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THE AMERICAN SYSTEM OF BROADCASTING AND ITS FUNCTION IN THE PRESERVATION OF DEMOCRACY*

BY

DAVID SARNOFF
President, Radio Corporation of America

THERE could be no more fitting auspices than those of the Town Hall for a talk on "The American System of Broadcasting." Your distinguished 44-year history as a molder of public opinion has upheld the finest traditions of our democracy. Your own radio forum—"America's Town Meeting of the Air"—has grown, out of an adventurous experiment, to become one of the most popular and important of radio programs.

GROWTH OF RADIO

It has been my privilege to be associated with radio for more than thirty years. At an age when the average boy is still wearing a football headguard or a catcher's mask, I was proud to wear a radio telegrapher's headset. The radio telephone was nothing but a dream, and radio broadcasting was not even that.

There were only a handful of us in those days, but during the intervening years thousands of able men and women have joined our ranks. A vast radio industry has grown up. No other industry ever grew so fast. The years and days and hours have been crowded with a never-ending procession of new discoveries, new developments, new services.

The pagan conception of Mercury serving the gods on Mount Olympus never approached the present-day reality of radio, the modern messenger that travels with the speed of light, encircling the globe seven times in a single second. Radio carries messages between all nations. Oceans, mountain ranges, and man-made boundaries alike are powerless to hold it back. It safeguards the passage of ships at sea and in the air. It has given mankind the greatest means of mass communication ever devised. It brings the voice and the music of civilization—and some day will also bring its living image—into the most isolated home.

Nature yields her secrets slowly and reluctantly. It has been a hard, exciting struggle to take these ether waves, that have filled the

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* Presented at the Town Hall Luncheon, Hotel Astor, New York, N. Y., April 28, 1938, on the occasion of the 44th Anniversary of Town Hall.

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atmosphere since the beginning of time, and in a single generation harness them to serve mankind.

Although my subject concerns broadcasting, I have not come here today as a broadcaster. I am speaking as one of the pioneers of a new art, of which broadcasting, however significant, is only a part. I speak as one who has watched that art develop from the beginning. I am concerned with the opposition to which all new arts are exposed, and with the forces which tend to shackle their freedom and curtail their development. I speak to preserve broadcasting as one of the free institutions of our democracy.

WHAT IS BROADCASTING?

Broadcasting consists of more than wavelengths, more than towers outside and equipment inside a radio station. It is a service of entertainment, culture, and information. The greatest significance of broadcasting is in the directness of its appeal, not merely in the speed and spread of its message. Many of its programs originate in a single local station, and are heard only in a single listening area. Here radio performs an important community service.

The national services of the American system of broadcasting, however, depend upon more ambitious programs, nationally distributed. In the broadcasting systems of other countries there is nothing comparable to the great transcontinental networks across the United States. These are voluntary associations of independent stations, each an important economic and social factor in its own community. During a portion of the time, each station broadcasts national instead of local programs. During the remaining time, stations associated with the National Broadcasting Company, for example, may choose whether they will broadcast national or local programs.

Without this linking of broadcasting facilities there would be no national service of broadcasting. Without networks the vast majority of the American people would never have the opportunity to hear the voice of their President, or the music of Toscanini, or the debates of the Town Meeting of the Air. Tapping the talent sources of the world, American network broadcasters have made a radio receiving set infinitely more valuable in the United States than it is anywhere else in the world.

BROADCASTING A YOUNG ART

When we talk about the American System of Broadcasting we are talking about something barely eleven years old. The first nation-wide broadcasting network was created by the National Broadcasting Com-

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pany in November, 1926. And because it is young, the American system is still developing, subject to constant experiment and change.

In its present state, there is only one certainty about the technical development of radio, and that is the certainty of change. Its greatest achievements still lie in the future. The public services of radio sight will soon be added to those of sound. Radio facsimile, which makes it possible to deliver a radio newspaper into the home, may supplement the regular services of the press. Television will bring us the faces and gestures of speakers and artists, as well as their voices, and will enable us actually to see news in the making. As new inventions create new channels in the ether, not only in short waves but in waves measured in centimeters and millimeters, the day will come when there will be more wavelengths than broadcasting stations to use them.

Whatever controls over broadcasting are necessary at the present time, it is important that they should be kept as flexible, as free from rigidity, as the art itself. Otherwise there is danger of tying up the future usefulness of radio in a strait-jacket. We should not try to regulate something as yet unborn; and we should not freeze an expanding art in any rigid code.

Relation of Radio to Government

If wavelengths were now available for an unlimited number of broadcasters, there would be no more need for special government regulation over broadcasting than over the printing of newspapers.

It is the allocation of station frequencies, which for the moment are limited in number, that creates a difficult task for the Federal Communications Commission. The Commission deserves great credit for having helped broadcasters to make the present American System of Broadcasting what its name says it is: something that is both systematic and American.

The law empowers the Commission to license broadcasting stations for periods not exceeding three years. In practice, however, the Commission grants licenses for only six months, on the theory that it is easier to reject an application for renewal than, for any reason, to cancel an unexpired license. When its license comes up for renewal, if the station has operated with technical efficiency, and if, in the opinion of the Commission, it has served "the public interest, convenience, and necessity," it gets another six months' lease of life. Twice a year, therefore, the substantial investment which the licensee has made in his business is placed in jeopardy.

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CENSORSHIP

The broadcasting controls established by law are intended primarily to regulate physical facilities, not programs. The law specifically withholds from the Commission the power of program censorship. Section 326 of the Radio Law of 1934 states:

> "Nothing in this Act shall be understood or construed to give the Commission the power of censorship over the radio communications or signals transmitted by any radio station, and no regulation or condition shall be promulgated or fixed by the Commission which shall interfere with the right of free speech by means of radio communication."

While direct Government censorship over radio programs is thus forbidden by law, the terms of the Government licenses leave the door open for an indirect—and more insidious—censorship. Any attempt to impose the ordinary "blue-pencil" censorship is little to be feared, because, being a conspicuous violation of the right of free speech, it would arouse a storm of public protest. But what is not conspicuous—and is therefore dangerous—is the effect on the mind of the broadcaster, resulting from attitudes that may be taken by the government toward stations, on matters outside the regulation of facilities.

Fear of disapproval can blue-pencil a dozen programs for every one that an official censor might object to. While practically nobody advocates a pre-program blue-pencil in the hands of government, few realize that post-program discipline by the government can be a form of censorship that is all the more severe because it is undefined.

Another aspect of government supervision over broadcasting, which is in effect a form of censorship, is the attitude in some quarters of the government toward the profits earned by broadcasters.

The grant of broadcasting licenses is only one of the many responsibilities of the Federal Communications Commission. It has supervision over all forms of wire and radio communication. In the field of two-way telephone and telegraph communication, control over rates is one of its most important functions. Here questions of investment value and profits are material.

But broadcasting is a one-way, not a two-way, medium. It is not a common carrier which the public hires to perform a fixed service. It is a medium of artistic and intellectual expression, free to the listening public. Its financial structure does not impinge upon the public interest, convenience or necessity.

While stations and networks represent substantial investments, broadcasting is essentially a personal service business. The earnings

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of stations cannot be judged on the basis of their investment, any more than those of a lawyer, doctor, theatrical producer or publisher. Income results, not from studios and transmitters, but from programs.

It is a strange assumption that the less money a broadcasting company makes, the better the public will be served. This attitude is contrary to all sound business principles and experience. In what way is it conceivable that the public will be given better programs if the broadcaster is deprived of both the incentive and the means to improve his facilities and service?

Adequate profits mean the continuance of private investment, and increased enterprise. Losses mean poorer programs, and, when private resources fail, government ownership. If government regulation of the economics of broadcasting results in a no-profit industry, investors may prefer to exchange their broadcasting equities for government securities. Then we shall have government ownership and 100 per cent control of broadcasting. Any further discussion of censorship would then be purely academic. We would have broadcasting of the government, by the government, and for the government.

We have but to look to the autocracies of Europe to see what such governmental control of broadcasting may mean.

BROADCASTING IN EUROPEAN AUTOCRACIES

Broadcasting in those autocracies serves the interest, convenience and necessity, not of the public, but of totalitarian government. It is allowed to present only one side of public issues. Its so-called news services are services of propaganda. When the dictator stands before the microphone, the citizens are regimented before the loudspeaker. At the same time, the public may be forbidden, under penalty of imprisonment, to listen to programs presenting any point of view contrary to that of the party in power.

It is no coincidence that in an autocracy where freedom of broadcasting does not exist, neither is there a free economy to which it might look for support. It is no coincidence that where freedom of thought and of speech are denied on the air, they are equally denied on the platform, in the university, and in the church. It is no coincidence that where you find broadcasting enslaved, you also find a slavish press.

BROADCASTING UNDER THE AMERICAN SYSTEM

Our American system of broadcasting is what it is because it operates in the American democracy. It is a free system because this is a free country. It is privately owned because private ownership is one of our national doctrines. It is privately supported, through commercial sponsorship of a portion of its program hours, and at no cost to the listener, because ours is a free economic system. No special laws had to be passed to bring these things about. They were already implicit in the American system, ready and waiting for broadcasting when it came.

Broadcasting did not take on the American system. The American system took on broadcasting.

In recent years we have witnessed a steady enlargement of the economic power of federal government. That very enlargement has put upon the defenders of democracy the need for greater vigilance. That is where radio and the press assume a new importance. In the European countries that have been lost to democracy, the dictators who accomplished that revolution did so through their control of radio and the press. Nor were they satisfied with that. Their next step was to use the same governmental power to destroy the freedom of religion and of education.

Every increase in the economic power of a government makes more precious and more important the vigilant maintenance of the freedom of thought, and the courageous, unflinching defense of the freedom of all forms of its expression.

RADIO AND THE PRESS

In its functions, its freedoms, and its responsibilities, broadcasting is essentially analogous to the press. It provides a forum for the spoken word, just as the press provides a forum for the written word.

The broadcasting networks perform for their affiliated stations the same service that the great press associations perform for their member newspapers. They assemble news and talent from the four corners of the earth, and deliver it swiftly and economically to local stations. And just as a press association franchise is a coveted asset for a local newspaper, so a major network connection is a principal factor in determining the importance and quality of service of a local broadcasting station.

The broadcasting station and the newspaper both have editorial functions, one in the selection of programs, and the other, of reading matter. Both also have commercial functions. Both are supported by advertising revenue. The income and influence of both depend upon circulation figures; of listeners in one case, readers in the other. Both have a legitimate investment asset of goodwill in the circulation they have built up.

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The broadcaster decides upon the relative interest to his audience of each program, and proportions his broadcasting hours accordingly. In so doing, he performs an editorial function similar to that of the newspaper in making up its pages or selecting its features. The care exercised by the broadcaster to present all sides of controversial public issues is in itself an editorial function of great importance.

There may be occasional abuses both on the air and in the press, but in a democracy it is the power of public opinion, rather than a government tribunal, which enforces standards of public expression.

This public censorship is in keeping with democratic principles. And it is a very real power, because it is exercised by direct control over the profits of the broadcaster. Broadcasters are competing every moment of the day for the listeners' interest. Program approval by listeners spells circulation and profits; disapproval spells losses and disaster.

If freedom means anything it means freedom to make mistakes as well as to do the right thing. Broadcasters have made mistakes, plenty of them. That is the way they learned to be broadcasters. I want them left free to make more mistakes. That is the way they will learn to be better broadcasters.

SUMMARY

Let me summarize the four beliefs about broadcasting concerning which I have tried this afternoon to give you the groundwork of my thinking:

First, The extent and value of the services of American broadcasting depend upon its freedom to develop and to operate with a minimum of regulation by the Government. Until and unless the radio art can provide as many wavelengths as there are broadcasters to use them, centralized regulation of technical facilities is essential. But the spirit of such regulation and its enforcement should differentiate clearly between technical operations and program services.

Second, While broadcasting should remain subject to all the laws that apply to other industries serving the public, it should be made morally as well as legally certain of its freedom from program censorship, other than the legitimate censorship of public opinion. There should be no censorship by intimidation or economic pressure. The station license should carry a longer term than six months. It should be revocable only for cause, and these causes should be clearly defined in advance.

Third, The progress of the American system of broadcasting, and the improvement of its program services, depend upon continued net-

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work development. Only by such development can we provide a finer national service, free to the public.

Fourth, and finally, Freedom of the air is inseparable from the freedom of thought, of speech, of worship, of education and of the press. These are the cornerstones of our American democracy. What helps one helps all; what injures one is an encroachment upon all; what destroys one destroys all, and thereby destroys democracy itself.

A free system of broadcasting can survive only under a democratic form of government, but it is no less true that democratic government itself will survive only if broadcasting is kept free.

American broadcasting asks no special privileges. It deserves none. It needs none. All it asks is the preservation of the American spirit of freedom.

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THE INTERNATIONAL TELECOMMUNICATION CONFERENCES OF CAIRO, 1938

BY
C. B. JOLLIFFE
Engineer-in-Charge, RCA Frequency Bureau

UNDER the procedure of the International Telecommunications Convention of Madrid, 1932, two conferences were held at Cairo, Egypt, beginning February 1, 1938,

(1) the International Radio Conference to revise the General Radio Regulations and associated documents,

(2) the International Telegraph and Telephone Conference to revise the Telegraph and Telephone Regulations.

The International Telecommunications Convention of Madrid, which is the basic document providing for the various regulations, was not subject to revision at these conferences and remains unchanged.

The two conferences were run simultaneously and many of the government delegates were representatives to both conferences. The organization of each, however, was independent and, except for a relatively few joint plenary sessions, the conferences were completely separate. All the meetings were held at the Heliopolis Palace Hotel, near Cairo.

Three agreements which are subject to ratification resulted from the work of the two conferences:

(1) General Radio Regulations
(2) Telegraph Regulations
(3) Telephone Regulations

The Telegraph and Telephone Regulations were signed April 4, 1938, the General Radio Regulations April 8, 1938. The effective date of all these documents is January 1, 1939 except Article 7 of the General Radio Regulations concerning allocation of frequencies, which becomes effective September 1, 1939. The United States signed the General Radio Regulations, but, as at past conferences of this kind, did not sign the other two sets of regulations.

RADIO CONFERENCE

ALLOCATION OF FREQUENCIES

The most important article of the Radio Regulations is Article 7, dealing with allocation of frequencies to services, since it provides the principal basis for many of the provisions which make up the rest

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of the regulations. In general, the allocation of frequencies to services made at Cairo follows those of Washington 1927 and Madrid 1932. The principal changes have to do with the arrangement of high frequencies assigned to mobile services to provide more adequately for aviation, additional frequency space for broadcasting, and the allocation of frequencies above 25,000 kilocycles.

AVIATION

The principal intra-European air routes have used for many years frequencies below 500 kc for communications between ground and airplanes, for direction finding and for communication between airports. Frequencies about 1500 kc, which are used principally in the United States, have only recently been used on European airlines and the service has not yet been fully organized on these frequencies. Consequently, with the growth of air transportation the frequencies for aviation below 500 kc have become very congested. Since the frequencies used are interspersed with frequencies used by marine services and long-wave broadcasting stations, there is a large amount of interference and much difficulty in providing safety communications. This has been remedied to some extent in the new convention by providing more exclusive frequencies for European aviation. To do this the band of frequencies 385-515 kc allocated to marine services was reduced to 415-515 kc in the European region. The allocation in other regions remains the same.

Two general calling frequencies were provided for aviation to be used on a voluntary basis: 333 kc for short distance operation where it is desired to use direction finders on the ground, and 6210 kc for use over the greater distances usually involved in intercontinental operation.

Practically all the major nations of the world have in operation or are contemplating long-distance intercontinental aviation routes. Communication over such routes is practical only by means of frequencies above 5000 kc. The nations of the world, during the past few years, have made assignments to aviation throughout the high-frequency bands assigned to mobile services, and consequently there has been considerable interference to the communication of those lines which are established. Also, on the routes on which test flights have been made across the North Atlantic, serious interference has been encountered. To provide communication on these intercontinental routes, frequencies were selected in each of the mobile bands above 6000 kc to be used on each of the projected intercontinental routes.

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The frequencies so provided for aviation are to be used for safety and navigation purposes and are not intended to be used to carry communication services for the public. While not specifically stated in the regulations, it is the intention that public service communications shall be carried on with airplanes flying over the seas in the same manner and by the same stations that provide this service for surface ships.

The frequencies provided are, in general, adjacent frequencies. They constitute one or more bands of frequencies in each mobile service band and are set up primarily for use on the intercontinental routes. As a secondary use Europe, Africa and South America will use these frequencies for communication on intracontinental airlines, provided no interference is caused to their use on intercontinental routes to which the frequencies are assigned. In that respect these bands constitute exclusive aviation bands within the mobile service bands. However, in order to protect the service of some existing stations, certain of these assignments were made with the provision that the priority of use by existing stations operating on these frequencies was recognized and these existing stations are thereby protected from interference.

BROADCASTING

The differences between the frequencies used for European broadcasting and for broadcasting in North America were continued. The band 160-265 kc was allocated for European broadcasting as under the Madrid Regulations. However, under the new regulations a European regional conference may allow one or several broadcasting stations in Europe in the band 150-160 kc in derogation of the general allocation to mobile services provided interference is not caused to the mobile services. The regulations also provide for the use of the frequency band 160-265 kc for broadcasting in South Africa, British India, New Zealand, and Australia, on condition that the stations which use these frequencies for broadcasting be placed in such a manner as to avoid interference with the service of countries which do not use these frequencies for broadcasting.

With respect to the frequency band 415-460, the European administrations are authorized to arrange among themselves for the operation of broadcasting stations which, by reason of their limited power and geographical position, will not interfere with the maritime mobile services. Under similar conditions European administrations are authorized to continue existing broadcasting stations in the band 515-550 kc.

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The standard broadcast band 550-1500 kc was extended to 1560 kc for broadcasting in Europe and provision was made for the use of 550-1600 kc for broadcasting in other regions, the portion of the band 1500-1600 kc being allocated on a shared basis with fixed and mobile services. The entire band is set up as an exclusive broadcasting band under the Inter-American Regional Arrangement.

The assignment of specific frequencies to broadcasting stations was not a subject for this conference. However, the conference did provide for a conference of European nations to assign specific frequencies in the broadcast bands below 1560 kc to European broadcasting stations. This conference will revise the allocation made by a similar conference of European nations held in Lucerne, Switzerland in 1933 following the Madrid conference. It is expected that the conference will convene in Switzerland in February 1939 and that a new allocation to European broadcasting stations will be agreed to and become effective September 1, 1939, the effective date of Article 7 of the convention. This conference will have many serious problems to consider, not the least of which is the resolution passed by the Cairo Conference that each nation is entitled to at least one frequency in order to carry out an effective national broadcasting service. The International Broadcasting Union is charged with the preparation of the tentative plan of allocation prior to the meeting of the conference.

One of the most difficult problems in allocation was the selection of frequencies for tropical broadcasting between 1500 and 6000 kc. This portion of the spectrum is at present allocated to other services, and full use of it is made by stations in the United States and Europe. The bands of frequencies allocated to tropical broadcasting appear in the Table of Allocation for the bands 2300-2500 kc, 3300-3500 kc, 4770-4965 kc. In each case broadcasting shares portions of these bands with other services. In the Americas only the bands 2300-2500 and 4770-4900 kc are permitted for tropical broadcasting and then only in accordance with the limitations set aside for specified American regions.

In brief, the countries of Central America, including the Canal Zone, may utilize frequencies between 2300 and 2400 kc provided interference is not caused to existing stations using this band. The nations of South America north of 5° south latitude are permitted to use the band 4770-4900 kc. The power of these stations is limited to 5 kw and their use is contingent upon not causing interference to existing stations. It is expected that allocation of these bands will provide for stations now operating outside and adjacent to the broadcast bands

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in 6000-6150 kc which cause much interference to international communications.

Above 6000 kc the following international broadcasting bands were increased as follows:

6,000- 6,150 increased to 6,000- 6,200
(50 kc from mobile service)
9,500- 9,600 increased to 9,500- 9,700
(100 kc from fixed service)
17,750-17,800 increased to 17,750-17,850
(50 kc from fixed service)
21,450-21,550 increased to 21,450-21,750
(200 kc from mobile service)

The other broadcasting bands, 11,700-11,900 and 15,100-15,350 kc, were approved for continued use without change. Provision is made for existing stations of other services to remain in the new portions of the bands, but the nations are obligated to move them to other parts of the spectrum as soon as possible. It is likewise provided that broadcasting stations operating in derogation of the general allocation table shall be moved to frequencies within the broadcast band. In addition the band 7200-7300 kc was allocated for shared use between amateur and broadcasting services in regions outside the Americas, their territories and possessions. In the Americas the band is allocated for the continued and exclusive use of the amateur service.

FREQUENCIES ABOVE 25,000 KC

The assignment of frequencies above 25,000 kc is, in general, different as between Europe and other regions of the world. Above 30,000 kc regions other than Europe maintain complete liberty to make assignments as the particular regions may desire; between 25,000 and 30,000 kc the allocation of the Havana Agreement is maintained with slight changes for the Americas. Above 30,000 kc the allocation of the Havana Agreement is reproduced in the new regulations as an appendix headed "Table Indicating an Allocation of Frequencies in Order to Serve as a Basis for Research and Experimentation on the American Continent". The purpose of this appendix is informative and is not a regulation.

In the European regions four bands are recognized for television, 40.5-58.5 Mc, 64-70.5 Mc, 85-94 Mc, 170-200 Mc. The remainder of the frequencies allocated is divided between aeronautics and stations of low power (less than 1 kw) with provision for assignment of 56-60 Mc and 112-120 Mc to amateurs should any administrations desire to utilize the band for such purpose.

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Because of the development of intercontinental air routes and the need for coordinating air navigational aids along these routes, the various administrations agree to protect from interference the following frequencies for aerial navigation on international air routes:

33,300 75,000 110,300 kc
38,000 94,300

The United States had no desire to allocate the frequencies 33,300 and 38,000 kc for this purpose, but the differences in development between Europe and the United States made a compromise necessary in order that aircraft of nations of either hemisphere might utilize the frequencies for which their respective aircraft might be equipped, regardless of their location along a given intercontinental route.

FREQUENCY TOLERANCES

Closely related to the allocation of frequencies is the tolerance required for stations operating in various services. In general, all transmitters are required to meet immediately the tolerances set up in the Tolerance Table of Madrid and by January 1, 1944 to meet the tolerances set up in the table of Cairo, which are more severe than those of Madrid. New transmitters installed after January 1, 1940 are required to meet the new tolerances at the time of installation.

With respect to frequencies above 1500 kc, in order to meet the requirements of all services for additional frequency space the tolerances for fixed and land stations are made more severe and the tolerance table is made mandatory for all nations rather than being appended to the regulations as a guide indicating good engineering practice.

With respect to ship stations which operate within the specific commercial ship bands of frequencies, the only requirement is that the ships shall maintain for a period of ten minutes the frequency on which they begin operation. This does not require that the ships operating in this band be assigned specific frequencies and in that respect recognizes the practice which has been in use in Europe for a number of years.

MARINE SERVICE

In the marine service particular attention was paid to improving the regulations having to do with general procedure within the mobile service and operations concerning calling and distress. The following paragraphs give some of the important results, but do not include many minor changes. The principal results regarding the marine services is the general clarification of all the articles relating to the service.

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The United States had proposed the elimination of traffic on 500 kc other than for calling, distress, urgent, and safety messages. This was supported by a few nations, but strongly opposed by most of the large maritime nations other than the United States. Under the new regulations in regions of heavy traffic ships may transmit only a single short message on 500 kc and coast stations are forbidden to use the frequency for traffic.

Since 1927 the United States has been endeavoring to eliminate spark transmitters. Under the provisions of the Madrid Treaty, spark transmitters with power greater than 300 watts are not permitted to operate after January 1, 1940. The exemption for these low-power spark transmitters was continued. However, their use was restricted to three frequencies, 375 kc for direction finding, 425 for traffic and 500 kc for distress calling. This restricts the interference which can be caused by this type of transmitter.

Two waves 425 and 480 kc were set up for use by Type A-2 transmitters to be used only by ships in regions of heavy traffic in Europe. No European coast stations may use these frequencies.

A coast station in a region of heavy traffic may be assigned a calling wave which is separated from the general calling wave of 500 kc by not more than 5 kc. This is common practice in various parts of the world for the purpose of eliminating interference, but has not been in strict accord with regulations.

The band in which no transmission is permitted during the silent period was decreased from the old band 460-560 kc to 480-520 kc.

The frequency 1650 kc was set up as a distress wave for low-power radiotelephone stations in the European region, in addition to its use in that region as a calling frequency.

The provision that all ship stations compulsorily equipped with radio apparatus be able to transmit and receive on two frequencies besides 500 kc was required in the band 365-485.

The provision of the Madrid Regulations concerning the frequency meter on board a ship which has caused considerable confusion was clarified so as not to require a frequency meter if the circuits of the transmitter are such as to permit the maintenance of the frequency within the accuracy of one part in 5000.

INTERNATIONAL CONSULTING COMMITTEE ON RADIO

The rules governing the operation of the International Consulting Committee on Radio (CCIR) were changed in more or less minor particulars. The scope of the CCIR was limited to technical questions and operating questions, the solution of which depend on considerations of a technical nature. This is, in effect, an extension of the scope of the CCIR, but will probably result in excluding automatically many questions now referred to the Committee.

Administrations and private operating agencies not adhering to the Radio Regulations are admitted to the meetings of the CCIR as a matter of right, but without the right of vote. The internal regulations for the CCIR meetings were changed to conform to actual practice in past meetings. The time of meetings was reduced from every five years to every three years. The actual functioning of the CCIR will not be materially different than in the past except that the International Bureau of the Union (Berne Bureau) will take over the administrative duties connected with the work of the Committee. This will probably result in more active coordination of the work between meetings and probably more constructive conclusions.

TELEGRAPH CONFERENCE

The principal problems before the Telegraph Conference were (1) unified rate for code and plain language messages, and (2) use of the international gold franc for fixing of international rates and settlement of telegraph accounts. One committee, and several subcommittees thereof, spent practically the entire time of the conference discussing these two questions, and considering proposals which had been made and studied for several years, and many new proposals which were made during the course of the conference. While the majority of the representatives were in favor of unification of code and plain language rates, no formula for such unification could be agreed to for the extra-European regime and the present differential was retained. For the European region, however, unification was adopted on a basis of 92 per cent of the present plain language rate. The existing ratios between the various classifications of messages were retained.

International telegraph rates and settlement of telegraph accounts contemplate the use of the international gold franc set up by the Convention as a monetary base. With the changes that have taken place in monetary systems throughout the world, this basis had been departed from by several administrations and considerable differences had developed resulting in more or less general confusion. It was expected that this conference would clear the confusion, but it was unable to reach any conclusion on the subject. Consequently the old regulations stand, with reservations by many nations and notice by some that they intend to make private arrangements with other operating agencies.

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The Telegraph Regulations with respect to the operation of international telegraph communications have been amended in many respects, some of which are major changes and other, minor changes in wording, etc. The major changes are included in the following:

1. Changes in rules regarding counting of words.
2. Obligatory transit handling of reduced rate classifications.
3. Tightening of restrictions against reforwarding agencies.
4. Admitting broadcasting news to the press classification.

A large number of minor changes were made in the Regulations which will result in better and more efficient handling of the international telegraph circuits.

LANGUAGE OF THE CONFERENCES

An outstanding accomplishment of the conferences was the advance made in the use of the English language. As provided in the Convention, French was the official language of the conferences and English translations by official interpreters were made of all speeches made in French. This is very satisfactory for the actual work on the floor of the conferences, but documents were issued in French only. For several years the Government of the United States has assumed the burden of translating all documents. The present conferences agreed that in the future all translations into English would be made by the Bureau of the Union, the expense being shared by the administrations and companies requesting copies. This will make the translations of all documents, including the books of proposals, generally available to all and at approximately the same time as the French documents. This should assist materially in facilitating the preparations for future conferences.

The next International Telegraph and Radio Conferences are to be held in Rome, Italy, in the fall of 1942.

ADDENDUM

The Hansell and Usselman paper entitled "A 200-Kilowatt Radiotelegraph Transmitter," in the April issue of RCA REVIEW, was prepared for and delivered before the Communications Group of the New York Section of the American Institute of Electrical Engineers in New York on November 9, 1937.

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AN INTERNATIONAL BROADCASTING SYSTEM

By

RAYMOND F. GUY

Radio Facilities Engineer, National Broadcasting Company, Inc.

IN 1925 there was installed at Bound Brook, N. J., what was, at that time, a "superpower" 40,000-watt transmitter, for WJZ. It was the natural sequel to the conviction of RCA, that the budding broadcasting industry offered great opportunities for a service to the American public which could be duplicated by no other medium. It was a notable step further to envision also an international service utilizing the new "short waves" which were beginning to show promise of reliable communication over very long distances. Accordingly, the Bound Brook plant was provided with two powerful transmitters, one dedicated to domestic programs and the other to international service.

By the standards of today, the 1925 stations were crude in many respects but the short-wave broadcasting stations of that period blazed trails which have been followed all over the civilized world.

International broadcasting is conducted under far different circumstances today. Its value in promoting good will and a better understanding beyond national borders has prompted all of the leading nations of the world to provide comprehensive foreign language service over elaborate and costly facilities. The American method is to promote international friendship, not by a barrage of propaganda, but by providing the instrument by which peoples become better acquainted. Knowing your neighbor may well lead to establishing bonds of peace, trade, and international prosperity.

For many years the National Broadcasting Company, the General Electric Company, and the Westinghouse Electric and Manufacturing Company short-wave stations operated independently of each other with the exception of the exchange of special program features from time to time and the transmission of suitable NBC Red or Blue network programs.

In May, 1938, the three companies, prompted by the desire to take a part in properly representing the United States in international broadcasting, developed a generally cooperative operation of their facilities. The stations included in this American service are:

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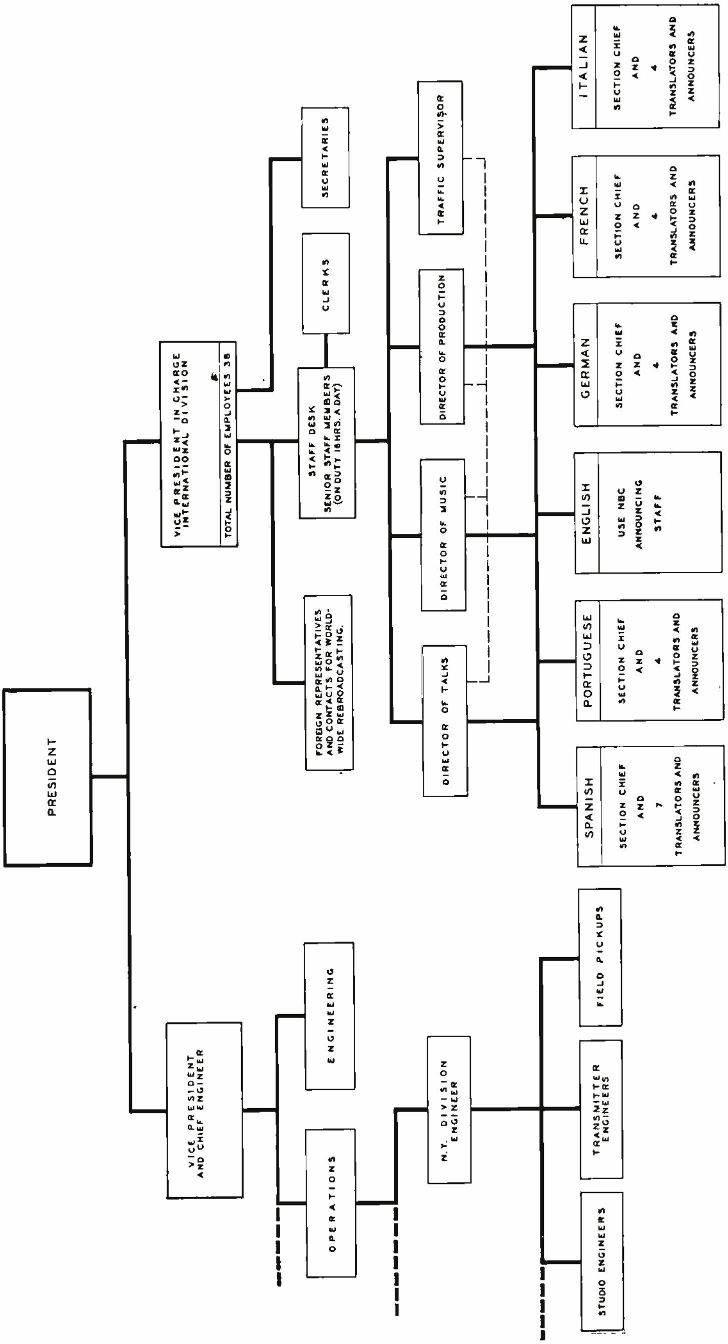

Fig. 1—Organization chart of the departments which are directly engaged in international broadcasting in NBC.

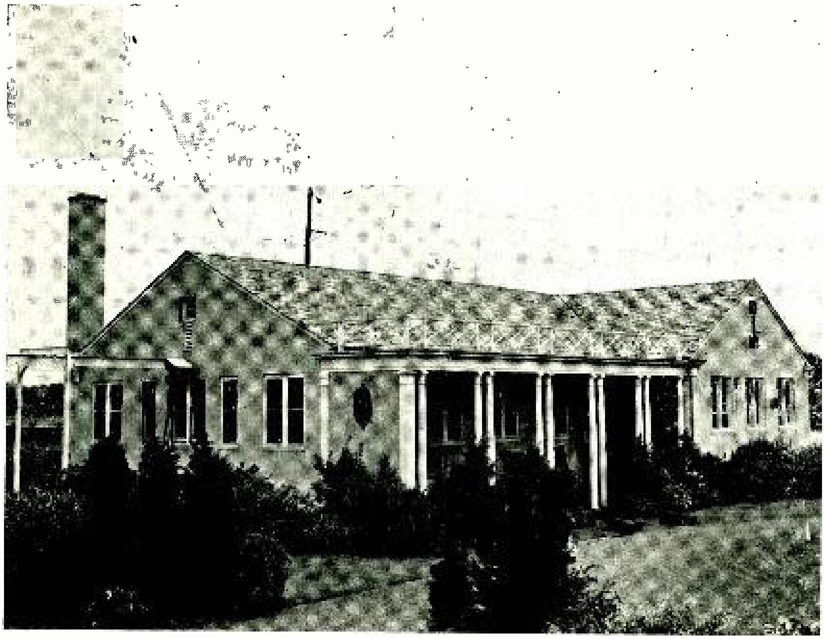

Fig. 2—Bound Brook, N. J., transmitter building which houses NBC Stations W3XAL, WJZ, WMFL, and W2XDG. The "International Wing" is at the far end.

