RADIO-ELECTRONIC *Engineering* SECTION

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A group of typical microwave components. Top to bottom, left: step-twist wave guide fitting, balanced mixer, wave guide junction, E-H tuner. Top to bottom, rt.: radar antenna, lighthouse tube, parabolic antenna.

THE BUSINESS END OF MICROWAVES

By LEO G. SANDS
Bogue Electric Mfg. Co.

Initial and operating costs of microwave equipment compare favorably with other means of communication.

PUBLISHED REPORTS indicate that approximately $150,000,000 has been invested in microwave relay systems for communications and television program service. Although this branch of the electron art is growing fast, the surface has barely been scratched. Its future expansion is assured because microwave relay systems provide more facilities for less cost than can be provided by overhead wire lines or buried cables.

The microwave art is comparatively new. Many of the techniques were learned during World War II through the development and application of microwave radar systems. After VJ Day there was much enthusiastic conversation about the immediate application of microwave relay systems. However, the wide scale application of microwave techniques to communications was retarded by high costs, inadequate experience and lack of developed equipment.

One of the first major microwave relay systems was installed by the *Western Union Telegraph Company* to provide communications facilities between New York, Philadelphia, Washington and Pittsburgh. The equipment, which was designed and built by *RCA*, is still in service today. Much was learned about propagation and equipment requirements through this pioneer installation.

Philco, in an effort to speed the growth of the television industry, realized that wide acceptance of television by the public hinged on the ability to provide network quality programs. Because common carrier facilities were not then available to television broadcasters, *Philco* designed and built a v.h.f. relay system through which they could pipe television programs from New York to their own television station at Philadelphia. This early system was later replaced by a microwave relay system of their own design. Now that common carrier facilities are available, *Philco's* privately owned microwave system is no longer in regular service.

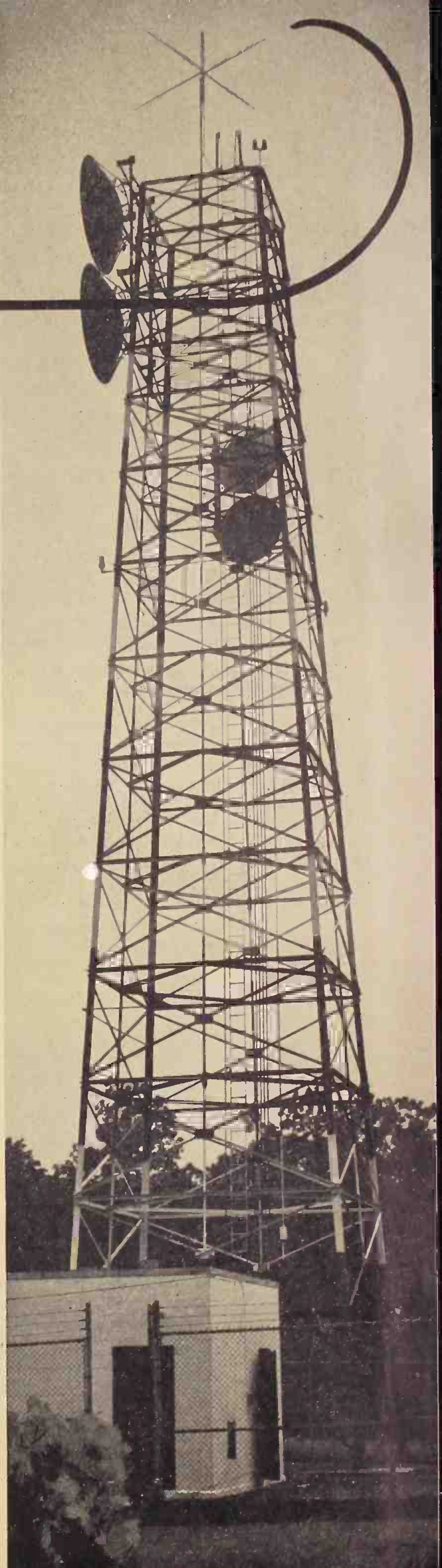
Utilizing the knowledge they had acquired in designing and building microwave systems for their own use, and the vast experience they had gained in radar and television, *Philco* designed and built a microwave relay system for the *Western Union Telegraph Company* which was capable of carrying television programs. This system, which was installed in 1948 between Philadelphia and New York, utilized two intermediate repeater stations, one at Neshanic, New Jersey and the other at Mt. Laurel, New Jersey.

Federal Telephone & Radio Corporation, a subsidiary of *International Telephone and Telegraph Company*, has been a major influence in the microwave industry since the beginning. *Federal* designed and installed several early microwave systems in this country, Canada and abroad. Today they have substantial orders for large microwave systems for installation in many parts of the world.

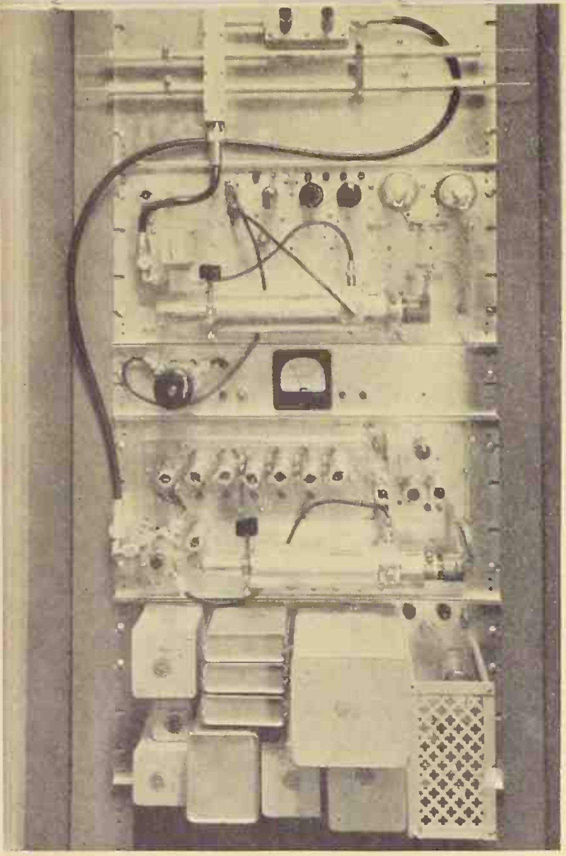
Another microwave pioneer is the *Sperry Gyroscope Company*. In collaboration with *Union Switch and Signal Company*, then a subsidiary and now a division of *Westinghouse Air Brake Company*, *Sperry* installed a temporary microwave system along the *Long Island Railroad* to demonstrate how microwaves could be applied to railroad communications and signaling.

General Electric Company was awarded a contract to build equipment for one of the world's longest microwave relay systems for the *Transcontinental Gas Pipe Line Company*. This giant radio relay extends from Falfurrias, Texas, through Houston and Atlanta, Ga. to Newark, New Jersey.

Another major builder of microwave relay systems is *Motorola, Inc.* This aggressive company has built and in- →



Repeater station on the Keystone pipe line communication system.



R.f. terminal bay of Federal PTM microwave communication link.

stalled several microwave relay systems for pipe lines, *Airinc* and other organizations. One of their early major installations was the 1000-mile system of the *Mid Valley Pipe Line Company.* One of their most recent systems was built for the *Texas-Illinois Pipe Line* which extends from Texas to the Civic Opera House in Chicago.

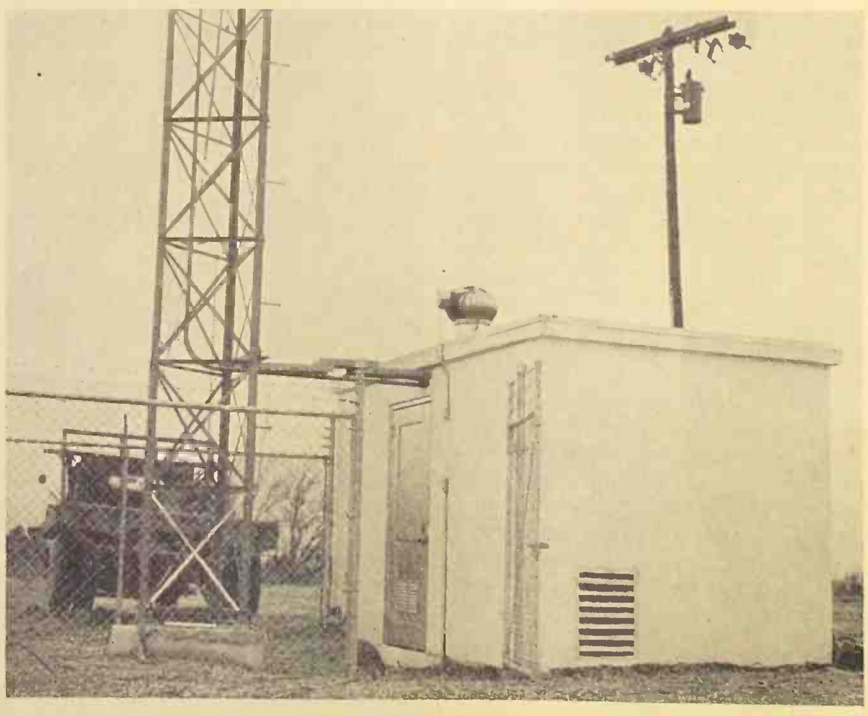
Philco is one of the largest builders of microwave relay systems for both communications and television relaying. Their television relays are used by the *American Telephone and Telegraph Company* and their communications relay equipment is being supplied to pipe lines, railroads and the United States Government. Their microwave contracts are reported to be in excess of $44,000,000.

By far the longest, most complex and costly single microwave relay system is the one operated by the *American Telephone and Telegraph Company* which links New York with San Francisco and Los Angeles. The equipment, built by *Western Electric Company,* is capable of transmitting hundreds of telephone conversations and several television programs simultaneously.

The railroads were among the first to grasp the significance of microwave relays as a means of communications. The *Chicago, Rock Island & Pacific Railroad* experimented with train radio communication in the 2600-megacycle band as early as 1946 under the leadership of Ernest A. Dahl, then electronics engineer for this railroad, and now with the National Bureau of Standards.

The first permanent microwave relay system to be installed by a railroad was contracted for by the *Chicago, Rock Island & Pacific Railroad* with *Philco* as the supplier. This pioneer railroad radio link joined Goodland, Kansas with Norton, Kansas. Because of the severe weather conditions encountered in western Kansas, the railroad sought means of providing more reliable communications. The microwave system was chosen to supplement and eventually supplant existing overhead wire lines which were too often prostrated by severe storms.

One of the microwave relay stations of the Texas Eastern Transmission Corporation.



The *Gulf, Colorado and Santa Fe Railway,* a part of the giant *Santa Fe* System, is installing the world's second permanent railroad-operated microwave relay system. This communications relay links the railroad's office building at Galveston with Beaumont, Texas, running across the oil well-dotted bare expanse of the Bolivar peninsula.

Only two railroads in America have installed microwave relay systems so far. Many more will replace pole lines with microwave systems when radio can be used to do away with pole lines entirely. Technologically this can be done today, but it will not be economically feasible until less expensive equipment is made available or until the railroads make changes in their modes of operation.

As railroads are operated today, it is necessary to provide communications facilities at frequent intervals along the right-of-way, sometimes every mile or two. Present-day microwave systems can be proved-in economically if repeater stations are placed at 15- to 30-mile intervals. With such wide separation of repeater stations, it is still often necessary to provide wire lines for connections to telephone booths and wayside offices between the microwave repeater stations. Through the use of portable radio telephones and frequent intermediate fixed v.h.f. radio stations, it would be possible to eliminate communications pole lines and to rely on v.h.f. and microwave radio entirely. Equipping all trains with radio communication equipment would still further reduce the need for pole lines and wayside telephones.

Another deterrent to the use of microwave relays by the railroads has been the reluctance of telephone common carriers to permit the railroads and other operators of private communications systems to tie in their microwave facilities to telephone company-owned switchboards.

Most of the railroads have agreements with telephone companies which permit them to connect railroad-operated wire line telephone circuits to the telephone-owned switchboards. This allows the use of railroad wire lines for long distance intercommunication between points on the railroad without toll charges. For example, a railroad official at city "A" may use the regular telephone on his desk to talk with another official at city "B" via the railroad's own wire line system. If this were not permitted, it would be necessary to have two telephones on every desk and two switchboard systems to transact business within the company and with outside organizations.

These agreements generally require that the railroad-owned wire lines follow the railroad right-of-way if connection with telephone company switchboards is desired. Until these agreements are modified to permit use of microwave links in lieu of wire lines, many railroads will be reluctant to install their own microwave relay systems. This general condition applies also to pipe line companies. It has been recently reported that some pipe line companies have been successful in getting permission to tie their microwave systems into telephone company-owned switchboards.

Probably more microwave equipment for private use has been purchased by pipe line companies than any other industry. This is true because there are so many newly established pipe lines that need communications for their operations and are faced with three alternatives: (1) leasing service from common carriers, (2) building their own pole lines, or (3) installing microwave relay systems.

If a pipe line leases communications service from a common carrier, the service charges are subject to Federal taxation. This means higher costs for the pipe line and a difficult competitive situation for the communications common carrier. Building of new pole line facilities is expensive and necessitates the acquisition of right-of-way as well as presenting a maintenance problem of great magnitude, particularly if the system is several hundred miles in length. It has been estimated that the cost of new pole line construction today is on the order of $1200 to $1500 per mile. Microwave relay is the obvious answer for pipe line operations.

Other users of microwave systems include power utilities, the various Defense Departments, Government agencies such as the Tennessee Valley Authority and the Bonneville Power Administration, etc. Microwave relays also provide facilities for uses other than communications, such as remote supervisory control, telemetering, power line fault location and facsimile transmission.

The cost of a typical microwave repeater station is given below:

Equipment		*Cost*
Microwave repeater	$5000 to	$10,000
Channelizing drop-off	1000	5000
Standby microwave	3000	10,000
Emergency power	500	5000
Antenna mast	1000	10,000
Shelter	500	3000
Fence	100	500
	$11,000 to	$43,000

The estimated figures do not include cost of land, surveys, roads and other expenses such as erection of power lines. The cost of a terminal station may be estimated similarly; however, some of the items may be eliminated if installation is made in an existing building which can serve as an antenna support and shelter.

The cost of maintenance can be small per channel mile as compared with the cost of maintaining wire lines. Every inch of wire line is vulnerable whereas maintenance of microwave systems is concentrated at repeater or terminal stations spaced 15 to 30 miles apart.

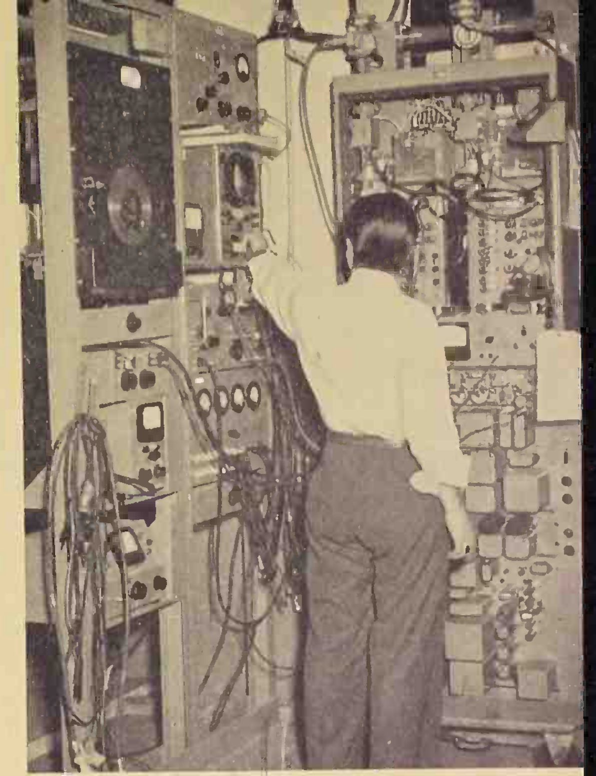
Annual Cost

The estimated annual cost of operating a microwave system over a 150-mile path in rough terrain or 200 miles in flat country is given below:

Maintenance	
Salary and travel expense of one maintenance man	$6500
Small tubes (annual change)	1000
Transmitter and power supply tubes (twice yearly)	3000
Building and tower maintenance, spare parts	1000
Electric power ($25 per month, per location)	2500
	$14,000
Depreciation	
Radio equipment (10-year life)	10,000
Buildings and towers (20-year life)	5000
Taxes	1000
	$16,000

The total investment in equipment for privately operated microwave relay systems is estimated at $12,000,000. Of the 16,000 miles of microwave systems in private operation, 12,000 miles are operated by the petroleum industry. The balance of the $150,000,000 figure which is the estimated total investment in microwave systems includes the vast *American Telephone and Telegraph Company* cross-country relays, military installations and other common carrier systems.

The microwave field would appear to be a lucrative one for the consulting engineer. However, few companies have utilized the services of consultants in planning their microwave systems. Because of the large investment required for a microwave system and the complexity of the system, prospective buyers of microwave equipment should avail themselves of the services of competent consulting engineering firms before proceeding. Persons trained to analyze problems of this magnitude and complexity can furnish the prospective buyer with many facts he might otherwise overlook.

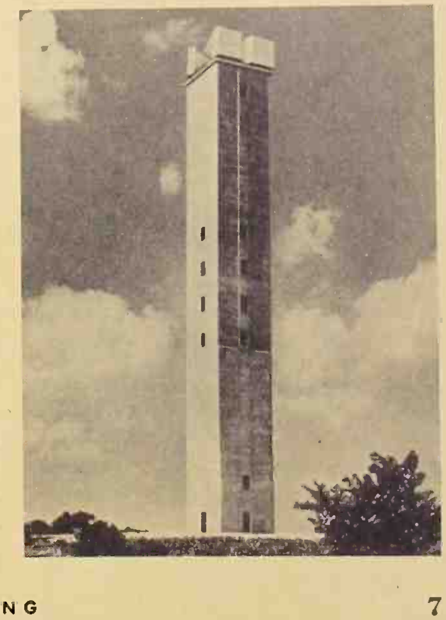


A technician is shown checking the operation of Philco microwave equipment.

Installing a microwave relay system is not quite as simple as it would appear at first glance. Microwave repeater stations cannot be located promiscuously at any readily accessible location. Much planning is necessary. After a study has been made to determine the number of communications channels that will be required and the most desirable type of equipment for the particular job has been selected, surveys must be made to determine locations of repeater and terminal sites.

(*Continued on page* 52)

A concrete microwave relay tower. Lens antennas are used in this system.



MICROWAVES—PRESENT and FUTURE

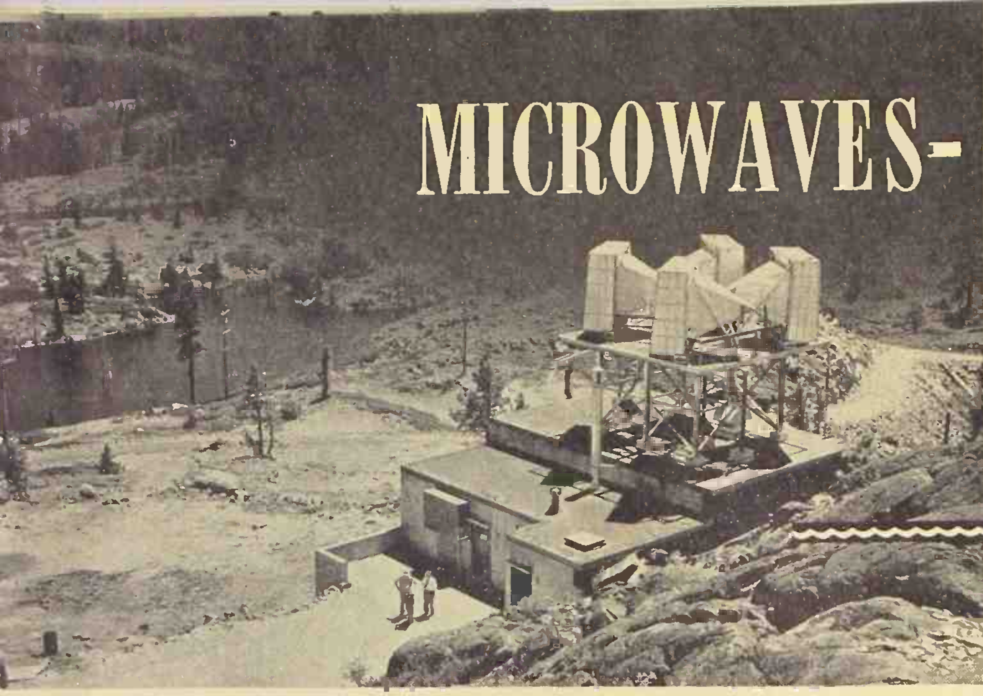


Fig. 1. The Cicco-Brite, Calif., station of the transcontinental microwave relay system installed by AT&T for transcontinental telephone and television service.

By
JOSEPH RACKER
Joseph Racker Company

The microwave region is ideal for expanded services in communications and other fields.

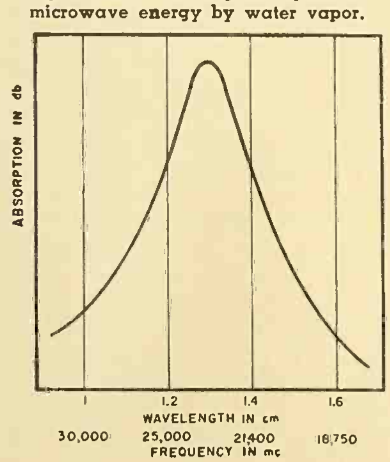
PREDICTION: In 1970 more microwave transmitters and receivers will be sold to the general public than any other type of equipment in the electronic field, including radio and television equipment. It is requested that those readers who may feel that this prediction is farfetched and unlikely, considering the present status of the art, withhold judgment until the conclusion of this article, for it will be demonstrated herein that the continued development of microwave techniques not only opens the door to many new applications, but stimulates expansion of existing services.

Before delving into the advantages and applications of microwaves, it should be clearly understood what microwaves are and how they are generated and transmitted. Microwaves have been defined in various ways by different individuals, but the best definition might be that microwaves are those radio frequencies whose wavelengths are comparable to the dimensions of the apparatus in which they are used. Microwaves are thus distinguished from conventional radio frequencies, whose wavelengths are of a higher order of magnitude than their equipment, and from light waves, whose wavelengths are very small compared to normal-sized units. This unique position of microwaves in the frequency spectrum provides a clue to their tremendous potentialities, namely, they can be used for applications normally associated with both "radio" *and* "light."

Generally, the microwave band is considered as starting at about 1000 mc. and ending at about 50,000 mc. In establishing the upper and lower limits of the microwave band, much depends upon what are considered practical dimensions for electronic apparatus. At 50,000 mc., for example, the components that are used are much smaller than those normally associated with electronic equipment. The size of components required for equipment operating at 100,000 mc. (quarter of a wavelength being .075 cm.) is believed to be too small for practical purposes in some applications.

What are the advantages of operation in the 1000 to 50,000 mc. ranges? One important advantage is the availability of considerable frequency spectrum. The overcrowded condition of lower frequency bands makes it almost mandatory that any future expansion of present facilities, or development of new products, should occur at microwave frequencies. Furthermore, it is possible to simplify the design and operation of equipment because of a freer use of the frequency spectrum.

Fig. 2. Curve showing absorption of microwave energy by water vapor.



Another very important advantage of operating above 1000 mc. is that in these ranges it is possible to obtain a high degree of directivity from simple, small-sized antennas. As a result, transmission of energy can be confined to a definite region, thereby opening the way to applications such as radar. In addition, concentration of energy in the desired direction provides antenna power gains on the order of 60 db and higher. Thus, a 1-watt microwave transmitter is usually adequate in many communication links which at lower frequencies would require outputs on the order of kilowatts.

Microwave propagation characteristics are particularly favorable for many applications. Three propagation characteristics are involved, namely, ground wave propagation, line-of-sight ranges, and noise-free transmission. Microwaves are transmitted via the ground wave only (for most practical purposes) and there are no sky wave reflections under normal atmospheric conditions. Hence, interruption of transmission due to "fading" caused by interaction of ground and sky waves very rarely occurs at microwave frequencies. The fact that transmission is limited to line-of-sight distances, plus the use of highly directional antennas, reduces to practically zero the possibility of interference between various services operating above 1000 mc. Also, noise energy (man-made and natural) decreases as the frequency increases so that at microwave frequencies it is virtually zero. These three characteristics add up to the fact that it is possible to achieve high-quality, noise-and interference-free transmission at microwave frequencies, with a very high degree of reliability.

Finally, microwave equipment can be considerably simpler than equivalent apparatus operating at lower frequencies. This is best illustrated by the microwave mixer, an interior view of which is shown in Fig. 7. R.f. signal and local oscillator transformer coupling is effected by simple loops, appropriately placed to assure proper matching. The cavity is a high Q resonant tank circuit. The crystal input transformer is another loop, mechanically designed to hold the crystal diode extension. Microwave energy is bypassed to ground from the crystal diode through an r.f. bypass capacitor consisting of a dielectric spacer. The crystal diode itself is contained within the connector, so that a 30-mc. i.f. signal is obtained at the output of this unit. The unit is tuned by a simple micrometer type screw which varies the position of the plunger inside the cavity. The mechanical simplicity of this mixer compares favorably with any available at lower frequencies.

Present State of the Art

The general impression of personnel not working on microwave equipment is that this equipment is expensive, complex, and difficult to operate. Until several years ago this may have been the case, but only because microwave components were in the early stages of development and quantity production techniques were not utilized. However, there is no inherent characteristic of microwaves which would make equipment operating at these frequencies costlier, more complex, or more difficult to operate. Quite to the contrary, a very rapid increase in the use of microwave equipment during the last few years resulted from the fact that this equipment proved to be more economical and simpler than equivalent equipment operating at lower frequencies, or wire lines.

Microwave oscillators, or transmitters, were at one time relatively unstable, inefficient, and had to be "custom made." This was due to the fact that conventional tubes could not be used for generation of microwave energy. Consequently new types of tubes employing entirely different principles, such as klystrons, magnetrons, traveling wave tubes, and lighthouse tubes, had to be designed. Naturally when these tubes were first developed they were relatively inefficient and costly. Furthermore, with little data and prior experience to guide the engineer, lengthy cut-and-try procedures were required to obtain stable operation.

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Looking into the future, one can visualize far simpler methods of generating microwave energy. It is known, for example, that light waves, which can be considered as radio waves operating at very much higher frequencies than microwaves, are very simply generated by passing current through a wire. At lower frequencies, the quartz crystal has a "natural" oscillation at a desired frequency. Thus far, no material having a natural frequency which occurs at microwave frequencies has been determined.

There is basis for belief that such a material exists, however. Consider the sharp absorption characteristics of water vapor and oxygen. Figure 2 shows the absorption of water vapor vs. frequency. As will be seen, the absorption starts to increase very sharply at about 30,000 mc., indicating that these frequencies correspond to some natural oscillation phenomena occurring among the water vapor or oxygen molecules or atoms. Recent reports of detection of microwave frequencies in cosmic rays further substantiate this belief.

This material, with a natural oscillation frequency in the microwave region, will most likely act in a manner similar to that of a light generator. That is, there will probably be a natural electron oscillation within the orbits of the atoms initiated by a current flow through the material. This material could be inserted at the focal point of a parabolic antenna, probably within a bulb. The microwave transmitter of the future may look like—and be as simple and inexpensive as—a flashlight.

Other microwave components such as transmission lines and cavities follow the same developmental pattern. Today commercial wave guides (see page 14) and cavities are available which can readily be adapted to virtually any application. These components can be manufactured on a mass production basis once the need for large quantities arises. It is interesting to note that as the frequency goes up, these components become smaller and easier to handle (up to about 10,000 mc. at least). Furthermore, the high directivity of antennas at microwave frequencies has eliminated the need for long transmission lines between transmitter and antenna. It is possible to place the antennas on the ground, as illustrated in Fig. 4, and beam the energy toward a reflector which then directs the beam in the desired direction.

Fig. 3. Portable microwave link equipment for television relaying.

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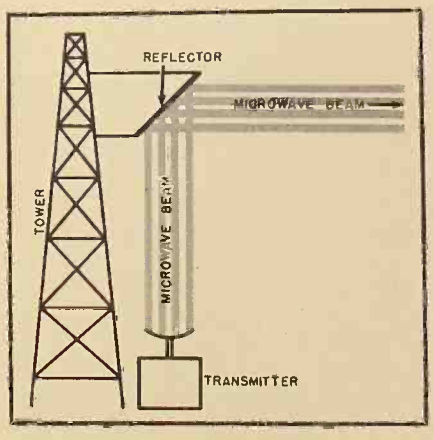

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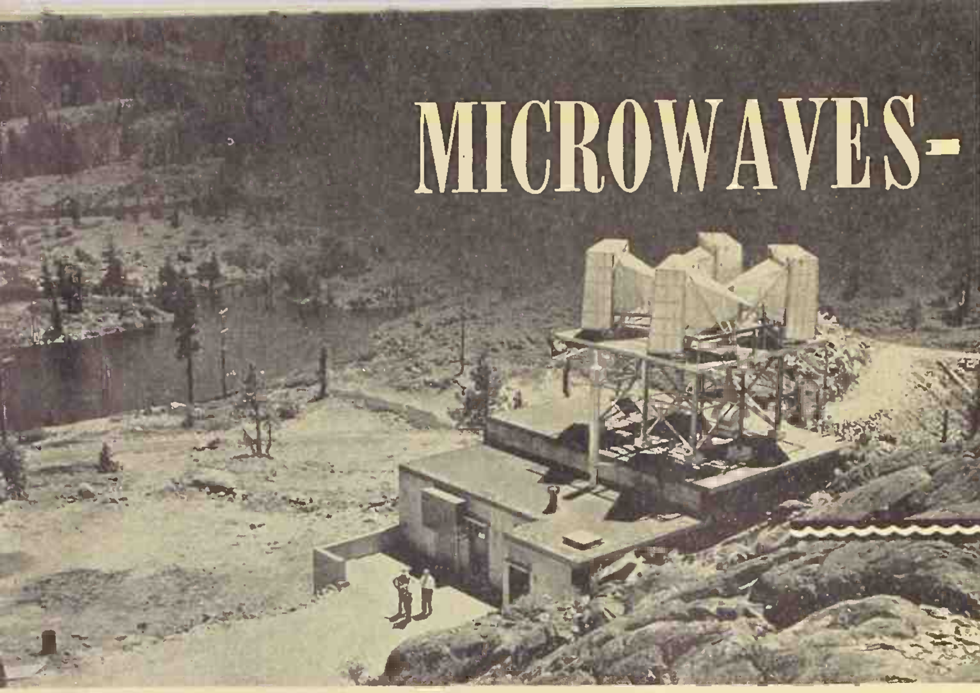

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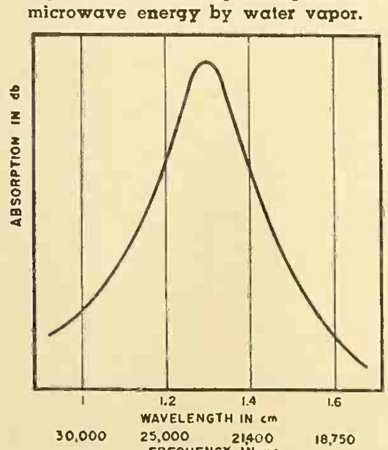

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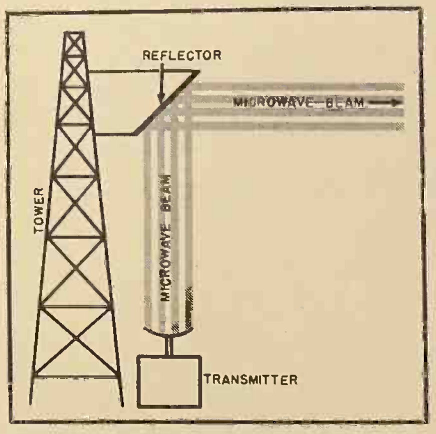


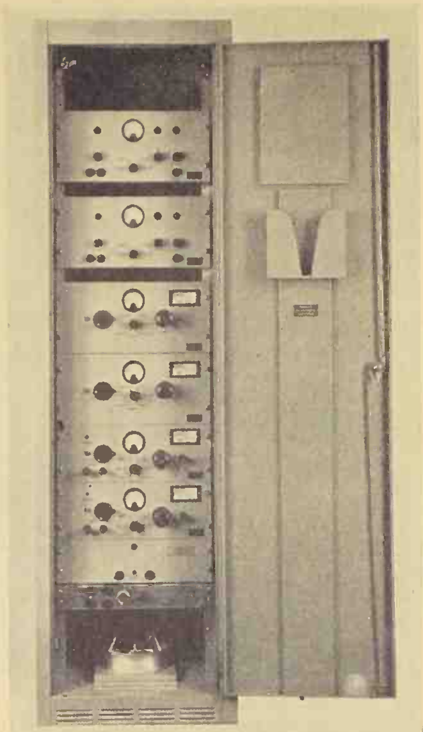


Fig. 5. A two-way repeater bay for a microwave link.

range of light. Finally, microwaves are used widely for instrumentation and testing purposes, particularly in aircraft.

Communications

Microwave radio links have been widely used during the past few years either to supplement existing television coaxial cable and telephone lines, or to replace them. Microwave radio links not only can be installed more rapidly and economically, but have also proven to be far more reliable. It has been generally true, in the case of wire lines, that just when telephone facilities have been most urgently required, they have been most susceptible to failure. This has been particularly distressing to such industries as railroads, pipe lines and power lines, which have suffered extensive damage during storms, floods, etc., due in part to the failure of the communication system.

That microwave communication links represent an excellent solution to this problem has been proven in at least one commercial installation where, during a recent storm, all wire lines were torn down but the microwave link continued to provide uninterrupted service. It is significant that the propagation of microwaves in adverse weather, such as icing conditions, is usually excellent.

In one commercial line comprised of two unattended repeaters (such as shown in Fig. 5) and a side circuit, which has been in continuous 24-hour-a-day operation for over two years, the outage time logged is about one-third that of wire lines. (Outage time is that time when telephone service is not available due to failure of the system.) This record is especially remarkable when it is realized that no standby units were installed here. When a failure occurred, a technician—who first had to be located—was notified. The technician then had to travel as much as 60 miles to the site and repair the equipment. Yet despite this procedure the outage time was considered too low to justify installation of standby units. In other installations having standby units, which are automatically switched into operation upon failure of the operating equipment, the outage time was reduced to practically zero.

As a result of the successful operation of these microwave links, many other installations have been started. A complete list may be found in the gate fold (P. 25). A large proportion of these links are 1000 miles long or over.

