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In This Issue...

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Editorial . . .

by John E. Remich

Manager, Technical Department

EXICON—The New X-Ray Technique

Almost every newspaper and magazine contains references to the glowing achievements in present-day electronics. New weapons systems for aircraft, guidance systems for missiles, giant computers, Texas Towers, the DEW line—all these are well-known and much talked about. It is unfortunate that the field of medical electronics does not receive such attention, for advances in this specialized phase of electronics may prove to have far more significance in the course of history.

One of the recent significant advances in this field is EXICON—short for Expanded Image Contrastor—developed jointly by Philco and the Albert Einstein Medical Center. EXICON promises to have far-reaching effects in the field of radiology. All of you are familiar with X-ray photographs, and are aware of their value in the diagnosis of disease. Although such X-ray pictures are invaluable to the physician, much of the story is often not apparent because of the limitations of human vision. It has been shown that the average human eye is incapable of detecting a contrast variation of less than two percent in gray tones. It is, however, precisely these minute variations which may determine the final diagnosis, and EXICON makes it possible to see such variations.

Basically, EXICON vastly enhances the contrast of the familiar gray X-ray photograph by converting such a photograph into electrical signals, which may then be electronically amplified and reconverted to light variations. To further enhance the contrast, the resultant picture is presented in color, with the colors of the spectrum representing different tones of gray. Thus the important minute variations may be easily seen and a more accurate diagnosis made.

Only the future can determine the true value of this technique, but present indications hold forth the hope that another milestone in medical progress has been passed.

"We are experiencing considerable difficulty in securing parts information on the AN/TRC-24 Radio Set. All technical manuals available omit any listing of Air Force stock number, Signal Corps stock number, manufacturer's part number, or any other information which might be used in re-ordering parts. I would appreciate any information that you can supply."

Leo J. Pinz
Philco TechRep Field Engineer

(You are not alone in wishing to obtain parts information on the AN/TRC-24. All available information—which is far from complete—is contained in the SIG 7 and 8 manuals. The manuals available are:

SIG 7 and 8 AN/TRC-24
SIG 7 and 8 OA-483/TRC
SIG 7 and 8 MK-123/TRC
SIG 7 and 8 MK-124/TRC

In these manuals there is some type of stock number for almost every item. Ed.)

"I am interested in obtaining technical data on a noise diode type L-1612 for which the plate current is 0.5 ma. This is to be used in conjunction with the development of a noise generator, to aid in noise figure measurement."

Bennett O'Bannon
Philco Team Leader

(The Lansdale Tube Co., Division of Philco Corporation has provided the information that no other company, to their knowledge, uses the "L" designation for tubes, and that no tube with this number is manufactured by them. However, they do manufacture a noise diode type L-1262A. This tube also has a plate current rating of 0.5 ma and is available from the Lansdale Tube Co. Ed.)

"It is planned to add in the near future courses on transistors, printed circuits, and single-sideband systems to those subjects currently being given. Any information pertaining to these subjects would be most welcome."

F. C. Farrar
Philco TechRep Field Engineer

(There are a number of excellent texts on transistors available. One of these, *Transistors Handbook*, by Bevitt, is currently being used by the Educational Extension Program of the TechRep Division. On the subject of printed circuits, the three pamphlets listed below are available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

"Printed Circuit Techniques"
(Catalog No. C13.4:468)
"New Advances in Printed Circuits"
(Catalog No. C13.10:192)
"Printed Circuit Techniques, Adhesive Tape Resistor System" (Catalog No. C13.4:530)

With regard to single-sideband systems, the December, 1956, issue of the *Proceedings of the Institute of Radio Engineers* was devoted entirely to SSB. Manuals on SSB are also available from the publisher of *CQ* magazine and from the ARRL. Ed.)

A SIMPLE LIN-LOG CURVE CHECK

by T/Sgt. Lee R. Bishop

This article describes a simplified test setup for checking the characteristic of a lin-log MTI receiver.

AT TIMES IN THE COURSE OF MTI trouble shooting, a case of poor cancellation may make a check of the receiver lin-log curve desirable. Since the conventional method of checking the curve requires the setting up of special test equipment, such checks are time consuming and have often been avoided in favor of component substitution. With the method described below, the curve may be easily and rapidly checked with the same equipment that is used to make the cancellation measurements.

The importance of a lin-log curve check in locating a possible source of poor cancellation cannot be overemphasized. This is particularly true in the case of a receiver which uses crystal diodes to supply the lin-log characteristic, because these crystals are extremely heat sensitive and therefore easily damaged.

As previously stated, the following check is made with equipment already on hand. No special connections, networks, etc., are required. The only materials needed are a synchroscope, a piece of ordinary graph paper, and the MTI Evaluator (UPM-41), which is generally near the test bench. Although the check procedure was developed specifically for the CPN-18 receiver, the principle may be applied to any receiver of the same type.

To perform the check, proceed as follows:

1. Calibrate the MTI Evaluator using the procedure in the Technical Order for the instrument. Trigger the MTI Evaluator with the synchroscope trigger.
2. Calibrate the synchroscope so that full-scale deflection is produced by a signal of 10 volts (r.m.s.).
3. Connect the TARGET OUT jack of the MTI Evaluator to the input jack of the MTI i-f strip.
4. Remove the first limiter tube following the detector (V8 in the case of the CPN-18). Removal of the tube is especially important because it prevents the limiting action from affecting the accuracy of the readings. Connect the VERTICAL INPUT jack of the synchroscope to the first grid pin of the limiter tube socket.
5. On the graph paper, let the "X" axis represent decibels with a scale of 1 db per division, and let the "Y" axis represent voltage with a scale of 5 divisions per volt. It has been found experimentally that these proportions offer the best compromise between reasonable graph size and optimum curve presentation. The VOLTAGE scale should run from 0 to 10 volts. The DECIBEL scale should start at —65 db and continue to 0 db. The —65 db level is in the region of minimum discernible signal (MDS) for the average receiver, and well within the linear portion of any curve. Thus it serves as a good starting point.
6. Turn the i-f gain control of the receiver under test fully clockwise. Turn the coho off. Grass should appear on the synchroscope. Set the MTI Evaluator for the operate pulse condition, and adjust the FIXED TARGET RANGE control to position the target at a convenient position on the synchroscope. Do not use the moving target for this check.

