF THE TENSOR CONCEPT TO THE COMPLETE ANALYSIS OF LUMPED, ACTIVE, LINEAR NETWORKS

By

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Summary—*With the aid of the tensor concept, an integral equation is derived which applies to any lumped, active, linear network with any initial conditions and any applied e.m.f.'s in any or all the meshes of the network. This integral equation is solved by means of the Mellin inversion theorem with the help of the theory of complex variables.*

The tensor integral equation is specialized to the case of any number of identical amplifier stages connected in cascade, each amplifier containing any number of meshes.

The salient features of the tensor method are illustrated by a simple two-mesh network.

The analysis of the shunt "peaking" type of video amplifier is given in addition to video amplifiers consisting of low-pass filters as described by Percival and Wheeler. Analysis shows that these amplifiers yield objectionable transients when subjected to a Heaviside unit e.m.f., but if the applied e.m.f. contains no frequencies above the cut-off frequency of the amplifier, the resulting transient is quite satisfactory. This indicates that noise may be more important when using these amplifiers than when using the conventional shunt "peaking" type amplifiers. Further, one of the two types of amplifiers considered is theoretically superior to the other.

I. Introduction

TENSOR analysis has been very successfully applied in the solution of divers complex engineering problems.[1] The success of the tensor concept arises primarily from the conciseness with which the interrelations of the components of a complex system can be expressed. The tensor notation of itself systematizes the work necessary to solve a specific problem, enabling one to proceed in a routine manner to the solution of the problem at hand once the equations of the system have been set up. This paper presents with the aid of the tensor concept an integral equation, the solution of which gives the complete solution under certain conditions of any n-mesh lumped, active, linear network. The method is illustrated by an example and applied in some detail to the solution of various television amplifier circuits.

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[1] See, for example, series of articles by Gabriel Kron in *G.E. Review* beginning p. 181, April, 1935. Also "Tensor Analysis and its Application to Equivalent Circuits," D. W. Epstein, RCA Review, Vol. III, p. 239, October, 1938.

II. THE INTEGRAL EQUATION FOR GENERAL n MESH NETWORK

The differential equation in tensor form of a lumped linear n-mesh network is

$$L_{\mu\nu}\frac{di^{\nu}}{dt}+R_{\mu\nu}i^{\nu}+S_{\mu\nu}q^{\nu}=E_{\mu};\ \mu,\ \nu=1,2,\cdots n \tag{1}$$

where $L_{\mu\nu}$, $R_{\mu\nu}$ and $S_{\mu\nu}$ are the covariant inductance, resistance, and stiffness tensors of the second rank respectively; i^{ν} and q^{ν} the contravariant[2] current and charge tensors of the first rank; E_{μ} the covariant applied e.m.f. tensor of the first rank.[3]

To explain the meaning of (1) consider for simplicity a two-mesh network, then μ, $\nu=1, 2$ and equation (1) written out in terms of the components of the tensors becomes

$$L_{11}\frac{di^{1}}{dt}+L_{12}\frac{di^{2}}{dt}+R_{11}i^{1}+R_{12}i^{2}+S_{11}q^{1}+S_{12}q^{2}=E_{1}$$

$$L_{21}\frac{di^{1}}{dt}+L_{22}\frac{di^{2}}{dt}+R_{21}i^{1}+R_{22}i^{2}+S_{21}q^{1}+S_{22}q^{2}=E_{2}$$

where L_{11}, L_{12}, L_{21}, L_{22} are the components of the tensor $L_{\mu\nu}$, similarly for $R_{\mu\nu}$, $S_{\mu\nu}$; and i^1, i^2 are the components of i^{ν}, similarly for q^{ν} and E_{μ}. It is thus readily seen that Equation (1) is Kirchoff's law expressed in the compact tensor form.

Following van der Pol,[4] multiply Equation (1) through by e^{-pt} and integrate with respect to t between zero and infinity. Here p is a complex number whose real part is greater than zero. Equation (1) then becomes

$$L_{\mu\nu}\int_0^{\infty}\frac{di^{\nu}}{dt}e^{-pt}dt+R_{\mu\nu}\int_0^{\infty}i^{\nu}e^{-pt}dt+S_{\mu\nu}\int_0^{\infty}q^{\nu}e^{-pt}dt=\int_0^{\infty}E_{\mu}e^{-pt}dt \tag{2}$$

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[2] The current is chosen as contravariant since velocity is contravariant and current is velocity multiplied by charge density which is a scalar; having chosen current as contravariant, voltage must be covariant since volt-amperes is a scalar and impedance must be covariant and of the second rank since $Z_{\mu\nu}i^{\nu}$ must be covariant of the first rank.

[3] For further elucidation see, for example, D. W. Epstein, RCA REVIEW, Vol. III, p. 239 (1938).

[4] *Phil. Mag.* VII, p. 1153 (1929).

Now by integration by parts

$$\int_0^{\infty} \frac{di^\nu}{dt} e^{-pt}dt = -(i^\nu)_0 + p \int_0^{\infty} i^\nu e^{-pt}dt$$

$$\int^{\infty} q^\nu e^{-pt}dt = \frac{(q^\nu)_0}{p} + \frac{1}{p}\int_0^{\infty} i^\nu e^{-pt}dt$$

where the integrated term vanishes at the upper limit and $(i^\nu)_0$ and $(q^\nu)_0$ are the contravariant current and charge tensors at time $t = 0$. Inserting the values obtained immediately above in equation (2) there results

$$\left(pL_{\mu\nu} + R_{\mu\nu} + \frac{S_{\mu\nu}}{p}\right)\int_0^{\infty} i^\nu e^{-pt}dt = L_{\mu\nu}(i^\nu)_0 - S_{\mu\nu}\frac{(q^\nu)_0}{p} + \int_0^{\infty} E_\mu e^{-pt}dt \tag{3}$$

$$Z_{\mu\nu}\int_0^{\infty} i^\nu e^{-pt}dt = \int_0^{\infty} E_\mu e^{-pt}dt + L_{\mu\nu}(i^\nu)_0 - \frac{S_{\mu\nu}}{p}(q^\nu)_0$$

where $Z_{\mu\nu}$ is the second rank impedance tensor of the network. Since ν in the terms $L_{\mu\nu}(i^\nu)_0$ and $S_{\mu\nu}(q^\nu)_0$ appears twice it is called a "dummy" suffix and indicates that $L_{\mu\nu}(i^\nu)_0 = \sum\limits_{\nu=1}^{n} L_{\mu\nu}i^\nu$. Hence, another letter may be used for ν without changing anything. To avoid confusion the ν on the right hand side of (3) will be changed to σ and (3) may be rewritten as[5]

$$\int_0^{\infty} i^\nu e^{-pt}dt = A^{\mu\nu}\left[\int_0^{\infty} E_\mu e^{-pt}dt + L_{\mu\sigma}(i^\sigma)_0 - \frac{S_{\mu\sigma}}{p}(q^\sigma)_0\right. \tag{4}$$

$$\mu,\ \nu,\ \sigma = 1, 2, 3 \cdots\cdot n$$

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[5] A more formal manner of obtaining (4) from (3) is to multiply both sides of (3) by the contravariant tensor $Z^{\mu\sigma}$, where $Z^{\mu\sigma}$ is the tensor called $A^{\mu\nu}$ above. Since $Z^{\mu\sigma}Z_{\mu\nu} = Z_\nu{}^\sigma = \begin{cases} 0, & \nu \neq \sigma \\ 1, & \nu = \sigma \end{cases}$
is merely a substitution operator, then

$$Z^{\mu\sigma}Z_{\mu\nu}\int_0^{\infty} i^\nu e^{-pt}dt = \int_0^{\infty} i^\sigma e^{-pt}dt$$

where the contravariant admittance tensor $A^{\mu\nu}$ is the inverse tensor of the covariant impedance tensor $Z_{\mu\nu}$.

$A^{\mu\nu}$ is defined as,

$$A^{\mu\nu} = \frac{\text{cofactor of component } Z_{\mu\nu}}{Z}.$$

and Z the determinant $\begin{vmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2n} \\ \vdots & \vdots & & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{nn} \end{vmatrix}$

For example, $A^{11} = \dfrac{\begin{vmatrix} Z_{22} & \cdots & Z_{2n} \\ \vdots & & \vdots \\ Z_{n2} & \cdots & Z_{nn} \end{vmatrix}}{Z}$

The generality of Equation (4) is readily apparent since it concerns all the mesh currents for any initial conditions, and for any applied e.m.f.'s in any or all the meshes. Carson's integral equation is a special case of Equation (4) where $(i^\sigma)_0 = (q^\sigma)_0 = 0$; $E_\mu = 1$, $0 \leq t \leq \infty$; and for particular values of suffixes μ, ν. For example, let $\mu = \nu = 1$, then (4) reduces to

$$\int_0^\infty i^1 e^{-pt} dt = A^{11} \int_0^\infty e^{-pt} dt$$

Since there is only one component, drop the suffixes; and upon integration Carson's integral equation results, namely

$$\int_0^\infty i e^{-pt} dt = A/p \qquad (5)$$

For an n mesh network Equation (4) represents n equations, one for each mesh current. Applied to a particular mesh, the first for instance, then $\nu = 1$ and μ, σ run from 1 to n. Thus for the input current or first mesh current (4) takes the form

$$\int_0^\infty i^1 e^{-pt}dt = A^{\mu 1}\left[\int_0^\infty E_\mu e^{-pt}dt + L_{\mu\sigma}(i^\sigma)_0 - \frac{S_{\mu\sigma}}{p}(q^\sigma)_0\right]$$

$$= A^{11}\left[\int_0^\infty E_1 e^{-pt}dt + L_{1\sigma}(i^\sigma)_0 - \frac{S_{1\sigma}}{p}(q^\sigma)_0\right] + \tag{6}$$

$$A^{21}\left[\int_0^\infty E_2 e^{-pt}dt + L_{2\sigma}(i^\sigma)_0 - \frac{S_{2\sigma}}{p}(q^\sigma)_0\right] + \cdots\cdot$$

$$+ \cdots\cdots\cdot A^{n1}\left[\int_0^\infty E_n e^{-pt}dt + L_{n\sigma}(i^\sigma)_0 - \frac{S_{n\sigma}}{p}(q^\sigma)_0\right]$$

where also further terms arise when the summation over σ from 1 to n is taken. The example worked out later will illustrate this.

Regarding the solution of Equation (4), note that the right-hand side of this equation is a function of p only, so rewrite it as

$$\int_0^\infty i^\nu e^{-pt}dt = A^\nu(p) \tag{7}$$

where

$$A^\nu(p) = A^{\mu\nu}\left[\int_0^\infty E_\mu e^{-pt}dt + L_{\mu\sigma}(i^\sigma)_0 - \frac{S_{\mu\sigma}}{p}(q^\sigma)_0\right. \tag{8}$$

There is only one continuous solution $i^\nu(t)$ of the integral equation (7) between $A^\nu(p)$ and $i^\nu(t)$. $A^\nu(p)$ is said to be the Laplace transform of $i^\nu(t)$ and a complete table of Laplace transforms would enable one to write down the solution of (7) immediately. In the absence of such a table the solution of (7) may be obtained by means of the inversion theorem which states that[6]

if
$$\int_0^\infty i(t)\,e^{-pt}dt = A(p) \tag{9}$$

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[6] This theorem is often called the Mellin Inversion Theorem. From a purely formal point of view the two equations (10) are merely Fourier Transforms (see, for example, Titchmarsh, Theory of Fourier Integrals, Section 1.3).

then
$$\frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} A(p)\,e^{pt}dp = \begin{cases} i(t), & t>0 \\ 0 \quad , & t<0 \end{cases} \qquad \begin{matrix} c \text{ real}, \geq 0 \\ j=\sqrt{-1} \end{matrix} \tag{10}$$

In general the conditions under which this theorem is valid are those which govern the Fourier Integral Transforms. In addition the solution (10) holds provided all the singularities of $A(p)$ lie to the left of $c + j\infty$, $c > 0$ where by a singularity of $A(p)$ is meant a point at which $A(p)$ becomes infinite. In this paper only pole singularities are considered where at a pole the function becomes infinite to a finite order. Thus, if p_1 is a pole

$$\lim_{p\to p_1} (p-p_1)^n A(p) \neq \infty$$

provided n is chosen large enough, but finite. The order of a pole is the value of n required to remove the discontinuity. Thus $p/p+1$ has a first-order pole at $p=-1$ and $(p/p+1)^2$ has a second-order pole at $p=-1$. From complex variable theory, the value of the line integral of a function around a path which encloses a pole is $2\pi j$ times the residue of the function at the pole. If the pole is of the first order, the residue is $\lim_{p\to p_1} (p-p_1)\,A(p)$. Thus, the residue at $p=-1$ of $p/p+1$ is $\lim_{p\to -1} (p+1)\dfrac{p}{p+1} = -1$ and the value of the line integral of $p/p+1$ around a path which encloses this point is $-2\pi j$. Similarly, the line integral of $1/p$ about the origin is $2\pi j$ since $\lim_{p\to 0} \text{p}\left(\dfrac{1}{p}\right) = 1$.

Since lumped, dissipative, linear networks are considered in this paper, $A(p)$ has, in general, complex roots which have negative real portions. Thus, $A(p)$ has pole singularities all lying on and to the left of the axis of imaginaries. The path of integration, $c - j\infty$ to $c + j\infty$ can then be deformed into a large semi-circle which includes all the singularities of $A(p)$. The integral (10) can then be evaluated by summing the residues of the integrand.