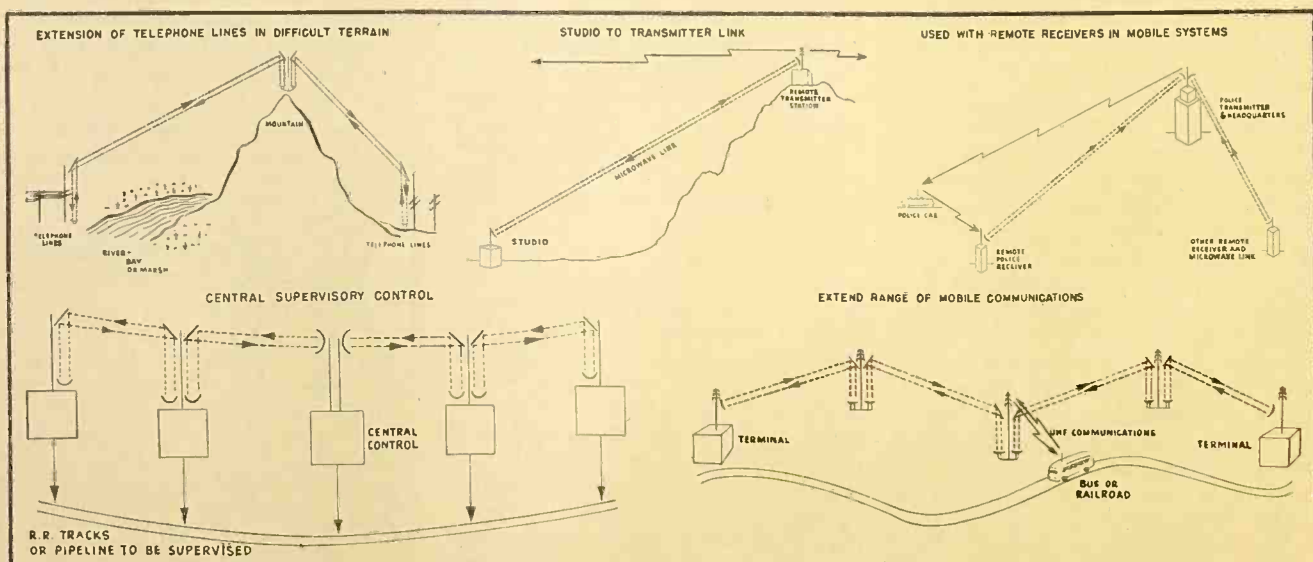
In addition to providing long line communication, microwave links have also been used to extend telephone lines over difficult terrain, to extend the range of mobile communications, to remotely control and check the operation of equipment along a railroad or pipe line route from a central location, and for transmission of broadcast material from studio to transmitter. These latter applications are illustrated in Fig. 6.

The best known and most extensive microwave radio relay system is the television link installed from coast to coast by the *American Telephone and Telegraph Company*. This system can transmit six television channels simultaneously in each direction. Or, if it is desired, one or more of these television channels can be used to transmit hundreds of voice channels. Using 107 stations, such as the one shown in Fig. 1, this 3000-mile link was built in about three years at a cost of approximately $40,000,000. As in other installations, the use of microwave equipment cut in about half both the cost and installation time required.

This backbone communication system is by no means the only way that microwave links are used in television broadcasting. Virtually every TV broadcast station has at least one studio-to-transmitter link, similar to the one shown in Fig. 3, which is used to relay programs from field pickups to the transmitter or control monitor. In addition, many stations not located on the main network route have the responsibility of tying in with the network system. Needless to note, the lifting of the freeze on television broadcast

(*Continued on page* 54)

Fig. 6. These sketches indicate some of the typical applications of microwave communication links.



NON-COMMUNICATION APPLICATIONS OF MICROWAVES

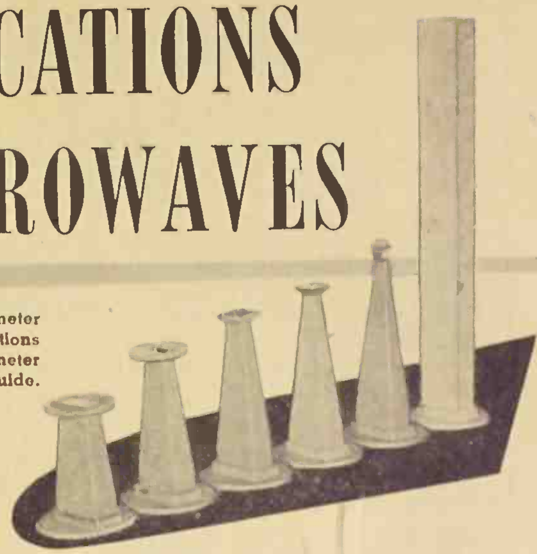


Fig. 1. A microwave calorimeter (left) with several sections (right) to match the calorimeter to various sizes of wave guide.

By
SAMUEL FREEDMAN
Transport Products Corp.

Radar, navigation, spectroscopy, calorimetry, medicine, all employ microwaves to advantage.

BETWEEN 1000 and 60,000 megacycles lie four far-reaching and important uses for microwaves in other than purely communicating or relaying functions. In order of position in the spectrum, they are: DME (distance measuring equipment); radar, including GCA (ground controlled approach); microwave calorimetry; and microwave spectroscopy. These applications are solving problems of expanding traffic and poor visibility, medical diagnosis, and resolution of the molecules of matter in a manner never before considered possible. The offshoots likely to develop are innumerable.

DME System

Distance and direction from a known ground point are the two items of information necessary to establish position in air navigation. The omnirange operating on very high frequency provides direction information, while the distance measuring equipment provides distance information.

In DME installations, the ground station receives and the aircraft transmits DME information on a choice of channels in the frequency band of 960 to 987.25 mc. The ground station responds and the aircraft receives back DME information on a choice of channels in the frequency band of 1187.25 to 1215 mc.

The power used in DME equipment ranges from several hundred watts to ten kilowatts peak power and comprises pulses having a duration of 2.5 microseconds at a repetition rate of between 15 and 500 per second. This corresponds to an average transmitting power of from less than a hundred milliwatts to as much as twelve watts.

The Transponder

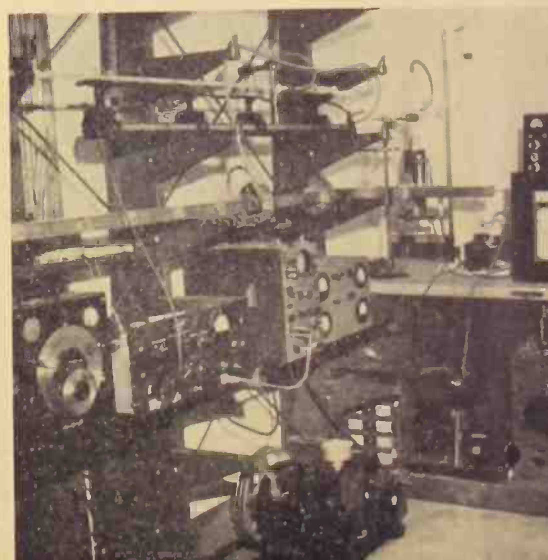
A block diagram of the DME transponder used at the ground station is shown in Fig. 4. The antenna receives an r.f. interrogation pulse from an aircraft which the receiver amplifies and converts into a video pulse. An adjustable, calibrated time delay is introduced between receipt of the video pulse and transmission of the pulse to the trigger tube. Several microseconds must elapse before the reply pulse can leave the antenna for a return trip in order to assure accuracy and to avoid confusion with another aircraft seeking the same information. The delay circuits increase the normal pulse delay to a standard interval so that this suppressed delay can then be cancelled out so far as the airborne DME is concerned. This is done by introducing an equivalent delay in the airborne tracking circuits.

The suppressed time delay may be shortened, in certain installations, in order to move the zero setting to a location away from the transmitter. For example, when DME is used in conjunction with an instrument landing system (ILS), the delay may be adjusted so that zero distance will be indicated on the aircraft mileage indicator at the runway touchdown point rather than at the transmitter site.

The trigger tube, activated by the delayed video pulse, prods the modulator with a properly shaped triggering pulse. The modulator, thus activated, puts out a high voltage d.c. pulse to the oscillator (transmitter) tube. The oscillator then converts the high voltage d.c. pulse to a radio frequency pulse and radiates the reply pulse to the aircraft via the same antenna. An identification code sends out DME identification signals at regularly spaced intervals. These are synchronized with the omnirange or ILS identification codes. Blanking circuits temporarily block video pulses from the time the trigger tube emits a pulse until after the transmitter pulse has been fired.

Automatic volume control (a.v.c.) reduces the sensitivity of the receiver

Fig. 2. Three microwave spectroscopy systems at NBS, represented by three straight wave guides at upper left.



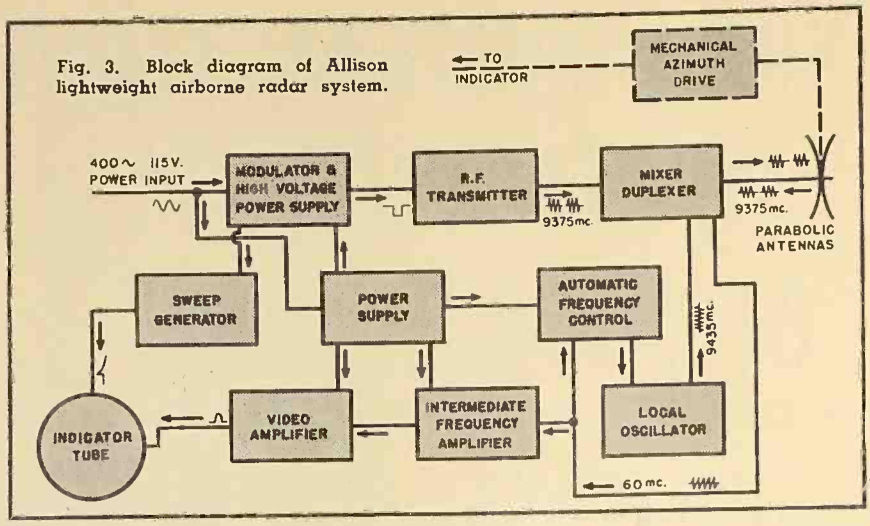


Fig. 3. Block diagram of Allison lightweight airborne radar system.

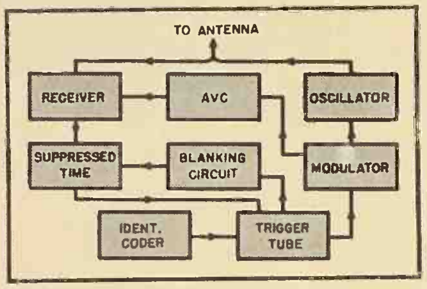


Fig. 4. Block diagram of distance-measuring equipment ground station.

when the transmitter reaches the full capacity of its duty cycle. The ground station is designed to handle replies to interrogation signals from 50 aircraft. When full capacity is reached, the a.v.c. reduces the receiver sensitivity. Thus, when there are more than 50 aircraft actuating the ground station, the interrogation signals from the more distant aircraft will not get through the receiver and the transmitter will not try to exceed its own capacity. If necessary, multiple DME transponders may be installed at certain busy locations to handle replies to large numbers of aircraft.

Although DME has some similarity to radar since it utilizes pulses of microsecond duration and comparable pulse repetition rates, it can reach out further with less power because it is a one-way rather than a two-way signal at each point. The aircraft transmitter only sends pulses from the aircraft to the ground DME station, for the ground DME station has its own transmitter on another frequency to send a pulse back each time. While the transponders may have a free-space range of 600 miles, in practice the service range is limited to about 115 miles when used in conjunction with omniranges, and 50 miles when used in conjunction with ILS, to preclude the possibility of picking up data from another station on the same operating channel. Effective range is governed by line-of-sight or horizon principles common to u.h.f. equipment.

The Interrogator

The DME airborne station is called an "interrogator" as compared to the ground station which is a "responder," or more correctly, a "transponder." The airborne DME unit is designed to give reliable indications of distance from the transponder up to a range of 115 miles at line-of-sight altitude with an accuracy within a quarter mile or 2 per cent, whichever is greater.

The transmitter is designed to emit pulses of a specified number of microseconds duration at a random rate of so many per second. These pulses are intentionally "scattered" unevenly in terms of time. The purpose of this feature is to avoid a stream of pulses from one aircraft spaced evenly ahead of a stream of reply pulses intended for another aircraft (which might cause the DME in either aircraft to present a false indication). With the pulses from each aircraft being transmitted at the random rate, there is minimum possibility of maintaining consistently even intervals between interrogation pulses from one aircraft and reply pulses for another aircraft over a long enough period of time to cause a false meter reading.

The airborne DME antenna, like the ground transponder antenna, is used for both transmitting and receiving. It is usually mounted in a streamlined lucite housing on the underside of the aircraft and is a half-wavelength long.

The receiver converts the reply pulses from the transponder into video pulses which go into the distance measuring circuits. The purpose of the tracking circuits is to measure the time delay between the transmission of pulses from the aircraft and the reception of corresponding reply pulses. In order to do this, electronic gates, delayed after each transmitted pulse, are used. The delay between the pulse transmission and the electronic gates is made equal to the delay time between the transmitted pulse and the received reply pulse. The gate delay is controlled in the airborne unit by a voltage which is increased in order to increase the delay. This voltage is also applied to the indicator meter, which will then actually indicate the delay time, and therefore can be calibrated in miles.

Radar

Any basic radar system contains six elements as follows: (1) A transmitter

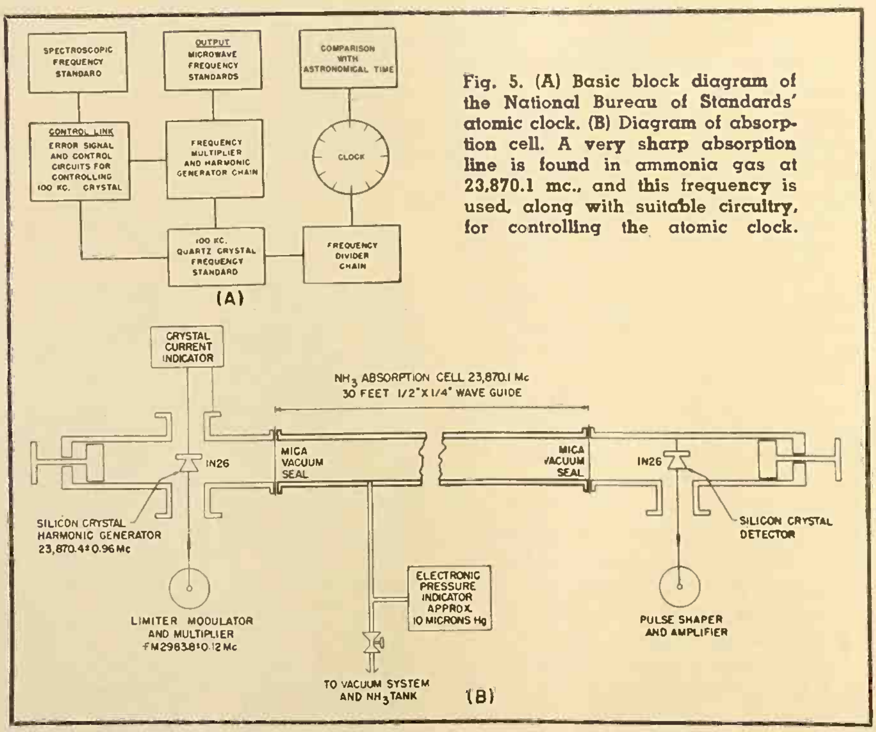


Fig. 5. (A) Basic block diagram of the National Bureau of Standards' atomic clock. (B) Diagram of absorption cell. A very sharp absorption line is found in ammonia gas at 23,870.1 mc., and this frequency is used, along with suitable circuitry, for controlling the atomic clock.

to produce outgoing signals. This is normally a magnetron tube operating either in the L band (1200 to 1600 mc.), S band (10-cm. or 3000-mc. region) or X band (3-cm. or 9000-mc. region). (2) A receiver to receive back the transmitted signal after it has been reflected off some distant object. (3) A modulator to pulse or key the transmitter. This converts low average power to high peak power during actual intervals of pulse transmission by a multiplication of power equal to the ratio of time off the air to time on the air (pulse interval to pulse duration). The pulse interval is necessary in order to receive back the reflected pulse and determine the distance to the object or target, since the transmitter and receiver are on the same frequency. (4) An electronic switch to permit transmission and reception on the same frequency with the same transmission line and antenna. (5) A cathode-ray tube indicator to analyze the received intelligence and derive the range of the target. (6) An antenna system to handle the outgoing and returning signals as well as to control their direction or bearing.

The minimum distance over which a radar can function cannot be less than the time it takes for the transmitter to send out a pulse and the receiver to start operating after its paralysis during the transmission of the pulse. If this requires one microsecond, no indication can be obtained closer than 328 yards divided by 2, or 164 yards.

The maximum distance over which a radar can properly detect signals is limited by the amount of time which elapses between two successive transmitted pulses. If a radar uses pulses of 1 microsecond with a repetition rate of 1000 pulses per second, then transmissions will total 1000 microseconds per second (or a thousandth of the total time). There will be an interval of 999 microseconds between pulses. 999 times 164 yards equals 163,836 yards maximum range. In practice, this may be reduced because of insufficient power from transmitter, lack of receiver sensitivity, inadequate antenna beaming, poor efficiency of the target or distant object as a reflector, etc. Also, in rare cases, a signal may be received over even greater distances, provided it returns during the interval between succeeding pulses. The total distance would then be basic maximum distance plus the amount of distance required for a subsequent sweep on the face of the cathode-ray tube.

Figure 3 shows a block diagram of a simplified *Allison* lighweight radar designed for aircraft. It has the following specifications:

Peak power	35 to 40 kw.
Weight including cables	60 lb
Number of tubes	35
Power load	500 watts at 115 volts, 400 cycles
Frequency band	9345 to 9405 mc.
Antenna scan	60 per minute
Pulse rate	400 per second
Pulse length	1.8 microseconds
Typical operating ranges	
on cities—up to 40 miles	
on mountains—up to 80 miles	
on aircraft—up to 20 miles	

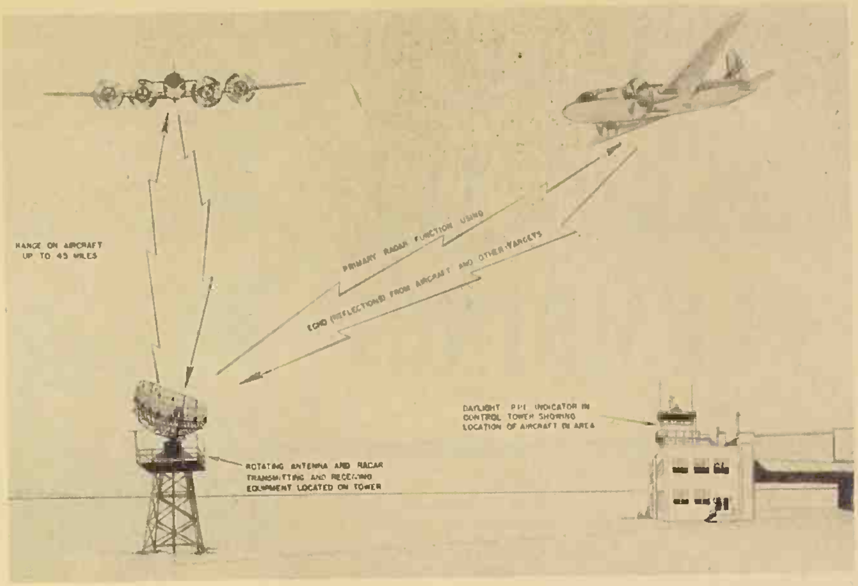


Fig. 6. Basic operation of a typical airport surveillance radar system.

Radar surveillance at airports is coming into extensive use. In a typical airway having high traffic density, there are a number of flight altitudes in the main trunk with separate lateral tracks provided at each altitude. The en route configuration is a system of parallel tracks feeding the main trunk. Tracks can also be segregated and so arranged that express traffic bypasses, either horizontally or vertically, those en route airports at which no stop is scheduled. Planes are accurately located by means of the radar surveillance equipment at the airport.

Figure 6 shows a basic system of radar surveillance equipment and the way in which it detects the direction and distance of incoming or passing aircraft. The information is conveyed by coaxial cable from the radar equipment to the plan position indicator in the control tower which shows direction and distance of all aircraft within radar detecting range.

GCA System

The *Gilfillan* GCA system, as a typical example, is a specially developed combination of search (3000-mc. surveillance radar) and precision scan (3-cm. or 9000-mc.) radar units for locating and guiding the aircraft down to the point of contact on the runway. The information is conveyed to the pilot of the plane by radiotelephone. No special equipment is needed in the plane other than already existent voice communication with the ground.

The GCA station is placed 500 feet to the side of the runway at the end opposite to that on which the plane is to land. Such equipment thus far has been located in trailers which could be moved to the appropriate position with respect to any runway in use. The search or surveillance radar scans a 30-mile area around the airport. Its operator directs pilots of inbound aircraft to the approach starting area at correct altitude. This area is about six miles from the approach end of the runway.

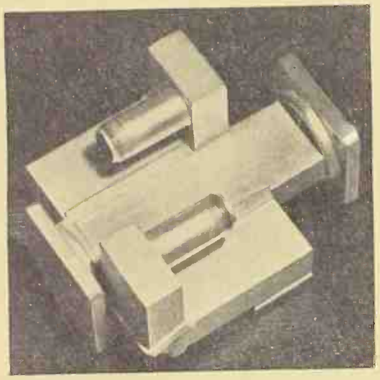
(*Continued on page* 62)

Fig. 7. Airport surveillance radar equipment mounted in truck and trailer.

SPECIALIZED MICROWAVE PLUMBING

A microwave receiver employing a new microwave wiring technique compared with a conventional magic T.

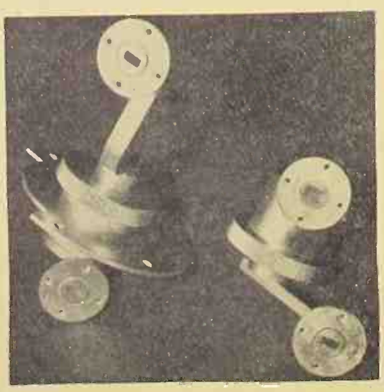
Equipment and techniques used for directing microwave energy into the desired channels.



A bi-directional coupler unit.

A balanced diplexer section.

Some K-band rotating joints.



THE MICROWAVE region of the frequency spectrum is usually considered to start at a frequency of about 1000 mc., and to extend from that point upwards. Another broad definition would be that the microwave region is that region where the dimensions of the equipment being used are comparable with the wavelengths employed. Thus, wavelengths of less than about 30 cm. (roughly 11¾ inches) make up the microwave spectrum. The upper limit is not specified exactly, but is usually considered to be the highest frequency at which an appreciable amount of experimental work has been conducted, or about 50,000 mc.

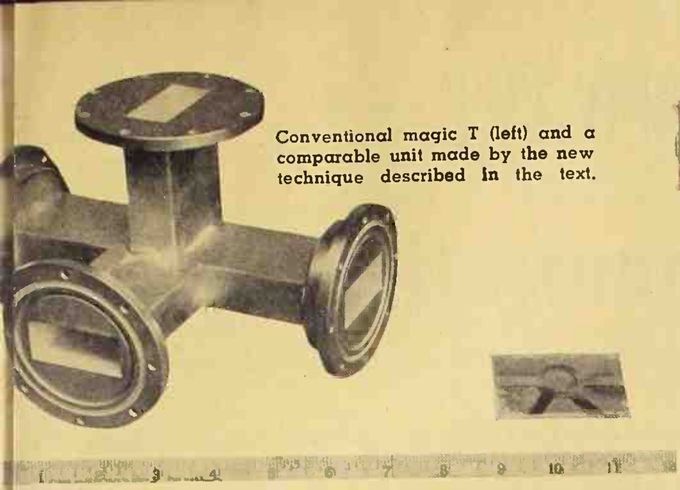
Transmission of energy at these frequencies can best be accomplished by means of wave guides, although special coaxial cable is sometimes used at the lower end of the range. Square, circular or rectangular guides may be used, but the rectangular form has certain advantages and is most widely used at present. The wave guide may be constructed of brass, copper, aluminum, or any other suitable material, as long as the inside surface is a good conductor of electricity.

Several other methods of guiding microwave energy have been explored in recent years, some of which show a great deal of promise. One particularly interesting scheme was presented by A. G. Fox of *Bell Telephone Laboratories, Inc.* at the National IRE Convention in 1952.

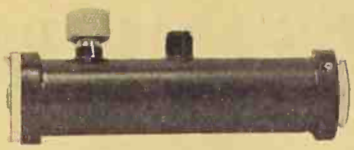
In the experiments described by Mr. Fox, it has been found that frequencies on the order of 48 kmc. will travel along a ribbon or small rod of nonconducting plastic such as polyethylene. This ribbon can be made very flexible, and the energy will follow fairly sharp bends. Energy can be launched onto the ribbon from a wave guide, and can be caused to re-enter a wave guide if desired. The actual electromagnetic field around the ribbon tapers off quite

Table 1. Manufacturers of wave guides and fittings.

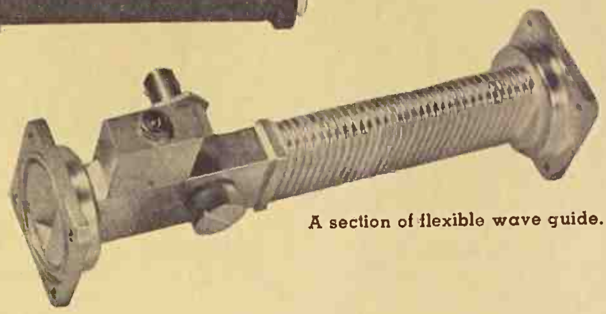
Airtron, Inc. 26 E. Elizabeth Ave., Linden, N. J.	Makepeace Co., D. E. Pine & Dunham Sts., Attleboro, Mass.
Bart Laboratories Co., Inc. 227 Main St., Belleville 9, N. J.	Microwave Development Labs., Inc. 220 Grove St., Waltham, Mass.
Bone Engineering Corp. 701 W. Broadway, Glendale 4, Calif.	Microwave Equipment Co., Inc. N. Caldwell, N. J.
Cook Electric Co. 2700 Southport Ave., Chicago 14, Ill.	N. R. K. Mfg. & Engrg. Co. 5644 N. Western Ave., Chicago 45, Ill.
Diamond Manufacturing Co. 7 North Ave., Wakefield, Mass.	Philco Corp. Tioga & "C" Sts., Philadelphia 34, Pa.
Electro Precision Products, Inc. 119-01 22nd Ave., New York, N. Y.	Schutter Mfg. Co., Carl W. 80 E. Montauk Highway, Lindenhurst, N. Y.
Federal Telecommunication Labs., Inc. 500 Washington Ave., Nutley 10, N. J.	Sperry Gyroscope Co. Great Neck, New York 14, N. Y.
Feiler Engrg. & Mfg. Co. 8026 N. Monticello Ave., Skokie, Ill.	Standard Metals Corp. 262 Broad St., N. Attleboro, Mass.
General RF Fittings Co. 702 Beacon St., Boston 15, Mass.	Technicraft Laboratories, Inc. Thomaston, Conn.
Kings Microwave Co., Inc. 719 Main St., New Rochelle, N. Y.	Titeflex, Inc. 500 Frelinghuysen Ave., Newark 5, N. J.
La Magna Mfg. Co., Inc. 51 Clinton Place, E. Rutherford, N. J.	Wheeler Laboratories, Inc. 122 Cutter Mill Rd., Great Neck, N. Y.



Conventional magic T (left) and a comparable unit made by the new technique described in the text.



Miniaturized S-band cavity having a tuning range of 200 mc. or more at about 3000 mc.



A section of flexible wave guide.

rapidly, so that proximity effects at distances of more than twice the width of the ribbon are not appreciable. By paralleling two ribbons for certain distances, it is easy to obtain a directional coupler having practically any desired value of coupling loss.

This work is still in the early experimental stages but the results so far indicate that this guided wave technique has excellent possibilities for use in the 48-kmc. range, and possibly for other ranges also.

Another method was first described by G. Goubau of the *Signal Corps Engineering Laboratories* at the National IRE Convention in 1950. In this method, the microwave energy is launched on a single conductor far above ground. The conductor is covered with a thin layer of insulation, and the wave is guided by the insulation and the conductor. Attenuation appears to be much less than with other types of transmission lines. Development work on this system is being continued.

A development which may well revolutionize microwave wiring was described by several engineers of the *Federal Telecommunication Laboratories* at the 1952 National IRE Convention. This development is based on the use of a ground plane acting as a mirror for a conductor placed above it. This conductor may be a wire or ribbon, and the space between it and the ground plane may be air or any low-loss dielectric. Chief advantages are cheapness, light weight, and greater tolerances in manufacture.

In one technique which has been perfected by *FTL* engineers, a sheet of plastic coated on both sides with copper foil is used as the raw material. One side is used as the ground plane, and the other side is etched to the desired configuration to give a straight wave guide or a fixture such as a hybrid junction or magic "T." A sample of this type of wiring as used in a microwave receiver is shown in the photograph on page 14.

When a ribbon is used as the conductor, the ground plane should be about three times the width of the ribbon. In samples of this construction which were demonstrated recently, a sheet of insulating material about 0.05 inches thick separated the ribbon and the ground plane.

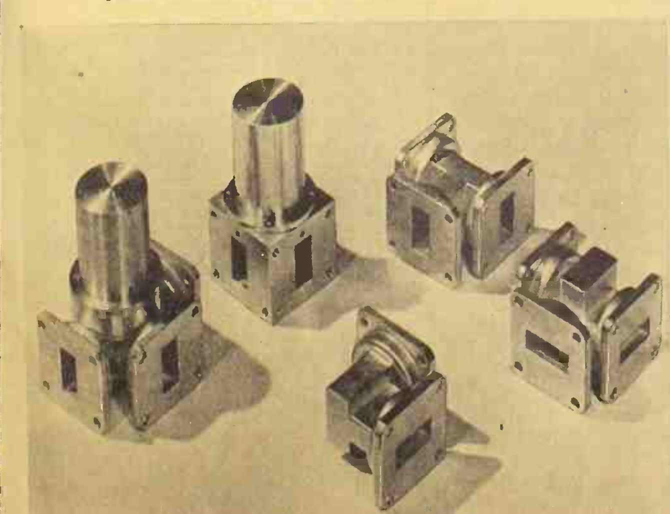
Many different techniques have been employed to produce a wave guide which is flexible, and several manufacturers are now producing flexible wave guides. The use of such guides is desirable where the exact degree of bending cannot be determined beforehand, or where some flexibility is desirable in the finished installation. Rigid wave guides are also manufactured with a wide variety of curves and bends to meet almost any installation problem.

Frequently it is desirable to twist the guide through 90°, more or less, for some specific application. To avoid undesirable effects, this twist must be fairly gradual. To overcome the excessive length of guide required for a twist of this kind, engineers at *Wheeler Laboratories* have developed a series of so-called "step-twist" wave guide components, which were described by Henry Schwiebert at the 1952 National IRE Convention. In these components, the twist takes place in a series of carefully predetermined steps, the number of steps and degree of twist per step being determined by factors such as the permissible standing wave ratio and the desirable bandwidth. This system permits a 90° twist to be made in a distance of about 1½ times the wave guide width, much shorter than is possible in the conventional twisted guide. Very low standing wave ratios can be obtained.

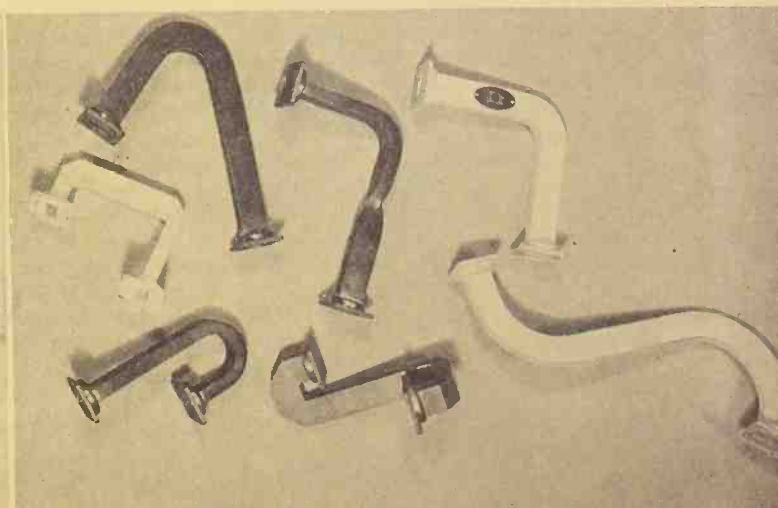
The internal wave guide dimensions to be used in any particular installation are determined by the frequency of operation and the peak power requirements. In general, the width must be

(*Continued on page* 52)

A group of aluminum microwave components composed of a switch, elbow and shunt and series tees.

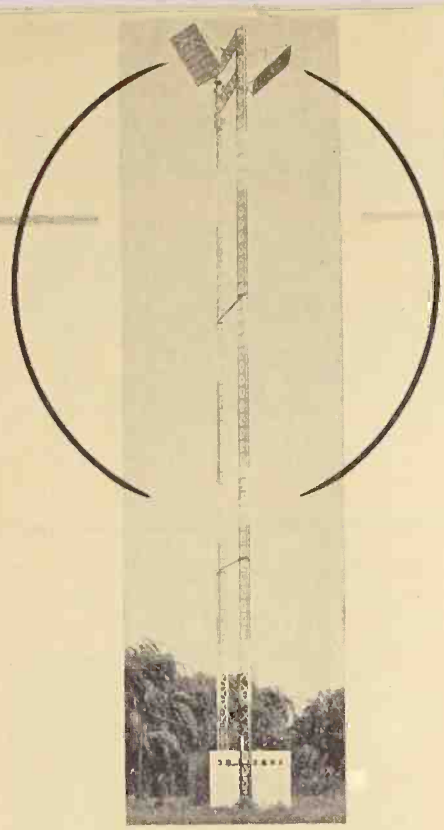


Some of the many wave guide shapes available to meet the requirements of individual applications.



MICROWAVE Communication Systems

An analysis of available frequency bands, costs involved, and a discussion of typical equipment.



A typical microwave relay station as installed by Motorola, Inc.

By
ERNEST A. DAHL
Electronics Engineer
National Bureau of Standards
Corona, Calif.

COMMUNICATION IS THE art of transmitting intelligence from one location to another. This intelligence may be in the form of telegraphic signals, telephone conversations, telemetering data, television programs, temperature readings, or any other type of information required.

The cost of transporting this information may be stated in terms of cost per message. Thus, all communication systems have a fundamental cost per message per mile.

Radio as used for years in point-to-point service has had the lowest cost per message of all types of communication systems. The amount of usable channel space available for this type of operation was, however, extremely limited in the past. With the advent of World War II and the utilization of frequencies above 1000 mc., a large amount of radio channel space became available. These channels are wider than previous standard radio circuits, and more intelligence can be transmitted over them. But before these channels could be utilized on a compatible basis with earlier point-to-point circuits, new techniques and arts had to be developed.

The communication art has now reached a point at which microwave radio offers an extremely reliable, low-cost system of communication. Several different types of microwave systems have now made their appearance. In order to analyze each system and its modulation and to compare radiating characteristics, this article will discuss in turn the fundamental economics of microwave communication relay systems, frequencies available at this time for these systems (and the advantages and disadvantages of each), different types of systems now available to users, and systems now in operation.

Economics of Microwave Relay

In a wire communication system as normally operated by a pipe line company or a railroad, the average cost per mile of open-wire line with no carrier telephone on it is about $1000. This will provide one talking channel and two or three telegraph channels, depending upon the type. If, however, a carrier is added to the talking channel on a system with a total length of 25 miles, a communication system works out to have a cost per mile of $1280 for three channels, $1580 for five channels, and $2440 for ten channels. If over the same 25 miles microwave radio is used, the first channel absorbs a cost of approximately $1140, a three-channel system $1180, a five-channel system $1200, and a ten-channel system $1316. Based on these figures for a one-channel system, the cost of a microwave system is $140 higher per mile than an open-wire system with no carrier. If it is based on the ten-channel system, the cost of a microwave system is approximately half that of a wire carrier system.

If a system is considered on cost per channel mile per year,* a one-channel microwave link amounts to $170 per channel mile per year. An open-wire communication system amounts to $150 per year. But on the same basis of 25 miles on ten channels, the microwave system has a cost figure of $19.80 per channel mile per year, while the open-wire carrier system has a cost of $36.60 per mile per year. This amounts to $16.80 less per microwave channel per mile per year. The microwave system is therefore only half as expensive to operate as the open-wire carrier system.