	Licensee	*Location*	*Frequency*	*Power*
W3XAL	Nat. Broadcasting Co.	Bound Brook, N. J.	6100 kc	25 kw
	Nat. Broadcasting Co.	Bound Brook, N. J.	17780 kc	25 kw
W9XF	Nat. Broadcasting Co.	Chicago, Ill.	6100 kc	12 kw
W1XK	Westinghouse E. M. Co.	Millis, Mass.	9570 kc	6 kw
W8XK	Westinghouse E. M. Co.	Pittsburgh, Pa.	6140 kc	25 kw
			21540 kc	5 kw
	Westinghouse E. M. Co.	Pittsburgh, Pa.	11870 kc	20 kw
			15210 kc	25 kw
W2XAD W2XAF	General Electric Co.	Schenectady, N. Y.	9530 kc	30 kw
			15330 kc	20 kw
	*General Electric Co.	Belmont, Cal.	9530 kc	20 kw
			15330 kc	20 kw

{Denotes common transmitter.

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* Under construction.

These facilities are now linked to Radio City in New York by 700 miles of special telephone circuits carrying international programs exclusively, and these lines are at times supplemented by Red and Blue network program circuits.

The cooperative operation of the international broadcasting facilities listed above makes possible a better service for several reasons:

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1. The program building facilities of the NBC, which it is believed are the most complete and comprehensive in the world, have taken over the task of building a large portion of the programs.

2. The combined technical facilities have enabled a wider and more effective distribution of these programs than could be obtained by the present facilities of any individual company. It has now become possible to transmit simultaneous services to Europe, South America, Central America, South Africa, Australia, New Zealand, and the Orient.

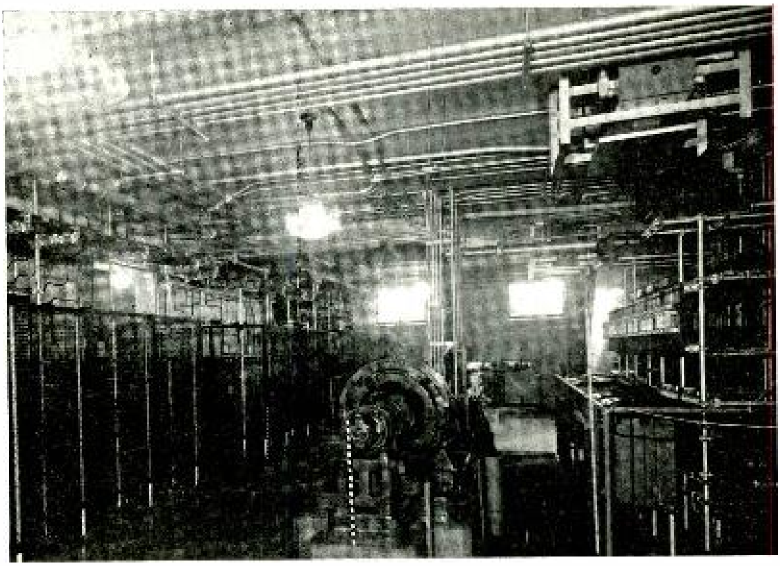

Fig. 3—Section of basement housing W3XAL apparatus.

3. Cooperative program construction results in more comprehensive program distribution without wasteful duplication of service.

EXAMPLES OF SERVICE PROVIDED

As an example of the service provided, when President Ortiz of Argentina spoke in Spanish in Buenos Aires in April, short-wave radio brought his message to the United States, together with a translation into English, which NBC carried over both Red and Blue Networks to the people of the United States and Canada. A Portuguese translation was immediately made and the message was transmitted in all three languages to the countries of Latin America. A recording of the speech and its English translation was then made and transmitted the same night by short wave to Australia, New Zealand, and Asia. The following morning another transcription of the speech was transmitted to Europe with translations in French, Italian, and German. Thus, by short wave radio this important address was made available in six languages and, at a convenient time in each case, to all parts of the world.

Only a few days later, Senor Aranha, former Brazilian Ambassador to the United States, made his first international address as Minister of Foreign Affairs of Brazil, in a speech transmitted to the United States. The speech, delivered in English, was translated into Spanish and Portuguese and transmitted in both languages to Latin America. It was then transmitted in English to Asia, Australia, and New Zealand. Again, the following morning, the speech was transmitted in the languages of Europe to listeners across the sea.

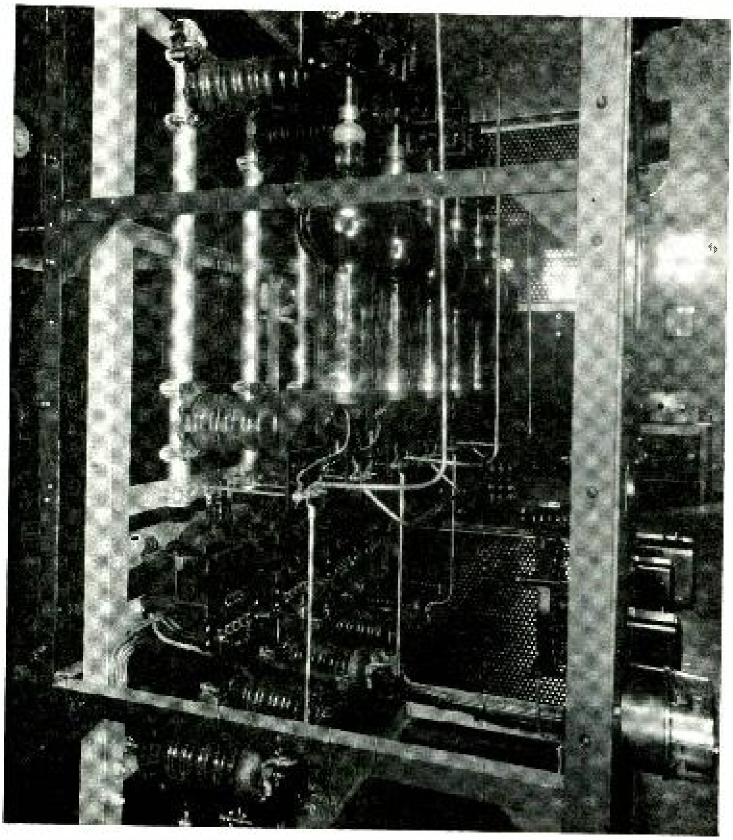

Fig. 4—One of the duplicate W3XAL 10-ampere, 12,000-volt rectifiers.

A few weeks later an important speech by our own Secretary of State Hull was carried to the same audiences.

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President Roosevelt's 1938 Pan-American address was transmitted to an NBC world-wide audience which was probably equalled in size only by the group of listeners to the abdication speech of King Edward a year and a half ago. The President's address was carried throughout the United States over the combined NBC Red and Blue Networks of over 130 American stations. It was also broadcast to foreign listeners in Latin America, South America, and Europe through stations W3XAL, W8XK, W2XAD, and W1XK. It was relayed to foreign stations in Buenos Aires, Rio de Janeiro, Havana, Bogota, Caracas, Montevideo, the Orient, Hawaii, Australia, England, Germany, France, South Africa, and Mexico City via the facilities of R.C.A. Communications and the American Telephone and Telegraph Company. The address in English was followed by Spanish, Portuguese, and Italian translations.

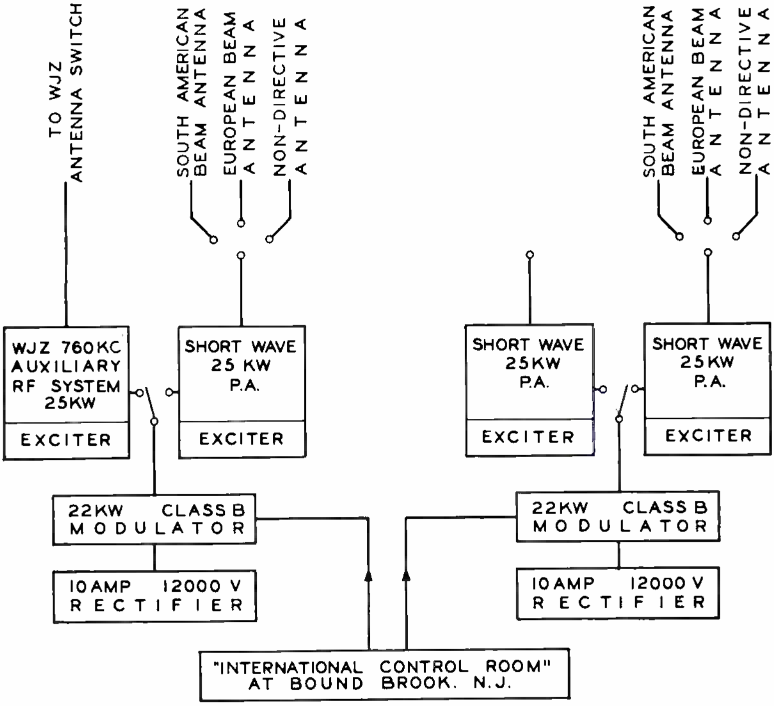

Fig. 5—Diagram illustrating the flexibility of the two 25-kw international transmitters.

FOREIGN PROGRAMS RELAYED TO AMERICA

Foreign programs play an increasingly important part in providing programs for American consumption. The comprehensive scope of

NBC endeavor in this field is indicated in the following table which tabulates only those programs brought to its networks by point-to-point international relaying through R.C.A. Communications or American Telephone and Telegraph Company facilities.

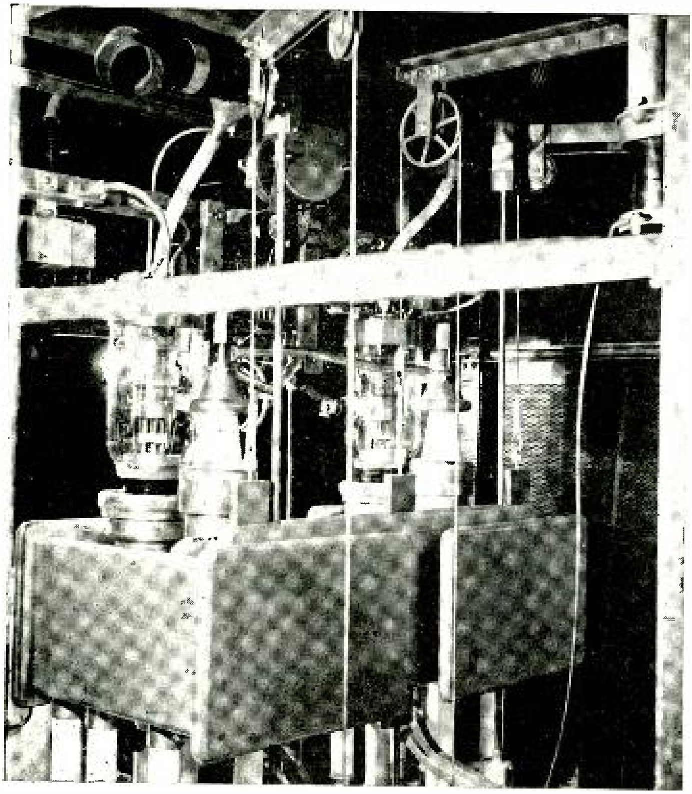

Fig. 6—One of the duplicate W3XAL 25-kw amplifier assemblies.

Year	*No. of Programs*	*No. Program Hours*	*Countries of Origin*
1930	95	48	
1931	142	73	
1932	149	51	
1933	143	52	
1934	278	113	36
1935	319	97	47
1936	514	146	53
1937	516	169	44

These programs bring to Americans, direct from the scene, the rise and fall of empires, events from distant battlefields, the voices of monarchs and dictators. They bring the celebration of Christmas

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from the Holyland and from the lands of the Eskimo, events from the world of sports, religion, and the arts and sciences.

The interconnected facilities required, to bring such a comprehensive service to American listeners, are indeed extensive. Point-to-point relay service is required for each program. For the simplest events, the foreign facilities consist of program pickup equipment, wireline connections through repeater stations, and powerful transmitters with highly directive antenna systems. The domestic facilities consist of complex diversity receiving systems, wireline connections to the broadcast control point, and thousands of miles of program line connections to networks of broadcasting stations. To bring a program from London to the living room of a listener in San Francisco requires an accumulative power magnification, with minor distortion and frequency discrimination, of 400 million billion billion billion billion billion times! This amazing amplification has now become a commonplace procedure! If a grain of sand were increased in weight that many times it would weigh 20 thousand billion billion times as much as the earth.

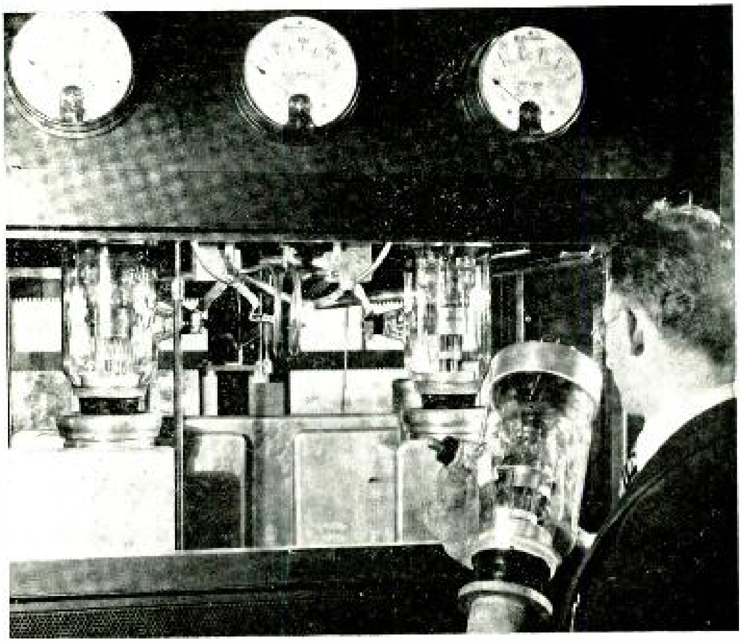

Fig. 7—25-kw amplifier assembly.

International program relaying service is provided through the facilities of R.C.A. Communications and the American Telephone and Telegraph Company. Upon request a program relay channel can be

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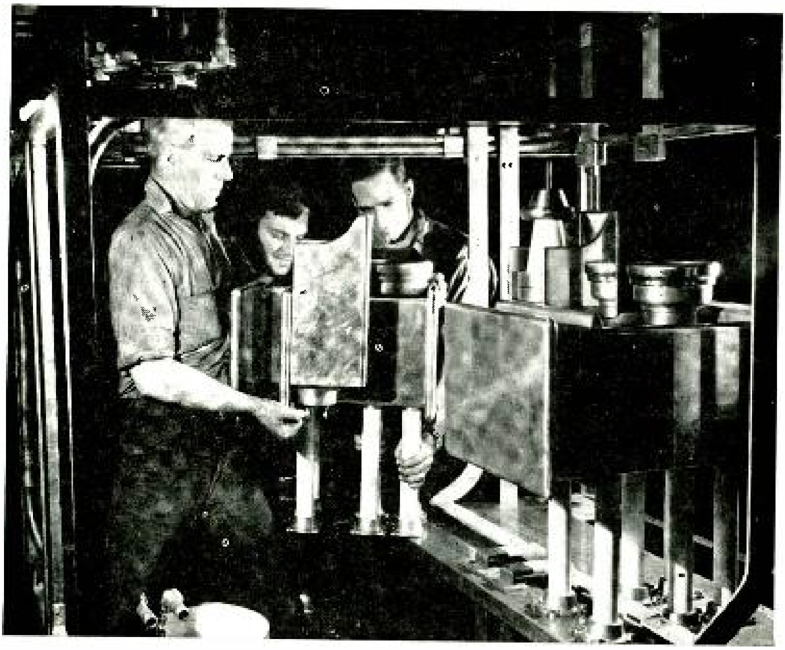

Fig. 8—One of W3XAL 25-kw high-frequency power amplifiers being assembled.

made available between the United States and any of the following countries:

Alaska
Albania
Argentina
Australia
Austria
Belgium
Brazil
British Guiana
Chile
China
Colombia
Cuba
Czechoslavakia
Denmark
England
France
Germany
Greenland
Guatemala
Hawaii
Hongkong
Hungary
Iceland
Ireland
Italy
Japan
Java
Lithuania
Mexico
Netherlands
Newfoundland
Norway
Palestine
Peru
Philippines
Poland
Russia
Scotland
Spain
Sweden
Switzerland
South Africa
Tripoli
Uruguay
Vatican City
Venezuela

The NBC has made use of this two-way relay service in transmitting to or receiving from every one of the countries referred to. Programs may be, and have been, relayed to nearly every country in Europe, Asia, and South America, by linking local stations and relay terminal points by long wireline connections.

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Fifteen years ago a New York theatre manager announced from the stage, with more enthusiasm than accuracy, that the next performance was to be broadcast to the world by radio. That over-optimistic announcement was prophetic. World-wide broadcasting is now a frequent occurrence and an excellent outcome of the American system of broadcasting. Astonishingly enough, even the matter-of-fact engineer, living by, and working with radio day by day, is no less awed by what he has wrought than the layman.

It is interesting to compare 1938 international broadcasting with the first American network rebroadcast of a foreign program. It took place in 1925 and was accomplished by stations WJZ and WRC with the assistance of the point to point facilities of RCA. Station 5XX, London, England, transmitting on 1600 meters, was received at Belfast, Maine, and relayed on 60 meters (approx. 5,000 kc.) to the writer at the RCA Research Laboratory near Van Cortlandt Park, New York City. From there it was transmitted to WJZ and WRC by wirelines. The transmissions were accompanied by so much static and interference that during an entire 20-minute broadcast there was less than one minute of intelligible music and speech—just enough to convince skeptics that for the first time the miracle of radio had brought them music from across the seas!

PROGRAMMING AN INTERNATIONAL SERVICE

The proper and thorough programming of international facilities involves certain complications encountered in only a minor degree in providing service within the borders of the United States. Europe, so to speak, goes to bed at approximately 6 P.M. New York time. Listeners in Russia turn off their radios even earlier. In addition to time differences, and of even greater importance, are language differences. A useful service to Latin America, South America, and Europe requires daily transmissions in six different languages, namely Spanish, Portuguese, English, German, French, and Italian. Transmissions in each of these languages require separate staffs of translators and announcers, each supervised by a section chief. In addition there is required a director of talks, a director of music, a director of production, and a traffic supervisor.

Matters concerning all of these groups are coordinated and supervised by a staff desk, consisting of senior staff members on relay duty sixteen hours per day. Supplementing the activities of the New York headquarters staff are foreign representatives and contacts through whom arrangements are made for transmission and reception of events of international interest.

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Early in 1938, coincidental with the inauguration of the cooperative operation of the international broadcasting facilities, a new NBC department was organized, known as the International Division. Transferred to this group were those specialists who had formerly functioned in international activities as members of various domestic departments. The international division consists of 38 persons directed by a vice-president in charge.

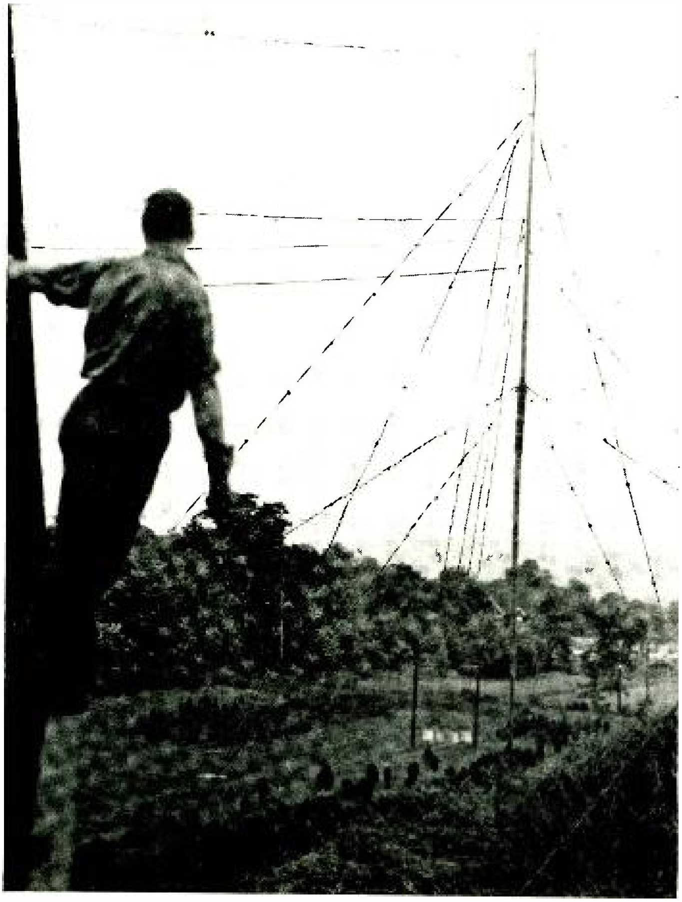

Fig. 9—Section of W3XAL European beam antenna photographed from 50-foot level of 250-foot short-wave antenna tower.

The engineering and operating functions, the construction and operation of facilities used by NBC in international broadcasting, are directed by the vice-president and chief engineer.

Figure 1 shows the organization chart of the departments which are directly engaged in international broadcasting in NBC.

The complexity and scope of the service provided is illustrated by the following schedule which covers the programs during one representative day transmitted through station W3XAL at Bound Brook, N. J.

TUESDAY, MAY 24th — STATION W3XAL

Service on European Beam 17,780 kc, 16.8 meters. 9:00 A.M. to 5:00 P.M.

9:00- 9:55	Breakfast Club. Announced in English.
9:55-10:00	Press Radio News. Announced in English.
10:00-10:45	Musical Interlude. Announced in English.
10:45-11:00	Women in the News. Announced in English.
11:00-11:15	News. Announced in Italian.
11:15-11:30	Viennese Ensemble. Announced in English and Italian.
11:30-11:45	Woman's Page. Announced in Italian.
11:45-12:00	Melody Matinee. Announced in Italian.
12:00-12:15	News. Announced in English.
12:15-12:30	Bailey Axton, tenor. Announced in English.
12:30- 1:00	Carnation Program. Announced in English.
1:00- 1:15	News. Announced in German.
1:15- 1:30	Escorts and Betty, popular songs. Announced in English and German.
1:30- 2:00	Jerry Sears Orchestra, popular music. Announced in German.
2:00- 2:15	News. Announced in French.
2:15- 2:30	Book of Songs. Announced in English and French.
2:30- 2:45	Woman's Page. Announced in French.
2:45- 3:00	Armchair Quartet. Announced in English and French.
3:00- 3:15	News. Announced in German.
3:15- 3:30	Dance Music. Announced in German.
3:30- 3:45	Arts in America. Announced in German.
3:45- 4:00	U. S. Army Band. Announced in English and German.
4:00- 4:15	News. Announced in French.
4:15- 4:45	Dansante. Announced in French.
4:45- 5:00	Organ Concert. Announced in French.

Service on Latin American Beam 17,780 kc, 16.8 meters.
5:20 P.M. to 9:00 P.M.

5:20- 5:30	News. Announced in English.
5:30- 5:45	Concert. Announced in Spanish.
5:45- 6:00	News. Announced in Spanish.
6:00- 6:15	Jimmy Richards Orchestra. Announced in English and Spanish.
6:15- 6:25	Top Hatters Orchestra. Announced in English and Spanish.
6:25- 6:30	Press Radio News. Announced in English.
6:30- 6:45	Base Ball Scores. Announced in English.
6:45- 7:00	Ray Kinney and His Royal Hawaiian Orchestra. Announced in English and Spanish.
7:00- 7:15	News. Announced in Spanish.
7:15- 7:30	Carol Deis, soprano and John Guerney, baritone. Announced in English and Spanish.
7:30- 7:45	Musical Revue. Announced in Spanish.
7:45- 8:00	Smooth and Sweet. Announced in English and Spanish.
8:00- 8:15	News. Announced in Portugese.
8:15- 8:30	Dance Orchestra. Announced in English and Portugese.
8:30- 8:45	Woman's Page. Priscilla Watson. Announced in Portugese.
8:45- 9:00	Concert Orchestra. Announced in Portugese.

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Service on Latin American Beam 6100 kc, 49.1 meters.
9:25 P.M. to 1:00 A.M.

9:25- 9:30	Program Résumé. Announced in Spanish.
9:30-10:00	Rosario Broudon Concert. Announced in Spanish.
10:00-10:30	Man About Town, popular program. Announced in Spanish.
10:30-10:45	News. Announced in Spanish.
10:45-11:30	The Composer's Library. Announced in Spanish.
11:30- 1:00	Dance Music. Announced in English and Spanish.

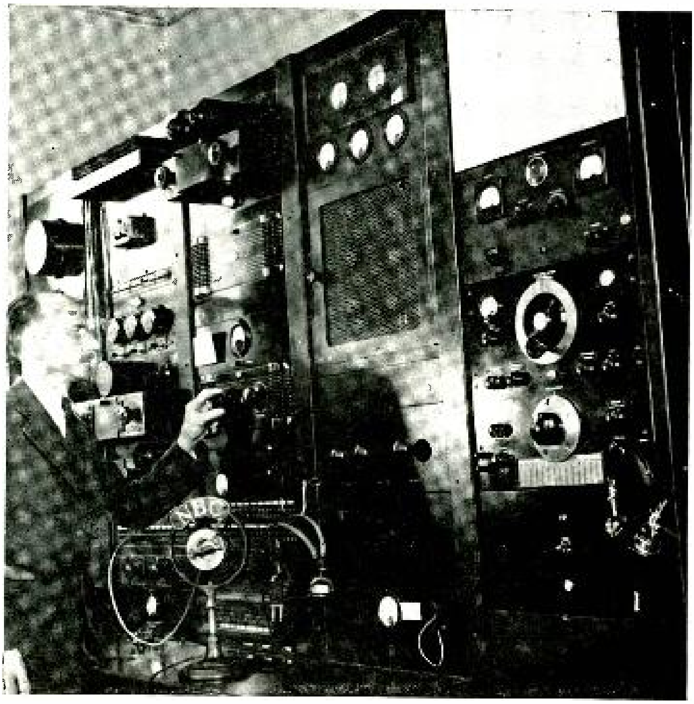

Fig. 10—W3XAL "International" control room.

A day's facilities schedule for W3XAL, W2XAD, and W8XK is shown below.

W3XAL:

8:55 A.M.- 5:05 P.M.	EDST.	European Beam, 17,780 kc, 16.8 meters.
5:15 P.M.- 9:05 P.M.	EDST.	Latin American Beam, 17,780 kc, 16.8 m.
9:20 P.M.- 1:00 A.M.	EDST.	Latin American Beam, 6100 kc, 49.1 m.

W2XAD:

8:00 A.M.-12:00 NOON	EDST.	Latin American Beam, 21,500 kc.
12:30 P.M.- 6:00 P.M.	EDST.	European Beam, 15,330 kc.
6:00 P.M.- 7:00 P.M.	EDST.	Latin American Beam, 15,330 kc.
7:15 P.M.-11:00 P.M.	EDST.	Latin American Beam, 9550 kc.

W8XK:

7:00 A.M.- 9:00 A.M. EDST.	European Beam, 21,540 kc.
9:00 A.M.- 7:00 P.M. EDST.	European and Latin American Beams, 15,210 kc.
7:00 P.M.-11:00 P.M. EDST.	Latin American Beam, 11,870 kc.
11:00 P.M.- 1:00 A.M. EDST.	Non-Directional, 6,140 kc.

A summary of transmissions during one representative week is shown below:

Station: W3XAL *Date:* SUMMARY—WEEK OF MAY 8, 1938

			Hrs. Min.
Total number of programs broadcast on 17780 kc.	273	Total number of hours. . . .	81–45
Total number of programs broadcast on 6100 kc.	55	Total number of hours. . . .	25–00
Total number of programs broadcast	328	Total number of hours. . . .	106–45

	Number of Programs	*Hrs. Min.*
(1) Total RED network programs.	54	16–40
(2) Total BLUE network programs	101	38–15
(3) Total Commercial Programs from Networks.	14	5–45
(4) Total Special Programs carried by Int'l. Div. only	157	46–05
(a) Talks		
Total News	62	14–50
Total Other Talks	34	7–30
(b) Total Music	59	22–43
(c) Total Special Events	2	1–02

Breakdown of Programs Carried by International Division Only

(1) *Talks:*

(a) News:

English	18	3–50
Spanish	14	3–30
Portuguese	5	1–15
German	10	2–30
French	10	2–30
Italian	5	1–15
Total News	62	14–50

(b) Other Talks:

English	. . .	. . . . .
Spanish	11	1–45
Portuguese	4	1–00
German	8	2–00
French	6	1–30
Italian	5	1–15
Total Other Talks	34	7–30

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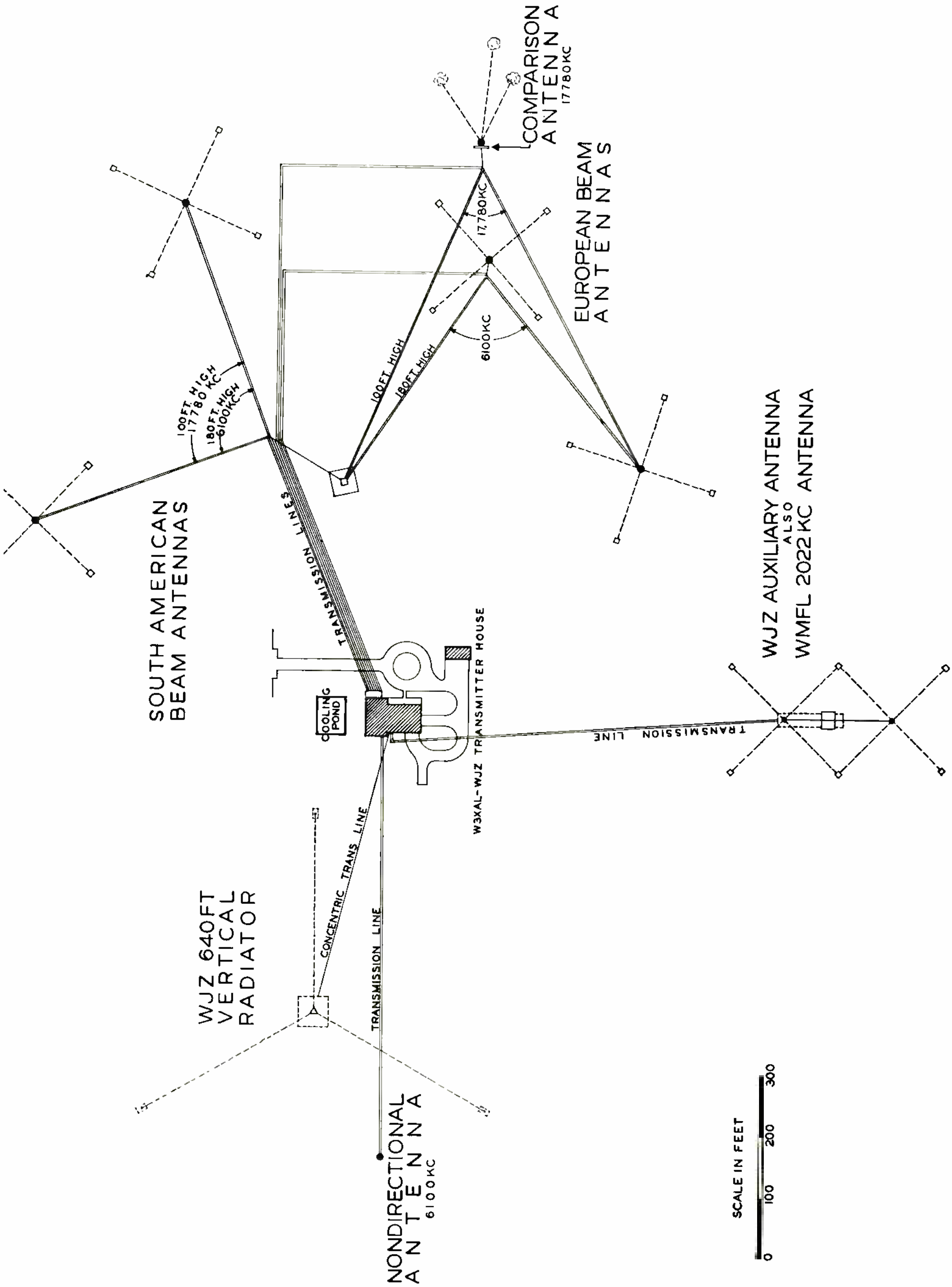

Fig. 11—Bound Brook plant plan.

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(2) *Music:*

	Programs	*Hrs. Min.*
(a) Live Talent	12	4–00
(b) Records	22	10–28
(c) Thesaurus	24	7–45
(d) Acetate Recordings	1	–30
Total Live Talent	12	4–00
Total Recordings	47	18–43
Total Music	59	22–43

(3) *Special Events:*

(a) Studio	...	.....
(b) Outside Pick-Ups	1	1–00
(c) Acetate Recordings	1	–02
Total Special Events	2	1–02
NOTE: Above totals do not include time for Station Sign-On and Sign-Off which amounts to	44	3–40
Total time on the air including Sign-Ons and Sign-Offs		110–25

New Facilities at W3XAL

Simultaneously with the inauguration of cooperative operation of the previously tabulated short-wave stations, NBC placed in service at W3XAL the first of two new and thoroughly modern 25,000 watt duplicate transmitters which had been under construction for eight months. These new facilities are located in the "International Wing" of the Bound Brook, N. J., Transmitter Building.