The solution of Equation (4) may thus be written as

$$i^{\nu}(t) = \frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} A^{\nu}(p)\,e^{pt}dp \tag{11}$$

$$= \frac{1}{2\pi j} \int_{c-j\infty}^{c+j\infty} A^{\mu\nu} \left[\int_0^\infty E_\mu e^{-pt} dt + L_{\mu\sigma} (i^\sigma)_0 - \frac{S_{\mu\sigma}}{p} (q^\sigma)_0 \right] e^{pt} dp$$

$$= \frac{1}{2\pi j} \int_{c-j\infty}^{c+j\infty} A^{\mu\nu} \left[\int_0^\infty E_\mu e^{-pt} dt \right] e^{pt} dp + \frac{1}{2\pi j} \int_{c-j\infty}^{c+j\infty} A^{\mu\nu} L_{\mu\sigma} (i^\sigma)_0 e^{pt} dp - \frac{1}{2\pi j} \int_{c-j\infty}^{c+j\infty} A^{\mu\nu} \frac{S_{\mu\sigma}}{p} (q^\sigma)_0 e^{pt} dp \tag{12}$$

The solution (11) is thus composed of three integrals (12). The first integral gives the currents at time t resulting from applied voltages E_μ; the second the currents at time t because of currents $(i^\sigma)_0$ flowing in the meshes at time $t = 0$; the third integral the currents at time t because of charges $(q^\sigma)_0$ on the condensers in the meshes at time $t = 0$. Hence each integral may be calculated separately and added to obtain the final currents.

The method of solving Equation (11) may be illustrated by considering only one integral of (12), for instance, the first,

$$i^\nu (t) = \frac{1}{2\pi j} \int_{c-j\infty}^{c+j\infty} A^{\mu\nu} \left[\int_0^\infty E_\mu e^{-pt} dt \right] e^{pt} dp \tag{13}$$

Further, consider only one current, say in the nth mesh and only one applied voltage, say in the first mesh, then (13) becomes

$$i^n (t) = \frac{1}{2\pi j} \int_{c-j\infty}^{c+j\infty} A^{1n} \left[\int_0^\infty E_1 e^{-pt} dt \right] e^{pt} dp \tag{14}$$

or since only one component is involved drop the suffixes and write

$$i = \frac{1}{2\pi j} \int_{c-j\infty}^{c+j\infty} A(p) \left[\int_0^\infty E e^{-pt} dt \right] e^{pt} dp \tag{15}$$

In this case $A(p)$ is the transfer admittance from the first to nth mesh.

III. GENERAL SOLUTION FOR n IDENTICAL STAGE AMPLIFIER

The final current flowing in the final mesh of an n-stage amplifier in which all the stages are the same can be found by an extension of the results for a single-stage amplifier.

Now consider an n identical stage amplifier, such as shown in Figure 1, with coupling circuits containing m meshes. Then the current in the mth mesh of the first stage is given by the integral equation.

$$\int_0^\infty \{i^m(t)\}_1 e^{-pt} dt = \mu A^{1m} \left[\int_0^\infty E_1 e^{-pt} dt \right] \tag{16}$$

where E_1 is the grid voltage on first tube, μ (in this section) is the amplification constant and where the subscript following the wavy bracket refers to the number of the stage under consideration. Then the voltage applied to the grid of the second amplifier stage will be $Rg \{i^m(t)\}_1$. The current in the mth mesh of the second stage is

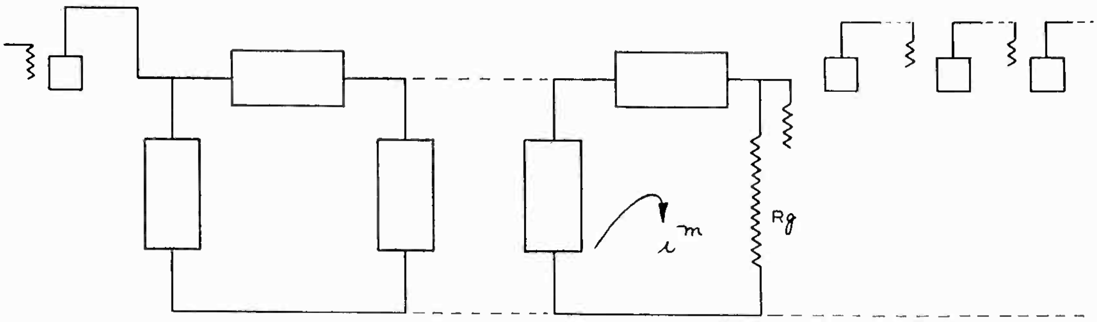

Fig. 1—n-stage amplifier with coupling circuits containing m meshes.

$$\int_0^\infty \{i^m(t)\}_2 e^{-pt} dt = \mu A^{1m} R_g \int_0^\infty \{i^m(t)\}_1 e^{-pt} dt$$

$$= (\mu A^{1m})^2 R_g \int_0^\infty E_1 e^{-pt} dt$$

Similarly the current in the mth mesh of the nth stage is

$$\int_0^\infty \{i^m(t)\}_n e^{-pt} dt = (\mu A^{1m})^n R_g^{\,n-1} \int_0^\infty E_1 e^{-pt} dt \tag{17}$$

(For the case where the nth stage is different from the $n-1$ preceding stages

$$\int_0^\infty \{i^m(t)\}_n e^{-pt} dt = (\mu_1 A^{1k})_n (\mu_2 A^{1m})^{n-1} R_g^{\,n-1} \int_0^\infty E_1 e^{-pt} dt \tag{18}$$

where k is the number of meshes in the output tube.)

Therefore, the current in the final mesh of the nth stage of the n identical stage amplifier is given by (19),

$$\{i^m(t)\}_n = \frac{R_g^{n-1}}{2\pi j} \int_{c-j\infty}^{c+j\infty} \left[(\mu A^{1m})^n \int_0^\infty E_1 e^{-pt} dt \right] e^{pt} dp \tag{19}$$

It is then necessary to calculate the sum of the residues of the function

$\left[(A^{1m})^n \int_0^\infty E_1 e^{-pt} dt \right] e^{pt}$ where the residues of $\left[A^{1m} \int_0^\infty E_1 e^{-pt} dt \right] e^{pt}$ correspond to the single-stage amplifier. For simplicity assume $E_1 = 1$, $0 \leqq t \leqq \infty$ then the sum of the residues of $(A^{1m})^n e^{pt}/p$ are desired where the residue at $p = 0$ gives the steady state term. In general $(A^{1m})^n e^{pt}$ can be written

$$\frac{(A^{1m})^n e^{pt}}{p} = \frac{[F(p)]^n e^{pt}}{p(p-p_1)^n (p-p_2)^n \cdots\cdot (p-p_m)^n}$$

where $p_1, p_2 \cdots\cdot p_m$ are roots of the denominator of A^{1m} when A^{1m} has been expressed as the quotient of two polynomials a form which is, in general, always possible.

To calculate the residue at $p = p_2$, for example, write

$$\frac{(A^{1m})^n e^{pt}}{p} = \frac{[F(p)]^n e^{pt}}{p(p-p_1)^n (p-p_2)^n \cdots\cdot (p-p_m)^n}$$

$$= \frac{f_2(p)}{(p-p_2)^n} = f(p)$$

where

$$f_2(p) = \frac{[F(p)]^n e^{pt}}{p(p-p_1)^n (p-p_3)^n \cdots\cdot (p-p_m)^n}$$

Since the function $f(p)$ has a pole of order n at $p = p_2$ an equation of the form

$$f(p) = \frac{b_{-n}}{(p-p_2)^n} + \frac{b_{-(n-1)}}{(p-p_2)^{n-1}} + \cdots\cdots + \frac{b_{-1}}{(p-p_2)} + \phi(p)$$

is true near p_2 and where $\phi(p)$ is analytic near and at p_2, i.e., it may be expanded in a Taylor series around p_2. The coefficient b_{-1} is by definition the residue of the function $f(p)$ relative to the pole p_2.

By Laurent's theorem

$$b_{-n} = \frac{1}{2\pi j} \int_c (p - p_2)^{n-1} f(p)\, dp$$

where c is a closed curve enclosing p_2 and no other singularity, so

$$b_{-1} = \frac{1}{2\pi j} \int_c f(p)\, dp = \frac{1}{2\pi j} \int_c \frac{f_2(p)}{(p - p_2)^n}\, dp$$

The theory of functions of a complex variable teaches that since $f_2(p)$ is analytic at and in the neighborhood of p_2 then the nth derivative of $f_2(p)$ at point p_2 is

$$\left.\frac{d^n f_2(p)}{dp^n}\right]_{\text{at } p_2} = \frac{n!}{2\pi j} \int_c \frac{f_2(p)}{(p - p_2)^{n+1}}\, dp$$

hence

$$b_{-1} = \frac{1}{2\pi j} \int_c \frac{f_2(p)}{(p - p_2)^n}\, dp = \frac{1}{(n-1)!} \frac{(n-1)!}{2\pi j} \int_c \frac{f_2(p)}{(p - p_2)^n}\, dp$$

$$= \frac{1}{(n-1)!} \left.\frac{d^{n-1} f_2(p)}{dp^{n-1}}\right]_{\text{at } p = p_2}$$

or

$$b_{-1} = \frac{1}{(n-1)!} D^{n-1} f_2(p_2)$$

Similarly, the residue at $p = p_k$ is $\frac{1}{(n-1)!} D^{n-1} f_k(p_k)$ where

$$f_k(p) = \frac{[F(p)]^n e^{pt}}{p(p - p_1)^n \cdots (p - p_{k-1})^n (p - p_{k+1})^n \cdots (p - p_m)^n}$$

Hence, the problem of finding the residues or the solution for a multi-stage amplifier is reduced to a problem in differentiation. The solution of a multi-stage amplifier in which there are groups of identical stages, each group differing from the other, is obtainable as a simple extension of the above process.

(To be continued)

THE USE OF GAS-FILLED LAMPS AS HIGH-DISSIPATION, HIGH-FREQUENCY RESISTORS, ESPECIALLY FOR POWER MEASUREMENTS

BY

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Summary—*A type of hydrogen-filled lamp suitable for use as a high-frequency resistance is described, which possesses unusually great heat-dissipation ability. This dissipation may be several hundred times that obtainable with vacuum lamps, and the gain is greatest for filaments of the smallest diameter. Other advantages are pointed out. The theory of heat loss in a gaseous atmosphere is summarized. Details of experimental lamps are given. Design data are presented in the form of a chart which includes, watts dissipated, resistance, temperature, and filament diameter.*

THE measurement of power output at high frequencies has always been a troublesome problem. The method most commonly employed is that of feeding the power into incandescent lamps which have been calibrated in terms of power dissipation versus filament brightness. This is quite satisfactory for long wavelengths, but limitations are encountered as the frequency is increased. The first limitation is on the filament length. This should be small in comparison with a wavelength in order to obtain a uniform current and temperature distribution. Second, the filament diameter should be small, in order to obtain a sufficiently high resistance. Third, the filament should be able to dissipate the power to be measured.

The third requirement is at variance with the first two. A short, thin filament cannot dissipate much energy in a vacuum since energy loss from high-temperature filaments in vacuo occurs largely by radiation and is proportional to filament surface area.

To present an idea of the gains which may be had with wire sizes and temperatures practicably obtainable, Table I has been prepared. W_V represents the heat loss in watts per centimeter length in vacuo, and W_H the loss for the same wire in hydrogen at atmospheric pressure. The gain is greatest for thin wires at low temperatures, and least for thick wires at high temperatures. It is seen that for a 0.010 inch wire at 3000° K the gain is only 3.8, whereas for a 0.00025 inch wire at 1000° K it is 1250. The gain is greatest for the thin, i.e., high-resistance, wires.

In addition to greater heat dissipation the gas-filled lamp has several other desirable characteristics. First, the dissipation is not proportional to filament surface area, as with a filament in vacuo. For small filaments, the heat dissipation varies but slightly as the diameter is changed. This permits a wide range of resistance without great change in dissipative ability. Second, the possible use of much smaller diameter wires eliminates the necessity of calculating the skin effect in many cases, since the r-f resistance may be taken equal to the d-c resistance. Third, whereas in vacuo the energy dissipated varies as a high power of the temperature (usually between 4 and 5), in a gas the variation follows a much lower power law. A variation following a fourth or fifth power law makes accurate readings difficult at high temperatures, due to the steepness of the rise in dissipation.

Loss of heat from filaments in gases occurs mainly by conduction and not by convection, as might at first be supposed (see Theory below). For this reason the dissipation is not noticeably affected by the shape of the bulb or its position, and errors due to these factors will not be important.

TABLE I

Heat Loss per Centimeter Length in Vacuo and in Hydrogen

Temp.	1000° *K*			2000° *K*			3000° *K*		
Dia.	W_V	W_H	W_H/W_V	W_V	W_H	W_H/W_V	W_V	W_H	W_H/W_V
0.00025″	0.0012	1.50	1250	0.06	5.70	95	0.50	36.00	72
0.0005	0.0024	1.70	710	0.12	6.60	55	1.00	41.00	41
0.001	0.0048	2.00	417	0.24	7.70	32	2.00	48.00	24
0.005	0.025	2.75	110	1.20	10.60	8.7	10.00	66.00	6.6
0.010	0.050	3.20	64	2.40	12.30	5.1	20.00	76.00	3.8

THEORY

The theory briefly summarized here was published by Irving Langmuir[1] in 1912. It is based upon the presence of a sheath of non-convecting gas about the hot wire. The sheath forms by virtue of the fact that the viscosity of a gas increases with the square root of the absolute temperature, whereas the convection forces increase much more slowly. Thus the gas in the neighborhood of the wire tends to become motionless as the temperature rises. Furthermore, the heat conductivity of the gas increases very greatly with temperature

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[1] *Phys. Rev.* 34, 401.

increase. For these reasons heat-conduction losses are much greater than convection losses, and the latter may be neglected without great error. The problem then becomes that of computing the heat transfer through a cylinder of motionless gas surrounding the wire.

By solving the differential equation for heat flow applicable to this case, the solution

$$W = S\ (\phi_2 - \phi_1) \tag{1}$$

is obtained, where W is the watts of heat energy conducted away per centimeter length, S is a form factor which depends upon the wire and sheath radii, and ϕ_2 and ϕ_1 are temperature factors determined by the temperatures of the wire and the outer sheath boundary respectively, and also by the thermal conductivity of the gas.

Langmuir shows that S may conveniently be expressed in terms of B, the thickness of the sheath for a plane surface. B is shown experimentally to be independent of temperature within the experimental error for any given gas. The factor S is thereby made to depend only upon the filament radius.