Carrying these figures a little further, a 200-mile communication system of the open-wire carrier type still represents an initial investment of approximately $1000 per mile, while the microwave communication system is now only about $740 per mile. On ten channels for a 200-mile system the cost of the open-wire carrier system is approximately $1220 per channel mile, and a ten-channel microwave radio system is $795. On the basis of cost per mile per channel per year, the open-wire carrier system has an operating cost of $150 on a one-channel basis, and the microwave radio system has a cost of $111. On the basis of ten channels, the open-wire carrier system runs $18.30 per channel mile per year, and the microwave radio system runs about $12 per channel mile per year.

Annual charges at 15% covering amortization, taxes, interest, etc. are assumed.

Table 1. A listing of the major manufacturers of complete, packaged microwave communication systems.

Allen B. Du Mont Labs., Inc.
1500 Main Ave., Clifton, N. J.
Federal Telecommunication Labs., Inc.
500 Washington Ave., Nutley 10, N. J.
Federal Telephone & Radio Corp.
88 Kingsland Rd., Clifton, N. J.
General Electric Co., Electronics Div.
Electronics Park, Syracuse, N. Y.
Link Radio Corp.
125 W. 17th St., New York, N. Y.
Motorola, Inc.
4545 W. Augusta Blvd., Chicago 51, Ill.
Philco Corp.
Tioga & "C" Sts., Philadelphia 34, Pa.
Radio Corporation of America
Camden, N. J.
Radio Engineering Laboratories, Inc.
36-40 37th St., Long Island City 1, N. Y.
Raytheon Manufacturing Co.
Waltham 54, Mass.
Telectro Industries
35-16 37th St., Long Island City 1, N. Y.
Westinghouse Electric Corp.
511 Wood St., Pittsburgh 30, Pa.

This indicates that in comparing costs of operating the communication systems over a period of a year, where the length is sufficient to support the cost of a microwave communication system installation, the cost per channel mile is approximately 33⅓ to 50 per cent cheaper per year, depending on the number of miles and the number of channels operated. For this reason pipe line companies, construction companies, railroads, and other private users of communications are starting a rapid swing to the use of microwave communication systems for point-to-point communications.

The cost figures on microwave radio equipment for these comparisons were supplied by *Motorola, Inc.* There is competitive equipment available, however, and these prices apply in general to all microwave radio equipment.

Available Frequencies

The Federal Communications Commission has assigned several frequency bands from 950 to 30,000 mc. for commercial point-to-point service. These bands do not include those assigned exclusively for common carrier service but includes 8 bands for point-to-point service. The basic characteristics of each of these bands will be discussed briefly. The breakdown of these frequencies is as follows: The 952 to 960 mc. band is the lowest frequency band assigned for point-to-point service and has the distinct advantage that more equipment and circuits are available for this range than any other. Fading is less severe in this band, but antennas for a fair power gain are larger than in the higher bands (diameter—4 ft.; gain + 19 db). Transmitters and receivers at this frequency are easily crystal-controlled, giving good stability without thermal controls and long warm-up times. Disc seal or lighthouse tubes can be used in the final stages, and some manufacturers guarantee 6000 to 8000 hours service. Solid-dielectric flexible cable can be used with only moderate losses in lengths up to several hundred feet, and the total bandwidth of 8 mc. can accommodate a large number of channels in a given area if full advantage is taken of antenna directivity and frequency spacing.

The next band is 1850 to 1960 mc. Inasmuch as this band and the 2110 to 2200 and the 2450 to 2700 mc. bands are relatively close together, they can be considered as having the same operational characteristics. These bands have greater width, and wide-band or time-division systems can be utilized, giving more channels for each carrier than in the lower bands.

Disc seal triode or lighthouse tubes have been developed which tend to follow any drift in signal of the transmitter and offset the lack of crystal control. Wave guides at this frequency are large and cumbersome, so that the combined use of short lengths of flexible coaxial cable and stub-supported lines is necessary. Smaller antennas can be used to give higher gain (4 ft. diameter—r.f. gain, + 25 db), and this compensates for the additional loss of power in the lines. Also, the increased antenna gain provides an adequate margin for covering the more severe fading which is expected in these higher bands.

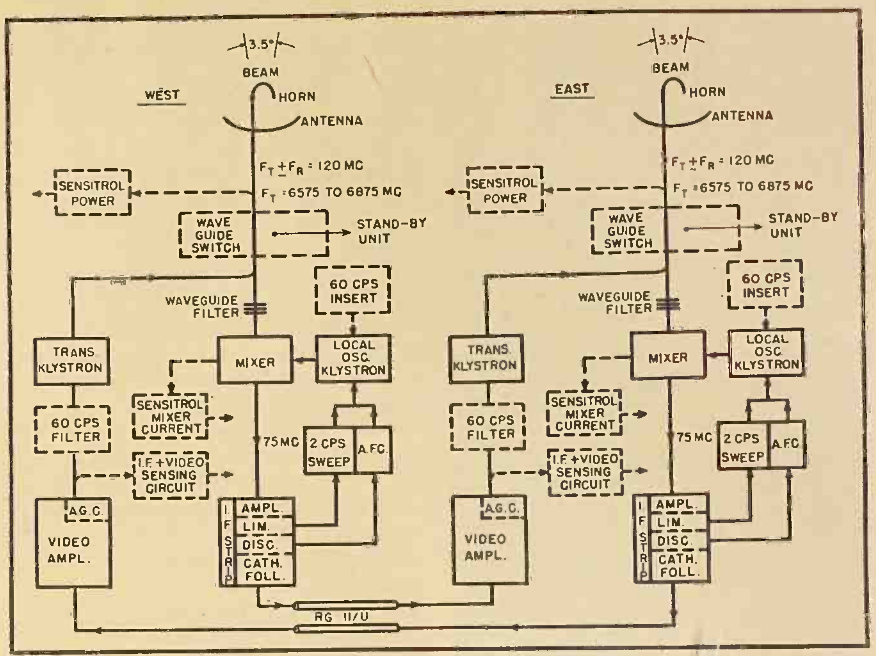


Fig. 2. Block diagram of a typical Motorola repeater station.

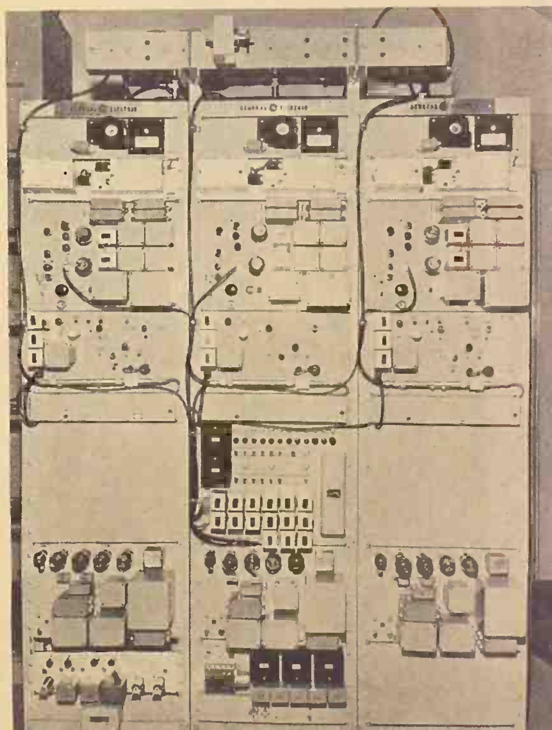
The 6575 to 6875 mc. band presents a number of controversial issues but possesses both extreme advantages and detrimental radiation characteristics. In this band the effect of high attenuation due to rainfall, snow, and extreme weather conditions is very high. However, the amount of time that outages from these causes would consume in the United States is extremely small. If the design of a system is such that enough power and antenna gain (3⅓ ft. diameter—r.f. gain, 35 db) are set up to cover the increased attenuation from weather effects, the advantages of this higher band would tend to override the disadvantages.

In the actual design of equipment for these frequencies, the use of klystron and magnetron tubes in transmitters and receivers is extremely economical. The tubes for these frequencies are small in size. Tube life is anywhere from 6000 to 10,000 hours, depending upon the rated condition of the tube in its operating circuit.

In this frequency band, antenna proportions are such that a small reflector will have an extremely high gain, thus permitting the use of a very narrow beam giving a high energy transfer from transmitter to receiver. This asset compensates for losses at these frequencies due to rain and snow. Also, the use of a highly directional antenna permits the use of passive reflectors, which are 45° reflectors placed on top of a tower with antenna and r.f. components placed close together at ground level. This results in a simpler and less expensive installation and extremely simple servicing, but it requires the use of a substantial tower with a minimum amount of sway. At these frequencies wave guides are also extremely efficient.

Wave guide systems actually provide

Fig. 3. Front view of the G-E UA-1-A microwave relay repeater station.



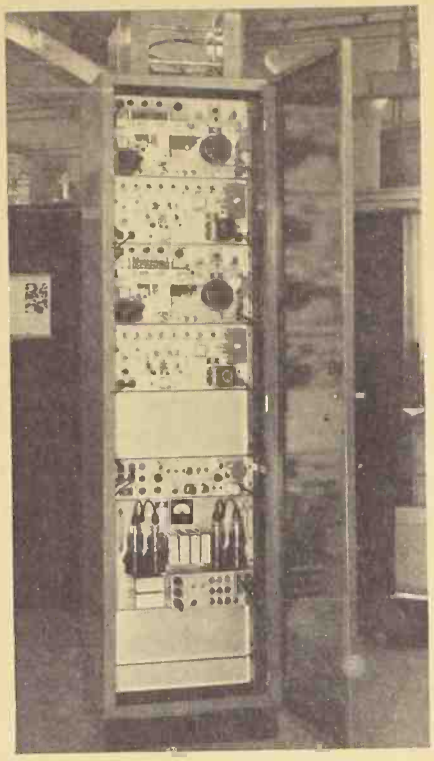


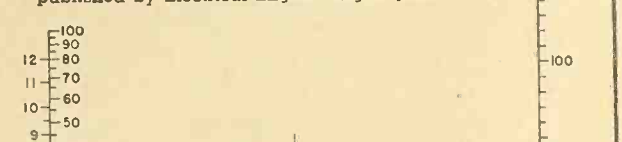
Fig. 4. RCA Type CW-20A repeater for two-way point-to-point communications.

the most efficient means of transferring high-frequency r.f. energy known at this time. The use of a wave guide permits the incorporation of very efficient wave guide filters, rendering practicable the use of one antenna for both transmission and reception. Furthermore, wave guides have an inherently high cutoff frequency, rendering the system impervious to transmission interference on bands below the transmitted frequency. The utilization of greater bandwidths at the higher frequencies permits wider modulation bands and allows the transmission of many channels of voice frequency.

These higher frequencies are in the efficient range of small klystron and magnetron tubes, and microwave power can be generated with three types of tubes. The first is the reflex klystron which is characterized by relatively low efficiency on the order of 30%, but is difficult to frequency-modulate in the present state of the art. The second type, the magnetron, is widely used in radar systems. The third type of tube which can be used is the traveling wave tube.

The next higher frequency band available is from 12,200 to 12,700 mc. This possesses further advantages in that smaller antennas can be used and antennas of the same size will give much higher gain. A much sharper beam can also be achieved. At these frequencies and at higher frequencies, the effects of rain and snow become much greater. A comparative figure is that at 3000 mc. a cloudburst will produce an attenuation of approximately 1½ db per mile. The same amount of rain at a frequency of 12,000 mc. will produce an attenuation of 9 db per mile. This attenuation makes these frequencies practically unusable for communication work at the present state of the art.

Fig. 5. Nomograph for determining free space attenuation of microwaves. From an article titled "Application of Microwave Channels" by C. R. Cheek, Westinghouse Elec. Corp., which was published by Electrical Engineering in June, 1951.



The additional channels available for future development are 16,000 to 18,000 mc. and 26,000 to 30,000 mc. These channels may become usable at later dates, but at the present time, other than for extremely short hops or for individual circuits, they are not usable for communication service.

In the actual layout and installation of a microwave system, a number of things must be taken into account. Since microwave signals do not follow the curvature of the earth, it is necessary to provide line-of-sight paths between the antennas. As an additional safety factor, a path clearance of at least 50 feet above all obstructions is recommended. Fading is more severe when grazing or near-grazing conditions exist than when adequate clearance at all points is available.

In the actual layout of such a system, the use of topographical maps and profile drawings of the region in question is highly recommended. This method enables an engineer to route the system properly and to allow for the height of the most prominent ridges or other obstructions along the transmission path. If topographical maps are not available for a region, aerial maps or navigation maps are sometimes available which provide similar information.

Usually a comparison of a number of locations at one end or another of a microwave link will provide a compromise location which will give the necessary antenna height and yet be a suitable location for termination of leased or privately owned telephone communication circuits. Microwave transmitters and receivers are normally rated in terms of the maximum number of decibels of attenuation through which they will operate successfully, and this rating is the total attenuation from the transmitter output terminals to the receiver input terminals. In calculations one must include both the loss in coaxial cable or wave guide at each terminal where such a transmission line is used, and the loss of energy in free space. The latter loss usually makes up by far the greater proportion of attenuation in the channel, and can be determined from the nomograph of Fig. 5 which relates the free-space attenuation in db with the frequency, distance, and antenna diameter in feet.

In calculation of the actual system layout, allowances for fading must be taken into consideration. At frequencies of 960 mc., an allowance of 0.5 db per mile for fading is conservative assuming 50-foot clearances. On frequencies of 2000 to 6500 mc., the free-space attenuation plus an allowance of 1 db per mile for fading and minor obstructions would be reasonable. With the use of this nomograph, the actual gain for a line-of-sight communication system can be set up.

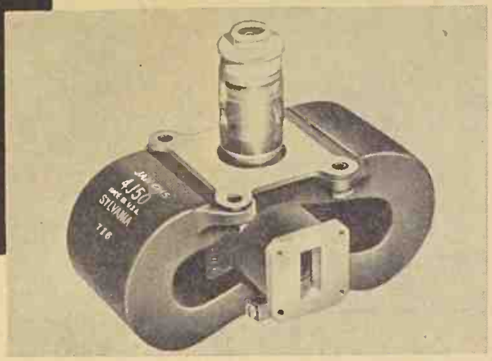
A representative relay system oper

(*Continued on page* 55)

TUBES for MICROWAVE APPLICATIONS

The Type 5768 planar triode, designed to minimize lead inductance.

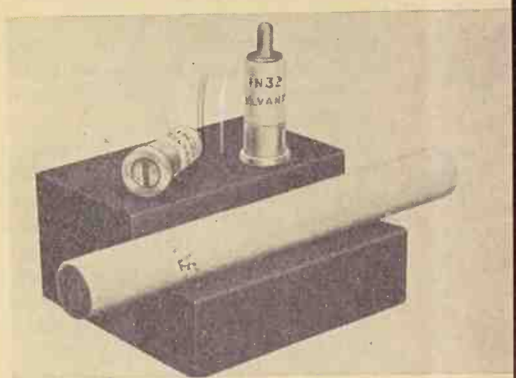
The Type 6BM6 reflex klystron uses only one toroidal cavity.



Type 4J50 magnetron with a wave guide output fitting.

By W. B. WHALLEY
Sylvania Electric Products Inc.

Many tubes have been developed for both receiving and transmitting purposes at microwave frequencies.



The 1N32 is a silicon video detector useful at frequencies up to 3000 mc.

MICROWAVE FREQUENCIES extend above 1000 mc. with corresponding wavelengths of 30 cm. or less. These short waves have operating characteristics that are particularly suitable for the majority of radar and wide-band multiplex relay systems for telephone and television signals.

The physical characteristics of the equipment used in the microwave region, particularly the antennas, are of great value in radar work where high directivity is desirable. For relay service, efficient operation is dependent on the reduction of multipath effects. Again, therefore, highly directional antennas are necessary. Because these antennas should be of reasonable size, the use of microwave frequencies is indicated.

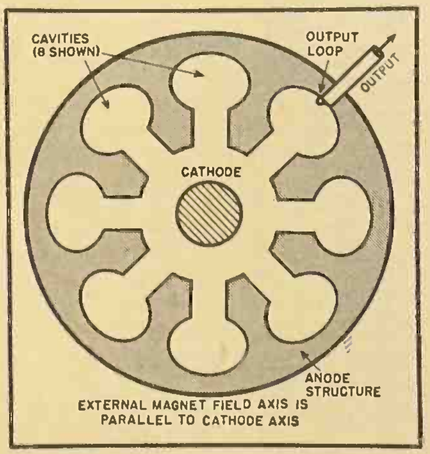
Another consideration that recommends microwavelengths for relay service is that a large number of these systems require wide-band transmission, as in the simultaneous transmission of several television programs over the same links. Only the microwave region provides sufficient frequency spectrum for this service.

Electron Tube Design

At power and the lower radio frequencies, the conventional vacuum tube is readily applied as a circuit component with supplementary resistance, inductance and capacity. But in microwave operation the velocity of electrons in a tube becomes an important consideration. The velocity of electrons in an ordinary receiving tube ranges from 1/100th to 1/10th of the speed of light, depending upon the plate voltage. This is relatively slow in comparison with the rate of voltage change at microwave frequencies.

The time required for electron passage, from cathode to plate, is called *transit time.* At microwave frequencies, transit time in a triode can be a large part of the time required for one cycle. This means that before the electron has completed its travel from cathode to plate, a reversal of grid voltage will reduce its velocity or will force its return to the electron cloud around the cathode. For this reason, characteristic curves which show the relation of voltage and current in conventional tubes at ordinary frequencies do not apply when those tubes are operated at microwave frequencies.

Fig. 1. Diagram of cavity magnetron.



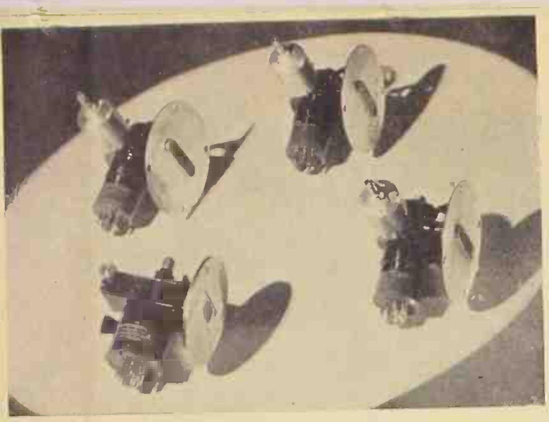
Conventional triodes, for example, will fail to operate in the microwave region. Also, each type of tube has a critical maximum frequency above which it will fail to operate because of the limitation of electron transit time. The critical frequency is determined by the dimensions of the tube elements and the operating d.c. or pulse voltage. Closely spaced elements and minimum values of interelectrode capacity and lead inductance are microwave requirements.

Types of Tubes

Since microwave tubes are operated more as a part of an electron stream in a system than as components in a conventional circuit, special triodes for microwave applications should be designed so that they may be easily inserted in the system.

In these special triodes, the physical shape and arrangement of elements represent an effort to provide electrical and physical properties which make them adaptable for microwave use.

Next in our discussion are such



A group of Sperry reflex klystrons.

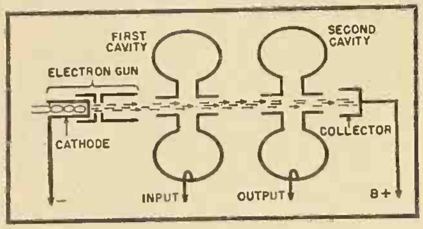


Fig. 2. Diagram showing the basic construction of a 2-cavity klystron.

tubes as have been specifically designed for microwave service. These tubes actually make the transit time phenomena useful in oscillators and amplifiers. Typical examples are klystrons and traveling wave tubes in which interactions between magnetic fields and the electron energies are used to give amplification.

Receiving tubes for microwave applications include:

A. Microwave amplifiers
   1. Planar and pencil type grounded-grid triodes for frequencies up to approximately 3000 mc.
   2. Critically designed planar triodes for relay networks at frequencies ranging from 3000 mc. to 4000 mc.
   3. Traveling wave tube amplifiers for frequencies from 1000 mc. to 5000 mc.

B. Microwave local oscillators
   1. Planar and pencil type grounded-grid triodes for frequencies up to approximately 2500 mc.
   2. Klystrons
   3. Tunable magnetrons

Receiving devices for microwave detection and mixing include:

1. Silicon crystal diodes as detectors and mixers for all microwave frequencies
2. Beam deflection tubes as mixers for frequencies up to 3000 mc.

Tubes for microwave transmission may be grouped as follows:

1. Low-power, specially designed planar triodes, as in A2 above
2. Klystrons
3. Continuous wave magnetrons
4. Pulse type magnetrons, capable of high peak powers

Even the small amount of power generated by some microwave transmitting tubes can be very effective because it is possible to use this small power with specially designed, compact, high-gain antennas. Available antenna gains increase as the wavelengths become shorter. For example, an antenna with a face dimension of 20 wavelengths by 20 wavelengths will measure only 5 feet by 5 feet at 4000 mc.

Planar Triodes

Planar triodes are designed to reduce lead inductances to a minimum, to produce reasonably close spacing between the plate and the grid, and very close spacing between the grid and the cathode. The grid terminal is formed as an annular ring to minimize inductance and to permit convenient fitting into a coaxial line or wave guide. Cathode and plate leads are similarly formed.

The internal grid discs are precision wound with very fine parallel wires. During manufacture, great care is taken in handling, storage and application of parts, in order to prevent damage to wire spacings or contamination by dust or airborne particles. Individual metal parts must be fabricated to precise dimension and contour.

Assembly of external plate and grid discs is followed by attachment of corresponding internal parts after they have been carefully prepositioned and riveted together. The cathode and heater sections are assembled into a "header." The two sections are then aligned and sealed together in a glass lathe.

Several types of planar triodes are produced for direct application to microwave systems operating at frequencies up to 3000 mc. Suitable types, used as pulse generators, will develop peak power outputs up to 200 watts.

Klystrons

Klystrons are widely used in microwave work for both oscillators and amplifiers. They fall into a tube classification in which the transit time is not a handicap.

A stream of electrons is produced by an electron gun similar to that of a television picture tube, and the electrons are accelerated past two or more toroidal cavities. Energy interactions occur between the electrons and the cavities so that the field in the first cavity will vary the electron velocity at the resonant frequency of that cavity.

The next cavity is located along the electron path at a point where the electrons are "bunched." Bunching is due to the faster electrons "catching up" with the slower electrons as a result of the modulation of the first cavity. This sets up oscillations (electromagnetic fields) in the second cavity.

If the first and second cavities are coupled together by means of a coaxial line or wave guide of correct electrical length, the tube will oscillate.

Reflex Klystrons

Reflex type klystrons use only one toroidal cavity. The electron stream is made to pass through the gap in one direction, is reflected by a negative potential at the collector, and returns through the cavity. The collector is shaped in such a way as to keep the electrons focused into a beam.

Oscillation is adjusted by varying the collector potential so that the returning

Table 1. Microwave tube manufacturers. Numbers indicate that the manufacturer produces the following types of equipment: 1, klystrons; 2, magnetrons; 3, miscellaneous microwave tubes; 4, crystal detectors and mixers; 5, bolometers.

Amperex Electronic Corp., 25 Washington St., Brooklyn 1, N. Y.	2, 3
Berkshire Laboratories, 624 Beaver Pond Rd., Lincoln, Mass.	4
Bomac Laboratories, Inc., Salem Rd., Beverly, Mass.	3, 4
Diamond Manufacturing Co., 7 North Ave., Wakefield, Mass.	4
Eitel-McCullough, Inc., 798 San Mateo Ave., San Bruno, Calif.	1, 3
Elm Laboratories, 20 S. Broadway, Dobbs Ferry, N. Y.	4
Empire Devices, Inc., 38-25 Bell Blvd., Bayside 61, N. Y.	4
Federal Telecommunication Labs., Inc., 500 Washington Ave., Nutley 10, N. J.	2, 3
Feiler Engr. & Mfg. Co., 8026 N. Monticello Ave., Skokie, Ill.	4
General Electric Co., Electronics Div., 1 River Rd. Schenectady, N. Y.	2, 3
General Electric Co., Electronics Div., Electronics Park, Syracuse, N. Y.	4
General Electronics, Inc., 101 Hazel St., Paterson, N. J.	3
General Instrument Corp., 829 Newark Ave., Elizabeth 3, N. J.	4
General Precision Lab., Inc., 63 Bedford Rd., Pleasantville, N. Y.	4
General Radio Co., 275 Mass. Ave., Cambridge 39, Mass.	4
General RF Fittings Co., 702 Beacon St., Boston 15, Mass.	4
Hewlett-Packard Co., 395 Page Mill Rd., Palo Alto, Calif.	4
H. M. R. Electronics, Inc., 36 Grove St., New Canaan, Conn.	4
Hytron Radio & Electronics Co., 76 Lafayette St., Salem, Mass.	3
Kemtron Electronic Co., 23 Brown St., Salem, Mass.	3, 4
Kings Microwave Co., Inc., 719 Main St., New Rochelle, N. Y.	4
Litton Industries, 1001 Brittan Ave., San Carlos, Calif.	2, 3
Monarch Radio & Television Corp., 61 Crescent St., Brooklyn 8, N. Y.	4
National Union Radio Corp., 350 Scotland Rd., Orange, N. J.	3
Philco Corp., Tioga & "C" Sts., Phila. 34, Pa.	1, 3, 4
Polarad Electronics Corp., 100 Metropolitan Ave., Bklyn. 11, N. Y.	4
Radio Corporation of America, Camden, N. J.	4
Radio Engrg. Laboratories, Inc., 36-40 37th St., L. I. City 1, N. Y.	4
Radio Merchandise Sales, 1165 Southern Blvd., New York 59, N. Y.	4
Raxco Mfg. Engineers, Inc., 300-302 First Ave., Peoria, Ill.	4
Sierra Electronic Corp., 1050 Brittan Ave., San Carlos, Calif.	4
Sperry Gyroscope Co., Great Neck, New York 14, N. Y.	1, 3, 4, 5
Sylvania Electric Products Inc., 70 Forsyth St., Boston 15, Mass.	2, 3, 4
Sylvania Electric Products Inc., 1740 Broadway, N. Y. 19, N. Y.	1, 2, 3, 4
Taylor Tubes, Inc., 2312 W. Wabansia Ave., Chicago 47, Ill.	3
Varian Associates, 990 Varian St., San Carlos, Calif.	1, 3
Vectron, Inc., 235 High St., Waltham, Mass.	4
Westinghouse Electric Corp., 511 Wood St., Pittsburgh 30, Pa.	2, 3
Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.	4
Weymouth Instrument Co., 1440 Commercial St., E. Weymouth 89, Mass.	4
Wheeler Laboratories, Inc., 122 Cutter Mill Rd., Great Neck, N. Y.	4

electrons are in correct phase with those moving toward the collector. The operating frequency is determined primarily by the dimensions of the cavity.

A family of reflex klystrons includes tubes suitable as broad-band microwave oscillators, for c.w. and pulse operation. Their design utilizes disc-seal construction similar to that of the planar triodes previously described. This type of construction contributes to compact physical size, ruggedness and good power dissipation.

C.w. oscillators include types 5836, 5837, 6BL6 and 6BM6. Types 5836 and 5837 are also suitable for pulse modulated oscillator service. The 5836 and the 6BL6 will operate satisfactorily from 1600 mc. to 6500 mc. Frequency range of the 5837 and the 6BM6 is up to 3800 mc.

These reflex klystrons are all small-sized and very similar in appearance, having almost identical dimensions. Electrical connection to resonator grids is made by means of gold-plated contact rings which are formed from disc seals. The contact rings are made of oxygen-free, high-conductivity copper which is reinforced by heavy brass rings. The top ring is of smaller diameter than the bottom ring to permit convenient insertion in microwave systems. This design makes insertion of the klystron comparable to the placement of an ordinary tube in its socket.

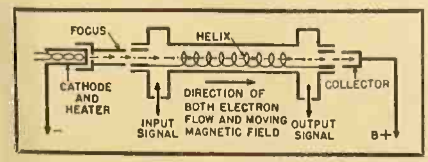
Traveling Wave Tubes

Traveling wave tubes are designed to utilize the interaction between a stream of electrons and a moving electromagnetic field. Thus transit time phenomena actually facilitate their operation. Typical traveling wave tube design is based on a structure with an electron gun, a helix and a collector. The electron gun is similar to the type used in television picture tubes. The helix, located in the central portion of the tube between the electron gun and the collector, ranges from 6 to 18 inches in length. The length of the helix is determined by the wavelength and desired operating characteristics. The collector is operated at a suitable positive potential with respect to the electron gun.

Through adjustment of the pitch of the helix to suit the velocity of electrons passing through it, and by careful adjustment of collector potential, electrons can be controlled so that they will move through the helix at almost precisely the same speed as that of the electromagnetic field along the helix.

As the beam moves through the electromagnetic field, it forms successive groups of bunched and debunched electrons. These electron groupings become intensified as they approach the far or collector end of the helix. In this way energy is accumulated through interaction between the electrons and the electromagnetic field. The amplified output is taken off by suitable coupling at the far end of the helix, similar to the coupling at the input end.

Fig. 3. Diagram showing the operation of a traveling wave tube.



Magnetrons

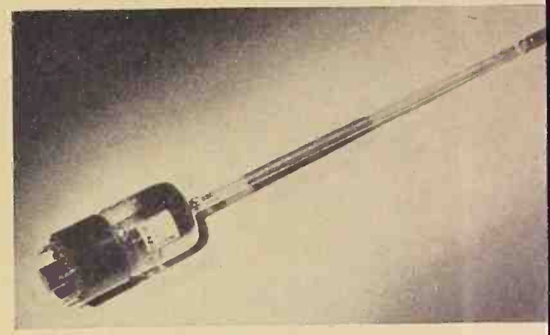
The most important type of magnetron for microwave applications is the multiple cavity type which has a structure somewhat similar in appearance to that of the field in a d.c. generator. Spaces between the poles are large compared to the thickness of the pole tips. At the center of the magnetron structure, an oxide-coated cathode is carefully spaced from the pole pieces in order to make the radial gaps as uniform as possible. A magnet, usually a p.m. type, is placed on the outside of the tube to provide a magnetic field extending through the center of the tube and parallel to the axis of its cathode.

A group of G-E lighthouse tubes.

When a positive d.c. voltage is applied to the anode or pole structure, electrons move from cathode toward the anode with an initial radial velocity. Since the electrons are moving in a d.c. magnetic field, their paths become a combination of radial and circumferential motion. As groups of electrons move past the pole pieces at the ends of the cavities, electromagnetic fields are set up in the cavities at a frequency which is an average of frequencies due to the dimensions of the individual cavities.

It is important for efficient operation and stable frequency that cavities be as nearly identical as possible, and that spacings between cavity tips and the cathode also be uniform.

Power at the desired frequency is obtained from the magnetron by means of a small loop placed in one of its cavities, close to the outer wall. The loop is connected to an insulated sealed lead extending outside the tube. Diameter of the lead is determined by the frequency range and the coupling to suit a typical coaxial line.



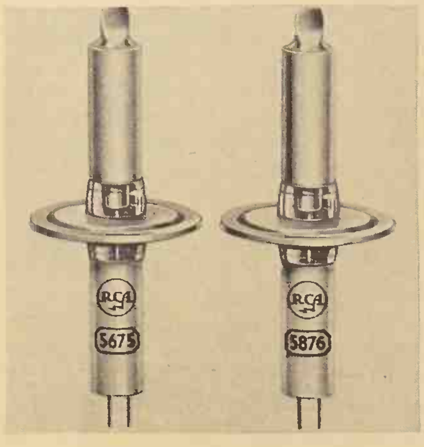
The Type 5929 Federal traveling wave tube can provide a power output of 10 watts between 3700 and 5500 mc.

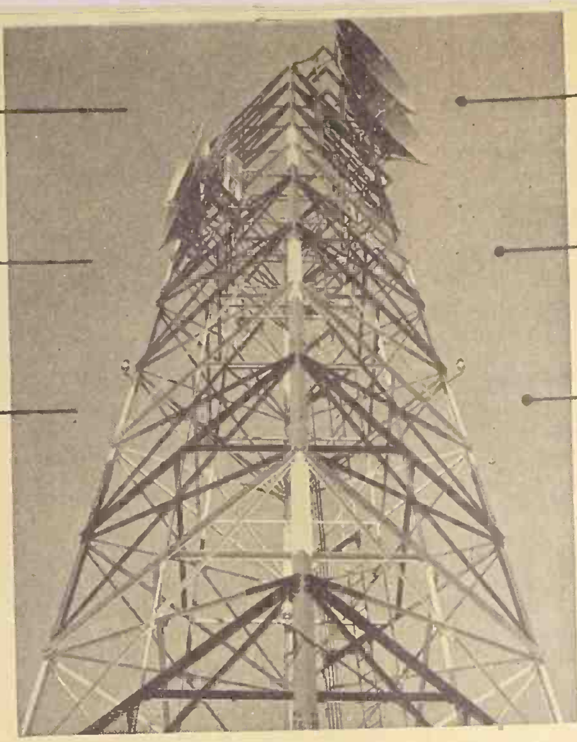
Radio receivers require either detectors for demodulation, or mixers. As stated earlier, the effect of transit time makes conventional vacuum tubes unusable at microwavelengths. However, crystal diodes of suitable and precise construction have negligible transit time characteristics, and they are, therefore, used in almost all radar receivers and in a majority of relay systems. These microwave crystals also have low shunt capacitances and low noise output. They provide excellent mixing and detection characteristics in the microwave region.

Typical *Sylvania* crystals that are specially designed for microwave services include Types 1N21B, 1N21C, 1N23, 1N23A, 1N25, 1N26, 1N53, and 1N76. These are silicon crystals which are produced from a very high purity silicon material, precisely alloyed to exhibit rectifying qualities. Ingots of the material are cut and ground to produce thin wafers and tiny squares which are assembled in special holders with point-contact "cat-whiskers." Diameter and shape of these cat-whiskers are carefully controlled to assure correct contact pressures. Physical dimensions and contour of the holders are

(*Continued on page* 44)

The RCA Type 5675 pencil triode (left) can be used as a grounded-grid amplifier up to 3000 mc. The 5876 (right) is useful in oscillator circuits up to 1700 mc., and as a multiplier to 1500 mc.





A group of parabolic reflectors mounted on a steel tower. The same type of antenna is used for receiving and transmitting.

ANTENNAS FOR MICROWAVE USE

By
ALAN SMOLEN
Joseph Racker Co.

Very high antenna gains are realized with simple and compact structures at microwave frequencies.

THE use of low power transmitters with highly directional, high gain antennas has been one of the principal reasons for the increasing applications of microwave equipment. To visualize the tremendous advantages that directional antennas have, consider that a one-watt transmitter operating into ten-foot parabolic antennas used for receiving and transmitting at 2000 mc. will provide the same signal strength as a pair of dipoles fed by one million watts!

The same advantage in directivity is possible at lower frequencies, but the tremendous size of antennas required to obtain this directivity offsets the advantage gained in radiation efficiency. At microwaves these advantages are obtained with practical-sized antennas.

An additional property of microwave antennas is the fact that, in most cases, they act as efficient radiators of microwave energy over a broad band of frequencies. This permits the use of pulse systems of modulation which lend themselves to multiplexing. As a result, a single antenna can be used for the transmission of several hundred simultaneous conversations by means of frequency- or time-multiplexing systems. The pulse systems have the further advantage of allowing peak pulse powers much higher than average, thus providing an improvement in signal-to-noise ratio.

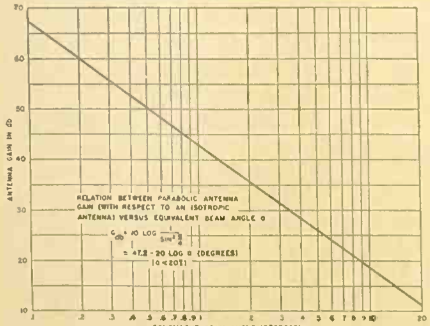
It is not possible to discuss the details of the wide variety of microwave antennas in a single article, but the basic principles of design fall into a group of classifications.