Figure 2 shows the transmitter building which contains the WJZ 50-kw Blue Network domestic broadcast transmitter, its 25-kw auxiliary transmitter, two 25-kw international transmitters, and also two lower-power domestic transmitters.

Figures 3 and 4 show views of the transmitting equipment in the "International Wing" of this building.

Figure 5 shows, by block diagram, the flexibility of the two 25-kw international transmitters.

Figures 6 and 7 show the simple and highly efficient 25-kw power amplifier construction. The white cones adjacent to the tubes are compressed-air neutralizing condensers.

Figure 8 shows one of the 25-kw amplifiers being assembled.

Figure 9 shows a section of W3XAL, European beam antenna, photographed from 50-foot level of 250-foot short-wave antenna tower.

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FIGURE OF MERIT FOR TELEVISION PERFORMANCE

By A. V. BEDFORD

RCA Manufacturing Company, Inc., Victor Division, Camden, N. J.

THE ambitious title of this paper might imply that a single number could evaluate a television system in every respect. This is not to be expected. However, of all the properties of a television picture, i.e., resolution, geometric accuracy, brightness, size, steadiness, etc., resolution is probably the most indicative of quality. Hence a method will be described for measuring resolution, not only for a certain area, but for the picture as a whole.

The best known resolution test chart is probably that used by optometrists in testing eyes and fitting spectacles. It consists of several horizontal rows of random letters of the alphabet, each row being of smaller type than that immediately above. Arbitrary numerical rating can be given to the picture transmitting system, which in this case is the patient's eyes and spectacles, by observing the height of the smallest row of letters which may be read accurately at a specified distance.

Such charts have been used to test television systems, but have been discarded due to the following reasons:

(1) Some letters of a given height are easier to discern than others, causing inconsistent readings.

(2) The reading gives no indication of relative horizontal and vertical resolution of the picture since legibility depends upon both vertical and horizontal resolution.

(3) Sequence of letters are indeliberately memorized resulting in erroneous readings.

(4) No accurate evidence is available to indicate the primary limiting factor, i.e., whether it is defocusing, imperfect interlacing, inadequate frequency response, or inadequate number of scanning lines.

At a very early date it was found that a pattern consisting of uniformly-spaced parallel black and white vertical bars could be used at variable distance from the pick-up device to determine limitation of horizontal resolution due to frequency response. When such a pattern is transmitted by a system using horizontal scanning, each pair of black and white bars causes the generation of a single cycle. Hence, by counting or calculating the number of bars required to equal a certain dimension in the transmitted picture at the greatest distance from the camera

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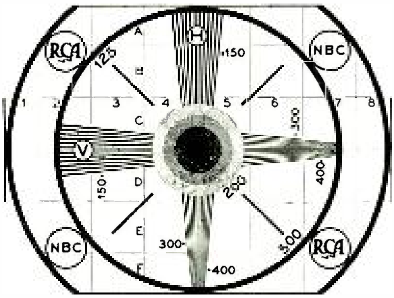
at which the bars can be distinguished, the frequency limit of amplifiers, etc., may be readily calculated.

If the same pattern is then rotated so that the bars are horizontal and the distance for resolving is adjusted again, the number of bars required to fill a similar distance in the transmitted picture indicates in similar units the vertical resolution of the picture.

The use of this chart obviously required considerable manipulation and checking in order to obtain accurate readings.

THE TAPERED WEDGE CHART

A change in the pattern design to one which employed converging bars forming a wedge made these tests much easier. Figure 1 shows a recent form of this pattern, which was designed by the National Broadcasting Company. It differs from a much earlier design by engineers of the RCA Manufacturing Company mostly in that three concentric circular areas of half tone shadings between black and white are provided in the center. It was made for a picture having a 4/3 aspect ratio in conformance with presently proposed United States television standards. In order to facilitate the adjustment of the pattern at the proper distance from the camera to fill completely the picture screen, two large circles are provided, one having a diameter equal to the height of the screen and the other having a diameter four-thirds as great or equal to the width of the picture screen. Two sets of test bars at right angles are provided. The vertical set is used for measuring horizontal resolution and the horizontal set is for vertical resolution. The vertical set consists of 23 alternate similar black and white bars which are spaced relatively far apart at the top and gradually less distance apart at the bottom, thus making a wedge shaped figure. Along the side of the figure are calibration numerals 150, 200, 300 and 400 which are intended to be legible when seen through any television system it is desired to test. The calibration numerals are read in units which may



ENGINEERING DEPARTMENT - NATIONAL BROADCASTING COMPANY INC

Fig. 1

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well be called "resolution bars" and indicate the number of bars (both black and white) having the width indicated which would be required to fill a distance equal to the *height* of the entire picture screen.

Similarly, the horizontal set of bars forms a wedge which extends across the screen with the bars converging to a point at the right hand side. The wedges are broken at the center of the pattern, to accommodate four concentric circles of different half-tone values, but no portion of the wedges is lost. The calibration of both wedges is identical so that equal readings on the two wedges indicate equal picture resolution per unit distance along the screen surface without regard to the aspect ratio. This chart has been used extensively in the RCA Television Field Tests due to its great ease of reading; but for rigorous measuring, the more complicated pattern described below is used.

SECTIONALIZED RESOLUTION CHART

The test chart which is now considered most useful for over-all resolution check is shown in Figure 2. It consists of 12 substantially identical major squares arranged in three horizontal rows to form a rectangle having a 4/3 aspect ratio. The squares have been assigned identifying numbers, 1 to 12, proceeding from the upper left hand corner, left to right. Each major square consists of four minor squares of equal size, but different patterns. Each major square contains a complete vertical wedge of thirteen tapered bars (black and white) which start in the upper right hand minor square with a resolution calibration of 100 "resolution bars," graduates to 150 at the middle and 200 at the bottom of that minor square. The wedge continues in the lower left hand minor square with 200 at the top, 250 in the middle and 300 at the bottom. The bars of the wedge are slightly curved so that a linear relation between distance along the wedge and resolution is obtained, facilitating intermediate readings. The horizontal wedge is similar, beginning with 100 at the left-hand side of the upper left minor square and finishing with 300 in the lower right-hand square. Numerals 1, 2, and 3, standing for 100, 200, and 300 are located on sample major square No. 6 to indicate the calibration in "resolution bars". On both vertical and horizontal bars the calibration indicates the number of bars of the indicated width that would be required to fill the screen vertically.

The area surrounding the "wedge" in the two lower minor squares of each major square is divided into four smaller areas which have been cross-hatched to produce the effect of different half tones from black to white. The value of these shades are marked in the sample major square No. 3, as fractions which indicate the shading as a portion of complete black.

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Use of the Sectionalized Chart

The sectionalized resolution chart as shown in Figure 2 can be used to determine facts covering the quality of a television system in the following respects:

(a) Vertical Resolution in any or all of the 12 portions of the screen.
(b) Horizontal Resolution in any or all of the 12 portions of the screen.
(c) Upper-frequency cut-off.
(d) Character of high-frequency "hang over."
(e) Focus of pick-up lens, and size and sharpness of Iconoscope and Kinescope scanning spots.

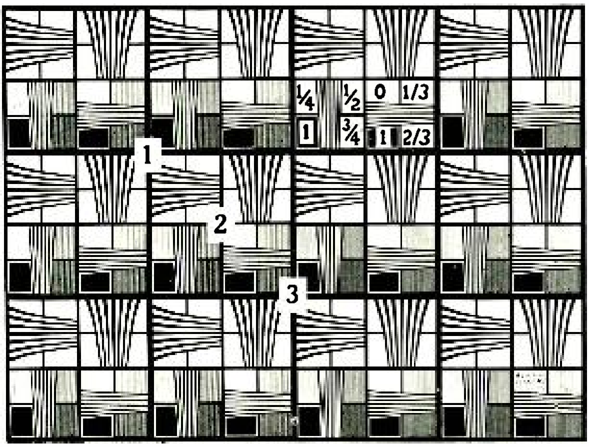

Fig. 2

(f) Over-all Resolution Figure of Merit.
(g) Half-tone transmission and saturation.
(h) Shading.
(i) Interlacing.
(j) Aspect ratio of transmitted picture.
(k) Deformation due to poor trapezium correction or other defects.
(l) Vertical-deflection linearity.
(m) Horizontal-deflection linearity.

In making any resolution test the apparatus should be adjusted so that black, white, and at least two intermediate shades between can be distinguished in the test chart, and preferably in the particular major square being read. The object of this requirement is to be sure that a false illusion of good frequency response is not being obtained

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by excessive amplification at certain frequencies being suppressed by saturation in the system.

The ultimate vertical resolution (a) may be read in any one of the twelve major squares by observing the point along the horizontal wedge at which the bars become substantially indistinguishable. However, a technique of reading to obtain a value which is more representative of the effective resolution is given below. In general, vertical resolution is independent of frequency characteristic, but is limited by optical focus, interlacing (i) and size of Iconoscope and Kinescope scanning spots (e). If these factors are not limiting, the ultimate limit is reached due to the scanning lines being random in location with respect to the converging resolution bars in the wedge, producing beating effects.

Horizontal resolution (b) in any one of the twelve squares may be read in the vertical-resolution wedge. This reading is definitely limited by the high-frequency response (c) of the transmission system since scanning across the vertical wedge produces a high frequency. Since only the fundamental frequency generated is required for adequate identification of the bars, a cycle is generated by each two bars (black and white). The generated frequency is:

$$f = \frac{HanR}{2} \; \frac{1}{(1-B)}$$

where H is the reading on the resolution wedge, a is total number of scanning lines, n is frame-repetition frequency, R is aspect ratio and B is the percent of the time (expressed as a fraction) at the end of each horizontal line to accommodate return of the scanning spot to the start of the next line. (The equation assumes uniform speed of scanning along the line.)

In certain improperly adjusted systems a high-frequency "hang over" (d) will be produced in the received picture immediately following in time, i.e., to the right hand side of a certain section of the resolution wedge. Such a "hang over" (d) which may be visible for one to six or more cycles is generally due to a sharp peak in the frequency response at the frequency corresponding to that portion of the wedge.

When vertical and horizontal resolution measurements are made, certain tricks may be employed to separate the several factors which limit the resolutions reading. For example one way to test for size of scanning spot in the Iconoscope (e) and optical focus on the Iconoscope plate is temporarily to reduce the amplitude of scanning in the Iconoscope so that only a small section of the Iconoscope plate and test

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pattern is scanned. This results in an enlarged view of a portion of the test pattern being reproduced on the receiving screen and generally permits the observer properly to discount response and excessive size of Kinescope scanning spot.

The Over-all Resolution Figure of Merit (f) is intended to be a numerical value which indicates on a relative basis, the total ability of the picture to convey information. It may be given as the total number of black and white dots which could be put in a scene to be transmitted with random location relative to the position of the scanning lines, and which could all be separately identified and located in the received picture. If this should be measured directly it would require transmitting a pattern consisting only of black and white dots. The dots might be arranged alternately in staggered rows somewhat like a checker board. However due to all areas of the picture not having identical resolution the dots should have different size and spacing in different areas in order to be just distinguishable in all areas.

The sectionalized resolution chart as shown in Figure 2 can be used to measure the Over-all Resolution Figure of Merit (f) with reasonable accuracy. It is assumed that the vertical and horizontal resolution readings obtained in each major square may be considered to be substantially the effective average values throughout the square. Then the product of the vertical and horizontal readings divided by 3 x 3 or 9 would represent the number of resolvable dots for that particular square since the resolution chart is calibrated in *each* direction in terms of the number of bars required to fill a distance equal to three times the height of one square. Then the Over-all Resolution Figure of Merit is:

$$m = \sum \frac{HV}{9} \quad \text{for 12 squares}$$

where H and V are the horizontal- and vertical-resolution readings respectively. For example, if the vertical and horizontal-resolution readings are 200 for each of the twelve squares, the Figure of Merit is 53,500, and for uniform readings of 300 it is 120,000. A figure of merit obtained in this manner may serve as a specification of performance or it may serve as a means of measuring progress in development of an experimental or commercial television system.

Since each major square of the chart has two different sets of calibrated shaded areas between black and white, the chart is helpful in judging the fidelity of half-tone (g) transmission. Also the calibrated half-tone areas may be useful as a comparative standard for

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evaluating the spurious output signal of the Iconoscope, which is known as "shading" or "dark spot" (h). However, no scheduled procedure for these tests has been established.

The test chart has a well defined 4/3 aspect ratio which is useful in checking picture aspect ratio (j). It also has abundant vertical and horizontal equally spaced straight lines which often is helpful in making either a quick rough check or a careful measurement of any deformation of the received picture due to stray magnetism, poor deflecting yokes, improper Iconoscope mounting, inaccurate compensation for the tilt of the Iconoscope plate (k) poor vertical (l) or horizontal deflecting (m) saw-tooth wave, or other causes.

TECHNIQUE OF READING THE CHART

It has been found that observers who desire to make honest and accurate readings of resolution, render readings on the chart when transmitted by an actual television system, which differ appreciably. This is due mostly to the observers' disagreement as to how *clearly* the individual bars should be defined in order to be read properly as "resolvable".

Without the use of some agreement as to the criterion of reading, the results will be inconsistent. Also, with the use of an improper agreement, the results may be consistent, but very erroneous and of no value as a measure of effective or useful resolution. For example, assume a television system in which horizontal resolution is limited by an amplifier response which very gradually approaches zero as the frequency increases. Then the *theoretical ultimate* limit of resolution must occur at the point along the vertical wedge at which the generated frequency is just below that at which the amplifier response becomes zero. Of course, due to the observer's eye requiring appreciable difference in brightness of black and white bars for identification, he could not read quite as high as to the point of zero amplifier response. Nevertheless he *could* read to a point at which the generated frequency, f_1, is down in amplitude to a very low value, say 10 percent of ideal. If the complete apparent fade-out of the bars is to be the criterion, the observer would be compelled to render this high reading. Now assume a second system in which the amplifier response is uniform up to a definite cut-off frequency which is the same frequency as the f_1 in the first case, beyond which the response is substantially zero. The observer would render the same reading as for the first system, that is, at the point where frequency f_1 is generated. The bars would be revealed in full contrast ahead of the reading point and entirely indistinguishable beyond. The readings for the two systems would be definite and different observers would give consistent readings, but the readings would be rather meaningless as a measure of useful resolution, since a picture transmitted by the first system certainly would be much inferior to the same picture transmitted by the second system.

Hence, it is apparent that the chart should not be read to the point of complete diffusion of the bars in every case, but rather it should be read to some sort of mean point between ideal maximum contrast between bars and complete optical diffusion of the bars. The writer believes that the most accurate and significant readings are obtained by adhering to the following rule: *"For obtaining EFFECTIVE RESOLUTION read a point along the wedge at which you estimate that the value of any resolution beyond this point to be offset or cancelled by less than maximum contrast of bars preceding this point."* The choice of a reading point by this convention requires a fairly delicate weighing and balancing of values in the mind. Nevertheless, the correct value must inherently be the result of balancing of optical and psychological values and it is believed that deliberate and conscious estimation of the effective mean by an intelligent person will give a fair value. A person of engineering or scientific experience, who is accustomed to reading instruments and making engineering estimates, would probably give a more accurate reading than a layman. In order to prevent personal eccentricities from causing great error it is advisable to use the average values of readings given by several persons when high impersonal accuracy is important, as for example in determining specifications for apparatus. *It is important that all observers be instructed in the convention for estimating the effective resolution.* If any other convention is to be used the observers should be carefully instructed in its method of execution.

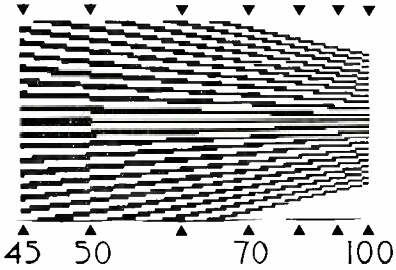

Fig. 3

In observing vertical resolution by means of the horizontal bars in a system, where limitation of resolution is due to the number of bars being comparable to the number of scanning lines involved in scanning the bars, a very confusing extraneous beat pattern is noticed.

The beat pattern is entirely a psycho-optical effect produced by the several bars falling at different and varying positions with respect to the scanning lines. Fig. 3 illustrates the general effect in a qualitative manner only. This diagram was graphically constructed to represent the received image in a hypothetical facsimile or television system in which the scanning spot in both the transmitter and receiver had zero width and a vertical length equal to the line pitch. The system transmitted no half-tone values, as any value which would normally be reproduced as a grey was reproduced as either black or white respectively depending upon the value being below or above the 50-per cent white value. The pattern transmitted was a group of straight alternate black and white bars which converge uniformly toward the right. In the figure the scanning lines are parallel and have a spacing the same as the bars at the extreme right hand side which is indicated by the "100" mark. The other numerals, 40 to 100, indicate in percent the ratio of the number of bars to the number of scanning lines at that point. If the pattern is viewed at a considerable distance and/or if the eyes are squinted the beat pattern can easily be seen as a diamond-shaped figure in the region between 60 and 80.

In making readings of vertical resolution with the charts of Figures 1 and 2 and an actual television system, observers acting under the convention for reading effective resolution given above, have generally read to a point where the ratio of bars to lines involved is 0.65 to 0.75.* In this region the extraneous figure appears to dominate the view at the expense of the legitimate bars. Since the bars can actually be distinguished by careful scrutiny well beyond the point at which the beat figure appears to dominate, it is more significant to read "effective" resolution according to the convention given.

No doubt the test charts and methods here presented have certain faults of inaccuracy and incompleteness, but their use has been of definite value in giving numerical evaluation to television progress.

Though the Sectionalized Chart was designed by the writer it can really only be considered an evolved by-product of the efforts of many engaged in the television art. The special influence of Mr. R. D. Kell and Mr. M. A. Trainer of the R.C.A. Manufacturing Company, Inc. should be noted.

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* "An Experimental Television System," by R. D. Kell, A. V. Bedford and M. A. Trainer—*Proc. of IRE*, Vol. 22, No. 11, Nov. 1934.

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PHOTORADIO TRANSMISSION OF PICTURES[1]

By

Henry Shore

Radio Corporation of America

THE transmission of pictures by means of electricity is a subject which has engaged the attention of many capable workers. Beginning in 1842, Alexander Bain, an English physicist, conceived and solved the problem in its broadest aspects so accurately that practically every system since devised, has employed principles first used by him.

Essentially, there is provided at the transmitting end means to scan each elemental area of the picture to be transmitted, to convert the light of each of the scanned areas into an electron signal proportional in intensity to the strength of the light received from the scanned element. At the receiving end the electrical impulse is reconverted into light, the value of which bears direct relation to the signalling energy. There are, however, additional considerations. Each of the reconverted elements of the picture must occupy the same relative position with respect to the reproduced picture as the scanned element occupied in relation to the original picture. At the receiver the reproducer must travel with respect to the picture surface at a speed identical with that of the transmitter; it must also start out in the same relative position as the transmitter in order that the picture received be undistorted.

The necessity of this maintenance of identical speeds and position relation, known as "synchronism" and "phasing" respectively, arises from the fact that in transmitting a picture wave three variables must be considered, namely, the two dimensions of the picture, the width and height, and the density of each elemental area. We have, however, only one dimension available in our transmitting channels, the instantaneous magnitude of the electric current. We must, therefore, rely upon some other factor to provide the two linear dimensions of the picture, which is time.

By selecting predetermined time intervals to transmit each of the elements, and knowing the position which each element is to have for

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[1] Based on a paper delivered before the Photographic Society of America, at Rochester, N. Y., April 26, 1937, and published in the Journal of that Society, December, 1937.

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a given instant, we can reassemble the picture by sending the proper amplitude of current at the correct instant. For example, we may describe a ludicrous system, but one which may nevertheless be effective in reducing the problem to its simplest terms of explanation. Two men are at opposite ends of a telephone circuit. The man at the transmitting position says "I will now send you picture element number one, for the upper lefthand corner. The value of this element is Four." By prearranged code, the receiving man knows that "Four" is one of say ten steps of value between white and black. Accordingly, he makes a mark upon a paper of the proper shade, *and in the proper place,* as directed. By some such cumbersome method, the receiving man may, after duly recording 12,000 separate messages of instruction, look upon one square inch of the complete picture being sent him. We return now to a consideration of more practical means of picture transmission by radio.

In practice, the task described is merely relegated to mechanical and electrical devices, which scan the picture to be transmitted in a predetermined fashion and at a predetermined speed. If we follow at the receiving point the same scanning trace with respect to the scanning pattern, in exactly similar speed, we automatically indicate for each instant of transmission the proper coordinate position of the elemental area, as well as its value in electric current.

This is the problem and its solution in its broadest aspects. Years have been spent by the many workers to perfect means of following a predetermined scanning pattern in precise time relation and in producing electrical impulses which are strictly proportional to the density of the elemental areas, and in reproducing those electrical impulses into elemental areas the density of which is strictly proportional to the electric impulses. Historically the simplest scanning means was a pendulum swinging back and forth across type faces in which a small light contactor rode over the faces to make electrical contacts. The closing of the contact transmitted a signalling impulse. At the receiving end a similar pendulum traced a similar path on paper. By electrolytic action the electrical impulse received from the transmitter would discolor that part of the paper in contact with the recording stylus in accordance with the contact of the original. After each swing of the pendulum the type face at the transmitter and the paper at the receiver would be advanced an appropriate distance. The surface of adjacent areas of the type-face contact therefore were in rough correspondence to similar areas contacted by the pendulum of the receiver. Such a system of scanning, because it depends upon back and forth action for its operation, is known as "reciprocating scanning".

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Following this ingenious device other systems were subsequently proposed. The next was one in which the picture to be transmitted was mounted on a drum. The scanning element was mounted on a screw advance parallel to the axis of the drum; and suitable gearing provided between the shaft of the drum and the lead screw caused the carriage to move longitudinally with respect to the drum as the drum was rotated by a motor. The gearing and the pitch of the screw determine the rate at which the scanning device so mounted travels. For present practice this is fixed to be about 1/100th of an inch for each revolution of the drum.

It will thus be apparent that the scanning path was that of a helix and, since the pitch is small, substantially parallel line scanning results. This is a so-called "rotary scanning system". Practically all other scanning systems are derived from these two either singly or as a combination of both rotary and reciprocal scanning. Either system provides a means for scanning each elemental area of the picture to be transmitted and the final choice is generally dependent upon other considerations. In general, the rotary system is preferred, since such systems may be maintained in synchronism more easily and do not suffer from back-lash and other mechanical imperfections as much as reciprocal scanning systems.

Transmitting heads, which constitute part of the scanning system, fall into two general classes—those representative of the earliest work in the field which make use of electrical contact and resistance variations, and those which make use of electrical light translating methods.

The first type of system is represented by the class in which the message to be transmitted is written or printed in special electrically conducting ink upon the message blank. A scanning stylus rides over the message blank and, in accordance with the changing electrical resistance it encounters, a varying electrical current is produced. Such systems have the disadvantage of being operative at only relatively low speeds, and because they do not compensate for varying thicknesses of the ink, spurious variations in resistance take place. These produce distortions in the transmitted signals. In the same category belong those systems in which an embossed image of the picture on thin metal foil is used or, alternatively, a half-tone plate is used in conjunction with a fine stylus. In either of these forms, the stylus making contact with the raised portions of the metal closes the electrical circuit to transmit pulses representative of the raised areas of the picture surface.

In the second class, light-translating elements, such as selenium cells of the variable resistance or bridge type, photoelectric, photo-

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voltaic and barrier layer cells, are represented. Either transparencies of the picture or the picture itself may be used in systems of this class. In the case of transparency, light is transmitted through a negative of the picture by means of a suitable optical system focused on the light translating element. In accordance with the variation of densities, corresponding variations in electrical currents are produced for actuation of the radio transmitter. Such a system has the disadvantage of requiring the preparation of a film for transmitting, and of not permitting the direct use of picture or message blank. The direct picture method employs a source of light to illuminate a small area of the picture. The reflection of this light is focused upon the light translating element to produce corresponding variations in electrical currents. In direct picture transmission systems of this class, a large source of light covering an appreciable area may be used, if a suitably apertured optical system, restricting to a small area the light falling on the light translating element, is also employed. Alternatively, the light may be focused through an aperture to the picture, the aperture being so dimensioned as to have the size of the smallest elemental area to be scanned. The reflected light is picked up and focused on the photoelectric cell. This latter method is preferred since it affords generally greater efficiency.

In the receiver, substantially the same arrangement for scanning the picture area is provided. That is to say, that if a reciprocating scanning system is used at the transmitter a similar reciprocating scanning system is used at the receiver, or if a rotary scanning system is used at the transmitter the same general type is provided at the receiver. Occasionally, however, and depending on the whim of the apparatus designer or operating conditions, a combination of a reciprocating scanning system at the transmitter and rotary scanning system at the receiver or the converse is used. Such systems, however, are inherently more difficult to synchronize and consequently, have not received much consideration from technical investigators.

Suitable means of synchronizing the receiving-driving mechanism must be provided, and here the methods and apparatus for maintaining the receiver in synchronism are as ingenious and variegated as the designers themselves. Some of the more important systems of synchronizing are the start-stop systems in which the receiver is running at a speed slightly higher than the transmitter, and is stopped at the end of each revolution. A synchronizing impulse, transmitted once during each revolution at the transmitter, actuates a clutch arrangement at the receiver. This engages the receiver mechanism with the driving means for one stroke after which the clutch is automatically disengaged, to be re-engaged by the next synchronizing impulse.

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Another method makes use of synchronous motors at the receiver and a synchronous generator at the transmitter. The alternating current generated by the synchronous generator is transmitted to the receiver and drives the receiver through a synchronous motor. Variations of speed occurring at the transmitter produce variations in the frequency of the current received, since the synchronous motor at the receiver follows faithfully the speed of that at the transmitter. This, of course, requires the transmission of relatively large amounts of synchronizing energy. Of course we cannot conveniently operate motors on both sides of an ocean from a single, and therefore, automatically synchronizing, source of power. To overcome this handicap at the receiver, another system makes use of a direct current motor of poor speed regulation. Mounted on the same shaft is a synchronous motor which is supplied by synchronizing energy from the transmitter. In this case, the d-c motor supplies the bulk of the power and the synchronizing energy can be reduced, accordingly, since it is only necessary in this system to supply enough energy to take care of the variations. At the present time, and since we have perfected means for generating alternating currents the precision of which can be maintained within one part in a million, independent driving sources at the transmitter and receiver are utilized. At the receiver the frequency of the driving energy is adjusted to that of the transmitter by means of phasing or synchronizing signals transmitted prior to the transmission of the picture, and once adjusted, requires no further attention. This is because the frequency is maintained to such a high order of precision, and the system has the advantage of eliminating the necessity for transmitting during the picture transmission any synchronizing signals.

We turn now to the actual recording of the signals. One is confronted with the difficulty of choosing from a large number of methods. Each method has its own peculiar advantages and disadvantages and the final choice is, therefore, governed by the factors which are peculiar to the particular installation.

In the early days, a simple ink recorder was used. This recorder, mounted upon a carriage similar to the transmitting scanning head, used a modified fountain pen with its point just clear of the paper. The incoming signal actuated an electromagnet which placed the pen point in contact with the paper. In accordance with the signals, a fine line was drawn each time the pen contacted the paper. Such a system, of course, is limited to relatively low speeds due to the inherent difficulties, due to mechanical inertia, of accurately and quickly actuating the pen. Difficulties were also encountered in the drying qualities of the ink; blurring and the like. To overcome this, a method

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of wax recording was used in which an ordinary drafting pen was fed with molten wax from a receiver through a capillary wick. By properly adjusting the temperature of the reservoir containing the wax, it could be made to congeal on the surface of the paper almost instantaneously upon contact with the paper. This eliminated many of the "blurring" difficulties which were encountered with the ink pen recorders. However, the temperature adjustment was critical and merely a draft was often sufficient to cause the wax to crystallize in the pen, resulting in failure of the recording process.

Other methods have been used along these lines in which the ink, in a fine stream or in the form of vapor, is projected toward the recording surface and either electrostatic or electromagnetic means used for diverting the stream of fluid from striking the paper. Such methods are capable of being used in fairly high speeds of recording, but have the disadvantage of being rather wasteful since the stream must be projected continuously and only permitted to strike the paper during the recording intervals. These methods, however, do have a very important advantage in that they do not require a paper which is specially prepared.

Still another class of recording method makes use of specially prepared paper. That is, a paper which has a sensitized surface. Paper of this class includes material used for electrolytic and pyro-recording. In the electrolytic system, the paper is coated with some chemical which is capable of being decomposed by electric current. Decomposition is effected by a light stylus in contact with the surface of the paper. In accordance with the received current from the transmitter, this occurrence of decomposition is generally accompanied by a change in color. The method is quite simple, but has a serious drawback in requiring a specially prepared surface. The fact that moisture must be present, in order that the electrical decomposition take place, requires the surface of the paper to be moistened before placing it upon the picture-support surface which is an added disadvantage. The wear at the stylus point is quite high and this requires constant replacement of the recording point. Furthermore, strong electrical currents have a tendency to produce a widening of the recorded line, which introduces serious distortions. The pyro-recording systems are typified by the chemically prepared surface and the wax prepared surface types of papers. In the chemically treated papers, a coating of salts, generally containing nickel, is placed on the paper. A jet of air, heated to a fairly high temperature, is directed upon the surface of the paper. Under the influence of heat, the salts on the surface of the paper decompose, leaving a black residue, and produce, accordingly, a picture the intensity of which is a function of the temperature of the air. For-

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tunately, this type of chemical reaction is non-linear and exhibits variations in intensity only over a very small range. Consequently, by running the temperature of the air above the saturation value of the decomposition effect, constant density recordings can be obtained.

In another variation of the same "heat" system, a layer of wax is deposited on the paper in the form of exceedingly fine crystals. Hot air similar to that described above is permitted to strike the surface, causing melting of the wax, which is absorbed by the paper. When the picture is finished, water ink is run over the surface of the picture, and because of the difference in properties of ink affinity between the areas of the crystalline and melted wax, copies in ink can be made. The ink is deposited only where the hot air has struck the prepared surface.

One rather important system of facsimile reproduction makes use of carbon paper facing a sheet of ordinary white paper. The two sheets of paper run between a straight edge and a cylinder upon which is raised a single spiral. The straight edge is actuated by transmitted currents through means of an electromagnet so as to press the carbon and white paper against the raised spiral of the drum. The point at which the pressure is exerted at any instant is between one point of the straight edge and one point of the spiral. As the drum rotates, the effect is, of course, to produce single line scanning across the width of the paper. By moving the paper in the same direction as the drum, line by line, scanning is accomplished, and the completed picture recorded.

In this same class of prepared papers (in the last instance, carbon paper was a necessary accessory) belongs the method of photographic recording. Here again there are available many ways of using the photographic properties of paper for recording. One system utilizes a fine stylus to scan the surface of the paper. The fine stylus is excited by high frequency electrical currents the intensity of which is varied in accordance with the received signals. Adjustment of the intensity of these high frequency currents to a point just below where ionization takes place, so that the transmitted signals may raise this level, results in the production of a corona discharge under the needle point of the stylus. This corona discharge is sufficient to produce the latent image, and following the recording of the picture the paper may be developed. A relatively insensitive emulsion may be used in this system, and recording may take place in a room having ordinary illumination without sensitizing the paper, thus obviating the necessity of dark-room recording.

Another method utilizes a light valve, similar to that used in the motion picture industry, for recording sound. It uses the incoming

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Of this system, there are two general types. The first system sends dots of constant duration, but spaces the dots in proportion to the amount of reflected light. If the portion of the picture being scanned is quite dark, the dots are spaced very closely together. Conversely, if the picture area is light, the dots are spaced quite far apart. Accordingly, when the received picture is looked at, the eye, seeing a number of dots very closely together, gives the impression of looking at a dark area, while that area in which the dots are spaced far apart appears to be a very light grey. Such a system, however, cannot provide very good detail and so the "Constant-Frequency Variable-Width" recording method has been developed to overcome this difficulty. In this latter system the number of dots sent per unit time is constant and, in present practice, may be as high as 100 dots per second. The width of the dot, however, may vary all the way from 10 per cent to 90 per cent of the interval between dots, and the variation of the width and the dot, that is, the time duration of the dot itself, is made proportional to the density of the elemental area being scanned. If, in addition to this, the alternate lines of dots are shifted with respect to one another, the resultant picture is a surprisingly light-true, half-tone picture, produced by conventional screening and printing methods. This is the system which is at present used commercially between the United States and Great Britain, Germany, and Buenos Aires. It is also used between New York and San Francisco.

It will be appreciated, of course, that at the receiver it is necessary only to record the duration of the dots faithfully to reproduce the picture. The amplitude no longer is of any consequence, and accordingly, therefore, limiting or saturating means of recording can be used. Along these lines, diversity reception is the practice.

The diversity system of receiving utilizes three separate antennas spaced from each other, generally about 1,000 feet apart, all of which receive signals from the same transmitter. Each antenna is connected to its individual receiver and the outputs of the three receivers are combined. Due to the fact that fading is not simultaneous at all geographically spaced locations, diversity reception utilizes the probability that the signals will not fade simultaneously at three separate points. Since the output of any one receiver is sufficient to actuate the recording mechanism, so long as there is not simultaneous fading at all three points, the recording is always a faithful reproduction of the transmitted signals. In practice, it has been found that, in a twenty-four hour day, such a system seldom gives more than a total of ten to fifteen seconds of fading. Suitable means are provided at the point where the signals are combined in order that the output may be independent of the actual sum of the three receiver outputs.

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That is to say, no output is produced unless one receiver is feeding energy to the output circuit, whereupon that output is fixed in amplitude and unchanged whether or not one or both of the other two receivers contribute to the output. These receivers are standard equipment for practically all point-to-point radio telegraph use in the United States, and so the transmitter, being used under identical conditions of ordinary radiotelegraph conditions, needs no special provisions for transmitting pictures by radio.