The factor ϕ is defined as

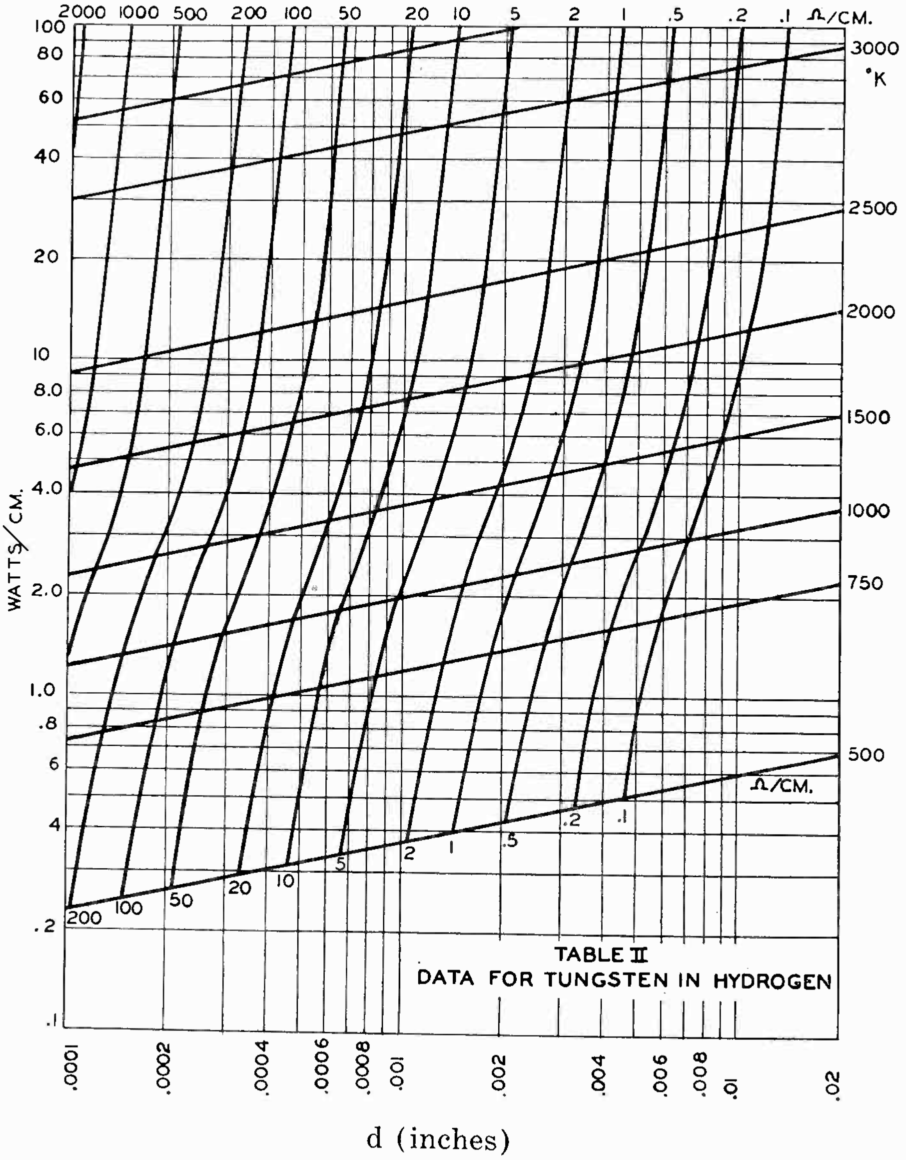
$$\phi = 4.19 \int_0^T k dT,$$

where k is the thermal conductivity, and T is the gas temperature which varies from T_2 at the wire surface to T_1 at the outer sheath boundary. Hence we have

$$\phi_2 - \phi_1 = 4.19 \left[\int_0^{T_2} k dT - \int_0^{T_1} k dT \right]$$

Since in cases of interest at present, T_2 is much greater than T_1, the second term will be neglected.

The factor ϕ_2 has been measured experimentally for hydrogen and found to agree with the theory satisfactorily up to a temperature of about 2300° C. At this point deviations become appreciable, the loss becoming greater than predicted theoretically. This is due to the dissociation of hydrogen molecules into atomic hydrogen, and results in a greatly increased efficiency of hydrogen as a cooling agent. Because of this discrepancy with the above given theoretical expression, in which no attempt was made to include effects due to gas dissociation, the experimental values of ϕ have been used in constructing Table II, instead of the theoretical ones.



Explanation of Table II

Table II represents a plot of the four factors: wire diameter *d* in inches, heat dissipation *W* in watts per centimeter length, wire temperature *T* in degrees Kelvin, and d-c resistance in ohms per centimeter. The diameters are expressed in inches rather than centimeters since that unit is commonly used by wire manufacturers. If any two of the above factors are given, the remaining two are uniquely determined and may be read directly off the chart.

The chart is based on the relation

$$W = S\phi.$$

Experimentally determined[2] values of ϕ for one wire size (0.0018 inch) were used, and *W* for other wire sizes was determined by using

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[2] *G. E. Rev.*, pp. 310-319, June, 1927.

Langmuir's computed values of *S*. The resistance data were taken from the work of Jones and Langmuir[3]. These data are plotted in the form of a family of constant-temperature curves, and a family of constant-resistance curves. Each point has four coordinates, *T*, *R*, *W*, and *d*, the first two (*R*, *T*) being read from the constant-temperature, constant-resistance curves as coordinates, and the second two (*W*, *d*) from the logarithmic scales along the left-hand and lower edges of the chart. As an example, suppose it is desired to have a load one centimeter long to dissipate 10 watts and have a resistance of 100 ohms. The intersection of the 10-*W* ordinate with the 100-ohm curve is located. From the other two coordinates of this point it is then found that the required diameter is 0.00036″, and the operating temperature is about 2350° K.

Sufficient experimental data to check the chart over its entire range are not available. In the region of diameters from 0.0004 inch to 0.002 inch and temperatures from 1000° to 2500°, the error has been found to be seldom more than 20 per cent. The chart is intended for use mainly as a guide in preliminary design. For greater accuracy lamps may be directly calibrated after construction.

Other gases than hydrogen may be used as cooling media, but hydrogen appears to be considerably superior. Available experimental data, although scarce, as well as theoretical considerations, indicate that the cooling efficiency drops rapidly as the molecular weight of the gas increases. For a temperature of 1500° K, Langmuir gives values of ϕ for hydrogen, air, and mercury vapor as 4.79, 0.74, and 0.18, respectively, and for 2500° K, 11.82, 1.87, and 0.48.

The pressure of the gas is not critical. Variations such as would be introduced by various barometric pressures during filling of the lamps, or due to the lamp temperature while filling, should not cause noticeable effects.

Materials other than tungsten may be used for filaments, to provide, for example, higher resistance. It is necessary, of course, that they withstand the required temperature, and be chemically inert with respect to the gas employed. However, Tables I and II apply only to tungsten in hydrogen.

LAMP CONSTRUCTION AND CALIBRATION

A typical lamp, used in the experimental work, is shown in Figure 1. These were used for the measurement of magnetron oscillator output at wavelengths of from 8 to 9 cms, and powers up to 20 watts. The bulb was made of Pyrex glass. Its length was 2½ inches and its diameter ½ inch. The dashed lines *C* indicate glass tubes which were used in introducing the hydrogen. These were eventually sealed off at points *a* and *b*. The wires *t* were of 0.040 inch nickel welded to tungsten pieces *g* at the seal. Their spacing and size was the same as that of the transmission line of the magnetron. The distance from the seal at *g* to the filament *f* was made such that a voltage node occurred at *g*, thus minimizing losses in the glass at *g*. With a filament of length 1.2 centimeters and diameter 0.0004 inch, this type of lamp provided a load of about 100 ohms capable of dissipating 25 watts at 2700° K.

The lamps were calibrated with d.c. against the readings of an optical pyrometer, which is one of the simplest methods for cases where the filament becomes visibly hot. The d-c calibrations for *W* and *R* may be used without correction only if the filament is so short that the h-f current distribution is essentially uniform, and of so small a diameter that skin effect is negligible. In any case, the error due to these factors may be calculated if desired.

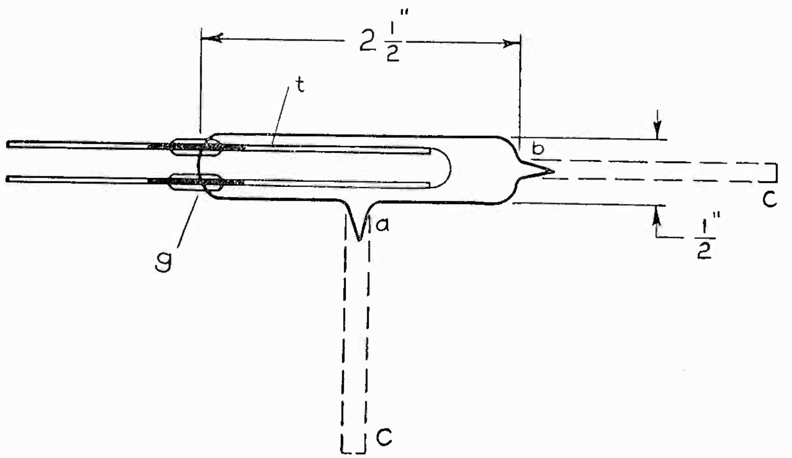

Fig. 1—Experimental load lamp.

Although the use of an optical pyrometer will generally be found the most convenient method of calibration, other methods may easily be devised. Instead of the regular pyrometer a duplicate lamp may be employed, this being operated by direct or low-frequency current and adjusted to equal the brightness of the h-f operated lamp. Also, calorimetric methods should be suitable. For rough measurements, a thermocouple or thermometer may be fastened to the lamp bulb, and calibrated in terms of lamp dissipation. Also, it is possible to devise bridge circuits in which the change in lamp resistance is used to indicate power output. Methods capable of employing lamps operating at low temperature are desirable from the standpoint of lamp life. In general lamps should be designed to operate at as low a temperature as possible in order to secure long life and prevent progressive change of resistance and dissipative ability.

AN ICONOSCOPE PRE-AMPLIFIER

BY

ALLEN A. BARCO

RCA License Laboratory

Summary—This paper describes a video-frequency pre-amplifier designed for use with the standard silver-caesium sensitized studio type Iconoscope. This unit constitutes a portion of the equipment used by the RCA License Laboratory to generate a complete standard television signal for laboratory test purposes.

Under normal operating conditions, the Iconoscope output current is of the order of a few tenths of a microampere. This current, when caused to flow through any practicable value of load impedance, produces relatively feeble signals. Hence, it is desirable to raise the signal level to about one-quarter volt (peak to peak video signal) before the signal is subjected to subsequent mixing, clipping, and transmission processes. This is done so that the signal will be well above any noise or hum introduced in transmission lines or control circuits.

Briefly, the amplifier consists of five stages, each employing a type 1851 tube. In its design and construction particular care was taken regarding signal-to-noise ratio, frequency response, and stability. The unique expedients necessarily employed to secure the desired characteristics are explained in a stage-by-stage analysis.

THE nature of the Iconoscope load impedance and the first amplifier-stage circuit merit greatest consideration in Iconoscope pre-amplifier design, for it is here that the ultimate limits of signal-to-noise ratio and frequency response are almost wholly determined. It is impossible to remove noise once it has been mixed with the video signal. Hence, it is desirable to amplify the signal as much as possible in the early stages, and to bring about this amplification with the introduction of a minimum of noise and frequency distortion.

These problems permit of more simple solutions than would, at first thought, seem possible. This is true because it has been found possible, and often entirely practicable, to permit the frequency response of the Iconoscope load circuit to depart from a flat characteristic and then, by means of proper correcting circuits, to restore the desired frequency characteristic in some subsequent stage. In other words, the process consists of first obtaining a good signal-to-noise ratio, with little regard to frequency characteristics, and then, after the signal is well above the noise level, correcting the frequency response to conform with the desired characteristic.

To be more specific, assume for the sake of discussion that the video-frequency band shall extend from a very low frequency (say 60 cycles, where the gain is independent of shunt capacitance) to a frequency at which the gain falls to 70.7 per cent. This is convenient because the Iconoscope load impedance consists of resistance and capacitance in shunt. Thus, it may be noted that the upper limit occurs at the frequency at which the shunt resistance and capacitive reactance are of equal magnitude. Assuming an ultimate desired band width of 5 Mc, Iconoscope output capacitance of 10 $\mu\mu$f, and the input capacitance of a type 1851 tube as 16 $\mu\mu$f (at 9000 g_m) ; we find, upon the inclusion of a few micro-microfarads for socket and stray-circuit capacitance, that the total capacitance shunting the Iconoscope load resistor is of the order of 28 $\mu\mu$f. Calculation reveals that, in order to achieve the assumed band width of 5 Mc, the load resistor should be about 1150 ohms. Such a low value of load resistor is perfectly satisfactory as far as frequency response is concerned, but is very undesirable from the standpoint of signal-to-noise ratio. This is true because the noise generated in the low-frequency range (where shunt capacitance may be neglected) by thermal agitation in the load resistor varies as the square root of the resistance, while the signal voltage (assuming the Iconoscope to be a constant-current source) increases directly as the load resistance.

Upon cursory examination, the condition existing in the upper-frequency range may appear to be quite different. Here, the signal voltage is determined almost entirely by the magnitude of the capacitance shunting the Iconoscope load resistor. The situation is further complicated by the fact that this capacitance also shunts the thermal noise generated in the load resistor. However, if the shunt capacitance and resistance are converted mathematically to their effective series values, the series resistance thus obtained may be used to calculate directly the thermal agitation potentials which are impressed upon the grid of the first amplifier tube. The effective series resistance decreases as the value of the shunt resistance is increased, thus causing an improvement in signal-to-noise ratio insofar as noise voltages produced by thermal agitation in the load resistor are concerned.

It is important to note that thus far we have been concerned only with the resistor thermal noise. However, increasing the load resistor provides an added advantage in that it gives a greater signal voltage and hence a better ratio of signal to tube-noise. Naturally, any improvement in signal to tube-noise ratio obtained by increasing the magnitude of the load resistor is appreciable only in the low-frequency portion of the video spectrum, where shunt capacitance may be neglected.