An antenna is designed to convert energy received at its input into a radiated electromagnetic wave which has certain desired characteristics of amplitude, polarization, and phase. In many cases the radiating system must be able to control each of these items in order to produce the desired results.

A means of classifying antennas is provided by the method used in controlling these parameters. Two basic methods are used, namely, arrays and optical methods. Amplitude and phase may be controlled in any array by feeding the elements through power-controlling devices and through different feed lengths. The element position will control the plane of polarization. If energy is distributed in an antenna by radiation (as a dipole antenna feeding a parabolic reflector), optical methods may be employed to vary amplitude, phase, and polarization in order to obtain a desired pattern.

The wide variety of microwave antenna types used for communication and radar may be broken down into a definite classification. This is shown in Fig. 5.

Fig. 1. Antenna gain vs. equivalent beam angle for a parabolic reflector.



Communication Antennas

A microwave antenna designed for a fixed communication system usually consists of a primary feed element which distributes energy over an aperture. The aperture is usually a lens or a parabolic reflector, while the primary feed may be a wave guide horn or a dipole and reflector. Directivity of the antenna is a function of both of these elements.

The principal properties of a microwave antenna are determined by the aperture, or in the case of a parabolic reflector, by the area of the reflector. A uniformly illuminated aperture will produce a concentrated, directive beam, the beam angle or width being inversely proportional to the linear dimension of the aperture and also inversely proportional to the radiated frequency.

The radiation from a directive microwave antenna is usually in the form of a cylindrical beam (the Fresnel Region) for a certain short distance and then gradually diverges into a conical beam with the apex located at the center of the aperture.

The gain of an antenna (G) is related to the effective area (A) and the wavelength (λ) and is given by:

$$G = 4\pi A/\lambda^2$$

The effective area $A = \eta S$, where S is the actual area and η the efficiency factor. The efficiency factor in most cases is approximately 0.5.

The terms "high gain" and "directivity" are interchangeable, some engineers preferring to use beam angles, while others prefer to use gain in decibels when referring to directive antennas. The relationship between gain, in decibels, and beam width, in degrees, is shown in Fig. 1.

There are four basic general characteristics which should be examined in discussing microwave communication antennas:

1. Gain or directivity
2. Bandwidth
3. Susceptibility to interference
4. Need for protection against the weather

In a fixed communication system, operating with antennas that are required to transmit and receive from single directions, it is always desirable to utilize the highest possible antenna gain. The maximum gain possible (minimum beam angle) is determined by the rigidity of the tower supporting the antenna and possible fluctuation of the beam in the atmosphere.

The rigidity of the tower seems to be no problem for antenna beams of approximately one degree. Fluctuation of the beam in the atmosphere will affect the vertical beam angle only. It is expected that the lower limit will be determined very shortly as a result of tests being made.

The simplest method of increasing the power received in a particular system is to increase the gain of the antennas. In a system in which the same type of transmitting and receiving antenna is used, the received power will vary as the square of the aperture area or the fourth power of the antenna diameter when parabolic reflectors are used!

Practical limitations on wind resistance and weight have limited reflector diameters to approximately 10 to 14 feet, but reflectors of larger diameters have been built, some as large as 50 feet, with gains of 60 db.

As mentioned in the introduction, microwave antennas are inherently broad-band. The antenna beam characteristic and impedance vary very little over a range in frequencies of as much as plus or minus 5%. At 2000 mc., this amounts to the order of plus or minus 100 mc. In order to utilize the bandwidth characteristic it is desirable to handle several communication channels on a single antenna. This results in maximum use of antenna and —more important—antenna supports, which are usually quite costly.

Several communication channels may be fed to a single channel by multiplexing systems, or by diplexing systems. In the former case the messages may be frequency- or time-multiplexed. In the latter case several different carrier frequencies are used and separated by selective cavity filters at the receiving end.

Parabolic Antennas

By taking advantage of the similarity of microwaves and light waves, and applying principles of optics, a simple and relatively common communication antenna has been developed, namely, the parabolic reflector. In a manner similar to that of a headlight reflector, the radiation from a feed is focused into a narrow beam, thus achieving a high degree of directivity. Radiation from the focus or feed is usually in the form of a spherical wavefront. The reflector converts the spherical wavefront into a plane wavefront or uniphase front.

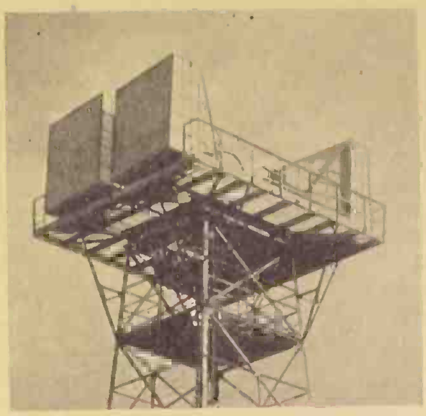
For most parabolic antennas, the gain over an isotropic antenna is given by:

$$G = 24R^2/\lambda^2$$

where R is the radius of the circle projecting across the rim of the parabola. Since the gain of the antenna is inversely proportional to the square of the wavelength, why not increase the frequency of operation and still maintain reasonable physical size? The answer lies in the propagational difficulties encountered in the higher microwave frequencies.

The power developed across a receiving antenna is a very small percentage of the power transmitted. There are several factors which are responsible for the higher attenuation between transmitting and receiving antennas. Among the factors peculiar to microwaves are the free space factor and absorption by the atmosphere.

The free space factor or attenuation results from the fact that the transmitted beam is conical in shape, and therefore the area of a plane through the cone increases with distance from



A typical lens antenna system shown mounted at the top of a steel tower.

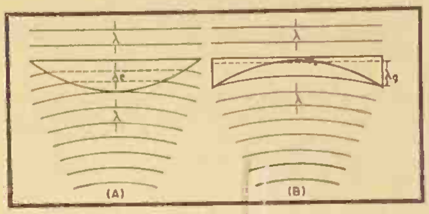


Fig. 2. Focusing action of (A) dielectric lens and (B) metal plate lens.

the transmitting antenna. Thus, when it reaches the receiving antenna, only a small percentage of the cone area may be intercepted by the relatively small receiving antenna.

A more difficult factor to analyze is the absorption of energy by the atmos-

Table 1. Manufacturers of microwave antenna equipment and accessories. 1, antennas for radar, communications, etc.; 2, towers, mounts and housings; 3, tuning, phasing, and coupling units; 4, feed systems.

Airtron, Inc.	26 E. Elizabeth Ave., Linden, N. J.	4
American Phenolic Corp.	1830 S. 54th Ave., Chicago 50, Ill.	4
Andrew Corp.	363 E. 75th St., Chicago, Ill.	1, 3, 4
Bart Laboratories Co., Inc.	227 Main St., Belleville 9, N. J.	1
Belling & Lee, Ltd.	366 Madison Ave., New York 17, N. Y.	2
Birnbach Radio Co., Inc.	145 Hudson St., New York 13, N. Y.	2
Bone Engineering Corp.	701 W. Broadway, Glendale 4, Calif.	1, 2, 4
Coil Winders, Inc.	61 Bergen St., Brooklyn 2, N. Y.	3
Electro Precision Products, Inc.	119-01 22nd Ave., New York, N. Y.	1, 2, 3
Federal Telecommunication Labs., Inc.	500 Washington Ave., Nutley 10, N. J.	1
Gadgets, Inc.	3629 N. Dixie Drive, Dayton, Ohio	1, 2
General Cement Mfg. Co.	919 Taylor Ave., Rockford, Ill.	1, 2, 3
General Precision Lab., Inc.	63 Bedford Rd., Pleasantville, N. Y.	1
General Electric Co.	Electronics Park, Syracuse, N. Y.	1, 4
H. M. R. Electronics, Inc.	36 Grove St., New Canaan, Conn.	1
IE Manufacturing Co.	325 N. Hoyne Ave., Chicago 12, Ill.	2
Johnson Co., E. F.	209 Second Ave., S. W., Waseca, Minn.	2, 3
Kennedy & Co., D. S.	432 S. Main St., Cohasset, Mass.	1, 2
Kings Microwave Co., Inc.	719 Main St., New Rochelle, N. Y.	1, 3, 4
La Magna Mfg. Co., Inc.	51 Clinton Place, E. Rutherford, N. J.	1, 2, 3
LaPointe Plascomold Corp.	Windsor Locks, Conn.	2, 4
Makepeace Co., D. E.	Pine & Dunham Sts., Attleboro, Mass.	4
Microwave Equipment Co., Inc.	N. Caldwell, N. J.	1
Motorola, Inc.	4545 W. Augusta Blvd., Chicago 51, Ill.	1, 2, 4
Network Manufacturing Corp.	213 W. 5th St., Bayonne, N. J.	1, 3
Northeastern Engineering, Inc.	Bedford St., Manchester, N. H.	1
Philco Corp.	Tioga & "C" Sts., Philadelphia 34, Pa.	1, 2, 3, 4
Radio Engineering Laboratories, Inc.	36-40 37th St., Long Island City 1, N. Y.	1
Radiomarine Corp. of America	75 Varick St., New York 13, N. Y.	1, 2
Radio Merchandise Sales	1165 Southern Blvd., New York 59, N. Y.	1, 2, 3
Radio Corp. of America	Camden, N. J.	1, 2, 4
Schutter Mfg. Co., Carl W.	80 E. Montauk Highway, Lindenhurst, N. Y.	1
South River Metal Prod. Co., Inc.	377-379 Turnpike, South River, N. J.	2
Sperry Gyroscope Co.	Great Neck, New York 14, N. Y.	1, 3
Thompson Products, Inc.	2196 Clarkwood Rd., Cleveland 3, Ohio	1, 2, 3, 4
Titeflex, Inc.	500 Frelinghuysen Ave., Newark 5, N. J.	4
Torngren Co., Inc., C. W.	236 Pearl St., Somerville, Mass.	1, 4
Truscon Steel Co.	Youngstown 1, Ohio	2
United States Gasket Co.	602 N. 10th St., Camden, N. J.	2
Vectron, Inc.	235 High St., Waltham, Mass.	1, 2
Ward Products Corp., The,	1523 E. 45th St., Cleveland 3, Ohio	1, 2, 3
Weymouth Instrument Co.	1440 Commercial St., E. Weymouth, Mass.	1, 2
Wheeler Laboratories, Inc.	122 Cutter Mill Rd., Great Neck, N. Y.	1, 4
Wind Turbine Co.	Market St. and Pa. R.R., W. Chester, Pa.	2
Woodwelding, Inc.	3000 W. Olive Ave., Burbank, Calif.	3
Workshop Associates, The	135 Crescent Rd., Needham Hts., Mass.	1, 2, 3, 4

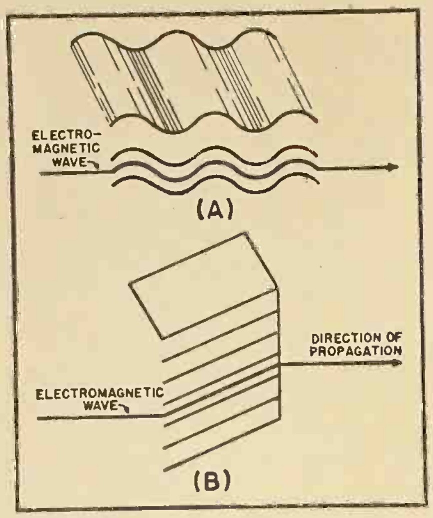


Fig. 3. Dielectric effect achieved by (A) serpentine plates and (B) slanted plates.

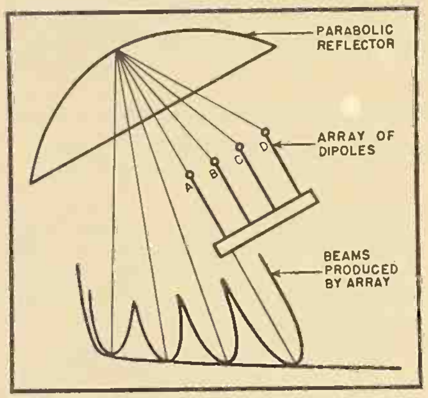


Fig. 4. A shaped beam which is achieved by an array of point sources as shown.

phere. The atmosphere is composed of a mixture of gases, dust particles, and water vapor. Unfortunately this mixture absorbs energy from a microwave beam of energy. The amount of absorption is a function of the frequency being transmitted and is usually very small for frequencies below 10,000 mc. Absorption is highest at approximately 60,000 mc. for oxygen and is highest at 25,000 mc. for water vapor. Water in the atmosphere in the form of fog, rain or clouds, decreases received energy by absorption and because it is a poor conductor of microwave energy.

An example of the difference in attenuation per mile during a heavy rainfall indicates that the attenuation at 3000 megacycles is only 0.3 db, while at 30,000 mc. the attenuation is 21 db. Thus the obvious advantage of maintaining reasonable physical sizes of parabolic antennas and increasing frequency above 10,000 mc. to achieve higher gains cannot be utilized.

Another disadvantage in the use of higher frequencies is the duct effect. A duct is usually considered as a kind of layer occurring in the atmosphere which traps microwaves and reflects them up and down between its boundaries as they travel outward from the transmitter. It results in some very unusual effects such as phenomenal ranges as long as 1500 miles, or, conversely, the inability of two stations very close to each other to maintain contact.

Similar to wave guides, ducts have a cutoff frequency and cannot propagate frequencies below it. The cutoff frequency is a function of the height or distance between the top and bottom layers of the duct—the greater the height the lower the cutoff frequency —with the result that only narrow ducts can propagate the higher microwave frequencies. As an example, a duct 25 feet in height will cut off at 16,700 mc. while a duct of 200 feet will propagate down to 750 mc. Thus the higher microwave frequencies are at a disadvantage in that at certain times of the day and year contact between line-of-sight stations may not be reliable.

Lens Antennas

Another device which takes advantage of the similarity of light and microwaves is the lens. The lens is a device for transforming the spherical waves transmitted radially by a point source into a flat or uniphase wavefront. This action will effectively focus the transmitted energy into a narrow, highly directional beam.

The lens has a wide tolerance in manufacture. It is also essentially a broad-band antenna. Whereas the machining tolerance of a parabolic reflector must usually be kept to a few hundredths of an inch, the allowable tolerance in the lens is usually on the order of a quarter wavelength or as much as one-fifth of an inch variation at 10,000 mc.

The feed in most parabolic reflectors is in the path of the reflected beam, with the result that there is interference in the beam and a waste of energy into the feed system. In microwave repeater systems a transmitting antenna is usually placed back to back with a receiving antenna. If parabolic reflectors are used, the spill-over will result in crosstalk, but use of a lens antenna eliminates the spill-over and will consequently remove it as a cause of crosstalk.

There are three general types of microwave antenna lenses: dielectric lenses, metal parallel-plate type, and metal path length lenses.

The fundamental principle of *dielectric lenses* is illustrated in Fig. 2A, which shows a point source emitting spherical waves. The spherical waves have a wavelength of λ in free space. When they enter the dielectric, however, the wavelength becomes λe. The wavelength in the dielectric is shorter than the wavelength in free space, which means that if a lens is used as shown in Fig. 2A, with the thickened portion in the center, the wavefront is effectively slowed down or delayed as it passes through the dielectric. The resultant produces a plane wavefront or uniphase wavefront which is the most directive pattern for an aperture of a given size.

The use of dielectric lenses has not been extensive because of the weight and bulk requirements. A lens may be constructed of lucite or polystyrene and will usually be many wavelengths thick if its focal length and aperture are large compared with its wavelength. This shortcoming has been overcome to some extent by the process of zoning, which will be discussed in connection with metal lenses. Unfortunately, zoning also limits the bandwidth of the lens to some extent.

The *metal plate lens* shown in Fig. 2B utilizes the principle that the wavelength of the signal being transmitted down a wave guide is greater than the wavelength in free space. This is just the inverse of the signal being transmitted through a dielectric. In this type of lens, the wavefront is effectively speeded up as it passes through the parallel plates of the lens and the top and bottom of the lens is therefore thickened. The longer wave guide length is caused by the presence of the sides of the wave guide, not the top and

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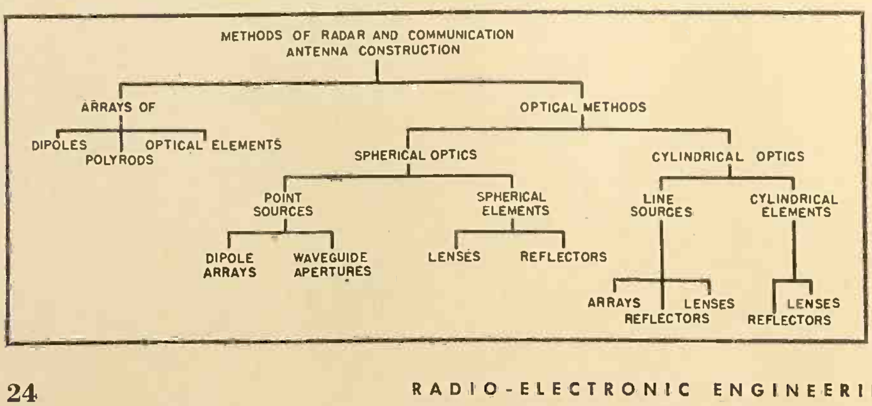
Fig. 5. Methods of radar and communication antenna construction.



Federal

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IT&T scientists, on March 31, 1931, conducted the *first* successful demonstration of radiotelephone communication via microwave across the English Channel, between Dover and Calais . . . inaugurated, in 1933, the world's *first* commercial microwave telephone circuit between Lympne, England and St. Inglevert, France. These two important milestones in microwave history are pictured below.

First demonstration of voice communication via microwave, between Dover and Calais, 1931.

One of towers used in first commercial microwave telephone circuit, between England and France, opened in 1933.

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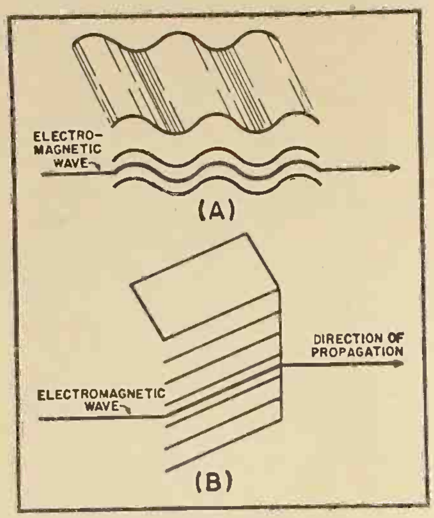

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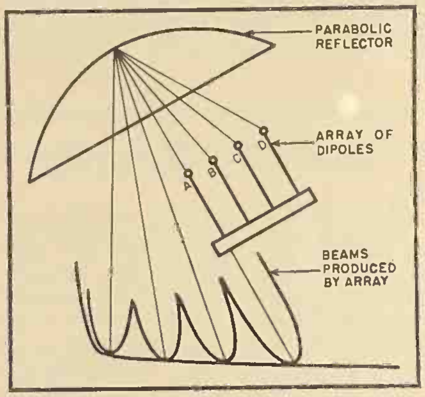

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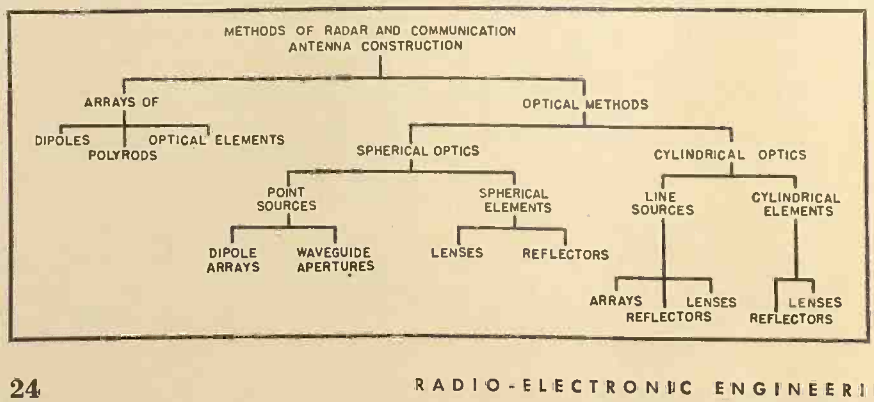


MICROWAVE STATION DIRECTORY

A listing of the major microwave installations in the U. S., including location, operating frequencies, and call signs.

EXPERIMENTAL—CLASS 1

American Telephone and Telegraph Co.
32 Avenue of the Americas, N. Y. C.
Within United States, 3950 (3700-4200) mc. KE2XEO

Bendix Aviation Corp.
East Joppard, Towson 4, Md.
Vicinity of Baltimore, Md., 3150-3160, 3170-3180, 3190-3200, 3210-3220, 9340-9380 mc. KE2XBZ

Cornell Aeronautical Laboratory, Inc.
4455 Gennesee Street
P. O. Box 235, Buffalo, N. Y.
Mobile—Vicinity of Buffalo Municipal Airport, 1500 mc. KE2XLL

Eastern Industries
Regent Street, East Norwalk, Conn.
(In any Location Within Limits of United States), 2475 (2450-2500) mc. KE2XBP

Electric Service Company
3530 Bagley Ave., Seattle 3, Wash.
(Mobile in Seattle, Wash., and Vicinity, including Puget Sound), 3123 (3000-3246) mc. KO2XBM

Electronic Technical Institute, Inc.
Venice Boulevard, Los Angeles, Calif.
Los Angeles, Calif., 3123 (3000-3246) mc. KM2XBO

Federal Telecommunication Laboratories, Inc.
67 Broad Street, N. Y. C.
Telegraph Hill, N. J., 1980 (1850-2110), 3950 (3700-4200) mc. KE2XAX
New York, New York, 1980 (1850-2110), 3950 (3700-4200) mc. KE2XAW
Nutley, N. J., 1980 (1850-2110) mc. KE2XCH

General Electric Company
Schenectady 5, New York
Vicinity of Syracuse, N. Y., 956 (952-960) mc. KE2XEV
Vicinity of Schenectady and Syracuse, N. Y., 915 (890-940) mc. KE2XGM
Vicinity of Syracuse, N. Y., 956 (952-950), 1920 (1850-1990), 2155 (2110-2200), 2600 2500-2700), 3950 (3700-4200) mc. KE2XFJ
Vicinity of Syracuse, N. Y., 2050 (1990-2110), 7000 (6875-7125) mc. KE2XGQ

Hazeltine Electronics Corp.
58-25 Little Neck Parkway, Little Neck, N. Y.
Mobile Vicinity of Little Neck, Long Island, N. Y., 1087.5 (960-1215) mc. KE2XGN

Illinois Institute of Technology
3300 Federal St., Chicago, Ill.
Chicago, Ill., 3000 mc. KS2XCA

Leland Stanford Junior University
Electrical Engineering Dept., Stanford, Calif.
Stanford, Calif., 3007 (2914-3100) mc. KM2XBX

Lenkurt Electric Company
1105 County Road, San Carlos, Calif.
San Carlos, Calif., 900, 955 mc. KM2XDY
Mt. Diablo, Calif., 900, 955 mc. KM2XDZ

Motorola, Incorporated
4545 Augusta Blvd., Chicago 51, Ill.
Chicago, Ill., 6585, 6625, 6665, 6825, 6865, 6805, 6705, 6745, 6785, 6685 mc. KS2XBI
Lombard, Ill., " KS2XBN
Nr. Plato Center, Ill. " KS2XBT
Nr. Wheaton, Ill., " KS2XBO
Chicago, Ill., 6665 mc. KS2XCT

Polytechnic Institute of Brooklyn
99 Livingston St., Brooklyn, N. Y.
Brooklyn, N. Y., 9375 (9345-9405) mc. KE2XLR

Radio Corporation of America
60 Broad Street, N. Y. C.
Camden, N. J., 1250 (1220-1280) mc. KE2XAN
Mobile (8 Units Within 40 Miles of Camden, N. J., a) 30.58-35.50, 43.50-47.58, 156.30-159.51 mc. b) 940 (920-960) mc. KE2XDE
Camden, N. J., 1920 (1850-1990) mc. KE2X1V
Clementon, N. J., 1920 (1850-1990) mc. KE2XIW
Arney's Mount, N. J., 1920 (1850-1990) mc. KE2XKJ

Radio Marine Corporation of America
60 Broad Street, New York 4, N. Y.
New York, N. Y., 3123 (300-3246), 9410 (9320-9500) mc. KE2XHI
New York, N. Y., 9375 mc. KE2XJF

Raytheon Manufacturing Co.
Foundry Avenue, Waltham, Mass.
Waltham, Mass., 3055 (3010-3110), 3070 (3020-3120), 9375 (9345-9405) mc. KC2XCZ
Waltham, Mass., 3070 (3020-3120), 9375 (9330-9420), 9375 (9345-9405) mc. KC2XCX
Waltham, Mass., 3123 (3000-3246) 5555 (5460-5650), 9410 (9320-9500) mc. KC2XCQ

Dr. E. Dillon Smith
5419 56th Place, East Riverdale, Md.
Vicinity of Washington, D. C., 1087.5 (960-1215), 2800 (2700-2900), 4300 (4200-4400), 9150 (8500-9800) mc. KG2XCN

The Sperry Corp.
Great Neck, Long Island, N. Y.
Mobile Aboard Ship, 9375 (9320-9430) mc. KE2XJE

Stanolind Oil and Gas Co.
910 17th Street, Washington, D. C.
Vicinity of Port Arthur, Tex., 3123 (3000-3246) mc. KK2XAP

State of Illinois, Water Supply Division
Box 232, Urbana, Ill.
Vicinity of El Paso, Ill., 2800 mc. KS2XCC
Vicinity of Champagne, Ill., 9375 (9345-9405) mc. KS2XBB

Video Corporation of America
229 West 28th Street, N. Y. 1
Area of New York, N. Y., 24,000 mc. KE2XLP

Western Union Telegraph Co.
60 Hudson Street, N. Y. 13
Nr. Monsey, N. Y., 4100 (4000-4200) mc. KE2XKQ
New York, N. Y., 4100 (4000-4200) mc. KE2XKR

Westinghouse Radio Stations, Inc.
1625 K Street N. W., Washington 6, D. C.
Vicinity of Baltimore, Md., 9410 (9320-9500) mc. KG2XBY

EXPERIMENTAL—CLASS 2

The Dow Chemical Co.
Freeport, Texas
Freeport, Texas, 2820-2860 mc. KK2XDH

Elm City Broadcasting Co.
1110 Chapel St., New Haven Conn.
New Haven, Conn., 6975-7000 mc. KCA 60

Geotronic Survey
335 South Sycamore St., Centralia, Ill.
(Mobile in Any Location Within the Continental United States), 9375 mc. KS2XAZ

The Peninsular Telephone Co.
519 Zack St., Tampa, Fla.
Tampa, Fla., 935 mc. KIB 47
Plant City, Fla., 895 mc. KIB 48
Bartow, Fla., 935 mc. KIB 49

Porto Rico Telephone Co.
P. O. Box 4275, San Juan (21), Puerto Rico
San Juan, P. R., 1860 mc. KUP 36
"Cerro Maravallas" P. R., 1980 mc. KUP 37
Ponce, P. R., 1860 mc. KUP 38
60 Hudson St., New York 13, N. Y.

The Western Union Telegraph Co.
New York, N. Y., 6115 mc. KEA 61
So. of Neshanic, N. J., 6155, 6195 mc. KEA 65
Mt. Laurel, N. J., 6115, 6235 mc. KEA 70
Woodbridge, N. J., 4165, 4195 mc. KEA 71
So. of Bordentown, N. J., 4045, 4195 mc. KEA 72
New York, N. Y., 4035, 4055, 4065 mc. KEA 73
S.W. New Brunswick, N. J., 4065 mc. KEA 74
New York, N. Y., 4035, 4045, 4055, 4065 mc. KEA 75
Camden, N. J., 4055, 4065 mc. KEA 76
So. of Neshanic, N. J., 4165, 4175, 4185, 4195 mc. KEA 77
Philadelphia, Pa., 6155 mc. KGB 22
Philadelphia, Pa., 4175, 4185 mc. KGB 28
Brandywine, Del., 4045, 4195 mc. KGB 29
Philadelphia, Pa., 4175, 4185 mc. KGB 30
Elkton, Md., 4165 mc. KGB 31
Baltimore, Md., 4035 mc. KGB 32
Severn, Md., 4195 mc. KGB 33
Washington, D. C., 4045, 4055 mc. KGB 34
Sellersville, Pa., 4035 mc. KGB 35
Honey Brook, Pa., 4165 mc. KGB 36
Red Lion, Pa., 4035 mc. KGB 37
Mt. Holly Springs, Pa., 4165 mc. KGB 38
Upper Strasburg, Pa., 4045 mc. KGB 39
Schellsburgh, Pa., 4175 mc. KGB 40
Bakersville, Pa., 4035 mc. KGB 41
Pittsburgh, Pa., 4165, 4175, 4185, 4195 mc. KGB 42
Pittsburgh, Pa., 4045, 4065 mc. KGB 43
Ligonier, Pa., 4055 mc. KGB 44
Frostburgh, Md., 4185 mc. KGB 45
Berkeley Springs, Md., 4055 mc. KGB 46
N.W. Frederick, Md., 4185 mc. KGB 47

MISCELLANEOUS

Bus

National Bus Communications, Inc.
141 West Jackson Blvd., Chicago, Ill.
Lombard, Ill., 2680 mc. KSA 523

Fire

City of Los Angeles, California
Los Angeles, Calif., 956 mc. KMC 88
Los Angeles, Calif., 952.120 mc. KMC 89
Los Angeles, Calif., 959.88 mc. KMB 92

City of New York
Boro Hall, 165 Stuyvesant Place, N. Y., 957 mc. KEB 51

Forestry—Conservation

State of Arkansas Forestry Service
Little Rock, Arkansas (Game and Fish) 959.0 mc. KKB 76
W. Little Rock, Ark., 957.0 mc. KKB 77

Forest Products

North Fork, California
North Fork, Calif., 959, 953 mc. KMH 84
Meadow Lake, Calif., 953, 959 mc. KMH 85

Highway Maintenance

State of California
N.W. San Bernardino, Calif., 957 mc. KMD 66
San Bernardino, Calif., 959 mcc. KMD 67

State of Idaho
Mica Peak, Idaho, 959 mc. KOE 54

Operational Fixed

Aeronautical Radio, Inc.
San Francisco, Calif., 6805 mc. KMB 97
San Francisco, Calif., 6705 mc. KMB 98
Los Angeles, Calif., 6705 mc. KMC 38
Los Angeles, Calif., 6805 mc. KMC 39
Seattle, Wash., 6705 mc. KOA 92
Seattle, Wash., 6805 mc. KOA 93
Island of Oahu, T. H., 6685-6805 mc. KUN 71

Special Industrial

Linton Summit Coal Co., Inc.
19 South 6th St., Terre Haute, Ind.
Terre Haute, Ind., 959 mc. KSC 54
S.E. Sullivan, Ind., 953 mc. KSC 53

TV Pickup

Florida Broadcasting Co.
Mobile, Area of Jacksonville, Fla., 2076-2093 mc. KB 6848

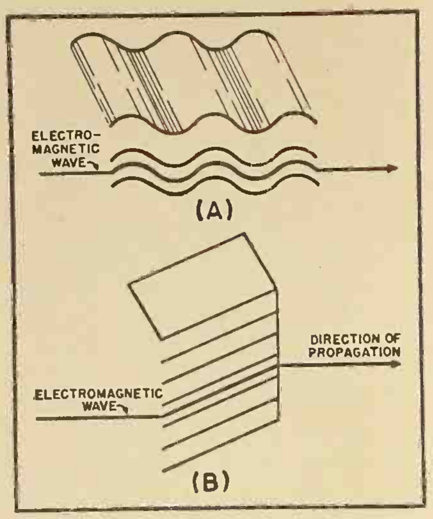


Fig. 3. Dielectric effect achieved by (A) serpentine plates and (B) slanted plates.

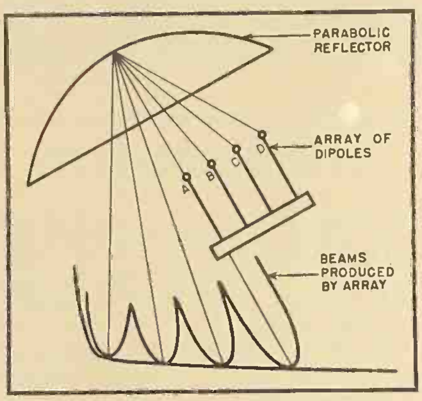


Fig. 4. A shaped beam which is achieved by an array of point sources as shown.

phere. The atmosphere is composed of a mixture of gases, dust particles, and water vapor. Unfortunately this mixture absorbs energy from a microwave beam of energy. The amount of absorption is a function of the frequency being transmitted and is usually very small for frequencies below 10,000 mc. Absorption is highest at approximately 60,000 mc. for oxygen and is highest at 25,000 mc. for water vapor. Water in the atmosphere in the form of fog, rain or clouds, decreases received energy by absorption and because it is a poor conductor of microwave energy.

An example of the difference in attenuation per mile during a heavy rainfall indicates that the attenuation at 3000 megacycles is only 0.3 db, while at 30,000 mc. the attenuation is 21 db. Thus the obvious advantage of maintaining reasonable physical sizes of parabolic antennas and increasing frequency above 10,000 mc. to achieve higher gains cannot be utilized.

Another disadvantage in the use of higher frequencies is the duct effect. A duct is usually considered as a kind of layer occurring in the atmosphere which traps microwaves and reflects them up and down between its boundaries as they travel outward from the transmitter. It results in some very unusual effects such as phenomenal ranges as long as 1500 miles, or, conversely, the inability of two stations very close to each other to maintain contact.

Similar to wave guides, ducts have a cutoff frequency and cannot propagate frequencies below it. The cutoff frequency is a function of the height or distance between the top and bottom layers of the duct—the greater the height the lower the cutoff frequency—with the result that only narrow ducts can propagate the higher microwave frequencies. As an example, a duct 25 feet in height will cut off at 16,700 mc. while a duct of 200 feet will propagate down to 750 mc. Thus the higher microwave frequencies are at a disadvantage in that at certain times of the day and year contact between line-of-sight stations may not be reliable.

Lens Antennas

Another device which takes advantage of the similarity of light and microwaves is the lens. The lens is a device for transforming the spherical waves transmitted radially by a point source into a flat or uniphase wavefront. This action will effectively focus the transmitted energy into a narrow, highly directional beam.

The lens has a wide tolerance in manufacture. It is also essentially a broad-band antenna. Whereas the machining tolerance of a parabolic reflector must usually be kept to a few hundredths of an inch, the allowable tolerance in the lens is usually on the order of a quarter wavelength or as much as one-fifth of an inch variation at 10,000 mc.

The feed in most parabolic reflectors is in the path of the reflected beam, with the result that there is interference in the beam and a waste of energy into the feed system. In microwave repeater systems a transmitting antenna is usually placed back to back with a receiving antenna. If parabolic reflectors are used, the spill-over will result in crosstalk, but use of a lens antenna eliminates the spill-over and will consequently remove it as a cause of crosstalk.

There are three general types of microwave antenna lenses: dielectric lenses, metal parallel-plate type, and metal path length lenses.