7. Starting with the FIXED TARGET attenuator at —65 db, plot the voltage amplitude of the fixed target pulse, as read on the synchroscope, in the correct spot on the graph. A voltage reading should be taken at each decibel setting from —65 to 0 db.

   NOTE: Use only the largest swing of the pulse as measured with respect to the baseline (positive for the CPN-18). Do not measure peak-to-peak amplitude.

Theoretically, when a lin-log function is plotted on a linear graph, the linear part of the receiver curve should be curved and the log part should be straight. In practice, however, the curve will be found to deviate somewhat from the theoretical shape since the crystals only approximate the desired lin-log characteristic. A graph of a typical response for a lin-log receiver is shown in figure 1.

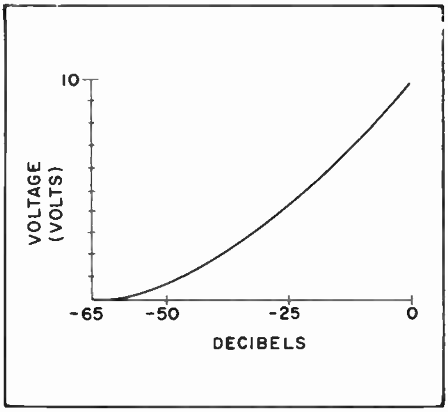

Figure 1. Typical Characteristic of Lin-Log Receiver

This check should be made whenever a new set of crystals has been installed or after the strip has satisfactorily passed a subclutter measurement. The graph obtained may then be used for reference in future performance checks and trouble shooting.

* * *

"What's Your Answer?"

The problem for this issue was submitted by Art Davidson, Philco TechRep Field Engineer assigned as a staff engineer at NAESU.

Given: Twelve batteries. Eleven are 1.5-volt batteries. The remaining battery is higher or lower in voltage than 1.5 volts by a significant amount.

Problem: Using series or parallel battery hookups and a meter, find which battery has the odd voltage, and determine whether this voltage is higher or lower than 1.5 volts. Only three voltage measurements may be made with the meter.

HEIGHT FINDER ALIGNMENT

by Bud M. Compton
Philco Site Engineer

This article describes a few of the errors most often encountered in height-finding radar equipments, the reasons for these errors, and methods of minimizing them. Reference material for detailed theoretical study of these errors is included at the end of the article.

As THE ART of radar height finding becomes more sophisticated, and improvement in equipment increases the attainable accuracy, it becomes worthwhile to reconsider the factors which affect accuracy. The factors which are most often encountered include the following:

1. Mechanical
   a. Antenna level
   b. Gyro level (if stabilized)
   c. Data potentiometers, synchros, etc., for height and angle information relative to antenna electrical axis
2. Electrical
   a. Power supply voltage
   b. Linearity of vertical and horizontal sweeps
   c. Angle marks, range marks, height lines, etc.
   d. Gyro calibration
3. Physical
   a. Earth's curvature
   b. Diffraction
   c. Refraction
   d. Ground reflection[8]
4. Equipment design limitations

This formidable list makes it apparent that academic study of these factors would become extremely cumbersome. Limitations are therefore arbitrarily imposed to the degree which is justified for field applications. Accordingly, the references at the conclusion of this article are given for extended theoretical research.

MECHANICAL FACTORS

Mechanical adjustments must be checked periodically because of antenna tower settling, wear of gears and shafts, and possible cold flow of metal under stress. An antenna out of level by as little as 1/10 of a degree introduces a height error of over 1000 feet at a range of 100 nautical miles. Furthermore, this type of height error is not constant throughout 360 degrees of azimuth. The variation of error is usually sinusoidal, thus complicating the problem. With gyro-stabilized equipment there is the added possibility that the gyro may be out of level. Antenna level is readily checked by use of a spirit level, an item which forms an integral part of many equipments. If the bubble remains centered during rotation of the antenna through a full 360°, then the antenna is level. In the case of gyro-stabilized equipment, the antenna platform must first be leveled, and for airborne radars the aircraft must also be leveled to its average flight attitude.

ELECTRICAL FACTORS

Electrical factors are self-evident and may normally be checked by routine procedures. As an example, sweep linearity may be checked on most equipments by using the presentation on the RHI. For a check on horizontal linearity of the sweep, it may be possible to compare the distance between range marks at short ranges with the distance at long ranges by switching between ranges and making use of scope persistence to note superposition. Vertical linearity is usually adjusted by use of the height mark. Here the height mark counter can be used to compare the vertical distance along, say, the 5-degree angle mark. Linearity exists when this vertical distance is the same from 10 to 50 miles as from 50 to 90 miles, or some other convenient range depending on the radar being calibrated. Errors arising from incorrect electrical alignment can be easily detected by utilizing a list of predetermined check points which gives the proper intersection points of height line with range and angle marks. Naturally, such a check list is prepared consistent with inherent design limitations,of the particular radar.

PHYSICAL FACTORS

Physical factors are the most elusive of all the items affecting field personnel. Diffraction is discussed first, since it is least amenable to compensation. This is the term applied to the phenomenon of the bending of radio waves as they graze obstacles. Television and communications coverage is often increased because of this phenomenon, but it always results in errors for height finders. Diffraction can be calculated when all the variables are known. In practice, however, the terrain surrounding a radar is far too complex to permit numerical evaluation. When a target is picked up under diffractive conditions, its true height will be less than that indicated by the height finder.