At this point it should be apparent that, for a given value of Iconoscope output-signal current, there are only two ways in which the signal-to-noise ratio may be improved without destroying the desired overall flat frequency-response characteristic. First, the value of the capacitance shunting the Iconoscope load may be reduced, thus permitting the use of a higher value of load resistor. Second, after obtaining minimum capacitance, the value of the load resistor may be further increased, disregarding the effect on frequency response for the present, but with the thought of correcting it in some subsequent stage. A combination of both of these methods was used in the final design of the pre-amplifier.

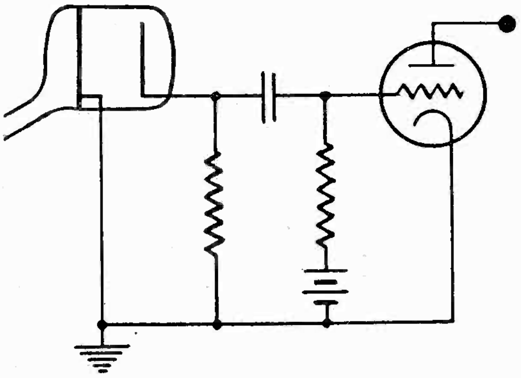

Fig. 1

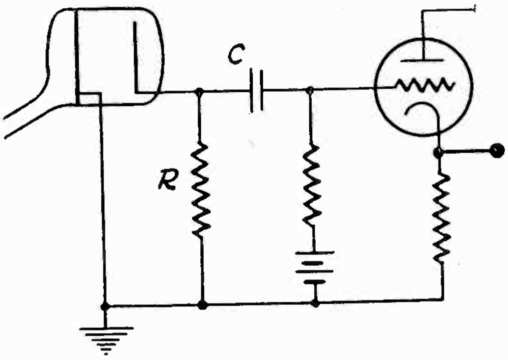

Fig. 2

FIRST STAGE

The evolution of the Iconoscope load and first amplifier circuits is shown in Figures 1 to 8. In Figure 1 is shown the conventional resistance-coupled circuit, similar in all respects to that used in conventional resistance-coupled audio-frequency amplifiers. Here the output is taken at the plate of the first amplifier. In Figure 2 the first amplifier is operated with an unbypassed cathode load and the output is taken at the cathode. This type of degenerative or cathode-loaded amplifier has a number of unusual characteristics. The most important of these (insofar as this stage is concerned) is the reduction of the effect of input impedance (grid-cathode) of the first amplifier by a factor $\frac{1}{1 + g_m R}$, where R is the cathode resistor and g_m the transconductance of the first amplifier tube. In the video-frequency range the input conductance is very small, so that its reduction is of little consequence. However, the reduction of the effect of input capacitance is appreciable; the normal input capacitance of 16 $\mu\mu$f is reduced to an effective value of about 2 $\mu\mu$f.

It is also possible to remove the coupling condenser C of Figure 2 because the Iconoscope signal plate is effectively capacitance coupled to the mosaic. Therefore no blocking condenser is needed. The removal of this condenser affords a slight measure of reduction in the stray-circuit capacitance. Obviously the resistor R of Figure 2, which formerly served as plate-feeding resistor in the conventional resistance-coupled audio amplifier, is no longer needed as it is not necessary to apply voltage to the Iconoscope signal plate.

With the aforementioned changes the circuit becomes that indicated in Figure 3 where, in addition, the proper bias has been obtained from a tap on the cathode resistor. As was previously mentioned, it is not necessary to supply a potential to the Iconoscope signal plate in order to make the system operative. However, it has been found that some improvement in shading characteristics may be realized by operating the collector at a potential equal to, or slightly positive with respect to, the signal-plate potential. The required potential may be conveniently obtained from the cathode of the first amplifier through a suitable filter as shown in Figure 4.

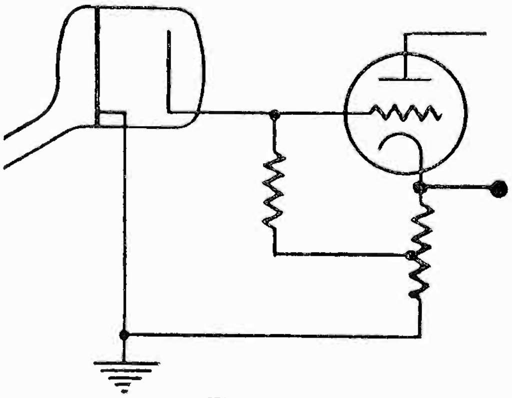
Fig. 3

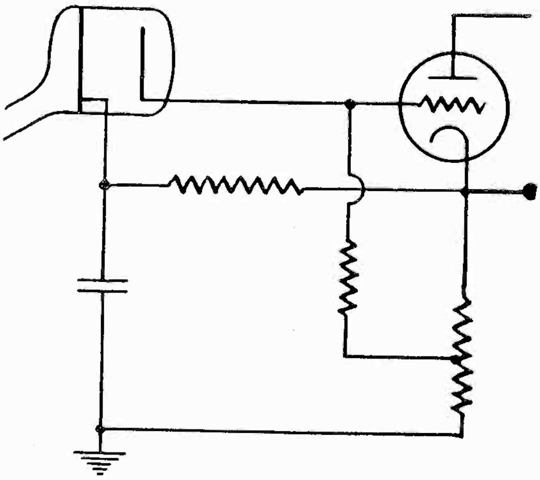
Fig. 4

Measurement revealed that the Iconoscope output capacitance could be separated into two parts. The first is the direct internal capacitance between signal plate and collector—about 5 $\mu\mu$f. The second is the capacitance between signal plate and the shielded case in which the Iconoscope is housed. This also was found to be about 5 $\mu\mu$f. Mathematical analysis of the cathode-loaded type of circuit shows that the apparent reduction in input capacitance is due to the fact that the cathode-signal voltage has approximately the same amplitude and phase as the grid-signal voltage. In accordance with this concept an electrostatic shield for the Iconoscope was constructed of fine wires, spaced about a half-inch and placed as shown in Figure 5. The shield was connected to the cathode of the first amplifier (Figure 6). This arrangement places the signal plate and its surrounding shield at nearly the same potential (signal voltage, not d-c potential). Hence any capacitative current, which would tend to flow between signal plate and ground in the unshielded arrangement, is reduced in the shielded circuit by the ratio of the grid-cathode voltage to the signal voltage (grid-ground). This very materially reduces the effective capacitance between signal plate and ground. Note, however, that the capacitance between shield and ground is effectivly placed across the cathode-load resistor of the first stage, but that this has no undesirable effect because it is characteristic of such degenerative amplifiers that the output impedance (at cathode) is approximately $\frac{1}{g_m}$. In the case of the 1851 this is about 110 ohms. Hence, the 20 $\mu\mu$f (approximate) of capacitance between shield and ground may be neglected for most practical purposes (reactance at 5 Mc is 1590 ohms).*

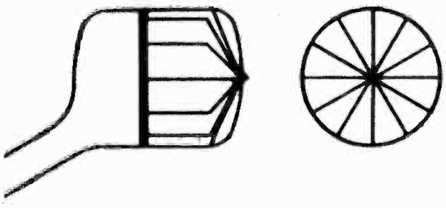

Fig. 5

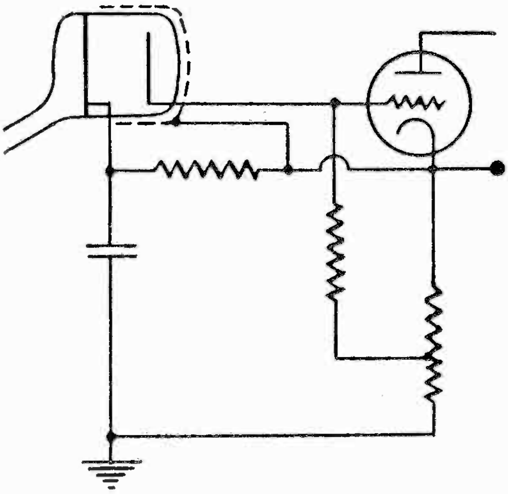

Fig. 6

By proper mathematical analysis it may be shown that the effective values of the Iconoscope load components (using constants given in the complete circuit diagram shown in Figure 7) are $R = 300{,}000$ ohms and $C = 8$ $\mu\mu$f. The value of 300,000 ohms (effective value) for the Iconoscope load resistor was chosen for the best possible signal-to-noise ratio commensurate with the ability to equalize the frequency response at the third amplifier stage. These values were checked by actual measurement and found to be substantially correct. There was, however, a slight increase in both R and C at the higher video frequencies because of slight phase shifts due to the net capacitance of approximately 40 $\mu\mu$f shunting the cathode-load resistor in the first amplifier stage. The increase in effective load resistance is caused by the introduction of a negative resistance component which, at very high frequencies, may be sufficient to permit oscillation. Hence, it was found

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* The use of the electrostatic shield was proposed independently at the laboratories of Electric & Musical Industries, Ltd., Hayes, Middlesex, England.

necessary to include the 100-ohm series grid resistor in the cathode-loaded stage (see Figure 7). The resistor should be of the non-inductive type and placed as near the grid pin as possible.

Theory and quantitative measurement have indicated that both the Iconoscope load-resistor thermal noise and the first-amplifier tube noise are of the same order of magnitude. It is apparent in such cases that some measure of improvement in overall signal-to-noise ratio may be realized by minimizing the noise contributed by the first-amplifier tube. Note that such is not always true. In cases where the resistor noise is larger (by, say, 10 times) than the tube noise, even complete elimination of the tube noise would result in only a fractional percentage reduction in overall noise.

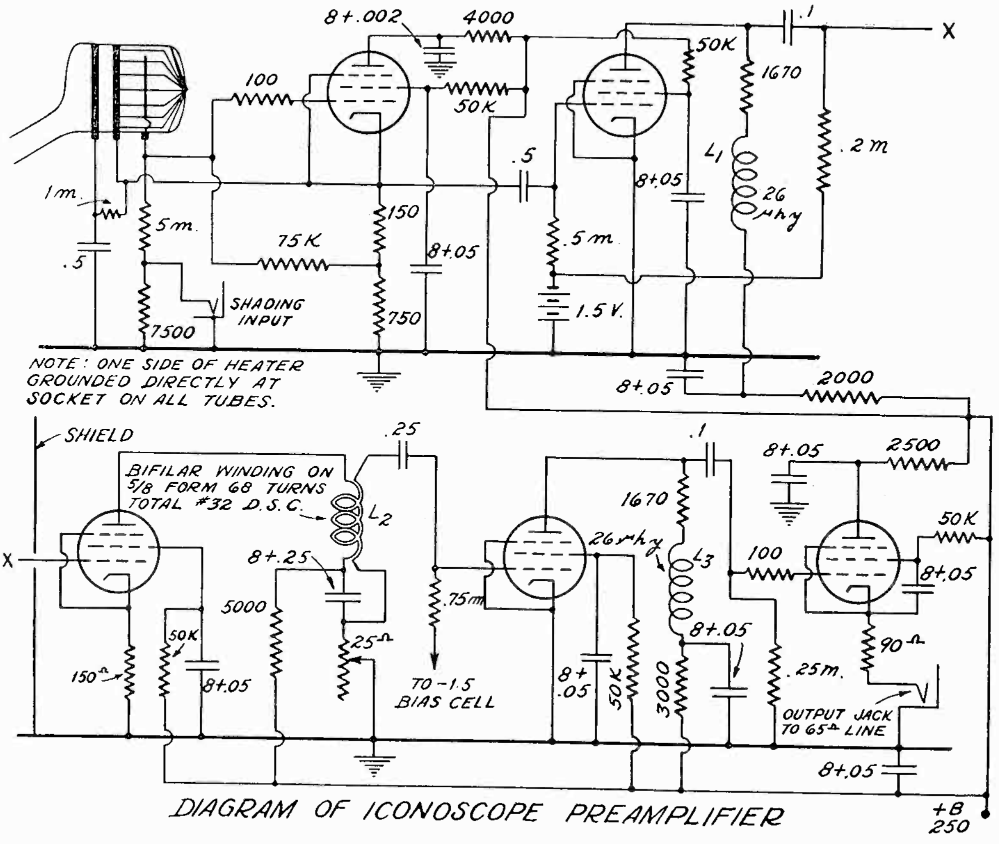

Fig. 7

Previous investigations of tube noise have indicated that some reduction of tube noise may be obtained by operating the first amplifier as a triode rather than as a pentode. This requires that the screen-grid bypass of the cathode-loaded stage be returned to ground rather than to the cathode. While this practice results in a slight increase in effective input capacitance it affords about 30 per cent reduction in overall noise voltage. The effect of the undesirable increase in input capacitance (caused by control-grid to screen-grid capacitance) may easily be compensated in the third stage.

There is another problem which, though not directly associated with the design of the pre-amplifier, may nevertheless be most conveniently dealt with at this point. That is the problem of shading-signal insertion. The need for shading signals arises from the fact that the Iconoscope has the characteristic, inherent due to its principle of operation, of having appear in its output a number of spurious signals in addition to the desired video signal. It is the purpose of the shading signals to neutralize or buck out the undesired spurious signals. Since the spurious signal may have an amplitude comparable to that of the video signal, it has been found desirable to neutralize this undesired signal at as low a level as possible. The major portion of the amplitude characteristic of subsequent amplifiers may then be devoted to the useful video signal without danger of overload, and the resultant loss in picture contrast which would occur if the shading signals were inserted near the end of the video chain.

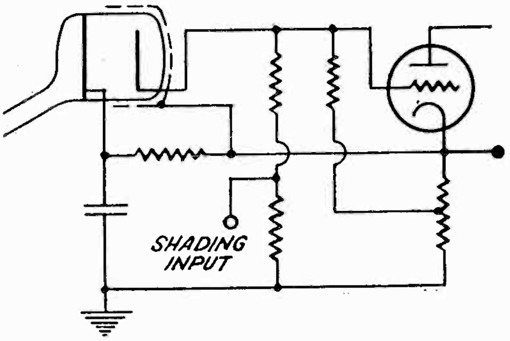

Fig. 8

The method used for inserting shading signals is shown in Figure 8. Here, the shading signals, produced in a separate unit, are fed into a 7500-ohm resistor which serves as the apparent constant-voltage source of shading signals for the Iconoscope proper. The shading signals are then applied to the grid of the first amplifier through a 5-megohm resistor. This must be done in order to make the shading signals at the first-amplifier grid appear as being derived from a constant-current source. In other words, the source of shading signals must not act as an appreciable shunt upon the Iconoscope load impedance.