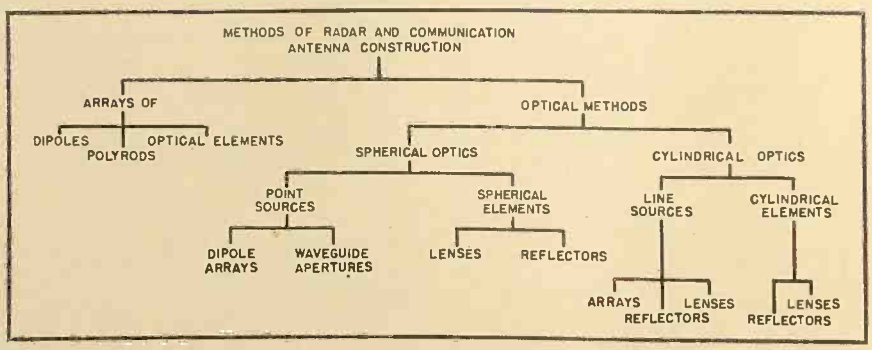
The fundamental principle of *dielectric lenses* is illustrated in Fig. 2A, which shows a point source emitting spherical waves. The spherical waves have a wavelength of λ in free space. When they enter the dielectric, however, the wavelength becomes λe. The wavelength in the dielectric is shorter than the wavelength in free space, which means that if a lens is used as shown in Fig. 2A, with the thickened portion in the center, the wavefront is effectively slowed down or delayed as it passes through the dielectric. The resultant produces a plane wavefront or uniphase wavefront which is the most directive pattern for an aperture of a given size.

The use of dielectric lenses has not been extensive because of the weight and bulk requirements. A lens may be constructed of lucite or polystyrene and will usually be many wavelengths thick if its focal length and aperture are large compared with its wavelength. This shortcoming has been overcome to some extent by the process of zoning, which will be discussed in connection with metal lenses. Unfortunately, zoning also limits the bandwidth of the lens to some extent.

The *metal plate lens* shown in Fig. 2B utilizes the principle that the wavelength of the signal being transmitted down a wave guide is greater than the wavelength in free space. This is just the inverse of the signal being transmitted through a dielectric. In this type of lens, the wavefront is effectively speeded up as it passes through the parallel plates of the lens and the top and bottom of the lens is therefore thickened. The longer wave guide length is caused by the presence of the sides of the wave guide, not the top and

(*Continued on page* 58)

Fig. 5. Methods of radar and communication antenna construction.



N.W. Marble Hill, Miss. KAE 54
N.E. Poplar Bluff, Miss. KAE 55
S. Parnell, Ark. KKE 89
W. Tupelo, Ark. KKE 90
Newport, Ark. KKE 91
S.E. Alexander, Ark. KKE 92
W. Biggers, Ark. KKE 93
Powhatan, Ark. KKE 94
S. Searcy, Ark. KKE 95
S. Malvern, Ark. KKE 96
S.E. Cushing, Tex. KKH 43
S.E. Cold Spring, Tex. KKH 44
S. Marshall, Tex. KKH 45
E. Hope, Ark. KKH 46
S.E. Okolona, Ark. KKH 47
S.W. Douglassville, Tex. KKH 48
N.E. Texarkana, Ark. KKH 51
N.W. New Caney, Tex. KKH 52
Houston, Tex. KKH 53
N. Houston, Tex. KKH 54
S. Lufkin, Tex. KKH 55
S.E. Moscow, Tex. KKH 56
N.W. Pinehill, Tex. KKH 57
W. Hungerford, Tex. KKH 58
N. Fulshear, Tex. KKH 59
N.W. Marshall, Tex. KKH 60
S. Downers Grove, Ill. KSC 23
W. Joliet, Ill. KSC 24
S. Cabery, Ill. KSC 25
S.E. Sibley, Ill. KSC 26
E. Mahomet, Ill. KSC 27
W. Hammond, Ill. KSC 28
N.W. Tower Hill, Ill. KSC 29
S. Vandalia, Ill. KSC 30
S. Hoffman, Ill. KSC 31
S.S.W. Nashville, Ill. KSC 52
S.S.W. Ava, Ill. KSC 56

Transcontinental Gas Pipe Line Corporation
2100 Niels Esperson Building, Houston 2, Texas

Nr. Neshanic, N. J., 1905 mc. KEB 68
Linden, N. J., 1855 mc. KEB 69
Westchester, Pa., 1855, 1905, 1955 mc. KGC 95
Nr. Tylersport, Pa., 1855 mc. KGC 96
Ellicott, Md., 1855, 1905, 1955 mc. KGC 97
Nr. Oxford, Pa., 1855 mc. KGC 98
Nr. Jacksonville, Md., 1905 mc. KGC 99
Nr. Myrtlewood, Ala., 1905 mc. KIC 74
Nr. Summerfield, Ala., 1905 mc. KIC 75
Nr. Rockford, Ala., 1905 mc. KIC 76
Nr. Jackson Gap, Ala., 1855 mc. KIC 77
(At Temporary Locations Along and Adjacent to Company's Pipe Line System from the North Carolina-Virginia Border to Connecticut) 1855, 1905, 1955 mc. KIC 78
" " " 1855, 1905, 1955 mc. KIC 79
" " " 1855, 1905, 1955 mc. KIC 80
" " " 1855, 1905, 1955 mc. KIC 81
" " " 1855, 1905, 1955 mc. KIC 82
" " " 1855, 1905, 1955 mc. KIC 83
" " " 1855, 1905, 1955 mc. KIC 84
(Temporary Locations Southeast United States) 1855, 1905, 1955 mc. KIC 85
Nr. Danielsville, Ga., 1855 mc. KIC 86
Nr. Billingsley, Ala., 1855 mc. KIC 88
Nr. Stockbridge, Ga., 1855 mc. KIC 89
Nr. Penhook, Va., 1905 mc. KIC 94
Nr. Appomattox, Va., 1855 mc. KIC 95
Nr. Gretna, Va., 1905 mc. KIC 96
Nr. Reidsville, N. C., 1855 mc. KIC 97
Nr. Cleveland, N. C., 1855 mc. KIC 98
Gastonia, N. C., 1855 mc. KID 20
Nr. Spartanburg, S. C., 1905 mc. KID 21
Nr. Franklin, Ga., 1855 mc. KID 22
Nr. Uniontown, Ala., 1855 mc. KID 23
Nr. Roanoke, Ala., 1905 mc. KID 24
Nr. Carrollton, Ga., 1905 mc. KID 28
Nr. Middleburg, Va., 1905 mc. KID 29
Nr. Iva, S. C., 1905 mc. KID 30
Nr. Honea Path, S. C., 1855 mc. KID 32
Nr. Unionville, Va., 1855 mc. KID 34
Nr. De Quincy, La., 1855 mc. KKC 47
Nr. Sour Lake, Tex., 1855 mc. KKC 48
Nr. Eunice, La., 1855 mc. KKC 49
Nr. Mauriceville, Tex., 1905 mc. KKC 50
Nr. Vossburg, Miss., 1905 mc. KKC 51
Nr. Dayton, Tex., 1905 mc. KKC 52
Nr. Laurel, Miss., 1855 mc. KKC 53
Nr. Tylertown, Miss., 1905 mc. KKC 54
Nr. Carson, Miss., 1855 mc. KKC 55
Nr. Reddochs, Miss., 1905 mc. KKC 56
Nr. Clinton, La., 1905 mc. KKC 57
Nr. Magnolia, Miss., 1855 mc. KKC 58
Nr. St. Francisville, La., 1855 mc. KKC 59
Nr. LeBlanc, La., 1905 mc. KKC 60
(Temporary Base in S.W. U.S.A. Along Company Operated Pipeline from Mississippi Border to the end of Pipeline in Texas) 1855, 1905, 1955 mc. KKC 67
Nr. Quitman, Miss., 1855 mc. KKC 69
Nr. El Campo, Tex., 1855, 1905, 1955 mc. KKD 22
Travis, Houston, Tex., 1855 mc. KKD 25
Nr. Refugio, Tex., 1855, 1905, 1955 mc. KKD 27
(Temporary Location Along and Adjacent to Company's Pipe Line from Mississippi-Alabama Border to N. Carolina-Virginia Border) 959 mc. KKD 48
" " " 953 mc. KKD 49
(Temporary Location Along and Adjacent to Company's Pipe Line from Texas-Mexico Border to Mississippi-Alabama Border) 959 mc. KKD 50
" " " 959 mc. KKD 52
" " " 953 mc. KKD 53
(Temporary Location Along and Adjacent to Company's Pipeline from Mississippi-Alabama Border to N. Carolina-Virginia Border) 953 mc. KKD 54
" " " 959 mc. KKD 55
(Temporary Location Along and Adjacent to Company's Pipeline from N. Carolina-Virginia Border to East Border of New York) 959 mc. KKD 56
" " " 959 mc. KKD 57
" " " 953 mc. KKD 58
Nr. Rosenburg, Tex., 1855, 1905, 1955 mc. KKD 59
Nr. Bloomington, Tex., 1855, 1905, 1955 mc. KKD 60
(Temporary Location Along Company's Pipeline from N. Carolina-Virginia Border to East Border of New York) 953 mc. KKD 61
Nr. Vanderbilt, Tex., 1855, 1905, 1955 mc. KKD 62
(Temporary Location Along and Adjacent to Company's Pipeline from Mississippi-Alabama Border to N. Carolina-Virginia Border) 959 mc. KKD 63
" " " 953 mc KKD 64
" " " 959 mc. KKD 65
" " " 959 mc. KKD 66
" " " 953 mc KKD 67
" " " 959 mc. KKD 68
" " " 953 mc KKD 69
" " " 953 mc KKD 70
(Temporary Location Along and Adjacent to Company's Pipeline from N. Carolina-Virginia Border to East Border of New York) 953 mc. KKD 71
" " " 959 mc. KKD 72
" " " 953 mc. KKD 73
" " " 959 mc. KKD 74
" " " 953 mc. KKD 75
" " " 959 mc. KKD 76
" " " 953 mc. KKD 77
" " " 959 mc. KKD 78
(Temporary Location Along and Adjacent to Company's Pipeline from Texas-Mexico Border to Mississippi-Alabama Border) 959 mc. KKD 79
" " " 953 mc. KKD 80
" " " 959 mc. KKD 81
" " " 953 mc. KKD 82
" " " 953 mc. KKD 83
" " " 959 mc. KKD 84
" " " 959 mc. KKD 85
(Temporary Location Along and Adjacent to Company's Pipeline from N. Carolina-Virginia Border to East Border of New York) 953 mc. KKD 86
" " " 953 mc. KKD 88
(Temporary Location Along and Adjacent to Company's Pipeline from Texas-Mexico Border to Mississippi-Alabama Border) 953 mc. KKD 89
" " " 959 mc. KKD 90
" " " 953 mc. KKD 91
" " " 959 mc. KKD 92
" " " 953 mc. KKD 93
(Temporary Location Along and Adjacent to Company's Pipeline from Mississippi-Alabama Border to N. Carolina-Virginia Border) 959 mc. KKD 94
" " " 953 mc. KKD 95
" " " 959 mc. KKD 96
" " " 953 mc. KKD 97
(Temporary Location Along and Adjacent to Company's Pipeline from N. Carolina-Virginia Border to East Border of New York) 959 mc. KKD 98
Nr. Bishop, Tex., 1855, 1905, 1955 mc. KKE 53
Nr. St. Paul, Tex., 1855, 1905, 1955 mc. KKE 54
Nr. Falfurrias, Tex., 1855, 1905, 1955 mc. KKE 56
Calallen, Tex., 1855, 1905, 1955 mc. KKH 42

Trunkline Gas Company
2332 West Holcombe Blvd., Houston 5, Texas

(Operating Frequency: 1880, 1930, 1980 mc.)
N.W. Macon, Tenn. KID 58
S.W. Brownsville, Tenn. KID 59
N.W. Friendship, Tenn. KID 60
N.E. Hornbeak, Tenn. KID 61
N.W. Arlington, Ky. KID 62
Houston, Tex. KKE 58
N. Barker, Tex. KKE 59
S.S.W. Porters, Tex. KKE 60
N. Moss Hill, Tex. KKE 61
N.W. Silsbee, Tex. KKE 62
N.N.W. Starks, La. KKE 63
S.E. Longville, La. KKE 64
N.N.E. Pitkin, La. KKE 65
E. Otis, La. KKE 66
S. Pollock, La. KKE 67
S.E. Clarks, La. KKE 68
S.E. Baskin, La. KKE 69
W.N.W. Epps, La. KKE 70
S.E. Kilbourne, La. KKE 71
E. Wayside, Miss. KKE 72
N.E. Shaw, Miss. KKE 73
E. Sumner, Miss. KKE 74
E.S.E. Longtown, Miss. KKE 75
N. Independence, Miss. KKE 76
E. McAllen, Tex. (1980 mc.) KKH 84
N. San Manuel, Tex. (1880 mc.) KKH 85
N.E. Oretta, La. KKL 77
W. Edith, La. KKL 78
W. Liberty, Tex. KKL 79
W.N.W. Joppa, Ill. KSC 34
S.W. Ozark, Ill. KSC 35
N. Braden, Ill. KSC 36
S. Johnsonville, Ill. KSC 37
E.N.E. Loogootee, Ill. KSC 38
S.E. Shelbysville, Ill. KSC 39
S.S.E. Bourbon, Ill. KSC 40

United Gas Pipe Line Company
P. O. Box 1407, Shreveport, La.

Shreveport, La., 954 mc. KKD 23

POLICE

Orange County, California

Satiago Peak, Calif., 954 mc. KMH 63

County of Santa Clara, California

San Jose, Calif., 951 mc. KMD 36
Copernicus Peak, Calif., 959 mc. KMD 37

City of San Diego, California

Lyons Peak, Calif., 954 mc. KMH 69

State of New Jersey Turnpike Authority

Newark, N. J., 953 mc. KED 42
Secaucus, N. J., 955, 959 mc. KED 43
New Brunswick, N. J., 957 mc. KED 44
Bordentown, N. J., 955, 959 mc. KED 45
W. Trenton, N. J., 953 mc. KED 46
Mt. Laurel, N. J., 957 mc. KED 47
Harrison Township, N. J., 959 mc. KED 48

State of Ohio

Massillon, O., 2804, 2808, 2812, 5140, 5195 mc. KQB 60

City of Dayton, Ohio

Dayton, O., 6705 mc. KQB 98

Commonwealth of Pennsylvania Turnpike Commission

Lionville, Pa., 957, 959 mc. KGC 59
King of Prussia, Pa., 957 mc. KGC 60
Morgantown, Pa., 957, 959 mc. KGC 61
Cornwall, Pa., 957, 959 mc. KGC 62
Bunchers Reesers Summit, Pa., 957, 959, 953 mc. KGC 63
N.W. Shippensburg, Pa., 959, 957 mc. KGC 64
N. W. Fannetsburg, Pa., 957, 959 mc. KGC 65
Nr. Wells Tannery, Pa., 957, 959 mc. KGC 66
S.W. Everett, Pa., 953, 957, 959 mc. KGC 67
S.W. New Baltimore, Pa., 957, 959 mc. KGC 68
N.W. Somerset, Pa., 957, 959 mc. KGC 69
Wilkinsburg, Pa., 957, 959 mc. KGC 70
Salem Church, Pa., 957, 959 mc. KGC 71
E. Darlington, Pa., 957, 959 mc. KGC 72
Harrisburg, Pa., 955 mc. KGC 73
Everett, Pa., 955 mc. KGC 74
Wampum, Pa., 957 mc. KGC 75

POWER

Amicalola Electric Membership Corporation
Jasper, Georgia

Jasper, Ga., 958 mc. KIJ 82

Blackstone Valley Gas and Electric Company
55 High St., Pawtucket, R. I.

Central Falls, R. I., 958 mc. KCB 70
Pawtucket, R. I., 954 mc. KCB 71

Brazos River Trans. Electric Coop., Incorporated
902 Amicable Building, Waco, Texas

Waco, Tex., 6685 mc. KKL 57
Whitney Dam, Tex., 6805 mc. KKL 58

Carolina Power and Light Company
Insurance Building, Raleigh, N. C.

Raleigh, N. C., 952.50 mc. KIB 86
Nr. Erwin, N. C., 959.50 mc. KIB 87

Central Arizona Light and Power Company
501 South 3rd Ave., Phoenix, Arizona

Phoenix, Ariz., 958.25 mc. KOB 54
Litchfield Park, Ariz., 956.75 mc. KOB 55
Nr. Phoenix, Ariz., 956.75 mc. KOB 99
(At Temporary Locations in Vicinity of Mingus Mountain, Nr. Jerome, Ariz.). 954.71 mc. KOD 42

Central Illinois Public Service Company
Illinois Building, Springfield, Ill.

(Operating Frequency: 6605, 6625, 6685, 6725, 6745, 6805 mc.)

S. Meredosia, Ill. KSE 41
Nr. Sinclair, Ill. KSE 42
Springfield, Ill. KSE 43
W. Pawnee, Ill. KSE 44
N. Pana, Ill. KSE 45
S. Windsor, Ill. KSE 46
Mattoon, Ill. KSE 47
N. Hutsonville, Ill. KSE 49
E. St. Elmo, Ill. KSE 50
E. Fairman, Ill. KSE 51
N.W. Mount Vernon, Ill. KSE 52
West Frankfort, Ill. KSE 53
Marion, Ill. KSE 54
S.W. Alto Pass, Ill. KSE 55
Grand Tower, Ill. KSE 56

Consolidated Gas Electric Light and Power Co. of Baltimore
Lexington Building, Baltimore 3, Md.

Windy Edge Switching Station, 959 mc. KGC 80
Turners Station, Md., 955 mc. KGC 81

City of Dayton, Ohio
15 E. Monument Ave., Dayton 2, Ohio

Dayton, O., 6705 mc. KQB 97

Detroit Edison Company
2000 Second Avenue, Detroit 26, Mich.

Detroit, Mich., 1975 mc. KQA 65

Duke Power Company
Box 2178, Charlotte, N. C.

Greenville, S. C., 959.5 mc. KIJ 74
E. Spartanburg, S. C., 952.4 mc. KIJ 75

Iowa Illinois Gas and Electric Company
Second Street, Davenport, Iowa

Fort Dodge, Iowa, 48.18 mc. KAB 547

City of Los Angeles, Department of Water and Power
Box 3669 Terminal Annex, Los Angeles 54, Calif.

Seal Beach, Calif., 1980, mc. KMD 93
Los Angeles, Calif., 1860 mc. KMD 94

Monona County Rural Electric Cooperative
128 West Broadway, No. Onawa, Iowa

Onawa, Iowa, 952 mc. KAC 87
S. E. Onawa, Iowa, 959 mc. KAC 88

New Orleans Public Service, Incorporated
317 Baronne St., New Orleans 9, La.

New Orleans, La., 955 mc. KKG 864

Niagara Mohawk Power Corporation
126 State St., Albany, N. Y.

Grafton, N. Y., 959 mc. KEB 74
Albany, N. Y., 953 mc. KEB 75

Northeast Missouri Electric Power Cooperative
P. O. Box 191, Palmyra, Mo.

Palmyra, Mo., 958 mc. KAD 33
Nr. Palmyra, Mo., 953 mc. KAD 34

Pacific Gas and Electric Company
245 Market St., San Francisco, Calif.

Newark, Calif., 953 mc. KMD 61
Oakland, Calif., 959 mc. KMD 62

Pennsylvania Electric Company
222 Levergood St., Johnstown, Pa.

Johnstown, Pa., 952.70 mc. KGA 81

The Potomac Edison Company
Hagerstown, Maryland

Williamsport, Md., 959 mc. KGD 20
Clearspring, Md., 953 mc. KGD 21

Public Service Company of Indiana
110 North Illinois St., Indianapolis 9, Ind.

Indianapolis, Ind., 1855 mc. KSC 32
Plainsfield, Ind., 1950.5 mc. KSC 33

Public Service Electric and Gas Co. of New Jersey
80 Park Place, Newark, N. J.

Pennsauken, N. J., 954 mc. KEB 92

City of Seattle, Washington

Gorge Switching Station, Wash., 1980 mc. KOD 95
Diablo Switching Station, Wash., 1860 mc. KOD 96
Seattle, Wash., 1860 mc. KOD 97
Bothell, Wash., 1980 mc. KOD 98

Southern California Edison Company
601 West 5th St., Los Angeles 13, Calif.

Mt. Wilson, Calif., 1960 mc. KMH 96
Mt. Wilson, Calif., 1980 mc. KMH 97
Mt. Wilson, Calif., 1900 mc. KMH 98
Pomona, Calif., 1900 mc. KMI 20
San Bernardino, Calif., 1900 mc. KMI 21
Santiago Peak, Calif., 1980, 1960 mc. KMI 22
Alhambra, Calif., 1880 mc. KMI 23
Alhambra, Calif., 1900 mc. KMI 24
Alhambra, Calif., 1880 mc. KMI 25

Southern Counties Gas Company of California
810 South Flower Street, Los Angeles, Calif.

Los Angeles, Calif., 6685 mc. KMB 36
Santiago Peak, Calif., 6805 mc. KMB 40

Springer Electric Cooperative, Incorporated
Box 678, Springer, N. M.

Springer, N. M., 73.50 mc. KKE 24

Union Electric Company of Missouri
315 North 12th Blvd., St. Louis, Mo.

Rivermines, Mo., 957 mc. KAE 66
High Ridge, Mo., 1945, 957 mc. KAE 67
Sullivan, Mo., 1985 mc. KAE 68
Belle, Mo., 1945 mc. KAE 69
Dixon, Mo., 1985 mc. KAE 70
St. Louis, Mo., 1975 mc. KAE 71
Lakeside, Mo., 1945 mc. KAE 72
Halifax, Mo., 959 mc. KAE 73

RAILROAD

The Atchison, Topeka and Santa Fe Railroad Co.
80 East Jackson Boulevard Chicago, Ill.

(Operating Frequency: 6590, 6680, 6740, 6830 mc.)

Pation, Tex. KKC 62
Beaumont, Tex. KKC 63
Morey, Tex. KKC 64
Galveston, Tex. KKC 65
White Ranch, Tex. KKC 66

Chicago Rock Island and Pacific Railroad Company
LaSalle Street Station, Chicago 5, Ill.

(Operating Frequency, 6590, 6740, 6680, 6830 mc.)

Clayton, Kan. KAB 62
Goodland, Kan. KAB 63
Dresden, Kan. KAB 64
Rexford, Kan. KAB 65
Levant, Kan. KAB 66
Norton, Kan. KAB 67

STUDIO TRANSMITTER LINK

All Oklahoma Broadcasting Co.
311 South Denver St., Tulsa, Okla.

Tulsa, Okla., 936.0 mc. KKA 83

Edwin Armstrong
435 E. 52nd St., New York 22, N. Y.

New York, N. Y., 946.5 mc. KEA 46

Auburn Publishing Co.
34 Dill St., Auburn, N. Y.

Auburn, N. Y., 950.5 mc. KEA 59

Baptist General Convention of Texas
505 N. Ervay, Dallas, Texas

Dallas, Texas, 950 mc. KGA 97

California Inland B'Casting Co.
2014 Tulare St., Fresno, Calif.

Fresno, Calif., 944.5 mc. KMA 26

Davenport Broadcasting Co.
324 Main St., Davenport, Iowa

Davenport, Iowa, 926.0 mc. KAB 51

Durham Radio Corp.
138 E. Chapel Hill St., Durham, N. C.

Durham, N. C., 940.5 mc. KIB 70

Wm. C. Forrest
RFD 2, Poynette, Wisc.

Poynette, Wis., 940.5 mc. KSB 85

Fort Industry Co.
500 Temple St., Detroit 1, Mich.

Detroit, Mich., 1990-2008 mc. KQB 96

Gazette Publishing Co.
Hotel Niagara, Niagara Falls, N. Y.

Niagara Falls, N. Y., 941.5 mc. KEB 21

General Electric Co.
60 Wash. Ave., Schenectady, N. Y.

Schenectady, N. Y., 947.5 mc. KEB 76

Hagerstown Broadcasting Co.
33 W. Franklin St., Hagerstown, Md.

Hagerstown, Md., 946 mc. KGA 79

Havens and Martin, Inc.
3301 W. Broad St., Richmond, Va.

Richmond, Va., 6975-7000 mc. KID 35

The Hearst Corp.
959 Eighth Ave., New York, N. Y.

Baltimore, Md., 6900-6925 mc. KGB 64

Roy Hofheinz
1520 Harrison St., Harlingen, Texas

Harlingen, Texas, 932 mc. KKH 73

Iowa State College of Agricultural & Mechanical Arts
Iowa State College, Ames, Iowa

Ames, Iowa, 940.5 mc. KAA 61

Jefferson Standard Broadcasting Co.
Wilder Building, Charlotte, N. C.

W. Charlotte, N. C., 933 mc. KID 98
S. Charlotte, N. C., 930 mc. KID 99
Charlotte, N. C., 2008-2025 mc. KIK 48

Johnson Broadcasting Co.
P. O. Box 147, Bessemer, Ala.

Bessemer-Birmingham Super Highway — Birmingham, Ala., 945.5 mc. KIA 32

KECC, Inc.
P. O. Box 808, Pittsburg, Calif.

Pittsburg, Calif., 936.0 mc. KMA 91

KTOK, Inc.
1800 West Main St., Oklahoma City, Okla.

Oklahoma City, Okla., 931.5 mc. KKA 79

Richard Field Lewis, Jr.
Winchester, Va.

Winchester, Va., 4000 mc. KIA 53

Middlesex Broadcasting Corp.
439 Concord Ave., Cambridge, Mass.

Cambridge, Mass., 940.5 mc. KCA 34

Midwest Broadcasting Co.
8th & Elm St., Coffeyville, Kansas

Coffeyville, Kansas, 931.5 mc. KAB 95

Moody Bible Institute of Chicago
820 N. La Salle St., Chicago, Ill.

Chicago, Ill., 950 mc. KSA 37

National Broadcasting Co.
60 Broad St., New York 4, N. Y.

Chicago, Ill., 926.5 mc. KSC 21
San Francisco, Calif., 946 mc. KMB 46

Nebraska Rural Radio Association
104 West 8th St., Lexington, Neb.

Lexington, Nebraska, 925.5 mc. KAC 89

James A. Noe
211 St. Charles St., New Orleans, La.

New Orleans, La., 936.0 mc. KKB 52

Pacifica Foundation
2054 University Ave., Berkeley, Calif.

Berkeley, Calif., 942.0 mc. KMD 98

Paramount Television Productions, Inc.
5451 Marathon St., Los Angeles, Calif.

Los Angeles, Calif., 2042-2025 mc. KMH 87

Philco Television Broadcasting Co.
1800 Architects Bldg., Philadelphia 34, Pa.

Philadelphia, Pa., 6950-6975 mc. KGC 92
Philadelphia, Pa., 6950-6975 mc. KGC 93

Radio Diablo, Inc.
798 San Mateo Ave., San Bruno, Calif.

San Bruno, Calif., 940.5 mc. KQDI

Regents of the University of Michigan
State St., Ann Arbor, Mich.

Ann Arbor, Mich., 950 mc. KQA 61

Rural Radio Network Inc.
306 East State St., Utica, N. Y.

Freeville, N. Y., 940.5 mc. KEA 97

Joe L. Smith, Jr.
East Beckley St., Beckley, W. Va.

Beckley, W. Va., 940.5 mc. KQA 55

University of Illinois
1010 So. Wright St., Urbana, Ill.

Urbana, Ill., 941 mc. KSE 20

WDOD Broadcasting Corp.
Hamilton National Bank Bldg., Chattanooga, Tenn.

Chattanooga, Tenn., 942.5 mc. KIB 79

WGBH Education Foundation
100 Franklin St., Boston, Mass.

Boston, Mass., 940.5 mc. KCB 85

RADIO-ELECTRONIC ENGINEERING
edition of
RADIO & TELEVISION NEWS
May, 1952

NEW LITERATURE

MICROWAVE EQUIPMENT

Westinghouse Electric Corporation's new eight-page booklet describes type FB-1 microwave equipment designed to provide reliable communication channels for telemetering, supervisory control, voice communication, protective relaying, teletyping, facsimile, and load control. The transmitter and receiver are block-diagrammed with tube types indicated, and complete specifications for the equipment are presented.

For a copy of this booklet, B-5448, write *Westinghouse Electric Corporation*, Box 2099, Pittsburgh 30, Pa.

CONTROLLING PYROMETERS

Just released by *Assembly Products, Inc.*, is a four-page bulletin describing their line of controlling pyrometers and related equipment, said to be available in nine temperature ranges from —200° to 3000°F. The various heat controlling applications possible with this equipment are given, and functions of continuous high limit on-and-off control or automatic shut-off and alarm are discussed.

A copy of Bulletin G-2 may be obtained by writing to *Assembly Products, Inc.*, Chagrin Falls 5, Ohio.

TRANSDUCER REFERENCE

An easy-to-use reference of transducers for use with cathode-ray oscillographs has been compiled by the Instrument Division of *Allen B. Du Mont Laboratories, Inc.*, 1500 Main Avenue, Clifton, N. J. which lists over 500 different types of analog transducers, arranged alphabetically according to their functions, and is available for 50 cents a copy.

Through the use of the *Du Mont* compilation, the cathode-ray oscillograph user may find the model, manufacturer, and mechanical and electrical characteristics of the transducer required.

STROBOSCOPES

Contained in the eight-page bulletin on stroboscopes published by the *General Radio Company* is an explanation of how the stroboscopes work, together with specific applications for the different instruments. The complete line of *General Radio* stroboscopes is described, and detailed specifications and prices are included.

Copies of this bulletin may be obtained from the *General Radio Company*, 275 Massachusetts Avenue, Cambridge 39, Mass.

TEKTRONIX INSTRUMENTS

Accurate descriptions and specifications of the complete line of *Tektronix* instruments are contained in a 45-page catalog now available on request from *Tektronix, Inc.*, P. O. Box 831, Portland 7, Oregon. Cathode-ray oscilloscopes, auxiliary amplifiers, square wave generators, and accessories are covered in this book, the pages of which are punched for easy insertion in a three-ring binder.

ELECTRONIC TESTER

Complete information on the *Westinghouse* industrial electronic surge comparison tester is now available in an eight-page bulletin, DB 85-960. Copies may be obtained from *Westinghouse Electric Corporation*, Box 2099, Pittsburgh 30, Pa.

Both principles and methods of operation of the tester, which is used mainly to locate insulation faults and winding dissymmetries in various electrical apparatus, are lucidly presented in this bulletin. Detailed specifications of both the portable and mobile models are given, along with considerations on their respective versatilities of application, and photographic examples of applications are included.

HIGH-MU POWER TRIODE

Lewis and Kaufman, Inc., Los Gatos, Calif., has issued a new technical data sheet describing the Type 250TH Los Gatos brand high-mu power triode. The tube is illustrated and dimensions, operating curves and electrical characteristics are given. Figures are also provided for typical operation and maximum ratings for the tube in service as a Class-B audio-frequency power amplifier and modulator and as a Class-C radio-frequency power amplifier and oscillator.

PRODUCTION CONTROL

A comprehensive outline of just what the Business Service Department of *Remington Rand Inc.* can do to help a manufacturer, regardless of size, to set up an adequate production control will be found in the newly released folder BSD-6. Copies of this folder may be had on request to *Remington Rand Inc.*, 315 Fourth Avenue, New York 10, N. Y.

ISOTOPE INSTRUMENTATION

Future uses of isotopes in industry can be vast. A bulletin entitled "Instrumentation for Isotope Utilization" is now available on request from the *Nuclear Instrument & Chemical Corp.*, 229 West Erie St., Chicago 10, Ill., which is intended to present a general picture of the radiation instrument factors to be dealt with in the employment of radioactive isotopes in industrial processes. It includes a brief discussion on the properties of alpha particles, beta particles and gamma rays, and covers the various types of radiation detectors available.

MICROWAVE TABLES

In recognition of the steadily increasing interest in molecular spectra investigations by microwave frequency techniques, the National Bureau of Standards has recently compiled a set of molecular microwave spectra tables which are being published in the form of an NBS Circular. NBS Circular 518 is available from the U. S. Government Printing Office.

The tabulation comprises 99 molecules, from the simpler diatomic molecules to more complex combinations such as chlorotrimethyl methane. About 1800 microwave absorption lines are included which range in frequency from 2000 to 150,000 mc.

MEASURING MAGNETIC PROPERTIES

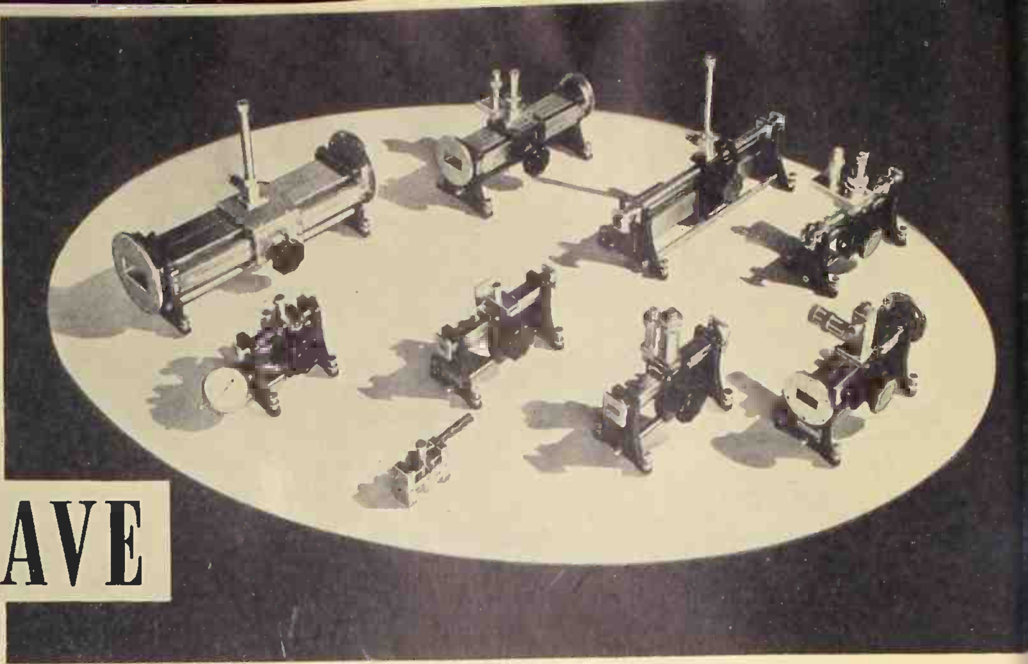
The application and operation of equipment used for measuring magnetic properties are described in a new bulletin released by *G-E's* Meter and Instrument Department.

Designated as GEC-777, this publication covers the *G-E* gauss meter, indicating fluxmeter, recording fluxmeter and fluxmeter calibrating unit, which make possible proper measurements of flux density, flux direction, and total flux. GEC-777 is available from the *General Electric Company*, Schenectady 5, N. Y.

NBS TABLES

The National Bureau of Standards announces the publication of its third edition of "Tables of the Exponential Function e^x." This edition is buckram bound, contains 537 pages, and may be

(*Continued on page* 44)



Impedance meters for measuring transmission line impedance at microwave frequencies. These coaxial and wave guide meters cover frequencies from 650 to 40,000 mc. Probe coupling is accurate to ± 2% and position can be read to accuracies as high as 0.01 mm.

MICROWAVE TEST EQUIPMENT

Highly specialized equipment is available for making tests and measurements in the 1000-50,000 mc. range.

The u.h.f. admittance meter for direct reading of admittance and susceptance.

THE NECESSITY for making accurate measurements of various electrical quantities at microwave frequencies has resulted in the development of various instruments designed specifically for this purpose. This development has been spurred in recent years by the tremendous increase in the use of microwaves, both for communication and non-communication purposes.

There are several basic problems which must be overcome before satisfactory measurements can be made in the 1000 to 50,000 mc. range. In the first place, the normal concepts of lumped inductance and capacity must be revised, and new concepts of distributed parameters established. The bypassing effect of even a very small amount of capacity may not be negligible—for example, a capacity of one micromicrofarad has a reactance of only 160 ohms at 1000 mc., and 16 ohms at 10,000 mc. A small value of inductance can have a very high reactance—one microhenry at 1000 mc. represents 6280 ohms of reactance, while the same inductance at 10,000 mc. would have ten times this reactance, or 62,800 ohms.