Refraction would cause little trouble if it could be measured readily in the air space of radar coverage. It is a function of temperature, moisture, and pressure distribution in the atmosphere, and is therefore a variable quantity. The variations consist of somewhat typical diurnal and seasonal changes, together with extreme fluctuations during abnormal weather. These characteristics of refraction are variable with geographical location. If height errors cannot be attributed to other causes, it is advisable to investigate the possibility of improper compensation for refraction. In order to accomplish this, it is imperative that a

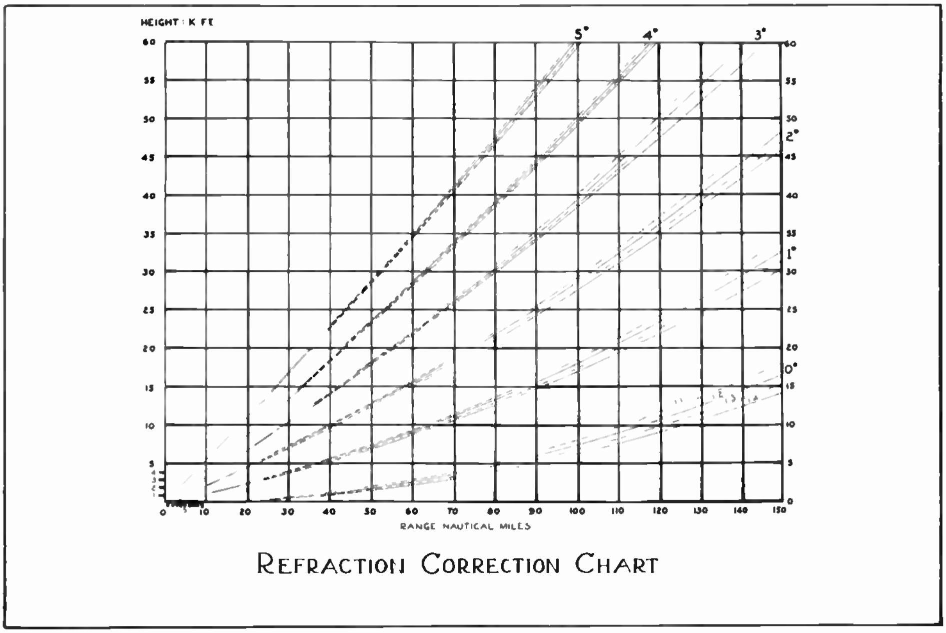

Figure 1. Refraction Correction Chart for Computation of Height Errors

log of all height accuracy checks be kept. Data from the log can be analyzed by using some system such as the chart illustrated in figure 1.

The log entries should include date, time, range, azimuth, indicated height, actual height, error, type of target, and some reference to weather. When interpreting log data it must be remembered that errors caused by out-of-level conditions are a function of azimuth, and that electrical misalignment causes errors which are independent of azimuth. Diffraction occurs only with grazing paths, and refraction varies with time, while all of the previously mentioned factors are independent of time.

The style of the accompanying chart was chosen to match the presentation of a particular radar (AN/MPS-14). (For sets having curved height lines and/or range marks, the familiar radio horizon type chart may be prepared. On this type of chart the earth's surface is depicted as curved rather than flat.) For each angle of antenna tilt there are four curves, the upper in each group is for $k = 1.1$, the second for $k = 1.2$, and so on through $k = 1.4$. Height ordinates were computed from the generally accepted equation:

$$D = \sqrt{2kah}$$

On solving for h, this becomes:

$$h = \frac{D^2}{2ka}$$

where D = distance to horizon
h = height of target
k = correction for refraction

$$= \frac{1}{1 - a(dn/dh)}$$

$= 4/3$ for standard atmosphere
a = earth's radius (20.9×10^6 ft)
n = refractive index

It should be noted that this relationship is not exact, but that the approximation is accurate enough for current usage with one exception. The equation is derived for zero antenna tilt and remains useful only at small angles. As the range of tilt exceeds several degrees with typical height finders, the refractive correction should be reduced as a function of the cosine of the nod angle, since there is less bending of the radio waves as the angle of propagation departs from being parallel to the plane of constant refractive index. Manufacturers have considered this problem, and some equipments utilize circuitry which varies the refractive correction as the antenna nods.

In using the chart, lightly mark both the true and indicated positions of the target on the chart. The antenna height must be subtracted from each of these readings. If the method of checking height uses an angle[6], rather than a point in space, it is only necessary to note the angle. Now determine which antenna angle on the chart comes nearest to the plotted points or angle. Next, step off (from the curve having the same value of k to which the RHI is calibrated) from this nearest angle group a distance equal to the separation between the true and indicated target positions. This distance is stepped off downward if the true position of the target was below the indicated position. This procedure normally results in the correct value of k. There are, however, times of transitory weather when the value of k will be found to lie outside the four values given on the chart. Whenever this occurs, it is advisable to re-check other possible factors that may explain, or contribute to, indications of extreme refraction. Repetitive checking of known targets by such methods will produce the data required for the determination of typical k values for a given site.

The chart may be used also to obtain check points for RHI calibration to any k value (within its limits). As an illustration, assume that the logs indicate an average summer value of 1.2 for k, rather than the value 1.1 to which the

RHI has been previously aligned. From the chart it can be found that for k = 1.2, the earth's curvature calibration at 0° and 150 miles is very nearly 16,600 feet, rather than 18,000 feet for k = 1.1. Check points at other ranges can be determined in a similar manner; always remember to add the site elevation to all values taken from the chart.

Conclusion

It would seem that height errors should not be tolerated for reasons other than diffraction, refraction, or worn-out equipment. Complacency is often a reason for lack of accuracy. By checking and re-checking, most alignment procedures can be improved to yield greater precision.

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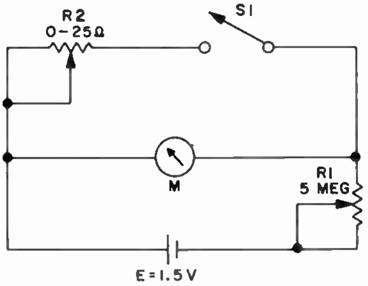
Determination of the Internal Resistance of a Meter

The following procedure provides a simple method by which the internal resistance of a meter can be found.



1. Connect the circuit as shown in the accompanying figure.
2. Set R1 for full-scale meter deflection.
3. Close S1.
4. Set R2 for one-half of full-scale meter deflection.
5. Disconnect R2 from the circuit and measure its resistance.

The measured value of R2 is now equal to the meter resistance, since one-half of the total current now passes through the meter. The accuracy of this procedure may be increased by increasing the value of both E and R1. In this case the ratio of R1 to the meter resistance becomes larger and, insofar as total current is concerned, thus decreases the effect of adding R2 in parallel with the meter.

John Krawczyk

FERRITES FOR WAVEGUIDES

(Editor's Note: This article, which deals with a recent development in the field of microwave electronics, originally appeared in the Digest of U. S. Naval Aviation Electronics and appears here through the courtesy of the Naval Aviation Electronics Service Unit.)