SECOND STAGE

The second-stage amplifier consists of an 1851 pentode amplifier employing the conventional shunt peaking to extend the frequency characteristic. This stage is compensated to 5 Mc and affords a gain of approximately 13. The technique of equalizing the frequency response by shunt peaking has had excellent treatment in numerous other papers and will not be discussed in detail here.

THIRD STAGE

This stage will be found to be unique in regard to its plate load and the method of coupling into the following stage. It is the function of the third stage to correct for the alteration in frequency response which occurs in the Iconoscope load circuit. The Iconoscope load consists, effectively, of 8 $\mu\mu$f and 300,000 ohms in shunt. Assuming the Iconoscope to be a constant-current source, and that the composite gain of the first and second stages is of magnitude A (constant throughout the video band), the output characteristic of the second stage may be represented by

$$E = I \left[\frac{R_1 \times \dfrac{1}{J\omega C_1}}{R_1 + \dfrac{1}{J\omega C_1}} \right] A$$

where $E =$ output voltage of the second stage.

$I =$ Iconoscope output current.

$R_1 =$ Iconoscope load resistance (effective value).

$C_1 =$ Iconoscope load resistance (effective value).

Since A and I are assumed constant, they may be denoted by the lumped constant K. After due simplification, the output characteristic may be seen to be of the form

$$E = K \left(\frac{R_1}{1 + J\omega C_1 R_1} \right)$$

The output obviously varies in phase and in amplitude as a function of frequency. Note, however, that if a third stage were used having a plate load of the form $R_2 + J\omega L_2$ the gain over three stages would be

$$K^1 \left(\frac{R_1}{1 + J\omega C_1 R_1} \right) (R_2 + J\omega L_2)$$

where K^1 is a new constant taken to include the g_m of the third stage. Simplification of this expression gives

$$K^1R_1R_2\left[\frac{1+\dfrac{J\omega L_2}{R_2}}{1+J\omega C_1R_1}\right]$$

Thus, it may be seen that if $\frac{L_2}{R_2} = C_1R_1$, the output of the third stage will be of constant amplitude and free of phase shift throughout the video band. The circuit would appear as shown in Figure 9. However, from a practical standpoint there are limitations to be taken into consideration. First, there is about 25 $\mu\mu$f of tube and stray-circuit capacitance shunting the load circuit of the third stage. This requires that the value of reactance of L_2 be kept small compared to the value of the shunt-capacitive reactance at the highest frequency to be amplified; i.e., the resonant frequency of the composite-plate load should fall well above the upper end of the video-frequency range. This condition may be fulfilled by making $L_2 = 15$ μh. With these constants, resonance occurs at about 8.2 Mc.

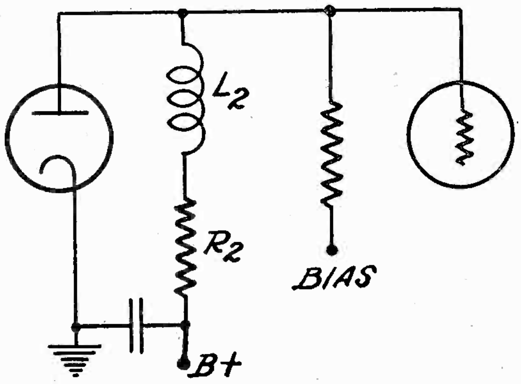

Fig. 9

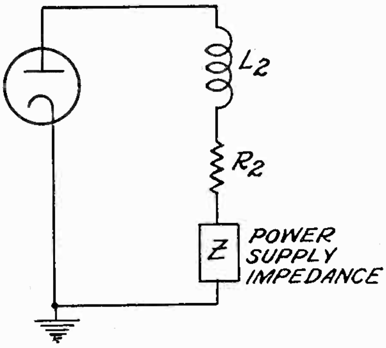

Fig. 10

The value of 6.25 ohms for R_2 $\left(R_2 = \frac{L_2}{C_1R_1}\right)$ is difficult, if not impossible, to obtain in practice. This is true because the power-supply impedance appears in series with the load as shown in Figure 10. In conventional plate-voltage supplies, the output impedance is a capacitive reactance of approximately 50 ohms at 60 cycles. Although an electronic-regulated supply would afford a much lower impedance, the condition would still be undesirable because the regulated-supply output-impedance varies both in magnitude and phase with respect to frequency. It may occasionally be negative in nature. Even if the supply had negligible impedance, the leads (from power supply to camera) may possess appreciable impedance.

The most satisfactory solution of the problem lies in making the load impedance of the form $R_2 + J\omega M_2$. It is then possible to eliminate the effect of power-supply impedance by means of the circuit shown in Figure 11. Here, a bifilar winding is used to secure high mutual inductance. The reactances of the windings are made to have their resonant periods (resonance with shunt-circuit capacitances) fall well outside the video-frequency band. The time constant of the components R_1 and C_1 is made sufficiently large to eliminate any appreciable attenuation or phase shift at low frequencies. The same is true of R_3 and C_3, which constitute a conventional grid-coupling circuit. The resistor R_2 is made variable (about 25 ohms total resistance). and its final value determined by observation of the picture after the unit is placed in operation. One excellent type of picture subject matter, for use when adjusting the low-frequency gain-control resistor R_2, consists of film titles, the high degree of contrast being particularly desirable. Incorrect adjustment of R_2 will be indicated by a smeared appearance of the picture. That is, an appearance of black or white shadows following the vertical edges of the letters. Upon correct adjustment of R_2 the edges become clear and sharp.

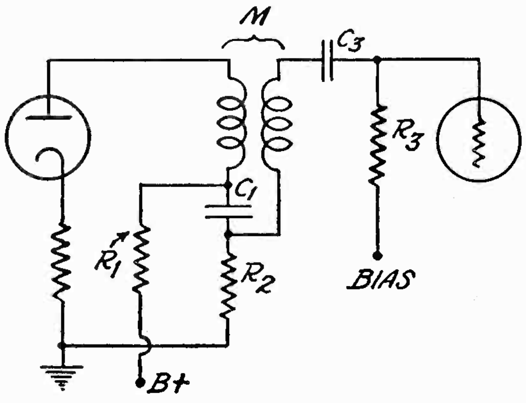

Fig. 11

The discussion thus far has been based upon the tacit assumption that the tube used in the third stage has a straight-line amplitude characteristic. However, such is far from true in practice, particularly when high g_m tube types are used with large grid swings. Non-linearity in the first and second stages may be neglected because the signal swing is small compared to the bias voltage, hence the tubes operate over only a small portion of the total characteristic. The third stage, however, operates with relatively large grid swing, the effect of which is to make the positive and negative plate-current excursions unequal. Oscilloscopic tests with a square-wave signal source have shown that in the event of excessive non-linearity of the third stage it is impossible to compensate precisely on both the positive and negative swings. The response of the first three stages to a 15-kc square wave may be made perfect on either positive or negative grid swings by the adjustment of R_2, but perfect response on both swings is possible only upon the inclusion of the 150-ohm unbypassed cathode load as shown in Figure 11. Here again is employed another of the useful features of cathode-loaded amplifiers—improvement in linearity of the amplitude characteristic.

While there are many other methods of compensating frequency response, this one has been found to be most desirable in regard to ease of adjustment, permissible gain per stage, and ability to correct accurately large variations in frequency response (about 50:1 in this case).

It should be noted that the principle of correcting a highly deficient frequency response at a subsequent stage has an additional advantage which may not be apparent upon cursory inspection. Since the overall gain of this amplifier is rather low (about 8 at the low-frequency end, 400 at high) in the low-frequency spectrum the effect of microphonics is greatly minimized. The use of the compensation principle would be advantageous in this respect even if it were ineffective in reducing noise.

FOURTH STAGE

The fourth stage is quite similar to the second stage. It too is in general a conventional video amplifier. However, it utilizes a somewhat higher value of load resistor by virtue of the lower value of shunt capacitance appearing in its plate circuit. The reason for the reduction in capacitance will be apparent upon consideration of the fifth stage.

FIFTH STAGE

In most practical applications it is desirable to locate the pre-amplifier in the camera head proper, directly beneath the Iconoscope. In such cases the output leads may range from 5 feet to 50 feet, or in some cases, even longer. It is convenient to have this output lead take the form of a concentric cable, all or a portion of which may be flexible. It is also desirable to be able to couple into, or out of, this cable without having to resort to excessively large blocking condensers or other undesirable coupling means which are usually necessitated by low-impedance lines. Again it is found convenient to use the degenerative or cathode-loaded amplifier. In this case, the principal reasons for using it are to provide a low-output impedance, and also to maintain the cable near ground potential insofar as direct current is concerned. As was previously mentioned, the reduction in effective input capacitance which is characteristic of the cathode-loaded amplifier is advantageous here, in that it permits the use of a higher value of load resistor in the plate circuit of the preceding stage, and hence greater gain.

The cathode-loaded output stage is shown in Figure 12. Here C_1 and R_1 are the conventional grid-coupling components. The value of R_2 is chosen so that R_2 plus the cable impedance is sufficient to furnish the correct value of bias necessary to maintain the zero-signal plate current of the 1851 at about 10 ma. This total value will normally be about 160 ohms. It has been found sufficient to terminate the cable at one end only.

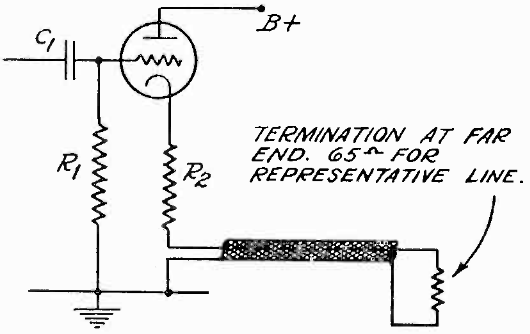

Fig. 12

POWER SUPPLY

The plate-voltage supply for the pre-amplifier should be capable of delivering about 60 milliamperes at 250 volts. It is highly desirable that this supply be of the voltage-regulated type, not necessarily because of the low output impedance afforded by such supplies, but rather because of its low hum level and its ability to remove the effect of line-voltage variations and surges which might cause changes in the plate voltage, and hence shifting of the picture background or brightness level. However, the factor of low output impedance is certainly not undesirable. As an additional safeguard toward greater stability, ample use has been made, throughout the pre-amplifier, of adequate plate-circuit decoupling filters. As has been pointed out in the many recent papers on video-frequency amplifier design, the decoupling filters also serve as equalizing networks which compensate for low-frequency response deficiencies in the grid-coupling circuits.

Note that all electrolytic condensers are bypassed by small paper or mica condensers. This must be done because electrolytics have been found to show appreciable impedance at the higher video frequencies.

PHYSICAL AND MECHANICAL CONSIDERATIONS

Since the particular model of Iconoscope pre-amplifier herein described was an experimental model, which was subjected to numerous and frequent changes, it is by no means intended to represent the optimum insofar as physical and mechanical considerations are concerned. However, there are a number of points pertaining to construction which, while they may not be considered desirable in every case, may at least suggest a possible method of attacking the problem.

For convenience in handling, and from the standpoint of portability, it is desirable to have the camera case of reasonable dimensions and, to facilitate experimental work, to have the components readily accessible for servicing or for circuit alterations. Hence, the pre-amplifier was built in a drawer, which was arranged to slide into the end of the camera case just beneath the Iconoscope. All leads, with the exception of those to the signal plate and collector of the Iconoscope, were brought out at the end of the drawer through jacks and plugs. The drawer was constructed of heavy sheet-brass with a bakelite bottom and a removable sheet-brass top. Additional shielding was provided internally by a lengthwise baffle, and externally, particularly on the bottom, by the camera case. All tubes were mounted in a horizontal position and staggered from side to side to provide short grid and plate leads.

Circuit elements and tie-points were mounted on the bakelite bottom. This served to reduce materially the stray-circuit capacitance. All bypass returns and grounds were made directly at each tube socket with short leads and well soldered connections.

While the unit may appear to be unduly compressed, a little experience with this type of construction will reveal the ease with which compactness may be realized.

ADJUSTMENT OF CIRCUIT CONSTANTS FOR PROPER FREQUENCY RESPONSE

As was previously mentioned, it will be necessary to measure the total shunt capacitances appearing in the plate circuits of the second and fourth stages, and to calculate the proper values of plate-load resistor and peaking inductance to be used in these stages. This must be done to take into account possible variations in capacitance caused by differences in construction and wiring.

A somewhat similar condition prevails with regard to the low-frequency response characteristic. Here it is necessary to make minor adjustments to eliminate errors caused by tolerances in grid-return resistors and in the electrolytic condensers used in the low-frequency plate-circuit equalizing networks. The adjustment may be facilitated by applying a 60-pulse-per-second square wave at the grids of the proper stages, and by observing the amplifier-output waveform on a reliable oscilloscope. The sequence of adjustments is as follows:

Apply a square wave to the grid of the fourth stage (remove the grid cap and apply the signal from grid to bias cell) and adjust the grid-return resistor of the fifth stage until the output, as observed on the oscilloscope, shows no wave tilt.

Apply the square wave to the grid of the first stage and adjust the grid-return resistor of the third stage until the output shows no wave tilt.

The time constants of the grid-coupling circuits of the second and fourth stages need not be adjusted, as it is desirable to have these as large as conveniently possible. The constants given in the circuit diagram have been found satisfactory.

OPERATION

This amplifier, when used in conjunction with an f:3.5 lens and a studio-type Iconoscope operating at about 0.1 microampere beam current (combined signal-plate and collector currents) is capable of producing an excellent picture. With outdoor pickup on a very cloudy day the noise level is so low as to be unnoticeable. Under the aforementioned conditions the output level is about 0.2 volt (peak to peak). Overload occurs at about 1.5 volts (peak to peak) output. However, this condition is rarely met in practice and may be prevented in cases of excessive illumination by stopping down the lens.

APPENDIX I

Analysis of cathode-loaded stage with particular regard to output impedance.

Throughout this discussion the tube used is assumed to be of the pentode type; that is, having a high dynamic plate resistance so that it may be considered as a constant-current device; also, grid-plate capacitance is assumed negligible and the screen grid is assumed to be by-passed to cathode.