Having described picture transmission by radio, in general, it is of interest to consider a complete system in detail. For this purpose the present photo-radio system of RCA Communications, Inc. will be described, since it is typical of a commercial system used today.

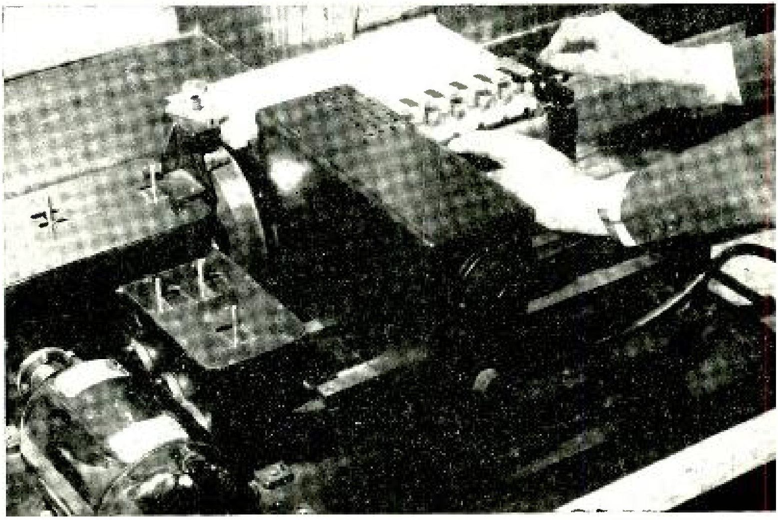

Fig. 1—Photoradio transmitter.

The photo-radio machine is arranged to serve either as a transmitting scanner or a recorder and makes use of a rotating drum and a lead screw upon which is affixed, in appropriate guides, a carriage. The carriage transports the unit which determines the function to be performed. An aluminum base carries the driving mechanism, the subject drum, gear box, and the line-advance lead screw with the carriage track assembly as illustrated by Figure 1; the machine being arranged in this case for visual recording. The gear box assembly serves to furnish four speeds of 20 to 60 revolutions per minute for the subject drum. The line advance may, similarly, in twelve steps between 40 and 300 lines per inch, be provided by simple gear shift. Thus, as the driving motor turns over, the drum rotates, and the lead screw drives the carriage longitudinally along the drum to trace out an electrical path. By making the line advance fine enough, the pitch of the helix is so small as to give substantially parallel line scanning.

To the rear of the drum, and tangential with it, is a loading platform upon which the subject is placed. A portion of the periphery of the subject drum is cut away and in the space thus provided, a series of gripper fingers similar to those used in the printing arts are provided to engage the leading and trailing edges of the subject surface. To load, the subject picture is pushed toward the drum surface along the loading platform, and a set of rollers normally held clear of the drum are let down upon it. Letting down the rollers automatically operates the grippers to place them in open position and when the gripper portion of the drum lines up with the leading edge of the paper, the grippers are tripped, seizing the paper and dragging it around the surface of the drum and off the loading platform. When the trailing edge of the paper is in line with the trailing edge grippers, these grippers are similarly triggered to seize and hold taut the paper firmly around the drum and the feed rollers are then lifted clear. Operation is then commenced with the carriage at the extreme left. For the transmitter, the scanning head shown in Figure 1 is mounted on the carriage. The indirect, that is, reflected light scanning system is used. A standard 75-watt automobile headlight lamp is used to provide the source of illumination for scanning. This is mounted at an angle with the scanner housing. Appropriate louvers in the sides and bottom are provided to afford ventilation. Horizontal and vertical adjustment of the lamp base is furnished properly to center the lamp with respect to its optical system, which comprises two lenses and an adjustable diaphragm. Positioned between the two lenses, the first of which is a condensing lens, is the variable diaphragm to provide a rectangular image. Calibrated adjustments are provided for regulating the height of the diaphragm in thousandths of an inch and the length in lines per inch, to correspond to the line advance. The second lens focuses the image of the diaphragm upon the subject drum and normal to this focused image is a pick-up lens for projecting the reflected light upon the photo-cell mounted within the scanner housing. The photocell current serves to modulate carrier wave energy. This is appropriately amplified and passed on to the constant-frequency variable-dot converting unit. The motor which drives the subject drum and lead screw operates at a speed of 1,800 revolutions per minute and is maintained at this speed with a maximum deviation of one part in 100,000.

This is accomplished by using a d-c motor of poor regulation, which normally runs at a speed above 1,800 r.p.m. Mounted on the motor shaft is an alternator, generating a frequency of 810 cycles. The output of the alternator is fed to a pair of vacuum tubes, also excited by a frequency of 810 cycles from the frequency standard, which in this instance is a tuning fork, electrically driven by a special thermionic tube circuit and maintained at constant temperature. The amount of energy which the tube alternator supplies to the vacuum tubes is dependent upon the difference between the frequency of the fork and the frequency of the alternator-generated currents. The more this frequency differs, the more energy is supplied to the vacuum tubes, and as more and more energy is supplied to the vacuum tubes, the motor speed is reduced. By suitable adjustment the alternator output is fixed to be approximately 50 per cent of its rated delivery when the speed is exactly 1,800 revolutions per minute. Consequently, any deviation in speed—as for example, a momentary drop—will decrease the load of the alternator and the motor speed will increase until the speed is again exactly 1,800 rpm.

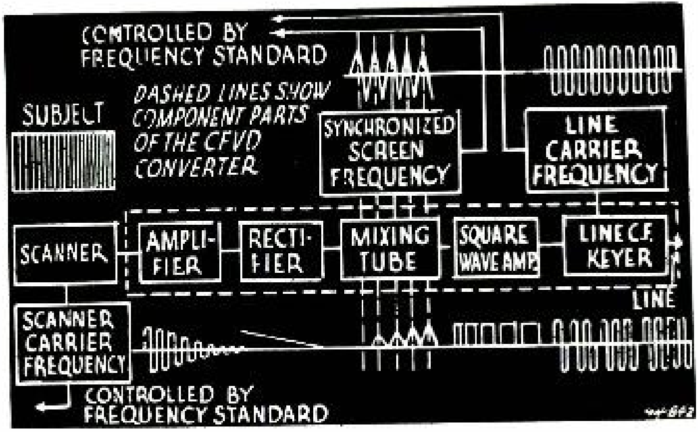

Fig. 2—Schematic block diagram of the constant-frequency variable-dot transmitting system.

As was pointed out above, the requirements of long distance transmission make it desirable to use constant-frequency variable-dot transmission but, as the output of the transmitting scanner is an amplitude-modulated carrier wave, it is necessary to convert these variations in amplitude to variations in dot-time duration. This is provided by an ingenious electrical circuit.

Figure 2 is a block diagram which shows the component parts of the electrical circuit and the shapes of the currents of the various steps in transforming the amplitude-modulated signal out of this scanner into constant-frequency variable-dot signals. The subject is indicated as one which shows progressively increasing densities and

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as the scanner passes over each elemental area, there is provided an amplitude-modulated wave as shown in the lower left-hand corner the amplitude of which decreases with increasing density. The amplitude-modulated carrier wave is rectified by the rectifier and is fed into the mixing tube along with electrical wave energy of constant amplitude and frequency, and its wave shape is that of a symmetrical saw-tooth. The frequency of this symmetrical saw-tooth wave-shape energy, known as the screen frequency, is controlled by the same frequency standard which controls the motor speed. The screen frequency is, therefore, synchronized with the motor speed. The rectified voltage serves to bias a triode tube so that the screen energy cannot pass but, as the amplitude of the rectified voltage decreases, more and more of the screen frequency energy is permitted to pass through the tube and the width of the base of the pulses which are permitted to pass is directly proportional to the amplitude of the rectified current. These pulses are then passed through a wave-shaping circuit known as a "square-wave amplifier", which converts the triangular impulses of varying heights into rectangular-shaped impulses of constant height, with bases which are equal to the base of the triangular impulses. Accordingly, the resultant rectangular pulses have a length which is proportional to the density of the elemental areas of the subject to be transmitted. These rectangular pulses are then used to key-line carrier energy for transmitting the impulses to the transmitting station, which is generally located at considerable distance from the photo-radio equipment. The line carrier energy serves to key the transmitter on and off in the conventional "dot-dash" fashion.

At the receiving point the radio signals are detected and transmitted to the receiving photo-radio equipment. The recording arrangement employs a universal machine identical to the transmitter, except that the lead screw carriage carries either a visual recording gun or a photographic recording gun. Generally, two receiving machines are employed; one having the visual gun for monitoring purposes, and the other a photographic recording gun for producing the final recorded picture. The visual recording gun is generally mounted beside the control rack, while the photographic recording machine is in a suitable dark room. The visual recorder comprises a very fine nozzle through which ink vapor produced from an air supply and atomizer is projected toward the picture surface through a very fine nozzle. In front of the nozzle is a small shutter actuated by an electro-dynamic unit, similar to those provided in modern dynamic loud speakers for broadcast purposes. Normally, when the shutter is in register with the nozzle, the ink vapor strikes the shutter and runs off of it into a little well. The incoming signal, after being appropriately amplified, actu-

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ates a keying unit which rectifies the signal and shapes the wave to provide quick acceleration to the shutter. Thus, an incoming signal pulls the shutter down clear of the nozzle and the ink vapor strikes the paper depositing a black dye, thereby building up the picture, element by element. Figure 3 is a photograph of the visual recording gun. For photographic recording the apparatus layout is essentially the same, except that a recording neon tube with an appropriate lens system is provided in the place of the visual gun unit. The tube is mounted on a base actuated by three cams, so that the tube may be rotated, as well as moved from side-to-side, and up-and-down. Longitudinal movement of the tube is provided by a sliding barrel and the optical system comprises a microscope objective lens for focusing light from the crater of the neon tube to the surface of the photographic film or paper. Mounted from the barrel of the tube on an angle of about 45 degrees is a simple magnifying glass focused upon the film at the point where light from the recording lamp is also focused. The operator can thus determine the correct adjustment of the lamp as the recording lamp is manipulated. An appropriate diaphragm is provided in this system, suitably calibrated, to insure that the resultant light will produce an image of an elemental area substantially the same as that transmitted.

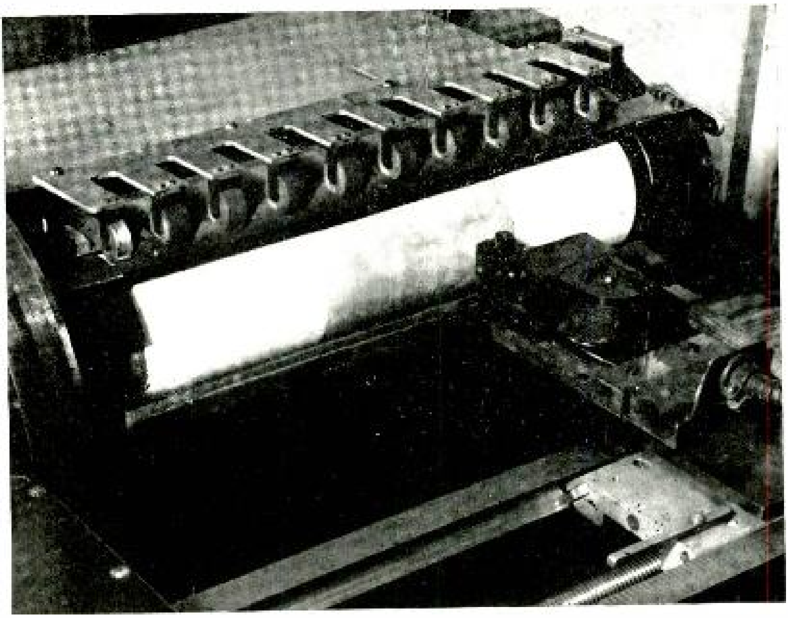

Fig. 3—Photoradio visual recorder.

The photographic recording system is shown in Figure 4. Film is

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usually employed in preference to paper, to make possible multiple printing. The film used is of the Printon type and has a spectral response comparable to that of a C5 ("tri-color blue") sunlight Wratten Panchromatic plate. This type is used in order that the relatively high levels of illumination in the dark room may not result in unwanted film exposure. The levels of illumination used in the dark room are necessary from an operating standpoint in order that the operator may read values on various control instruments necessary to the reception of pictures. The developer used for the film is one of quick-contrast, and permits considerable over-development without creation of "fog". However, it should be borne in mind that, since the recordings are at constant illumination out of the lamp, high contrast aids in the finished picture, because the picture is really made up of alternate rectangles of white and black components of uniform density, but variable area.

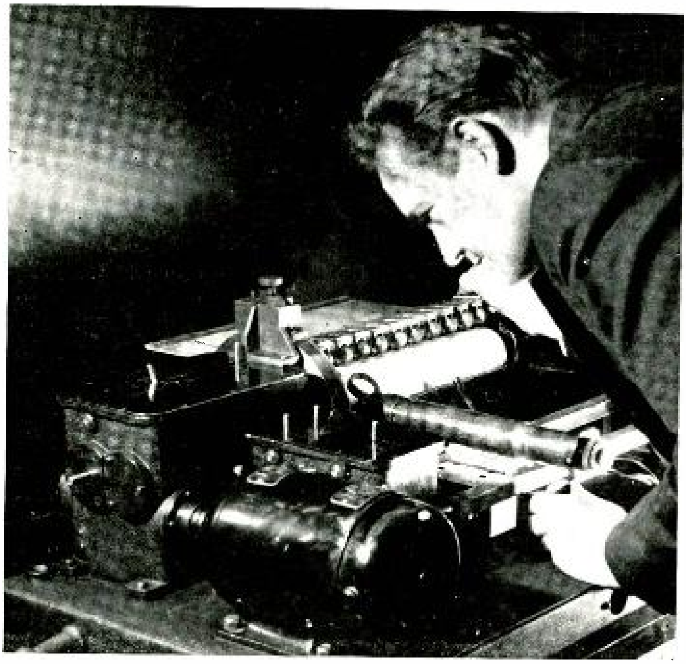

Fig. 4—Photoradio photographic recorder.

In printing, a bromide paper of extra contrast is used, and a corresponding developer provided for developing. An acid hypo-bath is used for a fixer. It will be appreciated that, under the circumstances, close control of bath temperatures and developing and fixing are obviated. The service of high skilled operators is, therefore, unnecessary.

To produce the half-tone effect in the pictures, it is necessary to shift the screen frequency on alternate strokes, in order that alternate lines may have spaces lining up with dots and, conversely, dots lining up with a space. This shifting in phase is provided at the transmitter simply by reversing the terminals from the screen frequency source as it is fed into the constant-frequency variable-dot converter. It is accomplished automatically by providing a cam mounted on a shaft which rotates once for two revolutions of the drum. The cam is cut so as to affect a contactor for one-half the revolution. The cam arrangement can be seen in Figure 1 attached to the rear gear box on the left-hand side of the machine. When the contactor is closed, a double-pole, double-throw relay, cross-connected to provide terminal reversal, is actuated so that during one-half revolution of the cam, energy is fed to the constant-frequency dot through the closed position of the relay. The next half revolution feeds the energy in the open position of the relay with an attendant reversal of phase of the screen frequency. The result of this step of operation can be seen in Figure 5 showing a picture transmitted and received by radio. When the line advance is very fine, the dot pattern produced is that of elongated rectangles. It does not provide as pleasing a pattern as when the height of the dot is substantially equal to the width of the dot. To overcome this, a second cam may be used which provides reversal of phase for every two lines instead of every other line.

The actual technique in transmitting a picture requires a determination of the condition of the transmitting medium. This is done by first transmitting what is called a "density wedge". Such a "wedge" is a standardized chart of densities of ten steps, varying from white to black. The entire range provides for 10 per cent increases in the duration of the dot transmissions. The operator at the transmitting point places this "wedge" on his transmitter and adjusts the control so that 10 per cent dots will be transmitted on the first step and 100 per cent or solid black signals will be transmitted on the tenth step. The subject drum is then started, and transmits a series of dots at constant frequency with a marking weight which depends on the step of the wedge. During each revolution, dots of 10 per cent, 20 per cent and 30 per cent, etc., are transmitted for equal intervals. At the receiving station a preliminary recording is made of the wedge. Due to circuit conditions, it is sometimes found that the dots are elongated to the extent that dots which are transmitted at 80 per cent of the marking interval actually fill-in to give 100 per cent marking. Likewise 10 per cent dots may be elongated sufficiently to show 30 per cent recorded dots. This has the effect of decreasing the contrast ratio of the transmitted subject. However, the receiving operator transmits

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back this information. Controls are provided at the transmitter, so that, by changing the amplification gain of the scanning head and the amplitude of the screen frequency, the weights of the dots can be changed to produce at the receiving station dots which cover uniformly the entire range from 10 to 100 per cent marking intervals. This pre-distortion of the transmitted impulses is, in effect, an electric means of changing contrast ratios in pictures and has made it possible to transmit improved pictures under adverse conditions of transmission, which formerly would have been so severe as to preclude the reception of pictures.

Fig. 5—Picture transmitted and received by radio.

With regard to the details which can be transmitted, some idea can be obtained from the fact that subject-matter is accepted where the type is no smaller than twelve-point and the area of interest is not less than ½ inch square. The screen frequencies used in present-day practice, together with the line width, provide pictures which are about the same as 65-screen half-tones. When the conditions of radio transmission are particularly good, that is, in the absence of magnetic storms and static, the details can be increased to almost twice this value. It is apparent that, since the received picture is in the form of a half-tone, line cuts can be prepared directly from the picture without the necessity of producing half-tones, with consequent further saving in time where the pictures received are for newspaper reproduction.

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SHIP-TO-SHORE HARBOR TELEPHONE EQUIPMENT

BY

H. B. MARTIN

Engineering Department, Radiomarine Corporation of America

FOR several years it has been possible for passengers on many express liners to converse by telephone with those on shore. Coastal stations for this service are maintained by telephone companies, either private or government owned, in the major countries of the world. Ship equipment for such service is large in size, expensive and of sufficient complication to require experienced radio personnel for its operation.

Coastal-harbor radiotelephone stations, operated by the local telephone companies are now in use at Boston, New York, Miami, Los Angeles, San Francisco, and Seattle. An additional station is now under construction at Norfolk, Virginia. Each station connects by land lines to its local telephone office through which calls may be routed to and from any telephone subscriber.

Since communication with these stations is strictly of the harbor or short-distance coastal type, the frequencies allocated for such service are relatively low compared to those used for radio communication with trans-oceanic vessels. In order to eliminate interference when more than one ship-and-shore station are working simultaneously, the receiving and transmitting channels are different for each locality. Shore stations transmit on frequencies between 2500 and 2600 kc and ship stations transmit on frequencies between 2100 and 2200 kc. For example, in order to carry on conversations with the New York telephone station, the ship would transmit on 2198 kc, and would receive on 2590 kc, which is the transmitting frequency of the New York shore station. Since the propagation characteristics of 2- to 3-megacycle frequencies confine the communication and interference range to a few hundred miles, identical frequencies may be used on the Atlantic and Pacific Coasts if desired.

Small low-powered and relatively inexpensive equipment (compared to apparatus for ocean-going ships) has recently been made available to the small-boat owner. The equipment has been designed particularly to serve the needs of the sportsmen who make use of craft 40 to 50 feet in length as well as tugboat and other harbor-craft operators. A photograph of the equipment herein described is shown in Figure 1. The transmitter and receiver cabinet is relatively small

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in size, occupying approximately three and one-half cubic feet. The controls necessary for the operation of the equipment have been made as simple as is believed possible and practical, consistent with good design, in order that the yacht owner or any of the crew, who are not necessarily radio technicians, may qualify and be licensed as third-class telephone operators by the Federal Communications Commission. The equipment operated by the holder of a third-class telephone license must be so arranged that the operation of controls will not affect the transmission frequency. For this reason, practically all of the transmitters designed for this type of service are crystal controlled. The transmitter illustrated in Figure 1 may utilize as many as six quartz crystals. The frequency-controlling circuits are pre-tuned, the proper frequency being selected according to the location of the boat. For example, the operator, if in the vicinity of Boston, would select the

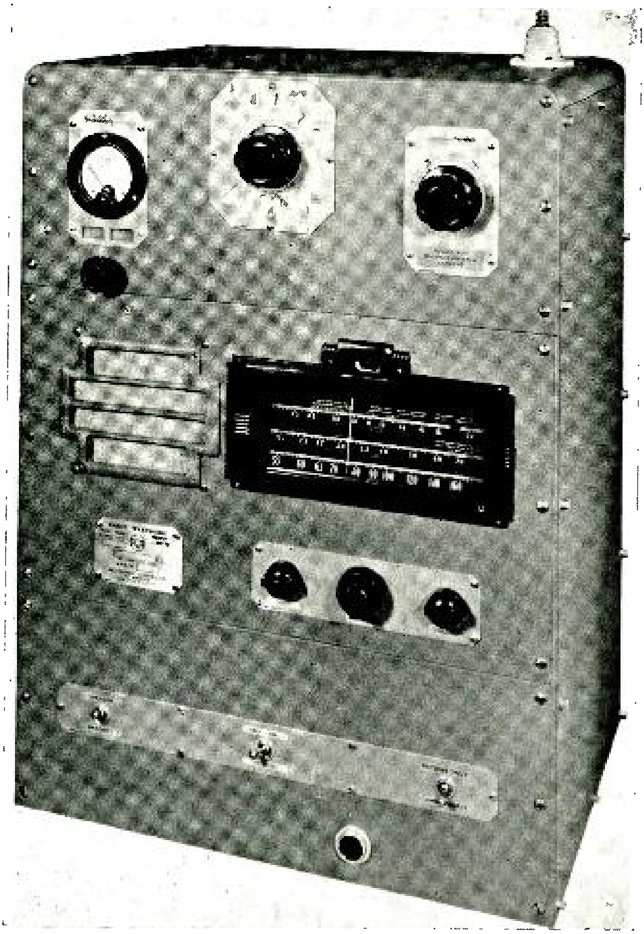

Fig. 1

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proper transmitting frequency merely by setting the master switch on the transmitter front panel to the position marked "Boston". The master-switch pointer also indicates the frequency to which the receiver must be tuned for the channel selected. If the boat moves to other waters, served by another harbor station, it is only necessary to reset the master switch corresponding to the locality of the shore station. A schematic circuit of the transmitter is shown in Figure 2. The power required for the operation of the equipment may be obtained from a source supplying 12, 32, 110 volts d.c., or 110 volts, 60 cycles a.c. When the ship's lighting supply is d.c., a small rotary converter is used to convert the power to 110 volts a.c. This is considered the most practical arrangement since it allows operation of a standard transmitter-receiver unit from a variety of power sources.

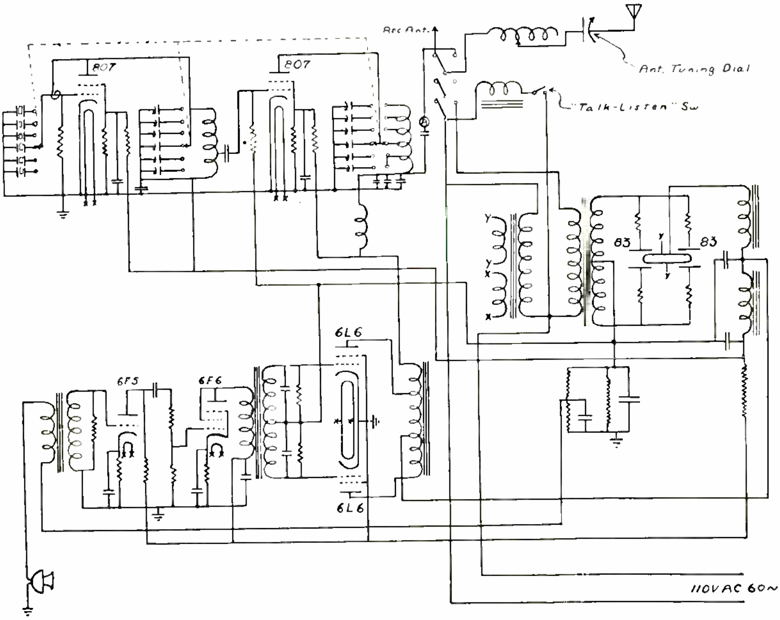

Fig. 2

Referring to Figure 2, it will be seen that the radio-frequency portion of the transmitter consists of two stages. The oscillator stage utilizes one RCA Type 807 beam tube, whose frequency is controlled by any one of six quartz crystals of the "V-cut" type giving good frequency stability over a large range of temperatures and obviating the necessity for maintaining the crystal at a constant temperature. The power-amplifier stage uses a tube of the same type and delivers 15 watts to the antenna. The plate circuit of the power amplifier is coupled to the antenna by means of common capacitance. This provides approximately uniform coupling over a band of frequencies and assists in the reduction of harmonic radiation. Since the equipment is de-

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signed for use on small boats having limited antennas, provision has been made so that any small antenna may be tuned by means of the tapped antenna loading coil and the antenna tuning condenser. This is shown more clearly in the schematic circuit, Figure 2. The transmitter may use antennas varying in capacity and resistance from 0.0001 to 0.0005 microfarad and 4 to 20 ohms, respectively. The plate and screen elements of the power-amplifier tube are modulated by the output of two 6L6 beam tubes operating as Class AB amplifiers. The modulator grids are driven by a 6F6 transformer-coupled amplifier which is, in turn, excited by a 6F5 microphone amplifier. The microphone used is of the standard single-button carbon type.

The receiver which forms a part of this equipment covers the frequency range of 540 to 1740, 2300 to 7000, and 7000 to 22000 kc, and includes a built-in loudspeaker. The equipment may, therefore, be used for entertainment purposes if desired. A Magic-eye tuning indicator is provided to facilitate the adjustment of the receiver to the shore-station's transmitting frequency. The receiver utilizes seven tubes in all and employs the familiar superheterodyne circuit. When the receiver is used for "Standing-by" (awaiting short-station calls) or for broadcast entertainment, a small tumbler switch on the front panel is thrown to "Receive Only" which turns off the transmitter filaments and conserves the power drain on the boat's battery system. Another switch allows the selection of either the loudspeaker or the receiver in the microphone handset. The handset receiver would normally be used for communication with the shore station or other ships and the loudspeaker for "Stand-by" or entertainment. A small snap switch on the front panel operates a relay which is used for transferring from send to receive. The position of the transfer switch is shown by the small pilot lights behind the panel which indicate, through an opaque screen, the words "Talk" or "Listen" so that no confusion arises during the conversation.

When communication occurs between ships, the same frequency (2738 kc) is used by both parties. In order to avoid overloading the receiver-input circuits the transfer relay, when in the transmit position, applies cut-off bias to all receiving tubes.

The U. S. Coast Guard maintains radio service at many of its principal stations. A constant watch is kept on the Coast Guard frequency of 2670 kc. Boat operators are cautioned not to communicate with the Coast Guard on routine matters, but are urged to make full use of their radio equipment in case of an emergency. The Coast Guard Stations, in addition to standing ready to serve boats in distress, broadcast frequent weather reports, storm warnings, etc. Thus radio is now giving the small-boat owner the convenience of a telephone as well as aiding safety of life at sea.

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A NEW CONVERTER TUBE FOR ALL-WAVE RECEIVERS

By

E. W. HEROLD, W. A. HARRIS AND T. J. HENRY

RCA Manufacturing Company, RCA Radiotron Division, Harrison, N. J.

INTRODUCTION

DURING the past few years, superheterodyne receivers have been designed almost entirely around special frequency mixers. In the American market there have been two forms of these mixers. The first, introduced in 1932, was the so-called pentagrid converter which performed the functions of both oscillator and mixer. The second, announced in 1935, was the type 6L7 which acted as mixer only, and required a separate tube for use as oscillator. These two forms, with minor modifications, have been manufactured in Europe; in the first form, a suppressor grid was added and the result called the octode; in the second, a small triode oscillator was combined in the same envelope with a mixer and the tube was called a triode-hexode or a triode-heptode, depending on the number of grids in the mixer.

The difficulties which have been encountered with the pentagrid converter by set designers have dated from the day when the all-wave receiver became an essential part of every manufacturer's line. Many of the difficulties can be attributed to the use of a sharply selective intermediate-frequency amplifier operating at the same frequency for all bands. In the high-frequency bands this practise results in a comparatively small separation between signal frequency and oscillator frequency and also requires very good oscillator frequency stability. The three chief faults of the American pentagrid converter types in an all-wave receiver are: (1) Too low a value of transconductance for the oscillator section; (2) change of oscillator frequency with a-v-c voltage; and (3) "space-charge coupling" between oscillator and signal circuits.

It was believed, and subsequently found to be the case, that the "space-charge coupling" of the pentagrid converter could largely be overcome by placing the oscillator voltage on an outer grid, and the signal on the first grid. This method of operation effectively prevented a tube design which could combine the functions of oscillator and mixer in the same section of the tube. The tubes made for such use, the 6L7 in this country and the triode-hexode in Europe, therefore required essentially a separate tube or a separate unit in the same

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envelope to effect frequency conversion. The use of separated oscillator and mixing units fortunately also eliminated the second major difficulty of the pentagrid converter, i.e., change of oscillator frequency with a-v-c voltage.

The first major difficulty of the pentagrid tube, namely low oscillator transconductance, could also be overcome when separate tubes were used for oscillator and mixer. Most set manufacturers, however, used the two-tube mixing combination only in the more expensive sets and a demand arose for a single-tube converter of improved performance. Many combinations of a triode with an outer-grid injection mixer were investigated, but it was not found possible to obtain high oscillator transconductance simultaneously with high conversion efficiency without considerable increase in heater power and high manufacturing cost.

One combination of oscillator and mixer, however, appeared to be highly advantageous without being inherently complicated or costly. This combination required inner-grid injection of the oscillator voltage, as with the pentagrid converter, and hence would not be free of "space-charge coupling", but utilized essentially separated oscillator and mixer sections so that the frequency shift was much reduced. At the same time it appeared possible to obtain a high oscillator transconductance.

This combination was used in a tube having a mixer section on one side of the cathode and an oscillator on the other side. It permitted separation of oscillator and mixer sections and provided ample cathode area for good performance in both with the normal heating power of 6.3 volts, 0.3-ampere. Before the new tube is described in more detail, it will be well to analyze operation of the pentagrid converter briefly in order to point out more clearly the differences between the two arrangements.

THE PENTAGRID CONVERTER

A cross-sectional view of the pentagrid converter tube is shown in Figure 1a. In the operation of the tube, the electrons which pass through the No. 1 grid (oscillator grid) are accelerated by the No. 3 grid (screen) and pass through it to form a dense space-charge in front of the negatively operated No. 4 grid (signal grid). Some of these electrons reverse their paths and return from this region; many receive a side component of velocity and, as shown in path A of the figure, are collected by the oscillator-anode rods. In a special tube with a solid No. 3 grid as in Figure 1b, it is found that the oscillator-anode rods receive almost no current. It is evident, therefore, that practically all the oscillator-anode current in the pentagrid converter

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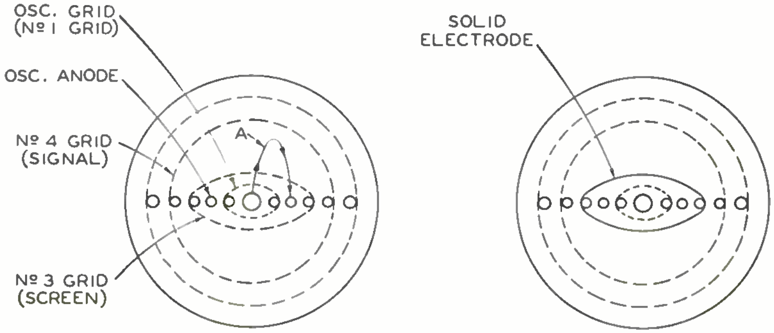
tube results from electrons returning from the region directly in front of the No. 4 grid. From this fact, it follows that the value of the bias voltage on the No. 4 grid (signal grid) greatly affects the oscillator-anode current and, therefore, the oscillator frequency. It is also clear that the oscillator-anode voltage must be considerably higher than the screen voltage in order to provide the side component of electric field needed to pull a sufficient number of electrons from the region between the No. 3 and No. 4 grids.

It should be noted that the pentagrid construction is highly advantageous in that practically the full cathode current, including the oscillator-anode current, is available just in front of the signal grid to create a dense space-charge. The signal-grid transconductance and consequently the conversion transconductance are, therefore, very high.



PENTAGRID CONVERTER
(a)

SPECIAL TUBE
(b)

Fig. 1—Cross-sectional view of the pentagrid converter and of a special tube made to check the theory of operation of the oscillator section.

The electrons which eventually reach the oscillator-anode are, so to speak, used twice; first, to aid in increasing the space-charge density ahead of the No. 4 grid, and second, to set up a current by their return to the No. 2 grid (oscillator-anode) and thus cause the oscillator section to function. Any construction of the pentagrid which causes the oscillator-anode current to be drawn directly from the cathode electron stream (as, for example, the positioning of the No. 2 grid rods at right angles to their present position) is subject to two disadvantages; the current available at the signal grid is reduced and the electron stream is partially demodulated since the variations of oscillator-anode potential are about 180 degrees out of phase with the oscillator control-grid potential.

There seems to be no way to retain the advantage of double use of the oscillator current and still prevent variations of signal-grid bias from changing the oscillator current. Thus, in any effort to reduce

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the chief faults of the pentagrid converter, it appears that a price must be paid in the way of either increased cathode current or somewhat reduced conversion transconductance.

THE NEW TUBE—TYPE 6K8

A cross-sectional view of the new converter tube is shown in Figure 2. The cathode is surrounded by a grid which acts as the oscillator grid on the lower side of the figure and as the modulator grid on the upper (mixer) side. The anode of the oscillator section is placed adjacent to one side only of the cathode and grid. On the opposite side of the cathode, a single grid serves the function of both inner and outer screen grids; the signal grid is placed inside the enclosure formed by the screen. The output anode is positioned as shown in the upper part of the figure.

