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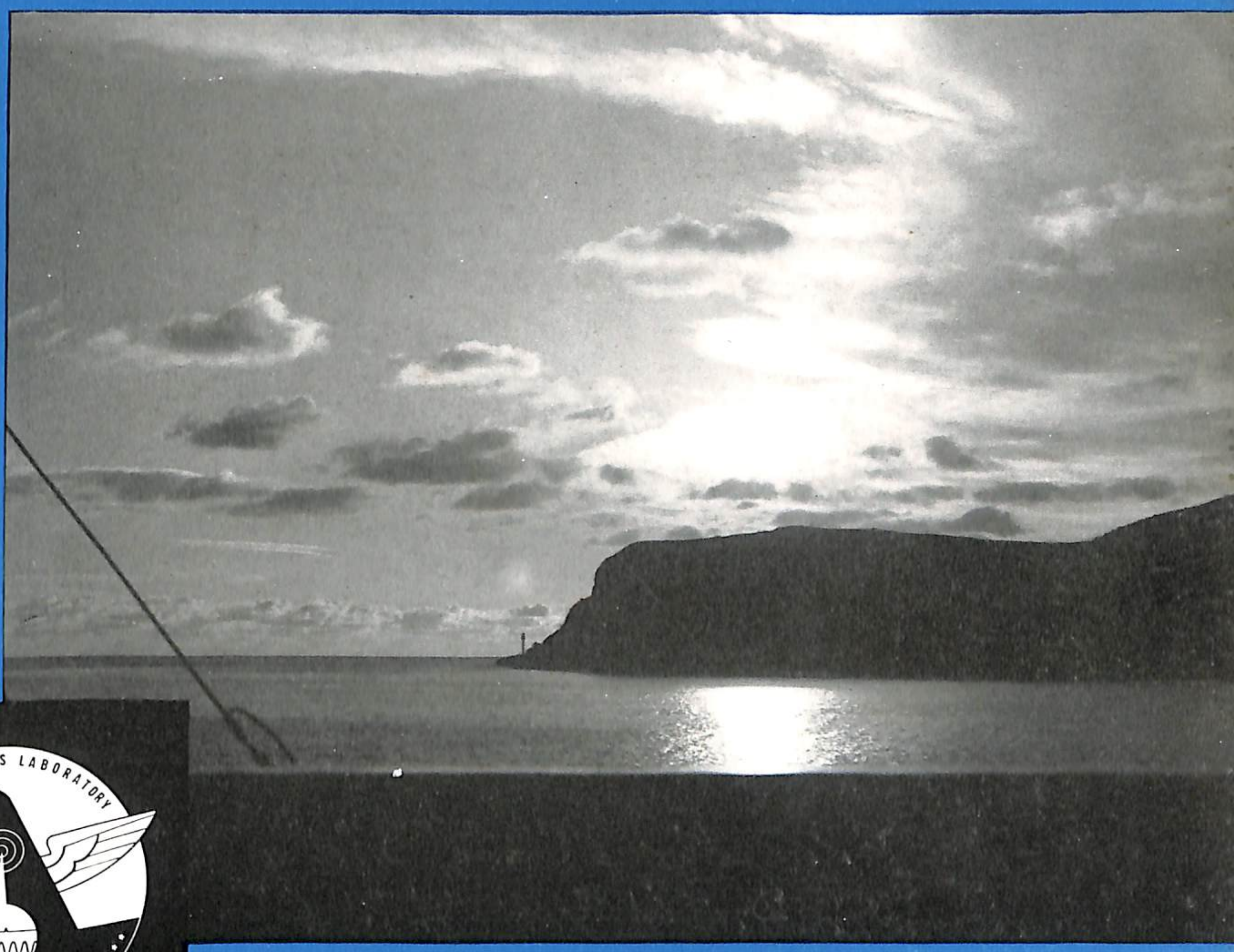
MAY 1948

BUSHIPS Electron



US NAVY ELECTRONICS LABORATORY

SAN DIEGO, CALIFORNIA

NavShips 900,100

Rear Admiral Charles D. Wheelock, U. S. N.

Deputy and Assistant Chief of the Bureau of Ships

Rear Admiral Charles Delorma Wheelock

U. S. NAVY

■ *Rear Admiral Wheelock, born in Riverside, California, July 28, 1897, attended grade schools in that city and Riverside Junior College for one year before his appointment to the U. S. Naval Academy in 1917.. While a Midshipman he served in the* USS MAINE *which operated with the Atlantic Fleet during World War I. Graduated and commissioned an Ensign in June of 1920, he was appointed Assistant Naval Constructor in the Construction Corps of the Navy with the rank of Lieutenant (junior grade) on June 23, 1922, and subsequently was promoted as follows: Lieutenant, February 6, 1926; Lieutenant Commander, June 30, 1936; transferred to the line of the Navy in that rank and designated for engineering duty on June 25, 1940; Commander, July 1, 1940; Captain, Otcober 3, 1942, to rank from June 20, 1942; and Rear Admiral, November 1, 1946.*

After graduation in June of 1920, Rear Admiral Wheelock served on the U. S. Rifle Team until September 1920. The following month he joined the USS PRAIRIE, *serving in that destroyer tender until May, 1921. He then had brief duty in the* NITRO *and* REINA MERCEDES *until August of 1921 when he reported for duty in connection with the Navy Rifle Team in Sea Girt, New Jersey. The following month he had similar duty at Camp Perry, Ohio.*

Rear Admiral Wheelock received instruction in naval construction at the Post-graduate School, Annapolis, Maryland, and continued that course at the Boston Naval Shipyard, the Massachusetts Institute of Technology, the Portsmouth Naval Shipyard, and received the Master of Science degree from the Massachusetts Institute of Technology in June, 1924. He then had brief duty under instruction in gas warfare defense at the Edgewood Arsenal, Edgewood, Maryland.

In August of 1924, Rear Admiral Wheelock reported for duty in the Industrial Department of the Puget Sound Naval Shipyard, Bremerton, Washington, serving until October, 1927, when he was transferred to duty in the Industrial Department of the Pearl Harbor Naval Shipyard. In March, 1930, he returned to the Puget Sound Naval Shipyard for duty in the Planning Division. From June, 1934, until September, 1936, he served in the USS DOBBIN.

Rear Admiral Wheelock reported in November, 1936, for duty in the Design and Construction Division, Bureau of Construction and Repair (later combined with the Bureau of Engineering and designated Bureau of Ships), Navy Department, Washington, D. C. For his service in ship design which extended to June, 1944, he was awarded the Legion of Merit with the following citation: "For exceptionally meritorious conduct in the performance of outstanding services to the Government of the United States, first as Assistant to the Head of the Contract Design Section and as Head of that Section, from the outbreak of hostilities to April, 1943; and subsequently as Head of the Design Branch of the Bureau of Ships from April, 1943, to June, 1944. Exercising unusual zeal, ingenuity, imagination and a rare combination of broad vision and keen perception of details, he profoundly influenced the design of new naval vessels as well as conversions and major alteration to vessels in service. In the field of warship design Captain Wheelock made many important contributions to the successful prosecution to the war."

Rear Admiral Wheelock was Production Officer of the Mare Island Naval Shipyard from July, 1944, until April, 1946, and for his services in that assignment received a Letter of Commendation with authorization to wear the Commendation Ribbon from the Secretary of the Navy. In May, 1946, he reported for duty in connection with the post-graduate course in naval construction and engineering at the Massachusetts Institute of Technology where he was made a Professor of Naval Construction and was placed in charge of the Institute's course in Naval Construction and Engineering.

On November 1, 1946, Rear Admiral Wheelock assumed duty as Deputy and Assistant Chief of the Bureau of Ships, Navy Department, Washington, D. C., in the rank of Rear Admiral.

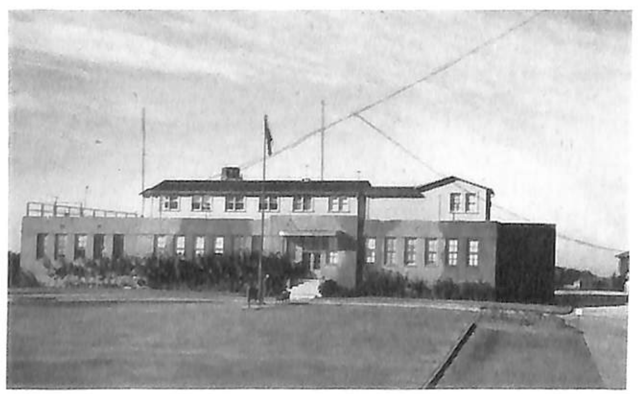
The U. S. Navy Electronics Laboratory

■ A major portion of the Navy's research, development, and systems planning in the field of electronics is carried out by the U. S. Navy Electronics Laboratory. Headed by a Naval officer, this is an organization composed primarily of civilian scientists and engineers aided by Naval officers and men. It is under the technical control of the Bureau of Ships, and its work program is largely determined by the scientific and technical problems assigned by the Bureau.

It is the function of N. E. L. to serve the Chief of the Bureau of Ships in the design, procurement, testing and installation planning of fleet electronic equipment. This is a broad responsibility. It requires work in theoretical science and basic research; in applied science from design up through production engineering; and in training for the operation and maintenance of equipment.

N. E. L. is located at San Diego, California. Its main group of buildings is situated high on Point Loma, some 400 feet above one of the busiest harbors on the Pacific Coast. A second group of buildings is on the waterfront adjacent to the channel leading into San Diego harbor. Here are located piers for mooring the laboratory's surface ships and its experimental submarine which carry the work in sonar and related projects out to and under the sea.

Many of the natural advantages that first brought the Navy to San Diego are particularly valuable to a research laboratory. The dry, equable climate permits uninterrupted outdoor tests and experiments during all months of the year. The weather is predictable yet variable enough to permit study of radio-wave propagation under many kinds of atmospheric conditions. The nearby harbors and the shallow continental shelf provide a wide variety of shallow-water conditions for the study of underwater sound transmission, and the development and testing of sonar devices; yet deep water, found in submarine canyons and oceanic troughs within a few hours run from the harbor, is more accessible than it is to any other major American laboratory.

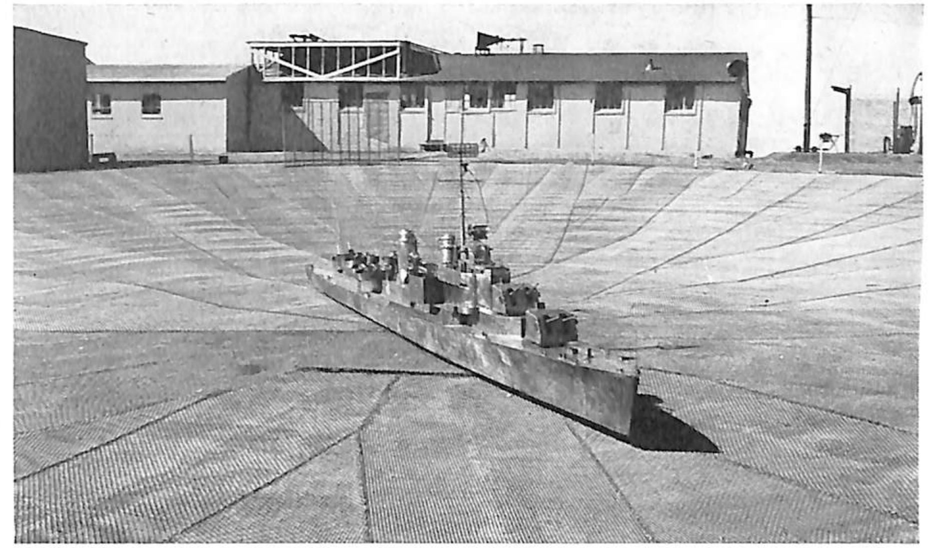


The Administration Building at N. E. L.

Dr. A. B. Focke

N. E. L. is the result of many years of planning by Naval scientists. Long before the outbreak of World War II, the Navy Department had realized a need for an electronics research laboratory with such natural facilities. Thus, in 1940, the Navy established a radio and sound research laboratory in the San Diego area. Throughout the conflict, the U. S. Navy Radio and Sound Laboratory, as it was designated, concentrated its skills on research and development in radar and radio communication. The work of this laboratory was co-ordinated with that of the University of California, Division of War Research, which was for the most part housed within the laboratory. When the university group discontinued its wartime studies along with other such university organizations over the country, its tasks were assumed by the Navy group which, in keeping with its increased responsibilities, was re-named the U. S. Navy Electronics Laboratory.

N. E. L. has been assigned many long-range projects. Among these is the antenna systems improvement program which is being carried out with the aid of scale-model ranges and ships. This subject was covered in recent issues of Electron.



The Navy Electronics Laboratory is organized under the leadership of a Naval officer who is directly responsible to the Bureau of Ships for the program of the laboratory. At present the Director is Captain Rawson Bennett, II. The progress of the work is directed by a civilian scientist, Dr. A. B. Focke, who is aided by a consulting staff. There are seven departments, five of which carry the burden of the scientific and technical efforts. The remaining two provide supply and administrative services.

Of the more than one thousand persons on board at N. E. L., one-half are professionally trained men and women—physicists; mathematicians; electronic, mechanical, and chemical engineers; all with their technical assistants. The other half of the staff is made up of supporting personnel, such as draftsmen, photographers, machinists, and maintenance and administrative groups.

Plans had been set up for several years future work when, in 1946, the Bureau of Ships assigned the laboratory a new list of problems and projects. These assignments are broad; they indicate a need for extensive work in a number of fields. They call for a long-term program of systems engineering—the study and improvement of all the electronic equipment on a single ship or class of ships. They call for a continuation of the wartime job of developing, modifying, and testing radio and radar communications equipment developed by this and other laboratories. They call for an extended program of studies of wave propagation—of the transmission of electromagnetic waves in the atmosphere and sound in the ocean. They call for the continued development collateral to the major research program of the Underwater Sound Laboratory at New London as well as of training aids. They also call for assistance to local training activities, to fleet units, and to other Navy research activities.

These programs are obviously far-reaching. They touch on all phases of electronics, with primary interest divided between the work in radio and radar, and work in sound and sonar. They also reach, however, into a considerable number of allied fields—in basic physics, mathematics, geology, geophysics, meteorology, marine biology, psychometrics (psychological tests and measurements), acoustical psychology, electrical, mechanical, and electronic engineering, and many others. The work in these fields is highly varied, ranging from basic research, through applied research and development, to equipment procurement and training of operators. The great bulk of the work, is of course, on radio and radar.

Space in this issue does not permit a thorough survey of all of the multitude of interesting projects under way at the U. S. Naval Electronics Laboratory. It is planned, however, that a future issue of Electron will bring to its readers a comprehensive inside story on this fine laboratory and its far-reaching projects.

Shorting the Indicator Unit Interlock Switch of the Model BN . . . . . .

After the indicator unit of the Model BN IFF Interrogator Responsor has been serviced, it is often desirable to make certain adjustments and tests, and to observe the interior of the equipment while it is in operation. In order that these tests and observations can be made the chassis must be completely removed from its case, a shorting bar must be inserted into the interlock switch, and then the chassis must be replaced in its case. It is necessary to disconnect all coaxial and cable connections to the indicator unit terminal boards in order to remove the chassis, and to reconnect all coaxial and cable connections in order to operate the unit for test purposes after it has been re-inserted into its case. After the tests are completed, this entire operation must be repeated in reverse order before normal operation may be restored.

This method of shorting the interlock switch not only consumes considerable time, but, in the case of indicator units installed in gun directors, also puts the serviceman at a considerable mechanical disadvantage and strain. The cramped quarters encountered seldom permit the proper application of the rules for handling heavy weights efficiently.

An alteration to the indicator unit that will permit easy shorting of the interlock switch, has been suggested by Mr. Maurice Gowdey of the Puget Sound Naval Shipyard. The bureau of Ships has approved this alteration as a servicing aid since it can be accomplished by ship's force without the issuing of any additional material or funds.

The detailed procedure is as follows:

1—Install a two-pole single-throw toggle switch in a suitable location inside the equipment. A suitable switch (S-252) may be drawn from spare parts (Item No. 213).

2—Install a red indicator light, similar to I-251, at a suitable observation point, to indicate when Interlock Switch S-251B is being bypassed.

3—Wire one side of the new switch (S-260) in parallel with Interlock Switch S-251B as shown in Figure 1.

4—Wire the other side of the new switch (S-261) in series with the new red indicator light, as shown in Figure 1. Power for the new indicator lamp can be taken from the 6.3-volt filament circuit which supplies Power Indicator Light I-251.

5—The new switch and the new indicator light should be labeled "Interlock Bypass Switch" and "Interlock Bypass Indicator", respectively.

6—As a safety measure, it may be desirable to mount the new switch on an angle bracket on the back top side of the chassis, with another angle bracket so mounted on the top of the case that the new switch will be closed automatically when the chassis is slid back into the case. This arrangement is shown in Figure 2. The switch and bracket should be mounted sufficiently far from the edge of the panel not to interfere with any flange or projections on the inside of the case, when the chassis is withdrawn from the case.

After this modification has been completed, the chassis can be partially withdrawn, necessary work can be performed, tests can be run, and the equipment can be observed in operation—all without going through the lengthy and laborious procedure outlined at the start of this article. This modification can be accomplished easily and economically, without altering existing equipment wiring, by merely adding the switch, light and associated connectors.

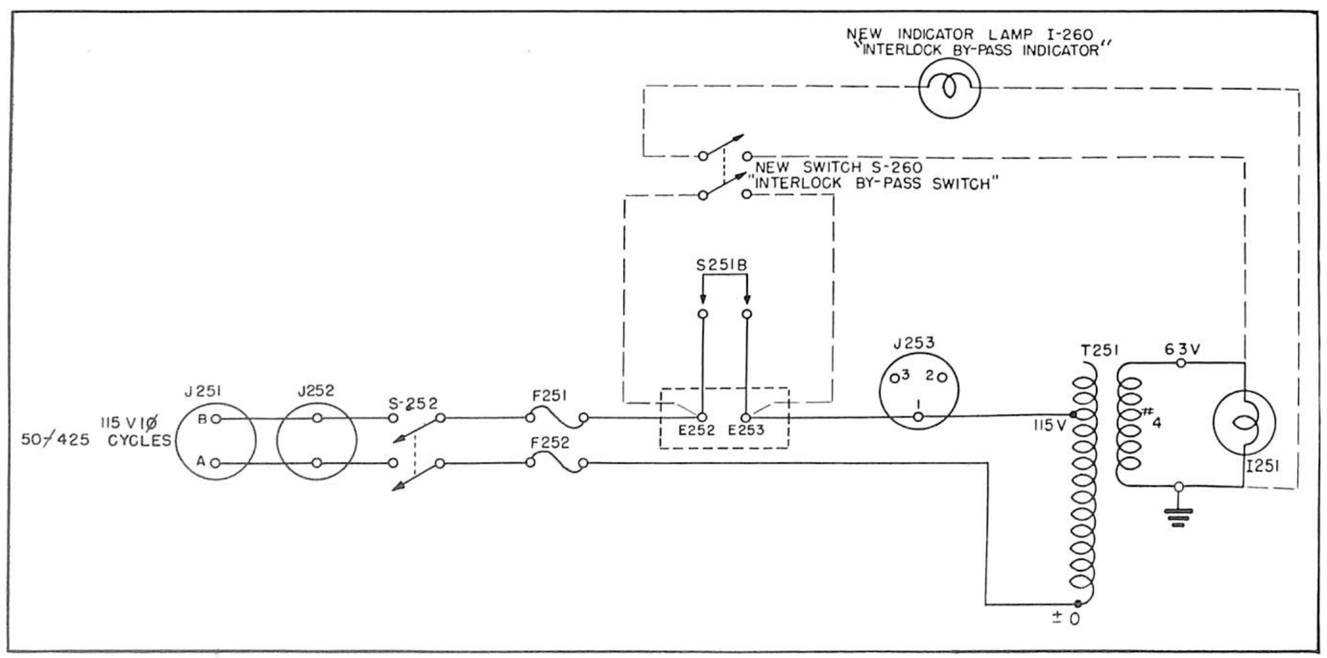


FIGURE 1—*Diagram showing wiring of the new switch and indicator lamp in the indicator unit of the Model BN Interrogator Responsor.*

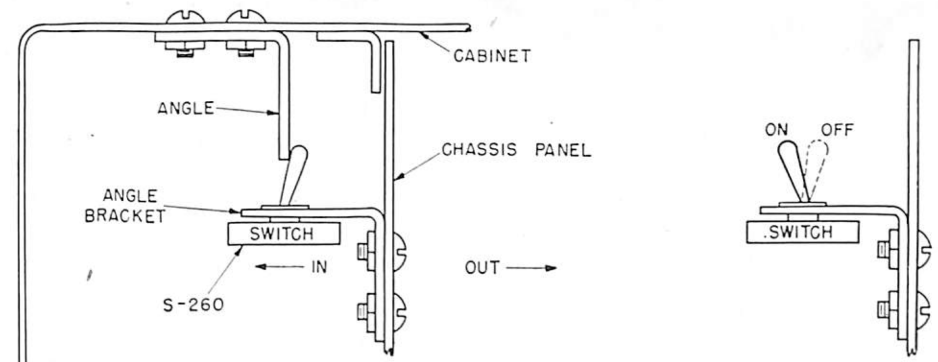


FIGURE 2—*Plan view of chassis, case, switch and angle brackets. On the left, chassis in case and switch automatically off; on the right, chassis out of case and switch either on or off.*

Type of Approach	Last Month	To Date
Practice Landings	8,089	99,219
Landing Under Instrument Conditions	306	4,977

SHANGHAI HEARD FROM

G.C.A. scores again, this time in China. With a ceiling of 20 feet and visibility limited to one-eighth mile, Pilot L. S. Leong, of the China National Aviation Corporation, brought his C-47 and eighteen passengers to a safe landing by aid of the G.C.A. unit at Shanghai. When he landed, he had only ten gallons of fuel remaining in his tanks.

Local officials were very much impressed with this exhibition of material perfection and teamwork.