INTRODUCTION

RECENT DEVELOPMENTS in microwave techniques have brought forth a series of waveguide fittings that utilize the unusual properties of some new types of magnetic materials. These materials are ferrites, a family of iron-containing ceramic materials with unusual combinations of magnetic and electrical properties. The new waveguide devices are already being applied in modern fire control radar where the characteristics of conventional TR and ATR tubes prevent full use of millimicrosecond pulse widths needed for high definition.

Ferrites are compounds containing oxygen, iron, and other metals such as zinc, manganese, magnesium, or nickel. As an example, the formula for one of the common magnesium ferrites is $MgO(Fe_2O_3)$. The ferrites are manufactured by mixing oxides of the required materials in powder form, pressing the powder into the desired shape, and firing the shaped mixture at a temperature of about 2000 degrees Fahrenheit. The finished material is a ceramic, and among its properties is that of high electrical resistance since it contains no metallic particles. Ferrites are extremely hard and brittle and cannot be machined. A wide variety of ferrites exist, with varying electrical and magnetic properties.

Ferrites have been used commercially for several years. A nickel-zinc ferrite is widely used in the deflection coils and flyback transformers of television sets, and magnetic recording tape makes use of a type of ferrite in powder form. At low frequencies, ferrites behave like iron alloys, having magnetic permeabilities of from 4 to 3000. Their major advantage is a high electrical resistance which prevents eddy currents and permits their use at frequencies where metallic iron cannot be used.

FERROMAGNETIC RESONANCE

The property of high electrical resistivity permits ferrites to be used at frequencies extending into the microwave region. At these super-high frequencies, resonance occurs within the iron atoms themselves, leading to unusual effects. In order to analyze these effects, it is necessary to delve carefully into the reasons for the existence of the phenomenon known as magnetism.

ELECTRON SPIN

A little known but fundamental property of electrons is that, in addition to their motions around the nucleus of the atoms, they spin on their own axes. This may be compared to the spinning of the earth on its axis as it rotates around the sun. The spin causes the

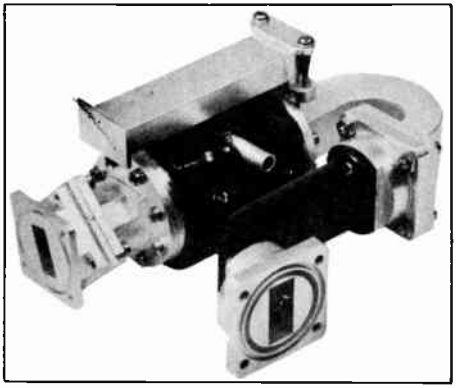


Figure 1. A Commercial Ferrite Isolator Utilizing the Faraday Rotation Principle. The operation of this model is diagrammed in figure 9.

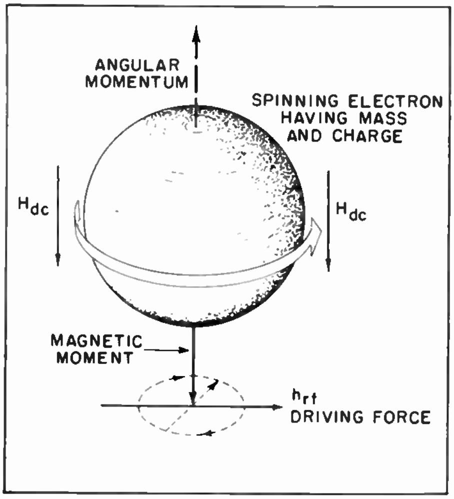


Figure 2. An Electron in a D-C Magnetic Field, with Its Own Magnetic Field Aligned with the D-C Field. The lower circle shows the natural direction of precession.

electrical charge on the electron to set up a magnetic field, as shown in figure 2, with the spinning charge acting like current flowing around a loop. All electrons, therefore, behave like very small magnets.

Atoms of most elements have as many electrons spinning in one direction as the other, so that the magnetic fields of the electrons cancel out or, if there is an uneven number, only one electron's magnetic field is left uncancelled. These atoms do not show any noticeable magnetic effects. Very careful measurements by physicists have shown that about half of all the elements are very slightly magnetic. Even oxygen, when liquefied, exhibits definite magnetic properties.

FERROMAGNETISM

In the iron atom, an unusual arrangement of electrons leaves four more electrons spinning in one direction than in the other. The uncancelled magnetic field of these four electrons leaves the iron atom with a strong magnetism. Each iron atom is a basic permanent magnet. Since the prefix *ferro* means iron, a magnetic effect caused by the magnetism of iron atoms is known as ferromagnetism.

GYROSCOPIC ELECTRONS

As a consequence of their spinning motion, electrons behave like very small gyroscopes. If a force is applied to the electron to tilt its spin axis, it will behave like any other gyroscope, and precess, or wobble. This may be illustrated by experimenting with a gyroscope and stick, as shown in figure 3. Normally, even with the gyroscope spinning, the stick will hang straight down, because of gravity. If one tries to move the stick rapidly from side to side, the gyroscope will force the stick to move, or precess, around in a circle in a direction determined by which way the gyro rotor is spinning.

If the stick is pulled to one side and released, it will precess around in a circle. The direction will be determined as before by the rotor, and the natural frequency by the momentum of the gyroscope and the gravitational field. If the force of gravity could be increased, it would be found that the natural precession frequency would increase proportionately. Those who are familiar

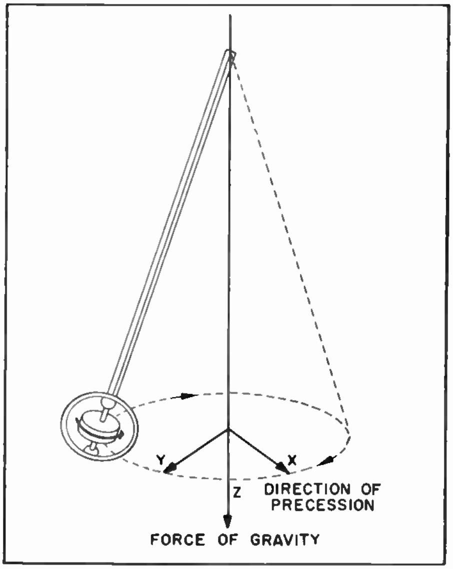


Figure 3. A Gyroscope Mounted on the End of a Freely Pivoted Stick Showing the Direction of Precession When a Force Is Applied in the X Direction

with resonance phenomena will realize that if a rotational force is applied to the stick at just the natural precession frequency, a very large amplitude of motion (or displacement from the vertical) will result, while a force applied at any other frequency will produce a much lower amplitude. Furthermore, if one tries to make the stick move around in the natural direction, the amplitude will build up; but if one tries to make it move around in the opposite direction, the movement will be resisted.