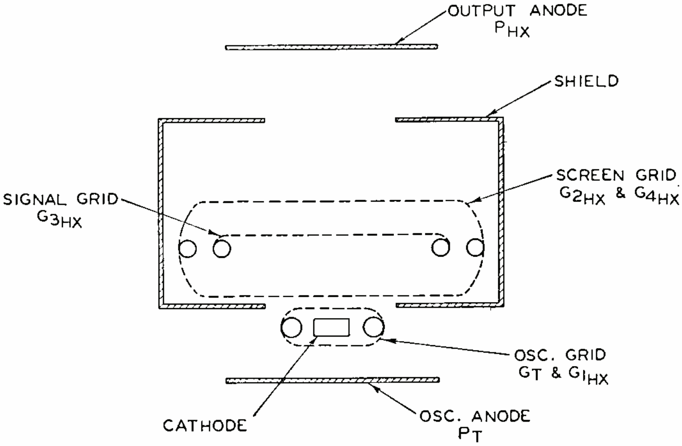

Fig. 2—Cross-sectional view of the Type 6K8 converter tube.

A rectangular cathode was used in order to realize the maximum effective cathode area. By this means, it was possible to design the tube with a very high oscillator transconductance without too great a sacrifice in conversion transconductance, even though only half of the tube was available for mixing.

It was realized that a highly desirable feature of a converter tube is a sufficiently high plate resistance to permit the use of high-impedance, i-f circuits. At the same time, in order to separate the mixer section of the tube from the oscillator section, it was desirable to use some form of separating shields. By arranging the shields in the shape of the channel members shown in Figure 2, it was found possible to combine the function of suppressor grid with that of the separating shields. Because of the inherent beam action of the electron

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stream on each side of the cathode, the shield channels do not interfere with the normal electron paths. The slit between which the electrons must pass on their way from screen grid to output anode does, however, lower the space potential sufficiently to suppress secondary emission and raise the anode resistance. To this end, the shields are connected internally to the metal shell of the tube.

Among the advantages to be expected from the construction shown are the inherently low capacitances due to the small physical size of the signal grid, output anode, and oscillator anode. Variations of signal-grid bias have negligible effect on the oscillator transconductance, and tube design is simplified because of the separation of oscillator and signal sections.

In many respects the construction represents a new departure in tube design. In the usual construction, a centrally located cathode is surrounded symmetrically by the other electrodes. Changes in tube characteristics caused by a small change in the position of the cathode toward one side or the other are approximately balanced out. In the new tube, however, this is no longer the case. For this reason, careful attention has been given to the structural strength of both the cathode and the surrounding grid. The final design has proven itself to be as capable of giving uniform characteristics as the more conventional structures for converter operation. It is not, however, expected that the tube will lend itself to special applications in which triode and hexode sections are used in fairly critical amplifier circuits.

CHARACTERISTICS OF THE 6K8

The new tube was designed to have the usual 6.3-volt, 0.3-ampere heater and 100-volt screen operation. The oscillator section was designed to have ample transconductance (about 3000 micromhos) at an oscillator-anode voltage of only 100. This is in marked contrast to the pentagrid tube which always required the oscillator-anode voltage to be appreciably higher than the screen voltage. The output-anode voltage may be either 100 volts or 250 volts. At 100 volts, there is a slight sacrifice in gain because of reduced output-anode resistance and conversion transconductance, as will be seen in the following tabulation.

Output-anode voltage	100 volts	250 volts
Oscillator grid leak............	50,000 ohms	50,000 ohms
Recommended oscillator grid current	0.15 ma.	0.15 ma.
Conversion transconductance ...	325 micromhos	350 micromhos
Output-anode resistance	0.3 megohms	0.6 megohms

The operating characteristics of the tube are somewhat better illustrated by the curves of Figures 3 and 4. In Figure 3, the conversion transconductance, output-anode resistance, and cathode current are plotted against current to the oscillator grid (and No. 1 grid of the hexode section) using the normal bias of —3 volts on the signal grid of the hexode section of the tube. It is seen that operation below the recommended value for grid current of 0.15 ma. is not desirable because of the sharp rise in cathode current and reduction in output-anode resistance. Thus, although an apparent maximum in conversion transconductance occurs at a lower value of grid current, the conversion gain into reasonable i-f loads is a maximum at about the recommended grid current. The recommended maximum value of cathode current is 16 ma.

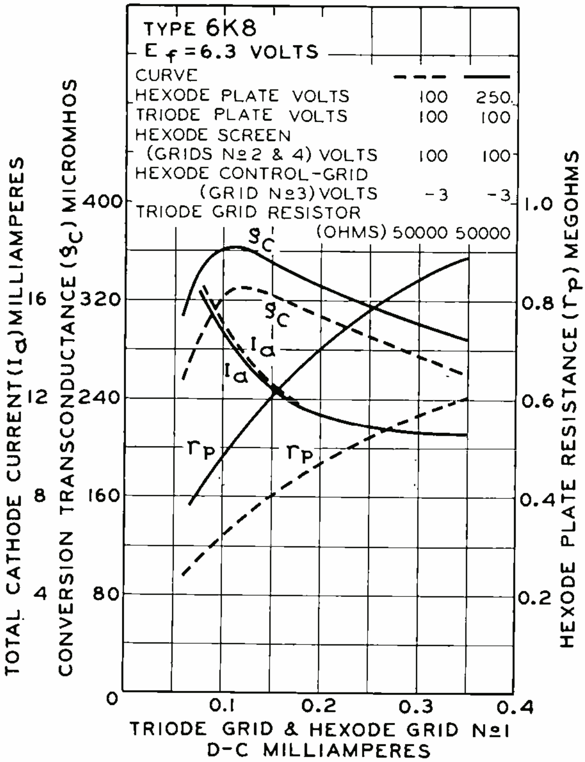

Fig. 3—Operation characteristics of the Type 6K8 converter tube.

Figure 4 gives the control characteristics of the signal grid (hexode grid No. 3). It is seen that the conversion transconductance is reduced to 1 per cent of its normal value when the signal-grid bias is

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increased to approximately —27 volts. The curve was taken with the recommended value of oscillator grid current. Other curves with grid currents ranging from 0.12 to 0.5 ma. are very similar to the one shown. When values of grid current below 0.10 ma. are used, however, that part of the curve below a conversion-transconductance value of 80 micromhos is considerably altered in shape and the tube gives rise to somewhat greater distortion of the r-f envelope for large signals than with the higher grid currents. This behavior indicates the

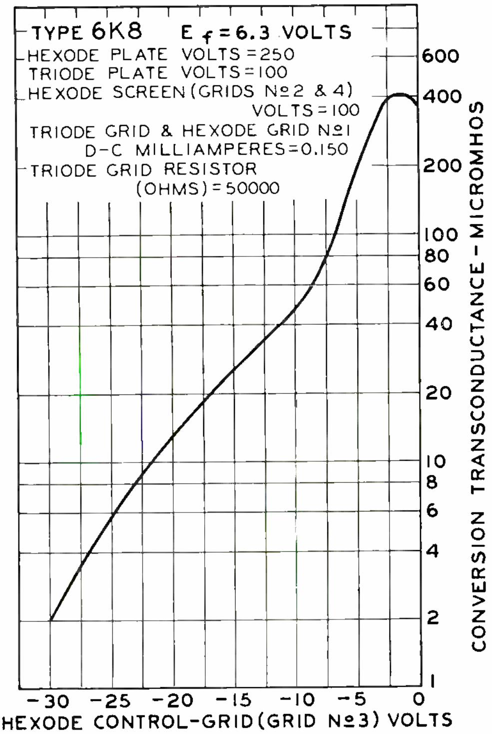

Fig. 4—Curve showing conversion transconductance of 6K8 as a function of signal-grid bias voltage.

desirability of operation *above* rather than *below* the recommended grid current.

The most important direct inter-electrode capacitances of the 6K8 are:—

Hexode grid No. 3 to all other electrodes = Signal input. .	6.6 $\mu\mu f$
Hexode anode to all other electrodes = Mixer output.	3.5 $\mu\mu f$
Oscillator grid and hexode grid No. 1 to all other electrodes (except oscillator anode) = Oscillator input.	6.0 $\mu\mu f$
Oscillator anode to all other electrodes (except oscillator grid and hexode grid No. 1) = Oscillator output.	3.2 $\mu\mu f$
Oscillator grid and hexode grid No. 1 to oscillator anode. .	1.1 $\mu\mu f$

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CIRCUIT CONSIDERATIONS

Circuits to be used with the 6K8 are essentially the same as those used with the pentagrid converter. If the 6K8 is plugged into a 6A8 socket in a receiver, the receiver will be operative, but some modifications in the circuit components are necessary in order to obtain optimum performance from the 6K8.

The high oscillator transconductance of the 6K8 and the relatively low excitation required (measured by the oscillator grid current) result in a reduction in the amount of feedback required in the oscillator circuit. The reduction of feedback is generally accomplished by a reduction in the number of turns on the oscillator-anode coil (tickler). In one receiver, this coil for the broadcast band originally had 25 turns; when adjusted for optimum performance with the 6K8, only 4 turns were used. The circuit employed used the series tracking capacitor to supply part of the feedback. In the same receiver, the tickler coil for the medium-frequency band was changed from 10 to 6 turns, and the tickler for the short-wave band, from 4 to 2 turns. The higher oscillator transconductance of the 6K8 often makes economies in design possible and permits the use of circuits or components which do not provide a sufficient margin of safety as regards oscillation for a tube having lower oscillator transconductance.

The tuned-anode type of oscillator circuit may be used with the 6K8; it offers the advantage of minimum coupling between tank circuit and oscillator grid. With this circuit, maximum oscillator-frequency voltage occurs at the oscillator anode, and coupling due to capacitance between the circuit elements connected to this electrode and those connected to the signal grid adds to the effect of the space-charge coupling in the tube. The induced oscillator-frequency voltage at the signal grid will consequently be greater than in the case of the tuned-grid circuit; it may be necessary partially to neutralize this voltage by adding a small capacitance between signal grid and oscillator grid. Such neutralization is also effective with the tuned-grid type of circuit, but the increase in sensitivity thus obtained is often accompanied by some loss of frequency stability. With the tuned-anode arrangement, the reduced coupling between the oscillator tuned circuit and the oscillator grid minimizes this difficulty.

In low-voltage receivers (particularly those of the "ac-dc" variety), other advantages of the new tube become apparent. Oscillator anode, screen, and hexode anode can all be operated at the same potential, the only differences in performance between 100-volt and 250-volt operation being the reduction in output-anode resistance resulting from

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the lower output-anode voltage and a small drop in conversion transconductance. Oscillator transconductance and consequently coil design requirements are no different from the case of higher-voltage operation; this feature permits the use of the same coils for both types of receivers. When the stability of the receiver against flutter is adequate, operation of screen and oscillator anode at the output-anode potential permits the elimination of some of the circuit components required with the pentagrid converter.

The reduction of the effect of signal-grid (avc) bias on oscillator frequency which has been made in the 6K8 results in a substantial improvement in the performance of the tube over that of the pentagrid converter. This improvement contributes particularly to the ease of tuning near the high-frequency end of the high-frequency band. In receivers using the pentagrid converter types, it is sometimes found that a strong signal in this frequency range cannot be tuned in to maximum intensity when approached from one direction. When the signal is approached from the other direction, if the receiver is tuned slightly beyond the point giving maximum output the signal suddenly disappears, and it becomes necessary to tune back past the point of maximum response to bring it in again. This cycle may be repeated several times by the operator before a satisfactory adjustment is found; then, if the signal fades, the output of the receiver drops to zero and does not come back when the signal strength is restored. These effects occur when the a-v-c voltage developed changes the oscillator frequency by an amount greater than the width of the frequency band passed by the i-f amplifier.

The curves of Figure 5 illustrate the effect of frequency shift on the tuning of a receiver. Curve A represents a signal not strong enough to operate the automatic volume control; the shape of the tuning curve in this case corresponds to that of the selectivity curve of the receiver. Curves C and C′ apply to a strong signal, C being the normal curve and C′ the curve observed when the avc affects the oscillator frequency. The arrows on curve C′ indicate the response for the two directions of tuning. The fact that the resonance peak on curve C′ is on the unstable part of the curve indicates that the signal will be lost in the event of fading. Curves B and B′ apply to a somewhat smaller signal; in this case fading will not result in the loss of the signal, but will result in detuning and, consequently, some distortion. This is indicated by the curves, since a vertical line through the peak of curve B′ passes through the sides of curves A and C′. It is also apparent that the peak of curve B′ may be approached from either direction.

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The frequency shifts indicated by curves B′ and C′ are 5 kilocycles and 20 kilocycles, respectively. The amount of frequency shift observed with pentagrid converters in typical receivers may reach 50 to 60 kilocycles when a strong signal is tuned in near the high-frequency end of the 6- to 18-megacycle band. When the 6K8 is used, the change in frequency experienced is generally less than 5 kilocycles. Therefore, curve B′ represents about the worst tuning condition which will be encountered with the new tube in the same band. For a large range of signals, tuning curves with the 6K8 approximate the normal curves A, B, and C.

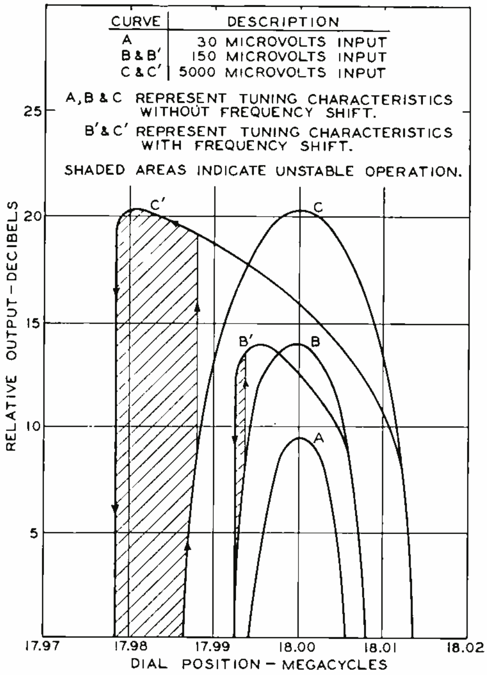

Fig. 5—Tuning curves of typical receiver with avc for an 18-megacycle signal.

Another effect observed with receivers using the pentagrid converter types is a change in the frequency of the oscillator when the capacitance of the r-f circuit is varied. The change makes it necessary to tune the oscillator back and forth through resonance during the process of alignment of the receiver. This effect is reduced with the 6K8, and while some rocking during alignment may be necessary, the time required for adjustment is reduced. It is probable, therefore, that the alignment will be better on the average in receivers using the 6K8 than in receivers using a pentagrid converter.

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The 6K8 may be used at frequencies considerably higher than those ordinarily provided for in broadcast receivers. The high oscillator transconductance and relatively low capacitances permit successful operation of the tubes at frequencies greater than 100 megacycles, and some conversion gain is obtainable at these frequencies. In one case, a receiver having a band from 20 to 60 megacycles was altered to use the 6K8. The performance obtained was comparable with that of the two-tube, oscillator-mixer circuit originally used. The two-tube circuits, however, retain several advantages. To be noted in particular are freedom from space-charge coupling if the 6L7 is used, and the possibility of still better oscillator-frequency stability than that offered by the 6K8. On the other hand, space-charge coupling in the 6K8 can be effectively neutralized by the connection of a suitable impedance (generally a small capacitance) between oscillator grid and signal grid. Also, in some ultra-high-frequency applications the circuits may be relatively less critical to frequency changes and coupling than those of the high-frequency ranges of broadcast receivers, particularly when higher intermediate frequencies are used.

In summarizing the comparison between the 6K8 and the pentagrid converter types, it is seen that the new tube offers marked advantages in oscillator stability and general high-frequency performance, and may be used under some conditions which have previously required the use of two-tube combinations. At the same time, the use of the 6K8 provides savings in circuit components and in costs chargeable to such items as testing difficulties.

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TECHNICAL EDUCATIONAL REQUIREMENTS OF THE MODERN RADIO INDUSTRY

Part III: Preparation for Technical Training

By

J. K. Whitteker

Chief Instructor, R.C.A. Institutes, Inc.

ALTHOUGH much has been said about the necessity of technical training for radio engineering, little mention has been made of the type of student upon whom it should be bestowed.

Not every boy is suited for engineering work any more than every boy has the aptitudes which go to make a good lawyer or doctor. Too frequently one hears the remark, that since a certain family has insufficient funds to give their boy a medical or legal training, they have decided to send him to an engineering school. Such haphazard decisions eventually result in disappointment to all concerned.

So complex are the qualifications necessary to the potential engineer that a decision to enter the profession should not be made without due deliberation and careful analysis. Many tests have been developed for the testing of aptitudes and it is quite possible to determine a boy's fitness for any profession with considerable accuracy.

It should be borne in mind that radio engineering is not a junk yard into which may be dumped those young men who, because of obstacles real or imaginary, or because of poor mental ability, are prevented from entering other professions.

As in other careers, the boy's preparation for entrance into a radio engineering school should begin as early in his secondary school life as prognosis of his engineering abilities can be made. Although such prognosis can be guided by the child's hobbies, these activities should not be taken too seriously.

"What," you may ask, "is to be found in a high-school record that gives a clue to a boy's aptitudes?"

Junior's record, let us say, indicates a minimum schedule in mathematics and the sciences, but a maximum schedule in the art subjects. The record of the boy next door, on the other hand, shows a maximum schedule in mathematics and the sciences, and a minimum in the arts. Therefore, since all engineering consists largely of a mixture of mathematics and physics seasoned with economics, it is quite evident that the boy next door has a better chance in radio than Junior, assuming that in each case the subjects taken are of the boy's own selection.

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As has been mentioned above, the importance of adequate secondary school preparation for the embryo engineer cannot be over emphasized. English should be studied throughout the entire four years, not only to gain facility in expression, but also to read with comprehension.

As in English, four years, if possible, should also be devoted to the study of mathematics. This subject, the universal language of science, is a mode of expression understood by technical people of all tongues. As many of the following mathematical courses should be studied as the school curriculum provides: elementary, intermediate, and advanced algebra, plane and solid geometry, and trigonometry. Not only is mathematics a required subject for entrance into professional schools, but it is also a most valuable item for prognosis of a boy's scientific abilities.

The sciences form a third group of secondary school subjects required for professional school entrance and usually consist of general science the first year, biology the second year, chemistry and physics the third and fourth years. While some question including biology in engineering school preparation, the value of its training in scientific methods and procedure should not be overlooked. A student's progress in this third group of courses, when correlated with that in mathematics, provides an excellent measuring stick for determining the boy's fitness to enter the engineering profession.

The fourth group of prepared subjects will be determined by any additional subjects required by the professional school which the student intends entering. If the subjects, additional to group one, two, and three, to make up the requisite fifteen points for entrance, are optional the student will do well to devote two years to history, one year to political science, and one year to economics. Among the non-prepared subjects, the student will find it advantageous to choose as many as possible from the following: 1. Free-hand drawing, 2. Mechanical drawing, 3. Shop practice, 4. Music appreciation, 5. Touch typing.

Another important phase of the student's secondary school training is his participation in various extra curricular activities, such as, science clubs, mathematics clubs, debating societies, etc. Such organizations tend to develop a spirit of cooperation and the ability to get along with fellow students. In other words, under proper guidance these organizations may be used as laboratories for personality development.

Even with such preparation there is considerable mortality among entered students in engineering schools, and although some of this can be traced to lack of adaptability to new environment, no small proportion is due to lack of ability to make the transition from high school

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to engineering school type of studies. The new student in engineering is called upon to utilize all of his previously acquired knowledge of mathematics and the sciences to solve the many problems in his new studies.

Since engineering school subjects are taught largely from a quantitative rather than qualitative viewpoint, the new student is required to exercise transfer of training* never before attempted. It is in the prevention of excessive mortality in making this transition that the Junior College serves a most important purpose.

Furthermore a great many young boys are graduating today from secondary schools at the age of seventeen. Such students lack the maturity of the student who is nineteen or twenty years of age, and as a result, usually make a poorer showing scholastically in engineering than the older boy. For such students the Junior College provides an intermediate training that is not only of great benefit in his future school work, but also permits the student to gain two years of age without the time being wasted.

Another important point is that scientific advances have so crowded the curriculum of the professional technical school, that more and more of the so-called cultural subjects have been crowded out; it is not that these subjects are considered of no benefit to the engineer. To the contrary, it is doubtful if any single profession has become as conscious of the necessity of a satisfactory cultural background as engineering.

However, as previously mentioned, the great range of scientific education which the engineer must acquire has made the inclusion of any great number of cultural subjects an impossibility. For this reason the professional technical school has come to depend more and more upon some sort of pre-engineering course which includes these cultural subjects. It is in conjunction with this phase of pre-engineering training that the Junior College finds one of the greatest fields of usefulness. With over five hundred such organizations already in existence in the United States and more being added each year, it is often possible for the student to obtain his pre-engineering training without leaving his home town.

Personality and ability to get along with fellow workers are two of an engineer's most essential attributes, and nowhere can these qualities be better developed than in the Junior College where the instructors are dealing with relatively small groups.

Since a considerable amount of an engineer's work involves the preparation and delivery of instructions and reports, next in impor-

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* By transfer of training is meant the ability to apply knowledge gained in one subject, such as mathematics, to the solution of problems in another subject as physics.

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tance is facility in the use of the English language, viz, ability to express oneself in a clear, concise, and accurate manner both orally and in writing. Further the engineer frequently develops equipment or makes scientific discoveries which are considered of such importance that he is asked to give a talk before an engineering society on his latest work. This involves appearing before an audience of several hundred people and making a public speech. It is in this respect that engineers as a group have had some difficulty. In this regard the pre-engineering training can make a most valuable contribution by giving considerable work in public speaking in their English courses.

Many engineers also fail to realize that in a business sense they are representatives of their company and that to people with whom they have business dealings, they are the company. Many situations have arisen where engineers either through their personal mannerisms and inability to get along with other people have discredited both themselves and the company which employed them. It is important that the engineer be trained to solve personality problems as well as technical problems, and it is here that the Junior College cultural background proves most useful.

The student contemplating an engineering career will therefore do well to expend the same time and care in planning his pre-engineering training that he does in arranging his technical school program.

A typical pre-engineering curriculum available in most of the Junior Colleges throughout the country is shown in Table 1.

Table No. 1.—Pre-Engineering

First Year

First Semester	*Second Semester*
English Composition	Advanced Composition
Vocational Sociology	Vocational Sociology
Solid Geometry	Analytical Geometry
College Algebra	Trigonometry
Mechanical Drawing	Mechanical Drawing
Chemistry	Chemistry
Physical Education	Physical Education
Fundamentals of Engineering	Fundamentals of Engineering

Second Year

First Semester	*Second Semester*
English Literature	English Literature
Dif. Calculus	Int. Calculus
U. S. History	U. S. History
Comparative Government	U. S. Government
Physics	Physics
Fundamentals of Engineering	Descriptive Geometry
	Fundamentals of Engineering

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AMATEUR RADIO

BY

W. L. KNOTTS

RCA Manufacturing Company, Inc., Camden, N. J.

THE term "amateur radio" is often misinterpreted. When the name "amateur radio operator" is applied to a person, that person is classified as a non-professional radio operator. In the field of amateur radio there are many professional men who earn their livelihood at commercial operating, but turn to amateur radio for recreation. However, the greater percentage are from other professions. Included in the amateur group are school boys, college men, engineers, doctors, lawyers, clergymen, and men and women from all walks of life. Their interest in amateur radio is varied. Some are interested in this pastime because of the pleasure they derive from the contact with others over the air. Some make it a hobby because of the great pride they take in building and operating equipment that is complex in nature. Still others are interested in radio from a research angle; they like to try out things about which they hear and read. There are still others who make their livelihood from engineering, manufacturing, and selling equipment to the amateur radio fraternity, although these men are usually amateurs before they enter the manufacturing or selling field.

The activities of amateur radio operators extend to many fields that attract public attention and serve the public interest. The most notable work of these men has been in the case of widespread disasters; often amateurs have maintained the only communication with relief agencies for several days at a time. Floods and tornadoes are perhaps the most spectacular disasters that bring out the real public interest in amateur radio. Their well-organized efforts are a result of preparedness and the experience of preceding years, together with the assistance of local relief agencies. Public interest in amateur radio during recent years has increased rapidly, since the all-wave home receiver has become universal. Many of the listeners have become so much interested in amateur radio activities that they have joined the ranks of the amateur radio operators.

Several years ago the equipment which was in use by the amateur was largely of his own construction. The complications were not

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many and the construction of his own apparatus was a comparatively simple matter. He followed the descriptions of equipment in magazine articles or the instructions submitted with a kit of parts that had been purchased. In recent years, the regulations governing the amateur bands have required a much higher grade of equipment and the engineering involved in producing equipment that is acceptable and workable has been beyond the capacity of the average man who does not know something of radio engineering.

Part of the fun in maintaining an amateur radio station is in keeping up to date with the rapid advances of the radio profession. Equipment manufactured to meet practically all the needs of amateur operators has been placed on the market by many manufacturers. Descriptions of this apparatus appear from time to time in periodicals; by close observation and careful planning, an amateur can construct equipment of similar nature. However, he may find that the time and money required to make this equipment himself is greater than the expenditure required to obtain the manufactured units. The apparatus required for an amateur radio station depends largely on the field the operator wishes to enter. The beginner must confine his activities to code telegraph transmissions, or to telephone transmissions in either the "160-meter band" or the ultra-high-frequency bands. The experienced operator after obtaining the necessary grade of radio license from the Federal Communications Commission may operate in any of the amateur bands except the 40-meter band, with either phone or telegraph. The 40-meter band is reserved for telegraphy only. The beginner will likely start off with equipment enabling him to use telephone in the 160-meter phone band. This equipment should be procured with future expansion in mind. The radio receiver that the beginner will use will undoubtedly cover practically all of the amateur frequencies. Some receivers do not cover the "5-meter band," while others do.

With the transmitter, other problems arise. A choice of equipment must be made that will strike a compromise between capabilities and expense. The present state of the art and the FCC regulations require quartz-crystal control of frequency or a suitable equivalent method. The beginner should take into consideration his future interest in radio when choosing the power rating of his first transmitter. A transmitter of nominal expense, size, and capabilities that will satisfy average conditions will have approximately 100 watts output. As the operator accumulates experience, he may want to increase this power or to expand the frequency range of the transmitter.

The FCC requires that the transmitter emit a pure wave, free from transients, excessive key clicks and over-modulation. To be sure of

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compliance with FCC regulations, the operator should employ some sort of cathode-ray-oscilloscope device to analyze the emitted wave. Other means are available, but are not so flexible nor so easily interpreted.

The effectiveness of any transmitter depends on the antenna used with it. The study of antennas has occupied more attention recently than in years before. Although antennas cannot be discussed in this short space to give the reader any practical information on their design, the greatest gain per dollar spent, after suitable equipment is already in the station, is obtained in work with the antennas.

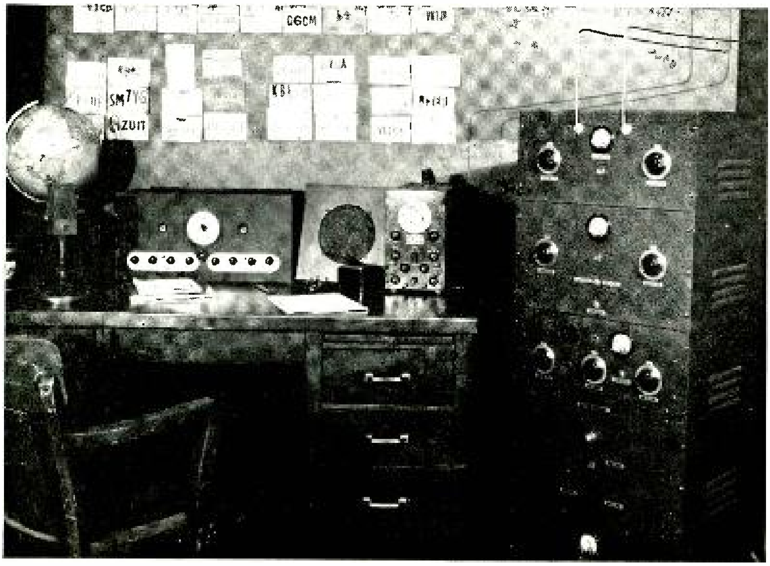

Fig. 1—A modern amateur station.

A field of amateur radio which has been of widespread interest in the last two or three years is that of the ultra-high-frequency bands, the most popular of which is the 5-meter band. That peculiarity of ultra-high frequencies which generally limits transmissions to the horizon makes possible the use of a large number of transmitters on the same frequencies in different localities, without interference. Very low power is adequate for covering the distances over which transmissions are usually made in ultra-high-frequency bands.

A popular device for use on the ultra-high-frequency bands is the so-called "transceiver." The transceiver is a transmitter when the control switch is in one position, and a receiver when the switch is in another. Thus, the circuit connections can be changed rapidly at the will of the operator. Transceivers have been used on many "field days" for group outings. "Treasure" hunts have been conducted where the object was to find a hidden transmitter through the aid of radio. Transceivers are quite useful for these field days and afford an easily portable means of communication between different searching parties. The result of these hunts is not only recreation, but a training of the operators in the field patterns of antennas and the actual workings of the radio compass.

A new field of radio that has recently been tackled by the amateur is the so-called microwave portion of the frequency band. These microwaves are of very high frequency and behave in much the same manner as light. Those amateurs who are principally interested in the research end of radio find a great pleasure in working with these frequencies. From the combined work of great numbers of amateurs, many new things are brought to light that find use in commercial fields.

Amateur radio provides not only amusement, but also a field of training for many men who are to become the leaders of the radio industry of future years. From time to time articles of special interest to the amateur radio operator will be published in RCA REVIEW. These articles will deal with equipment as applied particularly to amateur use. A typical amateur station is illustrated in Figure 1. This station includes an all-wave receiver, a 200-watt telephone-telegraph transmitter, a cathode-ray oscilloscope (which serves many purposes, the major one being that of modulation indicator), a speech amplifier that is actually part of the transmitter, and a velocity microphone. Other incidental equipment seen in the photograph of this station includes the globe, log book, and a few of the many "QSL" cards. These "QSL" cards represent a special hobby of the amateur radio operator. Contacts with other stations are often confirmed through the "QSL" card. Cards from the most out-of-the-way places or places of unusual interest are often displayed prominently in the amateur station. The cards in this photograph are arranged in groups of six, one from each continent, showing the number of times all continents have been contacted.

The radio amateur regards his position with a great deal of pride. He has obtained his license from the FCC by learning many necessary facts about radio and by learning the International Morse Code well enough to send and receive messages at the rate of 10 words per minute, or better. An examination is held by a local radio inspector to determine the fitness of the applicant. Applicants passing the examination are granted an operator's license. This license, which may be revoked for violations of FCC regulations, is zealously guarded by the holder as his certificate of membership in the fraternity of amateur radio operators.

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AN ELECTRO-MECHANICAL METHOD FOR SOLVING EQUATIONS

BY

ALLEN H. SCHOOLEY

Research and Engineering Dept., RCA Manufacturing Company, Inc., Harrison, N. J.

Summary—*An electro-mechanical method is described for finding the real and complex roots of high-degree algebraic equations having either real or complex coefficients. This method involves the adding (by series connection) of as many simultaneously variable voltages as there are terms in the equation. Each voltage is proportional to a particular term. The roots are found by adjusting the sum of the voltages to zero. Ways are described which will permit the rapid tracing of equations in their real and complex planes. An experimental model has been constructed for solving cubic and lower-degree equations for their real roots.*

INTRODUCTION

IT IS needless to emphasize the desirability of a quick method for obtaining the real and complex solutions of high-degree algebraic equations. Many important characteristic equations such as those of oscillating electrical and vibrating mechanical systems are of this type. Unfortunately, the methods set forth in engineering and mathematical books for solving these equations are much too involved and tedious to be used in any but the simplest or most important cases. The writer, therefore, has felt justified in devoting a considerable part of his spare time to the development of a device for doing this work.

BASIC PRINCIPLE OF OPERATION

Figure 1 shows the basic principle of operation of this method. Independent batteries are used to produce voltages proportional to the constants of each term of a given algebraic equation. The polarity of the batteries are made to correspond to the sign of the respective terms. These voltages, except the voltage for the constant term a_o, are applied to potentiometers having their resistances tapered linearly, quadratically, cubically, etc. The voltage across any part of each potentiometer is proportional to the value of a particular term for any value of the independent variable x between 0 and 1. For example: when the moving contacts of the potentiometers are to the left, all of the voltages will be zero (except the voltage for the constant term) corresponding to the point where the independent variable is zero. When the moving contacts are at the extreme right, the various voltages will represent the value of each term when the independent variable is equal to 1. The independent variable scale for each term

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will be linear from 0 to 1 due to the taper of the potentiometers. Thus, mechanical ganging of the sliders makes it possible to vary the independent variable of all terms with a single control. The separate term voltages are summed up by connecting them in series and reading the total voltage on a high-resistance voltmeter. This voltmeter will indicate the value of the dependent variable u for any value of the independent variable x as set on the ganged potentiometers. A real root will be identified by any position of the ganged potentiometers which will make the voltage u equal to zero.

To solve for the complex roots of a given equation, it is necessary to find the complex values of the independent variable which will make the dependent variable equal to zero. It will be shown later that the method outlined in the previous paragraph can be extended, by using a-c instead of d-c supplies, so that equations can be solved for their complex as well as real roots. With such an arrangement it is necessary to adjust the phase as well as the magnitude of the independent variable when exploring for the complex roots.*

SOLVING FOR REAL ROOTS

Consider a polynomial, with real coefficients, of the form

$$w = a_0 + a_1 z + a_2 z^2 + \cdots + a_n z^n = \sum_{j=0}^{n} a_j z^j \qquad (1)$$

where

$$w = u + iv \qquad \text{and} \qquad z = x + iy \qquad (2)$$

For the moment it will be assumed that the imaginary parts of the variables are zero. Therefore, equation (1) may be written

$$u = a_0 + a_1 x + a_2 x^2 + \cdots + a_n x^n = \sum_{j=0}^{n} a_j x^j \qquad (3)$$

A visual representation of this equation may be obtained by assuming particular values for the constants and plotting a graph of u vs. x. One way of doing this would be to plot the curves of each term separately and then to obtain the final curve by adding the results. In effect, the apparatus of Figure 1 will do this in terms of voltage.