At frequencies where the dimensions of the equipment are comparable to the wavelengths employed, radiation effects must be considered. At 10,000 mc., a half-wave dipole is less than one inch long! This means that care must be exercised in confining the energy to the desired points. Radiation and the skin effect, which becomes more and more a factor as frequency is increased, act to decrease the Q of circuits very rapidly. For this reason, wave guides and cavity resonators are used almost exclusively, although recent experiments indicate that the waves may be guided along strips of plastic or along an insulated wire without excessive radiation.

The electrical characteristics of interest in the microwave region are, in many cases, not the same as at longer wavelengths. The electric field has more meaning than potential difference, and power output to a matched load usually has more significance than voltage measurements.

Power Measurements

There are three principal devices for making power measurements in the microwave region: the microwave calorimeter, crystal detector, and bolometer.

The calorimeter method is discussed briefly in the article entitled "Non-Communication Applications of Microwaves" which appears on page 11 of this issue. Basically, the microwave energy is all absorbed in a water load and the power is calculated from the temperature rise of a specific quantity of water. This is a basic method, and with careful equipment design, very accurate power measurements can be made. This method gives the *average* power, regardless of duty cycle, waveform, etc., and is primarily useful in measuring powers greater than one watt. It is widely used in measuring the power output of radar devices.

A simple crystal detector can be used to indicate output power, although this method is not as accurate as might be desired. The r.f. power is rectified by the crystal and charges up a condenser. The voltage across this condenser then gives an indication of the power. The time constant of the RC circuit used will determine whether peak or average power is indicated. This method may be improved by modulating the microwave signal and employing an a.c. amplifier following the crystal detector. The sensitivity is thus greatly increased, and fairly accurate output power indications may be obtained by extracting only a very small amount of power from the source.

The most accurate measurements of small amounts of microwave power are made by means of bolometer-type devices. This general class of instrument takes advantage of the fact that the resistance of certain conductors varies as a function of the power absorbed. This change in resistance can be measured by a suitable bridge, which can be calibrated in terms of power.

An important problem in equipment of this nature is the matching of impedances. The change in resistance of the bolometer element can result in an appreciable mismatch if the resistance change becomes too large. Matching is usually relatively easy for one particular frequency, but becomes more complex if measurements are desired over a range of frequencies.

The sensitive material of the bolometer bridge may be a thermistor, platinum wire, or other suitable material, usually suspended between supports of heavier copper wire. This arrangement is used for measuring power from about one microwatt up to several milliwatts.

One company manufactures a line of r.f. wattmeters in which the power is dissipated in an accurate, fixed load resistor which accurately terminates the line. The voltage across this resistor is measured by a crystal detector. Since the resistance is fixed, the voltmeter may be calibrated in terms of watts. Various models are available for measuring power up to about 1000 mc. with an accuracy of 5%. Power outputs from ½ watt to 5 kw. may be measured with these devices. The load resistor may be air-cooled or water-cooled, depending on the dissipation required.

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Frequency measuring equipment may be divided into two main categories: primary and secondary standards. In the primary standard method, the frequency under measurement is compared with a highly accurate and stable signal generator. The secondary standard is a device which has been previously calibrated to read frequency directly.

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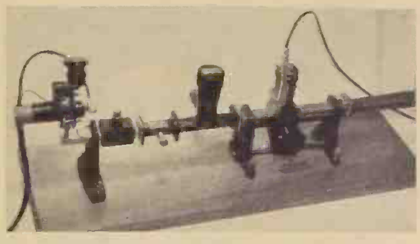
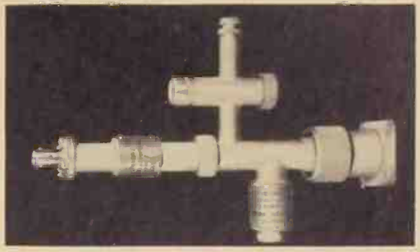
Attenuation

Several novel methods have been developed for attenuating microwave energy. A widely used device consists of a vane which is lowered into a wave guide through a slot. With careful design, the standing-wave ratio can be kept very low, and the amount of attenuation may be accurately calibrated for various positions of the vane.



Reflex klystron oscillator providing microwave energy in a typical laboratory wave guide measuring bench.

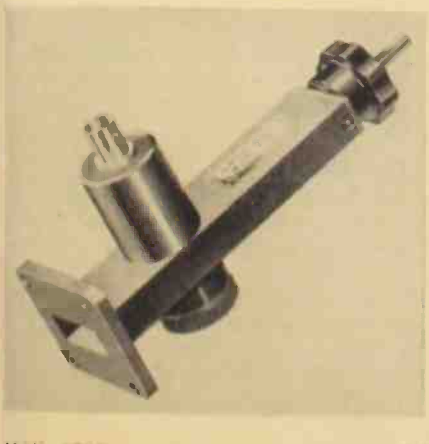


A fixed tuned coaxial crystal mixer. A series of variations are available covering frequencies to 5600 mc.

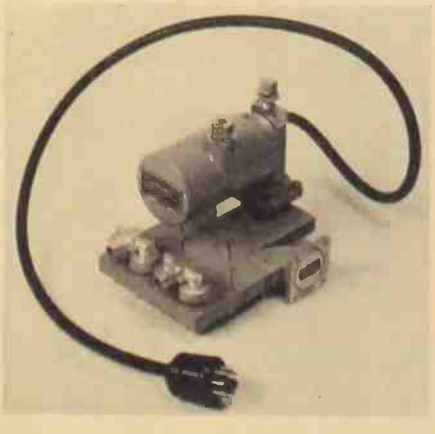
The General Radio Type 874-VR voltmeter rectifier is useful for voltage measurements up to 2500 mc.

Lossy transmission line may be used to provide the desired amount of attenuation at frequencies up to about 3000 mc. The transmission line is made lossy by the use of a center conductor

A detector mount for power measurements in the 2600-18,000 mc. range.



Double balanced mixer with local oscillator mount and variable attenuator.



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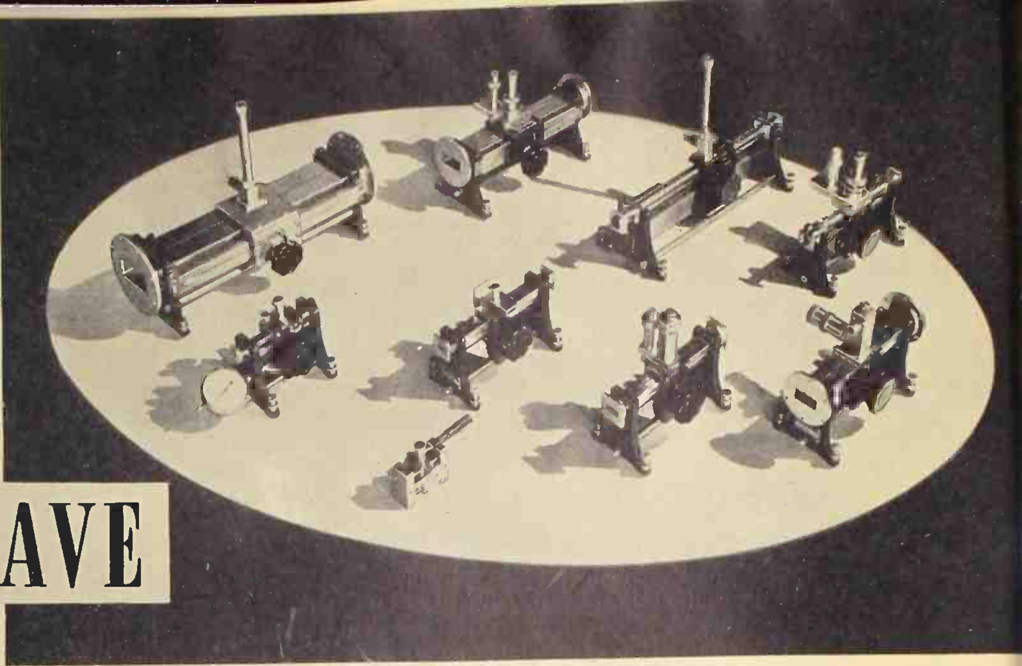

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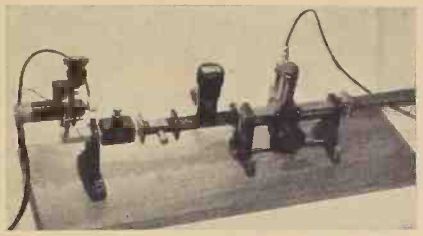

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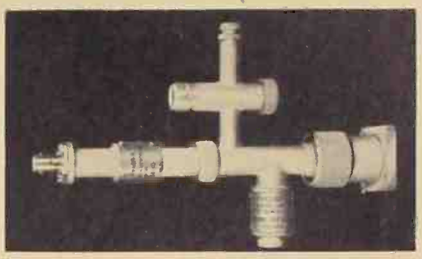

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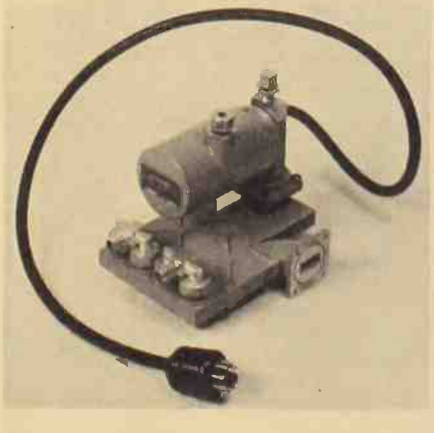
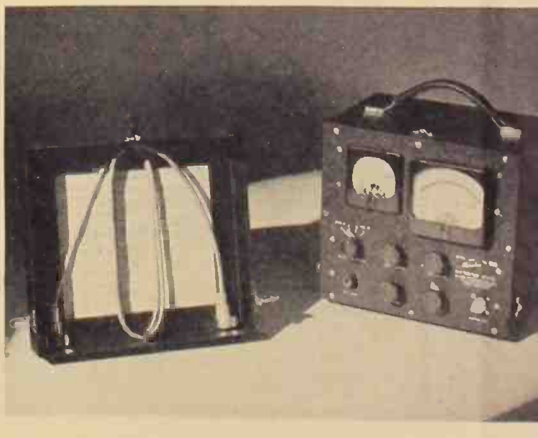
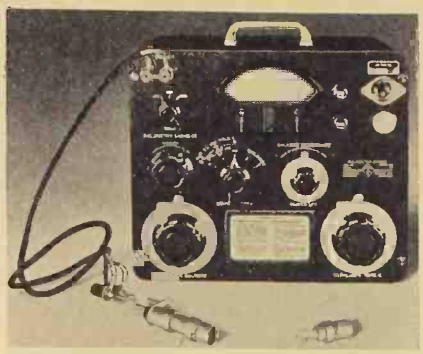


A wattmeter bridge for use with barretters to measure microwave power.





General Radio Type 1651-A bolometer bridge with thermistor element for power measurements up to 4000 mc.

of highly resistive material, or a dielectric material having high losses. For example, RG-21/U lossy cable uses a Nichrome center conductor and has a loss of 0.82 db per foot at 3000 mc. For greater losses, the center conductor of the coaxial cable may be made to have a higher resistance.

A wave guide operated in the region beyond cutoff will attenuate microwave energy very rapidly. The exact amount of attenuation per unit length can be accurately calculated.

Impedance

When a microwave transmission line is terminated in other than its characteristic impedance, reflections will occur and standing waves will be set up in the line. The magnitude of the standing waves is proportional to the degree of mismatch, and the position of maxima and minima along the line is proportional to the phase difference between the two impedances. Thus, by knowing the impedance of the line, the standing wave ratio, and the location of the maxima and minima, it is possible to determine the impedance of the line termination. This method is widely used for measuring impedance in the microwave region.

Several techniques are available for measuring standing waves. One consists of the use of a slotted transmission line (wave guide or coaxial cable) and a traveling probe. In a wave guide, the slot must be accurately machined and the probe depth accurately controlled, as variations could cause erroneous readings.

The probe itself has an effect on the results, but this effect can be precisely determined and allowed for. The output of the probe is connected to a crystal rectifier and suitable meter.

The magic T impedance bridge is very useful for rapid measurements of impedance. If the two test arms of a magic T are terminated in reflectionless loads, no energy will be delivered to the detector arm. However, if one test arm is properly terminated and the other is not, energy will appear in the detector arm in an amount depending on the mismatch. Thus, this device may be used to determine the degree of mismatch resulting from the insertion of an unknown impedance in one test arm.

Table 1. Microwave test equipment manufacturers. 1, signal generators; 2, standing wave detectors; 3, power meters; 4, probes, attenuators, etc.; 5, radar test equipment; 6, impedance measuring equipment; 7, wavemeters; 8, microwave tube testers.

American Electroneering Corp.	5025 W. Jefferson Blvd., L. A. 16, Calif.	1, 5
Andrew Corp.	363 E. 75th St., Chicago, Ill.	4
Bird Electronic Corp.	1800 E. 38th St., Cleveland 14, Ohio	2, 6
Bone Engineering Corp.	701 W. Broadway, Glendale 4, Calif.	4
Browning Laboratories, Inc.	750 Main St., Winchester, Mass.	2, 6
C. G. S. Labs., Inc.	391 Ludlow St., Stamford, Conn.	1, 2, 5, 6, 7
Cole Instrument Co.	1320 S. Grand Ave., Los Angeles 15, Calif.	5
Decimeter, Inc.	1436 Market St., Denver 2, Colo.	1, 7
Diamond Manufacturing Co.	7 North Ave., Wakefield, Mass.	4
Electro Precision Products, Inc.	119-01 22nd Ave., New York, N. Y.	4
Federal Mfg. & Engrg. Corp.	199-217 Steuben St., Brooklyn 5, N. Y.	1, 7
Feiler Engrg. & Mfg. Co.	8026 N. Monticello Ave., Skokie, Ill.	1, 2, 3, 4, 5, 6, 7, 8
General Communication Co.	530 Commonwealth Ave., Boston 15, Mass.	1, 5
General Precision Lab., Inc.	63 Bedford Rd., Pleasantville, N. Y.	1
General Radio Co.	275 Mass. Ave., Cambridge 39, Mass.	1, 2, 3, 6, 7
General RF Fittings Co.	702 Beacon St., Boston 15, Mass.	5
Guthman & Co., Inc., Edwin I.	15 S. Throop St., Chicago 7, Ill.	4
Hewlett-Packard Co.	395 Page Mill Rd., Palo Alto, Calif.	1, 2, 3, 4, 6, 7
H. M. R. Electronics, Inc.	36 Grove St., New Canaan, Conn.	1
Kay Electric Co.	Maple Ave., Pine Brook, N. J.	1, 2, 4, 5, 6, 7
Kings Microwave Co., Inc.	719 Main St., New Rochelle, N. Y.	1, 2, 4, 6
Leru Laboratories, Inc.	R. D. 4, Paterson, N. J.	1, 5, 8
Litton Industries	1001 Brittan Ave., San Carlos, Calif.	2, 6
Loral Electronics Corp.	794 E. 140th St., New York 54, N. Y.	5
Marconi Instruments	23-25 Beaver St., New York 4, N. Y.	1, 3, 4, 5, 7
Measurements Corp.	Boonton, N. J.	1, 3
Metropolitan Electronics & Instruments Co.	106 Fifth Ave., New York 11, N. Y.	1
Mico Instrument Co.	80 Trowbridge St., Cambridge, Mass.	7
Microlab	301 S. Ridgewood Rd., S. Orange, N. J.	1, 4
Microwave Dev. Labs., Inc.	220 Grove St., Waltham, Mass.	2, 6, 7
Microwave Equip. Co., Inc.	N. Caldwell, N. J.	1, 2, 4, 5, 6, 7
Millen Mfg. Co., Inc., James	Malden, Mass.	5
Monarch Radio & Tel. Corp.	61 Crescent St., Brooklyn 8, N. Y.	1, 2, 4, 5, 6, 7
Motorola, Inc.	4545 W. Augusta Blvd., Chicago 51, Ill.	1, 4, 5
Network Manufacturing Corp.	213 W. 5th St., Bayonne, N. J.	5
New London Instrument Co.	New London, Conn.	1
Philco Corp.	Tioga & "C" Sts., Philadelphia 34, Pa.	1, 4, 7
Polarad Electronics Corp.	100 Metropolitan Ave., Brooklyn 11, N. Y.	1, 5
Radiomarine Corp. of America	75 Varick St., New York 13, N. Y.	5
Rollin Co., The	2066 N. Fair Oaks Ave., Pasadena, Calif.	1, 2, 6
Sierra Electronic Corp.	1050 Brittan Ave., San Carlos, Calif.	1, 2, 6
Sperry Gyroscope Co.	Great Neck, New York 14, N. Y.	1, 2, 3, 4, 5, 6, 7, 8
Sylvania Electric Products Inc.	70 Forsyth St., Boston 15, Mass.	1, 3
Telectro Industries	35-16 37th St., Long Island City 1, N. Y.	4, 7
Teletronics Laboratory, Inc.	352 Maple Ave., Westbury, L. I., N. Y.	1
Thompson Products, Inc.	2196 Clarkwood Rd., Cleveland 3, Ohio	7
Triplett Elec. Instrument Co.	Bluffton, Ohio	8
Vectron, Inc.	235 High St., Waltham, Mass.	1, 2, 4, 5, 6, 7
Weston Electrical Inst. Corp.	614 Frelinghuysen Ave., Newark 5, N. J.	5, 8
Weymouth Instrument Co.	1440 Commercial St., E. Weymouth, Mass.	4, 7
Wheeler Labs., Inc.	122 Cutter Mill Rd., Great Neck, N. Y.	1, 2, 4, 5, 6, 7

Hewlett-Packard Model 430 B microwave power meter for measurements to 3000 mc., depending on bolometer mount.

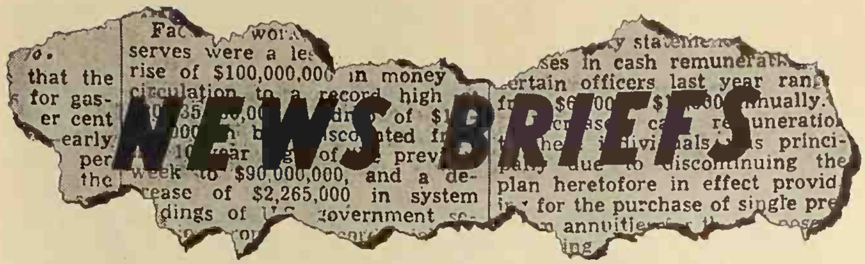
A device is now available on the market for the direct measurement of susceptance and conductance at frequencies up to 1500 mc. In this device, called the admittance meter, the currents flowing in three coaxial lines fed from a common source at a common junction point are sampled by three adjustable loops. The coupling of each can be varied by rotation of the loop. One line is terminated in a conductance standard, one in a susceptance standard, and one in the unknown circuit. The outputs of the three loops are combined by connecting all in parallel, and when they are properly oriented, the combined output is zero. Dials connected to the various loops give direct readings of conductance and susceptance.

Signal Sources

Several commercial signal generators for use in the microwave spectrum are available. Klystron tubes seem to be the favorite for the oscillator, and top frequencies run as high as 11,000 mc. and more. Provision is made for external modulation of any desired kind, and—with some units—internal modulation is provided. Stability is somewhat dependent on price, but an accuracy of ½ of 1% with a direct-reading dial is claimed by one manufacturer, with another claiming a long-term drift of less than 100 kc.

Voltmeters

Although voltage measurements in general are not as important at microwave frequencies as at lower frequencies, at least one meter is commercially available which can read voltages quite accurately as high as 2500 mc., subject to certain corrections, and will give usable indications at even higher frequencies.



TURNPIKE MICROWAVE SYSTEM

The completion of the New Jersey Turnpike was marked by a highly dramatic demonstration of the *RCA* microwave and mobile communication system which covers this 118-mile super-highway. By utilizing a public address system in the Essex Hotel, where a dinner was being given to celebrate the occasion, a roll call of turnpike personnel on duty at key points along the highway was conducted. A large, electrically wired map of the turnpike flashed colored lights to indicate points of contact as communication with highway personnel was established through the six base stations.

The *RCA* radio installation obviates the need for underground cables or overhead pole-and-wire lines as a means of communication, and assures continuous functioning through sleet, snow, wind and rain.

V.H.F. RADIO WAVE PROPAGATION

A new theory for the propagation of v.h.f. radio waves beyond the horizon has been developed by Dr. J. Feinstein of the NBS staff which suggests a new role for the gradual change in the refractive index of the atmosphere with height. This change, or gradient, leads to reflection as well as refraction of v.h.f. waves as they travel out into space from the transmitter. The amount of reflection is small, but it is enough to lead to appreciable propagation of signals beyond the horizon.

Radio communication at longer ranges than line-of-sight now appears feasible at the v.h.f. frequencies, thus increasing the possibilities for such communication service as aircraft-to-ground transmission and mobile radio telephony. It means also that high-powered TV stations located farther apart than line-of-sight distance may interfere with each other.

ARMOUR FOUNDATION ENGINEERS

Theodore Saltzberg and George A. Forster have been appointed assistant engineers in the electrical engineering department at the Armour Research Foundation of the Illinois Institute of Technology. Both of these men are graduates of Illinois Tech.

Mr. Saltzberg, who received his master's degree this year, gained experience as a junior development engineer for *Motorola, Inc.*, while Mr. Forster served as electrical designer for *Vern E. Alden Company.*

EXPERIMENTAL RADIO RELAY

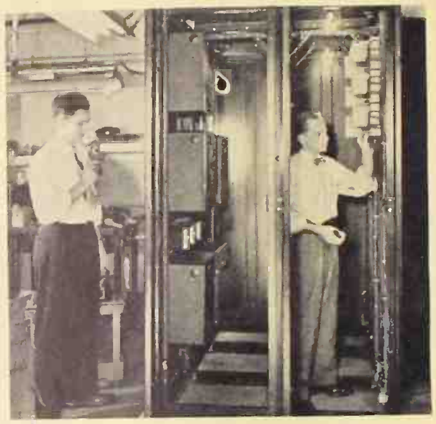
To help develop and test new and improved communications equipment for civilian and military uses, *General Electric* engineers at Electronics Park have built and are operating experimentally a 60-mile multi-channel microwave relay radio communications system.

The engineers literally talk to themselves while operating this system. From a telephone handset in the laboratory, their voices are relayed four times over the 60-mile course and are heard from a loudspeaker in the same laboratory with no noticeable time lag.

Signals are beamed from an antenna atop the laboratory to a relay station 15 miles to the south. This station, unattended, relays them to another station on a hill 15 miles further south, where they are automatically placed on another channel and beamed back to the Park over the same route.

EXPANSION AT MOTOROLA

Motorola's Carrier and Control Systems Engineering Department, formerly a part of the Carrier and Control Development Engineering Department, has been expanded as a result of the rapidly growing increase in carrier, telemetering, and control systems engineering and sales activity.



Duties of the department include analyzing and designing individual systems to meet customers' requirements whether it be for power line carrier or other control equipment for power utilities, pipe lines, railroads, or other industries. The photograph shows *Motorola* engineers checking over audio frequency carrier terminal equipment before shipment to a customer.

NATIONAL ELECTRONICS CONFERENCE

The eighth annual National Electronics Conference will be held September 29, 30 and October 1 at the Sherman Hotel in Chicago. Dr. J. A. M. Lyon, of the electrical engineering department at Northwestern Technological Institute, has been named president of the 1952 National Electronics Conference, Inc., and Mr. Kipling Adams, of *General Radio Company's* Chicago office, has been named chairman of the board.

RADIO RELAY IN TEXAS

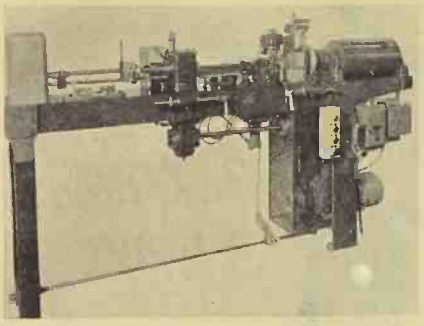
On February 11, radio relay was introduced into Texas as a link was placed in service between Austin and San Antonio by the Long Lines Department of the *American Telephone and Telegraph Company* and the *Southwestern Bell Telephone Company.* Initially equipped to carry over 100 telephone circuits, the ultimate capacity of the system is expected to be over 1000 telephone circuits and two television channels.

(*Continued on page* 60)

NEW PRODUCTS

GRID WINDER

The *Kahle Engineering Company's* grid winder, especially designed to produce pitches up to 500 turns per inch,



is constructed for vibration-free operation and increased durability. Provision is made for variable pitch and for swaging the side wires.

Accurate stop and start positioning is achieved by brake motor and push button control. The pneumatic cutter rises and disappears automatically, leaving the work field clear for complete accessibility. Because the lead screw nut is never disengaged, grid winding is always in perfect register.

Detailed information may be obtained by contacting the manufacturer at 1323 Seventh Street, North Bergen, N. J.

CRYSTAL OSCILLATOR

Standard frequency harmonics of 1 mc., 100 kc., and 10 kc. are available with the new *GR* Type 1213-A unit crystal oscillator manufactured by the *General Radio Company*, 275 Massachusetts Avenue, Cambridge 39, Mass. The 1-mc. crystal is a plated, wire-mounted, hermetically sealed unit with a low temperature coefficient of frequency.

Usable 1-mc. harmonics extend to 1000 mc., and the 100-kc. and 10-kc. har-

monics to at least 250 and 25 mc., respectively. With good receiving equipment the 10-kc. harmonics can be used to 30 mc. and higher. Crystal frequency can be readjusted at any time to agree with standard-frequency transmissions from radio station WWV, or other sources of standard frequencies.

"FLYING TYPEWRITER"

Capable of reproducing 24,000 characters per minute, the "Flying Typewriter" introduced by *Potter Instrument Company, Inc.*, Great Neck, N. Y., may provide the answer to a need long felt in the fields of computing, data-handling, and communications. Of par-

ticular advantage in communications is its ability to be serially fed over a channel of telegraph bandwidth.

The major portion of the equipment is an electronic serial-parallel storage unit which accepts information in coded pulse form from an external source, such as a computer, magnetic tape, punched cards, communication lines, etc. Eighty channels corresponding to the characters per line may be serial- or parallel-fed according to input requirements. Information is alternately stored and extracted in these channels, completing the cycle once for each line printed.

SYNCHRO ZEROING

The Synchronull Model U100, designed for zeroing synchros of all types and sizes, has been announced by *Ultrasonic Corporation*, 61 Rogers Street, Cambridge, Mass.

A simple switching operation automatically selects proper test-circuit connections for each type of synchro as well as the proper sequence of test circuits for the zeroing operation, thus eliminating the possibility of making improper connections. High sensitivity

in the null-indicating tuning eye permits the ultimate in zeroing accuracy; ten millivolts, corresponding to about 0.6 minutes of angular error, can be clearly and instantly detected.

AIRCRAFT TESTER

An aircraft tester which may help to prevent future aviation accidents by providing more adequate pre-flight inspection is now available. Capable of testing reversible propellor circuits during pre-flight checks, this instrument is known as the *Bogue* nacelle tester, and one of the plants of the *Bogue Electric Manufacturing Company* at Paterson, N. J., is devoted exclusively to its production.

Tested in actual use for over a year, the *Bogue* nacelle tester is a portable instrument mounted on rollers which automatically checks aircraft electrical circuits. By means of rapid disconnect plugs, the tester is connected to the elec-

trical circuits leading into an aircraft nacelle. It checks each of 200 circuits within the plane in less than ten seconds.

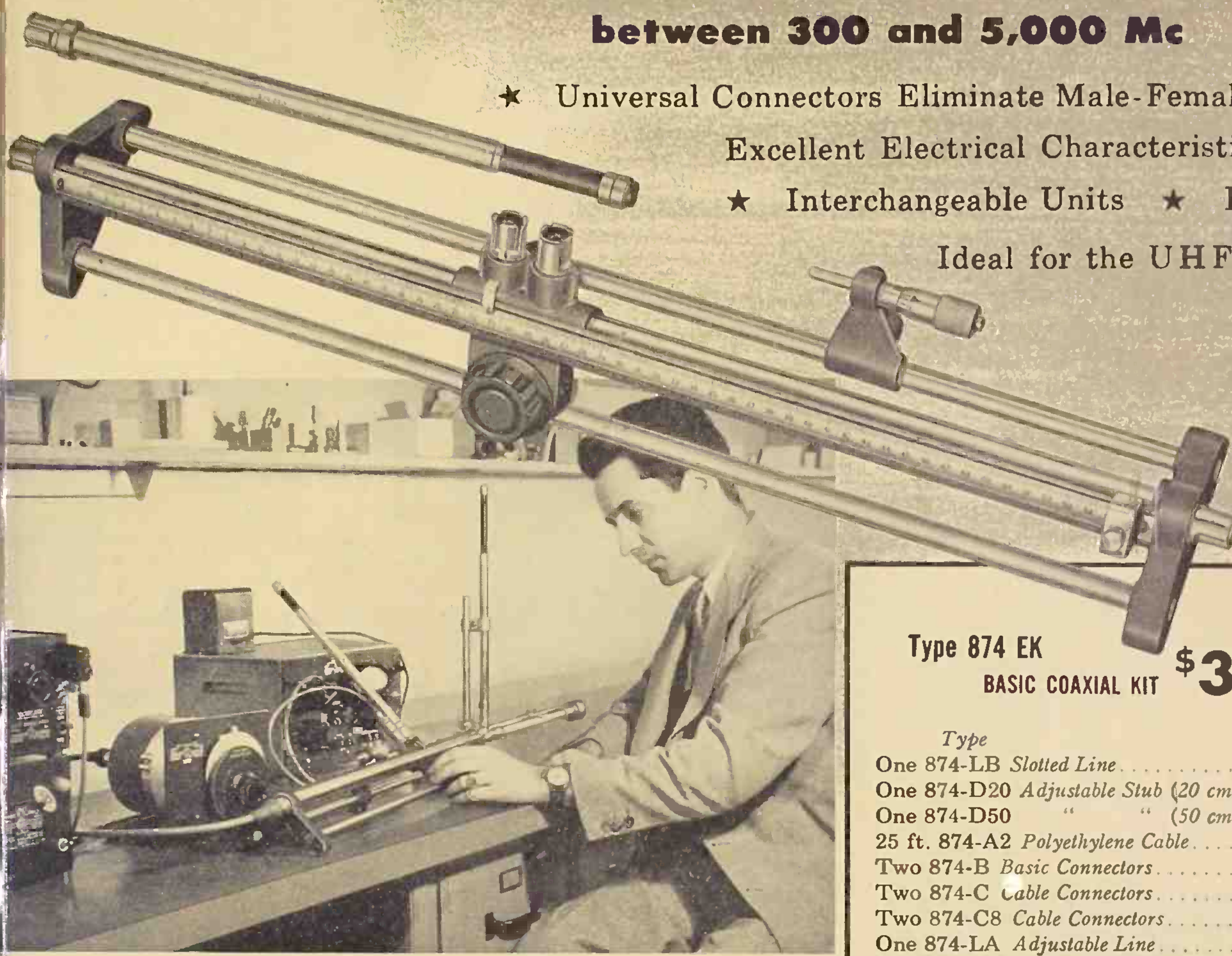
SUBMINIATURE RESISTORS

A new series of small resistors has been introduced by the *Daven Company* to meet the miniaturization program of

Basic Slotted Line Equipment

for measurements of **POWER ☆ VOLTAGE**
IMPEDANCE ☆ ATTENUATION ☆ STANDING-WAVE RATIO
between 300 and 5,000 Mc

★ Universal Connectors Eliminate Male-Female Adaptors
Excellent Electrical Characteristics ★
★ Interchangeable Units ★ Inexpensive
Ideal for the UHF T-V Band



Type 874 EK
BASIC COAXIAL KIT **$342.25**

Type	*Cost*
One 874-LB *Slotted Line*	$220.00
One 874-D20 *Adjustable Stub (20 cm)*	10.50
One 874-D50 " " *(50 cm)*	12.00
25 ft. 874-A2 *Polyethylene Cable*	6.75
Two 874-B *Basic Connectors*	2.50
Two 874-C *Cable Connectors*	4.00
Two 874-C8 *Cable Connectors*	4.00
One 874-LA *Adjustable Line*	15.00
Two 874-P *Panel Connectors*	5.00
One 874-Q1 *Adaptor to Type N*	4.50
Two 874-R20 *Patch Cords*	12.00
One 274-NF *Patch Cord*	2.50
One 874-Q6 *Adaptor*	2.00
One 274-NE *Shielded Connector*	5.50
One 874-T *Tee*	7.50
One 874-WM *Matched 50-Ohm Termination*	10.50
One 874-WN *Short-Circuit Termination*	3.50
One 874-WO *Open-Circuit Termination*	2.00
One 874-Z *Adjustable Stand*	12.50
Complete Kit $342.25	

'OR a relatively small investment, any ıboratory can be equipped with slotted ıne measuring equipment with which a onsiderable number of impedance and tanding-wave measurements can be made. 'he Type 874-EK Basic Coaxial Kit is ffered as a complete package for this urpose.

The G-R Type 874-LB Slotted Line is one f the important basic measuring instruents for use at ultra-high frequencies. Vith it the standing wave pattern of the eld in a coaxial transmission line can be determined quickly, simply and accurately.

The G-R Slotted Line is a 50-ohm, air ielectric, coaxial transmission line with longitudinal slot in the outer conductor. The inner conductor is supported at ts ends only, by two Type 874 Connectors minimizing reflections and discontinuities caused by dielectric supports.

A probe, mounted on a carriage with a 50 cm maximum travel, samples the field within the line. A built-in crystal rectifier is used as a detector of the r-f voltage induced in the probe. The rectifier is tuned to the operating frequency by means of adjustable stubs. Terminals are provided so that a receiver can also be used as a detector.

A large number of associated elements and inexpensive auxiliary units are available. These include Unit Oscillators, Unit Power Supplies, Amplifiers and Detectors, Mixer Rectifiers, Voltmeter Rectifiers, Bolometer Bridge, Voltmeter Indicator, Attenuators, Line Elements, Filters, Adaptors, etc.

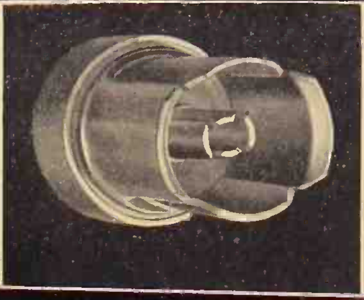
GENERAL RADIO Company

275 Massachusetts Ave. Cambridge 39, Mass.

90 West St. NEW YORK 6 *920 S. Michigan Ave.* CHICAGO 5
1000 N. Seward St. LOS ANGELES 38

For a 16-page Booklet describing the Complete Line, Fill-In the Coupon below

The versatility of the entire line of G-R u-h-f measuring equipment is based on the Type 874 Connector vith which all coaxial elements are equipped. These universal male-female connectors are designed for simple, quick, plug-in connect and disconnect. Each will plug into any other. Their electrical and shielding characteristics are excellent. Conversion adaptors for use with other types of terminals are available.



Send me the 16-Page Booklet describing the complete line of G-R slotted line measuring equipment. 540

Name ....

Address ....
STREET

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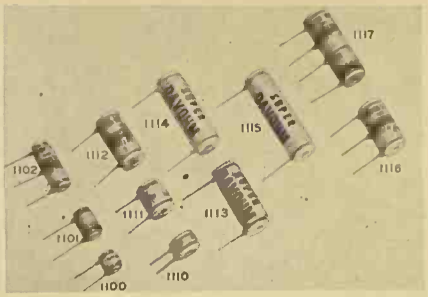
CITY ZONE STATE

the armed forces, aircraft and electronics industries.

Resistance values from 20,000 ohms to 2 megohms are available in sizes from ¼" diameter x 1⅜" long. Maximum values of resistance may be obtained by use of various types and sizes of wire.



For additional information, write to the *Daven Company*, 191 Central Avenue, Newark, N. J.