Pilot Leong had had no previous experience with G.C.A. landings.

ADDITIONAL LOUDSPEAKERS

An additional quantity of 5000 type 49546 loudspeakers are being furnished under contract NObsr-39331. These speakers are physically and electrically similar to the speakers supplied under contract NXsr-55603, the only difference being in the type of volume control. The same installation and operation instructions apply to both, and the component parts are directly interchangeable.

VACUUM TUBE FAILURE TERMINOLOGY

Each pad of Electronic Equipment Failure Report Cards, NavShips 383 (Rev. 3-47), is interleaved with notes which, if followed, will help personnel prepare better and more complete failure reports. If a tube failure is being reported, the column in the report headed TYPE OF FAILURE refers to Note 7. This note reads as follows:

"7. Select appropriate *number* from table below to describe *type of tube failure.* (This permits analysis by tabulating machine.)

(1) Gassy.	(12) Loose elements.
(2) Air leak.	(13) Loose base.
(3) Open filament.	(14) Broken base.
(4) Low emission.	(15) Broken glass.
(5) Intermittent short.	(16) Glass strain.
(6) Permanent short.	(17) Result of component failure.
(7) Arcing.	
(8) Noise.	(18) Other (specify in remarks).
(9) Microphonic.	
(10) Poor focus (CR).	(19) Normal life.
(11) Screen defects (CR).	(20) Unstable operation."

To help technicians in the field recognize these various types of failures and differentiate between them, the Electronics Division has prepared a brief description of what is meant by each of these terms plus two new ones that have been added—"(21) Overload." and "(22) No Oscillation."

(1) Gassy. Excessive gas content is indicated (except in mercury-vapor and other gas tubes) by a pink or blue glow within the envelope and excessive plate and screen current, when plate or screen voltage is applied.

(2) Air leak. If the vacuum is completely lost, the filament will burn up and produce a cloud of gray smoke when filament potential is applied. (Caution: Do not confuse this condition with the symptoms described under "(16) Glass strain.")

(3) Open filament. The filament may be fractured due to excessive vibration or shock, or burned out due to excessive voltage or evaporation of material during long use.

(4) Low emission. This is indicated by low plate current, and the fact that a substitute tube performs normally in the same socket. This condition is usually the result of long use. In tubes having thoriated filaments, it can result from overloads or gas, and frequently can be corrected by reactivating the filament by applying a ten percent excessive filament voltage, with no other voltages applied. Since detailed procedure varies for different tube types, no details can be given here.

(5) Intermittent short. This can be indicated by unstable operation, excessive current, or intermittent sparking within the tube. (Note: This is primarily applicable to tubes used in receivers.)

(6) Permanent short. Excessive currents, causing protective devices to trip.

(7) Arcing. This occurs mostly in high-voltage devices, such as rectifiers and transmitting or magnetron tubes, operating with potentials above 1000 volts. It can also be caused by flash-backs in mercury-vapor tubes.

(8) Noise. This is indicated by noise in a receiver, or "grass" or "flutter" in a cathode-ray tube presentation. This noise can be prolonged by tapping on the tube.

(9) Microphonic. This condition is indicated by a howl in a receiver, caused by mechanical vibration or acoustical feedback, such that it can be prolonged or increased by tapping on the tube.

(10) Poor focus (CR). This applies to cathode-ray tubes and is evidenced by a wide spot or baseline which can not be corrected by adjustment of controls. Controls are assumed to be operating normally.

(11) Screen defects (CR). This applies to cathode-ray tubes and is evidenced by burning of the screen or loss of light output in the "used" areas. Burned areas appear darker than surrounding areas when tube face is viewed under normal light.

(12) Loose elements. This condition can be recognized by shaking the tube, and is caused by poor welding and similar faults. (Caution: Loose particles within the tube do not always affect tube performance, especially when they are within the base and outside the vacuum.

(13) Loose base. Determined by inspection.

(14) Broken base. Determined by inspection.

(15) Broken glass. Determined by inspection.

(16) Glass strain. This is a result of improper annealing during the manufacture of the tube, and causes the glass to crack for no apparent reason in smooth straight lines which usually completely or partially encircle the tube. In contrast to this, glass breaks due to shock are usually jagged.

(17) Result of component failure. A tube failure may be the result of a failure of an associated component, such as a blower fan, a capacitor, a resistor, or the result of a change in circuit conditions such as loss of bias voltage, disconnection of an antenna, or detuning of a load circuit.

(18) Other. Specify details in column on card headed "Nature of Failure and Remarks."

(19) Normal life. A tube has reached the end of its normal (or useful) life when it no longer meets minimum performance standards as indicated either by a tube tester or by a performance test.

(20) Unstable operation. This condition is indicated by erratic tube performance, and may be caused by excessive circuit voltage or current fluctuations, improperly tuned circuits, operation of tube under conditions which exceed maximum rated values, and the like.

(21) Overload. This is evidenced by excessive heating, due to failure of other circuits.

(22) No oscillation. This applies to tubes used as oscillators, and can be caused by a tube, component or circuit failure.

EVOLUTION OF THE MODEL JT SOUND RECEIVING EQUIPMENT

■ The model letters JP were originally assigned to a directional sound receiving equipment using a magnetostriction circular-shaped hydrophone supported and trained by a D-2 training system. This equipment was primarily designed for use aboard small patrol craft while on station (at rest). The development of the Models JP-1, JP-2, etc. semi-directional sound receiving equipment for submarines followed in order to provide top-side low-frequency listening. In these equipments the hydrophone was changed from the "ring" type to a line type.

These submarine Model JP equipments which originally operated in the 100- to 12,000-cycle frequency band, were later modified and changed to the Model JT. This was done by the addition of certain units which increased the maximum operating frequency to 100 kc, and provided a better means for obtaining bearing accuracy through the use of RLI (right-left-indicator) circuits and amplidyne power train control.

The identifying letters JP were eliminated by the modification of the equipments to the Model JT, and proper identification can be obtained from the new JT nameplates which were provided at the time of the changeover. In order to standardize the nomenclature used in reporting shipboard inventories of sonar equipments, all personnel are requested to refer to the Model JT Sound Receiving Equipment only by its Navy model letters JT and the proper equipment serial number. Such designations as JP/JT, JP-1 and JT, JP-2/JT, JT-1, JT-2, etc., are not to be used.

OZONE IN THE EARTH'S ATMOSPHERE

■ Predictions of weather, ionopheric disturbances, and radio transmission conditions may be improved as a result of measurements now underway under the cognizance of the National Bureau of Standards. It is well-known in scientific circles that a direct correlation exists between the latitude of a point of observation and the season of the year, on the one hand, and the concentration of ozone in the earth's atmosphere, on the other. The series of tests are for the purpose of finding out whether there is a corresponding correlation between ozone concentrations and current weather conditions. The ozone, a gas which is a form of oxygen (except that each molecule consists of three atoms of oxygen instead of the two which occur in a molecule of ordinary oxygen), is diffused throughout the atmosphere at heights up to approximately fifty miles. The greatest concentration seems to lie at a height of fifteen or twenty miles. Since the ozone, it is believed, is produced from the oxygen of the air by the action of ultra-violet rays in sunlight—the same rays that produce the ionization in the ionosphere several hundred miles up—a correlation may be expected between ozone concentrations and ionospheric conditions. The latter greatly influence long-distance radio transmission, as is well-known, leading to varying degrees of multiple reflection of radio sky waves between earth and ionosphere—and hence fading of radio signals. Just how useful ozone concentration measurements will be in predicting radio propagation disturbances remains to be seen, of course.

The tests, which are being conducted in the Organ Mountains of New Mexico, will also serve as a check on ozone concentration data obtained during V-2 rocket flights at the White Sands Proving Ground.

The data on ozone concentration is obtained by measuring the spectral energy distribution and intensity of sunlight in the ultra-violet region from about 2900 A to about 3400 A. Sunlight is greatly affected by the presence of ozone, which is markedly absorbent in this region. Knowing the spectral distribution and intensity of sunlight before it penetrates the earth's atmosphere, the observer may calculate the ozone concentration by taking measurements on the sunlight after it has passed through the atmosphere and reached the earth. Data is obtained in the desired u-v band by using calibrated optical filters passing radiation above 2900 or 3100 A, in combination with a calibrated photocell sensitive to wavelengths below 3400 A.

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Introductory Concepts to MICROWAVES

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This article is reprinted from the catalog of the firm of De Mornay Budd, makers of microwave test equipment and special waveguide fittings. Its study will lead to a better understanding of microwave peculiarities and techniques, and will add another bit of worth-while knowledge to the store already retained by our technicians and engineers.

Some of the concepts described here are complicated and may at first seem difficult to grasp. It is hoped, however, that all personnel engaged in work involving microwaves, such as radar maintenance, make a concerted effort to dig out of this article the real good that is in it.

INTRODUCTION

Microwaves are the shortest wave lengths or highest frequencies employed in radio communication, detection and navigation. Although considerably longer than the wave lengths of light, these waves are recognized to possess many properties commonly found in the optical region of the electromagnetic spectrum.

The subject of microwaves has long held great interest both in pure and applied fields of science. It has taken a half century after Hertz's discoveries for these microwaves to be put to practical use. This delay was due to the lack of the necessary technical tools. These tools comprised new types of vacuum tube design and behaviour, waveguides, cavities and a sufficient understanding of transit time and reactance problems associated with super-high-frequency alternating-current phenomena.

The magnitude of the research and development involved in bringing microwaves to their present state of development has been made possible only through the joint cooperation of governments, universities and industry operating under the pressure of World War II. During this period, progress has been made in individual years that, under normal conditions would have taken a similar number of decades. Approximately three billions of dollars were spent for microwave developments and applications (principally radar) during this time by the United States alone.

In microwaves, the engineer and the physicist have truly closed the gap separating their respective endeavors. The engineer reached microwaves by the development of equipment and techniques involving a reduction in wave length from thousands or hundreds of meters down to centimeters or millimeters. The physicist reached microwaves by coming down in frequency from the spectrum of light. Conversely, the engineer had to explore much higher frequencies while the physicist had to explore much longer wave lengths. Both have been limited by the development and availability of suitable electron tubes for the actual generation of frequencies between 300 and 30,000 megacycles. They also had to develop an entirely new line of transmission and measuring equipment, popularly called "microwave plumbing."

MICROWAVES vs. MEDIUM FREQUENCY CONCEPTS

For the engineer and technician whose past radio experience has been largely confined to the very-high frequency band or below, microwaves are unique in many respects.

At low frequencies, inductance and capacitance are almost exclusively "lumped," while at the microwave frequencies they are almost exclusively "distributed." This is a basic difference. It is true because at low frequencies, the physical dimensions of inductors and capacitors are very small as compared to the wave length, while at microwave frequencies the physical dimensions of any circuit component are comparable to the wave length.

Consequently, no capacitors or inductors, as known for low frequency techniques, are employed. Instead, inductive and capacitive effects are obtained by direct action on the magnetic and electric fields through the use of special structures or components.

Another basic phenomena is the skin effect which confines all the current to the surface of a good conductor. This makes it possibe to propagate energy through a hollow pipe without radiation to the exterior and to use resonant cavities in place of LC resonant circuits.

The wave lengths involved for microwaves may, in practice, be as short as one centimeter (0.4 inch) or less, while the frequencies attained may be as high as 30,000 megacycles or more. The high a-c frequencies involved in microwave operations, if used with lumped inductance or capacitance as on low or medium frequencies would create prohibitive conditions because:

1—Any inductance or conductor, despite its ideal path for the passage of d.c., increases in reactance with increase of frequency to the point where it behaves like a virtual insulator or extremely high resistance. This is in accord with the formula for inductive reactance (X_L):

$X_L = 2\pi \times$ frequency in cycles $\times$ inductance in henries.

2—Any capitance or condenser, despite its ability to block the passage of d.c., decreases in reactance so as to effectively represent a virtual short circuit or very low resistance to the passage of a.c. at ultra- or super-high frequencies. This is in accord with the formula for capacitive reactance (X_c), namely:

$$X_c \text{ (in ohms)} = \frac{1}{2\pi \times \text{frequency in cycles} \times \text{capacitance in farads}}$$

3—The total reactance (X) would be of very high order, made up almost entirely of that attributed to inductance. The reactance of any series circuit is equal to the inductive reactance subtracted by the capacitive reactance, thus:

$X = X_L - X_c$

(all expressed in ohms).

4—The Q or ratio between ratio of energy stored to energy dissipated becomes of a very high order. If we were to consider the Q or ratio on the basis of a-c resistance divided by d-c resistance, an infinite value might develop. Except as the band width may be affected by modulation, high orders of Q convenient to develop on microwaves make possible such practical advantages as: (a) Signals of greater selectivity; (b) Concentration of the over-all transmitted power or received responses into a very narrow band of frequency spectrum rather than distribution over a wider band; (c) Employment of receiving equipment with a much narrower band pass, thereby permitting improved signal-to-noise ratios; (d) Utilization of increased amplification in the receiver because of higher signal-to-noise ratios. This improves intelligibility, sensitivity and range.

5—The new concept for the Kennealy-Heaviside layer and the earth, used in long range radio communication, is that it represents "Nature's wave guide." Microwaves artificially and much more ideally simulates this condition by means of wave guides, which are in reality hollow rectangular or cylindrical pipes.

6—Whereas the general concept is that d.c. or low radio frequencies utilize the cross section of a conductor for the transmission of electrical energy, this becomes increasingly untrue as the a-c frequency is increased. The current actually tends to confine and utilize only a path which is closer and closer to the surface until, in the case of microwaves, the bulk of the current actually travels within the first few millionths of a meter thickness of the conductor. This is known as *skin effect*. A conductor which because of its cross section has negligible resistance for d.c. or low frequencies behaves as if it was of a much smaller gauge for the passage of microwave a-c frequencies. Measurable parameters in low frequency work are voltage and current, whereas at microwave frequencies, the parameters are the *voltage standing-wave ratio* (v.s.w.r.) and positions of voltage maxima and minima. To minimize the losses resulting from skin effects, microwave components are either gold or silver plated. Gold plating also safeguards against corrosion.

NUMERICAL ANALYSIS OF THE MICROWAVE REGION

Microwaves are generally considered to be the region of the frequency spectrum above 300 megacycles in frequency or below 1 meter in wave length. In the absence of a standard nomenclature for the frequency above, or the wave length below, microwaves, the region between microwaves and infrared may be known as "ultra-microwaves."

The Federal Communications Commission in the United States has designated the frequencies between 300 and 3000 megacycles as the ultra-high-frequency band (u—h—f) while frequencies between 3000 and 30,000 megacycles have been designated as the super-high-frequency band (s—h—f).

Microwave radar developments during and after World War II resulted in the need for a more detailed break-down in the microwave spectrum that more closely corresponded with the standard components adopted for general use. Although additional letters are occasionally used to indicate certain frequency regions, the following designations are rather generally used.

TABLE I—*Letter designations of r-f bands*

Band	*Frequency (in Mc)*	*Wave Length (in cm)*
P	225 to 390	133.3 to 76.9
L	390 to 1550	76.9 to 19.37
S	1550 to 5200	19.37 to 5.77
X	5200 to 11,000	5.77 to 2.75
K	11,000 to 33,000	2.75 to 0.909

The radio spectrum is dominated, so far as opportunity and channel space are concerned, by the microwave region. This is apparent from table II.

NUMERICAL ANALYSIS OF THE ELECTRO-MAGNETIC SPECTRUM

Although the microwave spectrum has abruptly increased the available frequency spectrum 100 times within this decade, it still represents an infinitesimally small part of the electro-magnetic spectrum which remains to be explored and developed.

New units of wave length need to be employed in order to discuss the spectrum with reasonable convenient numbers. Prior to World War II, the "meter" was the principal unit used to indicate wave length. The development of radar during World War II made the "centimeter" a common word for expressing wave length. In the future, millimeters, microns, milli-microns and finally angstrom units will necessarily be employed. The units which may be encountered and their dimensional relationships are tabulated as in Table III.

The corresponding dimension and frequency in kilocycles which a wave length in each of the above units would represent are shown in Table IV.

James C. Maxwell, the Physicist, predicted in 1865 that a varying electric or magnetic field should propagate into space and produce a noticeable effect at a distance. He set forth the theory that light is an example of this kind of propagation, having a very high frequency and a very short wave-length. He claimed that exactly the same phenomena should also occur at frequencies much lower than light where they could be generated by experimental electrical devices. This was subsequently achieved on the ultra-high frequency portion of the microwave region by Hertz in 1887 and on medium or low frequencies by Marconi near the close of the same century. Since the available technical tools at the time consisted of crude spark gap techniques, Marconi found it necessary to move the art in the low frequency direction, away from microwaves or short waves, until the vacuum tube and its subsequent refinements became available in later years.

TABLE II—*Channel space in the radio frequency spectrum*

Wave Length Band in Meters	*Frequency Band in Kilocycles*	*Approximate Number of Kilocycles Per Meter Change in Wave Length*	*Approximate Number of Meters Per Kilocycle Change in Frequency*	*Official FCC Band Abbreviation (Frequency)*
Very Long Waves (Infinity to 10,000)	0 to 30	Below 0.1	Over 333	Very low (v.l.f.)
Long Waves (10,000 to 1000)	30 to 300	0.5	20	Low (l.f.)
Medium Waves (1000 to 100)	300 to 3000	5	.2	Medium (m.f.)
Short Waves (100 to 10)	3000 to 30,000	500	.002	High (h.f.)
Very Short Waves (10 to 1)	30,000 to 300,000	50,000	.00002	Very high (v.h.f.)
Ultra Short Waves (1 to .1) (microwaves)	300,000 to 3,000,000	5,000,000	.0000002	Ultra high (u.h.f.)
Super Short Waves (.1 to .01) (microwaves)	3,000,000 to 30,000,000	500,000,000	.0000000002	Super high (s.h.f.)

TABLE III—*Dimensional relationship in linear measurement*

Meter	*Decimeter*	*Centimeter*	*Millimeter*	*Micron*	*Milli-micron*	*Angstrom unit*
1 meter	10	100	1,000	1,000,000	1,000,000,000	10,000,000,000
.1	1 decimeter	10	100	100,000	100,000,000	1,000,000,000
.01	.1	1 centimeter	10	10,000	10,000,000	100,000,000
.001	.01	.1	1 millimeter	1,000	1,000,000	10,000,000
.000001	.00001	.0001	.001	1 micron	1,000	10,000
.000000001	.00000001	.0000001	.000001	.001	1 milli-micron	10
.0000000001	.000000001	.00000001	.0000001	.0001	.1	1 angstrom unit

TABLE IV—*Relationship of wave length to frequency*

Wavelength unit	*Equivalence in inches*	*Equivalence in Kilocycles*
1 meter	39.37″	300,000
1 decimeter	3.937″	3,000,000
1 centimeter	.3937″	30,000,000
1 millimeter	.03937″	300,000,000
1 micron	.00003937″	300,000,000,000
1 milli-micron	.00000003937″	300,000,000,000,000
1 angstrom unit	.000000003937″	3,000,000,000,000,000

The tabulation below covers the generally known wave lengths and frequencies of the entire electro-magnetic spectrum at this time. For average convenience, the wave length is given in centimeters and the frequency in kilomegacycles (millions of kilocycles or billions of cycles) based on approximate or rounded figures.

TABLE V—*Electromagnetic spectrum*

Region	*Wavelength limits (centimeters)* *maximum*	*minimum*	*Frequency limits (kilo megacycles)* *minimum*	*maximum*	*Remarks*
Radio	3,000,000	.1	.00001	300	v.l.f./l.f./m.f./h.f./ v.h.f./u.h.f./s.h.f./Exp.
Infra-Red	.1	.00008	300	375,000	Heat & black light.
Light (visible)	.00008	.000038	375,000	790,000	Starts with red, progresses through orange, yellow, green, blue and violet.
Ultra-Violet	.000038	.0000012	790,000	22,500,000	Chemical & invisible.
X-Rays	.0000012	.0000000006	22,500,000	45,000,000,000	———
Gamma Rays	.000000014	.0000000001	45,000,000,000	270,000,000,000	Radioactive.
Cosmic Rays	.0000000001	indefinite	270,000,000,000	indefinite	Little known.

THE DISPLACEMENT CURRENT

The usual conception is that a varying magnetic field is associated with a wire carrying alternating current. Conversely, a voltage is induced across the terminals of a wire which lies in, or is cut by, a varying magnetic field.

This is helpful in understanding the existence and propagation of electro magnetic fields, such as those covered by Maxwell's equations. These equations or laws, useful when worked by mathematics, are really nothing more than convenient brief descriptions of what is elementarily described in this section. Maxwell's laws or equations are applicable wherever currents and fields may exist. The theory that Maxwell evolved in 1865 prevails to this day. His equations are the most important, if not the only adequate means available in understanding and evaluating the theory associated with modern microwave techniques.

In the case of microwaves, it is necessary to develop a broader vision of the significance of Maxwell's equations. It is necessary to analyze the phenomena on the basis of wave guides and to cease thinking of a wire or coil. Instead, it is necessary to consider that a dielectric or empty space will be substituted for a wire or coil.

Since it may be difficult to conceive of a current without a wire or some metallic conductor to carry it, suppose we first consider a solid conducting wire where a current of "*i*" amperes is flowing steadily. Then, the magnetic lines of force will be closed circles in planes which are perpendicular to the axis of the wire. Biot and Savart's law states that the work done by a unit magnetic pole carried around the wire along the lines of magnetic force is numerically equal to the current in the wire. This law may be computed or written as follows:

$\int H\text{-dl} = i$

Where:

H is the magnetic field intensity vector or force acting up a unit magnetic pole. It is given in ampere turns per meter.

l is length in meters.

H-dl is the elementary work done by displacing the force *H* along the elementary path *dl*.

$\int$ indicates summation of all these elements of work around a closed path. The wire is considered in infinitesimally small parts or elementary paths since conditions are varying everywhere along its length.