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* Since preparing this article, the writer has discovered that Messrs. H. C. Hart, I. Travis and associates at the University of Pennsylvania have independently developed a practically identical method. Their work is published in the January, 1938 issue of the *Journal of The Franklin Institute* under the title, "Mechanical Solution of Algebraic Equations." In the present article the method is extended to solve equations with complex coefficients.

Mr. R. L. Dietzold and Mr. R. O. Mercner describe "The Isograph—A Mechanical Root-Finder" in the December, 1937 issue of the *Bell Laboratories Record*. This purely mechanical machine is made to solve up to tenth-degree equations for their real and complex roots.

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A real root of an equation is defined as any value of x which when substituted into the equation will make it equal to zero. In other words, intersections of the curve $u = f(x)$ with the x axis are solutions; and for the machine, the point or points where the resultant voltage becomes zero are solutions.

To explore a function between $x = 0$ and $x = -1$, it will be necessary to change the polarity of the coefficients a_1, a_3, etc. by reversing the polarity of the batteries supplying the voltage for the odd power terms. This can be shown by substituting $-x$ for x in equation (3) and observing that under this condition

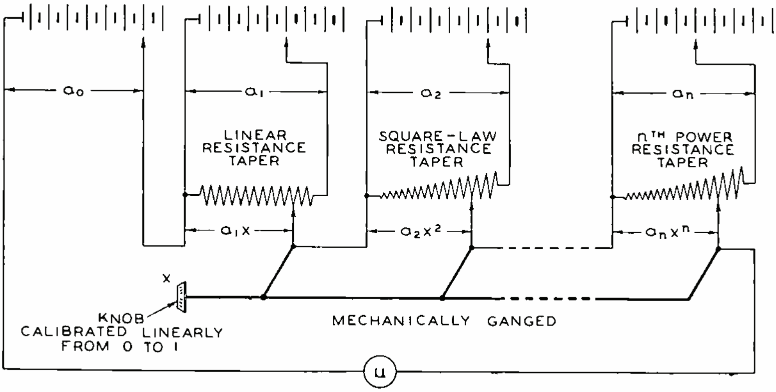

Fig. 1—Electro-mechanical method for solving equations of the form $u = a_o + a_1x + a_2x^2 + \cdots + a_nx^n = \sum_{j=0}^{n} a_jx^j$ for their real roots.

$$u = a_0 - a_1x + a_2x^2 - a_3x^3 + \cdot \cdot \cdot \pm a_nx^n \qquad (4)$$

To explore the equation between 0 and 10, $10x$ is used in place of x and equation (3) becomes,

$$u = a_0 + 10a_1x + 100a_2x^2 + \cdot \cdot \cdot + 10^na_nx^n \qquad (5)$$

Therefore, it will be necessary to change the voltages corresponding to the respective coefficients by factors of 1, 10, 100, etc. Under this condition the range of x on the linear scale of the ganged potentiometers will be from 0 to 10. To explore from 0 to -10, it will be necessary, as before, to reverse the polarity of the odd-power terms. The range of x can be extended indefinitely by a similar readjustment of the respective coefficient voltages. Figure 2 shows the factors which must be used in setting the coefficients to read x over various ranges.

The question of obtaining very large voltages from the batteries

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immediately arises. This difficulty can be overcome by dividing the whole equation by a factor large enough to reduce the largest coefficient to an equivalent voltage well within the capabilities of the apparatus. Under this condition the reading of the voltmeter u will be reduced by the same factor.

SOLVING FOR REAL AND COMPLEX ROOTS

To get a complete picture of an equation, it is necessary that the variables be considered as complex, as is shown in equation (1). A complex root is defined as any value of $z = x + iy$ which when substituted into the equation will make $w = u + iv$ equal to zero.

Range of x	Set a_0 using factor	Set a_1 using factor	Set a_2 using factor	Set a_3 using factor	---	Set a_n using factor
0 - 10^{-m}	1	10^{-m}	10^{-2m}	10^{-3m}	---	10^{-mn}
⋮	⋮	⋮	⋮	⋮	---	⋮
0 - 0.1	1	10^{-1}	10^{-2}	10^{-3}	---	10^{-n}
0 - 1	1	1	1	1	---	1
0 - 10	1	10	10^{2}	10^{3}	---	10^{n}
0 - 100	1	10^{2}	10^{4}	10^{6}	---	10^{2n}
⋮	⋮	⋮	⋮	⋮	---	⋮
0 - 10^{m}	1	10^{m}	10^{2m}	10^{3m}	---	10^{mn}

Fig. 2—Factors which must be used in setting the coefficients of an equation in order to read x over various ranges.

It is now convenient to make use of the polar form for the variables z and w of equation (1). Thus, recalling that

$$z = x + iy = \rho\varepsilon^{i\theta}, \text{ where } \rho = (x^2 + y^2)^{1/2} \text{ and } \theta = \tan^{-1}\frac{y}{x} \qquad (6)$$

and

$$w = u + iv = R\varepsilon^{i\phi}, \text{ where } R = (u^2 + v^2)^{1/2} \text{ and } \phi = \tan^{-1}\frac{v}{u} \qquad (7)$$

we have

$$z^2 = (x + iy)^2 = \rho^2\varepsilon^{i2\theta}, \text{ etc.}$$

Equation (1) then becomes

$$R\varepsilon^{i\phi} = a_0 + a_1\rho\varepsilon^{i\theta} + a_2\rho^2\varepsilon^{i2\theta} + \cdots + a_n\rho^n\varepsilon^{in\theta} = \sum_{v=0}^{n} a_j\rho^j\varepsilon^{ij\theta} \qquad (8)$$

In equation (8) $a_j\rho^j$ is the magnitude of the vth term and $v\theta$ is its phase.

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A machine for continuously adjusting ρ and θ in accordance with the conditions on the right-hand side of equation (8) to the point or points where R equals zero will give the real and complex solutions of the equation from the settings of ρ and θ. This can be done by producing separate voltages of the right magnitude and phase corresponding to the respective terms of equation (8). These voltages can then be added by connecting them in series and thereby give the value of $w = R\varepsilon^{i\phi}$ at any point $z = \rho\varepsilon^{i\theta}$. The real and complex solutions of the equation will be indicated at the point or points where $w = 0$. Figure 3 is a schematic diagram of apparatus which will accomplish this result. A series of similar a-c generators are driven by a motor on a common shaft. Therefore, they all operate at the same frequency. The phase relationship of each alternator with respect to the first one is adjustable by means of a single knob. This knob operates a gear arrangement coupled to the stators. The rate of

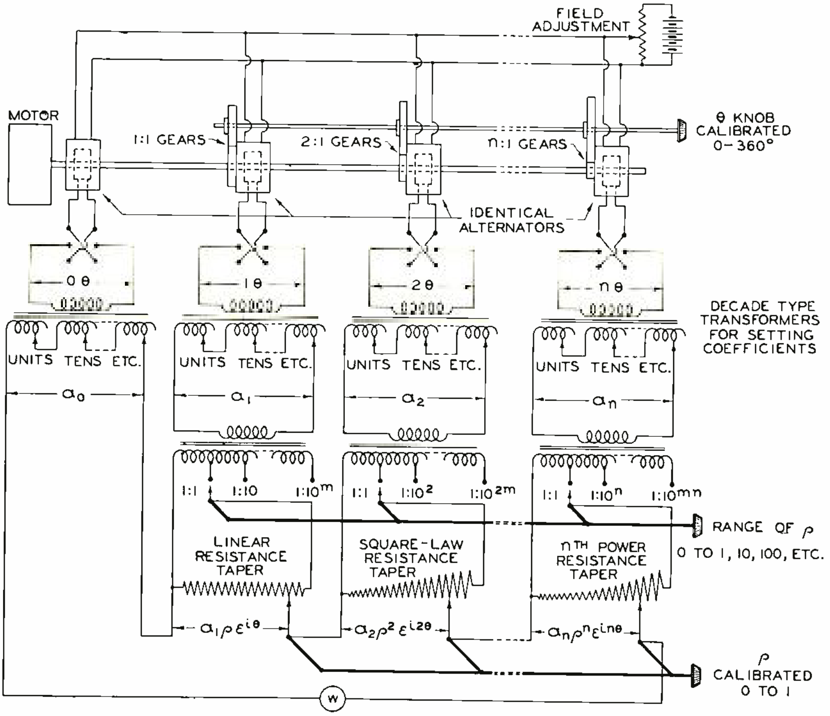

Fig. 3—Electro-mechanical method for solving equations of the form

$$w = a_0 + a_1\rho\varepsilon^{i\theta} + a_2\rho^2\varepsilon^{i2\theta} + \cdots + a_n\rho^n\varepsilon^{in\theta} = \sum_{j=0}^{n} a_j\rho^j\varepsilon^{ij\theta}$$

for their real and complex roots.

rotation of the respective stators are in the relationship, 0:1:2:3: etc. Expressed in terms of θ, the phase relationship of the respective generators will always be: 0θ, 1θ, 2θ, 3θ, etc., in accordance with equation (8). The calibration of the knob should extend from zero to 360° for one complete cycle of θ.

The constant and uniform output voltage of each alternator is made continuously variable from zero to a maximum in the secondary circuit of decade-type transformers. The values of the constants a_0, a_1, a_2, etc. of equation (8) are set by means of these transformers.* Reversing switches are used to take care of the sign of the respective terms.

The voltages a_0, a_1, a_2, etc. are applied across potentiometers having linear, square-law, cubic, etc. resistance tapers, respectively (considering for the moment that the multiplying factor transformers are omitted). The moving contacts of these potentiometers are mechanically ganged with the knob calibrated linearly from 0 to 1. The outputs of the various ganged potentiometers are connected in series together with the voltage a_0, and the resulting voltage is read by the meter w.

The real and complex roots of an equation, the constants of which have been set, may be found by simultaneously manipulating the phase and magnitude adjustments until w indicates zero.† The solution or solutions may be read on the phase and magnitude knobs. These readings may be converted into real and imaginary parts by using equation (6).

The above set-up allows exploration of the function between $\rho = 0$ and $\rho = +1$. (It is to be remembered that ρ cannot have negative values). When the function is to be explored from $\rho = 0$ to $\rho = 10$, 100, etc., the same reasoning as outlined in the paragraph of equation (5) applies. Likewise, the table of Figure 2 may be used for extending the range of ρ. The only change necessary in the table is to replace "Range of x", in the top left-hand corner with "Range of ρ."

In view of convenience, multiplying-factor transformers are shown in the respective term circuits. These transformers have turn ratios of 1:1:1 . . . (no transformer needed), 1:10:100: . . . , 1:100:10000: . . . , etc., to change the order of magnitude of ρ without changing the setting of the coefficient transformers. If the taps on these trans-

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* Using this arrangement, it will only be necessary to maintain the output voltage of the alternators at the same arbitrary level and the constants can be set on the dials of the transformers rather than set on potentiometers and read from multi-range a-c meters.

† The phase adjustment may be left at zero and the apparatus operated to give the real roots only. Under such circumstances, the ganged potentiometers of Figure 3 will indicate $\rho = x$.

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formers are ganged, ρ can be observed over any range, 0 to 1, 0 to 10, 0 to 100, etc., by operating a single switch.

To keep the voltages of the transformers within safe and observable values, it would be desirable to adjust simultaneously the fields of the a-c generators by means of a single control. It is not necessary that the absolute value of the various voltages be known when the roots of an equation are determined.

SOLVING EQUATIONS WITH COMPLEX COEFFICIENTS*

Modification of the apparatus of Figure 3 will permit the solution of equations with complex as well as real coefficients. This can be shown by assuming the coefficients of equation (8) to be constant complex quantities where,

$$a_j = a_j' + ia_j'' = |a_j| \, \varepsilon^{i\alpha_j} \tag{9}$$

Then equation (8) becomes

$$\begin{aligned} R\varepsilon^{i\phi} &= \sum_{j=0}^{n} |a_j| \, \rho^j \varepsilon^{i(\alpha_j + j\theta)} \\ &= |a_0|\varepsilon^{i\alpha_0} + |a_1|\rho\varepsilon^{i(\alpha_1+\theta)} + \cdots + |a_n|\rho^n\varepsilon^{i(\alpha_n+n\theta)} \end{aligned} \tag{10}$$

Previously it was assumed that the various alternators of Figure 3 were in phase when the θ knob was set at zero. Suppose we now arrange for making an independent phase adjustment for each alternator when $\theta = 0$. If these independent phase adjustments are calibrated from 0 to 360° for one cycle of θ, it will be possible to set directly α_0, α_1, α_2, etc. respectively, on these scales. To set $|a_0|$, $|a_1|$, $|a_2|$, etc., the regular adjustments (and calibration) of Figure 3 for setting the real coefficients a_0, a_1, a_2, etc. are used. If it is desired to change the complex coefficients from polar to rectilinear form or vice versa, equation (9) may be used.

To adapt the machine again for solving equations with real coefficients, the α_0, α_1, etc. adjustments are all set at zero and $|a_0|$, $|a_1|$, etc. will equal a_0, a_1, etc. respectively.

EQUATION TRACING EQUIPMENT

Since voltmeter u of Figure 1 will give u for any point x as set on the potentiometers, the device might be used to plot $u = f\ (x)$. It would be possible to have the machine trace the function by means of a two-dimensional recording device, such as a cathode-ray oscillograph.

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* Polynomials with real coefficients must, when set equal to zero, have real and/or conjugate complex roots. However, if a polynomial has complex coefficients, the roots will be real and/or complex.

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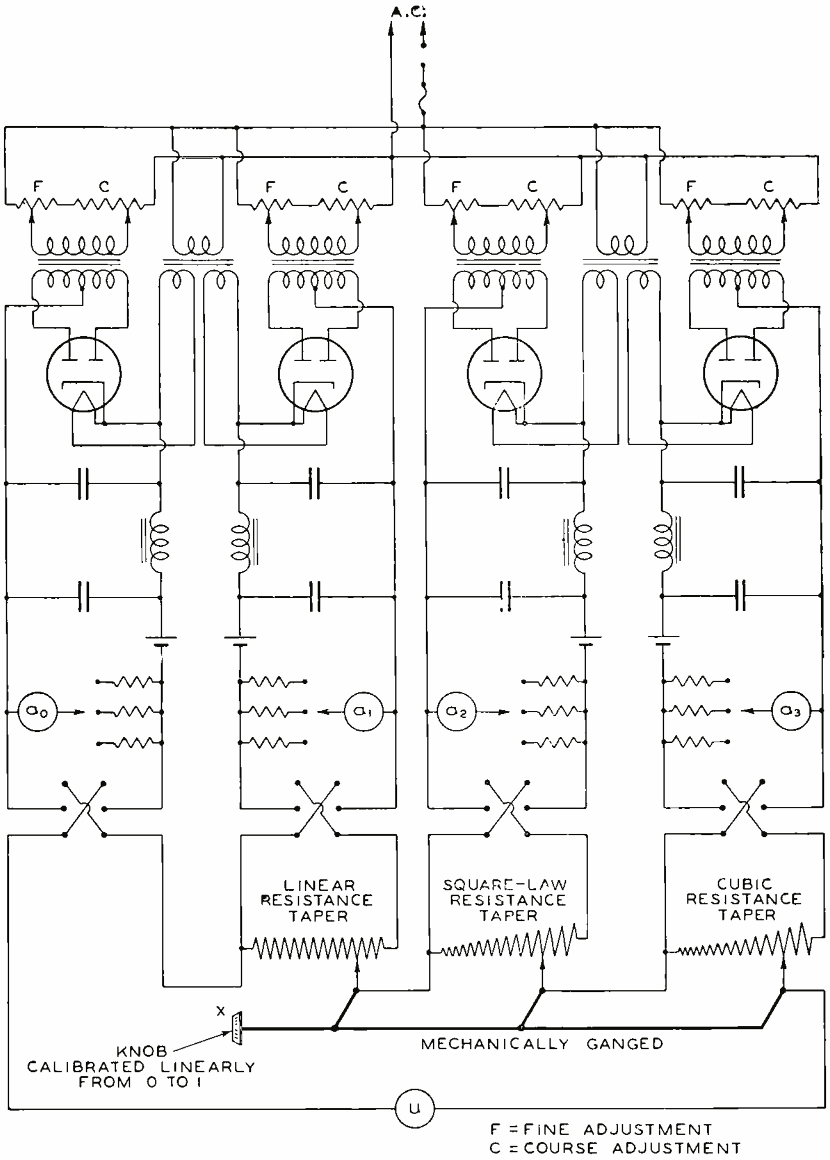

Fig. 4—Diagram of an experimental machine used for solving cubic and lower degree equations for their real roots.

For example, the voltage u could be applied to the vertical deflecting plates and the voltage across the linear potentiometer applied across the horizontal plates. The movement of the spot on the screen would reproduce the curve of the equation being examined. It would be well

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to rotate the ganged potentiometers by means of a motor at a rate comparable with the persistence of vision of the eye and thus produce a steady trace. This set-up would make it possible to vary the term constants and observe directly the resulting trace. In this manner experimental curves could be duplicated and the equation read from the coefficient settings.

Modification of the apparatus of Figure 3 would allow its use in plotting functions of a complex variable. Suppose w is a device which will continuously record the magnitude and phase of this voltage with respect to a_0 on a two-dimensional graph. Then, by arranging to automatically trace ρ and θ as they are varied, it would be possible to observe simultaneously the w and z planes for a given function. For quantitative measurements, it would be necessary to know the absolute magnitudes of ρ and R in terms of a_0.

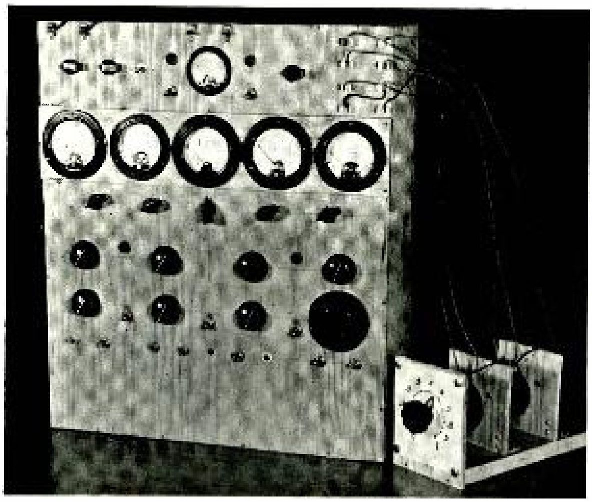

Fig. 5—Experimental equation-solving machine.

EXPERIMENTAL MACHINE

Figure 4 shows the schematic diagram of a machine made to demonstrate the workability of the basic principle outlined above for cubic or lower-degree equations. A view of the physical apparatus is shown in Figure 5. It consists of four identical power supplies, having independent d-c output voltage control by means of potentiometers in the primary circuits of the rectifier transformers. Small batteries are used to balance out the residual voltage due to the so-called contact potential of the rectifier tubes. Separate multi-range voltmeters indi-

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cate the coefficient voltages as set by using the coefficient potentiometers. The necessary reversing switches are provided at the output of each voltage supply. The ganged potentiometers are modified General Radio Type 371 potentiometers. The resistance elements of this type of potentiometer are wound on a rectangular card which is wrapped around the body of the device. Because of this construction, a linear resistance taper is obtained. For higher-degree resistance tapers, it is necessary to change the shape of the resistance card. For a very thin card, the degree of the card taper will always be one degree less than the resistance taper.

It would be possible to give a resistance taper to a linear potentiometer by controlling the mechanical movement of the sliding contact. This could be done readily by a cam arrangement. It is felt, however, that actual tapering of the resistance element is more simple than mechanical tapering. It has been suggested that ganging of a linear and a square-law potentiometer could be used to give a cubic taper. This procedure could be extended to give most any high-degree taper by using low-degree potentiometers. However, there appear to be practical limitations to this method. For example, the current through the potentiometers would not be constant, and hence the voltage taper would not depend solely upon the resistance taper.

The accuracy of the experimental machine was found to vary from about 3 per cent to 10 per cent depending on the value of the roots of the equation being solved. The errors could be accounted for by inaccuracies in setting the coefficient voltages and inaccuracies of the tapered potentiometers.

FUTURE DESIGN CONSIDERATIONS

Undoubtedly problems, many of which cannot be anticipated, will be encountered in constructing a practical equation-solving machine. The degree of the equation to be solved and the accuracy desired will obviously determine the necessary complexity and precision of the apparatus.

The ratio of the resistance of a particular tapered potentiometer at full scale to the resistance at one-tenth scale varies directly as 10 raised to the power of the resistance taper. For high-degree tapers, this resistance ratio becomes very great. However, there seems to be little advantage in having resistance ratios much greater than the practical ratio of the maximum to minimum coefficient voltages. In other words, for a high-taper potentiometer, there will be a low setting where the output voltage will be less than the lowest observable voltage, even when maximum voltage is applied across the potentiometer.

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It seems, therefore, that varying parts of the lower sections of the high-degree potentiometers can be considered as having zero resistance. This should simplify their construction. The possible accuracy of the potentiometers is, of course, a function of their physical size.

It is interesting to note that the magnitude of the roots of many practical high-degree equations are small. If they are large, it usually follows that the low-degree terms will have large coefficients compared to the high-power terms. This tends to keep the various voltages applied across the tapered potentiometers nearer the same order of magnitude. High-degree equations with roots of large magnitude would make difficult the design of the multiplying-factor transformers in Figure 3. For this reason, it may be desirable to omit these transformers and use the method of Figure 2 for changing the range of ρ.

Possibly there are other phase-changing devices which may have advantages over the a-c generators discussed. Variable brush-contact resistance and bad waveform may be objectionable in this type of phase changer.

Certain cases and regions of transcendental equations may be solved in two ways by the general method set forth. First, the transcendental terms may be reduced to their equivalent power series and then the resultant equation solved by neglecting the higher-order terms. Second, by using suitably tapered potentiometers with associated voltage supplies, it would be possible to create voltages proportional to the transcendental terms. These voltages could be connected in series with the other terms and a balance found in the same way as discussed previously. Fractional power terms could be handled in like manner.

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GRAPHS FOR EXPONENTIAL HORN DESIGN

By

A. J. Sanial

Research Department, RCA Manufacturing Company, Inc., Camden, N. J.

When designing exponential horns for specific purposes some form of the fundamental equation

$$\frac{S}{S1} = \varepsilon^{mx}$$

(where S = area at distance X from throat, and $S1$ = area of throat) is used, depending upon what values are given or assumed to start with. Finding cross sectional areas or diameters, length, taper, etc. involves substitution of variables and taking logarithms or antilogarithms, usually for a dozen or more increments. While not difficult the processes are slow, but they can be speeded up considerably by using the simple graphical methods herein described. The accompanying charts are made up for this purpose. By starting with the known or assumed constants of the desired horn and using the correct chart, the unknown variables are consecutively found as the succeeding charts are used. In this way either unknown constants of existing exponential horns can be quickly found, or the size and shape of horns to meet certain acoustic requirements and/or space limitations can be determined.

The four charts with their ordinates, their bases, and their use are as follows:

I. Rate of Taper vs. Cut-off Frequency

The relation for acoustic power

$$\frac{dW}{dt} = \frac{\rho c A^2}{SS_1} \sqrt{1 - \frac{m^2}{4K^2}} \quad *$$

shows the horn transmission is zero when

$$2w = mc$$

and this chart is computed from the latter.

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* I. B. Crandall, "Theory of Vibrating Systems and Sound".

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II. MOUTH DIAMETER VS. THROAT DIAMETER.

A family of straight lines for quickly obtaining the ratio of these two diameters is used with Chart III. A third scale of ratio values is given so that lines for other ratios can be drawn in.

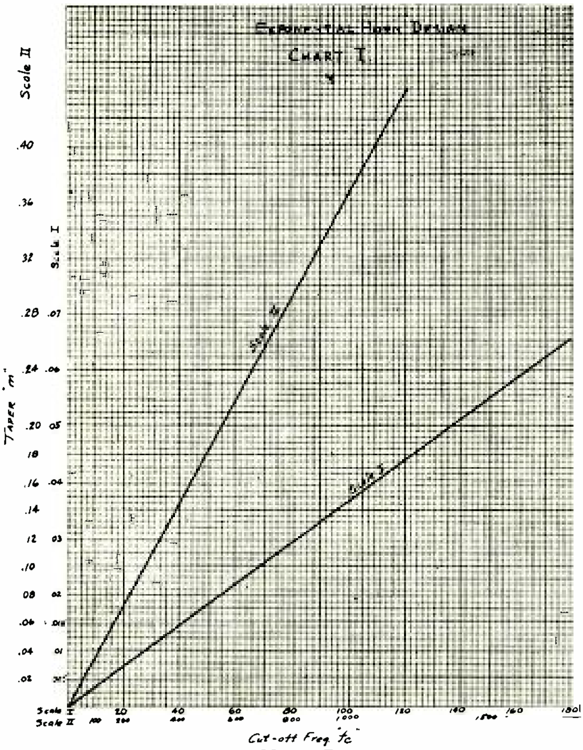

Chart I

III. HORN LENGTH VS. LOG RATIO OF MOUTH DIAMETER TO THROAT DIAMETER

This is based on the horn equation

$$L = \frac{2.302}{m} \operatorname{Log}_{10} \left(\frac{D_M}{D_T} \right)^2$$

where the ratio for the square of the diameters is used in place of the corresponding areas. Straight lines of different slopes for several values of taper are shown. The value of taper of any horn line, other than those shown, can be quickly obtained from its intercept with the $\frac{1}{m}$ scale. The reciprocal value of taper is used as it is proportional to the length, hence the linear ordinate scale of the paper can be utilized.

IV. HORN LENGTH VS. LOG HORN DIAMETER.

This chart is useful in finding the diameter of a horn at any distance from the throat, after its curve has been plotted. The horn curves satisfy the relation

$$L = \frac{4.6}{m} \operatorname{Log}_{10} \left(\frac{D_L}{D_T} \right)$$

and are straight lines on the chart because of the logarithmic scale of abscissae. The slopes depend on the value of taper, m, as in Chart III.

Where it is necessary to extend the range of the charts, two scales are shown, the second being a multiple of the first. The scale applying to the parameters on each curve, are indicated accordingly.

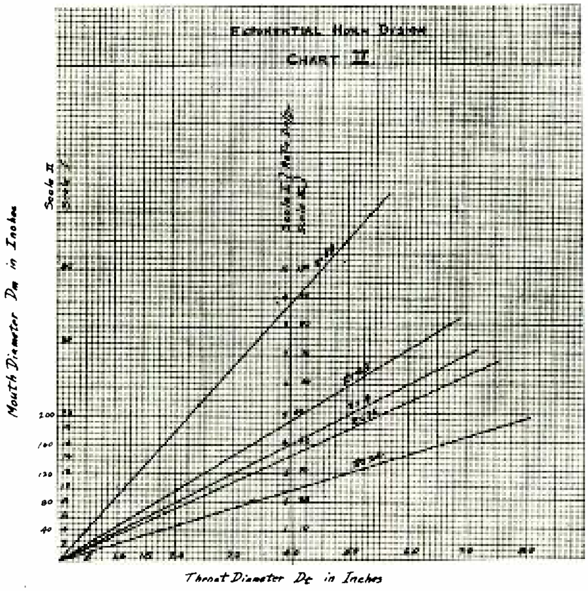

Chart II

To show just how these charts are used, some examples are given below, in each of which the assumed constants and the unknown ones are different. Note that the dimensional values throughout are in the English System of units, except for m. The formulæ given above are modified by the proper conversion factor to obtain the values of horn dimensions given in the charts, in the English System of units.

Example No. 1, let f_c, the cut-off frequency of the horn, be 75 cycles; D_m, the diameter of the mouth, be 24 inches, and the length 40 inches. Find the throat diameter D_t, and enough of the other diameters at other sections of the horn to determine its contour.

From Chart I, $m = .0275$. Referring to Chart III, at $L = 40$ and $m = .0275$, the ratio $\dfrac{D_m}{D_t} = 4$. D_t is obviously 6 inches so that Chart II need not be used. The latter chart is useful where the diameters and ratios involved are not simple whole numbers.

Other diameters of this horn are obtained from Chart IV by plotting its curve which is a straight line. Two points only are needed, and these are now known,—($D_t = 6$, $L = 0$) and ($D_m = 24$, $L = 40$). The straight line is drawn through these two points, and if desired can be extended to include greater lengths and diameters as shown. As all points on this line lie in the horn contour, as many values of diameters as desired, together with the respective distance from the throat end can be obtained from it.

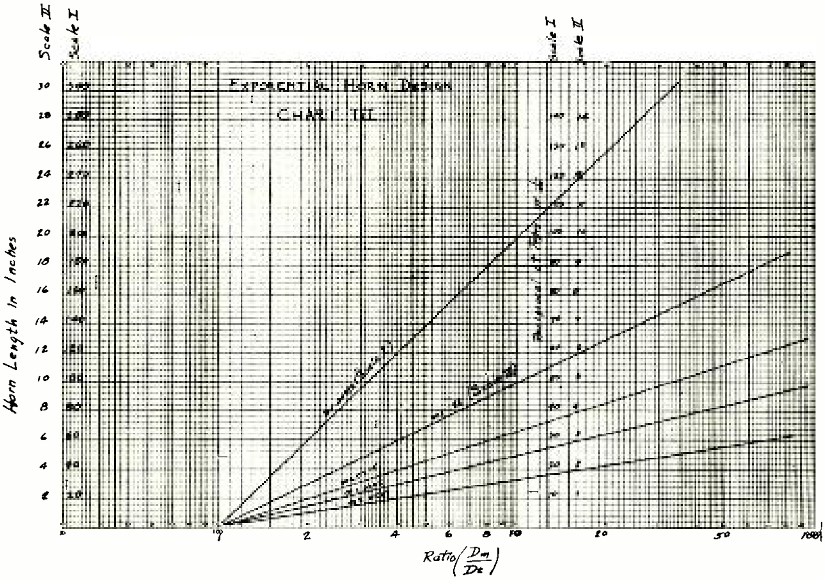

Chart III

Example No. 2. Here we assume a horn of which we know three dimensions. We wish to know its cut-off frequency and shape. Let $D_m = 72$ inches, $D_t = 2$ inches, $L = 308$ inches. Find f_c. As $R = 36$, from Chart III, $m = .00912$ and from Chart I, $f_c = 25$ cycles. Using D_m, D_t and L; plot a straight line on Chart IV, from which all the necessary points to determine the horn contour can be obtained, as before.

Example No. 3. Suppose we have a speaker unit which must be coupled to a 2-inch throat, and that the horn cannot be more than 45 inches long. In addition, the cut-off frequency is to be 150 cycles. What is the mouth diameter and contour of the horn? Given $D_t = 2$ inches, $f_c = 150$ cycles, $L = 45$ inches. Find D_m.

From Chart I, $m = .0547$ so from Chart III, $R = 24$. D_m is, of course, 2×24 or 48 inches (or a line can be drawn from $R = 24$ on Chart II and the value of 48 read off at $D_m = 2$, if the graphical method is adhered to). The linear curve for this horn is shown on Chart IV.

Example No. 4. Here we have a horn which is to have $D_t = \frac{1}{2}$ inch, $D_m = 24$ and $f_c = 500$ cycles. What is the length? As $R = 48$ and

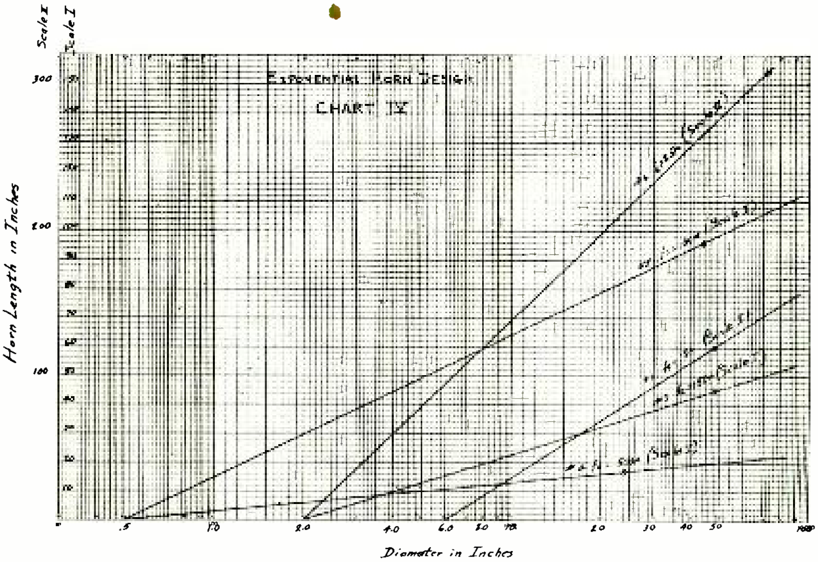

Chart IV

$m = .182$ from Chart I, then from Chart III, $L = 16.7$ inches. The contour line is shown on Chart IV.

To cover cases in which it is desired to design a horn from "scratch", and where it is sometimes difficult to decide where to start, the following method is suggested, and an example is given.

1. Determine the cut-off frequency. This is usually fixed somewhere below a certain frequency, by other requirements of the system.

2. Find the taper required by this cut-off frequency, Chart I.

3. As the throat diameter is usually fixed, select a limiting value of mouth diameter, either from physical considerations, or acoustic requirements. The latter are mainly smoothness of response near cut-off, and directional characteristic. It is generally desirable to make the

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mouth diameter as large a fraction as possible of the wavelength of the lowest transmitted frequency. The directional effect of the lower frequencies increases with mouth area.