Electrons behave in a rather similar fashion. Since gravity has little effect on the electron, a steady d-c magnetic field may be applied to line up the axes of the spinning electrons. Any precession quickly dies out when this field is applied. If an alternating field is applied at right angles to the steady field, the electrons will wobble, or precess, in the same fashion as the stick and gyroscope do when a sideways force is applied. The natural precessional frequency of an electron in a d-c field is somewhere between 3 and 9 kilomegacycles, depending on the field strength. Thus, if the applied a-c magnetic field is at this natural frequency, the precessional motion will build up and cause frictional damping effects to increase, since the entire iron atom is forced to vibrate. Energy will be extracted from the a-c field and dissipated by heating the ferrites.

FERRITE ATTENUATOR

If a piece of ferrite is placed in the center of a waveguide and a d-c field is applied, as shown in figure 4, frequencies at the resonant frequency of the ferrite electrons will be attenuated, while other frequencies will pass with little attenuation. This resonant attenuation frequency may be varied over a limited range by varying the strength of the d-c field.

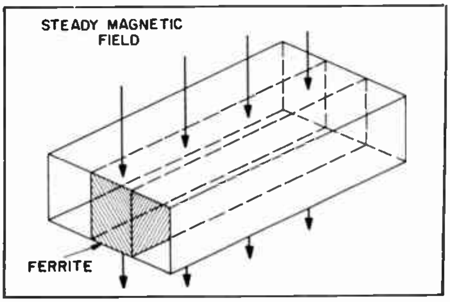


Figure 4. A Ferrite Slab Mounted in the Center of a Waveguide Causes High Attenuation at the Ferromagnetic Resonant Frequency.

ONE-WAY ISOLATOR

An electromagnetic wave traveling along a waveguide will produce, at a point off the centerline of the guide, a rotating magnetic field. This is illustrated in figure 5. When the wave is moving from right to left, the magnetic field at a stationary location, A, will be pointing up, as shown. When point 2 arrives at A, the magnetic field will be directed to the right. Similarly, as points 3 and 4 on the wave arrive at A, the field direction will appear to rotate clockwise. Thus, any point off the center of the waveguide will see a rotating magnetic field as the electromagnetic wave goes by.

By applying this same analysis to a wave traveling from left to right, it can be demonstrated that the magnetic field at A will rotate counterclockwise.

Assume that a piece of ferrite can now be placed in the waveguide at A, as shown in figure 6. The d-c magnetic field is applied, and either the magnetic field strength or the microwave frequency is adjusted to make the ferrite's electron resonant frequency equal to the microwave frequency. Under these con-

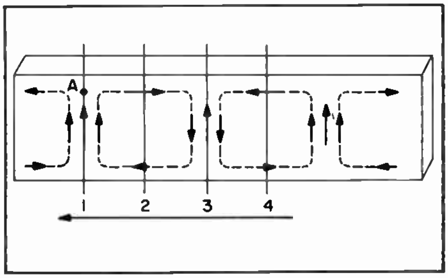


Figure 5. Stationary Point A, Off the Centerline of the Waveguide, Sees a Clockwise Rotating Magnetic Field as Points 1, 2, 3, and 4, on the Moving Wave Pattern, Go Past.

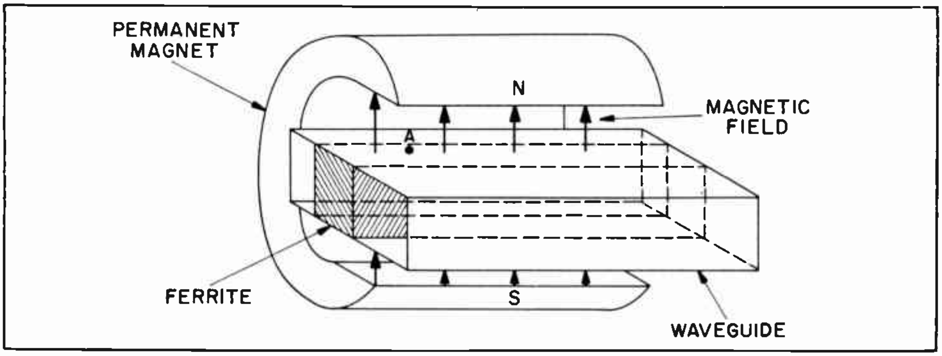


Figure 6. A Ferrite Slab, Mounted at the Off-Center Point A, Will Act as a One-Way Device.

ditions, a wave traveling along the guide from left to right will act as a rotating force on the electrons in the iron atoms in the direction of natural precession. The precession will build up to a very high amplitude and cause the power absorbed from the electromagnetic wave to be dissipated in the ferrite as heat.

A wave traveling from right to left will not suffer much attenuation. Its rotating magnetic field will attempt to push the electrons around in the opposite direction to their natural precession and no large movements will occur. Thus a wave traveling from left to right will suffer as much as a 10-decibel attenuation, but one traveling from right to left will lose only about 0.4 decibel. The above is a rather simple isolator, consisting of a short piece of waveguide, a permanent magnet, and a piece of ferrite.

FARADAY ROTATION

When microwaves are passed through a piece of ferrite in a magnetic field, another effect occurs. If the frequency of the microwaves is well above the ferrite's electron resonant frequency, the plane of polarization of the wave will be rotated. This is known as the Faraday rotation effect, and is illustrated in figure 7. A rod of ferrite is placed along the axis of the waveguide, and a d-c magnetic field is set up along the axis by a coil. Suppose a wave entering at the left end is vertically polarized. As it enters the section containing the ferrite, it will set up limited precession motion of the electrons. The magnetic fields of the wave and the precessing electrons interact, and the polarization of the wave is rotated. Upon leaving the ferrite, the wave is polarized at a 45-degree angle if the correct length of ferrite has been selected.