TRANSFORMER AMPLIFIER

Sterling Instruments Company, 13331 Linwood Avenue, Detroit 6, Mich., announces its new Model 301 differential transformer amplifier. Designed for use with Series O *Schaevitz* linear variable differential transformers, and *Schaevitz* accelerometers, this instrument is capable of statically and dynamically measuring displacement, force, vibration, torque, acceleration, pressure, thickness, etc. The instantaneous data may be presented on the screen of a cathode-ray oscillograph, while permanent records can be obtained with direct-writing recorders or recording galvanometers.

For further information, please address inquiries to the Engineering Department of the *Sterling Instruments Company*.

DUAL-BEAM OSCILLOGRAPH

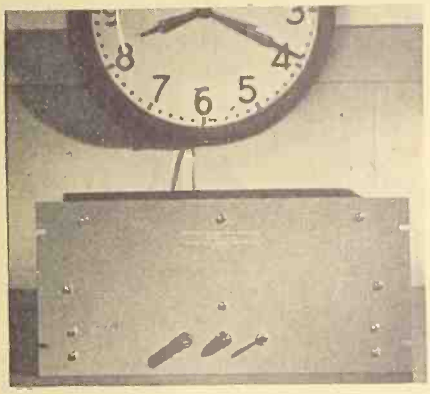
Designated as Type 322, the new *Du Mont* dual-beam oscillograph was engineered specifically for general-purpose laboratory and industrial applications. This compact instrument is essentially two *Du Mont* Type 304-H oscillographs in a single cabinet, and offers all of the features of Type 304-H with the additional advantage of dual-beam presentation on either common or individual sweeps, amplitude calibration of either axis of both channels, and conveniently centralized controls.

The Type 5SP cathode-ray tube employed in the dual-beam oscillograph is operated at an over-all accelerating potential of 3000 volts, producing a bright trace capable of excellent resolution. Stable high-gain a.c. and d.c. amplifiers are provided for both axes.

A bulletin describing this unit and giving complete specifications is available from the Instrument Division, *Allen B. Du Mont Laboratories, Inc.*, 1500 Main Avenue, Clifton, N. J.

FREQUENCY MULTIPLIER

Designed to be energized by a 10-cps input at 5 volts minimum, the Model 134 *Sierra* clock-drive generator manufactured by *Sierra Electronic Corporation*, 813 Brittan Avenue, San Carlos, Calif., produces a 115-volt 60-cps output of 5 watts. Developed for use in a continuous frequency-monitoring arrangement, the unit incorporates its own power supply and includes a control to permit the adjustment of output voltage under various load conditions.

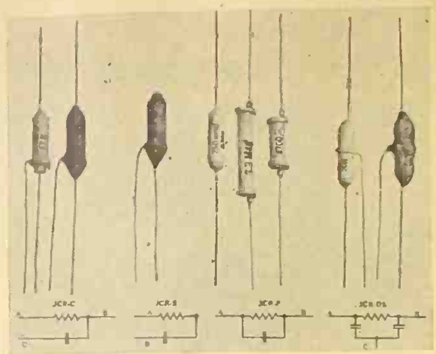


In the basic application, a secondary standard frequency, divided if necessary to 10 cps, is fed to the Model 134 generator. Since the generator multiplies by 6, the output frequency is 60 cps ± 6 times the frequency error of the input. Other applications may suggest themselves wherever frequencies are to be multiplied by a factor of six.

CAPRISTORS

Four new capristors are now being manufactured by *Jeffers Electronics, Inc.*, DuBois, Pa., a subsidiary of *Speer Carbon Company*, which are said to reduce assembly time, save space, reduce costs and provide full ratings of equivalent standard resistors and capacitors in the manufacture of radio, television and radar equipment.

Capristors, a combination of capacitors and resistors equivalent to simple forms of printed circuits, are larger than printed circuits but provide higher ratings. Available either non-insulated, with white enamel, or insulated with a thermosetting dip type coating, vacuum wax impregnated, they can be used for diode filters, bandpass filters, interstage coupling elements and other resistor-capacitor circuits.



ELECTRON MICROSCOPE

Screen magnification of the new microscope being manufactured by the Research & Control Instruments Division of *North American Philips Co., Inc.*, 750 South Fulton Avenue, Mount Vernon, N. Y., is continuous from 1000X to 60,000X. This instrument is capable of producing micrograms of 30 Angstroms resolution or better, and accelerating potentials of 40, 60, 80 and 100 kv. are available.

The unit has a beam oscillator for rapid determination of exact focus, thereby eliminating the necessity for a series of exposures with conjunctive time loss.

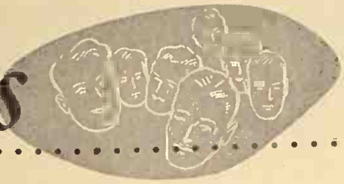
Because it has an extremely large field, the *Philips* microscope permits recording in a single photograph areas which might otherwise require a mosaic of six individual sections.

REFLECTION PLOTTER

One of the major causes of collisions at sea—the factor of human error in the navigation of ships—has come a

(*Continued on page* 51)

Personals



ROBERT L. BATTS, pioneer in radio communications, has joined *Motorola's* Communications and Electronics Division at Chicago as engineer and field representative. Mr. Batts helped design and build the world's first police radio system, his specific achievement being the first practical police mobile radio receiver. He recently completed 22 years with the city of Indianapolis as a captain in charge of communications.

EDWARD L. BEAUDRY, JR., formerly the president of *Kay Electric Company,* Pine Brook, N. J., is now the president of *Chase Resistors Company* which has a new factory located at 9 River Street, Morristown, N. J. *Chase* manufactures carbon film resistors, under *Western Electric* patents, which are known as "stablohms" and are designed for use where stability under widely varying ambient conditions is a problem.

MATTHEW D. BURNS, newly appointed general manager of the Radio Tube Division of *Sylvania Electric Products Inc.* at Emporium, Pa., joined the Pennsylvania predecessor company of *Sylvania* in 1921. Active in development and production work on several early types of radio tubes, he was made factory superintendent in 1932, manager of the receiving tube plant in 1939, and since 1946 has been general manufacturing manager of the Radio Tube Division.

ARTHUR J. COSTIGAN, responsible for many developments in the maritime mobile communications service during his 40 years in the industry, has been awarded the Marconi Memorial Medal of Achievement. He began his radio career with the *Marconi Wireless Telegraph Company of America* in 1912 as a shipboard operator, and is now vice president in charge of communications of the *Radiomarine Corporation of America.*

ERNEST A. MARX has been appointed director of the International Division of *Allen B. Du Mont Laboratories, Inc.*, in which position he will be responsible for the coordination and extension of all export activities including licensing of foreign manufacturers for *Du Mont* products. Mr. Marx, formerly general manager of *Du Mont's* Receiver Sales Division, brings to this new post 25 years of pre-war foreign export and financial experience.

CARL A. SALMONSEN has been appointed general manager of the *General Electric Company's* newly formed Industry Control Department at Schenectady. Starting with *G-E* as an office boy in 1909, Mr. Salmonsen served in many and varied capacities throughout his more than 42 years with the company until, in 1949, he was named for his most recent position as manager of manufacturing of *G-E's* former Large Apparatus Department.

New Literature

(*Continued from page* 33)

obtained from the Government Printing Office, Washington 25, D. C., for $3.25 a copy.

In addition to including the regular tables of ascending and descending exponentials, this volume presents the value of e and $1/e$ to 2556 decimal places and appends a table containing the ascending and descending exponentials of integers.

INSTRUMENT TRANSFORMERS

Now available from the *General Electric Company,* Schenectady 5, N. Y., is a 1952 edition of the company's instrument transformer buyer's guide, which contains basic, up-to-date information on the complete line of *G-E* instrument transformers.

This fully illustrated, 94-page publication, *GEA*-4626E, gives ratings, ASA accuracy classifications, and prices for all *G-E* indoor and outdoor potential and current transformers, metering outfits, and potential and current portable transformers.

Tubes for Microwaves

(*Continued from page* 21)

provided for convenient insertion in coaxial lines and wave guides.

In the "cartridge" type holder, silicon is secured to a threaded end plug. The end plug is inserted in an end cap, and the assembly is secured to a ceramic body. The opposite end of the body carries a contact pin with the catwhisker. Metal parts of the holder are gold-plated to provide good electrical conductivity and resistance to corrosion. Cartridge type silicon crystals are usually used in applications below 10,000 mc.

In "coaxial" type crystals, the silicon is secured to a metal end plug for fitting to an external sleeve. The center conductor is mounted coaxially with the internal sleeve by means of an insulating bead. One end of the catwhisker is welded to the center conductor. Coaxial type silicon crystals are suitable for frequencies above 10,000 mc.

The polarity of silicon crystals has been standardized in terms of an equivalent diode so that the base of the cartridge type and the outer sleeve of the coaxial type correspond to the anode. The pin, used in both types, corresponds to the cathode.

In microwave mixer service, silicon diodes require very little oscillator power. Power required can be supplied from planar grid triode oscillators or from klystrons.

For GAS SWITCHING TUBES TR-ATR-PRE TR *and* MICROWAVE COMPONENTS *Consult . . . Bomac*

Bomac has available an extensive line of TR, ATR, Pre TR and attenuator tubes covering all the frequency bands and power levels in use. Many types are in high level production; specialized types can be supplied on short notice.

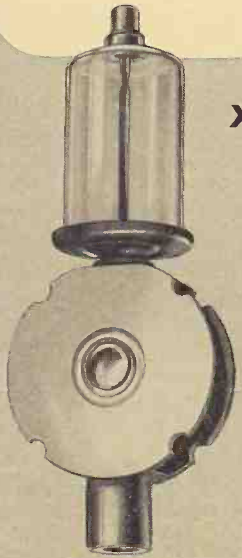
The Bomac engineering staff includes personnel who have been associated with TR development since the inception of Microwave Radar and have made major contributions to TR development. Their accumulated experience is at your disposal.

K BAND

1B26
1B36
BL-11

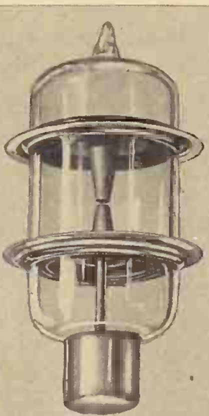
X_b BAND

1B50
1B51



X BAND

BL-3
1B24A
1B35
1B37
1B60
724B
6038
ATR388
1B63A



S BAND

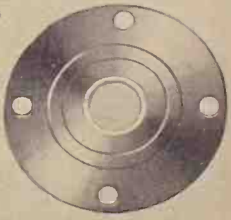
1B27	1B57
1B38	1B58
1B44	1B62
1B52	721B
1B53	5792
1B54	5793
1B55	5853
1B56	ATR387

L BAND

1B23
1B40

PRESSURIZING WINDOWS

BL105
BL106
BL107
BL112
BL114



Catalog available on request. Write (on your company letterhead) Dept. O, Bomac Laboratories, Inc., Salem Road, Beverly, Massachusetts.

WE INVITE YOUR INQUIRIES REGARDING

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TECHNICAL BOOKS

"ESSENTIALS OF MICROWAVES" by Robert B. Muchmore, to be published by *John Wiley & Sons, Inc.*, 440 Fourth Ave., New York 16, N. Y. Tentative publication date, July, 1952; tentative price, $4.50.

This book represents a notable contribution to the literature on the rapidly expanding field of microwaves. Although written for the engineer with a considerable background in electromagnetic theory and mathematics, it depends primarily on well-written text material for explaining basic concepts and applications, and only rarely calls on mathematics for assistance.

Starting with basic field theory, the author leads logically into a discussion of the characteristics of microwaves in transmission lines such as wave guides and coaxial lines. This is followed by material on cavities, filters, and microwave antennas of all kinds. Tubes for use at microwaves, such as klystrons, magnetrons, and traveling wave tubes, are given an extensive treatment. Noise in the microwave region is covered briefly. The final chapters are concerned with relay systems, radar, applications in physical research, and measurements.

"FUNDAMENTALS OF ELECTRONICS AND CONTROL" by Milton G. Young, Professor of Electrical Engineering, and Harry S. Bueche, Associate Professor of Electrical Engineering, University of Delaware. Published by Harper & Brothers, 49 East 33rd Street, New York 16, N. Y. 525 pages. $6.00.

This text provides a basic approach to electronic problems for engineering students of all types. Assuming only an elementary knowledge of direct and alternating currents, it is designed to give a broad understanding of the operation of electronic tubes and equipment used in the fields of industrial control and measurement, electrical communication, and power transformation.

Up to date in every respect, it covers such recent developments as magnetic amplifiers, transistors, crystal diodes, strain gages, electromechanical transducers, varistors, and the like. The MKS system of units is used.

A large selection of problems has been included—to most of which the answers are supplied—and much usefu supplementary data provided in the thirteen appendixes. Carefully selecte reading lists follow each chapter.

DIRECTORY of MICROWAVE EQUIPMENT MANUFACTURERS

A—Antennas
B—Test Equipment
C—Tubes
D—Wave Guides
E—Radar Equipment
F—Amplifiers, Receivers
G—Complete Systems
H—Misc. Components
I—Crystals

Aerolux Light Corp. ... C
653 11th Ave., New York, N. Y.

Aeronautical Electronics, Inc. ... B, I
P. O. Box 6043, Raleigh, N. C.

Air Associates, Inc. ... F, G
511 Joyce St., Orange, N. J.

Airtron, Inc. ... A, D
26 E. Elizabeth Ave., Linden, N. J.

American Electroneering Corp. ... B, E, F, G
5025-29 W. Jefferson Blvd., Los Angeles 16, Calif.

American Lava Corp. ... A
Chattanooga, 5, Tenn.

American Phenolic Corp. ... A, D
1830 S. 54th Ave., Chicago 50, Ill.

Amperex Electronic Corp. ... C
25 Washington St., Brooklyn 1, N. Y.

Andrew Corp. ... A, B, D, H
363 E. 75th St., Chicago, Ill.

Applied Science Corp. of Princeton ... B, F
P. O. Box 44, Princeton, N. J.

Art-Lloyd Metal Products Corp. ... B
2973 Cropsey Ave., Brooklyn 14, N. Y.

Assembly Products, Inc. ... B
Main at Bell St., Chagrin Falls, Ohio

Associated Research, Inc. ... B
3758 W. Belmont Ave., Chicago 18, Ill.

Astron Corp. ... H
255 Grant Ave., E. Newark, N. J.

Atlantic Electronics Corp. ... D, E, H
4 Manhasset Ave., Port Washington, N. Y.

Bart Laboratories Co., Inc. ... A, D, H
227 Main St., Belleville 9, N. J.

Beede Electrical Instrument Co. ... B
Penacook, N. H.

Belling & Lee, Ltd. ... A
366 Madison Ave., New York 17, N. Y.

Berkeley Scientific Corp. ... B
2200 Wright Ave., Richmond, Calif.

Berkshire Laboratories ... B, C
624 Beaver Pond Rd., Lincoln, Mass.

Bird Electronic Corp. ... B, H
1800 E. 38th St., Cleveland 14, Ohio

Birnbach Radio Co., Inc. ... A
145 Hudson St., New York 13, N. Y.

Bliley Electric Co. ... I
Union Station Bldg., Erie Pa.

Bogart Mfg. Corp. ... D
315 Siegel St., Brooklyn 6, N. Y.

Bogue Electric Mfg. Co. ... F, G, H
52 Iowa Ave., Paterson 3, N. J.

Bomac Laboratories, Inc. ... C
Salem Rd., Beverly, Mass.

Bone Engineering Corp. ... A, B, D, H
701 W. Broadway, Glendale 4, Calif.

Boston Insulated Wire & Cable Co. ... D
65 Bay St., Dorchester 25, Mass.

Breon Laboratories ... I
1520 Evergreen Rd., Williamsport, Pa.

Brew & Co. Inc., Richard D. ... D
106 Concord Ave., Belmont, Mass.

Browning Laboratories, Inc. ... B
750 Main St., Winchester, Mass.

Burlington Instrument Co. ... B
203 N. Third St., Burlington, Iowa

Centralab, Div. of Globe-Union, Inc. ... A, B
900 E. Keefe Ave., Milwaukee 1, Wis.

C. G. S. Laboratories, Inc. ... B, D
391 Ludlow St., Stamford, Conn.

Clark Crystal Co. ... I
2 Farm Rd., Marlboro, Mass.

Collcraft, Inc. ... D, H
3716 N. Cicero Ave., Chicago 41, Ill.

Coil Winders, Inc. ... A, D, H
61 Bergen St., Brooklyn 2, N. Y.

Cole Instrument Co. ... B
1320 S. Grand Ave., Los Angeles 15, Calif.

Columbia Wire & Supply Co. ... D
2850 Irving Park Rd., Chicago 18, Ill.

Condor Radio Mfg. Co. ... D, E, F, G, H
116 N. Montezuma St., Prescott, Ariz.

Cook Electric Co. ... B, D, E, F, H
2700 Southport Ave., Chicago 14, Ill.

Daven Co. ... D, H
191 Central Ave., Newark, N. J.

Decimeter, Inc. ... B, H
1436 Market St., Denver 2, Colo.

DeJur Amsco Corp. ... B
45-01 Northern Blvd. Long Island City 1, N. Y.

Diamond Manufacturing Co. ... B, C, D
7 North Ave., Wakefield, Mass.

Dielectric Materials Co. ... D
5315 N. Ravenswood Ave., Chicago 40, Ill.

Du Mont Labs., Allen B., Transmitter Div. ... F, G
1500 Main Ave., Clifton, N. J.

Eidson Electronic Co. ... I
1802 N. Third St., Temple, Texas

Eitel-McCullough, Inc. ... C
798 San Mateo Ave., San Bruno, Calif.

Electro Impulse Laboratory ... D
62 White St., Red Bank, N. J.

Electro Precision Products, Inc. ... A, B, D, H
119-01 22nd Ave., College Pt., New York, N. Y.

Elm Laboratories ... C, E
20 S. Broadway, Dobbs Ferry, N. Y.

El-Tronics, Inc. ... B
2647 N. Howard St., Philadelphia 33, Pa.

Empire Devices, Inc. ... B, C, H
38-25 Bell Blvd., Bayside 61, N. Y.

Erie Resistor Corp. ... H
644 W. 12th St., Erie, Pa.

Etched Products Corp. ... B
39-01 Queens Blvd., Long Island City 4, N. Y.

Federal Mfg. & Engrg. Corp. ... B
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500 Washington Ave., Nutley 10, N. J.

Federal Telephone & Radio Corp. ... B, C, E, G
88 Kingsland Rd., Clifton, N. J.

Feiler Engrg. & Mfg. Co. ... B, C, E, F, G, H
8026 N. Monticello Ave., Skokie, Ill.

Filtron Co., Inc., The ... H
131-05 Fowler Ave., Flushing, L. I., N. Y.

Gadgets, Inc. ... A
3629 N. Dixie Drive, Dayton, Ohio

General Cement Mfg. Co. ... A
919 Taylor Ave., Rockford, Ill.

General Ceramics & Steatite Corp. ... A
Cranes Mill Rd., Keasbey, N. J.

General Communication Co. ... B, E
530 Commonwealth Ave., Boston 15, Mass.

General Electric Co., Electronics Div. ... C
1 River Rd., Schenectady, N. Y.

General Electric Co., Electronics Div. ... A, C, E, F, G, I
Electronics Park, Syracuse, N. Y.

General Electronics, Inc. ... C
101 Hazel St., Paterson, N. J.

General Instrument Corp. ... C, D, F, G, H
829 Newark Ave., Elizabeth 3, N. J.

General Precision Lab., Inc. ... A, B, C, D, E, F, G, H
63 Bedford Rd., Pleasantville, N. Y.

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General RF Fittings Co. ... B, C, D
702 Beacon St., Boston 15, Mass.

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Hastings Instrument Co., Inc. ... E
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H. M. R. Electronics, Inc. ... A, B, C, E, F, G, H
36 Grove St., New Canaan, Conn.

Hytron Radio & Electronics Co., Div. of CBS ... C
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IE Manufacturing Co. ... A
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209 Second Ave., S.W., Waseca, Minn.

Kay Electric Co. ... B
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Kemtron Electronic Co. ... C
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Kennedy & Co., D. S. ... A
432 S. Main St., Cohasset, Mass.

Kings Microwave Co., Inc. ... A, B, C, D, H
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K. V. Transformer Corp. ... B, H
4412 Park Ave., New York 57, N. Y.

La Magna Mfg. Co., Inc. ... A, D
51 Clinton Place, E. Rutherford, N. J.

LaPointe Plascomold Corp. ... A, H
Windsor Locks, Conn.

Lapp Insulator Co., Inc. ... A
LeRoy, N. Y.

Leru Laboratories, Inc. ... B, C, E, F, G
R. D. 4, Paterson, N. J.

Lewis & Kaufman, Inc. ... C
P. O. Box 337, Los Gatos, Calif.

Link Radio Corp. ... F, G
125 W. 17th St., New York, N. Y.

Litton Industries ... B, C
1001 Brittan Ave., San Carlos, Calif.

Loral Electronics Corp. ... B, E, F
794 E. 140th St., New York 54, N. Y.

Machlett Laboratories, Inc. ... C
Springdale, Conn.

Makepeace Co., D. E. ... A, D
Pine & Dunham Sts., Attleboro, Mass.

Marconi Instruments ... B, I
23-25 Beaver St., New York 4, N. Y.

Marion Electrical Instrument Co. ... B
400 Canal St., Manchester, N. H.

Measurements Corp. ... B
Boonton, N. J.

Melpar, Inc. ... B, D, E, G, H
452 Swann Ave., Alexandria, Va.

Meters, Inc. ... B
5353 N. Keystone Ave., Indianapolis 20, Ind.

Metropolitan Electronics & Instruments Co. ... B
106 Fifth Ave., New York 11, N. Y.

Mico Instrument Co. ... B
80 Trowbridge St., Cambridge, Mass.

Microlab ... B, D, H
301 S. Ridgewood Rd., S. Orange, N. J.

Microwave Development Labs., Inc. ... B, D, H
220 Grove St., Waltham, Mass.

Microwave Equipment Co., Inc. ... A, B, D, H
N. Caldwell, N. J.

Millen Mfg. Co., Inc., James ... B, D, H
Malden, Mass.

Miller, August E. ... I
9226-9228 Hudson Blvd., N. Bergen, N. J.

Monarch Radio & Television Corp. ... B, C, D, E, F, G, H
61 Crescent St., Brooklyn 8, N. Y.

Motorola, Inc. ... A, B, D, F, G, H
4545 W. Augusta Blvd., Chicago 51, Ill.

Mykroy, Inc. ... A
Arlington Heights, Ill.

National Union Radio Corp. ... C
350 Scotland Rd., Orange, N. J.

Network Manufacturing Corp. ... A, B, E, F, H
213 W. 5th St., Bayonne, N. J.

New London Instrument Co. ... B
New London, Conn.

Northeastern Engineering, Inc. ... A, B, G
Bedford St., Manchester, N. H.

N. R. K. Mfg. & Engrg. Co. ... D, E
5644 N. Western Ave., Chicago 45, Ill.

Orthon Corp., The ... B, H
196 Albion Ave., Paterson 2, N. J.

Phalo Plastics Corp. ... D
25 Foster St., Worchester 8, Mass.

Philco Corp. ... A, B, C, D, E, F, G, H
Tioga & "C" Sts., Philadelphia 34, Pa.

Polarad Electronics Corp. ... B, C, E, F, H
100 Metropolitan Ave., Brooklyn 11, N. Y.

Polytech Devices, Inc. ... I
1180 E. Grand St., Elizabeth, N. J.

Polytechnic Research & Development Co., Inc. ... B, C, D, H
202 Tillary St., Brooklyn 1, N. Y.

Press Wireless Mfg. Co., Inc. ... A, B, D
Cantiague Rd., Hicksville, N. Y.

Product Development Co., Inc. ... A
Arlington, N. J.

Radar Engineers ... B
110 University St., Seattle 1, Wash.

Radio Engineering Laboratories, Inc. ... A, C, F, G, H
36-40 37th St., Long Island City 1, N. Y.

Radiomarine Corp. of America ... A, B, E, F
75 Varick St., New York 13, N. Y.

Radio Merchandise Sales ... A, C, D
1165 Southern Blvd., New York 59, N. Y.

Rahm Instruments, Inc. ... B
12 W. Broadway, New York, N. Y.

Raxco Mfg. Engineers, Inc. ... C
300-302 First Ave., Peoria, Ill.

Raytheon Mfg. Co. ... C, G
Waltham 51, Mass.

R. C. A. Victor, EPD ... A, C, D, F, H
Front & Cooper Sts., Camden, N. J.

Reeves Instrument Corp. ... E, F
215 E. 91st St., New York 28, N. Y.

Roller-Smith Corp. ... B
Bethlehem, Pa.

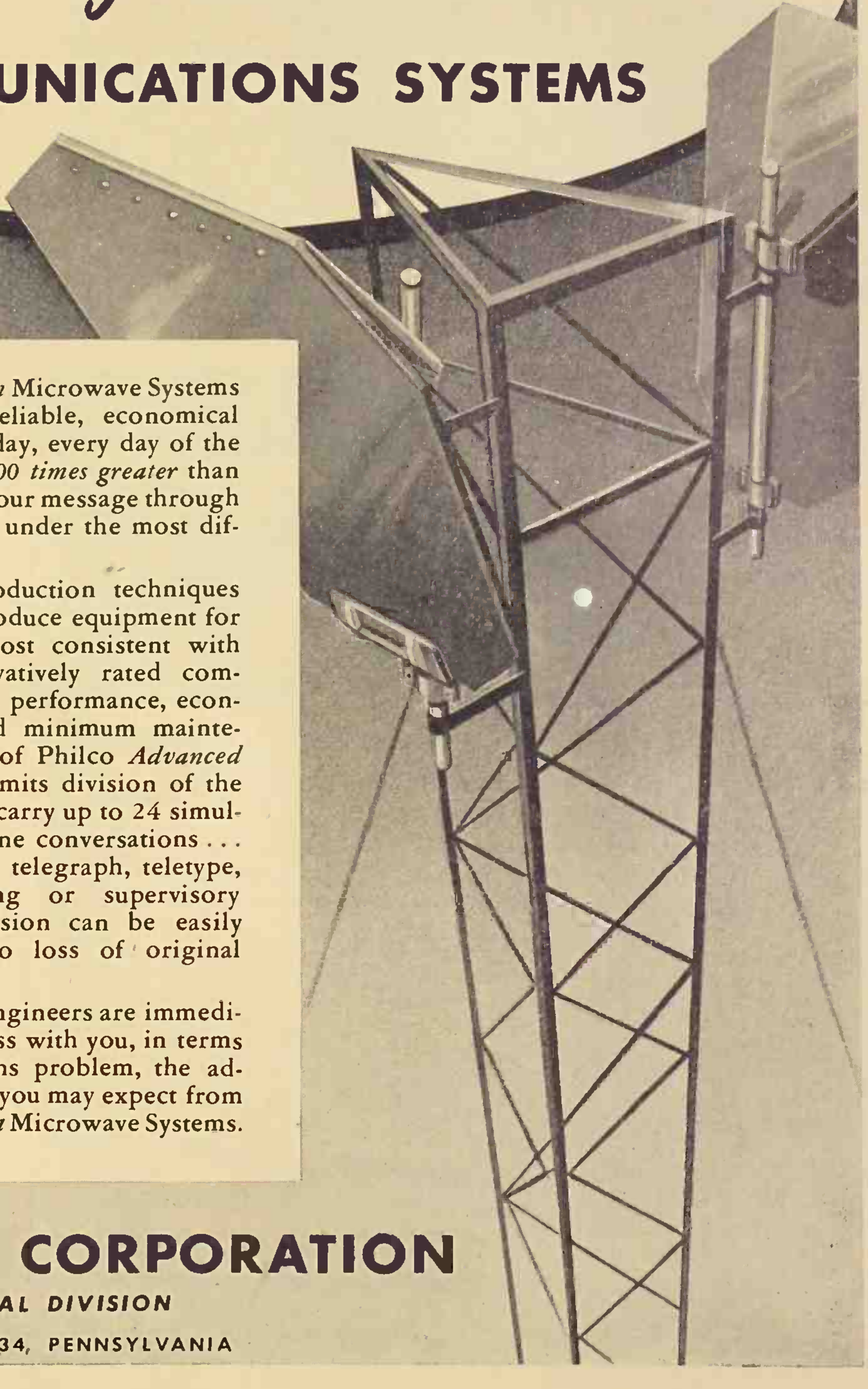
Rollin Co., The ... B, H
2066-2070 N. Fair Oaks Ave., Pasadena 3, Calif.

Don't Settle for Less Than . . .

PHILCO

Advanced Design MICROWAVE

COMMUNICATIONS SYSTEMS



Philco *Advanced Design* Microwave Systems are engineered for reliable, economical operation 24 hours a day, every day of the year. A signal level *1000 times greater* than normally needed gets your message through clear and strong, even under the most difficult conditions.

Philco's exclusive production techniques make it possible to produce equipment for the lowest possible cost consistent with high quality. Conservatively rated components insure reliable performance, economy of operation and minimum maintenance. The flexibility of Philco *Advanced Design* Microwave permits division of the broadband channel to carry up to 24 simultaneous 2-way telephone conversations . . . or further division for telegraph, teletype, telemetering, signaling or supervisory circuits. Future expansion can be easily accomplished with no loss of original investment.

Philco regional sales engineers are immediately available to discuss with you, in terms of *your* communications problem, the advantages and economy you may expect from Philco *Advanced Design* Microwave Systems.

PHILCO CORPORATION

INDUSTRIAL DIVISION

PHILADELPHIA 34, PENNSYLVANIA

Schutter Mfg. Co., Carl W. . . . . A, D, H
80 E. Montauk Highway, Lindenhurst, N. Y.
Scientific Radio Service I
4301 Sheridan St., University Park, Md.
Selectar Industries, Inc. . . . . D
401 E. 138th St., New York 54, N. Y.
Servo Corp. of America . . . . E
2020 Jericho Turnpike, New Hyde Park, N. Y.
Sickles Div., F. W., General Instrument Corp. . . . . C, D, F, G, H
165 Front St., Chicopee, Mass.
Sierra Electronic Corp. . . . . B, C, E, F, G, H
1050 Brittan Ave., San Carlos, Calif.
South River Metal Prod. Co., Inc. . . . . A
377-379 Turnpike, South River, N. J.
Sperry Gyroscope Co. . . . . A, B, C, D, E, F, G, H
Great Neck, New York 14, N. Y.
Standard Crystal Co. I
400 Armstrong Ave., Kansas City, Kansas
Standard Metals Corp. . . . . D
262 Broad St., N. Attleboro, Mass.
Standard Piezo Co. I
265 E. Pomfret St., Carlisle, Pa.
Stoddart Aircraft Radio Co. . . . . B
6644 Santa Monica Blvd., Hollywood, Calif.
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70 Forsyth St., Boston 15, Mass.
Sylvania Electric Products, Inc. C
1740 Broadway, New York 19, N. Y.

Taylor Tubes, Inc. C
2312 W. Wabansia Ave., Chicago 47, Ill.
Technicraft Laboratories, Inc. . . . . D, G
Thomaston, Conn.
Telectro Industries . . . . B, D, G
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Telemetering Associates . . . . B, G
P. O. Box 6, Silver Spring, Md.
Teletronics Laboratory, Inc. . . . . B, F
352 Maple Ave., Westbury, L. I., N. Y.
Tel-Instrument Co., Inc. . . . . B
50 Paterson Ave., E. Rutherford, N. J.
Terpening Co., L. H. . . . . H
16 W. 61st St., New York 23, N. Y.
Thompson Products, Inc. . . . . A, B, D, E
2196 Clarkwood Rd., Cleveland 3, Ohio
Thor Ceramics, Inc. . . . . A
225 Belleville Ave., Bloomfield, N. J.
Titeflex, Inc. . . . . A, D, H
500 Frelinghuysen Ave., Newark 5, N. J.
Torngren Co., Inc., C. W. . . . . A, E, F
236 Pearl St., Somerville, Mass.
Transradio, Ltd. . . . . D
138A, Cromwell Rd., London, S. W. 7, England
Triplett Elec. Instrument Co. . . . . B, C
Bluffton, Ohio
Truscon Steel Co. . . . . A
Youngstown 1, Ohio

United States Gasket Co. . . . . A
602 N. 10th St., Camden, N. J.

Valpey Crystal Corp. . . . . D, I
1244 Highland St., Holliston, Mass.
Varian Associates . . . . C, D
990 Varian St., San Carlos, Calif.
Vectron, Inc. . . . . A, B, C, D, E, F, H
235 High St., Waltham, Mass.

Walkirt Co. . . . . B, H
5808 Marilyn Ave., Culver City, Calif.
Ward Products Corp., The, Div. of Gabriel Co. . . A
1523 E. 45th St., Cleveland 3, Ohio
Weinschel Engineering Co. . . . . B
919 Jesup Blair Drive, Silverspring, Md.
Westinghouse Electric Corp. . . . . C, G
511 Wood St., Pittsburgh 30, Pa.
Westline Electronics Co. . . . . B
11656-60 W. Olympic Blvd., Los Angeles 64, Calif.
Weston Electrical Instrument Corp. . . . . B, C
614 Frelinghuysen Ave., Newark 5, N. J.
Weymouth Instrument Co. . . . . A, B, C, D, H
1440 Commercial St., E. Weymouth 89, Mass.
Wheeler Laboratories, Inc. . . . . A, B, C, D, E, F, G, H
122 Cutter Mill Rd., Great Neck, N. Y.
Wind Turbine Co. . . . . A
Market St. & Pa. R. R., W. Chester, Pa.
Woodwelding, Inc. . . . . A, B, H
3000 W. Olive Ave., Burbank, Calif.
Workshop Associates, The, Div. of Gabriel Co. . A, E
135 Crescent Rd., Needham Heights, Mass.

The Editors of RADIO-ELECTRONIC ENGINEERING have spent a great deal of time and effort to insure the accuracy of this Directory. If any errors or omissions are noted, we would appreciate it very much if you would be good enough to call them to our attention.

New Products

(Continued from page 42)

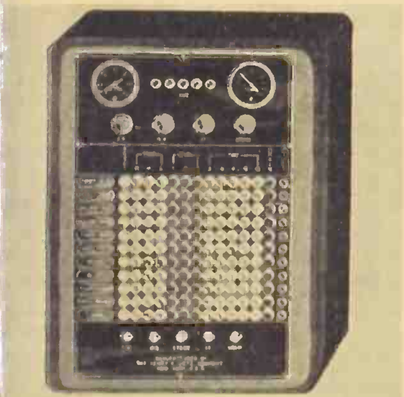
tep nearer to elimination with the development of a navigating "crystal all" which makes it possible for a nariner to interpret more accurately he movements of nearby vessels.

This device, developed by *Raytheon Manufacturing Company*, Waltham 54, Mass., and known as a reflection plotter, s used in conjunction with shipboard adar systems. It provides radar with visual course and speed recording eature which permits a navigator to eep track of all vessels within danger ange, and to plot the course and progess of those likely to cross, meet or vertake him.

Also developed by *Raytheon* is a raar signal simulator which makes posible a realistic presentation identical o a radar-scanned image without the nvestment of time and expense necesary to set up an entire radar system.

IMED OPERATIONS PRESELECTOR

Cat. 125 timed operations preselector rovides for the adjustment of the timng of each cycle of a process independntly, and can be used to energize a numer of electrical devices or circuits durng a single cycle of a process. Manuactured by *The Henry G. Dietz Company*, it consists of a single synchronous notor timer which delivers a repetiious fixed time impulse. Any multiple



f this impulse can be preselected by neans of pushbuttons for the desired ime interval of each cycle.

This unit has the particular advanage of being an electrically operated evice requiring no cams, clutches, or ther mechanical parts subject to wear, nd does not depend for its operation pon any parts having definite life limiations. It is extremely flexible, being ble to work from any value of voltage, ither a.c. or d.c. For further details, vrite to Henry G. Dietz, *The Henry G. Dietz Company*, 12-16 Astoria Bouleard, Long Island City 2, N. Y.