4. From the ratio, $R = \frac{D_m}{D_t}$, and the taper m, determine the length necessary. Charts II and III.

5. With D_t and D_m as abscissæ on the log scale, plot against ordinates $L = 0$ and $L =$ length, respectively, and connect with a straight line.

6. Select diameters of various sections of the horn as desired, and find corresponding values of L, or distance from throat, from this straight line.

Example No. 5. A horn is needed for a driving mechanism having a ½ inch diameter throat and must have a cut-off frequency of 100 cycles.

The maximum allowable mouth diameter is 44 inches. What is the length necessary, and how does the contour change with length?

As the ratio $D_m/D_t = 88$, and the taper is found to be .0365, from Chart III, $L = 96$ inches. Curve 5 on Chart IV is drawn from the known points ($D_t = ½$, $L = 0$) and ($D_m = 44$, $L = 96$) and gives all the points on the horn contour necessary to determine the design.

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CARRIER AND SIDE-FREQUENCY RELATIONS WITH MULTI-TONE FREQUENCY OR PHASE MODULATION

BY

MURRAY G. CROSBY

R.C.A. Communications, Inc., Riverhead, N. Y.

Summary—*The equation for the carrier and side frequencies of a frequency or phase-modulated wave is resolved for the case of two applied modulating tones. It is shown that when more than one modulating tone is applied, the amplitude of the carrier is proportional to the product of the zero-order Bessel Functions of all of the modulation indexes involved. The amplitudes of the side frequencies are proportional to the products of Bessel Functions equal in number to the number of tones applied and having orders respectively equal to the orders of the frequencies involved in the side frequency. Beat side frequencies are produced which have higher-order amplitude and do not appreciably widen the band width occupied by frequency modulation.*

PREVIOUS analyses of the carrier and side-frequency relations in frequency and phase modulation have considered either the case of a single tone as applied modulation,[1,2,3] or the case of telegraph transmission[2] where the Fourier resolution shows a tone and its harmonics to be present. It is the purpose of this paper to develop the equations for the carrier and side frequencies so that their characteristics will be known when more than one modulating tone is applied.

In amplitude modulation the addition of a second modulating tone merely produces an additional pair of side frequencies which are displaced from the carrier frequency by the frequency of the tone. These side frequencies have amplitudes which are linearly proportional to the carrier amplitude and the depth of modulation at which the tone is applied (assuming a linear modulator). However, in frequency and phase modulation this linear relation between the depth of modulation and the amplitudes of the side frequencies does not exist and a separate development is required for the multi-tone case.

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[1] John R. Carson, "Notes on the Theory of Modulation," *Proc. I.R.E.*, Vol. 10, pp. 57-64, Feb. 1922.

[2] Balth. Van der Pol, "Frequency Modulation," *Proc. I.R.E.*, Vol. 18, pp. 1194-1205, July 1930.

[3] Hans Roder, "Amplitude, Phase, and Frequency Modulation," *Proc. I.R.E.*, Vol. 19, pp. 2145-2176, Dec. 1931.

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In the case of frequency modulation the instantaneous frequency for the two-tone case is given by:

$$f = F_c + F_{dp} \sin pt + F_{dq} \sin qt \tag{1}$$

where F_c = the carrier frequency, F_{dp} = frequency deviation applied by the tone having angular velocity p and F_{dq} = frequency deviation applied by the tone having angular velocity q.

Since the instantaneous frequency is the rate of change of phase, (1) must be integrated to find the phase angle.

$$\omega t = 2\pi \int_0^t (F_c + F_{dp} \sin pt + F_{dq} \sin qt)\, dt$$

$$= \omega_c t - \frac{F_{dp}}{F_{mp}} \cos pt - \frac{F_{dq}}{F_{mq}} \sin qt \tag{2}$$

where F_{mp} and F_{mq} = the modulation frequencies of the tones and $\omega_c = 2\pi F_c$.

If, for simplification $F_{dp}/F_{mp} = P$ and $F_{dq}/F_{mq} = Q$, the frequency modulated wave is:

$$e = E \sin (\omega_c t - P \cos pt - Q \cos qt) \tag{3}$$

Equation (3) could also represent a phase-modulated wave in which $P = \phi_p$ and $Q = \phi_q$, where ϕ_p and ϕ_q are the phase deviations applied by the tones.

By applying the addition formula for the sine to Equation (3), the following is obtained.

$$\begin{aligned} e = E \sin \omega_c t\, [&\cos (P \cos pt) \cos (Q \cos qt) - \sin (P \cos pt) \\ &\sin (Q \cos qt)] - \cos \omega_c t\, [\sin (P \cos pt) \cos (Q \cos qt) \\ &+ \cos (P \cos pt) \sin (Q \cos qt)] \end{aligned} \tag{4}$$

Substituting the following Bessel Function expansions in Equation (4),

$$\cos (x \cos \phi) = J_0(x) - 2J_2(x) \cos 2\phi + 2J_4(x) \cos 4\phi - \ldots\ldots. \tag{5}$$

$$\sin (x \cos \phi) = 2J_1(x) \cos \phi - 2J_3(x) \cos 3\phi + 2J_5(x) \cos 5\phi - \ldots. \tag{6}$$

obtaining the products of the series, applying the addition formulas for the sine and cosine, and rearranging gives:

$$\begin{aligned} e = E\, [&J_0(P)\, J_0(Q) \sin \omega_c t - J_1(P)\, J_0(Q) \cos (\omega \pm p)\, t \\ &- J_2(P)\, J_0(Q) \sin (\omega \pm 2p)\, t \end{aligned}$$

$$
\begin{array}{l}
+ J_3(P)\ J_0(Q) \cos (\omega \pm 3p)\ t \\
+ J_4(P)\ J_0(Q) \sin (\omega \pm 4p)\ t \\
- \dots\dots\dots\dots\dots\dots \\
\\
- J_0(P)\ J_1(Q) \cos (\omega \pm q)\ t \\
- J_0(P)\ J_2(Q) \sin (\omega \pm 2q)\ t \\
+ J_0(P)\ J_3(Q) \cos (\omega \pm 3q)\ t \\
+ J_0(P)\ J_4(Q) \sin (\omega \pm 4q)\ t \\
- \dots\dots\dots\dots\dots\dots
\end{array}
$$

$$
\begin{array}{l}
- J_1(P)\ J_1(Q)\ [\sin (\omega + p \pm q)\ t + \sin\ (\omega - p \pm q)\ t] \\
+ J_1(P)\ J_2(Q)\ [\sin (\omega + p \pm 2q)\ t + \sin\ (\omega - p \pm 2q)\ t] \\
+ J_1(P)\ J_3(Q)\ [\sin (\omega + p \pm 3q)\ t + \sin\ (\omega - p \pm 3q)\ t] \\
- \dots\dots\dots\dots\dots\dots\dots\dots \\
\\
+ J_2(P)\ J_1(Q)\ [\sin (\omega + 2p \pm q)\ t + \sin\ (\omega - 2p \pm q)\ t] \\
+ J_2(P)\ J_2(Q)\ [\sin (\omega + 2p \pm 2q)\ t + \sin (\omega - 2p \pm 2q)\ t] \\
- J_2(P)\ J_3(Q)\ [\sin (\omega + 2p \pm 3q)\ t + \sin (\omega - 2p \pm 3q)\ t] \\
- \dots\dots\dots\dots\dots\dots\dots\dots \\
\\
+ J_3(P)\ J_1(Q)\ [\sin (\omega + 3p \pm q)\ t + \sin\ (\omega - 3p \pm q)\ t] \\
- J_3(P)\ J_2(Q)\ [\sin (\omega + 3p \pm 2q)\ t + \sin (\omega - 3p \pm 2q)\ t] \\
- J_3(P)\ J_3(Q)\ [\sin (\omega + 3p \pm 3q)\ t + \sin (\omega - 3p \pm 3q)\ t] \\
+ J_3(P)\ J_4(Q)\ [\sin (\omega + 3p \pm 4q)\ t + \sin (\omega - 3p \pm 3q)\ t] \\
+ \dots\dots\dots\dots\dots\dots\dots\dots \\
\\
- J_4(P)\ J_1(Q)\ [\sin (\omega + 4p \pm q)\ t + \sin\ (\omega - 4p \pm q)\ t] \\
- J_4(P)\ J_2(Q)\ [\sin (\omega + 4p \pm 2q)\ t + \sin (\omega - 4p \pm 2q)\ t] \\
+ J_4(P)\ J_3(Q)\ [\sin (\omega + 4p \pm 3q)\ t + \sin (\omega - 4p \pm 3q)\ t] \\
+ \dots\dots\dots\dots\dots\dots\dots\dots \\
\\
- J_5(P)\ J_1(Q)\ [\sin (\omega + 5p \pm q)\ t + \sin\ (\omega - 5p \pm q)\ t] \\
+ J_5(P)\ J_2(Q)\ [\sin (\omega + 5p \pm 2q)\ t + \sin (\omega - 5p \pm 2q)\ t] \\
+ \dots\dots\dots\dots\dots\dots\dots\dots
\end{array}
\qquad (7)
$$

From (7) it can be seen that the amplitude of the carrier is proportional to the product of the zero-order Bessel Functions of the two quantities P and Q which would be the modulation index (F_{dp}/F_{mp} or F_{dq}/F_{mq}) for frequency modulation, or the deviation in radians (ϕ_p or ϕ_q) for phase modulation. The side frequencies present are not only those which would be present with one tone on at a time, but include beat side frequencies which are produced in a manner similar to the way in which beat frequencies are produced in a detector. The amplitudes of these beat side frequencies are equal to the products of Bessel Functions having orders equal to orders of the tone frequencies involved in the side frequency.

A similar resolution for the three-tone case shows that the carrier is proportional to the product $J_0(P)\ J_0(Q)\ J_0(R)$ where R is the modulation index of the third modulating tone. The beat side frequencies are produced in the same manner with more possible combinations, but with their amplitudes proportional to three Bessel Functions the

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orders of which depend upon the orders of the tone frequencies involved in the side frequency. Thus it may be assumed that as the number of tones increases, the number of Bessel Functions in the amplitude coefficients increase in the same accordance while the number of side frequencies increases at a very high rate due to the great number of beat combinations which are possible.

Since side frequencies are produced which are displaced from the carrier by the sum of all the tone frequencies involved, it might be assumed that the band width occupied by frequency modulation is rather alarming. However, investigation of the amplitudes of these beat side frequencies shows that their amplitudes are rather small as far as out-of-band interference is concerned and that the major portion of the side bands remain in a channel approximately equal to twice the frequency deviation or the maximum modulation frequency whichever is the greatest. The reason for this is that when two tones are applied the frequency deviation is divided between the two tones so that the modulation indexes are made lower than the index which would exist with a single tone. The Bessel Functions of these indexes are also low so that the resultant amplitude coefficient is made quite small since it is the product of two rather low quantities. For instance, take the case of a frequency modulation system with a deviation ratio[4] of unity and a maximum modulation frequency of ten kilocycles. If an eight-kilocycle tone were applied at full deviation (ten kilocycles) the first-order side frequency would have an amplitude of 0.51 and the second order 0.17. Now if the deviation were equally divided between an eight-kilocycle tone and a nine-kilocycle tone, their first-order side frequencies would have amplitudes of 0.298 and 0.268, respectively, the second-order side frequencies 0.048 and 0.038, respectively, while the beat side frequency corresponding to the sum of the two-tone frequencies would have an amplitude of 0.08. Thus, dividing the deviation between the two tones reduces the second-order side-band out-of-channel interference and produces a beat side frequency having an amplitude which is less than that of the single-tone second-order side frequency. Hence, it can be seen that the greater the number of frequencies present in the modulating wave, the more will the wave be confined to its channel. This is especially true for the case of program or voice modulation where the lower modulating frequencies have the highest amplitudes. It is also especially true for the case of the frequency-modulation systems with the higher deviation ratios.

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[4] The deviation ratio referred to here is the ratio between the maximum frequency deviation the system is capable of and the maximum modulation frequency for which the system is designed. This factor might be called the "system" deviation ratio. For further information regarding the deviation ratio see the following reference: Murray G. Crosby, "Frequency Modulation Noise Characteristics," *Proc. I.R.E.*, Vol. 25, pp. 472-514, April, 1937.

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GRAPHICAL SOLUTIONS FOR A TRANSMISSION LINE TERMINATED BY AN ARBITRARY COMPLEX LOAD IMPEDANCE

BY

WALTER VAN B. ROBERTS

Patent Department, Radio Corporation of America

IN THE days when radio wave lengths were measured in thousands of meters, wires were just wires and capacities and inductances as a consequence were found only in big condensers and coils. Now, however, we are using, for long distance communication and for television, wave lengths so short that connecting wires between different parts of a transmitting station for example must be considered as transmission lines rather than mere connections. Where such connecting lines are long compared to a wave length, as in the case of the line conveying radio-frequency power from a transmitter to its antenna, it is important for the purpose of minimizing losses in the line to arrange to have the line terminated by a pure resistance equal to its characteristic impedance. Otherwise waves are reflected back along the line to produce standing waves which uselessly dissipate power. In most cases the impedance of the antenna or other load fed by the line does not satisfy the requirement mentioned above so it becomes necessary to interpose some device that will "tune out" the reactive component of the load impedance and also transform its resistive component to a value equal to the line impedance. Perhaps the simplest device for this purpose is a short section of line similar in nature to the main transmission line, but of different characteristic impedance. Usually there is some combination of characteristic impedance and length for this matching section (and the length never need be as great as half a wave length) which will produce the desired result. Unfortunately there is no simple rule for determining what the necessary characteristics of this matching section are for any arbitrary load. It is the object of the accompanying charts to make at least an approximate solution of this problem relatively simple.[1] The charts may also be used for related calculations where a matching section of line is terminated by a load. For instance, if the constants of the matching section and load are specified completely, Chart I gives the resulting

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[1] For another graphical treatment of transmission line problems see Roder, *Proc. I.R.E.*, Feb., 1933.

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input impedance at the input terminals of the matching section. Or, if the load and the characteristic impedance of the matching section are given, the length required to make the impedance at the input terminals of the matching section a pure resistance may be obtained, together with the value of this resistance, from Chart II, and so on.

The charts as reproduced herewith are too small for very accurate results, and there are not enough curves drawn for each family to insure great accuracy of interpolation. The chief virtue of the curves used in the charts, however, is that they are mostly circles and in every case may be drawn up easily with ordinary drawing instruments. Hence for accurate computations the actual charts may be considered merely as illustrative of the method and the particular curves appropriate to any given problem may be drawn on a large scale. For example, to anticipate the description of the charts, let us suppose we are using Chart II and want to read accurately the quantities determined by the circles intersecting at the point 2, 2. None of the curves shown on the chart pass through this point. But all that is required is to draw a circle passing through this point and cutting the horizontal axis at points which are reciprocals of each other. Then these reciprocal values are the exact numbers applicable to the circle. Similarly another circle is drawn through the point 2, 2 and cutting the vertical axis at points that are negative reciprocals of each other. Again the numbers applicable to this second circle are given by its intercepts with the vertical axis. (The second circle may alternatively be defined as the circle the center of which is on the vertical axis and which cuts the point 1, 0 as well as the given point 2, 2). In similar fashion it will be obvious how to draw any intermediate curve desired on any of the other charts.

PART I

The arrangement considered in what follows is shown in Figure 1. In the case where the load is a pure resistance and the line is an exact multiple of a quarter-wave length the results are simple and well known. In the general case, however, analytical methods are rather tedious and in order to facilitate the approximate solutions of the general case Chart I was developed from the basic equation of the system in its alternative forms 1, 2, and 3.

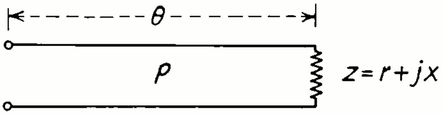

Fig. 1

$$Y/\sigma = \frac{\rho + jz \tan\theta}{z + j\rho \tan\theta} \tag{1}$$

$$Y/\sigma = z/\rho + \frac{1 - (z/\rho)^2}{z/\rho + j \tan\theta} \tag{2}$$

$$Y/\sigma = j \tan\theta + \frac{1 + \tan^2\theta}{z/\rho + j \tan\theta} \tag{3}$$

where Y = input admittance, θ = the electrical length, ρ = the characteristic impedance of the line, and $\sigma = 1/\rho$.

It is well known that if a point traces a straight line in the complex plane, its reciprocal traces a circle passing through the origin of the complex plane. By varying θ in Equation (2) we find that the locus of Y/σ is a circle in the complex plane with its center on the real axis. This circle passes through the point z/ρ and cuts the real axis at inverse points. This same circle is the locus of Y/σ for all values of z/ρ that lie on the circle. Hence if we plot a family of circles cutting the real axis at inverse points we need to select only the one that passes through the given value of z/ρ to obtain the locus of Y/σ as θ varies. As $\tan\theta$ varies from $-\infty$ to $+\infty$ the resulting value of Y/σ always travels clockwise around the circle starting from the point z/ρ.

On the other hand if we use Equation (3) and let x vary, the locus of Y/σ is a circle tangent to the vertical axis and having its center on a parabola defined by the equation

$$\text{Abscissa} = \frac{1/2}{r/\rho} \left[1 + (\text{ordinate})^2\right]$$

The center of the circle is at the point on the parabola the ordinate of which is $\tan\theta$. The lower branch of the parabola thus corresponds to negative values of $\tan\theta$. In this case the value Y/σ always travels clockwise around the circle starting from the point of tangency with the vertical axis. Let us call such a circle a "θ circle".

We now have two circles, the first determined solely by the given value of z/ρ and the second determined by the given values of r/ρ and θ. Both circles represent Y/σ so their intersection is a point where Y/σ has a value corresponding to the given values of x and θ. It will be noted that there are always two intersections. Since x increases algebraically as the θ circle is traced clockwise, the second intersection that is met when one traces the θ circle clockwise from its point of tangency to the vertical axis must correspond to a positive value of x while the other intersection corresponds to a negative value of x.

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The use of Chart I is perhaps most readily explained by means of a numerical example. Suppose we have given $z/\rho = 0.5 + 0.9j$ and $\tan\theta = 1.6$. Then the given value of z/ρ determines the circle that cuts the real axis at the point 4. Next, at a height 1.6 on the parabola marked $r/\rho = 0.5$ place the point of a pair of dividers and adjust the dividers to trace a circle tangent to the vertical axis. Follow this circle clockwise from the point of tangency around to the second (since the value of x was positive) intersection with the first mentioned circle. The second intersection is found to be at the point $0.28 + 0.2j$ which is therefore the value of Y/σ that results from the given load and line.

By suitable variations of the same method other problems may be solved such as for example to find the length of line required to obtain some desired one of the values of Y/σ that can result from a given load and line impedance. In particular it might be required to find the length of line that will make Y/σ a real quantity. That problem, however, may be more readily handled by the use of Charts II or III.

In any case it is a good idea to check any results obtained from the chart by substitution in the basic Equation (1).

PART II

Chart II is primarily for the purpose of determining for a given load and matching section impedance what length of line will make the input a pure resistance, and what the resistance is. Chart III is identical with Chart II except that its scale is increased to permit more accurate readings in the region of the greatest practical interest. The arrangement considered is again shown in Figure 2 and the Equations (4), (5), and (6) are the equations used in constructing the charts.

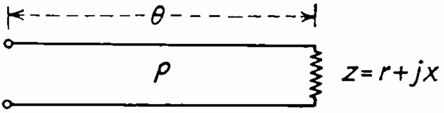

Fig. 2

$$\frac{\text{Input Impedance}}{\rho} = \frac{z + j\rho\tan\theta}{\rho + jz\tan\theta} \tag{4}$$

$$\tan\theta = \frac{1 - [(r/\rho)^2 + (x/\rho)^2]}{2\,x/\rho} \pm \sqrt{\left\{\frac{1 - [(r/\rho)^2 + (x/\rho)^2]}{2\,x/\rho}\right\}^2 + 1} \tag{5}$$

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$$R/\rho = \frac{r/\rho\ (1 + \tan^2 \theta)}{(1 - x/\rho \tan \theta)^2 + (r/\rho \tan \theta)^2} \qquad (6)$$

Equation (5) gives the length of line that makes the input impedance a pure resistance.

Equation (6) gives the input resistance, R, when the length of line is that determined by Equation (5).

From Equation (4) it is found that as θ varies the ratio of input impedance to line impedance it traces a circle in the complex plane the center of which is on the real axis and which passes through the point z/ρ and cuts the real axis at inverse points. Any value of z/ρ lying on this circle generates the same circle. Chart II contains a family of circles cutting the real axis at inverse points so that for any given value of z/ρ it is only necessary to select the circle passing therethrough to obtain the locus of all possible values of the ratio of input impedance to line impedance obtainable by varying θ. Two of these values are real and numerically equal to the abscissae of the points of intersection of the circle with the real axis.

From Equation (5) we find that for any value of z/ρ there are two possible values of $\tan \theta$ both of which make the input impedance real. The two values are negative reciprocals of each other so one merely represents an extra quarter-wave length of line as compared to the other. The positive value corresponds to the shortest length of line that makes the input impedance real. If $\tan \theta$ is fixed at a given value, Equation (5) when plotted, shows that z/ρ must lie on a circle the center of which is on the vertical axis and which cuts the vertical axis at a point having the ordinate $\cot \theta$ and also at a point having the ordinate $-\frac{1}{\cot \theta}$. The chart gives a family of such circles. It will be seen that a change in sign of x in Equation (5) alters the signs of the two possible values of $\tan \theta$. Hence the rule:

If x is positive, either (a) the first of the two marked numbers on each of the families is used, or, (b) the second number on each family is used. The latter combination corresponds to a line a quarter-wave length longer than is necessary to make the input impedance real.

If x is negative, either (a) use the first number on the θ curves together with the second number on the R/ρ curves, or, (b) use the second number on the θ curves together with the first number on the R/ρ curves. Here again the combination (b) corresponds to a line a quarter-wave longer than combination (a).

The chart essentially provides a graphical solution of Equations (5) and (6). Since a given value of z/ρ establishes both a θ circle and

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an R/ρ circle, both these quantities may be read directly from the numbers on the circles that intersect at any given value of z/ρ, using the rules given above for choosing which of the numbers on each circle to read.

As an example of the use of the chart in this manner let us suppose we have given $\rho = 200$, $r = 100$, and $x = 300$. Hence, $z/\rho = 0.5 + 1.5j$. This point lies approximately on the circle for which $\cot\theta = 1.6$ and also on the circle $R/\rho = 7$. Hence if the length of the line is made $\cot^{-1} 1.6$ the input impedance will be a pure resistance of 1400 ohms. On the other hand, if we had used the second number on each circle we would have found $\theta = \cot^{-1}(-0.625)$ and the input resistance would have been 28.6 which is, of course, just the change introduced by adding an extra quarter-wave of line.

If R, ρ, and r are given, suitable values of x and θ may be found. For example let $R = 600$, $\rho = 150$, and $r = 150$ whence $r/\rho = 1$ and $R/\rho = 4$.

The $R/\rho = 4$ circle cuts the value $r/\rho = 1$ at the point $1 + 1.5j$ which at once tells us that $\theta = \cot^{-1} 2$ and $x/\rho = 1.5$. On the other hand there is also the other intersection which gives as a possible value $x/\rho = -1.5$. Since this is negative we use the second number on the θ circle and find $\theta = \cot^{-1}(-2)$. It will be seen that the negative value of x requires a line just as much longer than a quarter-wave length as the line required by the positive value of x is shorter than a quarter-wave length. It is also evident that no solution is possible unless $r/\rho > \rho/R$.

If ρ is unknown, but R and z are given, one way to find ρ is to assume a few values for ρ and try them as explained in the preceding example until a value is hit upon that yields the desired value of R.

However, to avoid this cut and try process, Charts IV and V have been derived from the family of circles of Chart II by dividing each circle of the latter family by one or the other of the numbers marked thereon.

Chart V is the same as Chart IV except that the scale is changed to permit reading further on the right-hand side of the chart. To use these charts, plot z/R and read directly from the member on the circle passing there-through the required value of ρ/R. Since R is known, this gives ρ. Knowing ρ, the required length of line may be obtained from Chart II or III as before. As an example, let us suppose $R = 600$ and $z = 240 + 180j$. Then $z/R = 0.4 + 0.3j$ and this point on Chart IV falls on the circle marked 0.5. Hence, $\rho = 300$. This gives $z/\rho = 0.8 + 0.6j$ whence, from Chart III $\cot\theta = 1$ and $R/\rho = 2$ or $R = 600$ which latter of course we already know. The first number on the θ circle is used

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because it is the first number on the R/ρ circle that brings us back to the desired value of R. Note that if z/R falls to the left of the line tangent to the two families of circles, and outside the limiting dotted circle of the left hand family, no single-matching section can convert the given load z into the desired resistance R. This, however, does not mean that z cannot be transferred into some pure resistance, and the latter in turn transformed into the desired resistance by a suitable quarter-wave line in the well-known way.

The foregoing examples should make the procedure for solving other problems obvious. Again, however, it is well to check the results obtained, by substitution in the general formula of Equation (4).

Although it has no bearing on the use of the charts it is interesting to note that Chart II is the right-hand half of the map of the equipotentials and lines of force due to a pair of oppositely-charged parallel cylinders, the right-hand cylinder coinciding with any one of the R/ρ circles of the chart. In other words, following the method of conjugate functions (see Jeans' Electricity and Magnetism, pages 261 to 268 for example) the transformation $U + jV = \log \dfrac{z-1}{z+1}$ gives rise to exactly the same curves as Chart II. This transformation permits the calculation of the capacity per unit length between two parallel-cylindrical conductors such as ordinarily used in transmission lines. It must, however, be merely a mathematical coincidence that this is the case, for there was no assumption made that the transmission line treated in the charts was composed of such conductors. The charts apply equally well to any shape of conductors since only the characteristic impedance entered into the basic formulae.

The above-mentioned transformation leads to a value of capacity, in cms per cm length, given by the expression $\dfrac{1}{4 \cosh^{-1} s/d}$ between round conductors of diameter d spaced s between centers. The same transformation can be used to obtain the capacity between parallel cylinders of unequal diameter, either external to each other or with one located eccentrically within the other like the R/ρ circles of Chart II.

If it is assumed that electric waves travel along the conductors with the velocity of light, the inductance per unit length follows from the capacity and the characteristic impedance is, therefore, thirty times the reciprocal of the capacity per unit length, the impedance being in ohms, the capacity being cms, and the unit length being in cm. Hence for parallel-round conductors the characteristic impedance is 120 $\cosh^{-1} s/d$.

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This formula seems just as simple as the usual formula $120 \log_e \frac{2s}{d}$ and has the advantage of giving physically reasonable results for values of s/d approaching unity while the log formula incorrectly indicates a lower limit of about 84 ohms even for infinitesimally small separation between conductors.

METHODS OF USING CHARTS

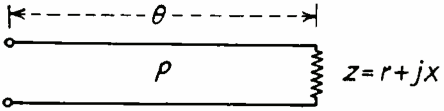

Fig. 3

CHART I

Y = Input admittance
ρ = Line impedance
θ = Electrical length of line
z = Complex load impedance
$\sigma = 1/\rho$

Primary purpose of chart: to determine Y, the quantities ρ, θ, and z being known. Considering the chart as the complex plane with the real axis horizontal and the imaginary axis vertical, plot the point z/ρ using the coordinate scales marked on the chart, and note the circle on which this point falls. Next pick out the parabola marked with the given value of r/ρ, r being the resistance component of z. Pick out the point on this parabola having vertical-coordinate $\tan \theta$. With this point as a centre, draw lightly in pencil a circle tangent to the vertical axis at the left of the chart. This circle intersects the first-mentioned circle at two points. If the reactive component of z was inductive, the second point of intersection encountered when tracing the pencilled circle clockwise from its point of tangency has coordinates which are the real and imaginary parts of Y/σ. But if the reactive part of z was condensive, the other intersection gives Y/σ.

METHOD FOR USING CHARTS II OR III

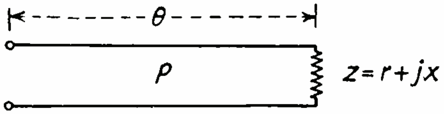

Fig. 4

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Given a line of characteristic impedance ρ terminated by a complex load impedance z, to determine what electrical length θ of the line will make its input impedance a pure resistance, and to determine the value of this resistance.

Considering the chart as a complex plane with real coordinates marked on the horizontal axis and imaginary coordinates those marked on the vertical axis, plot the point z/ρ. Read the values of cot θ and R/ρ from the numbers on the two circles that intersect at this point. There are always two sets of results. If the reactance component of z was inductive, one set of results is obtained by reading the first number on each of the circles and the other set of results is obtained by reading the second number on each of the circles. If the reactance was capacitive, read the first number on one circle together with the second number on the other circle, thus again obtaining two possible sets of results.

METHOD FOR USING CHARTS IV OR V

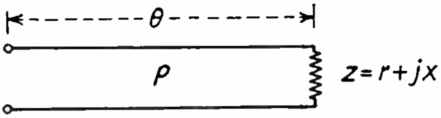

Fig. 5

To determine what value of characteristic impedance ρ of line is required to transform a given complex load impedance z into a given pure resistance R:

Considering the chart as a complex plane with real coordinates marked along the horizontal axis and imaginary coordinates marked on the vertical axis, plot the point z/R and read ρ/R from the circle passing through this point.

If the point z/R falls outside the dash-line circle and has a real part less than unity, no solution is possible.

To find the required length of line, use the value of ρ found as above and apply Chart II or III.

More circles may be added by noting that the number on each circle is the square root of the value of its intercept with the axis.