Consider now, in lieu of a solid wire, the same wire with a short section of it removed, resulting in a small gap in its length. Now, the circuit would be open. By d-c conceptions, current can not flow in such a case. However, current *does flow*. It flows if the voltage between the two sections of wire is steadily increased or varied as in the case of an a-c voltage. The gap represents a condenser which the current is charging up. The capacitance of such a condenser (if the gap is narrow as compared to the cross section of the wire) is computed as follows:

$$C = \mathcal{E} \frac{A}{s}$$

Where:

C is the capacitance in farads,

$\mathcal{E}$ is the dielectric constant of the medium,

A is the area of the plates which in this case is the cross section of the wire in meters squared, and

s is the distance between the plates which here is the gap width in meters.

Charging a condenser therefore means changing the charge on its plates and thereby changing the electric field across the dielectric.

A magnetic field H must exist everywhere around the sections of the wire in order to satisfy Biot and Savart's law. Maxwell stated that the *same* magnetic field also exists around the gap so long as the current keeps flowing in the wire and the condenser is charging or discharging in accordance with the direction of current flow.

A changing magnetic field is associated with a changing electric field in the dielectric, just as it is associated with an alternating current flowing in a wire. So far as the magnetic field is concerned, it is the same thing to deal with an actual current flowing in a wire as to deal with a changing field in a dielectric. The dielectric may be either air, polystyrene, empty space, etc.

It can be said, therefore, that a changing magnetic field is associated with a *displacement current* in a dielectric which along with the magnetic effects of the usual a-c *conduction current* makes up the total magnetic field intensity. The conduction current exists when the wire is there to carry the energy. The displacement current exists when the wire is *not there* to perform this function. It is the displacement current which makes it possible to have energy in free space and in a waveguide.

Displacement current and conduction current are indistinguishable by their magnetic effects. In the case of conduction, there exists a conductor which has resistance losses with length. In the case of displacement current there is no conductor or wire to produce such losses. Instead, the losses are divided between the dielectric and the walls of the waveguide. These values are very much lower than for any practical wire at microwave frequencies. In microwaves, a wave guide consisting of a hollow pipe is an efficient transmission line.

Displacement current exists only in the presence of a time-varying electric field in a dielectric. The magnetic field varies also. This differs from a steady d-c conduction current which gives rise to a nonvarying magnetic field. It is experimentally found and theoretically demonstrated that the combination of varying electric field and varying magnetic field, which is called an *electromagnetic field,* has a tendency to propagate in the dielectric instead of remaining localized in the vicinity of the conductor. It is this tendency to propagate, which increases with frequency, that makes radio communication possible. The velocity of such propagation is dependent only on the medium, being equal to:

$$c = \frac{1}{\sqrt{\mathcal{E}\,\mu}}$$

where c is the velocity in m/sec,

$\mathcal{E}$ is the dielectric constant in Farad/m, and

μ is the magnetic constant in henry/m.

In the case of air or vacuum, c is 3×10^8 m/sec. The product of frequency by wave length is always equal to the velocity of propagation, so that $f\lambda = c$. This relationship between frequency and wave length makes it possible to find either one as soon as the other is known.

THE TRANSMISSION LINE AND STANDING WAVES

The conventional transmission line may be analyzed as a "return circuit" type. Transmission lines are used to conduct or guide electrical energy from one point to another. A wave guide is one form of transmission line.

In the case of power frequencies such as 60 cycles, the wave length is in the order of 5,000,000 meters long. At such a frequency, a transmission line 100 miles long would represent less than a twenty-fifth part of the wave length. In the case of microwaves however, such a transmission line length would be between 5,000,000 and 500,000,000 wave lengths long.

When power is fed to one end of any transmission line, the power which will be available at the other end will always be less. Furthermore this loss is greater than can be attributed to the line's ohmic resistance and the length of the line. Losses result from skin effect, dielectric losses and radiation. It may be described as being due to the displacement current which is the result of the capacitance existing across the line.

Specifically, a conductor has resistance and also inductance. When there are two separated conductors, there will also exist capacitance between them. A pair of separated conductors will also have resistance between them, since the distance between them is equivalent to a very high resistance (insulation such as air) which may be called shunt conductance.

All these factors give a two-conductor open line a characteristic impedance. This characteristic impedance is the impedance that is the ratio of voltage to current which exists across the input terminals of a theoretical line of infinite length. In radio applications, this may be some value between 50 and 600 ohms. Another type of two-conductor line is the coaxial type of line with a characteristic impedance of the same order as that of the two-wire line.

If wave guides are included under "transmission lines," the impedance has a much wider variation since it is a one-conductor transmission line. When the impedance of a wave guide is defined as the ratio of the transverse electric to the transverse magnetic field, it can vary between zero and infinity.

Anything that changes the ratio of the transverse electric field to the transverse magnetic field in the waveguide, or the ratio of voltage to current in a two-conductor line, will cause power reflection at the point of the change. The reflected power results in a wave traveling backwards from the reflection source to the generator. This wave is superimposed on the direct wave. When two waves are traveling on the same transmission line in opposite directions, they result in alternate points of high and low energy called *standing waves.* This is because the position of the voltage maxima and minima (as well as the position of current maxima and minima) does not change with respect to the point where the reflection occurs. The presence of standing waves on a transmission line is an indication that reflections occur somewhere along the line and consequently not all the power is delivered to the load. Part is reflected back and is therefore lost for the purpose of transmission.

If the change in impedance occurs at the load itself, the load will reflect back some power and will not utilize the whole amount of power conveyed to it. In this case, the load is *mismatched.* A well-matched load introduces no reflections and absorbs the total power delivered to it. A measure of the power lost by the load is the reflection coefficient K, ratio of reflected voltage to direct voltage. Another related quantity is the voltage standing-wave ratio (v.s.w.r.) which is the ratio of the voltage at the maximum point to the voltage at the minimum point.

An infinitely-long transmission line (something which can not exist in practice) will have voltage and current maximas and minimas occurring at identical points and will be in phase. The waves will be moving down the line and there will be no detectable standing wave ratio. An infinitely long line may be considered as terminated in its characteristic impedance. No standing waves will exist in such a line.

In practice, however, there is no such thing as an infinitely-long transmission line. Dimensions must be finite and usually a load is attached to the line. In this case, matching of the load can be accomplished by means of several types of matching devices. These substantially are such as to cause a reflection of opposite character to that of the load. If the two reflected waves have equal amplitude and opposite phase, they tend to cancel each other with the result that no reflected wave travels in front of the matching device. Thus, if the load is capacitive, the matching device should be inductive, etc. If the frequency is so high that a practical length of line can be made a substantial part of a wave length, capacitive and inductive effects can be obtained simply by varying the length of the line.

MICROWAVE TRANSFORMERS

The phenomena existing in a two-wire line or waveguide as its dimension is changed between zero wavelength and a quarter wavelength makes possible conditions that on lower radio frequencies always require specially provided coils, condensers, transformers, resistors and insulators.

Many or all of these components can actually be eliminated by taking advantage of the inversion, capacitive, inductive and transformation effects existing along some quarter wavelength dimension of an over-all half wavelength.

Figure 1 shows various effects or conditions possible to exist along a two-wire shorted or open line or waveguide by introducing a-c energy at one point and observing it at some subsequent point.

Typical effects or results which may be developed by use of such a transmission line of appropriate fractional wave length are:

1—Capacitance in lieu of a condenser.

2—Inductance in lieu of coils.

3—A series LC circuit behavior at a point midway between effects 1 and 2 above.

4—A parallel LC circuit behavior at a point midway between effects 2 and 1 above.

5—A step-up transformer by introducing energy at a point of low impedance and removing it at a point of higher impedance with a resulting auto-transformer effect.

6—A step-down transformer by suitable connection at points of low impedance or vice versa to condition 5.

7—An a-c insulator of conducting material by connecting to point of high impedance.

8—Any value of impedance between virtual zero and virtual infinity will exist somewhere along a quarter wave length section of two-wire transmission line or a waveguide pipe of either an open line or shorted line type. It merely requires suitable connection or probing at the correct point within the quarter wavelength dimensional length.

9—Conditions can be inverted by moving a quarter wavelength away from a previous condition.

10—Conditions may be repeated by double-inversion (two quarter wavelengths removed from these conditions).

Modifications or adaptations of the above listed phenomena or transformations can be utilized in innumerable ways to simplify microwave equipment, limited only by human imagination and ingenuity.

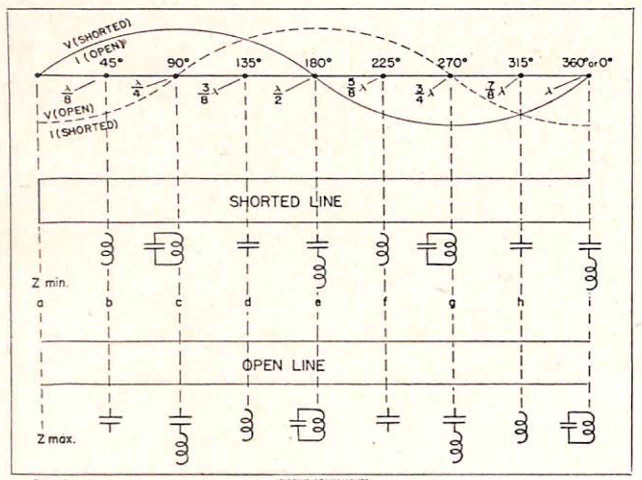

FIGURE 1—*Circuit Equivalents*

TRANSMISSION LINE INVERSION PHENOMENA

Figure 1 shows the circuit equivalents which actually exist in either a shorted or open two-wire line. The same reasoning applies also to a waveguide.

Eight conditions are spotted in this illustration. It should be understood that these conditions do not abruptly occur but gradually change from one condition to an adjacent condition as the distance is increased along the cycle. It should also be recognized that the entire cycle of events repeat themselves every half wavelength, even though it is shown as the opposite alternation of an a-c sine-wave cycle.

Assuming that we have two identical two-wire lines or waveguides, except that one is completely closed or shorted at one end, then the following conditions may be noted:

The solid sine-wave line is what the voltage will be for the shorted line and what the current will be for the open line. The broken or dotted sine-wave line is just the opposite, namely, what the voltage will be for the open line and what the current will be for the shorted line. Wherever the voltage is shown as minimum, or the current as maximum, then the impedance will be minimum or virtually zero. Wherever the voltage is shown as maximum, or the current is shown as minimum, then the impedance will be maximum or virtually infinite. The various values between minimum and maximum will be available for impedance, voltage and current at different points along the line as illustrated. It will repeat itself endlessly every half wavelength down the line. At the end of the cycle (360 degrees), the cycle repeats itself as if it were the beginning of the cycle (zero degrees).

The conditions illustrated may be summarized as in Table VI.

Thereafter: 1⅛ wavelength conditions for either shorted or open lines will be the same as at ⅛th wavelength. It will also be the same for 2⅛th, 3⅛th wavelengths, etc., and for other fractions of a wavelength plus some whole number of wavelengths.

Wavelength may be measured as a half wavelength between any two maxima or minima of either current or voltage. It may be further verified by taking readings at several such adjacent pairs of maxima or minima anywhere farther down the waveguide or transmission line. This will hold true for either a shorted or an open line.

TABLE VI—*Analysis of circuit equivalents depicted in figure 1*

Condition	*Shorted Line*	*Open Line*
"a" Zero degrees Zero wave length	1. Minimum impedance. 2. Minimum voltage. 3. Maximum current.	1. Maximum impedance. 2. Maximum voltage. 3. Minimum current.
"b" 45 degrees ⅛th wave length	1. Voltage and current are nearly equal. 2. Impedance is an intermediate value. 3. The circuit behaves like pure inductance.	1 & 2. Same as for shorted line but opposite in phase. 3. The circuit behaves like pure capacitance.
"c" 90 degrees ¼ wave length	1. Maximum impedance. 2. Maximum voltage. 3. Minimum current. 4. The circuit behaves like a parallel resonant circuit of capacitance shunted by inductance.	1. Minimum impedance. 2. Minimum voltage. 3. Maximum current. 4. The circuit behaves like a series resonant circuit comprising a capacitance in series with an inductance.

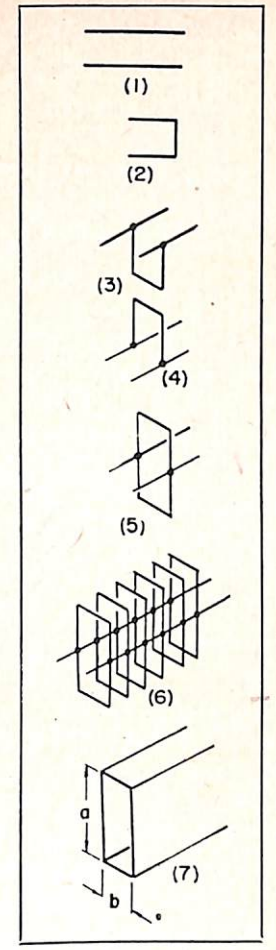

FIGURE 2—*Physical Concepts of a Waveguide*

PHYSICAL CONCEPT OF A WAVEGUIDE

A waveguide is the equivalent of a coaxial cable with the central conductor and supporting insulation spacing removed so that all that remains is a hollow pipe.

In practice, waveguides are hollow pipes, normally rectangular or cylindrical and fabricated out of material having good electrical conductivity.

Waveguides become increasingly necessary and finally indispensable for the transmission and propagation of radio frequency energy when the wavelength dimension is reduced to inches or even less as in the case of super high frequencies. This is particularly true when the distance between the central conductor and the inner sheath of a coaxial cable, for example, approaches the dimension of a quarter wavelength. At that limit, a coaxial cable becomes either impossible or unpredictable in actual practice. The radio frequency energy under such a condition takes complex or unpredictable paths other than down the longitudinal path provided by the central conductor. It may, for example, try to take lateral or semi-lateral paths as if the central conductor were the earth and the conducting inner sheath wall of the coaxial cable were an ionospheric reflecting layer. While it is conceivable that a set of conditions involving extremely careful dimensions and uniformity of the cable can permit the use of coaxial cable at super high frequencies, it becomes much more feasible and efficient to utilize simple waveguide pipe.

Figure 2 shows the physical detail concepts of a standard waveguide most commonly used in microwave work. The details are broken down into seven parts for easier understanding.

Part 1 illustrates two simple parallel wires or an open line.

Part 2 illustrates a shorted quarter-wave line comparable to that described for condition "c" in figure 1. Here it is to be used as an a-c insulator even though it is of electrically conductive metal.

Part 3 shows the same shorted quarter-wave line of Part 2 attached to and below the open line of Part 1.

Part 4 shows the same type and size of shorted quarter-wave line attached to and above the open line.

Part 5 shows parts 3 and 4 combined to form a closed metallic loop. The two-wire open line of part 1 can still function as heretofore, as the short circuits of the quarter-wave shorted lines are at opposite impedance as described for figure 1.

Part 6 shows a large number of similarly developed closed loops.

Part 7 shows an infinite number of closed loops, so many in fact that it became a solid pipe. The exact center of the "a" dimension for the larger side walls corresponds to the two wires shown in part 1. From the center upwards corresponds to quarter-wave a-c insulators shown in parts 2 and 4. From the center downwards corresponds to quarter-wave a-c insulators shown in parts 2 and 3.

Thus, an open line has become a solid pipe. The "a" dimension determines the lowest frequency which can propagate down the waveguide and still make longitudinal headway The "b" dimension determines the maximum amount of power which the waveguide can safely handle without flashover within the waveguide. It affects the characteristic impedance of the waveguide. The "b" dimension must be substantially less (usually a little less than half) than the "a" dimension to avoid any possibility of it usurping the latter's function as to cut-off frequency.

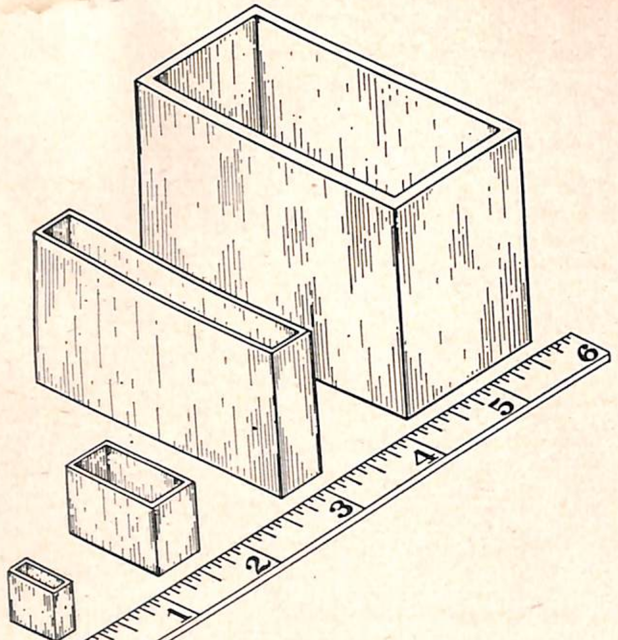

FIGURE 3

Figure 3 is a drawing of standard types of rectangular waveguide used on the so-called S band (3000 megacycles), X band (10,000 megacycles) and K band (about 30,000 megacycles).

ELECTRICAL CONCEPTS OF A WAVEGUIDE

An analysis of waveguide behavior is a three-dimensional study and is difficult to conceive by any single illustration. A conducting pipe can only serve as a waveguide if the electric field is zero at the supporting sides ("b" dimension) for the two reflecting surfaces ("a" dimension). More correctly, it may be said that the tangential electric field is zero at any (perfectly) conducting surface. This results in two possible conditions: 1—Zero electric field at the side walls, or 2—electric field perpendicular to the walls (top and bottom).

The development of the fields and resultant electrical behaviour in a waveguide can be shown in the following eight illustrations:

Figure 4a shows the electro-magnetic field in free space. A, B and C are wave fronts with the voltage distribution indicated. The two nodes (between A and B, and between B and C) are the zero points. The equivalent of sine wave distribution exists since "A" is indicated as maximum positive, "B" is indicated as maximum negative and "C" is indicated as maximum positive. "A" to "C" equals the wave length in free space. "A" to "B" or "B" to "C" equals a half wave length in free space. The direction of propagation is from "C" to "A" in the illustration.

Figure 4b shows the same field entering an open end of a waveguide. The dotted lines show various points along the wave fronts striking the wall of the waveguide at different points but at the same angle of incidence. The solid lines are the same points but at the angle of reflection. The angle of incidence is equal to the angle of reflection, or vice versa. "A" is the wide dimension of the waveguide which decides the lowest cut-off frequency or longest wave length which the waveguide can accept.

Figure 4c shows the same points of Figures 4a and 4b, reforming in the waveguide as wave fronts again. They are now split into two parts illustrated as "A[1]" (negative) and "A" (positive). This occurs because as each charge of the wave front strikes the wall of the guide and is reflected, it changes polarity. A condition exists where as each wave front is reflected, it reverses phase and reinforces the next similar polarity wave front. It is by this means that propagation in a waveguide is possible. Without the complex manner in which the charges of a wave front reinforce each other, wave travel along a guide would not be feasible.

The boundary conditions or dimension of the waveguide have now created a voltage distribution of the charges in the wave fronts. The charges cannot exist at the boundaries of the "a" dimension because of the condition that prevails. A positive and a negative charge occur simultaneously at the wall of the guide and cancel out. One charge is moving toward and the other away from the wall of the guide. Since it has been shown and Maxwell's equations state that there can not be any voltage maximum occurring at the boundary, it must be zero at the boundaries. If it is to be zero at the boundaries, then it will be maximum at the center or between the boundaries. This is a result of the moving charges cancelling and reinforcing each other. The cancellations occur less and less as the charges move towards the center of the guide until finally a maximum voltage condition exists.

Since the angle of the wave front in the waveguide is dependent on the "a" dimension, and since the wave which entered the waveguide was based on its wave length in free space, angle *alpha* has changed with respect to the angle of the wave front preparatory to entering the waveguide shown in figure 4b. It must now be based on the wavelength in the waveguide instead of in free space. Angle *beta* may be considered to be the angle of incidence while angle *alpha* is the angle of reflection Thereafter, the wave fronts reflect between the walls at the same angle as they travel down the longitudinal axis of the waveguide.