A more accurate explanation of the Faraday rotation may be given by considering the linearly polarized wave as the sum of two circularly polarized waves rotating in opposite directions. The component wave that is rotating in the same direction as the natural precession motion of the ferrite electrons will have some of its energy absorbed, while the counter rotating component will not lose energy. This causes the velocity of propagation for the former component to be somewhat less than for the latter, and the plane of polarization is rotated in the direction of the faster moving wave. For any type of ferrite, the angle of rotation is proportional to both the ferrite length and the strength of the d-c magnetic field. It does not depend on frequency.

The most important effect of the Faraday rotation is that the direction of rotation depends only on the electron spin in the ferrite, so that a wave going past the ferrite rod in figure 7 will always be twisted as shown, regardless of which direction it is traveling. The direction of rotation may be changed by reversing the d-c magnetic field in the ferrite.

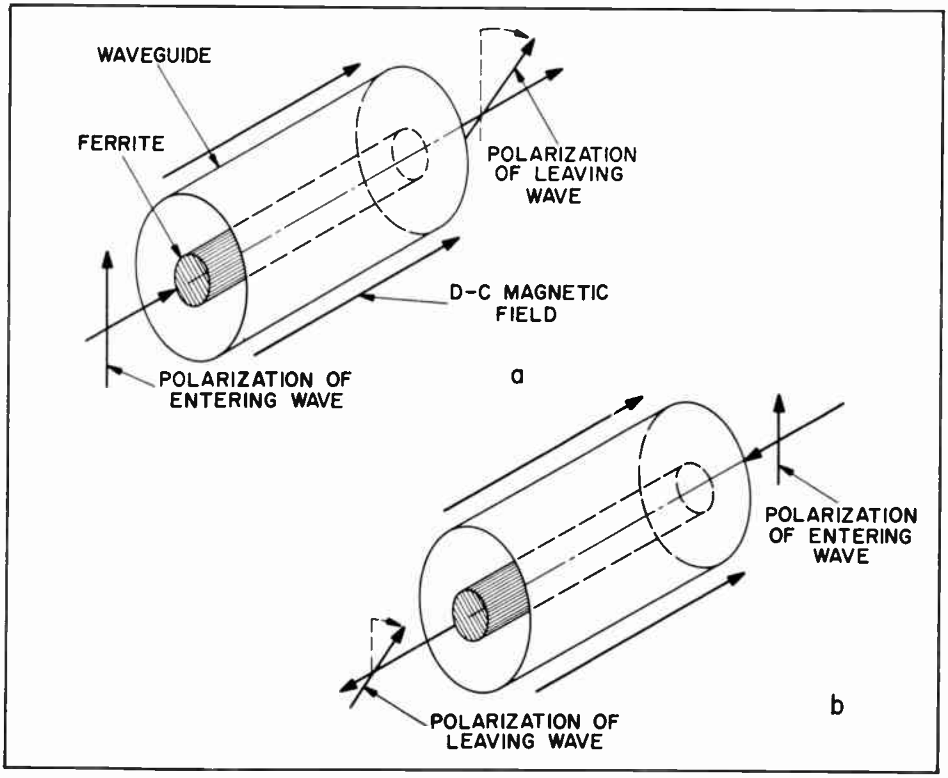


Figure 7. Faraday Rotation Occurs as the Wave Travels Past the Ferrite Rod. The plane of rotation is always shifted clockwise as viewed from this angle, regardless of which way the wave travels.

FERRITE ISOLATOR

A practical device utilizing the Faraday rotation is shown schematically in figure 8. A plane-polarized wave traveling in the guide goes through a rectangular-to-round waveguide transition. As the wave passes the ferrite, its plane of polarization is rotated 45 degrees clockwise, and enters the rectangular output waveguide, as shown in part a of figure 8. However, if a wave travels through the guide in the reverse direc-

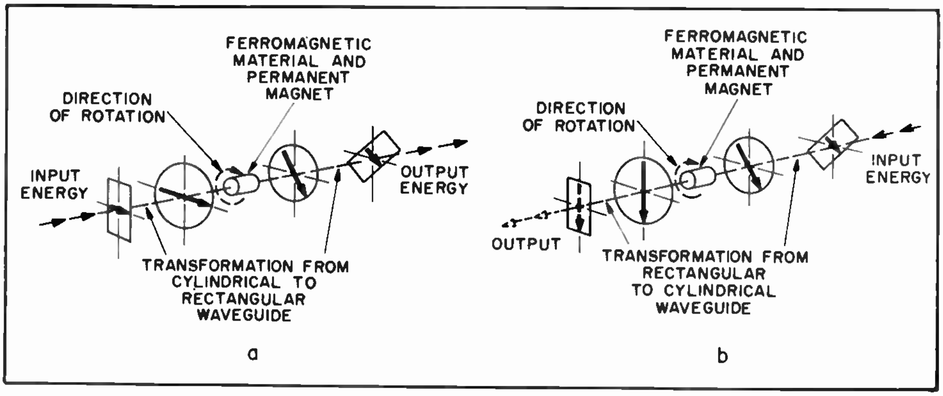


Figure 8. Ferrite Isolator. Part a shows the action of a wave traveling in the forward direction, while part b shows a wave being attenuated in the reverse direction.