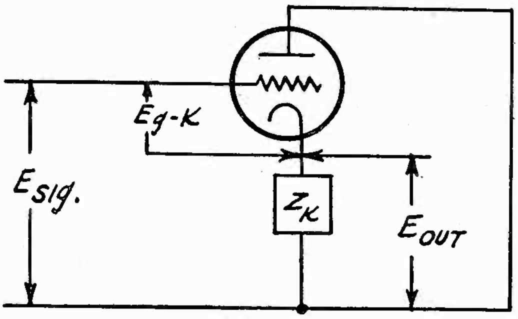

Fig. 13

The dynamic circuit of a cathode loaded stage is shown in Figure 13. D-c components have been eliminated for the sake of simplicity.

Upon examination of Figure 13 the following relationships may be noted.

$$I_p = E_{g-k}\, g_m \tag{1}$$

$$E_{g-k} = E_{\text{sig}} - E_{\text{out}} \tag{2}$$

$$E_{\text{out}} = I_p\, Z_k \tag{3}$$

Substituting (2) and (3) in (1)

$$I_p = (E_{\text{sig}} - I_p Z_k)\, g_m \tag{4}$$

or

$$I_p = \frac{E_{\text{sig}}}{\dfrac{1}{g_m} + Z_k} \tag{5}$$

The equivalent circuit for this expression is shown in Figure 14.

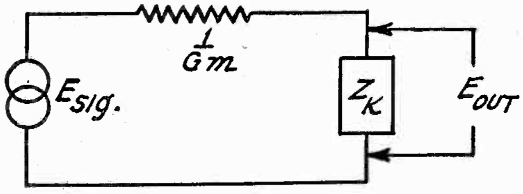

Fig. 14

The following useful conclusions may be drawn regarding cathode-loaded stages. Note that $\frac{1}{g_m}$ is of the form of resistance. The output impedance equals $\frac{1}{g_m}$, which in the case of the 1851 is 110 ohms.

If Z_k is purely resistive in nature and large compared to $\frac{1}{g_m}$ the gain is constant with respect to frequency and almost equal to unity.

Specifically, the gain is

$$A = \frac{Z_k}{\frac{1}{g_m} + Z_k} \tag{6}$$

APPENDIX II

Analysis of cathode-loaded stage with particular regard to reduction of apparent input capacitance.

In Figure 15 is shown the dynamic circuit of a conventional amplifier.

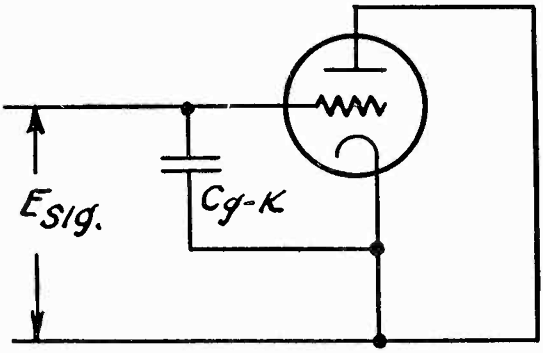

Fig. 15

Here the reactive component of the input impedance is seen to be

$$X_{\text{in}} = \frac{E_{\text{sig}}}{I_g} = \frac{1}{J\omega C_{g-k}} \tag{7}$$

In the case of the degenerative or cathode-loaded stage shown in Figure 16 we may say

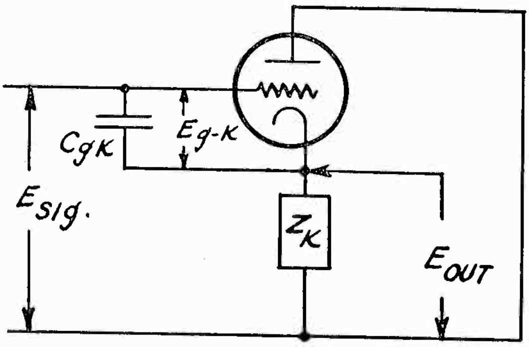

Fig. 16

$$I_g = \frac{E_{\text{sig}} - E_{\text{out}}}{\dfrac{1}{J\omega C_{g-k}}} \tag{8}$$

It is advantageous to make note of the fact that

$$E_{\text{out}} = E_{\text{sig}} \left[\frac{Z_k}{\dfrac{1}{g_m} + Z_k} \right] \tag{9}$$

as given in Appendix I equation (6).

Then, substituting and rearranging (8)

$$I_g = E_{\text{sig}} J\omega C_{g-k} \left[\frac{\dfrac{1}{g_m}}{\dfrac{1}{g_m} + Z_k} \right] \tag{10}$$

whence by equation (7)

$$X_{\text{in}} = \frac{1}{J\omega C_{g-k} \left[\dfrac{\dfrac{1}{g_m}}{\dfrac{1}{g_m} + Z_k} \right]} \tag{11}$$

By comparing (7) and (11) it may be noted that the grid-cathode portion of the input capacitance has effectively been reduced by a factor

$$\frac{\dfrac{1}{g_m}}{\dfrac{1}{g_m} + Z_k} \quad \text{or} \quad \frac{1}{1 + Z_k g_m}$$

For a type 1851 with resistive cathode load of 900 ohms this factor is about .11.

It must be noted that if the screen grid is bypassed to cathode the entire input capacitance is decreased by the given factor. However, it has been found desirable to return the screen bypass to ground for purposes of improving the signal-to-noise ratio. In this latter case only the grid-cathode portion of the input capacitance is effectively reduced.

Naturally this analysis also holds true for cases in which it is desirable to reduce the effect of grid-cathode capacitances which are in the external circuit and not necessarily interelectrode capacitances.

It is interesting to note that if Z_k contains capacitive reactance, a negative resistance component is introduced into the input impedance.

A similar analysis may be made for the case in which it is desired to determine the apparent resistive component of the input impedance when the grid-return resistor is brought back to a tap on the cathode-load resistor. The dynamic circuit to be considered in this case is indicated in Figure 17.

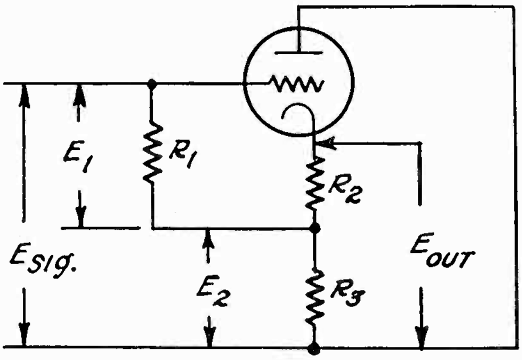

Fig. 17

From equation (6) Appendix I it may be noted that

$$E_{\text{out}} = E_{\text{sig}} \left[\frac{Z_k}{\dfrac{1}{g_m} + Z_k} \right]$$

whence

$$E_2 = E_{\text{out}} \frac{R_3}{R_2 + R_3} = E_{\text{sig}} \left[\frac{R_2 + R_3}{\dfrac{1}{g_m} + R_2 + R_3} \right] \frac{R_3}{R_2 + R_3}$$

$$= E_{\text{sig}} \frac{R_3}{\dfrac{1}{g_m} + R_2 + R_3}$$

but the effective input resistance is

$$R^1 = \frac{E_{\text{sig}}}{I_g} = \frac{E_{\text{sig}}}{\dfrac{E_1}{R_1}} = \frac{E_{\text{sig}}}{\dfrac{E_{\text{sig}} - E_2}{R_1}}$$

$$R^1 = \frac{E_{\text{sig}} R_1}{E_{\text{sig}} - E_{\text{sig}} \dfrac{R_3}{\dfrac{1}{g_m} + R_2 + R_3}}$$

cancelling E_{sig}

$$R^1 = R_1 \frac{1}{1 - \dfrac{R_3}{\dfrac{1}{g_m} + R_2 + R_3}}$$

ANTENNAS*

By

H. H. BEVERAGE

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MARCONI, during his early work with wireless telegraphy in 1895, used a simple dipole oscillator similar to those used by Heinrich Hertz in his classical experiments eight years earlier. Marconi soon discovered that he could greatly increase the range of transmission by connecting one side of the dipole oscillator to earth and the other side to an elevated plate. By using structures of greater and greater elevation to support his antenna, he found that the range of transmission increased. Since the wavelength emitted by this early equipment was a function of the length and size of the antenna, it is evident that Marconi's success quickly set a trend toward the use of longer and longer wavelengths as well as larger and higher antennas. When Marconi transmitted the historic letter "S" from Poldhu to Newfoundland in 1901, the antenna at Poldhu was supported by masts about 200 feet high, and it is probable that the wavelength was between 2000 and 3000 feet. During the next 20 years, it is not surprising that the trend toward the use of longer wavelengths continued which in turn called for higher antennas to increase the efficiency of radiation, and antennas of larger area to hold the voltage down to reasonable values when the antennas were energized by the hundreds of kilowatts found necessary for reliable communication over great distances. By 1921, it was not unusual to find some long-wave transmitting antennas supported by towers 800 feet high, and other types of antennas over a mile long. The Alexanderson multiple-tuned antenna is a familiar example of the latter type.

During this period, the bugbear to long distance communication was atmospheric disturbances, more commonly known as "static". It was found that static originated mostly over land masses, so that, in general, on transoceanic circuits, the static originated in a direction

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* A "guest editorial" in *Radio and Television,* April, 1939. Reprinted by permission.

more or less opposite to the direction from which the signals were arriving over their ocean path. Consequently it was possible to reduce greatly the effects of static by using directive reception. Numerous arrangements were used with varying degrees of success, such as the unidirectional "loop-vertical" combinations of Pickard, the ground wires of A. Hoyt Taylor, and the long antennas supported on poles, such as Weagant's antenna and the "Wave Antenna". The voltages induced in these long antennas traveled at nearly the velocity of light so that very long antennas could be used effectively, the usual length being 8 to 10 miles for the transoceanic wavelengths in general use at that time.

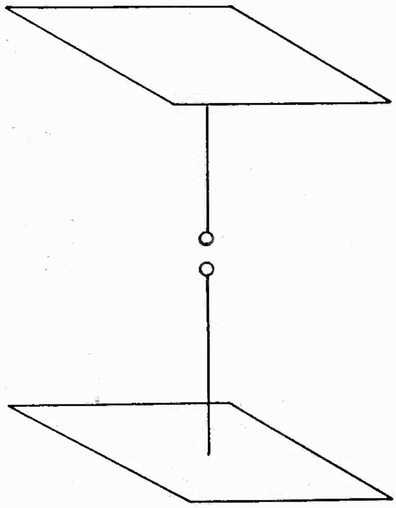

Fig. 1—Hertzian di-pole antenna.

The Wave Antenna was the first antenna to utilize the traveling wave principle, as distinguished from standing waves. Its effectiveness was due in large part to its simplicity which eliminated the critical adjustments that were required in its predecessors which depended upon some sort of a balancing arrangement.

The second era of long distance radio communication started with the discovery, during the early 1920's, that short waves below 100 meters were useful for long distance communication in the daytime, as well as at night. For these short wavelengths, it was practical to return to the Hertzian dipole as a radiator. It also became feasible to use directivity in the transmitting antenna to project a large proportion of the radiated power in the desired direction. It was logical that the first directive antennas should consist of arrays of dipoles with reflectors. Very effective arrays were developed as exemplified by the

British Marconi Beam antenna, the German Tannenbaum antenna, and the arrays developed in America by the A. T. & T. Company and the RCA. These antennas, however, were relatively expensive to construct and maintain, and as the number of short-wave circuits rapidly increased, it was necessary to develop less expensive types of antennas. Economical and effective antennas were devised consisting of wires several wavelengths long orientated in such a way as to concentrate the radiation in the desired direction. Typical antennas of this general classification which have found wide use are the harmonic wire antenna, the V-shaped antenna with reflector, the Rhombic antenna, and the Marconi Series-Phase antenna. The latter two are generally terminated in a dissipative network equivalent to their surge impedance so that they employ traveling waves rather than standing waves.

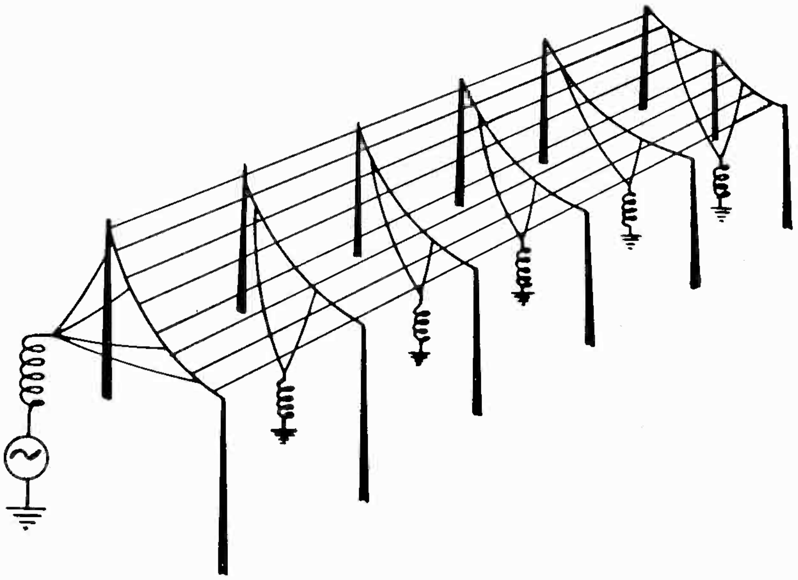

Fig. 2—Alexanderson multiple-tuned antenna.

The early short-wave receiving antennas were frequently arrays similar to the transmitting arrays, but less costly receiving antennas were eventually developed by the operators of radio communication services. In America, the antennas most generally used for trans-oceanic services are the Rhombic antenna and the Fishbone antenna, both of which are of the traveling wave type.

The short waves have been very useful as a means for studying the characteristics of the ionosphere and the mechanism of radio transmission in general. This knowledge has been useful in connection with studies of propagation in the broadcasting spectrum. The anti-fading service area of broadcasting stations have been approximately doubled by antennas designed to suppress the radiation at high angles above the horizon.