Figure 4d illustrates another type of portrayal showing how Maxwell's equations are heeded in a

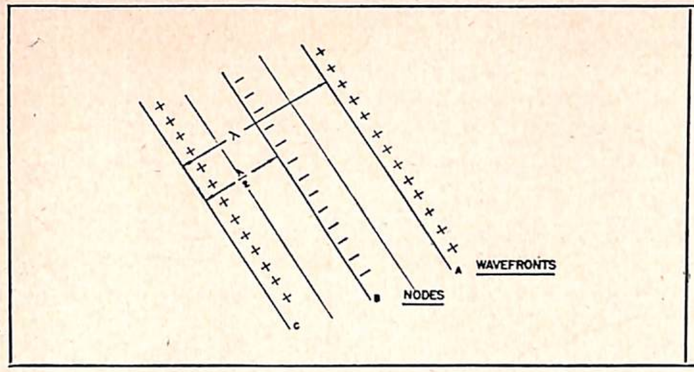

Figure 4a ELECTROSTATIC FIELD IN FREE SPACE

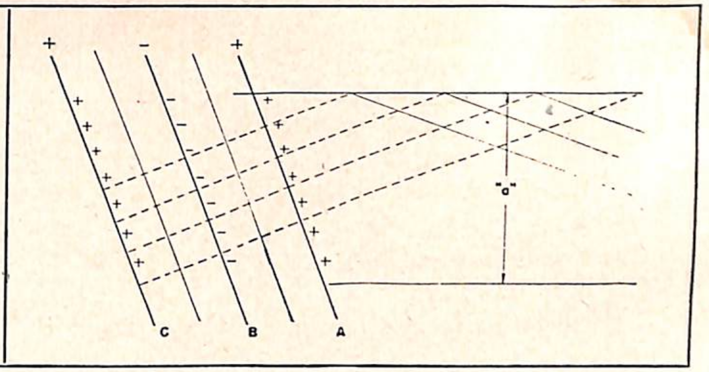

Figure 4b ELECTROSTATIC FIELD ENTERING OPEN WAVEGUIDE

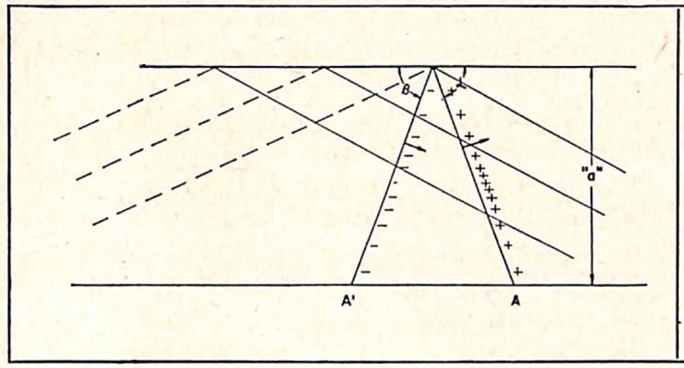

Figure 4c WAVEFRONT "A" SHOWN IN THE GUIDE SPLIT INTO TWO PARTS

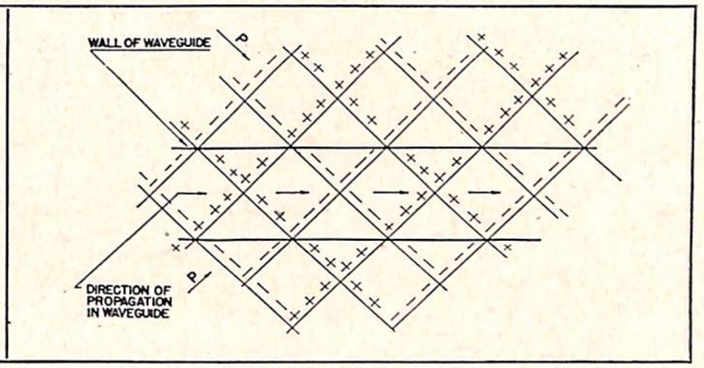

Figure 4d VIEW SHOWING HOW WAVES CANCEL EACH OTHER AT WALL OF WAVEGUIDE AND MAX. + AND MAX. – OCCUR IN THE CENTER

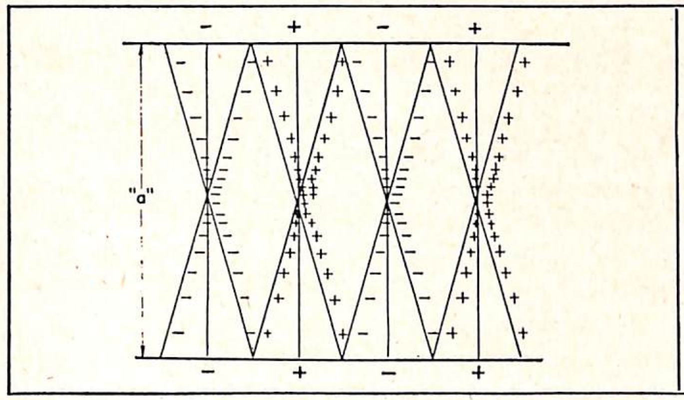

Figure 4e MAX. VOLTAGE POINTS CAUSED BY CROSSING WAVEFRONTS

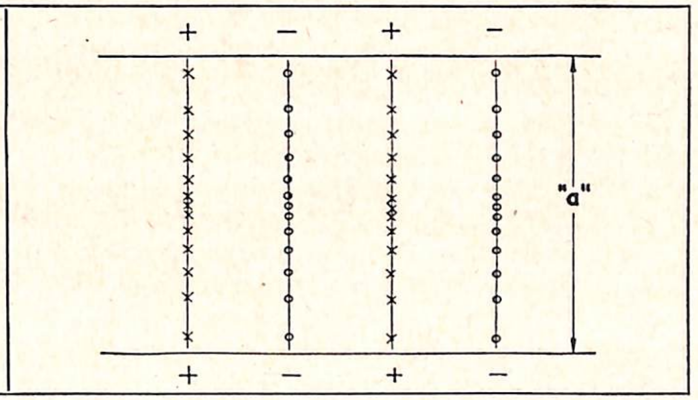

Figure 4f VOLTAGE VECTORS SHOWING SINE WAVE DISTRIBUTION ALONG THE GUIDE AND ACROSS THE GUIDE

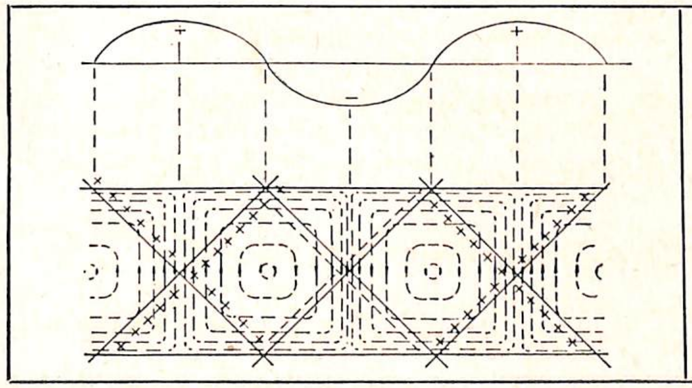

Figure 4g ELECTRICAL SINE WAVE DISTRIBUTION AND ELECTROMAGNETIC BOUNDARY CONDITIONS

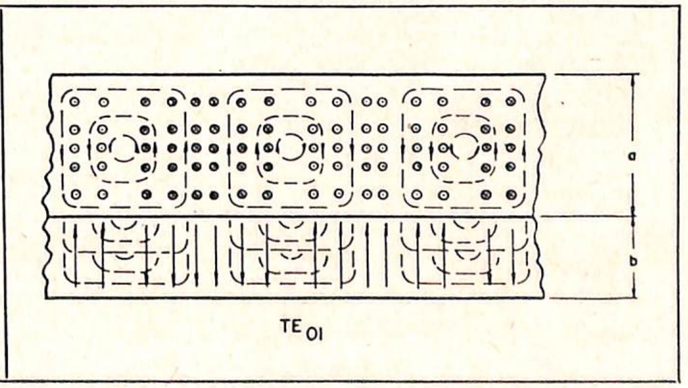

Figure 4h ENERGY DISTRIBUTION FOR TE_{01} MODE

De Mornay•Budd, 475 Grand Concourse, New York 51 waveguide as compared to what it would be in free space. The positive and negative values at the walls add to zero and cancel out so that the electric field is zero at every point. On the other hand, in the center of the waveguide, the positive values and the negative values add to maximum in every case.

Figure 4e shows the wave fronts in a waveguide. The wave fronts are steeper because the wave fronts overlap in the course of reflecting from wall to wall. In doing so, they produce voltage gradients shown as vertical lines labeled minus or plus.

Figure 4f shows the voltage vectors as the result of the wave front condition of figure 4e. They correspond to the negative and positive symbols shown in the previous figure. Figure 4f shows a half sine wave distributed across the "a" dimension and 1½ sine wave length distribution down the longitudinal axis of the waveguide.

Figure 4g shows the electric fields as they cancel out at the walls of the waveguide (comparable to figure 4d) plus the magnetic field distribution which is zero in the center and maximum at the radius, corresponding to the distance from center to the side walls. The magnetic field at its maximum in every alternation fills the entire "b" dimension of the waveguide with such a distribution pattern. Each half-wave length corresponds to one pattern. The illustration shows two half patterns and two full patterns totaling to 1½ wave lengths. The sine wave shown corresponds to the electric field distribution in the center of the waveguide. It exists at right angles to the magnetic field.

WAVEGUIDE MODES

While the mechanical construction of any waveguide is apparently simple in that it seems to be a hollow pipe, the electrical phenomena which it must house is complex to analyze. The complexity may result from the many methods of introducing or removing energy, as well as the innumerable ways, modes or patterns, that the waves can conceivably travel. This will depend on the waveguide dimensions as well as the wavelength or frequency of operation, which can be properly adjusted. The efficiency may be anything from virtually zero to nearly 100%, depending on the energy distribution, waveguide dimensions for the wavelength involved and the coupling provisions.

The method of introducing the energy into a waveguide together with the shape and dimensions of the waveguide and the frequency determine the distribution of the electric and magnetic fields therein. The distribution of these electric and magnetic fields determines the *mode* of transmission.

The mode is a pattern which the energy will or can follow throughout the waveguide. Any waveguide may have many modes. In any single waveguide having uniform dimension, there will always be one dominant mode. The dominant mode, by definition, is the mode with the lowest cut-off frequency and it does not depend on how the guide is excited. It depends only on the geometrical shape of the waveguide.

The mode or pattern which the energy follows throughout the waveguide is designated either TE (Transverse Electric) or TM (Transverse Magnetic) in type.

TE or Transverse Electric means that the electric field in the waveguide is perpendicular to the axis of the guide. It has no component along the length or long axis of the waveguide.

TM or Transverse Magnetic means that the closed loops of the magnetic field are in planes perpendicular to the axis of the guide. It has no component along the long axis of the guide

Figure 4h shows the electric and magnetic field distribution in a typical wave guide operating with the TE_{01} mode. The first numeral of $_{01}$ indicates that zero half-wave patterns exist across the cross-section of the guide along one dimension, while the second numeral indicates that 1 half-wave pattern exists across a dimension at right angles to the first. To introduce or extract energy from this waveguide, it is necessary to insert a probe wherever there is a concentration of electric field in the center of the "a" dimension, along correct points down the longitudinal axis of the waveguide. It may also be done by the use of a loop wherever there is a concentration of the magnetic field in the center of the "b" dimension, along correct points down the axis of the waveguide.

In the case of circular waveguides, the first number indicates the number of full-wave patterns of the electric component, encountered in traversing the internal circumference of the cross section. The second number indicates how many half patterns will be crossed on the diameter.

Merely doubling the frequency for a fixed waveguide dimension, or doubling the waveguide dimension for a fixed frequency will double the number of patterns which may exist in the waveguide and change the mode of operation.

THE CUT-OFF FREQUENCY

Figure 5 shows "nature's waveguide" as it is commonly employed for long-range short-wave communication in free space. The transmitting antenna propagates wave fronts which strike the ionized layers above the earth either directly or by reflection from the earth's surface. The points between points of contact of subsequent reflections

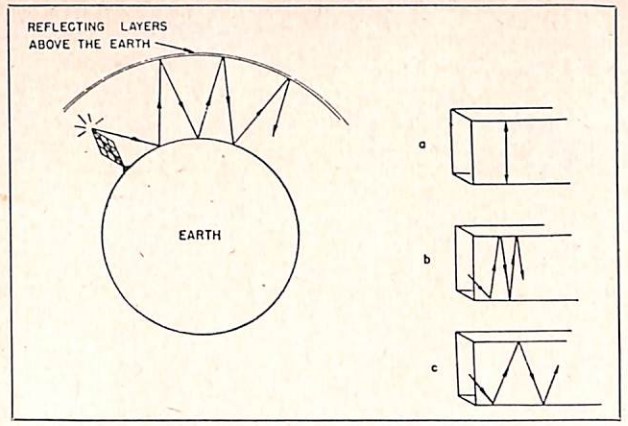

FIGURE 5

is characterized by either no signals or weak signals. The points where the energy strikes the earth either directly or by reflection are characterized by strong signals and is seemingly independent of distance from the transmitting source to the receiving point.

Figure 5(a), 5(b), and 5 (c) are fabricated waveguide comparisons with respect to the behavior of "nature's waveguide." In both cases, the frequencies which can be propagated or passed are limited by the cut-off frequency. Cut-off of the dominant mode in the rectangular pipe occurs when the width is 0.5 of the free space wavelength. In practice, attenuation may be high and transmission impractical for values lower than 0.7 of the free space wavelength.

As compared to "nature's waveguide" depicted in figure 5, the following comparisons may be made:

Figure 5(a) shows the behavior of a fabricated waveguide at the cut-off frequency. The energy or wave front will reflect back and forth without any forward motion. Any longer wave length or lower frequency cannot enter the waveguide. "Nature's waveguide" has an "a" dimension (distance between earth and the ionized layers) too great at all times for this condition.

Figure 5(b) shows how the wave fronts progress down the waveguide longitudinally as the wavelength is less or the frequency is higher than cut-off It is comparable to medium-frequency sky-wave operation for "nature's waveguide."

Figure 5(c) shows the broadening of the angle as the wavelength is further reduced and the frequency correspondingly increased without changing the waveguide dimension. It is comparable with high-frequency (short-wave) sky-wave operation for "nature's waveguide."

If the frequency is further increased, the angle will increase further so that less reflections need to occur for a given amount of progress down the waveguide. In the case of "nature's waveguide," such an angle will, because of the height of the reflecting layer, result in the first reflection returning at a distance exceeding the dimensions of the earth and be lost in space.

The fabricated waveguide is constant in "a" dimension and resultant performance. "Nature's waveguide" is constantly varying in "a" dimension because of hour, season, night and day and the influence of the sun. In practice, a fabricated waveguide is unvaryingly limited as to maximum wavelength it can pass. On the other hand, "nature's waveguide" is varyingly limited by the shortest wavelength or highest frequency it can return to earth, as the density and height of the reflecting layers change with time of day or night and with season as well as other factors.

ENERGY VELOCITIES IN WAVEGUIDES

The velocity of energy propagation in a waveguide will differ from that in free space. Specifically, the *group velocity* will be less, while the *phase velocity* will be greater than the speed of light.

Group velocity has reference to the propagation of radio frequency energy down a waveguide. It must always be less than the velocity of such energy through free space, so far as propagational progress down the waveguide is concerned. This is attributed to the fact that the waves do not travel directly down the waveguide. Instead, they reflect from wall to wall. The length of their path is therefore the angular length followed by its zig-zag course rather than the straight waveguide length. The longer path which the group velocity follows necessitates a reduced rate of progress down the waveguide. It is the velocity in free space over a longer or indirect path, as determined by the angular reflections within the waveguide On higher frequencies, the angle is such that there will be less reflections in a given length of waveguide [see figure 5 (c)]. On lower frequencies, the angle is such as to produce more reflections in a given length of waveguide [see figure 5 (b)]. This means that the group velocity more closely approaches the velocity in free space as the frequency is increased inside a given waveguide dimension.

Phase velocity is the product of frequency times wave length. The wave length is actually the distance between two planes of the same phase perpendicular to the direction of propagation. In a waveguide, this distance is longer than in free space because of angular reflections. Therefore, the apparent velocity of propagation of phase velocity is greater than in free space.

Microwave energy in traveling down a waveguide must therefore be evaluated in a manner comparable to sky-wave operation on lower frequencies rather than direct-path transmission that could exist in free unobstructed space.

WAVEGUIDE BENDS AND SHAPES

A straight run of waveguide has relatively-low losses. The principal losses will be due to interior skin effects and that of the dielectric. The skin-effect losses are minimized by plating the interior of the waveguide with gold or silver. Silver has the best conductivity but is inclined to oxidize. Gold has slightly less conductivity than silver but will not corrode or oxidize with time and exposure.

The larger the inner perimeter, the lower will be the transmission loss in any waveguide. A clean smooth surface is required, as small changes in internal dimensions due to either corrosion, dirt or imperfect machining, acts as a constriction within the waveguide which results in mismatch or reflections.

Waveguides, when run in other than straight directions, are subject to impedance mismatch and increased losses. Unless carefully designed, serious impedance mismatch can result, due to non-uniformity of dimension and spacing between the waveguide walls. Discrepancies of this type will make the waveguide less ideally correct for a particular frequency or mode of operation. Instead, it will become correct for some other frequency and/or operating mode. If a waveguide is twisted sufficiently, it will also result in a change of polarization.

When necessary to bend the waveguide along its run, the bend should be as gradual as possible in order to minimize losses in transmission efficiency. A bend in a waveguide can be compared to a transmission line provided with two lumped reactances at the beginning and at the end of the bent section.

The problems associated with executing a change of direction in a waveguide system (such as for a bend or elbow) are both mechanical and electrical. The mechanical problems are those encountered in bending, cutting and soldering the metal waveguide. The electrical problems include keeping the entire waveguide line electrically as "flat" as possible and not to introduce any discontinuity because of changes in direction. Reflections also occur at the junction plane between straight and bent waveguide sections.

WAVEGUIDE AND CAVITY APPLICATIONS

Cavity resonators are a modification and special application of waveguides. They are metal chambers built up of simple geometrical shapes such as cylinders, spheres, cones, etc. It may be a waveguide closed at both ends with energy introduced and removed at such points as may be correct for the desired mode of operation. The electro-magnetic fields in a cavity are wholly internal. If made of metal walls thicker than the depth of electrical field penetration (skin effect), the electric field on the outside of the cavity may be completely isolated from the interior of the cavity. The current flow is restricted to that surface of the metal chamber, in this case the inside, which is exposed to the electric field. Large currents may actually flow on this inner surface with practically none on the outer surface of the cavity. So long as the field is bottled up within the cavity, there will be no electrical coupling to adjacent objects and no energy will be lost by radiation.

Cavity resonators may be used for functions such as:

1—Tuning in signals on a particular frequency by varying the dimension of the cavity. De Mornay Budd manufactures several types including calibrated types where the internal dimension may be varied or tuned by an externally controlled calibrated micrometer adjustment.
2—To provide a circuit having a high order of Q.
3—To couple two circuits together such as coaxial to coaxial, coaxial to waveguide or waveguide to waveguide.
4—To couple two circuits of different characteristics such as two different impedances, a large to a small coaxial or waveguide, etc.
5—To couple the electric or magnetic field. The r-f energy may be introduced into or removed from the resonant cavity either inductively, capacitively or by radiation.

The full list of applications for waveguides are unlimited in the field of microwaves so long as the wave length dimensions are physically convenient to utilize. They may be principally summarized as follows:

1—The most important application is for the transmission of energy from a source to a load.
2—To act as a bandpass filter.
3—To act as a band eliminator.
4—To serve as a fixed or variable attenuator.
5—To simulate the ionosphere and the earth on microwaves.
6—To develop a high Q.
7—To replace open wires or coaxial cable as a transmission line, where these would be both physically and electrically impossible on such high frequencies or short wavelengths.
8—To act in lieu of an antenna for propagation directly into space by means of a flared end, thereby becoming an electromagnetic horn.
9—To serve as a step-up, step-down or one-to-one transformer.
10—To provide capacitance effects when used with wavelength less than a quarter wavelength, open-circuited.
11—To produce the effect of circuit inductance when used with lengths less than a quarter wavelength close-circuited.
12—To simulate a series resonant circuit or short circuit when used for a quarter wavelength, open-circuited.
13—To simulate a parallel resonant circuit or open circuit when used for a quarter wavelength, close circuited.
14—To invert the impedance by use of a quarter-wave section.
15—To match any impedance to another impedance by use of the correct length of waveguide within an overall half wavelength.

SKIN PENETRATION OF METALLIC CONDUCTORS

In effect, it is true to claim that d.c. and very low a.c. energy flow *in* conductors while a.c. at microwave frequencies flow *on* conductors. A situation develops where a conductor having negligible resistance to the flow of d.c. has appreciable resistance for a.c., since the latter can only utilize a current path restricted to the surface.

GRAPH FOR COMPUTING THE RESISTANCE AND DEPTH OF PENETRATION OF METALLIC CONDUCTORS ON FREQUENCIES BETWEEN 100 AND 100,000 MEGACYCLES WITH REFERENCE TO A METALLIC STRIP ONE CM. WIDE AND 1 METER LONG.

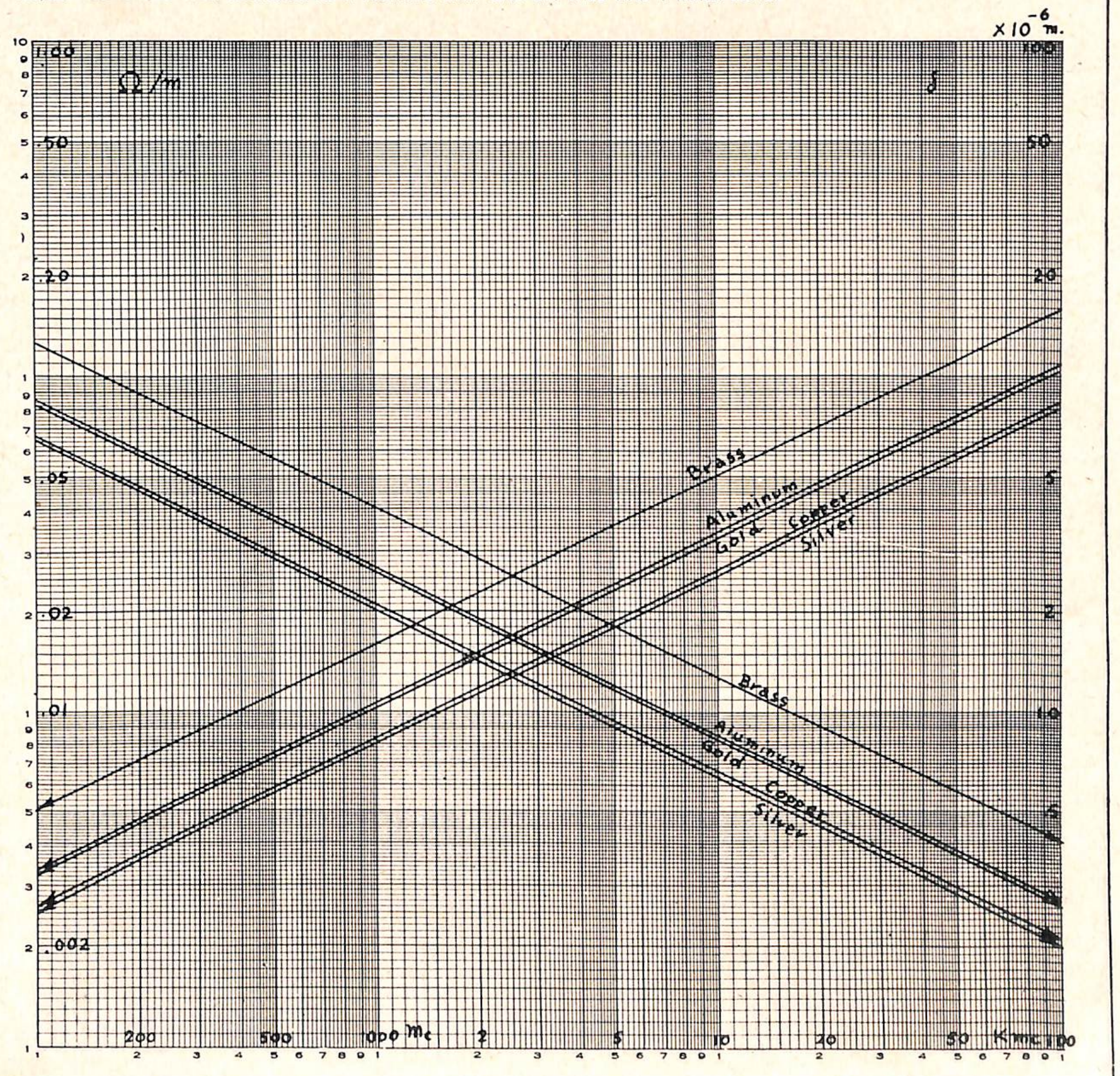

FIGURE 6

TABLE VII—*Skin penetration in metallic conductors*

Metal	100 Mc		1000 Mc		10,000 Mc		100,000Mc	
	ohms	*depth**	*ohms*	*depth**	*ohms*	*depth**	*ohms*	*depth**
Brass	0.005	12.6	0.016	4.0	0.05	1.26	0.16	0.40
Aluminum	0.0034	8.6	0.011	2.7	0.034	0.86	0.11	0.27
Gold	0.0032	8.2	0.0103	2.6	0.032	0.82	0.103	0.26
Copper	0.0026	6.6	0.0083	2.1	0.026	0.66	0.083	0.21
Silver	0.0025	6.5	0.008	2.0	0.025	0.65	0.080	0.20

* Depth is given in millionths of a meter.