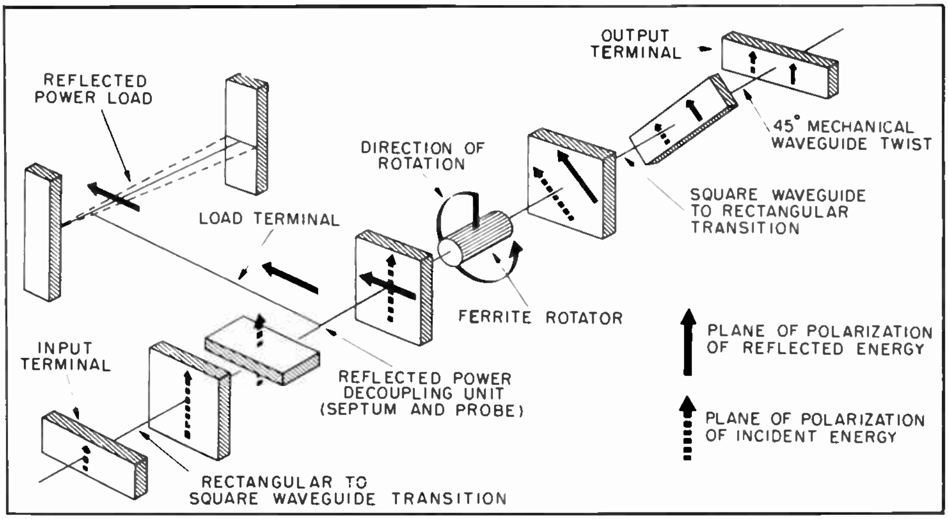


Figure 9. Ferrite Isolator with Separate, Reflected-Power-Absorbing Load. The ferrite section is set up to twist the wave polarization 45 degrees.

tion, it will also be rotated 45 degrees clockwise, as shown in part b of figure 8, and will be at 90 degrees to the plane of the rectangular output waveguide. The waveguide cannot accept this cross polarized wave, and the energy will be reflected. Properly oriented vane type absorbers will absorb this energy without affecting waves traveling in the forward direction.

In isolators designed to handle high power, the reflected wave — after its polarization is rotated—can be coupled out to a separate power-absorbing load. A commercial isolator of this type is shown in figures 1 and 9.

Isolators of the Faraday rotation type are capable of handling more power than the ferromagnetic resonance type, since the reflected energy does not have to be dissipated in the ferrite. Some modern isolators of the Faraday rotation type can provide 30 db attenuation in the reverse direction for only 0.1 db loss in the forward direction. Most commercial models of this device incorporate a 22½ degree step twist at the input and output waveguide flanges, so that they may be inserted in a plumbing system without causing unwanted twists.

One-way isolators ordinarily use permanent magnets surrounding the center waveguide. These provide the d-c magnetic field along the axis of the ferrite and permit the isolator to be installed as a self-contained unit.

The most important use of the one-way isolator is in keeping reflected energy from the magnetron, where frequency stability is dependent upon the impedance into which the magnetron works. In a typical radar system, a relatively large and possibly time-varying mismatch caused by the scanning antenna is connected to the magnetron by many wavelengths of transmission lines. This condition often causes excessive frequency pulling and a poor spectrum. In fixed-frequency systems, these effects can be minimized by judicious selection of components, and by tuning procedures. However, for tunable systems where frequency bandwidths of about 10 percent are required, these procedures are not usable. The use of ferrite isolators has proved to be one of the most advantageous methods of minimizing

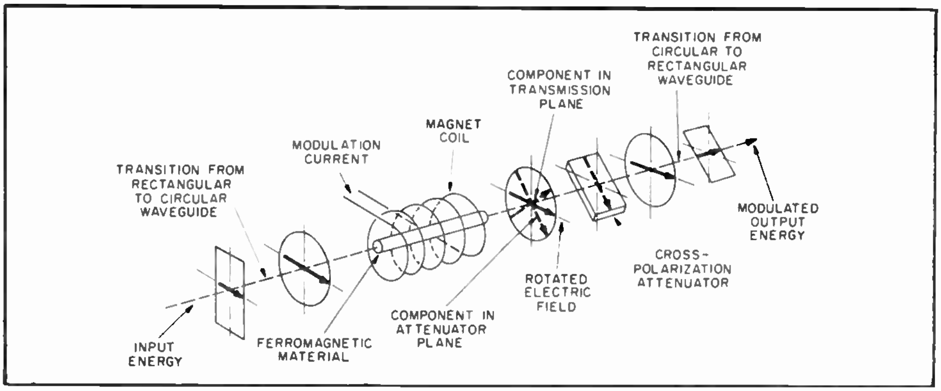


Figure 10. Ferrite Isolator with an Electromagnet, Permitting Variable Attenuation.

the effects of mismatch in magnetron circuits.

VARIABLE ATTENUATOR

An interesting variation of the ferrite isolator can be made by using an electromagnet around the guide, as shown in figure 10. An input wave, entering at the left side, comes in polarized with its E lines horizontal, as shown. If there is no coil current, it will pass the ferrite with no rotation, and suffer an attenuation of 3 db in entering the rectangular output guide that is mounted at a 45-degree angle. If current flows through the magnetizing coil in one direction, the ferrite will twist the wave polarization 45 degrees to the left,.and it will enter the output guide, but will be reflected and absorbed by the cross polarization vane attenuator. This permits the attenuation of the device to be varied from 0.1 to 30 db merely by changing coil current.

This device can be used to produce an amplitude-modulated microwave output merely by feeding the magnetizing coil with the output of an audio amplifier. It permits a wave having a constant frequency and amplitude to be amplitude-modulated with no attendant frequency modulation.

Another important application is in the receiver section of a radar set. A variable attenuator can be placed immediately before the receiver detector crystals. When the transmitter pulse is about to be generated, a step current can be applied to the variable attenuator to cause maximum attenuation. This will protect the crystals before the transmitter pulse hits them, instead of afterwards, as is the case when gas type TR tubes are used. After the pulse, the attenuation can be reduced slowly, protecting the crystals from strong reflections from nearby objects and providing automatic gain control as the range increases. This type of attenuator cannot, of course, protect the crystals from any strong pulses that may enter the antenna from another nearby radar set.

MICROWAVE APPLICATION

Ferrite isolators are a new development and have not as yet appeared in many equipments. In the next few years, however, they will become familiar devices. Typical applications of these isolators are as follows:

1. Load isolation between a microwave source and its load, to prevent reflections from affecting the generator.
2. Coupled-circuit isolation, coupling several microwave circuits to a common output and preventing one source from affecting any other.
3. Modulating microwaves with pure amplitude modulation.
4. Fast action radar duplexers.

When a new development, like ferromagnetic resonators, becomes available to a rapidly expanding field like microwave technology, the many devices that will result cannot be foreseen.

DESIGN CRITERIA FOR MUTUAL INDUCTANCE TRANSDUCERS

(Editor's Note: This article appears through the courtesy of NBS.)