We are now entering upon the third era of radio communication, the development of the ultra-short waves. These waves do not ordinarily travel via the ionosphere and are limited in their reliable range to distances not greatly in excess of the horizon. This quality is an advantage in many ways since it makes it possible to duplicate the use of these frequencies without interference at points on the order of 200 miles or so apart. It is interesting to note that there are as many cycles between 5 meters (60 megacycles) and 10 meters (30 megacycles) as there are in the entire radio spectrum above 10 meters. The services that will undoubtedly develop in the ultra-short wave spectrum may eventually become as important, or even more important, than the services now existing in all of the rest of the radio spectrum. For example, the ultra-short wave band is the only part of the spectrum suitable for high-definition television. Bands of 6 megacycles width in this spectrum have already been earmarked by the Federal Communications Commission for experimental television transmission.

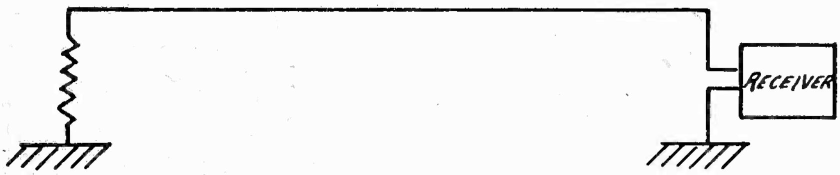

Fig. 3—Wave antenna.

We have seen that in the transition from the long waves to short waves, there was a radical change in the type of antennas that were found useful and necessary for the new services. Will the development of the ultra-short wave spectrum see a radical change in antenna structures such as we do not dream of today?

In the long distance use of shortwaves, a limit was found in the concentration of the radio beam that could be used successfully. To obtain a high power gain, it was necessary to concentrate the radiation into a narrow beam in the vertical plane as well as the horizontal plane. It was found that there is no single vertical angle at which the radiation can be launched that will be effective over a considerable period of time. The classic work of the Bell Laboratories in the development of the MUSA system indicates very clearly that the signals may travel over several bundles of rays, but that these paths are quite variable and require a wide range of vertical angles to obtain reliable communication over a considerable period of time. This phenomenon sets a limit on the usable concentration of the radiated or received radio energy. As a practical matter, an antenna with a concentration which produces a power gain of 100 is probably close to the useful limit. Will a similar limitation in the concentration of power be found on the ultra-short waves? No such limitation is known today, and as the wavelength becomes shorter, it is practicable to build antennas that will highly concentrate the radio beam. Will we see strange contraptions with power gains of 1000 or more on relay chains carrying television network programs and multiplexed mass communication? If power gains of a high order can be used, the transmitter power required will decrease in proportion so we may see a miniature "acorn" tube transmitter associated with an enormous directive antenna structure. The possibilities of using radio repeaters even smaller than telephone type repeaters, and concentrations of energy that reduce the attenuation over a given path to a very low value are indeed intriguing to the imagination.

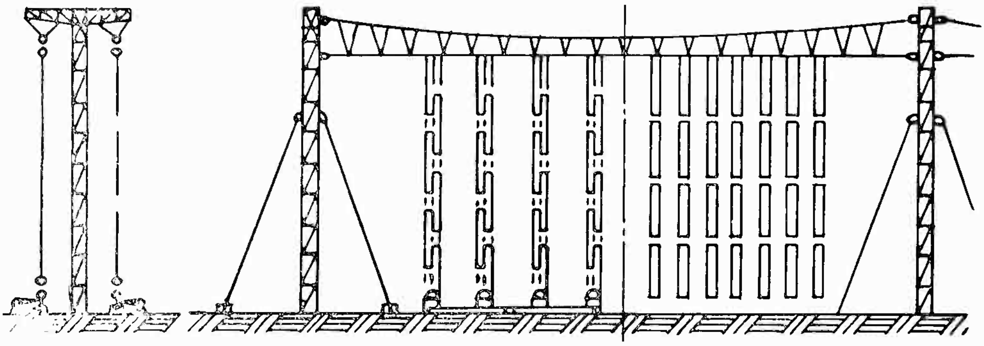
Fig. 4—Marconi beam antenna.

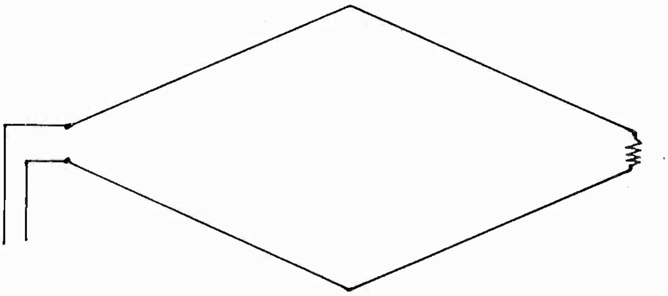
Fig. 5—Rhombic antenna.

Another factor that will affect the antenna design for the ultra-short waves is the necessity for providing antennas covering an extremely wide band for high-definition television. We have already seen some radical departures from familiar forms of antennas in this field in the television antenna recently erected on the Empire State Building in New York. Here we see radiator elements looking like Indian clubs which project from an expanding throat and appear somewhat like the streamlined nacelle of a modern air liner. By this unusual design, a radiator is obtained which electrically looks like a resistance over the complete octave of frequencies from 30 to 60 megacycles, a band many times wider than provided by any omni-directional antenna known to the prior art. In other words, this antenna has a flat characteristic over a range 30 times as wide as the normal broadcasting band.

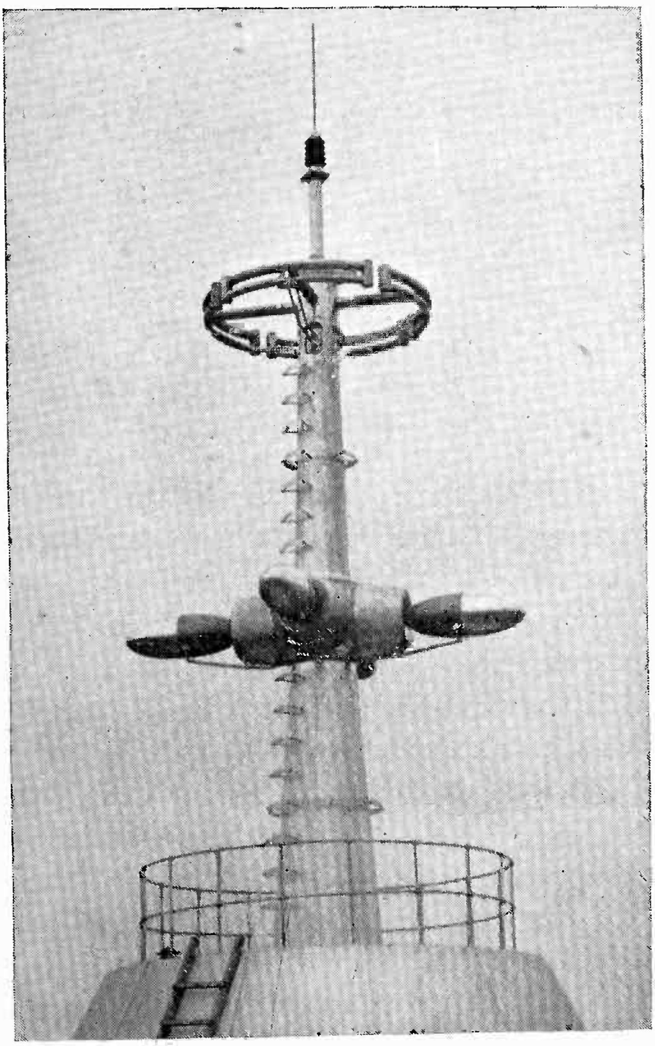

Fig. 6—Empire State Building television antenna.

As we learn how to use shorter and shorter wavelengths, we may well expect to see increasingly radical antenna designs which have little resemblance to the antennas that have been familiar to us in the long-wave and short-wave fields.

EFFECT OF ELECTRON TRANSIT TIME ON EFFICIENCY OF A POWER AMPLIFIER

BY

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Summary—*Measurements of the plate efficiency of a neutralized triode amplifier operated at high frequencies are reported. The results are compared with those obtained for an oscillator operated at the same frequency. At a frequency at which the oscillator efficiency approaches zero the amplifier efficiency is found to be reduced to only 50 per cent of the low-frequency value. It is shown that the difference in efficiency is primarily due to a large phase angle between the plate current and the grid voltage produced by the electron transit time.*

IN a recent paper[1] W. G. Wagener discusses the effect of electron transit time on amplifier efficiency and presents generalized curves of transit-time-efficiency factors for triode oscillators and amplifiers. Wagener refers to the work done early in 1936 by the author, who at that time suggested that in a neutralized amplifier, or in any amplifier in which the phase of output voltage is independent of the phase of input voltage, the efficiency of a tube as an amplifier will be higher than as a triode oscillator at higher frequencies when, as a result of electron transit time, appreciable phase difference may exist between grid voltage and plate current. In order that this suggestion might be checked, curves of plate efficiency versus transit angle were obtained for a push-pull cross-neutralized amplifier. These curves clearly demonstrated the improved performance of a tube as an amplifier and indicated the possibility of extending the high-frequency limits of conventional tubes. It is the purpose of the present paper to present the original data on amplifier efficiency as affected by electron transit time and to discuss the significance and usefulness of such information for the design of high-frequency power-amplifier tubes.

The study of the effect of electron transit time on the performance of tubes at high frequencies has been the subject of many recent publications. Starting with the original work of Benham[2] and other investigators, [3,4,5,6] we find that a satisfactory theory confirmed by experiment, has been developed for analyzing the high-frequency performance of conventional diodes and triodes. However, application of this theory is limited to receiving tubes because small radio-frequency signal amplitudes are assumed in the theory. The problem of high-frequency power tubes where r-f voltages comparable with the d-c voltages are involved, still is in need of an adequate theoretical treatment, although attempts to find a solution have already been made.[7] Lacking an adequate theory, a researcher and designer has to resort to experiment to obtain the quantitative information necessary for design of high-frequency power tubes.

The purpose of the author's original work was to determine the effect of electron transit time on the plate efficiency of a tube operated as an amplifier and to compare it directly with the transit-time effect in the case of an oscillator. For this comparison to be sufficiently significant, it was necessary to use the same tube, under the same operating conditions, and to use the same circuit both for the amplifier and for the oscillator tests, except for the addition of neutralizing condensers for the amplifier tests. The circuit is shown in Figure 1. Two developmental h-f triodes (similar to RCA-834) were used. Variable air condensers connected to grids and plates by short low-inductance leads were used for capacitive cross-neutralization. Low-loss, parallel-wire, tuned transmission lines were used as circuit elements to facilitate tuning and loading adjustments. The filaments were also tuned by means of half-wave lines. The excitation for the amplifier was obtained from an oscillator coupled inductively to the grid lines. The load consisting of one or two ten-watt lamps was placed across the plate line and the value of output impedance was adjusted by varying the position of the load lamps along the plate line. It was found necessary to change the adjustments of the neutralizing con-

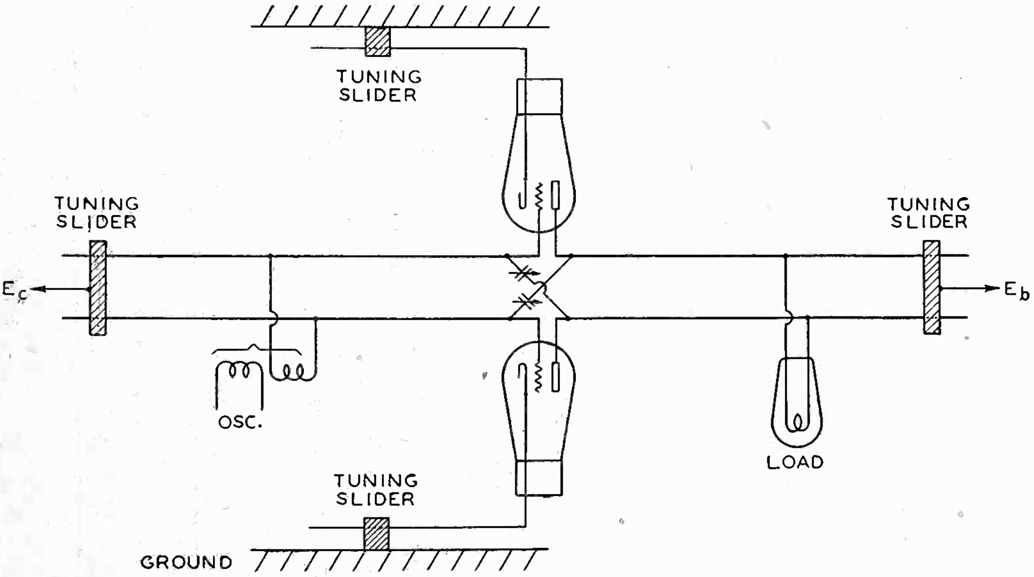

Fig. 1—A schematic diagram of the amplifier circuit.

densers when the frequency was changed because of lead inductance. For each frequency, the setting was adjusted to obtain a minimum transfer of energy from input to output circuit. The plate voltage was reduced below normal so that an increased power dissipation on the plate would not be a limitation at higher frequencies.

First, oscillator-efficiency data for a frequency range from 180 to 300 megacycles were obtained with the neutralizing condensers removed, and then the amplifier-efficiency data were taken. To obtain results which would directly indicate the relative plate efficiency of oscillator and amplifier, the following procedure was adopted. The low-frequency performance as oscillator or amplifier was checked against the performance calculated from the static characteristic curves of each tube used in the experiment. The grid and plate currents were noted so that for amplification tests at high frequency, the grid excitation could always be adjusted to give approximately the same average grid and plate currents. This adjustment was considered to indicate approximately the same input voltage, the error due to variation in magnitude and phase of plate voltage being small because of the high amplification factor of the tube ($\mu = 10$). The negative bias on the grid was adjusted so as to obtain approximately class B operation at low frequency and was kept the same at higher frequencies.