Note: The resistance increases in accordance with the decrease in skin depth of penetration. Between 100 and 10,000 Mc or between 10,000 and 100,000 Mc, it can be noted that the frequency was increased 100 times while the resistance increased as the square root of the increase, or only 10 times. The depth of penetration decreased inversely to the increase in resistance.

Figure 6 is a calculated graph showing the five principal types of conductors or plated surfaces (brass, aluminum, gold, copper and silver), used for the transmission of microwave energy. The graph is calculated to show frequency versus a-c resistance versus depth of penetration. It is based on a metallic strip one centimeter wide and one meter in length. In practice, the strip may be much less in width to increase the resistance and much shorter in length to reduce the overall resistance. As laid out in figure 6, skin effect may be computed and compared by use of table VII.

Various conclusions may be reached in comparing the different types of metals described above. In practice, there are innumerable materials which may be used either plated or unplated. The best to date are brass, copper, aluminum or the application of silver or gold plate on such materials.

Normally, all test components are supplied with an overall gold plate, which has proved to be the best compromise for freedom from corrosion, conductivity and permanence of electrical characteristics.

RADCM MODIFICATION KIT MX-833/SL

The radar countermeasures Modification Kit MX-833/SL is designed for use with the Model TDY-1 Radio Transmitting Equipment and the Model DBM-1 Radar Direction-Finder Equipment. It is designed to provide an operator with remotely-controlled switching facilities for any and all antennas and associated receivers, panoramic adaptors and pulse analyzers in the radar counter measures system.

This modification kit makes obsolete the manual method of antenna selection heretofore employed in the RADCM system room, eliminating such equipment as the J-116/SPR Antenna Selection Panel and the Navy Type CWI-24695 Lever Switch. It also makes possible the automatic switching from one to the other of the model TDY-1 antennas installed on the pedestal.

Attention is invited to the fact that these modification kits will be available only as outlined in the Material Improvement Project No. 125, Bureau of Ships No. 67-23 dated 20 May, 1947, since only 25 kits have been procured from the Designers for Industry, Cleveland, Ohio, under Contract NObsr-30017 dated 14 May, 1946. The first two kits received have been submitted to Operational Development Force for evaluation tests. The balance will be shipped to Mechanicsburg, Pennsylvania, for reshipment.

Each modification kit weighs approximately 293 pounds crated, and 194 pounds uncrated. The complete kit, including equipment spares, is contained in seven packages. Operation is from 110-volt $\pm 10\%$, 60-cycle a.c., and the maximum current required is 30 amperes. These 25 kits provide as an interim measure an automatic control feature for the present RADCM system, until such time as the Model AN/SLR-1 (formerly the AN/SPR-5) Countermeasures Receiving Set and the AN/SLT-1(SN) Countermeasures Transmitting Set become available for shipboard installation. The availability date for this equipment has been tentatively assumed to be late 1949.

In the meantime, with the Modification Kit MX-833/SL switching arrangement, it is possible to use either the DBM-1 antennas or the TDY-1 antennas as search or direction-finding antennas. Also, facilities are provided for connecting search receivers to the various antennas. By means of remotely-controlled coaxial switches, the individual units of the TDY-1 and the DBM-1 can be connected in several combinations. The control is accomplished from a central location, and pilot lights are provided to indicate the position of all coaxial switches.

The external wiring for the automatic switching including associated equipment and antennas is given in Bureau of Ships Drawing RE 100J 209A (which supersedes Drawing RE 100J 190C). Activities desiring to do so can obtain copies of this drawing from the Electronics Officer at any Naval shipyard. It is expected that elementary outline and interconnecting dimensional drawings for Modification Kit MX-833/SL will be available for distribution as soon as the kit is approved for shipboard installation.

The installation of Modification Kit MX-833/SL can be accomplished by ship's force (2 men) in approximately two weeks time if the ship's transmitting and receiving functions are located in the same room. If a ship has two spaces allowed, one for each function, then Naval shipyard availability will be required before the kit can be installed.

PULSE CODE MODULATION

By H. S. BLACK

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■ A new technique for long-distance multi-channel telephony has been developed that is capable of unusually fine fidelity and is entirely undisturbed by all but abnormally high noise. Theoretically, the value of the peak noise may be nearly equal to the peak signal. With this new system, employing a procedure known as pulse code modulation, the voice is transmitted as a sequence of on-or-off pulses, which are coded to represent the values of the signal at regularly spaced short intervals. It lends itself readily to multiplexing by time division, and thus will permit a single circuit to provide a number of channels. Pulse code modulation requires extra frequency space, and at present seems particularly adapted for transmission over microwave radio-relay systems. An eight-channel system employing these principles was produced, and gave very satisfactory transmission and exceptional freedom from interference during extensive and rigorous trials. Other work carried on simultaneously by W. M. Goodall, Radio Research, resulted in the development of an experimental system using a different method of coding. Pulse code modulation by another method is proposed in a U. S. patent issued to A. H. Reeves and assigned to International Standard Electric Corporation.

One of the major problems of telephone transmission has been the reduction of noise and distortion that is picked up along the path or introduced by associated equipment. Up to the present time, noise and distortion has remained a controlling factor in long-distance transmission. This is principally because of the cumulative building up of noise and other transmission impairments with each of the many amplifications necessary over long distances.

The development of pulse code modulation, commonly referred to as PCM, makes it possible to remove noise and distortion as a limiting factor by basing the reconstruction of the continuous message wave at a receiving station on the arrival or failure to arrive of pulses, nothing more. At every repeater point in a PCM system, simply this presence or absence of pulses is all that is required to permit the message to be regenerated and given a fresh, noise-free start. In a well-designed PCM system, there should be practically no transmission impairment due to adding repeaters. Except for a small delay, chiefly due to the finite velocity of propagation, the code characters delivered by the last repeater correspond to the code input at the sending end, and thus will convey the identical intelligence carried by the code output of the first transmitter.

At any instant the voltage produced by a telephone transmitter may be positive or negative as the pressure of the acoustic wave becomes greater or less, and because of the rapidly changing character of speech, with its irregular and complex intonations, and because the resulting voltage may have any of an infinite number of values between the plus and minus limits fixed by the system, it might seem impossible to substitute a simple sequence of coded on-or-off pulses for it. Conversion of voice to coded pulse signals is possible, however, by use of two principles: sampling and quantizing.

It was shown many years ago that if a signal is sampled instantaneously at regular intervals and at a rate slightly higher than twice the highest signal frequency, then the samples will contain all of the information of the original signal. This means that if a voice wave were plotted, it could be reproduced in all its detail from the values of a set of ordinates erected at equally spaced intervals provided the separation of the sampling ordinates be not greater than half the period of the highest component frequency of the original wave. If a voice wave, for example, is passed through a low-pass filter whose cut-off frequency is below 4,000 cycles, all of the information necessary for its distortionless reconstruction is contained in a set of very short samples of the voice wave taken at regular intervals at the rate of 8,000 per second. No intrinsic distortion is involved.

Application of the sampling principle reduces the problem to one of sending a finite number of bits of information giving the values of the samples of the voice wave. However, the complete translation problem still is not solved because the samples may and generally will occupy a continuous range, and thus an infinite number, of values. This difficulty is resolved by a second step: the application of the quantizing principle to the samples obtained.

If one experimenter were obtaining points on a curve and calling them to a second person for plotting on a graph, it would be necessary for them to agree on the precision with which they must work. If they agreed to use two significant figures, for example, they might choose coordinate paper with 99 lines above and 99 below the axis. Each point then would be plotted on one of these lines. Those experienced in curve plotting would expect to obtain a good likeness to the original smooth curve in spite of the fact that only 199 possible discrete values of sample had been used.

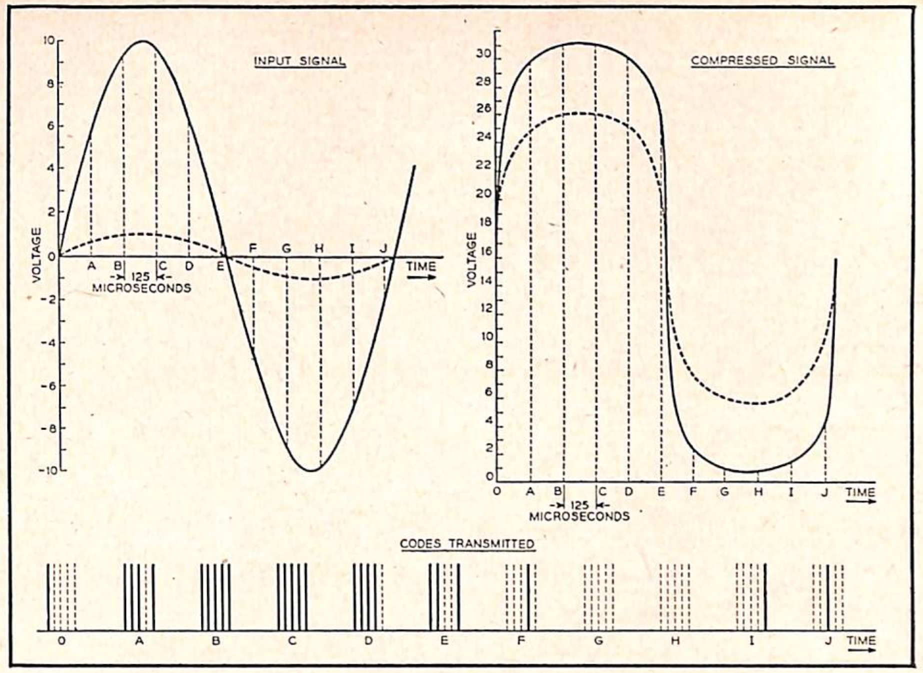
The quantizing principle states that each of a set of small ranges into which a larger range may be divided is assigned a single discrete number or character, such as that corresponding to the mean of the range. In the example above, any value from −0.5 to +0.5 would be called zero, or any value between 94.5 and 95.5 would be called 95. It is quite apparent that some distortion or granularity is inherent in the application of the principle of quantization to an electrical signal carrying the information of the spoken word. The greater the size of the range assigned to a given character and the fewer characters used, the greater will be this granularity. The problem then is to determine the smallest number of steps into which voice signals may be quantized without serious distortion, and what should be the size of each step.

The range of voltages covered by voice signals, from the peaks of a loud talker to the weak passages of a weak talker, is roughly of the order of a thousand to one. If the range of voltage assigned to each code character were small enough to keep the granularity within the desired limits, and if the range assigned to all characters were the same, it would be necessary to assign about a thousand characters to cover the full voltage range. By making the steps vary approximately logarithmically, nearly uniform percentage precision is obtained throughout most of the range and far fewer steps are needed. It has been found by experience that sixteen steps which vary logarithmically give quite intelligible speech; that thirty-two give acceptable quality even if several such systems are connected in tandem; and that the granularity introduced by a well-designed system using 64 characters is little enough so that the reconstructed speech wave is reproduced to a high degree of fidelity as judged by experienced observers. With simple on-or-off pulses, the number of available characters is equal to 2 raised to a power equal to the number of pulses comprising the code. Thus with four pulses per character, sixteen characters are possible, with five pulses, thirty-two characters, and with six, sixty-four. A five-pulse binary code will therefore give acceptable quality, whereas a six-pulse code will afford high quality.

Application of the sampling principle permits the reduction of a continuous voice signal to 8,000 discrete samples per second, and application of the quantizing principle permits each sample to be represented with sufficient accuracy by coded characters that use the various combinations of five or six on-or-off pulses.

Pulse code modulation also permits multiplexing the channels by time division. If the pulses are short, so that the five or six on-or-off pulses comprising one character can be sent in a small fraction of the 125-microsecond interval between characters, the clear time may be occupied by code pulses from other voice channels, thus permitting multiplex operation with many channels.

How the sampling and the quantizing principles permit a voice frequency wave to be transformed to a sequence of pulse codes is indicated in the diagram on page 266. At the upper left are shown two sine waves which may be assumed to represent in idealized form the highest volume signal to be transmitted and a lower signal. The sampling points, spaced 125 microseconds apart, are indicated by dashed lines and marked O, A, B . . . J,



Transformation of voice to code pulses. The input signal, represented as a sine wave at the upper left, is compressed logarithmically to give the curve shown at the upper right. Samples are taken every 125 microseconds and each sample is converted to a five-pulse binary code as shown in the lower line. To permit all eleven codes to be indicated, the time scale is distorted —making the time between successive codes much shorter than it actually is.

inclusive. It is the voltage values of the original wave at these points, after they are quantized to a logarithmic scale and then coded, that are to be transmitted. Since the values of the samples to be transmitted are on a logarithmic scale, the voice wave may be passed through a logarithmic compressor to give the curve at the upper right. It will be noticed that the effect of this compression is to increase the relative values of the low voltages and to decrease those of the high voltages. For the graph at the upper right the ordinate scale, instead of extending to positive and negative values from a zero axis, starts from the bottom of the negative loop of the highest volume signal to the top of the positive loop of the same signal, and the intervening distance is divided into thirty-two equal spaces marked from 0 to 31 on the diagram. A value of signal falling anywhere within the limits of the No. 4 space, for example, is transmitted as a 4 in binary code.

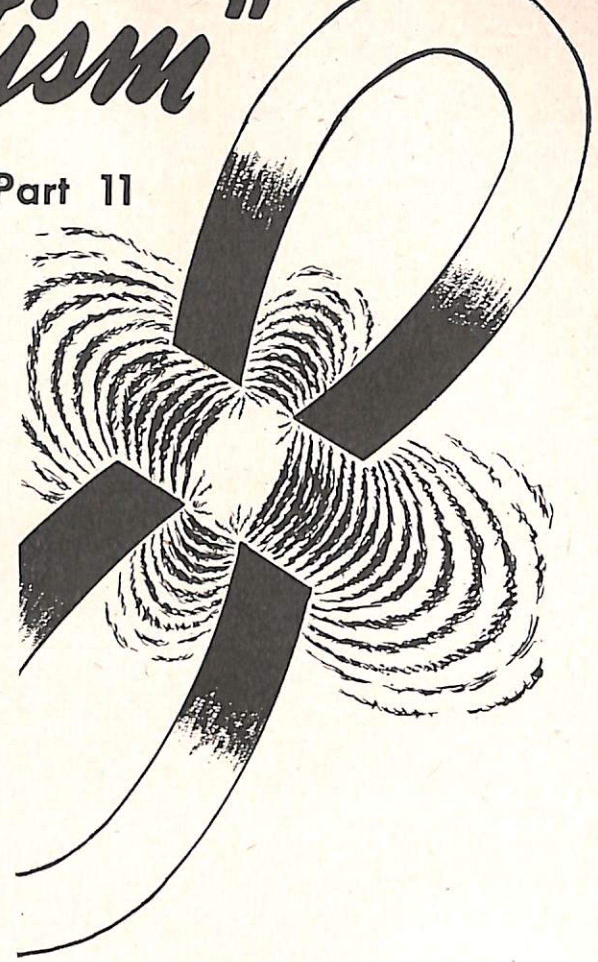
Along the horizontal time axis below the two curves are the eleven code patterns that would be transmitted to represent the values of the eleven samples as obtained from the curve at the upper right. A solid line is used to indicate a pulse, and a dotted line, the absence of a pulse. To permit all eleven codes to be shown across the width of the page, it has been necessary to distort the time scale. Actually the codes are spaced 125 microseconds apart since the samples are taken at the rate of 8,000 characters per second, while each code itself requires only about 16 microseconds. On a true time scale there is space for the codes for eight channels.

A single-channel PCM system carrying speech runs at 8,000 characters per second, and the eight-channel system mentioned earlier, shown in the photograph on Page 267, runs 64,000 per second. The pulsing speed is 8,000 × 8 × 5, which is 320,000 on-or-off pulses per second. It is apparent that high-speed electronic devices must be used to attain such speeds of operation. Surprisingly large numbers of possible devices have been proposed, ranging from standard types of vacuum tubes to more complex structures, and many of them have been tried out experimentally.

Pulse code modulation appears to have exceptional possibilities in its freedom from interference especially when applied to systems having many repeaters in tandem, but its full significance to the radio and wire transmission of the future may take some time to reveal.

"Magnetism"

BASIC PHYSICS Part 11



EARLY HISTORY OF MAGNETISM

The property, called magnetism, which gives certain metallic substances the power to attract certain other substances to it, has been known for centuries. The ancients discovered that a certain black mineral possessed this property in a natural state. The particular ore (or, subsequently any substance that exhibited this property) came to be known as a magnet. The terms magnet and magnetism were probably derived from the place called Magnesia, in Asia Minor, where the ore was first found in plentiful quantities. A natural magnet is composed of oxides of iron (FeO and Fe_2O_3) and is chemically known as magnetite.

Magnets were originally called "lodestones" or "leading stones" because it was discovered that, when they were suspended at the centers and free to rotate in horizontal planes, they would align themselves in a general north-south direction. The end which always pointed north was called the north-seeking or positive pole of the magnet; the other end, the south-seeking or negative pole. The signs of polarity (+) and (–) have no direct connection with electric current flow, but are used simply as a convenient, arbitrarily-accepted designation.

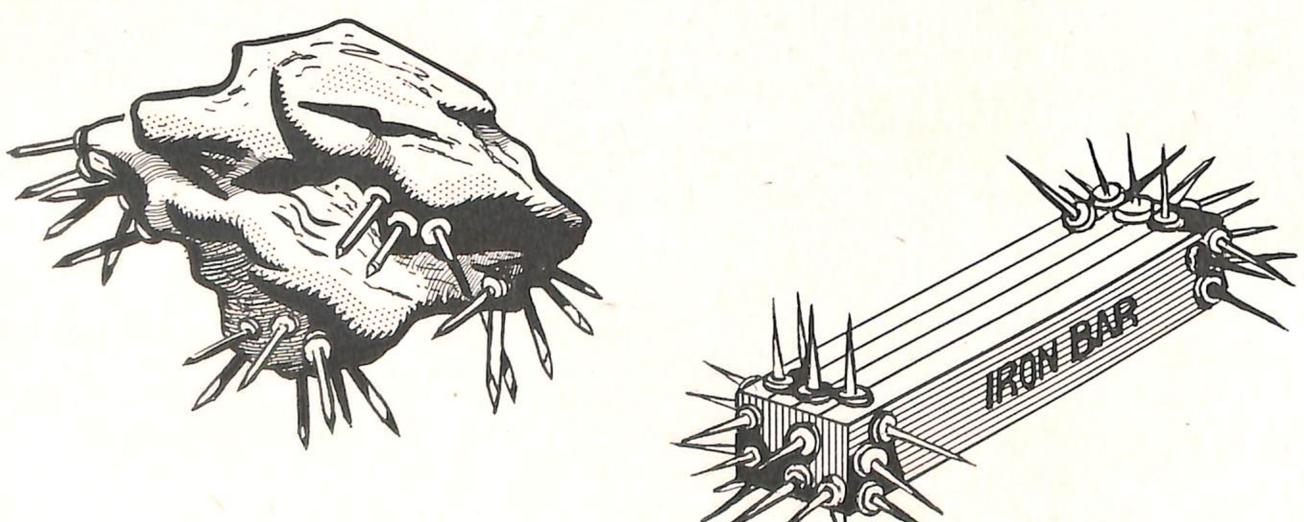
Prior to 1820, magnetism was not thought to have any connection with electricity, but was merely described as a peculiar property of iron oxide, or magnetite, which enabled it (1) to align itself in a north-south direction when free to rotate horizontally, (2) to attract a certain few other substances, and (3) to impart magnetic properties to these substances.

THE PHYSICAL PROPERTIES OF MAGNETISM

The property of a magnet to attract other magnetic substances can be demonstrated by dipping both a natural and an artificial magnet into a basket of small iron nails as in figure 1. Note that nails are attracted to both magnets in quantities determined by the strength of each individual magnet, and their distribution about the surface of any particular magnet varies, some regions attracting a high concentration of nails, other regions no nails at all. The regions of concentration are known as the poles of the magnet. The artificial bar magnet more aptly demonstrates paired poles of equal strength since the two poles of the bar magnet, see Figure 1 B, show the same concentration of iron nails. Often, in a natural magnet, there are more than two of these regions, and this indicates the presence of several paired poles. Note that the natural magnet figure 1 A has more than two poles.