Microwave Plumbing

(*Continued from page* 15)

greater than a half-wavelength so that the guide will be operating above its cutoff frequency. The height is usually roughly one half the width, which seems to be adequate for all peak powers normally encountered. For example, a typical brass wave guide for the L band (1120-1700 mc.) has internal dimensions of 6½" x 3¼". The cutoff frequency is 908 mc., and the power-handling capacity about 12 megawatts. Smaller wave guides for higher frequencies will have correspondingly less power handling capacity.

Occasionally a wave guide system is pressurized, that is, filled with a dry gas such as nitrogen under pressure to keep moisture from entering the system. The wave guide can also be filled with any type of dielectric material to give characteristics which may be desirable in certain applications. The smaller guides frequently are silver-plated inside to reduce the attenuation.

Many specialized wave guide fittings are available for specific applications. One such unit is the magic T or hybrid junction, a matched directional coupler with a coupling coefficient of ½. The low-frequency analog is the hybrid coil used in telephone repeater circuits.

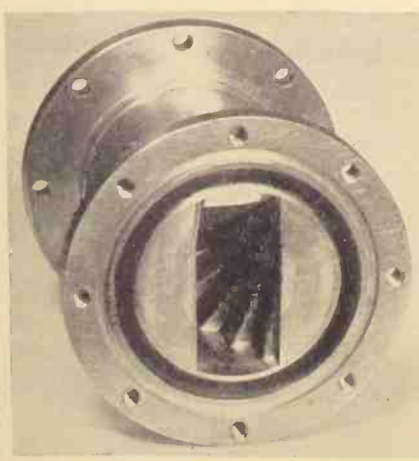
The magic T is used principally in impedance bridges, balanced mixers, balanced duplexers, and microwave discriminators. A comparison between a conventional wave guide magic T and a magic T constructed by using the *FTL* techniques described previously is shown on page 15 (photo at top, left). Both units operate in the same frequency range. The tremendous advantages of the new construction from the standpoint of weight, size, ease of construction, and cost are readily apparent.

A wide variety of directional couplers is available within the industry. A directional coupler is a stationary standing wave detector which can separately sample either the direct or reflected waves, or both, in a wave guide transmission line. It has many advantages over probe coupling.

Shunt and series tee sections are used principally for connecting units into a wave guide line in a series or shunt fashion. Power division, frequency measurement, detection and impedance matching can be accomplished when the tee section is used in conjunction with auxiliary devices.

Many other wave guide devices are available, such as attenuators, bolometer mounts, slotted wave guides, etc., but the majority of these are used for making measurements of various kinds, and are briefly discussed in the article entitled "Microwave Test Equipment" on page 34 of this issue.

Step-twist 90° wave guide section of the type described in the text.



The Business End

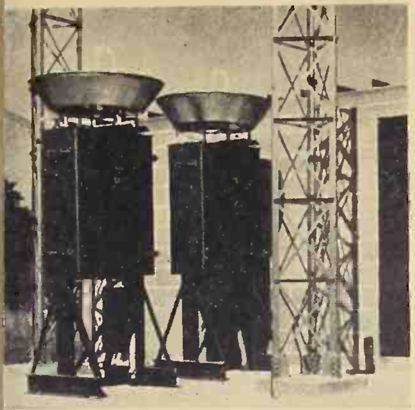
(*Continued from page* 7)

The first step in locating repeater stations is the paper survey which consists of a detailed study of available topographic maps. Maps are not available for some areas and maps do not normally indicate locations of man-made obstructions which might lie in the path of the proposed microwave beam. Therefore, after a careful paper study, field surveys must be conducted to determine that true line-of-sight conditions exist between proposed microwave antennas.

When the sites have been selected, negotiations must be conducted to acquire rights to use the properties as radio station sites. Usually there is no road leading to the selected site, so a road must be built. Power lines for operating the equipment must be erected. An equipment shelter, an antenna mast and a protective fence are usually erected at the site. These require money, brains, manpower and time. It means employment for many kinds of skills and business for many suppliers.

Many organizations contemplating the installation of microwave relay systems do not have sufficient technical personnel on their payrolls to handle microwave maintenance. Here lies opportunity for technicians and engineers! However, the great demand by manufacturers for persons skilled in electronics is depleting the reservoir of trained manpower available for microwave maintenance and installation work.

A number of railroads on the other hand have well organized communications departments. They have had need for skilled communications engineers to plan, install and maintain their large communications networks. Because of the growing demand for two-way radio in rail operations, the railroads have added electronics specialists to their payrolls. The railroads have been abl



Motorola remote-type microwave radio relay installation, available for 24 channels.

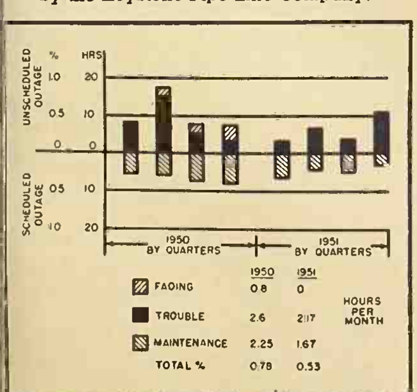
.o attract skilled personnel because of :he security they offer, pension plans and the romance of railroading.

The pipe lines, too, operate their own communications networks, and many have competent communications engineering organizations. The "pipeiners," as they call themselves, have formed the Petroleum Industry Electrical Association which serves as a fountainhead for information and exchange of ideas relating to communications and electrical problems.

The microwave industry is still in its infancy, but—in spite of its youth—is an important topic of conversation at meetings of oil men, railroaders, utility engineers and other potential users of point-to-point radio. A few short years ago, there was more conversation than action. Today there is still much conversation and also a great deal of action which can be measured in dollars—a great many dollars. And this is only the beginning.

The author wishes to acknowledge the kind cooperation of the *Transcontinental Gas Pipe Line Corporation, Texas Eastern Transmission Corporation, Keystone Pipe Line Company* and *Philco Corporation* for providing some of the information used in this article.

Record of continuity of service of a microwave relay system operated by the Keystone Pipe Line Company.



Present and Future

(*Continued from page* 10)

station licenses will stimulate an even greater demand for microwave equipment.

Radar

The development of radar equipment which can detect objects far beyond the normal range of light, both day and night, through fog and rain, is mainly responsible for the present advanced status of microwave techniques. For only at microwave frequencies could radio energy be beamed with small-sized antennas, and only small-sized antennas could be used on most aircraft. Because of the importance of radar during the war, it became imperative that methods of microwave generation and transmission be improved. The result was the initiation of a large scale research and development program which accelerated the advancement of microwave techniques.

While radar is primarily military equipment, it has also found commercial application in control towers of airports and as navigational aids for ships in crowded seaports. Many of the advances made in radar techniques during the past few years are, of course, military secrets. Undoubtedly, when this information becomes available, the improved techniques will be applied to commercial equipment.

Instruments

Microwave equipment not only has the facility to "see" objects, but also to determine accurately their distance and azimuth. This factor, plus the small size of microwave components, has made the equipment valuable when used for instruments, particularly in aircraft. Altimeters, distance measuring equipment, and other navigational instruments have found wide usage in commercial aircraft as well as military aircraft.

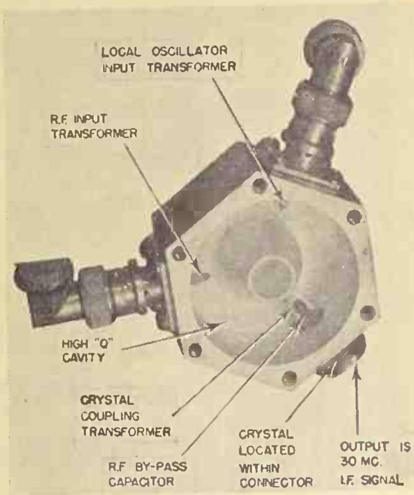


Fig. 7. Interior of r.f. mixer.

Looking Into the Future

It is reasonable to assume that microwave equipment will be used to an increasing degree in each of the applications cited above. It is quite possible, for example, that radio link equipment will be used in all communication systems which extend over five miles. In television, portable links will be developed that will eliminate the necessity of dragging large cables with the camera equipment. The picture signal generated by the camera chain will be relayed to the control room via microwave radio, thereby permitting complete freedom of movement for the camera personnel.

At microwave frequencies, general use of transmit-receive devices may become possible. Furthermore, with the development of simpler and better microwave generators, it is likely that these devices can be produced at an individual cost comparable to that of a flashlight. Should this occur, general use of "walkie-talkie" communication sets and remote control equipment capable of turning "on and off" light and appliance switches or opening and closing doors can be readily envisioned. Radar type equipment can be built for use in aiding the blind. And anti-collision sets can be engineered for automobiles which will notify the driver that an object exists in front of the car. Circuits for every one of these devices should become practical about 1970, if microwave techniques continue to advance at the present rate.

CALENDAR
of Coming Events

MAY 5-7—RTMA, AIEE, and IRE sponsored government—industry conference on Quality Electronic Components, Washington, D. C.

MAY 8-10—Acoustical Society of America 43rd Meeting, Hotel Statler, New York, N. Y.

MAY 10—IRE New England Radio Engineering Meeting, Copley Plaza Hotel, Boston, Mass.

MAY 12-14—IRE National Conference on Airborne Electronics, Hotel Biltmore, Dayton, Ohio.

MAY 16-17—Fourth Southwestern IRE Conference and Radio Engineering Show, Rice Hotel, Houston, Texas.

MAY 19-22—Radio Parts and Electronic Equipment Show, Conrad Hilton Hotel, Chicago, Ill.

MAY 23-24—Chicago Audio Fair, Conrad Hilton Hotel, Chicago, Ill.

AUGUST 27-29—IRE Western Convention, Municipal Auditorium, Long Beach, Calif.

SEPT. 29-OCT. 1—National Electronics Conference, Sherman Hotel, Chicago, Ill.

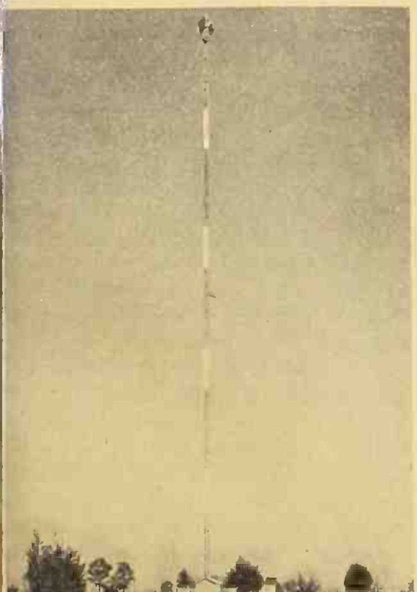
Microwave Systems

(Continued from page 18)

ting in the 940 to 960 mc. band is the *RCA* Type CW5A for short haul use, hat is, a system up to 300 miles in ength. This system has a transmitted ower of approximately 2 watts. It ses crystal frequency control and freuency multiplication of 324 times. The requency stability of the carrier is ± .005%. The over-all distortion for he system is less than 0.5%. The transmitted audio band is ± 2 db from 300 to 30,000 cycles, for a reference level of 000 cycles.

With the addition of channeling quipment, as many as seven voice hannels may be operated simultaneusly over a single radio circuit, depending upon the number of hops and he kind of traffic carried. Channeling quipment is available to break each of hese voice bands into as many as 16 ignaling circuits for telemetering signaling or supervisory control functions. The *RCA* system is designed to provide —in the absence of fading—a signal-tonoise ratio of 40 db in each of the oice bands. This type of system utilizes arabolic antennas connected to the ransmitters and receivers by solid oaxial cable or semi-flexible gas-filled oaxial line, depending on the length of he line. Either four-foot or ten-foot arabolic reflectors can be used, depending upon the system requirements. n order to provide a complete duplex adio link with this equipment, two

A microwave repeater station operated by Transcontinental Gas Pipe Line Corporation. The antennas consist of parabolic reflectors mounted at the top of a tall, guyed tower. All r.f. equipment, power supplies, etc., are located in the concrete building at the base of the tower.



parabolas are required at each end of the circuit.

An example of the system described above is the 960-megacycle relay system used for communication on the Pennsylvania Turnpike.

The next system to be described operates in the 1850 to 1990 mc. band and is the *General Electric* Type UA-1-A fixed station microwave communication system. It possesses the advantage of having both transmitter and receiver crystal-controlled, and provides pulse-width modulation which allows automatic synchronization of each channel. Since the intelligence is carried on the trailing edge of the transmitted pulse, the signals admitted do not provide intelligence on any equipment other than the demodulator intended for this system.

The *G-E* system uses one antenna both for transmitting and receiving, thus permitting simpler tower structures. Each voice channel can be subdivided to provide combinations of telephone, teletype, telegraph, telemetering, signaling, and supervisory control circuits. The transmitter itself employs a 2C39A lighthouse tube operating as a doubler in the r.f. output stage; it provides approximately 1 watt of output power in the frequency band from 1850 to 1990 mc.

The microwave receiver employed in this UA-1-A system is a self-contained single-conversion superheterodyne, and is crystal-controlled. The basic crystal operates at 70 mc.; six stages of multiplication are employed by a local oscillator to provide the proper frequency for conversion of the incoming signal to 60 mc. This conversion is obtained in a silicon crystal mixer, matched to the duplexer through a selective tuned cavity. Located on a separate chassis is a 60-mc. i.f. amplifier with 8-mc. bandwidth, providing eight stages of amplification, pulse detection, a.g.c., and output amplifier. Amplified screen-controlled a.g.c. is used to minimize detuning in the presence of strong signals. Through the use of crystal control, a carrier frequency stability of .005% is obtained, and the receiver sensitivity is 100 db below 1 watt.

Since the transmitter and receiver are designed to be operated at ground level, it is good engineering practice to use only one antenna for both transmitting and receiving in one direction. Therefore, a duplexer is provided which gives two bandpass filters. One is between the transmitter and the antenna, and the other is between the receiver and the antenna. The attenuation between transmitter and receiver is sufficient to permit simultaneous transmission and reception over one antenna and one transmission line with a frequency separation of only 50 mc. The duplexer assembly also includes coaxial relays to switch the r.f. circuits with an automatic switching panel for auxiliary operation.

The multiplexing equipment provides all circuits necessary to multiplex up to 24 channels on a single microwave carrier. Multiplexing is accomplished by time division and employs pulse-length modulation. The equipment is furnished in two groups, a 12-channel basic installation and a 24-channel expansion unit. The design is flexible so that a 12-channel installation can be expanded to 24 channels by the addition of power supplies and suitable adjustments to the timing circuits. Expansion within either of the two groups can be accomplished by the addition of interchangeable modulator and demodulator chassis.

In the *General Electric* system, the leading edges of the channel pulses are fixed intervals apart, while the trailing edge occurs earlier or later in accordance with the modulating audio voltage. In a 24-channel system there is approximately a 100-microsecond interval between pulses, giving a repetition rate of approximately 8 kc. With the 12-channel system the repetition rate is increased to 16 kc. In either case, the synchronizing pulse is roughly 4 microseconds wide, while the channel pulses are 1.5 microseconds wide unmodulated. Full modulation varies the length from 0.75 microsecond to 2.25 microseconds. Thus, in short, the transmitter waveform produces a timing wave for the whole system.

The third microwave communication relay system to be described operates in the 6575 to 6875 mc. range—the *Mid Valley Pipe Line* system, which operates between Longview, Texas, and Lima, Ohio. This system is owned jointly by the *Standard Oil Company of Ohio* and the *Sun Oil Company*. It provides the following communication facilities: (1) two voice frequency circuits assigned to party-line telephone service, (2) three voice frequency circuits assigned to private-line telephone work, (3) a one-party line teletype circuit, and (4) two communication circuits for v.h.f. drop-off communications with *Mid Valley's* two-way mobile radios. Additional circuits are available for additional requirements. The network includes 36 repeater stations, spaced 14 to 37 miles apart.

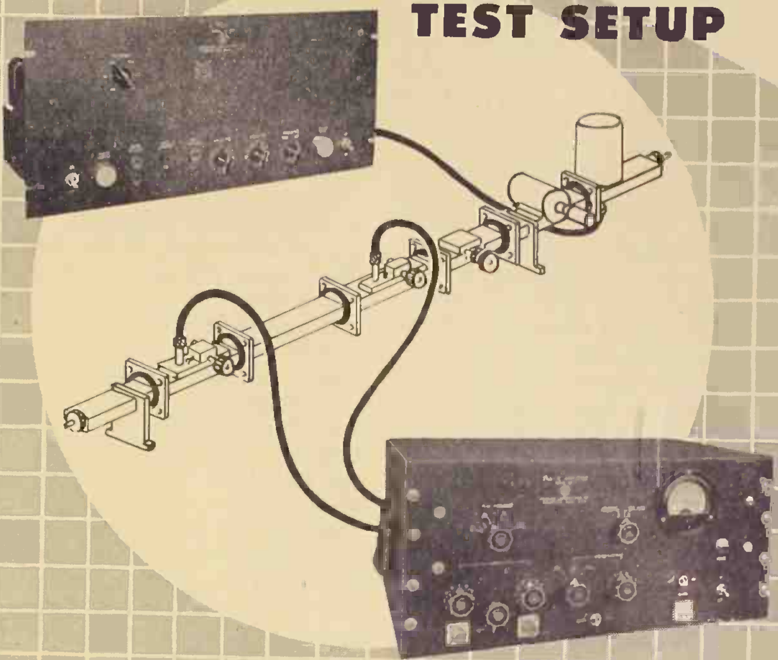
This system, as set up by *Motorola*, operates with a single antenna for both transmission and reception and with the 45° flat passive reflectors atop the towers. The radiating antenna and electrical equipment are placed on the ground and are easily accessible for servicing. The passive tower-top reflector, a special sheet of reinforced metal perforated to reduce wind resistance, has no cable, wave guide, or other electrical connections to the ground-level installation. The reflector requires no further adjustment after initial tower installation and orientation are completed. When the microwave beam strikes one of the 45° reflectors, it is directed downward to a 40-inch parabolic reflector at the base of the tower.

The beam is then amplified and re-transmitted from the second r.f. housing to the reflector above, and then sent on its way to the next relay station. This process continues until the beam and the signal impressed on it arrive at the terminal point or other desired intermediate station.

The type of repeater station used by *Motorola* is one in which demodulation of the actual audio components of the signal does not occur; instead, the signal is reamplified at the intermediate frequency used. Fig. 2 shows a typical 6875-mc. relay station which amplifies the 75-mc. i.f. voltage with modulation. At each relay station the transmitting frequency differs from the frequency of the carrier, on which messages are being received, by 120 mc. This prevents interference that would be produced if a portion of the transmitted signal were picked up by the receiver at the same station. It also allows for the use of a common antenna for simultaneous receiving and transmitting, a feature achieved by using quarter-wave space-type cavity separation filters.

On the *Motorola* system installed for the *Mid Valley Pipe Line Company*, the frequency bandwidth is 10 mc., and the subcarrier channels are continually multiplexed so that many messages or control circuit functions are transmitted simultaneously without mutual interference.

This *Motorola* equipment incorporates a double-frequency modulation system in which each voice input channel frequency modulates an individual subcarrier transmitter on a frequency in the 120 kc. to 1 mc. range. Each miniature plug-in subcarrier transmitter employs two double-triode tubes. The triode is a voice limiter, the second is an oscillator, the third is a frequency modulator, and the fourth is a cathode follower. The output of these subcarrier transmitters is collected into one video cable, which in turn connects to the transmitter klystron, to produce the modulating carrier. Wide-band deviation of ±5 mc. for 100% modulation is standard. At a relay point, a microwave demodulating unit equipped with a discriminator recovers the subcarrier frequencies. The video signal is then applied to modulate the transmitter directly, or it can be supplied to the subcarrier receivers for complete audio



detection at the terminal station. The subcarrier detectors employ conventional limiters and discriminators.

The majority of systems now being manufactured have provisions for duplication of all equipment at repeater stations. In case of a failure of any section or part of this equipment, automatic changeover to the standby equipment takes place immediately, and automatic signaling equipment sends back indications of the type of failure (such as tower light failure, transmitter failure, receiver failure, or power failure). In some cases the trouble report (plus a visual alarm) is actually recorded on tape, with the repair and change back also indicated. This gives an automatic, complete history of troubles as they develop on the relay systems. The use of automatic standby equipment should eliminate outages.

The systems described are typical of available systems although many changes in modulation, frequency control, antennas or power generation may occur. Microwave radio systems must now be considered an efficient and economical means of long distance point-to-point communication.

Microwave Antennas

(*Continued from page* 24)

bottom. Therefore the top and bottom may be removed completely and the effect of the lengthening of the guide wavelength will still be maintained.

In the parallel plate lens, advantage is taken again of the zoning mentioned in connection with the dielectric lens. The lens profile as shown in Fig. 7 is reduced each time a thickness is reached which is equivalent to a phase advance of one wavelength. A further increase of thickness would have the same effect as if the wavelength of thickness were removed and just the increase allowed to remain.

One of the most important advantages of the parallel plate antenna lens is its ability to withstand warping and twisting without the beam pattern or gain being seriously affected. If the lens thickness and plate spacing are correct, the lens may undergo as much as 30° angular rotation with very little effect on the beam produced.

In the case of a parabolic reflector, the contour of the reflector must be kept to within approximately a thirty-second of a wavelength of the desired dimensions to avoid serious effect on the gain and directional pattern obtained. This is particularly difficult in the case of short-wavelength, large-aperture reflectors. For a 3-cm. antenna, the allowable tolerance would be approximately one quarter of an inch. If the diameter of the parabolic reflector were on the order of ten feet, any attempt to limit the departure from a parabolic curve to one quarter of an inch would be difficult under wind stress, warping etc.

As mentioned previously, the use of a horn antenna eliminates the problem of spill-over. Use of lenses also permits the use of short horns which allow a better mechanical structure. The rigid lens aperture furnishes a rigid support for a dielectric cover, thus preventing the formation of ice on the antenna surface. Ice formations introduce losses and cause mismatches which reduce the efficiency of the system.

The parallel plate lens suffers from a bandwidth problem in that it is somewhat frequency-sensitive. In practice it has been found that the bandwidth is approximately 12 per cent with some small effect on gain and beam width. The bandwidth may be increased if the relative position of the feed and lens can be adjusted. If the frequency changes, it has been found that the point at which the energy is focused will vary; and if the feed positions can be changed, the bandwidth or useful frequency range may be increased.

The *metal path length lens* utilizes a principle that enables the elimination of the top and bottom of the wave guide used in the parallel plate lens. In this type of lens the top and bottom of the wave guide are retained, since they have no effect on the wavelength, and the sides of the guide are eliminated.

A wavefront will not be changed while passing through a wave guide with the sides removed because the electric field is perpendicular to the plates. Now, if the path is changed as shown in Fig. 3A, the path through the curved or serpentine set of plates must be longer than the straight line path above and below the plates, and the wave passing through these plates will undergo a delay relative to the wave passing above and below the lens plates.

If instead of the serpentine plates shown in Fig. 3A a series of tilted parallel plates is used, the same result will be accomplished. Figure 3B shows a tilted parallel plate lens. The path is longer for the wave arriving at the center than for the wave arriving at the top or bottom, with the result that the center wave is delayed and the top and bottom waves are not delayed at all.

A series of grid wires may be used in place of the solid plates in each of the lenses described above. If the wires are

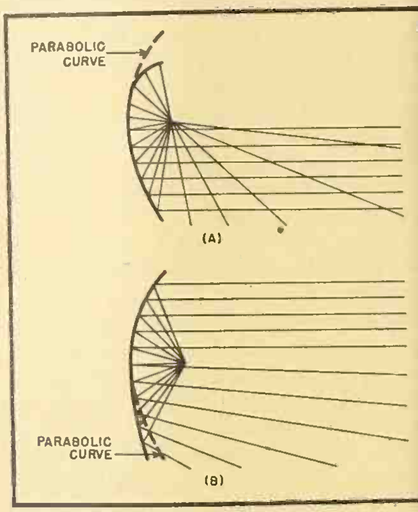


Fig. 6. Two methods of distorting a parabola to produce a fan beam.

placed less than a half-wavelength apart, the effect on the transmitted wave is the same as that of a solid plate. The wire grid is embedded in a polystyrene foam which is light and low-loss for microwaves.

If the path length type of lens is enclosed in a full shielded horn, the ens will be independent of frequency or frequencies higher than the second mode frequency. It therefore constitutes an extremely broad-band antenna, an advantage which the parallel plate antenna lens does not possess. The tolerance in mechanical construction is even greater than in the parallel plate type. Since the lens principle is a function of the tilt angle, the plate spacing s not important as long as the second mode spacing mentioned before is not exceeded. Another advantage is that he plates need not be flat, provided again that the second mode spacing is not exceeded.

Radar Antennas

The parabolic and lens antennas described above have a pencil-shaped radiation pattern, that is, they are directive in both horizontal and vertical planes. This type of pattern is very desirable in gun directing radar sets where excellent resolution between close targets must be obtained.

While a pencil-like beam is very desirable for gun directing radar, it is not quite as useful in early warning or general search radar sets. For with this radiation pattern, a complicated and time-consuming procedure is required to scan both horizontal and vertical planes adequately. To simplify this problem of dual scanning a "fanned" beam antenna is used, that is, one which directive in the horizontal plane only. With this type of pattern, it is only necessary to scan along the horizontal plane.

Rather than review the multitude of radar antennas that have been used, it might be of greater interest to describe radar antennas that use shaped reflectors, because they will show the ways in which it is possible to vary a standard antenna in order to achieve special pattern. The antennas designed to accomplish this function of specially shaped beams are called shaped beam antennas. They distort the normal antenna beam pattern into some predetermined shape to permit shorter scanning periods.

For example, a shipborne antenna for surface search requires a narrow beam in azimuth so that it may resolve two close targets, but it also requires a wide vertical beam width so that contact may be maintained with the target even though the ship rolls and pitches. Thus, if the ship rolls while it is tracking a target, the wide elevation beam will enable the radar to illuminate the target and receive an echo from it.

In aircraft radar measuring height, a different beam shape is required for efficient scanning. The vertical or elevation pattern should be sharp to allow accurate and rapid elevation scan; however, the azimuth pattern should be wider in order to reduce the time required for azimuth sweeping. A broad azimuth pattern will allow the target to remain in the beam long enough for the height to be determined.

The beam for surface search by aircraft should be sharp in azimuth for the reasons given previously. In elevation however, an even illumination of the ground is desired. Even illumination requires that little energy be transmitted down from the antenna to the ground and that more energy be beamed ahead to the distant ground targets, so that echos returning from far targets and from targets below will have approximately the same intensity. This will prevent overloading the receiver from strong ground returns or sea returns. A similar pattern is usually desired for antennas designed for ground-to-air search. These patterns are called cosecant squared power patterns.

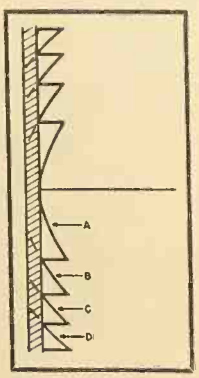
To produce beam shaping, the phase front and the intensity of illumination across an aperture may be varied. The aperture may be a wave guide or a series of dipoles in a line feed. Normally the radiation would be directed from a feed back to a reflector, and the reflector would focus the energy into a narrow beam. If the energy is deliberately defocused, it will be dispersed instead of being concentrated in a narrow beam. In order to defocus in one plane only, the point source may be extended to a line source or the reflector may be modified in some manner.

If an array of dipoles or horns is used instead of a point source feeding a parabolic reflector, the resulting beam pattern will be as shown in Fig. 4. The horns are usually fed in different phases and in different intensities to give a resultant pattern which is smooth and is made up of the individual patterns due to the four driving radiators. Such a beam is used by aircraft for scanning large ground areas.

If a point source is used instead of a line feed, a flared beam may be achieved by shaping the reflector. Two methods of achieving a shaped beam are shown in Fig. 6. In Fig. 6A, the top of the reflector is shaped to produce a flared pattern downward. In Fig. 6B, the bottom of the reflector is curved to produce approximately the same antenna pattern. In both cases the feed is placed at the focus of the section of the reflector that is parabolic.

Other methods may be used to obtain shaped beams for specific applications. These are primarily used in radar systems of various kinds, since most communication links require a narrow, pencil-shaped beam for point-to-point communications.

Fig. 7. Profile of "step" metal lens.



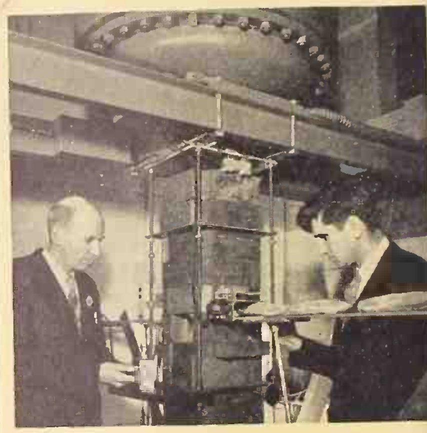
News Briefs

(*Continued from page* 38)

The Austin-San Antonio section is part of an over-all *Bell System* plant expansion program designed to give better and faster telephone service to residents in the Houston-Dallas-San Antonio triangle. A coaxial cable between Houston and Dallas was installed in October of last year, and the final link between Austin and Dallas, to be provided by microwave radio relay, is planned for early 1953.

HIGH SPEED STERILIZATION

For the past two years work has been under way at the *General Electric Company*, Schenectady, N. Y., on the use of high velocity electrons in destroying micro-organisms, with a view to eventually applying the process to the sterilization of food and drugs.



Through the use of a one million-volt x-ray unit, material is shot with an ionization dose of one million equivalent roentgen units in seven seconds at a distance of 10 cm. A dose of this magnitude is lethal for most molds and bacteria and, because the temperature rise is relatively small, the method has possibilities for the sterilization of temperature-sensitive materials, such as penicillin and blood plasma.

MOBILE RADIO PLANT

Establishment of a Mobile Radio Communications Department for a complete line of vehicular and railroad mobile radio equipment has been announced by *Federal Telephone and Radio Corp.*, Clifton, N. J. Under the new setup, all mobile radio operations, including the production of railroad radiotelephone equipment—an activity formerly handled by the *Capehart-Farnsworth Corporation* in Fort Wayne, Indiana—are centered in *Federal's* newly acquired plant in Passaic, N. J. thus integrating the activities of these two associates of *International Telephone and Telegraph Corporation.*

Microwave Index

Feature articles on microwaves which have appeared in Radio-Electronic Engineering.

Non-Communication

(*Continued from page* 13)

Two precision radar beams (operating at 3 cm.) scan the approach sector in azimuth and elevation. This is done with one radar alternately switched between elevation and azimuth antenna reflectors at a rapid enough rate to show up separately and continuously on the AZ-EL (cathode-ray azimuth-elevation indicator tube). They give the ground operator precision measurements of distance and lateral and vertical displacement of the airplane. By voice instructions to the pilot, the plane is controlled by the ground operator in such a way that it will follow an approach path corresponding to a line drawn on the maps on the face of the AZ-EL indicator.

Microwave Calorimetry

Figure 1 shows equipment resulting from a modern development that may have far-reaching effects in fields other than electronics. This unit is a microwave calorimeter which is designed to measure the true or absolute power of any microwave source, such as a radar transmitter, magnetron, etc. It consists of a device for circulating a specific amount of water through glass tubulation housed in a wave guide which terminates from a microwave power source. The water absorbs all of the microwave energy, and the water temperature is raised accordingly. By comparing the temperature difference between the water entering and the water returning from the water load or glass tubulation in the wave guide, power can be accurately measured without regard to its degree of continuity or peaked pulse rating.

Although designed for measuring microwave power by absorbing all the microwave r.f. power and converting it into heating of circulating liquid, the same apparatus with little or no modification may be used for sea water freshening research, blood studies, etc., by circulating such fluids through the system. It does this more by microwave spectroscopy rather than microwave calorimetry techniques, depending on the radar or microwave source which provides molecular resonance frequencies.

Microwave Spectroscopy

In microwaves, the shortcomings of the higher frequencies for one application may be of great advantage in other applications. The best example of this is in the region above 20,000 mc. where signals have high attenuation due to the presence of gases in the atmosphere which resonate at such frequencies and absorb power. This has resulted in the development of a microwave spectroscope.

When a gas such as ammonia is placed in a wave guide sealed with mica windows to prevent leakage (while still transparent to passage of microwave energy), certain specific frequencies are attenuated much more than the remainder. Microwave spectroscopy has provided excellent data regarding absolute intensity and the variation with pressure of the shape of the absorption lines of molecules. The intensity values are useful in identification while line breadth reveals information concerning intermolecular collisions and forces.

The common medium used in initial microwave spectroscopy setups from which research studies progress to other mediums and frequencies is the ammonia molecule, NH_3, which is a pyramid comprising a nitrogen nucleus at the apex and three hydrogen nuclei at the base. When this molecule is exposed to microwave energy at a frequency of 23,870.13 mc., (ammonia shows 12 absorption lines on specific frequencies between 20,000 and 40,000 mc.), the strongest absorption will take place—for the molecule then can turn itself inside out in the arrangement of its atoms. Power is absorbed in the process, and shows up as an absorption line in the spectrum.

Several microwave spectroscopy setups as used at the National Bureau of Standards are shown in Fig. 2. Similar setups are now in use in various laboratories and universities, principally in the physics and chemistry departments. A somewhat similar setup controls the famous NBS "atomic clock" which provides an accuracy of better than one second in thousands of years because the clock circuits are tied in with the stable absorption frequency of the ammonia molecule.

Some of the uses of microwave spectroscopy thus far have been in the

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nalysis of hydrocarbons to determine nteratomic distances, molecular strucure, molecular flexing and rotation, ne analysis of evaporated vapors of ecaying fruits and vegetables in orer to seek clues on ways of safeguardg against decay, and the study of quid dielectrics. However, the greatest se may yet develop in the field of edical diagnosis. As far back as 949, Dr. Sebastian Casalaina, who is onnected with a hospital at Spadra, alifornia, which provides for some 000 mentally deficient patients, sumarized the ways in which the phenomena associated with asymmetrical olecules such as ammonia might be pplied to evaluation of the various ormones in humans and animals.

Whereas the ammonia molecule has n average distance between its nitroen nucleus and each hydrogen nucleus f 1.01 Angstrom, and the average disance between the hydrogen nuclei is 63 Angstrom, the height of the pyramid being 0.38 Angstrom, the protein molecule such as a hormone is considered to be many times larger. Such a molecule is much more complex; over a hundred different atoms are linked together to form one molecule. The size, complexity and nonsymmetry of hormone molecules may show up in microwave spectroscopy if experiences to date have any meaning.

Hormones have specific effects on life functions, acting through the medium of blood on other parts of the body. Hormones are secreted by glands, excreted into the bloodstream and carried by the blood to all parts of the body. There is at least one type of hormone for each gland.

The field of microwave spectroscopy is of tremendous importance in innumerable types of research which will not stop until hundreds of thousands of different types of molecules have been studied up and down the microwave spectrum. Comparing the hormones of the various glands of humans in poor health with those of humans in good health as they exist in the bloodstream from glandular excretions may make microwaves a great factor in human health and medical diagnosis.

Erratum: The subheading in Table 2, page 20, of the April 1952 issue, in the article titled "Point-Contact and Junction Transistors," should be changed as follows: "Grounded Base" should read "Characteristics," and "Grounded Emitter" should read "Typical Operation (Grounded Base)."

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52 .... Wheeler Laboratories
55 ... Transcontinental Gas Pipe Line Corp.

COVER PICTURE (Page 1)

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2nd from top left ...... Microwave Development Lab., Inc.
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Bottom left........... Hewlett-Packard Co.
Top rt......... Bell Telephone Laboratories
Ctr. and bottom rt...... General Electric Co.