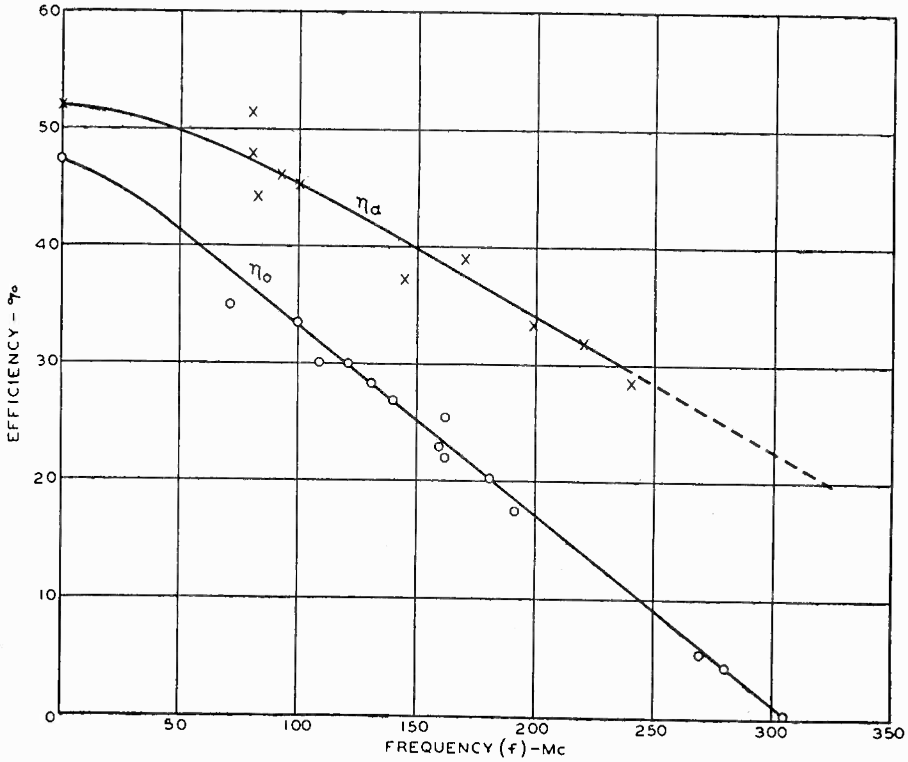

Fig. 2—Variation with frequency of amplifier (η_a) and oscillator (η_o) efficiency.

Figure 2 shows the curves of oscillator efficiency (η_o) and amplifier efficiency (η_a) versus frequency (f). The oscillator-efficiency curve extends practically to a limit of oscillations, i.e., $f = 310$ Mc, where the efficiency approaches zero. The amplifier curve was measured only up to a frequency of 240 Mc because of the difficulties in neutralization at higher frequencies. It can be seen that at the limit, when oscillator efficiency approaches zero, the power-amplifier efficiency is reduced to only one-half of the normal efficiency obtained at low frequencies. (The difference in efficiencies at $f = 0$ is due to grid power required for excitation in the case of an oscillator.)

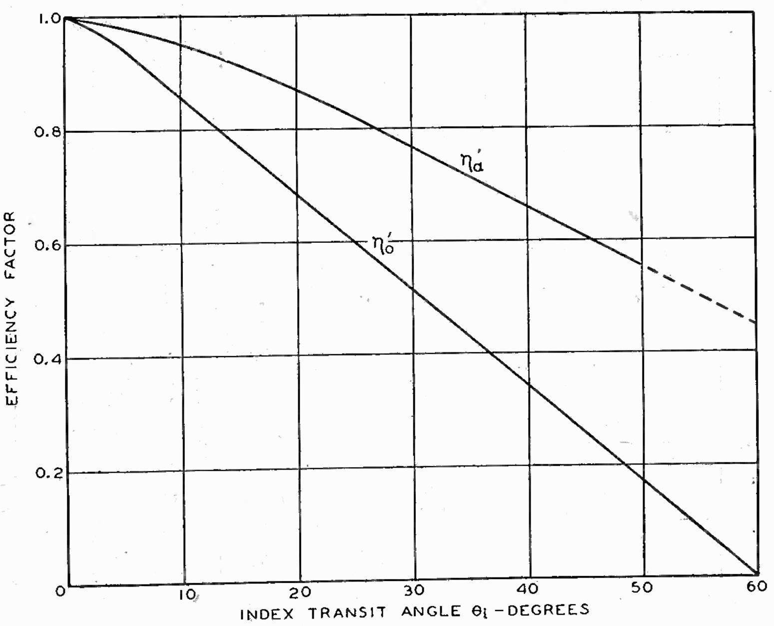

Fig. 3—Efficiency factors for amplifier (η'_a) and oscillator (η'_o) plotted against the index transit angle (θ_i).

To make the above information on variation of efficiency with frequency more generally useful, the curves were replotted as shown in Figure 3. Here the "transit-time efficiency factor" η' (θ_i) is plotted against the electron transit angle (θ_i). The transit-time efficiency factor η' (θ_i) is defined as the ratio of efficiency at a given first (cathode-grid) transit angle to the efficiency at low frequency, i.e.,

$$\eta' (\theta_i) = \frac{\eta (\theta_i)}{\eta (O)} \tag{1}$$

The transit angle θ_i, referred to above, can be called the index transit angle and is defined as the product of the operating angular frequency and the transit time between cathode and grid computed for peak grid voltage at low frequency. Experience indicated that this generalized representation of experimental results, while not wholly justified theoretically, is very useful in analyzing and predicting the performance of tubes at high frequencies.

It is realized, of course, that the index transit time is a fictitious transit time and does not correspond to the actual electron transit time at high frequencies. However, it has been selected as a convenient transit-time index, easily calculable from tube dimensions and voltages. The formulas and chart, given by W. R. Ferris[6] are very useful for this calculation. The actual transit time varies during the r-f cycle when the r-f voltage amplitudes are large compared with direct voltages. To give an idea of variation of transit time during an r-f cycle, the curves of Figure 4 may be of interest. They represent the variation of transit angle in a temperature-limited diode during a positive half-cycle computed for the case of class B operation. The crosses indicated in the figure correspond to the values of the index transit angle calculated for the peak voltage.

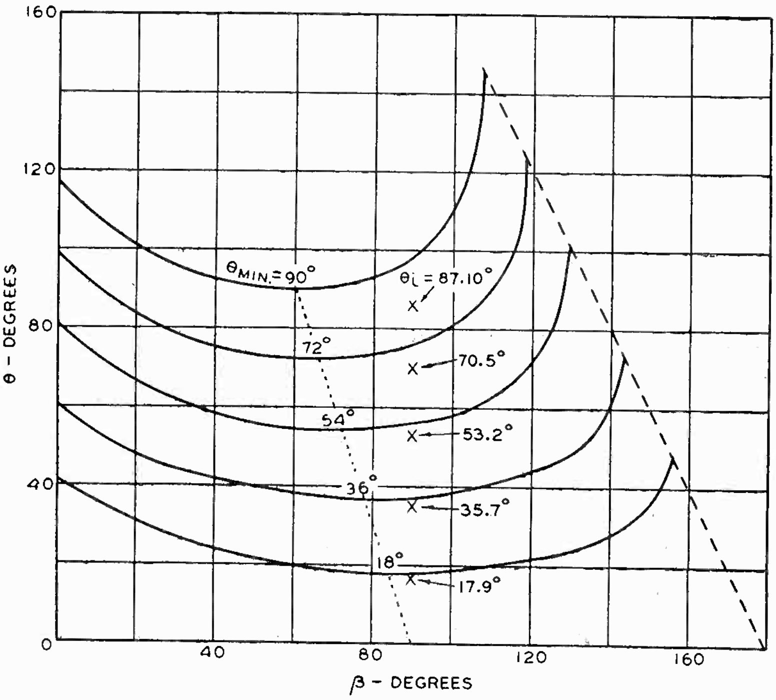

Fig. 4—Variation of electron transit angle in a temperature limited diode during a positive half-cycle for different values of index transit angle. β expresses the time at which electrons leave the cathode.

One may expect that qualitatively an analogous situation exists in the case of a space-charge-limited tube. The transit time for electrons starting in the beginning and near the end of the positive half-cycle will be greater than for electrons starting near the peak of the voltage wave. Some electrons starting near the end of the half-cycle will not reach the grid at all and will be returned to the cathode with appreciable velocity to produce cathode bombardment. The actual shape of the current pulse has not been calculated, but a qualitative description given by Wagener[1] is sufficient to explain the drop in efficiency of an amplifier.

The decrease in efficiency with frequency of an oscillator is more rapid than in the case of an amplifier. Two effects contribute to this difference in performance. First, due to increased input-circuit losses and electron-input loading the driving power increases with frequency. Since it is derived from the plate output of the oscillator the apparent plate efficiency will be lower. However, an estimate of the additional driving power at the highest frequency indicated that it would account for only a 10 per cent reduction in output power as compared with the low-frequency performance.

The second effect is the change in phase of plate current with respect to plate voltage due to electron transit time. In an oscillator employing grid-plate capacity for feed-back the coupling admittance at high frequencies is so high that the best adjustment that can be obtained is the one in which the grid-plate voltage phase does not differ materially from 180°. Therefore in the oscillator the phase shift in plate current due to electron transit time cannot be corrected. In the neutralized amplifier, however, the phase of output voltage can be adjusted for optimum condition, that is, a 180° phase angle between plate current and plate voltage can be realized even for large transit angles. If the electron loading effect is neglected and one assumes that the shape of the current pulse is a function of transit angle only and is the same for both the amplifier and oscillator, then one might consider that the difference in efficiency in the case of an oscillator is due primarily to the uncorrected phase angle between the place current and plate voltage.

The efficiency of an oscillator and amplifier can be expressed as

$$\eta_o = \frac{I_p E_p}{I_b E_b} \cos \phi \tag{2}$$

$$\eta_a = \frac{I_p E_p}{I_b E_b} \tag{3}$$

where

ϕ = phase angle between the plate current and plate voltage of an oscillator due to electron transit time.
I_p = fundamental component of r-f plate current.
E_p = fundamental component of r-f plate voltage.
I_b = average plate current.
E_b = average plate voltage.

If the magnitudes of currents and voltages are assumed to be the same in oscillator and amplifier, then the ratio of efficiencies will be

$$\frac{\eta_o}{\eta_a} = \cos \phi \tag{4}$$

As a first approximation, it may be assumed that the phase angle is directly proportional to transit angle, i.e.,

$$\phi = K\theta_i \tag{5}$$

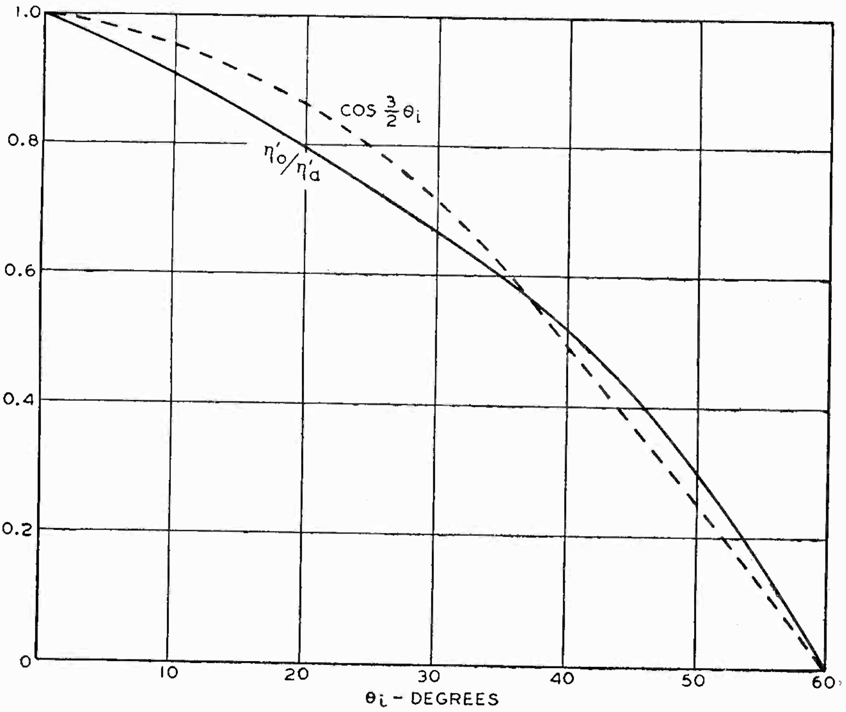

Fig. 5—The experimental curve of η'_o/η'_a and the function $\cos \frac{3}{2} \theta_i$ plotted against the index transit angle.

Since at $\theta_i = 60°$, $\eta_o/\eta_a = 0$, we conclude that the constant of proportionality $K = 3/2$. Therefore,

$$\frac{\eta_o}{\eta_a} = \cos \frac{3}{2} \theta_i \tag{6}$$

In Figure 5 the experimental curve of $\frac{\eta'_o}{\eta'_a}$ computed from data of Figure 3 is shown together with the curve representing the relationship (6). In view of the experimental error, the agreement between the simple theory and the experiment is quite satisfactory. One may consider, then, that the difference in efficiency of oscillator and amplifier is primarily due to the plate-current phase lag caused by finite electron transit time and that, as a first approximation, the efficiency of an amplifier can be calculated from the relationship (6) when the oscillator efficiency is known.

The above information, although not complete and not as accurate as might be desirable, can be used as a first approximation in the design of high-frequency tubes. To illustrate its use, suppose it is desired to design a triode amplifier to be operated at a frequency f. Ordinarily from mechanical considerations a minimum grid-cathode spacing will be selected. Then the design will be carried out as is usually done for low-frequency tubes. The required peak grid voltage will be calculated and then an estimate of the grid-cathode angle at the operating frequency will be made. From the curve of Figure 3, the transit-time efficiency factor can be found and the previously assumed values of plate efficiency and plate dissipation corrected accordingly. The tube dimensions are corrected to correspond to the new value of plate dissipation. A second approximation can then be made.

In conclusion, it may be stated that at present empirical data are the only guide for the designer of high-frequency power tubes. The author is hopeful that a more refined experimental technique will make it possible to separate and evaluate accurately the different effects (circuit losses, grid-plate transit time) influencing the high-frequency performance of power tubes. Such an experimental analysis would greatly aid in the design of high-frequency tubes. In addition, the development of a satisfactory theory is also highly desirable and important, particularly when a design of tubes differing materially from the conventional is contemplated.

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