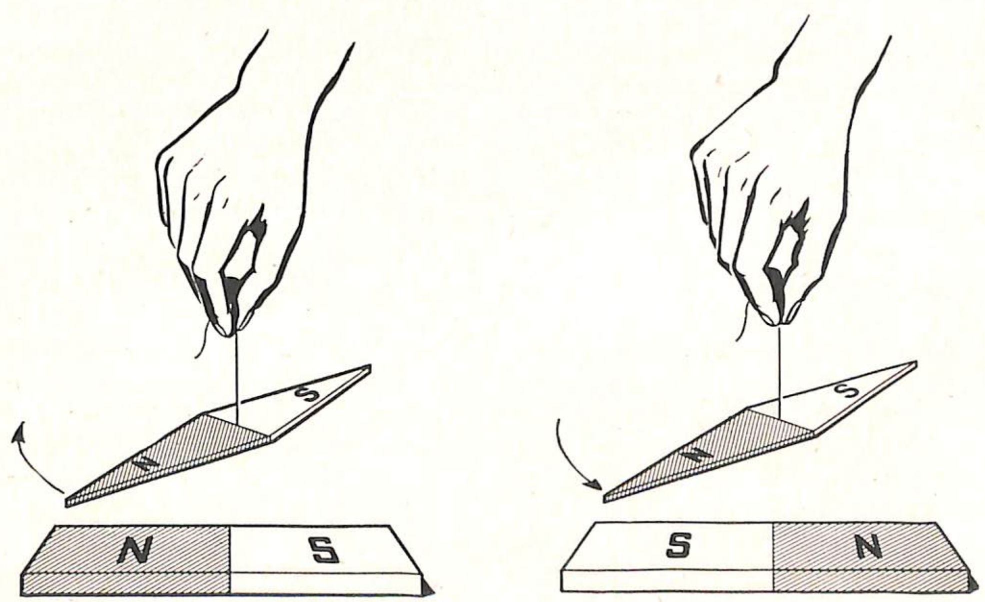
In figure 2 two magnets are used to show that the poles of a magnet have opposite effects. When the north pole of the pivoted magnet is brought near the north pole of the fixed bar magnet, a repelling force is evident that forces the north poles apart. When the south pole is brought into the vicinity of the north pole of the fixed magnet, an attraction is noted that draws the two ends together. From these findings is obtained the law: *Like poles repel and unlike poles attract.* Note that this law applies to both magnetic and electric fields.

The magnetic field. The region external to the magnet, within which the effect of its magnetism is perceptible, is known as its *field.* The field is strongest near the poles, and becomes rapidly weaker as the distance from them increases. Figure 3 offers a simple visual demonstration of the field about a magnet. Iron filings have been sprinkled on a sheet of glass or paper that is then laid on a bar magnet. By gently tapping the paper, the filings, under the influence of the magnetic poles induced in them, will arrange themselves end-to-end in lines that have the same direction as the lines of magnetic force and thus they indicate the direction of the magnetic field of the magnet. The varying intensity of the field is shown by the density of grouping of the filings, especially at the region of the poles.



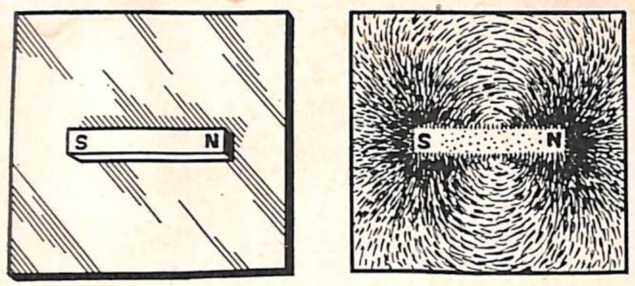
A B

FIGURE 1—*(A) Lodestone or natural magnet. (B) Artifical or bar magnet. The poles are shown by concentration of nails where lines of force are strongest.*

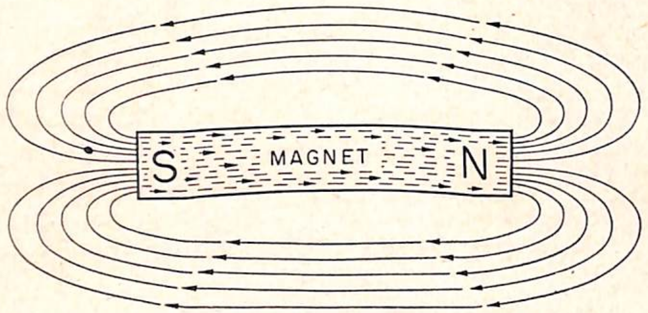


A REPULSION B ATTRACTION

FIGURE 2—*(A) Suspended magnet rotates away from fixed magnet when unlike magnetic poles are brought together. (B) Unlike poles exhibit attraction, and suspended magnet rotates toward south pole of fixed magnet.*



A



B

FIGURE 3—*(A) Magnetic field about a bar magnet indicated by iron filings sprinkled on plate of glass placed on bar magnet. (B) Magnetic field shown by lines indicating direction and approximate concentration of lines of force originating at N-pole and terminating at S-pole. Dashed lines within the magnet from the S-pole to the N-pole represent lines of magnetization.*

When studying magnetic fields, this means of visualizing or mapping the field of force about a magnet is a great help in predicting the behavior of the field. From the distribution of the iron filings in figure 3 (A) it is evident that the force of the magnetic field extends about the magnet in apparent lines indicated by the alignment of the iron filings, and that magnetic force of the field is most intense at the poles and diminishes as the distance from the poles increased. These lines are called *magnetic lines of force,* and are defined as purely imaginary lines or curves representing the force, or stress, existing in the space through which the magnetic field is effective. The direction of the lines of force at any point is that of the field at that point, or the direction in which a single positive unit pole (north pole) would be caused to move if placed at that point in the field.

The apparent physical characteristics of magnetic lines of force are in many ways similar to those of electrostatic lines of force. They distribute themselves as if they repelled one another when they are parallel and have the same direction, and attract one another when they have parallel, but opposite directions. They act as if they were under tension at all times, but, unlike electrostatic lines, they exist in *closed loops,* that is to say, they leave the magnet at the north pole, pass outside and around the magnet, enter the magnet via the south pole, and go through the magnet to the north pole in one continuous loop, without beginning or end. The magnetic lines of force acting in that part of the closed loop within the magnet itself are called *lines of magnetization;* those acting in that part of the closed loop external to the magnet (in the magnetic field) are called *lines of force.* The lines of force, being imaginary, do not, of course, possess such physical properties as elasticity, but *act* as if they did.

Magnetic substances. Any substance that is attracted by a magnet or that may be made to assume the properties of a magnet is termed a magnetic substance. When a substance is changed from its normal state to one in which it has all the properties of a magnet, it is said to be magnetized, the process of change being that of *magnetization* or *magnetic induction.* Only those substances that are capable of being magnetized appreciably are called *magnetic substances;* all others are referred to as *nonmagnetic.* The ability to acquire magnetism is possessed to the greatest extent by pure iron, and rather feebly by nickel and cobalt in their elementary forms; however, iron oxides, and alloys of iron and a few certain other elements display magnetic properties, the degree depending upon their chemical compositions.

A summation of magnetic characteristics. The principles of magnetism may be more easily grasped by first reviewing the general characteristics of magnets, magnetic fields, and magnetic substances, before the effects are studied, so that the nomenclature is thoroughly clear.

The *poles of a magnet* are the regions where magnetism is most evident. Magnetic poles exist in pairs, having equal strength but opposite polarity or effect. In natural magnets or lodestones and in magnets of irregular shape more than one pair of poles have been found. Artificial magnets are manufactured from metallic magnetic materials, and are produced in various strengths, sizes and shapes usually as bars or horse-shoe-shaped pieces. Such artificial magnets have only one pair of poles.

The space in the immediate vicinity of a magnet, where the properties of magnetism are perceptible is designated as the *magnetic field.* Imaginary lines of magnetic force exist in continuous loops which pass through the poles of the magnet. The lines passing from the north to the south magnetic poles through the magnetic field are called lines of force; the lines passing from the south to the north magnetic pole of the magnet, within the magnet or magnetic itself substance, are called *lines of magnetization,* or *lines of magnetic induction.* The characteristics of lines of force and lines of induction are shown in figure 3 (B). Note that lines of force leave the north pole of the magnet at right angles to the pole face. Note also that lines of induction within the magnet are parallel. *The axis of the magnetic field is the axis of the paired poles.*

It follows that no substance can exist as a magnet without, 1—*paired poles of equal strength and opposite polarity, and 2—an attendant magnetic field of force.* Conversely, a magnetic field cannot exist and demonstrate the effects and properties of magnetism without paired poles. A magnetic field or region exhibiting magnetic properties may be referred as a *magnetic dipole* (at least for distances far from the magnet), since the field has at least one set of paired poles of equal strength but opposite effect. The concept of magnetic dipole is essential in explaining many of the effects produced in magnetic substances by magnetism and other aspects of magnetic theory.

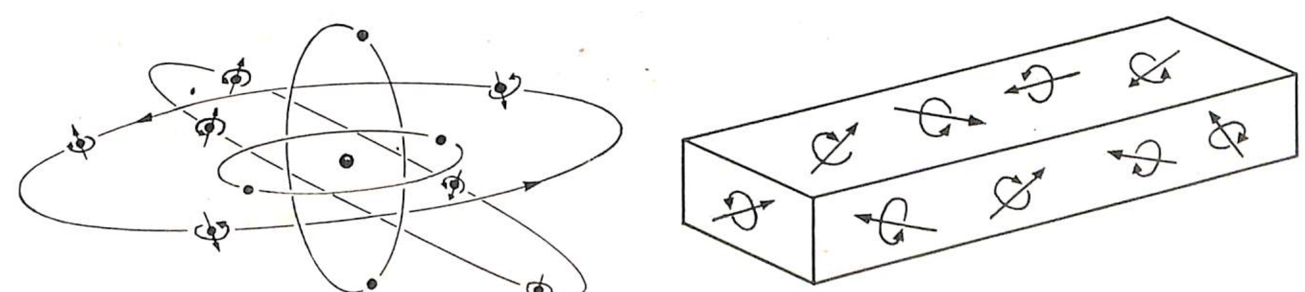
THE ELEMENTAL THEORY OF MAGNETISM

Early in the last century, Wilhelm Weber, a German physicist (1804-1890), who had been experimenting with natural magnets and magnetic substances, advanced the theory that all magnetic substances were made up of minute magnetic regions or elementary dipoles, and that when the magnetic field axes of these dipoles were oriented at random —a condition that effectively cancelled the effects of the individual fields—the substance was unmagnetized. He further theorized that, under the influence of an external magnetic field produced by a magnet, these magnetic dipoles turned so that their axes aligned parallel to, and in the same direction as, the lines of force in the applied field. The substance could then be said to be magnetized. He concluded that the degree of magnetization depended upon the completeness with which the total magnetic fields or regions within the magnetic substance were turned parallel to the applied field.

This theory has been substantiated to a great extent by modern spectral analysis of metals and gases. It is believed that electrons, which rotate in their assigned orbits within the atomic structure, also spin or have rotary motions about their own axes, and that because of these motions and the electrons mass, associated magnetic fields exist which represent kinetic energy of motion. This is shown in figure 4A. In most elements, opposing rotational movements of electrons in the same orbit causes the fields to nullify each other. In a few metals, such as iron, nickel and cobalt, however, the crystalline structures are such that there are more electrons spinning in one direction than the other; throughout certain minute regions, each containing some 10^{15} atoms, these uncompensated spins have the same direction. This results in an intense magnetic field within these regions. These magnetic regions have been given a special name: *magnetic domains.*

Normally the forces exerted by these dipoles are directed in haphazard directions and within limits more or less fixed by the internal friction of the atomic or molecular structure of the substance. Figure 4B shows the random directions of the magnetic field axes within a magnetic substance which exhibits little or no external magnetic effects because of the cancellation of most of the internal magnetic dipoles. The arrow heads represent the north poles of the dipoles and thus indicate the directions in which these magnetic forces are exerted.

As would be expected, energy is required to change the position of the axes of the magnetic dipoles within a substance. The effectiveness of the applied energy is contingent, in part at least,



A B

FIGURE 4—*(A) Hypothetical magnetic axes due to electron spin. The outer orbit is shown with more electrons spinning in one direction than the other. (B) Random direction of magnetic regions in an un-magnetized bar of magnetic material due to uncompensated spins.*

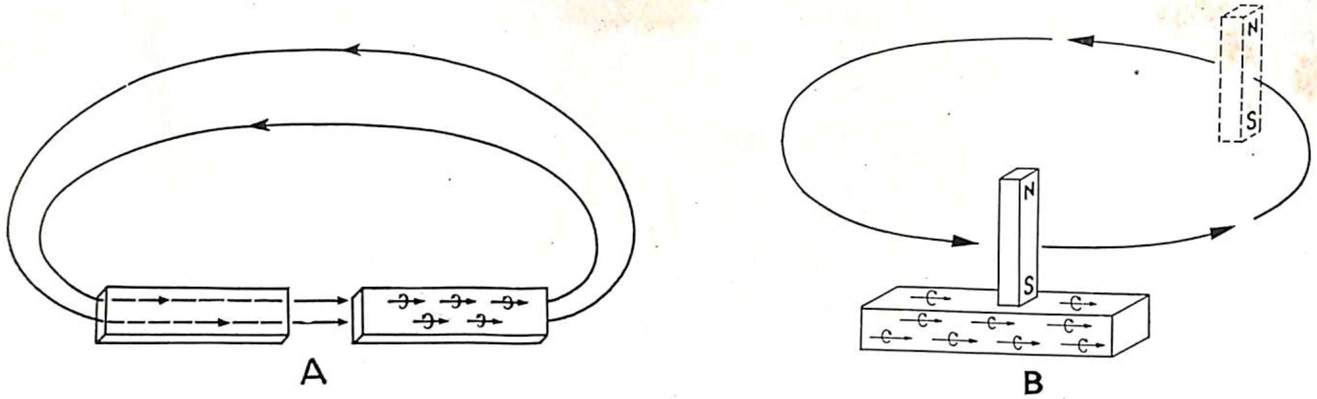


FIGURE 5—*(A) Alignment of magnetic domains under the influence of a magnetic field. (B) Magnetic state induced by stroking with a bar magnet.*

upon the essential atomic or molecular nature of the substance. When a magnetic substance is placed in a magnetic field, the kinetic energy of that field compels the axes of the magnetic regions or dipoles in the substance to align themselves parallel to and in the same direction as the lines of induction. In accomplishing this work, it follows that for the same substance, the greater the applied magnetism is, the greater the degree of magnetization will be. That certain metals have stronger magnetic properties than others is due to the *peculiar motion of the electrons within their respective atoms or molecules,* and *the ease with which the axes of the magnetic dipoles are moved* when any given amount of energy is applied. It is believed that certain internal forces that vary from one kind of atom to another or from one type of molecule to another, cause "friction" which restricts changes in magnetic dipole positions. This "friction" is present only slightly in magnetic materials that do not retain much magnetism, but occurs to a greater extent in materials utilized as permanent magnets.

Magnetic induction. The magnetic state is induced in a magnetic substance when the majority of axes of the dipoles within the substance are caused to assume the same direction. In this state the dipoles no longer cancel out one another but combine to exert a powerful external magnetic force in one direction. Work must be done in overcoming the internal forces which maintain the normal random state of the magnetic fields within a substance. The energy to accomplish this work can be supplied in several ways. It may be entirely furnished by an inducing field. The presence of a magnetic field is always necessary to determine the ultimate direction of the induced magnetic field. Heat and physical shock, as sources of additional energy, may be employed to assist the induction process, but if the heat or shock is too great it causes excessive atomic agitation which prevents alignment of the magnetic axes.

As an illustration of the above theory, when an unmagnetized bar of iron or steel is brought into the immediate vicinity of a magnet or stroked with a magnet as shown in figure 5, a certain magnetic state is induced in the bar. The bar will then have all the properties of a magnet, but to a lesser degree.

A similar bar of unmagnetized iron or steel can also be magnetized simply by aligning it in a north and south direction and striking it lightly with a hammer. This bar also will possess magnetic properties, set up by the weak energy of the earth's magnetic field, suddenly bolstered by energy supplied by a physical force.

Magnets produced by induction methods described above are called artificial magnets. For industrial purposes, electrical means are used to produce magnets of much greater strength.

The above studies of induction lead us to believe that natural magnets came into being as a result of the action of the earth's magnetic field on the molecular structure of iron oxide substances over centuries of time.

In figure 6, note that the presence in a magnetic field of another magnetic substance, such as a piece

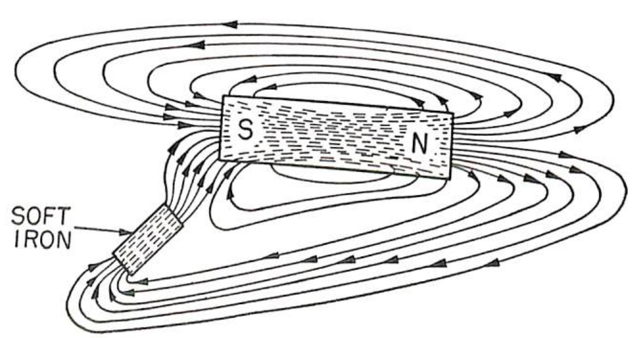
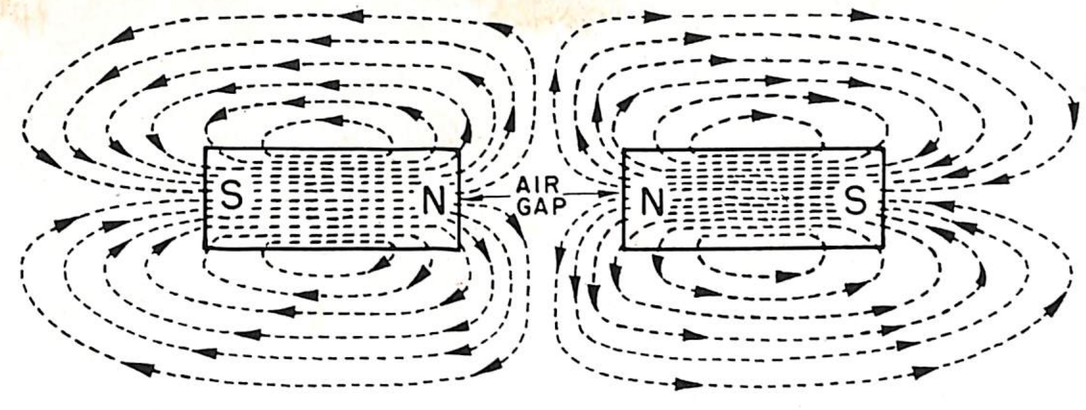
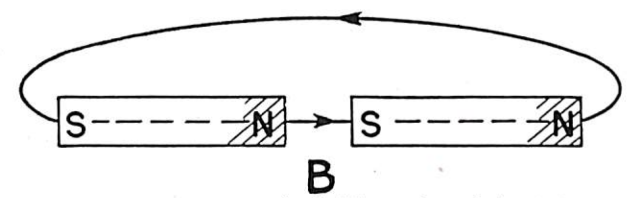


FIGURE 6—*Magnetic field distortion caused by the introduction of a piece of magnetic substance.*



A LINES OF FORCE



B

FIGURE 7—*(A) Magnetic field produced by two unlike N-poles. A similar pattern results when two S-poles are used. (B) Simplified field pattern when unlike poles are used.*

of iron, causes distortion of the field. The lines of force concentrate themselves with the magnetic substance. The reason for this concentration of the lines of force is that the density of the lines—the degree of concentration—is a measure of the magnetic field strength; the field is much stronger within the iron than in the air, because of reasons that have already been discussed. This principle explains the use of pole pieces in meters and motors, when it is desirable to prevent dispersion of lines of force which always occurs when lines of induction leave a magnet and enter the air.

Field distortion caused by bringing like or unlike magnetic poles together is shown in figures 7A and 7B. In figure 7A where like poles oppose one another, it is important to note that no lines of force cross, and that all loops remain intact. The distortion of the magnetic fields shown is caused by the tendency of lines of force travelling in the same direction to repel each other. Like effects are obtained with opposing south poles.

On the other hand when unlike poles are brought together as shown in figure 7B, and the fields are mapped by the use of iron filings, the field pattern is different. Take special note of the lines of force near the adjacent poles. This is the only part of the field where distortion is evident. The tendency of lines of force having approximately the same direction to "repel" one another is indicated by the slight bulging out of the lines of force in this area.

When the magnets in figure 7B are drawn apart, distortion in the area between the adjacent poles become greater. As the distance between the poles increases, the lines of force spread apart more and more, and are soon attracted to the lines of force travelling in the opposite direction in the outer loop which, in turn, begins to show distortion, as shown in figure 8A. Eventually these lines of force on opposite sides of the loop tend to draw together until they finally merge to form a figure-eight shape, then separate to form two smaller but independent loops as indicated in figure 8B.

The same field effects and distortions are noticeable when a single bar magnet is broken in two and drawn part. After separation the magnetic field of each magnet will consist of closed loops of shorter overall length than those of the original bar, but the original number of lines of force remains unchanged, so it follows that each magnet possesses the same number of lines of force or magnetism as the original bar. From these findings it is to be concluded that the strength of a magnet is dependent, not upon its length, but upon its cross sectional area.