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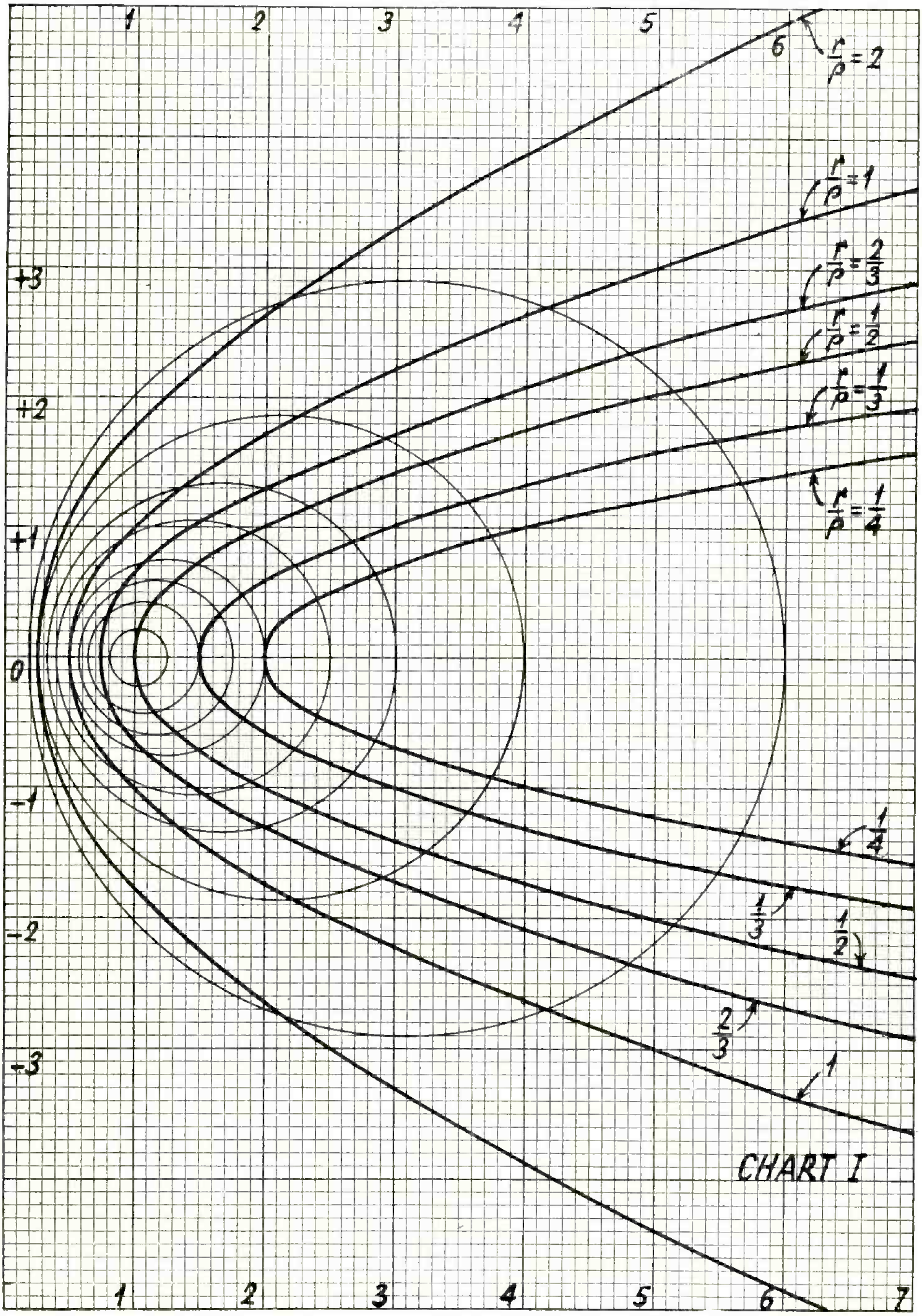
1
2
3
4
5
6
$\frac{r}{p}=2$
$\frac{r}{p}=1$
$\frac{r}{p}=\frac{2}{3}$
$\frac{r}{p}=\frac{1}{2}$
$\frac{r}{p}=\frac{1}{3}$
$\frac{r}{p}=\frac{1}{4}$
+3
+2
+1
0
-1
-2
-3
$\frac{1}{4}$
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1
CHART I
1
2
3
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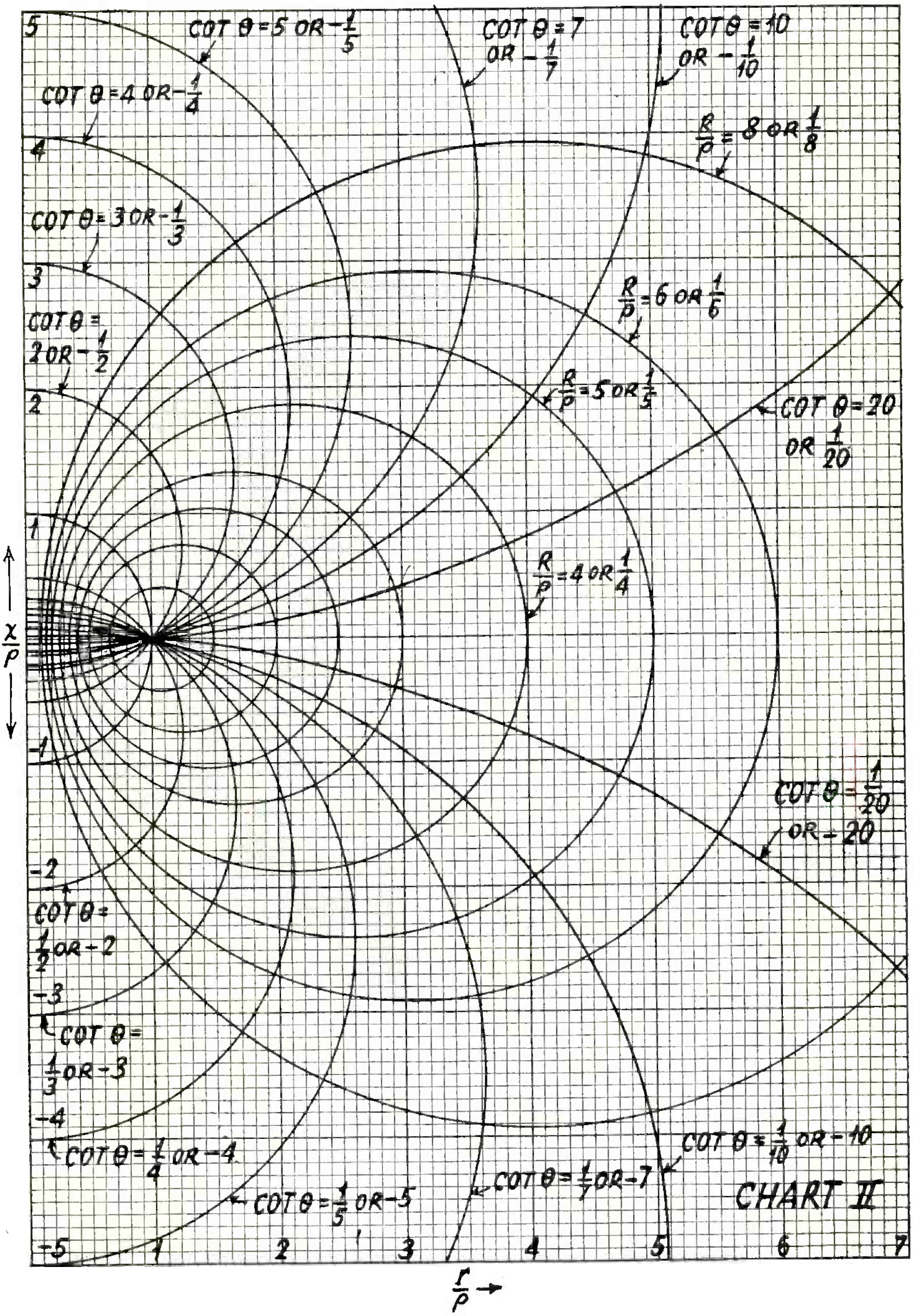

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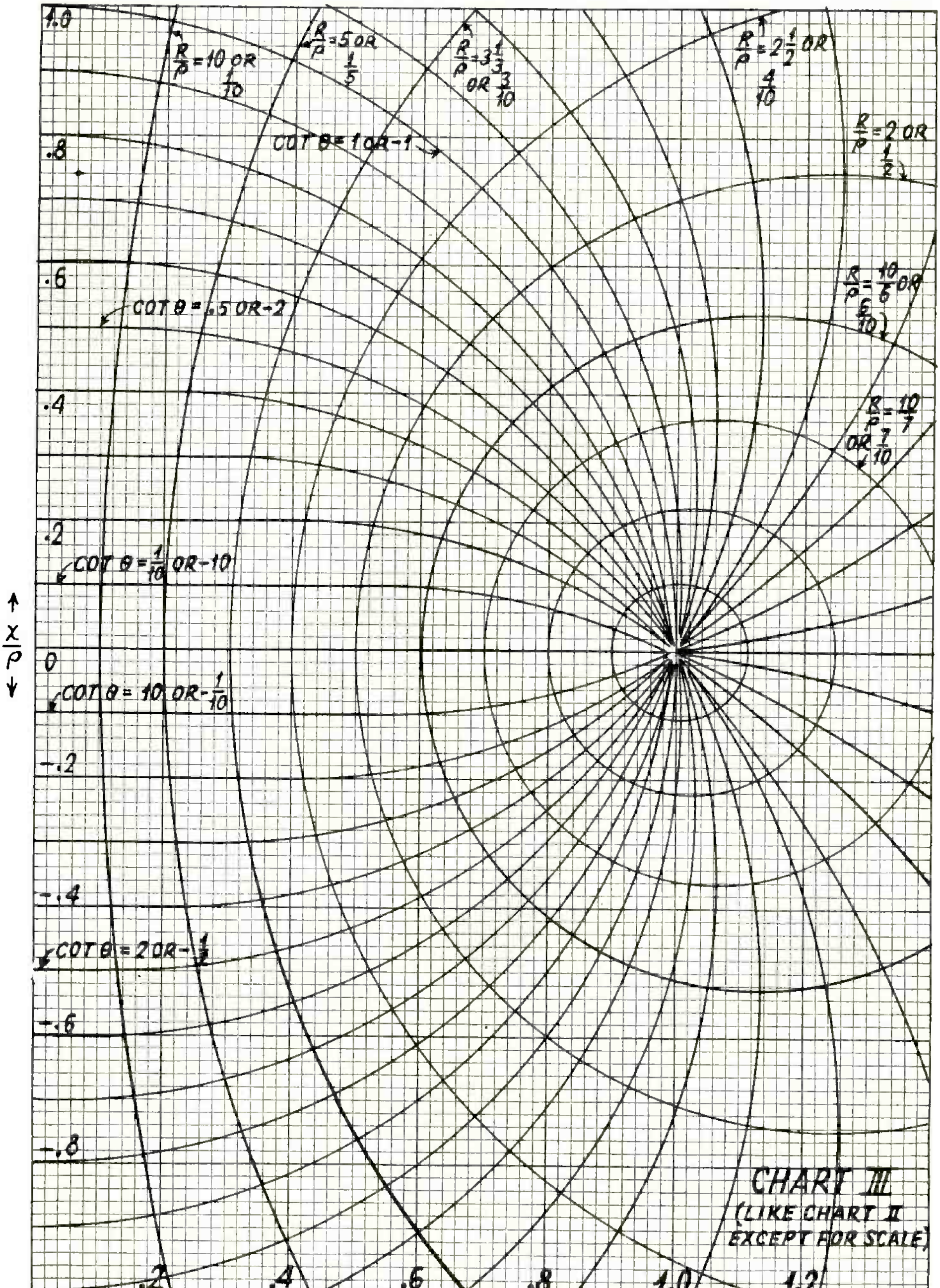

CHART III (LIKE CHART II EXCEPT FOR SCALE)

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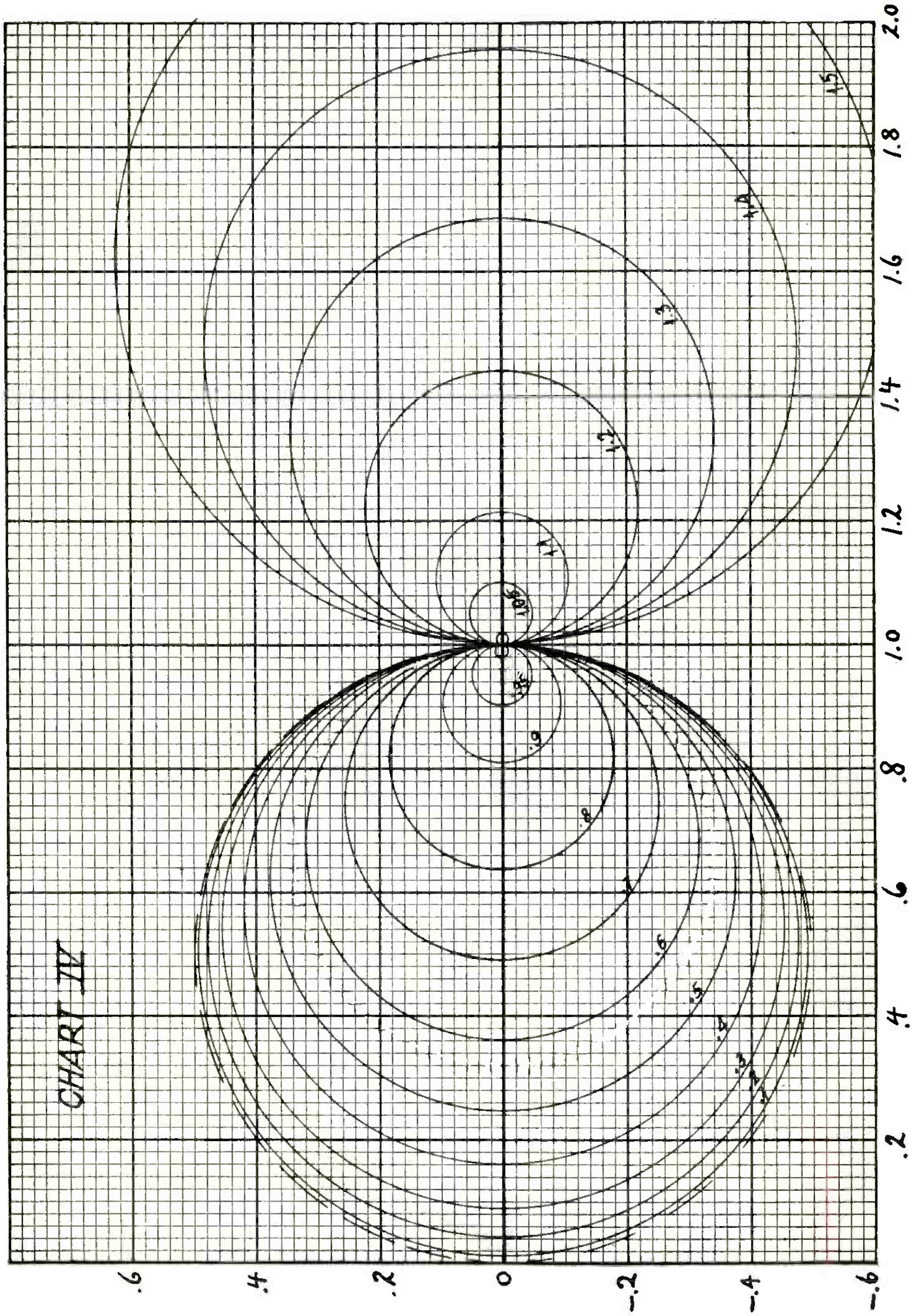

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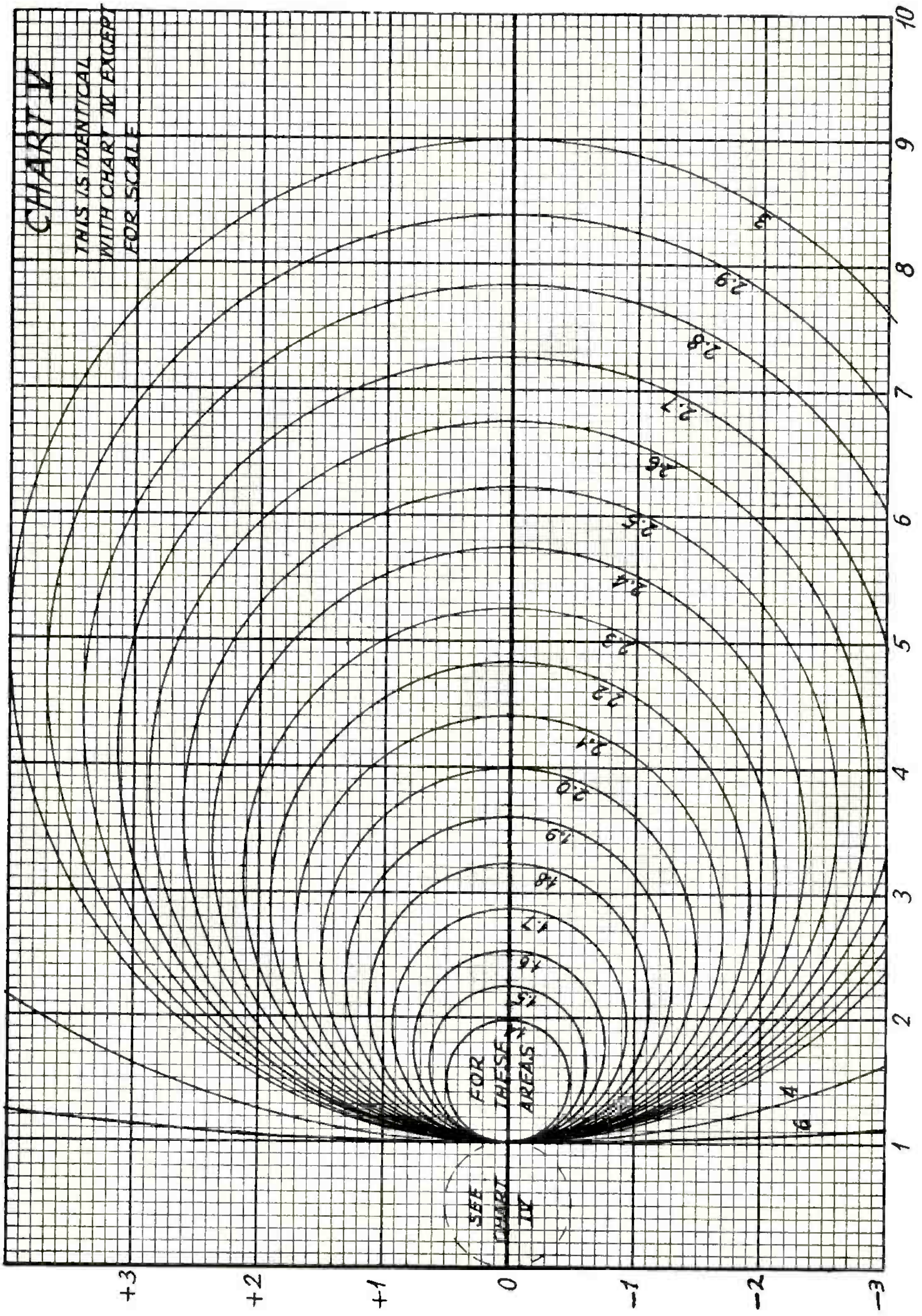

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LINEAR RECTIFIER DESIGN CALCULATIONS

By

EDMUND A. LAPORT

High Power Section, Transmitter Engineering Department
RCA Manufacturing Company, Inc., Camden, N. J.

LINEAR diode rectifiers are widely employed for monitoring radio telephone transmissions. The diode itself is a non-linear device, the internal resistance of which decreases as the anode voltage is increased. To make a diode rectifier linear, resistance is added in the plate circuit. When the added resistance is very large with respect to the diode resistance at any point in its operating range, the resultant plate current as a function of applied voltage approaches linearity. The problem in design is to determine the degree of linearity resulting from various values of added resistance, and from that the intrinsic distortion of the rectifier.

The problem is enlarged as the degree of modulation to be monitored approaches unity. It is further complicated as the tolerance on intrinsic distortion is lowered, such as when the rectifier is used to measure small amounts of envelope distortion in high-quality broadcast transmitters and for stabilized feedback service between antenna and the input to the audio system. It is extremely difficult to test a linear rectifier for distortion because of the necessity of obtaining a carrier wave with zero envelope distortion at all amplitudes of modulation. For this reason, intrinsic distortion must be determined by calculation.

The usual method of design is to plot the diode characteristic in Cartesian coordinates, with plate current as a function of applied voltage, from published characteristics or from measurements; then, with arbitrary values of added resistance, to plot a new function by adding the drop in the external resistance to that of the tube for all values of plate current. This done, one attempts to determine the actual linearity of the resulting dynamic characteristic.

This procedure may be outlined briefly in the following manner, with the aid of Figure 1.

The voltage drop in the tube is known from published data, which are in the form

$$i_p = K e_p^{x}$$

Both K and x are obtainable from the static characteristic of the diode.

Upon attempting to formulate procedure, it becomes evident that to obtain E as a function of i_p is much easier than the desired reversed form. The above formula can be solved for e_p, which becomes

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$$e_p = \sqrt[x]{\frac{i_p}{K}} \qquad \text{(tube drop)}$$

and

$$e_r = i_p R_o \qquad \text{(resistor drop)}$$

The dynamic characteristic, obtained by adding the tube and resistor drops, is therefore

$$E = f(i_p) = \sqrt[x]{\frac{i_p}{K}} + i_p R_o$$

Since in reality the applied voltage is the independent variable, and i_p the dependent, the function must be solved for i_p. A straightforward mathematical solution for i_p is impractical so one takes the step graphically, as in Figure 1. When the usual Cartesian coordinate method is employed, the measurement of curvature in the dynamic characteristic becomes impossible long before the intrinsic distortion becomes negligible.

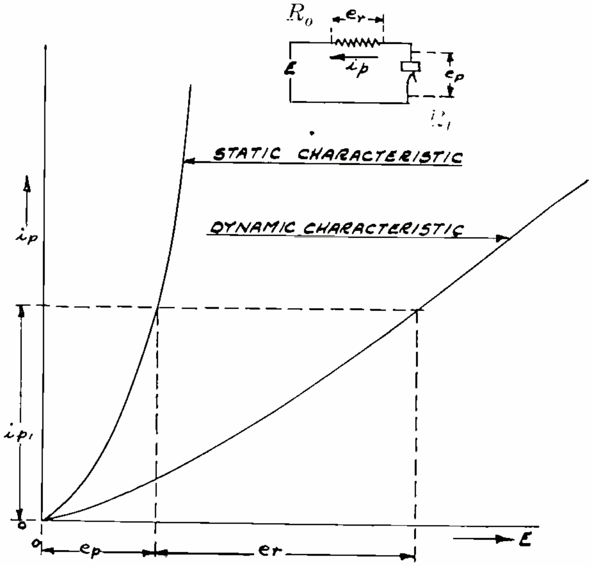

Fig. 1

This difficulty is removed when the same curves are plotted in log-log coordinates. Since all power functions become straight lines in this system, the static characteristic will be a straight line. The exponent x appears as the slope of this line, which for most thermionic diodes is of the order of 1.4 to 1.5, depending on the tube design. We also know that when enough resistance has been added in the circuit to give perfect linearity, the dynamic characteristic will have a slope of unity. The approach to linearity is determinable then by measurement of slope and not of curvature. Slope can be accurately measured when the dynamic characteristic has been carefully plotted.

Experience has shown that dynamic characteristics so plotted for the values of R_o/R_t, required in practical designs, appear as straight lines also, even though their slopes may depart a considerable degree from unity. Academically, the function in question is not a power function, but if after very careful plotting it appears as a straight line

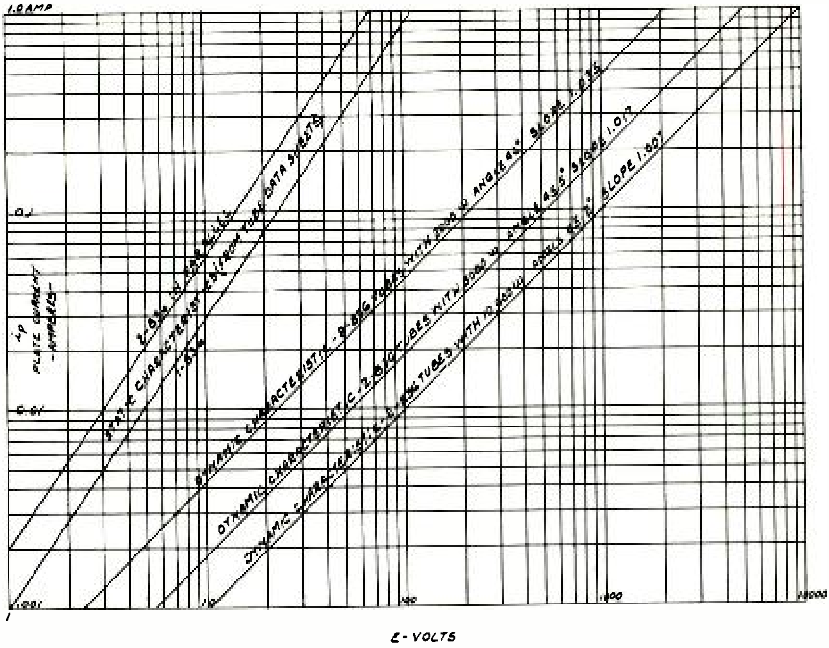

Fig. 2

in log-log coordinates it can be treated as such with negligible error.

Therefore, after carefully plotting the function as outlined, for the full range of i_p, its slope is measured as the tangent of the angle of the line with respect to the E axis. This is represented in Figure 2.

One desires to know, of course, what intrinsic distortion results from a known dynamic characteristic curve. Here again the method described may be extended to yield the necessary information.

As an empirical power function the dynamic characteristic can be written

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$$i_p = AE^y$$

where A is a constant which can be found by solution if desired.
E is the applied voltage.
y is the slope of the dynamic characteristic.

Substitute for E some arbitrary value E_1, upon which is superimposed a sine wave of relative amplitude M and obtain

$$i_p = AE_1\,(1 + M \sin \theta)^y$$

where $1 + M \sin \theta$ is the envelope equation of an amplitude-modulated wave, M being the modulation factor.

The factor $(1 + M \sin \theta)^y$ can be expanded by the generalized binominal theorem. This expansion contains all the information of interest, since A and E_1 merely are present as constant proportionality factors. In the expansion, we obtain

$$(1 + M \sin \theta)^y = 1 + yM \sin \theta + \frac{y(y-1)}{\underline{\lvert 2}} M^2 \sin^2 \theta + \frac{y(y-1)(y-2)}{\underline{\lvert 3}} M^3 \sin^3 \theta \ldots\ldots\ldots$$

Out of these terms, in order, are derived the d-c value, fundamental value, and second, third, etc. harmonics. An interesting quality of the result is that odd harmonics are sine terms and even harmonics are cosine terms. Another interesting result is that a component of d.c. proportional to M^2 is contributed by the $\sin^2 \theta$, a component of fundamental proportional to M^3 is contributed by the $\sin^3 \theta$, etc. Each harmonic amplitude is proportional to M to a power equal to the harmonic order.

In this way, therefore, one can determine at the outset the slope of the dynamic characteristic which must be obtained to keep intrinsic distortion within defined limits, and can proceed by graphical steps to find the added resistance which gives this slope.

Thermionic diodes have one property which compromises this, as well as other methods of analysis of linear rectifiers, in that electron initial velocity and contact difference of potential between anode and cathode materials influence results at low values of current. It is necessary to bias out exactly this static potential for linear rectification at low currents. In design one must carefully avoid energy storage effects which produce biasing and consequently threshold distortion. The typical application requires that the dynamic characteristic for the rectifier pass through the origin of coordinates.

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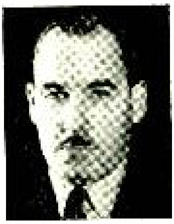
OUR CONTRIBUTORS

ALDA V. BEDFORD attended the University of Texas where he obtained a degree of B.S. in Electrical Engineering in 1925. While there he spent one summer in the employ of the Dallas Power and Light Company and, during the latter part of his term was engaged as assistant in the physics department. He joined the General Electric Company in 1925, starting in the general engineering department and later transferring to the testing department and research laboratories, working on sound recording by film and disc, audio amplifiers, loudspeakers, sound-printers for film, and television. While in Schenectady he obtained an M.S. in E.E. degree from Union College. Since 1929 he has been employed in the laboratories of the RCA Manufacturing Company, first on disc sound recording and then on television.

MURRAY G. CROSBY joined the branch of the Radio Corporation of America which is now R.C.A. Communications, Inc., in 1925. He was engaged in the operating and design departments of that branch until 1926, when he took a leave of absence and returned to the University of Wisconsin for one semester and received his degree of B.S. in Electrical Engineering. Since that time he has remained in the research and development division of R.C.A. Communications, Inc. His work has been mainly on the subject of frequency modulation and he is one of the early workers in that field. Mr. Crosby is a member of the Institute of Radio Engineers.



RAYMOND F. GUY entered the marine service of the Marconi Company in 1916, served on several ships, and resigned in 1918 to enlist in a regular army Signal Corps Replacement Company. After a year overseas he entered Pratt Institute and graduated in electrical engineering in 1921. After short periods with the Shipowners Radio Service and The Independent Wireless Telegraph Company, he became one of the original staff that built and operated WJZ, then located at the Westinghouse plant in Newark. After two years of pioneering in the new service of broadcasting, Mr. Guy accepted a position as Field Supervisor for WJZ and WJY when the broadcasting operations were transferred to Aeolian Hall, New York City. In 1924 he joined the RCA Research Department, heading the broadcast engineering section, where he engineered the RCA stations, did consulting work for clients, and directed development of new RCA broadcast transmitters and associated apparatus. In 1929 he transferred to the National Broadcasting Company to organize and head the Radio Facilities Department. He is a Registered Professional Engineer of New York State and a member of the Institute of Radio Engineers. He has served on a number of IRE technical committees during the past eight years.

WILLIAM A. HARRIS is a native of Indiana. He received his B.S. degree in Electrical Engineering from the Rose Polytechnic Institute in 1927. He was in the radio department of the General Electric Company, 1927-1928, and in receiver development work for the same company, 1928-1929. Since 1930 he has been engaged in research and engineering work for the RCA Victor Company and the RCA Manufacturing Company at Harrison, N. J. Mr. Harris is an associate member of the Institute of Radio Engineers.

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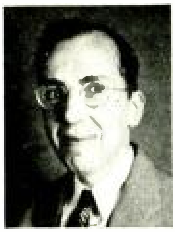
Edward W. Herold received a B.Sc. degree at the University of Virginia in 1930. He was employed in the research section of the Bell Telephone Laboratories from 1924 to 1927. During 1927 and the summers of 1928 and 1929, he worked in the engineering department of E. T. Cunningham, Inc. Since 1930, Mr. Herold has been in the advanced tube-development group of the Radiotron Division of the RCA Manufacturing Company at Harrison, N. J. He became an associate member of the Institute of Radio Engineers in 1930.

Charles B. Jolliffe received his B.S. degree in 1915 and his M.S. degree in 1920 from West Virginia University, and his degree of Ph.D. from Cornell University in 1922. He was an instructor in physics at West Virginia University 1917-1918 and 1919-1920 and Cornell University 1920-'22. From 1922 to 1930 he was Assistant Chief of the Radio Section of the Bureau of Standards where he engaged in research on radio wave propagation and the development and maintenance of standards of frequency. This work resulted in several scientific publications. He was Chairman of the Fourth Annual Convention of the Institute of Radio Engineers, held in Washington in 1929. Dr. Jolliffe was appointed Chief Engineer of the Federal Radio Commission on March 1, 1930, and continued in that capacity when that government agency was reorganized as the Federal Communications Commission in 1934. He resigned from the Commission on November 12, 1935, to accept his present position as Engineer in Charge of the RCA Frequency Bureau. In the past ten years he has attended all the international radio conferences as one of the American delegates or as an expert adviser. Dr. Jolliffe is a Fellow, Institute of Radio Engineers; a Fellow, American Association for the Advancement of Science, and a member of Phi Beta Kappa, Sigma XI, American Institute of Electrical Engineers, International Committee on Radio, and the International Scientific Radio Union, as well as of the Bonnie Briar Country Club at Larchmont, N. Y.

Edmund A. Laport was radio operator at KDKF station in 1921. The following year he was transferred to New York to become receiver service technician for the Westinghouse Company. In 1923 he went with the General Electric Company at Schenectady as laboratory assistant of transmitter development. Rejoining Westinghouse a year later as transmitter engineer, his work at Chicopee Falls included transmitter test, production, broadcast transmitter design and in charge of installation and field engineering. In this period he installed three high frequency telephone stations in China, two broadcasting stations in Italy and several in the United States. Mr. Laport was a radio consulting engineer in 1933-34, and then joined Wired Radio, Inc., as transmission engineer specializing in modulation developments. He started his present engineering activities on high-power broadcast transmitter design for RCA Manufacturing Company in June, 1936. He is a member of I.R.E. and of the American Meteorological Society.



Thomas J. Henry received his degree of B.S. in Chemical Engineering at Bucknell University in 1925. From 1926 to 1930 he was engaged in radio-tube design work for the Westinghouse Lamp Company; from 1930 to 1935 in tube-design engineering for the RCA Radiotron Company, and since 1935 in design engineering for the RCA Manufacturing Company at Harrison, N. J. Mr. Henry has been an associate member of the Institute of Radio Engineers since 1929.

Warren L. Knotts is an alumnus of the University of Illinois, class of 1926. Following his graduation he worked successively for the Commonwealth Edison, the Apex Electric, and the Dennison Manufacturing companies, Chicago. He then engaged in the manufacture of radio receivers and special apparatus. The Company was dissolved in 1932 and Mr. Knotts went to work with Lear Developments on aircraft radio equipment. He became Eastern Representative of Lear Developments early in 1933, and in 1934 joined the engineering forces of RCA Manufacturing Company.

H. B. Martin received a B.S. degree at the University of Illinois in 1928. Following graduation he was employed by Westinghouse at East Pittsburgh. In 1929 he became attached to the Signal Corps Procurement Office, New York, and was later transferred to the Signal Corps Laboratories, Fort Monmouth, N. J. In 1930 he was employed by the Radiomarine Corporation of America for flight testing of aircraft radio equipment. From 1932 to 1935 he was on the instruction staff of RCA Institutes. He is now Assistant Chief Engineer of Radiomarine Corp.

Walter van B. Roberts is a graduate of Princeton University. Before the World War he was connected with the Western Electric Company under H. A. Frederick. He became Head of the Department of Radio and Signalling in the School of Military Aviation in June, 1917, and from March, 1918 to the close of the war he was technical officer of Sound Ranging Section Number 1, on the American front. He later taught in Princeton University from 1919 to 1924. In 1924 he joined the RCA Technical and Test Department and in 1927 transferred to the Patent Department of RCA. Dr. Roberts is a fellow of the Institute of Radio Engineers.

Arthur J. Sanial completed his course in electrical engineering at the University of Illinois in 1924 and received a B.S. degree. He previously had been a commercial radio operator and a worker on automatic circuits for the Illinois Bell Telephone Co. In 1924 he joined the Bell Laboratories as field engineer on trans-Atlantic radiophone development. He is co-patentee of the speech "Scrambler" used on the trans-oceanic radiophone. Mr. Sanial went with the Fox Film Company in 1928, in charge of group, designing and manufacturing Movietone recording amplifiers. In 1933 he was with Martin Johnson as chief sound engineer on his last expedition to Africa. He became associated with the Arma Engineering Company in 1934 and, in addition, carried on a private consulting business from 1932 to 1936 in electronic and communication engineering. Since 1936 he has been with RCA Manufacturing Company as loudspeaker design engineer.

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David Sarnoff, President of the Radio Corporation of America, has been continuously identified with radio since 1906. He received his early education in New York public schools and later was graduated from Pratt Institute, where he took the electrical engineering course. He is a fellow, Institute of Radio Engineers, and served as secretary and director of I.R.E. for three years. Mr. Sarnoff is a member, Council of New York University; member, Academy of Political Science and member, American Institute of Electrical Engineers. He holds the honorary degrees of Doctor of Science from St. Lawrence University, Doctor of Science from Marietta College, and Doctor of Literature from Norwich University. He is an honorary member of Beta Gamma Sigma and an honorary member of Tau Delta Phi. He is a colonel SC—Res., U. S. Army.

Allen H. Schooley was graduated with the degree of B.S. in Electrical Engineering from Iowa State College in 1931. In 1932 he received his M.S. degree from Purdue University. Between 1932 and 1936 he did radio servicing, was a computor for the United States Coast and Geodetic Survey, and spent a year at the State University of Iowa doing graduate work in engineering and physics. Mr. Schooley joined the RCA Radiotron Division in 1936, and is now an engineer in the advance development section of the RCA Manufacturing Company at Harrison, N. J. He is an associate member of the Institute of Radio Engineers.

Henry Shore, a native of Boston, received his B.S. degree from the Massachusetts Institute of Technology in 1924, his M.S. from the Carnegie Institute of Technology in 1925 and New York Law School degree of LL.B., 1938. He was a Carnegie Institute Research Fellow, 1924-5; a Corning Glass Research Fellow, University of Wisconsin, 1925-6, and a Research Assistant at M.I.T., 1926-7. He became a licensed professional engineer, New York, in 1931, and a registered patent attorney in 1937; was Research Assistant ASME, 1921-5; Research Assistant NELA, 1923-4; Research Engineer, RCA, 1927-9, and Design Development Engineer, R.C.A. Communications, 1929 to 1934. Since 1935 he has been an assistant in the patent department of RCA. Mr. Shore is a fellow, A.A.A.S.; a member, American Physical Society; member, Society of Rheology, and a member of the Institute of Radio Engineers.

J. Kenneth Whitteker received his early radio training at the United States Army Signal School, Fort Monmouth, N. J., where, upon graduation, he was retained as an instructor for two years. During the Summer vacation periods he devoted his time to direction-finder research. Later he was associated with Kolster Radio and with C. A. Earl in production control and inspection work for a period of two years. Mr. Whitteker became a member of the staff of R.C.A. Institutes in 1930, and was appointed to his present post of Chief Instructor in 1931.

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