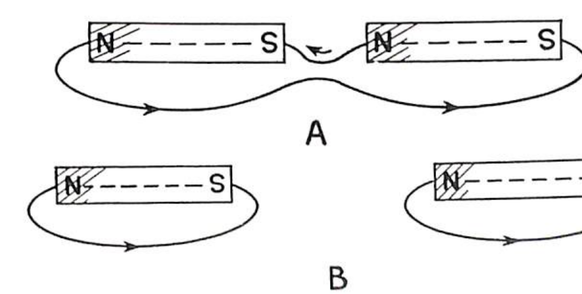


FIGURE 8—*(A) Simple illustration of "attraction" between lines of force directed oppositely. As the magnet is drawn apart, the lines of force pinch in even more until finally the one closed loop is pinched off into two separate loops, as in (B).*

Magnetic field intensity. It is well to remember that the direction of the lines of force at any given point in a magnetic field is the direction a unit north pole would move if placed at that point in the field. The idea of a unit north pole must be taken figuratively, since it is physically impossible for a north pole to exist without its companion south pole of equal strength and opposite polarity; if a magnet is cut in two, there will exist two separate magnets, each complete with opposite poles of equal strength.

The field about a magnet has been mapped with the aid of iron filings. In figure 3, field intensity was indicated by the concentration of the iron filings in the proximity of the poles of the magnet and the direction of the field indicated by the arrangement of the iron filings. Each individual bit of iron was acted upon by the lines of force in the magnetic field, becoming a minute magnet by induction. Its position in the field conformed to the direction of the lines of force at that point.

Direction and intensity of magnetic fields can be studied still better with the aid of a small compass, or pivoted magnetized needle, placed in the same horizontal plane as the magnet. The behavior of this instrument will illustrate that a magnetic field is a vector quantity—a force acting in a certain direction—as shown by successive positions of the compass in figure 9. At any of these positions, note that there are four forces acting simultaneously; one of attraction and one of repulsion at each of the two ends of the compass needle. The resultant of these forces, each of which acts in a different direction, tends to turn the compass needle about its pivot axis until the opposing forces are equal. The compass needle is then tangent to the line of force. The north end of the compass indicates the direction of the lines of force at that point in the magnetic field. By placing the compass at different positions, the intensity and direction of the magnetic field can be mapped with considerable accuracy. It should be remembered, that the earth's magnetic field is always present, so that the field indicated by the compass is the resultant of the combined fields of the earth and the local magnet. The effect of the earth's magnetic field, however, will be negligible if the magnet is strong enough. In any case, the data can be corrected for the earth's field.

On careful examination of figure 9 B, it will be seen that the resultant force acting on the south pole of the needle is greater than that acting at the other end. This is because it is nearer the north pole of the magnet, and the attraction vector, which comprises most of the resultant, is slightly larger than the repulsion vector at the other and more distant end of the needle. The result is an unbalanced force tending to move the needle toward the nearest pole of the magnet. Moreover, the two resultants do not lie quite in the same straight line, so that there is a small unbalanced force acting at right angles to the needle and tending to draw it sidewise. If the needle is free, as when it is mounted on a floating cork, for example, it moves both longitudinally and transversely toward the attracting magnet. Similar motion also takes place when an unmagnetized piece of iron is near a magnet, or, in general, whenever there is a non-uniform magnetic field. Then a motion occurs in the direction of increasing field intensity, or toward the more powerful field in the vicinity of a pole.

If the length of the compass needle is made very small, the difference between the two resultant

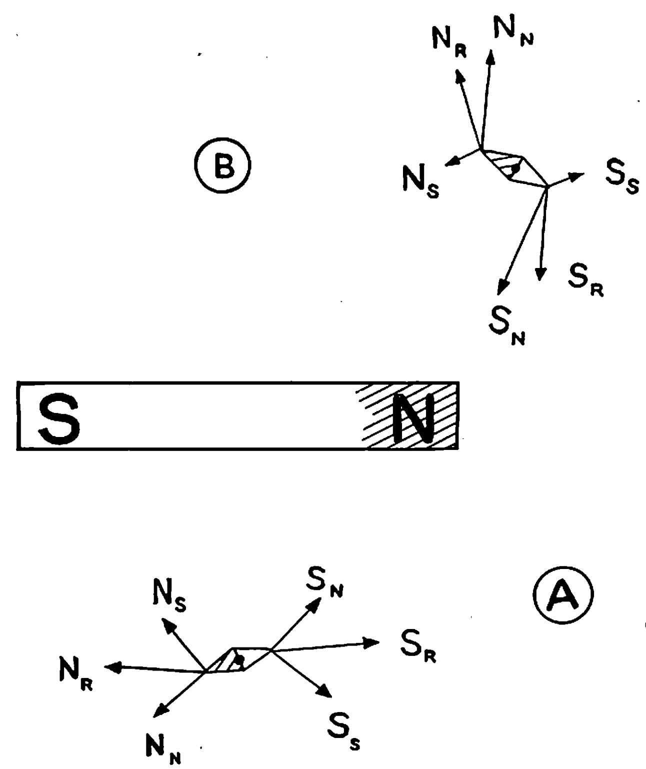


FIGURE 9—*(A) Compass needles indicate field direction and vectors show relative instantaneous effects of the N-pole and S-pole. The force of the bar magnet north pole attracting the north pole of the compass is N_n. The repulsion force between the south pole of the bar magnet and the compass north pole is N_s. The resultant force on the compass north pole is N_r; a similar nomenclature applies to the compass south pole. (B) In the vicinity of the north pole of the bar magnets, the vectors are such that the compass tends to move toward the magnet, and to rotate as well.*

forces becomes negligible, they are oppositely directed, and the needle does not move toward the magnet. This would be the case when any needle is acted on by the earth's field, for it is very small in comparison with the distances to the magnetic poles of the earth. Thus, if a floating magnet were acted on by the earth's field only, we should have rotation, but no translation, which is precisely the action of a compass. The same is true in any uniform field, as will be explained more fully when this action is used in conjunction with meters.

Magnetic flux. Magnetic lines taken as a whole are called magnetic flux. The magnitude of the flux may be expressed as so many lines, and is the actual amount of magnetism present. The density of the magnetic field lines—the so-called *flux density*—is a measure of the magnitude of the magnetic field strength, called the *magnetic field intensity.* It is expressed as a number of lines per unit cross-section area.

The magnetic state of a substance is determined by the alignment of the axes of internal molecular or magnetic-domain magnets. The degree of magnetization becomes greater as more and more axes are brought into alignment with the inducing field. This is, of course, dependent upon the molecular structure of the magnetic material and the ease with which they can turn. Lines of force or flux will induce a state of magnetism in a substance; therefore, it can be assumed that flux is actually produced by a magnetizing or magnetomotive force which can be compared to the electromotive force, or difference of potential, in electrostatics.

The ease with which the magnetic axes within a substance can be aligned in parallel under the influence of an inducing field will determine its degree of magnetization and, therefore, the flux lines it can accommodate per unit of cross sectional area. When alignment of all axes is complete, a condition known as *saturation* exists, beyond which the magnetization cannot be increased.

From figure 6, it has been noted that magnetic substances are capable of accommodating more flux lines per cross sectional area than would pass through a similar area of air. The ratio between these flux densities is called the *magnetic permeability* of the substance.

Magnetic materials. Magnetic materials are divided into two general classes called *paramagnetic* and *diamagnetic.* Those called paramagnetic, 1—are more permeable than air (that is to say, they have greater flux density than air and tend to concentrate such lines of force as may pass through them) and 2—attempt to assume a physical position that will enable the substance to accommodate the greatest possible number of lines along their axis. Those classed as diamagnetic, 1—are less permeable than air, and 2—tend to disperse lines of force by assuming a position at right angles to the direction of the field.

The magnetic permeability of any given magnetic material, except for a few in the paramagnetic group, is a constant which is independent of the strength of the magnetizing field. This means that all materials, whether elements or substances, except those few abnormal ones in the paramagnetic group, have intense internal molecular friction which is why only a relatively few molecular magnets are capable of being aligned with an inducing field.

Materials of the paramagnetic group which behave abnormally under the influence of a magnetic field, have permeabilities which depend not only upon the element or alloy, but also to a great extent upon the strength of the field. The permeability of these substances, therefore, are not constants. Since iron in its purest form is the most abnormal of the group, all materials having this property, including nickel, cobalt and their alloys, are said to be *ferromagnetic.* Several non-ferrous elements and alloys display similar properties: for example, Heusler's Alloy, which is composed of magnesium, antimony, copper and aluminum in various proportions. Under certain temperature conditions, oxygen and gadolinium also develop a strong intensity of magnetization. Ferromagnetic materials are further subdivided into two groups: 1—magnetically hard materials which require a large magnetizing force, and 2—magnetically soft materials, which have high magnetic permeability under relatively weak fields of induction.

Permanent magnets are made from the so-called hard group of alloys which, although very difficult to magnetize, retain their magnetism for a sufficiently long period to warrant classification as permanent magnets. Magnetic hardness, or permanence of magnetism, can be attributed to the rigidity with which the magnetic domains are constrained by the inherently-greater intermolecular friction of such material; although it is harder to align them, once they are in a magnetically-aligned position it is extremely difficult to disturb this alignment. An ideal alloy will retain a higher percentage of the magnetism induced by a magnetizing force and preserve this induction against de-magnetizing influences ordinarily encountered, these two necessary properties being called residual induction and the de-magnetizing or coercive force, respectively.

The magnetic field left in a permanent magnet after the initial magnetizing force is removed is called the *residual induction;* the strength of the magnetic field which must be set up to cancel the residual induction in a permanent magnetic is called the de-magnetizing or *coercive* force.

Materials for permanent magnets are chosen for retentivity based on the amount of coercive force, or magnetizing force in the opposite direction, required for de-magntization. These include hardened carbon or alloy steels containing a small percentage of maganese, chromium, cobalt, tungsten or combinations. Recent trends are toward the use of an alloy of carbon-free steel containing aluminum, nickel and cobalt. This combination, known as Alnico, is much stronger for any given unit of cross section than other materials and will retain its magnetism with such tenacity that it will lift as much as 1500 times its own weight. Due to this strength, Alnico can be utilized effectively in small dimensions and has become prominent in the manufacture of dynamic loud speakers, microphones, telephone receivers, phono-pickups, high voltage ignition magnetos, motors, and other devices.

Permanent magnets are adversely affected by vibration, shock, or extreme changes in temperature and should therefore be treated with care. Electrical indicating instruments containing permanent magnets may lose some of their sensitivity or be permanently damaged by extreme changes in temperature or the shock occasioned by dropping. Alternating-current fields can also have a detrimental effect on magnetism. For example, watches that have become defective by being accidentally magnetized are usually de-magnetized by the jeweler who simply places them in the field of a coil energized by commercial 60-cycle alternating current.

Soft magnetic materials have a high degree of magnetic permeability, and can, therefore be magnetized even to saturation by comparatively small magnetic fields; upon removal from such fields, however, they rapidly lose virtually all of their induced magnetism. These materials can be used to shorten flux paths and thus minimize losses in magnetic circuits, such as exist in meters and motors, by furnishing a path of greater permeability. In each instance, the permeable material increases the total flux by decreasing the flux path in air. Soft magnetic materials are also used as shielding to provide a flux path around instruments or transformers and thus protect them from the undesired magnetic effects of adjacent magnetic fields.

Since soft magnetic materials retain little residual magnetism they are useful in the alternating current field. Silicon steel, for example, is made into thin laminations for power transformers chokes, relay solenoids, etc., and is widely used because of its low cost and generally satisfactory characteristics.

THE EARTH'S MAGNETIC FIELD

The fact that a compass needle, or any other magnet which is suspended and free to pivot, will align itself (generally speaking) in a north-south direction indicates that the earth is surrounded by a magnetic field. The distribution of this field is indicated roughly in figure 10. Note that the magnetic core within the earth may be irregularly shaped, that its length is slightly less than the diameter of the earth itself, and that its axis is displaced approximately 17 degrees from the earth's axis.

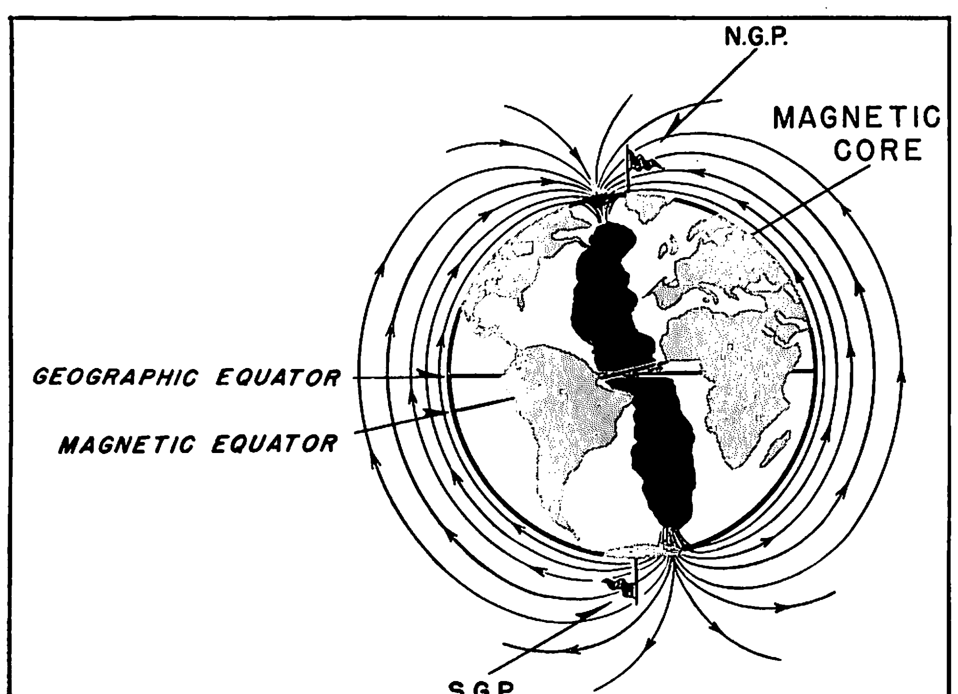


FIGURE 10—*The earth's magnetic field. The inclination of the earth's magnetic axis is approximately 17° from the geographic axis.*

The regions where the lines of force are vertical are termed the magnetic poles. Note that the magnetic lines of force emanate from a region near the south geographic pole and enter the earth near the north geographic pole, and that the direction of the earth's field outside the body of the earth is from south to north. The magnetic pole in the northern hemisphere is actually the south magnetic pole, while the magnetic pole in the southern hemisphere is the north magnetic pole. The reason for this apparent confusion is understandable. The ancient mariner who held a compass or magnet in his hand saw one end of it turn towards the north and called that end the north-seeking pole. He identified the north magnetic pole with the north geographic pole. He had no way of knowing that the north magnetic pole of a compass or a magnet moves in the direction of the field, and that since the earth's field has a south-to-north direction, the north pole of a compass or magnet points to the earth's south magnetic pole which is near the north geographic pole. For practical purposes, of course, one never considers the earth as a magnet, but follows tradition and calls the magnetic pole in the northern hemisphere the "north magnetic pole." If this is remembered, no confusion should exist when reference is made to the magnetic and geographic poles.

The north magnetic pole is located near Ross Sea, Antarctica, in the region of the south geographic pole and the south magnetic pole is located on Boothia Penninsula in northern Canada, almost directly north of Omaha. Recent magnetic surveys have demonstrated that the earth's magnetic lines of force are vertical not in one particular spot, but occur that way in several regions within an area of several hundreds of miles.

An irregular line varying in latitude from 15 degrees S. in South America to 20° in Africa represents the earth's magnetic equator. See figure 10. On this imaginary band encircling the earth at points equidistant from the magnetic poles, the earth's magnetic lines of force are horizontal. At any other place on the earth's surface, the magnetic field will have a vertical as well as a horizontal component. This can be measured by means of an instrument called a *dip circle,* which is simply a needle of magnetic material that is balanced perfectly on a horizontal axis before it is magnetized. Being in neutral equilibrium with gravity, it will only move when activated by the earth's magnetic field. When a dip circle aligns itself with the earth's magnetic field in a north-south direction, its position indicates the vertical angle of the lines of force composing the field. This angle varies from zero degrees or horizontal at the magnetic equator to 90° or vertical at the magnetic poles. For example, at New York a dip needle would point downward at an angle of 72° with the horizontal: this angle is called the *inclination,* or *angle of dip.*

A compass used for navigation or for geographic indication utilizes only the horizontal component of the earth's magnetic field. Since the earth's field has a vertical component as well as a horizontal component at all places other than the magnetic equator, the magnetized indicator of a compass is balanced to off-set the weak torque due to the vertical component. A sketch of a simple compass is shown in figure 11. The indicating part is an accurately-balanced magnetized needle pivoted on a hard metal point with a jewelled bearing to reduce friction to a minimum. Under the influence of the lines of force in the earth's magnetic field, the needle will align itself north and south, the end pointing toward the south magnetic pole is usually painted black and called the north-seeking or north pole. From previous explanations, we know that the south magnetic pole is in the geographic north polar region. With this type of compass, to establish other compass points, it is necessary to rotate the entire instrument until north on the compass card is directly underneath the north end of the indicating needle. Unfortunately, too, it must be placed in a stable horizontal position to prevent erroneous readings caused by the needle rubbing on the compass card. Most compasses of this type have a lock which lifts the needle free of its bearing and locks it in stationary position when not in use and prevents damage to the bearing in case of shock.

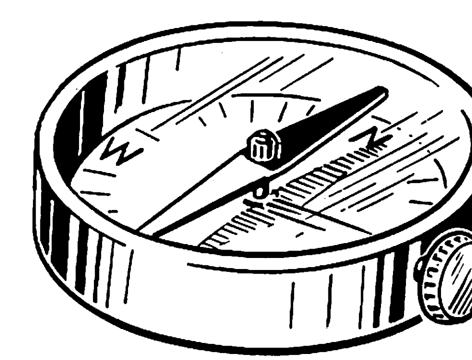


FIGURE 11—*Simple pocket compass with pivot lock.*

The main element in the modern shipboard compass is a properly marked compass card beneath which are mounted several sealed cylindrical tubes filled with magnetized steel wires. These tubes are parallel to the north and south indications on the compass card. The card with these attachments is buoyed and placed on a pivot in a non-magnetic container which is completely filled with a mixture of water and alcohol and then sealed. The card is then free to rotate under the influence of the earth's magnetic field. The container itself is supported on rings and gimbals to permit its maintaining a horizontal position regardless of the ship's pitch and roll.

Since the earth's magnetic pole is approximately 1400 miles from the north geographic pole (see figure 10) the compass will not point true north. The angle that it makes with the geographic meridian is called the *variation* of the compass. For instance, a compass at New York City would point 11½° west of geographic or true north and at San Francisco, 18° east. Navigation charts indicate the amount and direction of the variation.

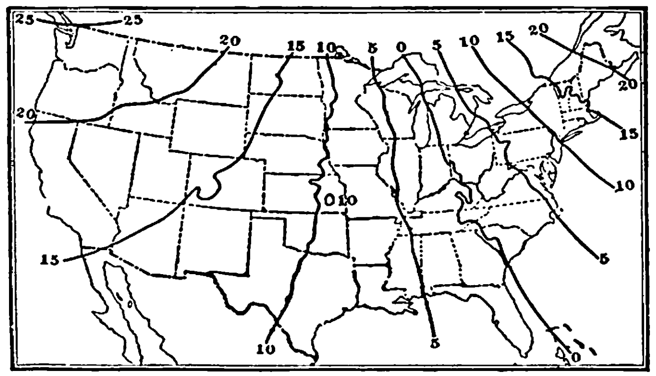


FIGURE 12—*Isogonic lines of magnetic variation for the United States.*

Figure 12 shows a chart of the United States on which lines have been drawn through all points of equal magnetic variation. Such lines are called *isogonic* lines. A line connecting points where the variation is zero is called an *agonic* line. At any point on the earth's surface through which an agonic line passes, a compass needle will point true north.

The variation at any given place on the earth's surface does not always remain the same year after year. Changes occur to some extent over long periods of time. These are called secular or world-wide changes. There are also changes within the year called *diurnal changes,* and changes within the lunar month as well as small daily changes. Large erratic changes occur during magnetic storms and these are sometimes concurrent with the appearance of sunspot activity. Much effort has been expended in attempting to explain terrestrial magnetism and to account for its changes, but too little is known about the magnetic sources within the earth to establish a reliable theory as to the exact nature of the earth's magnetism.

The total compass error aboard ship is the algebraic sum of the variation and the deviation. Variation is the error inherent in a particular position on the earth's surface. Deviation is the error introduced as a result of induced and permanent magnetism in the iron of a ship, and is in turn somewhat dependent upon the orientation of the ship with the earth's magnetic lines of force. Much of shipboard deviation can be compensated for by placing large iron spheres and permanent magnets in the immediate vicinity of the compass mounting structure in such a manner that they will exert compensating polarity effects opposite to those of the ship's magnetic field. This cancellation will leave only a small amount of residual deviation to be figured in calculating the total compass error.

This matter of variation and deviation has been of vital importance to mariners for years on all vessels carrying magnetic compasses, from the lowly freighting schooner lumbering down the coast to the sleek luxury liner smartly hurrying across the Atlantic. Many ships, men and cargoes have been lost because variation and deviation were not taken into account. It is always well to remember that many arts of paramount practical worth depend on the abstractions of physics.

QUESTIONS—PART II—BASIC PHYSICS

1. Given the knowledge of true north, describe how you would determine and properly label two unmarked magnets.

ANSWERS TO PART 10

1. 12-ohm branch, .0833 mhos, 9.163 amps.
   17-ohm branch, .0588 mhos, 6.468 amps.
   53-ohm branch, .0188 mhos, 2.068 amps.
2. Applied voltage of 112 volts.
   Total current of 12.84 amps.
3. 82 ohms = .0121 mhos.
   16 ohms = .0625 mhos.
   25 ohms = .0400 mhos.
   Same at 98 volts.
4. Increase, decrease, increase.
5. 17.4 ohms.
6. Conductance method.
7. 20.9 ohms.
8. 2295 watts.
9. Approximately 50%. No.
10. 18.9 ohms.

AUTOMATIC COMMUNICATION METHODS

By Commander E. H. Conklin, U.S.N.

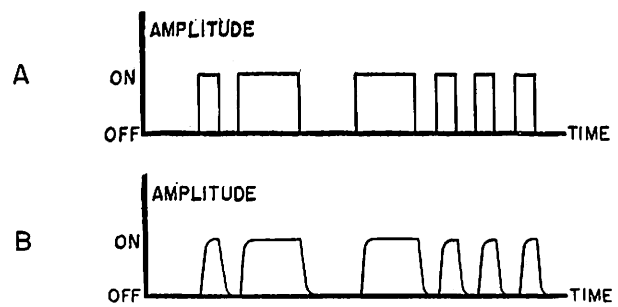
C-W SIGNALS

In view of the widespread increase in radioteletype use in the Navy—including every shore circuit carrying heavy traffic, and with one or more equipments on essentially all large combat ships—it is frequently desirable to review the features of automatic forms of communication.

The basic characteristics of a manually-operated radiotelegraph circuit are widely understood. One man sends dots and dashes, while the other tries to interpret them. The dots are short periods of transmission, spaced by a silent period their own length, while dashes are three times the basic dot-length. When properly spaced, a silent period of three dot-lengths is used to separate characters, and of five dot-lengths to separate words. The letters "a" and "b" are shown in Figure 1(a).

This simple picture turns into a complex picture exhibiting interference to adjacent channels if the dots start and stop instantaneously; for that reason, some kind of signal-shaping network or "key-click filter" is likely to be inserted to slow down the starting and stopping of the radiation—to prevent sharp corners on the oscilloscope picture—in order to reduce the tendency to generate frequencies much higher than the basic keying frequency. Such higher frequencies create interference to adacent radio channels. The rounded-off signals will be something like those pictured in Figure 1 (b).

This operation has introduced distortion into the waveform of the keying signals, inasmuch as the received signal will not exactly duplicate the original keying, but the manual operator may not notice the change until the "gradualness" of the "on" and "off" is stretched out appreciably. However, some things can immediately be appreciated about this distortion:

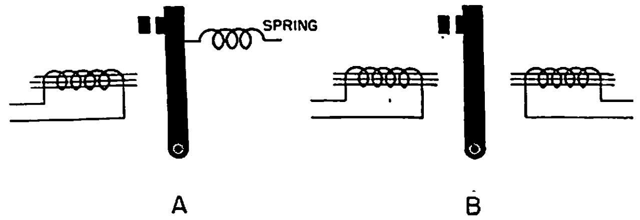


1—As the signal fades up and down, different *lengths* of dots, compared with the space length, will result. This change in the ratio of "on" to "off" in a series of dots is called *bias distortion* in radio teletype terminology, and brings about a reduction of the amount of other distortions that can be accepted before printing errors occur.

2—If the gradualness of the change from "on" to "off" is so much that one "on" starts to run into the next one, or if there are other places in the equipment which appear to react slowly, there may be *characteristic distortion,* which depends on the length of the "on" and "off" signals. This would be a peculiarity of the system—a characteristic of it—and would cause some letters to tend to print incorrectly, but would not make all "off" elements sound like "on" elements, nor the reverse. An example of this is the keying of the Navy's v-l-f transmitters at speeds around 60 words per minute; the antenna builds up to perhaps 1/3 power on dots and full power on dashes; but, although it turns off completely after a dot, it still puts out power for an appreciable time after a dash.

3—If noise clicks and other causes of errors happen occasionally, these create what is known as *fortuitous distortion.* A better name might have been "unfortunate distortion."

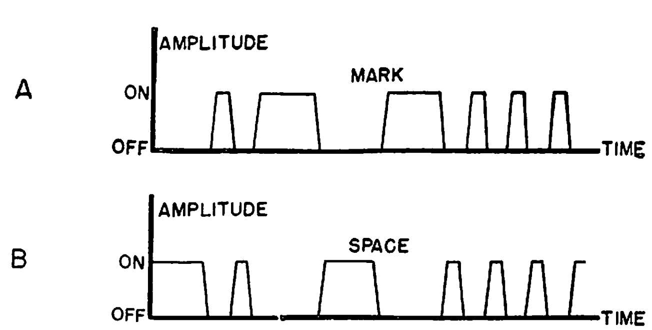
The bias distortion described above is almost bound to happen, even in a perfectly-adjusted system, if on-off transmitter keying is used during fading conditions. Furthermore, the most frequently-encountered type of fading on high frequencies can be attributed to wave interference between a signal that, being reflected from the Kennely-Heaviside or ionospheric layer back to the earth and up again, took the lesser number of "hops" between the transmitting and receiving points, and the signal that took the next greater number of hops. Inasmuch as the distances traveled to the ionosphere and back down to earth are different for the two signals, there may be a change in travel time amounting to as much as 4 milliseconds. This is nearly 20% of the dot length at 60 words per minute, so it is appreciable. When these things happen, the change in apparent starting time for any dot creates a difficult problem for any communication



system which requires synchronized distributors running at each end of the circuits, and even for a "start-stop" system in which the receiving equipment comes to a complete halt at the end of each character and starts on time again with the beginning of the next character. The word "character" here not only refers to letters, numbers, and punctuation, but also to shift, space, and other combinations in the teletype code.

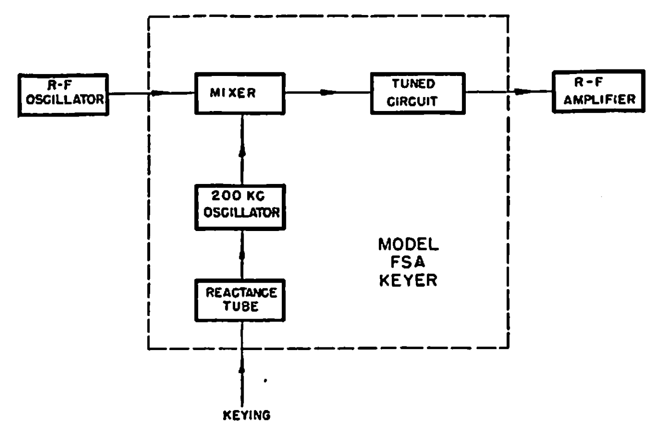
The effects of the changing bias distortion with fading, however, can be reduced. In the ordinary on-off keying system, it may be considered that reception is being effected through some application of an electrical relay—like a telegraph sounder —which has an armature that is pulled down by the signal passing through a coil, and which is restored by the action of a spring in the absence of a signal. This is pictured in figure 2 (A). It will be seen immediately that the restoring of the armature could have been accomplished, if necessary, by passing a current through a second magnet which can replace the spring. This is pictured in figure 2 (B).

Now, should the transmitted signal, which consists of "on" signals and "off" periods, be accompanied on a separate frequency by the transmission of signals sent out during each interval of the first "off" period which is called a "space" signal—it would be possible to provide a second receiving system to operate the restoring magnet. The "on" or "mark" signal in figure 1, then, would still look about the same, as reproduced in the upper half of figure 3, but the "off" or "space" signal would be transmitted as reverse keying, as shown in the lower half of the figure.



It will take only a moment to see that the timing involved will produce a "space" signal equal to the "on" or "mark" signal in approximately one-half the time because the two receiver outputs will become equal at about the midpoint of the time occupied by the gradual change. Furthermore, if *both* signals fade up and down in volume, this point of change-over will tend to remain approximately constant, with the result that the variations in the bias distortion will tend to be eliminated.

This type of keying—the transmission of an "on" or "mark" signal on one frequency, and of an "off" or "space" signal on another—is termed *frequency-shift keying.* Its use has become very general in recent years, because it has removed one of the largest causes of distortion in signals during their transmission and reception, which has previously caused much trouble in producing satisfactory copy of signals with ordinary land-line teletype printers.



FREQUENCY-SHIFT KEYERS

Although a simple manner of producing what used to be called "back-wave keying" could be devised, such as by keying a capacitor or shorted turn in an oscillator circuit in the transmitter, there are advantages in doing it a different way. A few equipments have been used in which the keying operated a reactance-tube that changed the oscillator frequency. This method will be used in the new keyers for TCK transmitters. More commonly, however, the oscillator frequency is shifted approximately 200 kilocycles by the superheterodyne method used in receivers, simply by injecting a 200-kilocycle frequency into a mixer tube that is also fed with the oscillator frequency. Filters can then take out the lower or upper sideband, and the resulting output frequency (off-set 200 kilocycles from that of the oscillator) can be fed into the transmitter. This is pictured in figure 4. With this arrangement, the 200-kc oscillator can be shifted in frequency the desired amount (usually 850 cycles) in a manner that remains the same regardless of the oscillator frequency. Inasmuch as the shift is multiplied by frequency multipliers in the transmitter, it also is desirable to insert a switch that accurately divides the 850-cycle shift by the multiplication factor in the transmitter. This is done in the standard Navy Model FSA Frequency-Shift Keyer. With the key up, the transmitter produces full power output, but on a frequency that differs by 850 cycles from that when the key is down.

With the development of new Navy transmitters containing more stable oscillators, such as the X-TEJ, some circuits will also be designed to accomplish this internal shift whenever desired, and in the standard amount.

FREQUENCY-SHIFT CONVERTERS

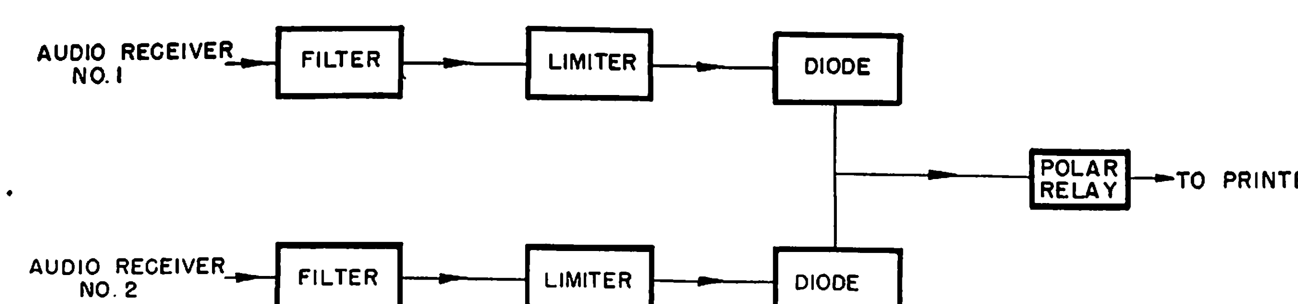
In order to take advantage of the transmission of the "off" or "space" signals (which was not done in the early days when a similar signal was transmitted for other reasons) some way must be devised to produce a change in receiver output that is exactly opposite in the two receiving channels. Originally, this was accomplished by using two separate receivers on the two signals; now, however, the amount of shift or *spread* is reduced to a point where a considerable part of one receiver is used for both "mark" and "space" signals. The early converters, such as the AN/FGC-1 and Navy model FRC, took the audio beat-note output of the receiver, and, by use of two sets of selective audio filters, obtained a *polar* or push-pull reversing d-c output by bucking the rectified output from one filter against that of the other. This detection can also be done effectively with a discriminator circuit like those used in frequency-modulation reception, the main difference being in the linear change of output with frequency desired in f.m., and in the square-topped curve available from the filters. This polar current reverses itself between "mark" and "space" and can operate a polar relay such as type 255-A. The make-and-break contacts of this relay can then key the usual 60-milliampere teletype printer line-current, by the on-off or "neutral" method. The block diagram of this audio type of converter is given in figure 5.

Fortunately the severity of fading of radio signals can be reduced by reception by two independent means, and combination of the results. Reception on two different frequencies accomplishes this, but it increases the chances of interference, and uses more frequencies than should be allowed for one radio circuit. Inasmuch as the fading in spaced antennas occurs at different times, "space-diversity" reception is considered best where there is room for the antennas.

Diversity arrangements can be applied to the above converter by using duplicate systems up to the point of rectification, where the best signal may be selected electronically. Inasmuch as selective fading on high frequencies may reduce the volume of a "mark" signal in one receiver—the "space" remaining loud, and reducing the "space" signal in the second receiver while the "mark" remains loud—it is best to arrange the diversity connection so that the best "mark" between the two receivers operates against the best "space" signal. This is done in the model FRC converter, a form which may become obsolete mainly because of its size and weight. Its performance however, should not be underestimated.

A second type of audio converter could be designed (it has been used in the model CXKJ, an early model of the AN/SGC-1 modulated-tone terminal unit) in which the receiver audio output passes through only one filter, wide enough to pass both the "mark" and "space" tones. The signals are separated in an audio-frequency discriminator, whose midpoint (which does not respond) is tuned to the center of the filter band-pass. A tone higher than that of the midpoint causes direct current to flow in one direction, whereas a lower tone causes it to flow in the reverse direction.

More recently, converters that operate at the intermediate frequency of a receiver—or at other radio frequencies—have come into vogue; these do not have to put up with interference which may result from the audio image created by the beat-note methods of reception. One form—and what may be the best converter yet designed—is the Navy model FRF (similar to the model FRH except for



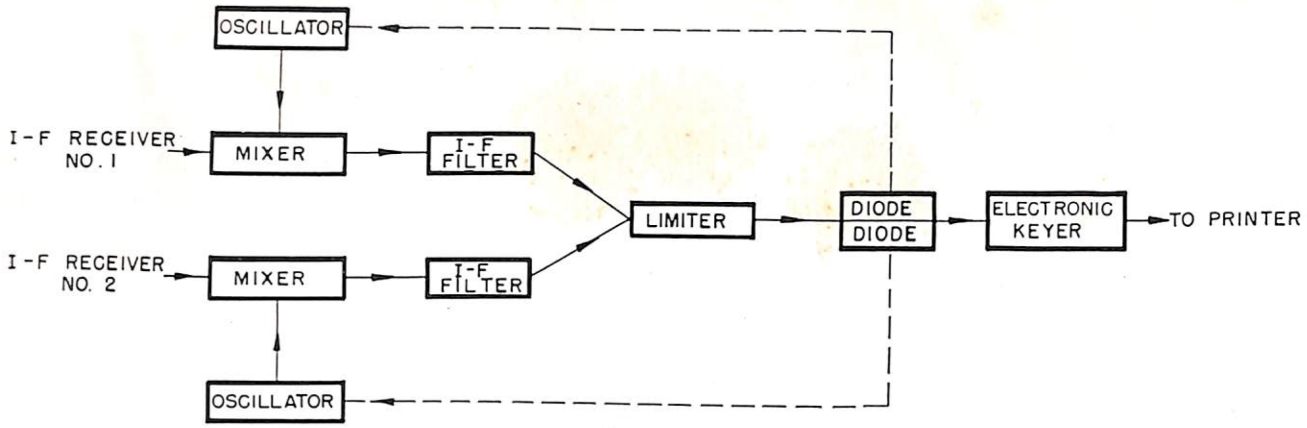


FIGURE 6

the i.f. of the receiver with which it is used). This contains sharp i-f transformers—or filters if you prefer that term—to produce a bandwidth of either 300 or 600 cycles, approximately. These selective stages are followed by the discriminator circuit. The usual electronic complications, however, make the full explanation much less simple: First, the signal from one receiver is converted by superheterodyne methods to 50 kc.; that from any second receiver, as would be required in diversity reception, is converted to a lower frequency. Having two different frequencies going into the effective portions of the converter, it is possible to run them through the same limiter tubes and two discriminators in series, without any trouble. After the discriminators, there is an automatic-frequency-control circuit which works back on the oscillators in the frequency-changing portion, to give a small degree of electronic tuning if the signal does not drift more than about half a kilocycle. A block diagram of this arrangement appears in figure 6.

A common shipboard converter is the model FRA. This contains an i-f amplifier, followed by a locking oscillator which operates into the discriminator. At this point, however, the system becomes quite novel. The discriminator has no dead center, but, because of a condenser across the diodes, has instead a "sliding" center. As a result, it cannot set itself up on a constant "on" or "mark" signal as is transmitted during idle periods of teletype operation. This discriminator connects through a condenser to an audio amplifier, thus "differentiating" the signal and producing an output only during the very short period when the signal *changes* from a "mark" to a "space" (or the reverse); it does not use the part of the signal that remains "on" or "off". The audio amplifier delivers pulses to a counter circuit whose output is alternately turned "on" or "off". An additional circuit is added which makes the converter assume that any constant signal must be "on" or "mark", and that any later pulse must be a change to "off"; if that pulse is not followed, within the length of time of one character at a speed of 60 words a minute, by a change back to "mark," the circuit automatically changes over to "mark" on the assumption that the pulse was interference rather than a desired signal.

MODULATED TONE METHODS

It is also possible to transmit intelligence by leaving the carrier on, and keying a tone. This m-c-w method has been used for the past several years on radioteletype, by modulation of a voice transmitter with a type TH-1/TCC-1 terminal unit. Thus unit provides "on-off" keying of a tone. In the CXKJ, a later model that is to be replaced with the AN/SGC-1, two tones are used in a manner similar to an audio-frequency converter operating on frequency-shift-keying. One tone provides the "mark" signal, and the other provides the "space." The production equipment for shipboard and for harbor circuits will use tones not over 700 cycles, so that the two sidebands of the modulated signal will stay within a 1500-cycle total band, to make its use possible on narrow high-frequency c-w channels, as well as on u-h-hf.

As was recently described in the ELECTRON, a much more complicated modulated-tone system has been in use between major shore stations. In it, numerous tones provide six teletype channels, by what may be termed "frequency-division multiplex" methods. Two tones are sufficient to operate one teletype circuit but the equipment was not designed for space-diversity reception, so fading is reduced in it by operating a second pair of tones on the same teletype channel, thus obtaining a form of "frequency-diversity" action. Because the resulting 24 tones take up quite a slice of the frequency spectrum, one sideband is eliminated from the transmitter by using "single-sideband" methods. The suppressed sideband frequently is used for voice communication, although it could carry six more teletype channels.

FACSIMILE

There are a number of automatic methods which have been proposed and tested, using forms of facsimile or picture transmission. Some of these operate from a teletype tape at the transmitting end, which simplifies use with existing teletype relays; the reproduced copy at the receiving end, at the present stage of development, is not as easily relayed as is teletype tape. Consideration has been given to facsimile methods for obtaining very small recorders in small craft but, with the development of teletype converters and printers weighing in the vicinity of 30 pounds, facsimile methods are receiving a great deal of competition from improved teletype methods, even where weight is a primary factor.

MAY 1948 VOLUME 3 NUMBER 11

BUSHIPS Electron

A MONTHLY MAGAZINE FOR ELECTRONICS TECHNICIANS

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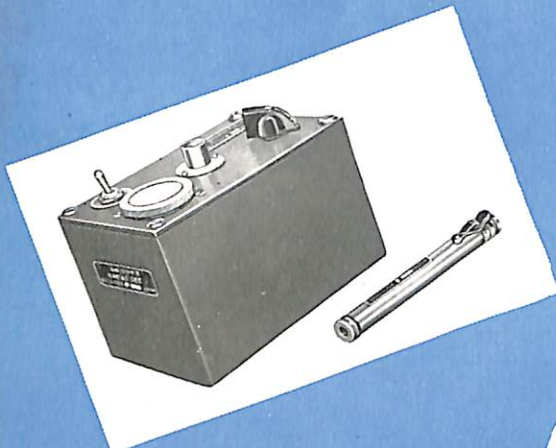
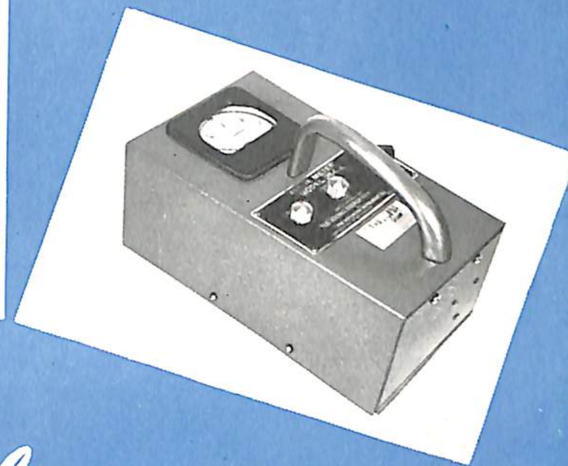
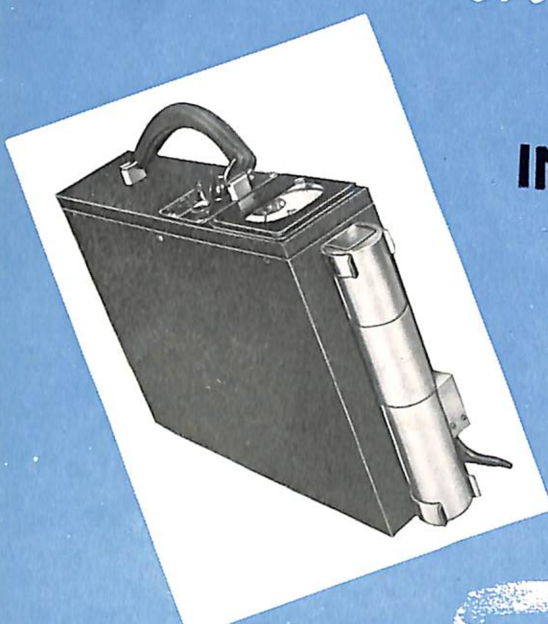
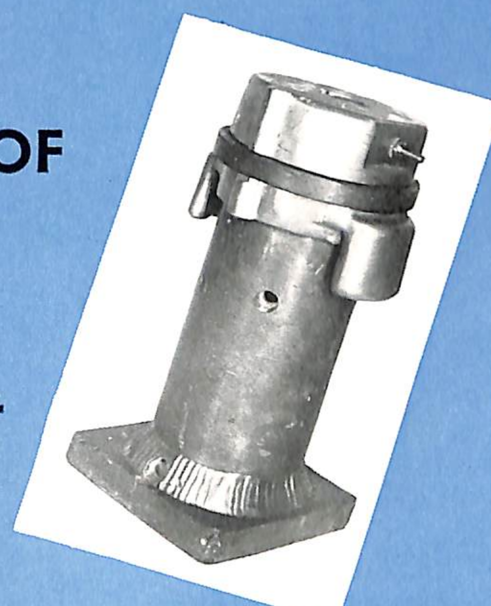




What are these gadgets?

FOR THE INSIDE STORY OF RADIAC





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