SINCE THE ORIGINAL DEVELOPMENT of the mutual inductance transducer (figure 1) by M. L. Greenough, of the National Bureau of Standards, the device has found increasing application at the Bureau in electronic distance-measuring instruments. The transducer detects extremely minute changes in the position of a nearby conducting plate, and can be made to record such changes with an accuracy of 5 percent or better. This useful characteristic, together with ease of calibration, has led to its adoption in a number of noncontacting displacement gauges for both static and vibratory types of measurements. Examples include an electronic micrometer, a manometer, an oil-film thickness indicator, a vibration pickup calibrator, and others.

Until recently, design analysis of the transducer has been restricted to its immediate use in a particular instrument. However, there has been a growing need for general design criteria for use in future applications. To provide the necessary data, H. M. Joseph and N. Newman, of the Bureau's electronic instrumentation laboratory, have made a detailed study of the device's operating principles, with major emphasis on transducers using highly conducting reference plates. Their investigation was carried out as part of a program of basic instrumentation sponsored at the Bureau by the Office of Naval Research, the Air Research and Development Command, and the Atomic Energy Commission. The results include a number

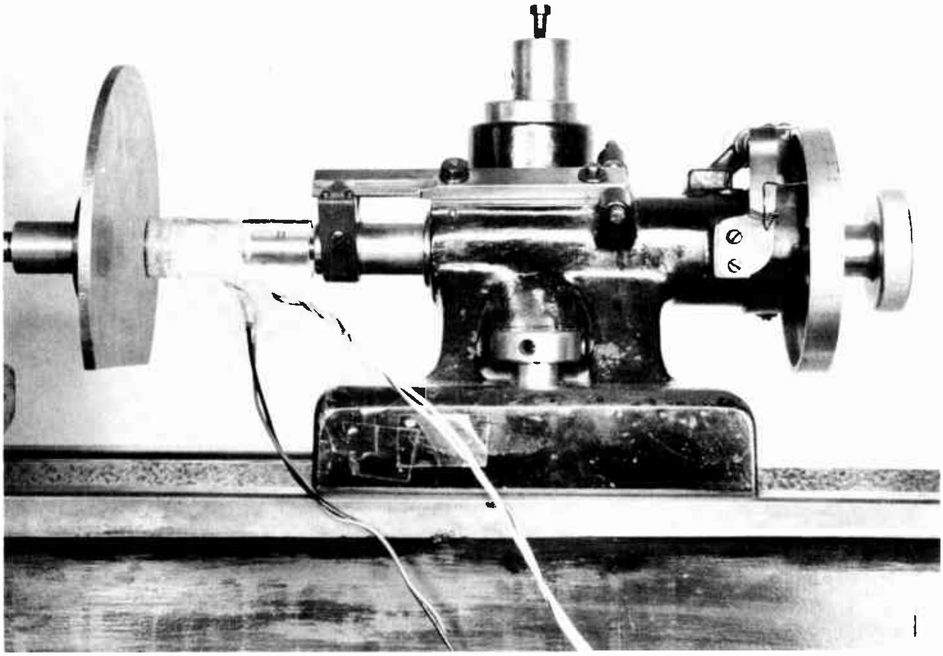


Figure 1. Experimental Setup of the NBS Mutual-Inductance Transducer. Plate at left is reference surface; coils are wound on plastic form. Graduated wheel at right is calibrated for measuring changes in surface-to-coil distance. As this distance changes, mutual inductance between the two coils changes, and can be detected through suitable electronic circuitry and indicated on a calibrated meter.

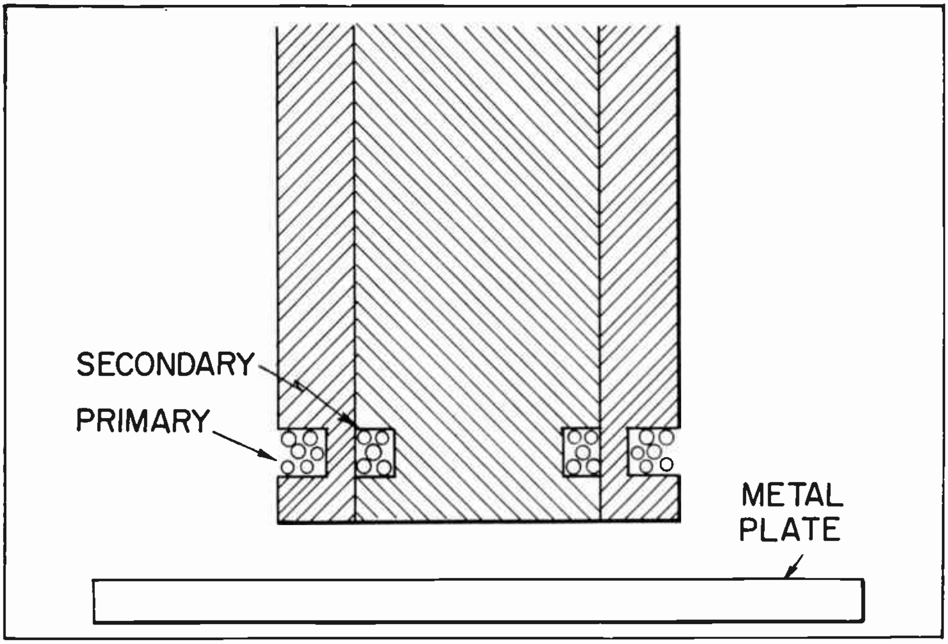


Figure 2. Schematic Diagram of a Typical NBS Mutual Inductance Probe. Both primary and secondary coils are fixed with respect to each other. Metal reference plates may be vibrating, provided that the highest mechanical frequency is less than the electrical frequency of the current energizing the primary coil.

of design recommendations for obtaining optimum combinations of stability, sensitivity, and linearity over the range in which the instrument is to be used.

A typical mutual-inductance probe, as shown in figure 2, contains two coplanar, coaxial coils wound on a dielectric core. An r-f source that is regulated with respect to the product of the frequency and the current energizes the primary coil. The a-c voltage induced in the secondary coil then depends on the distance from the probe to the reference plate. Suitable electronic circuitry detects and amplifies the output voltage from the secondary coil, and this voltage is indicated on a calibrated meter that gives the change in probe-to-surface measurement in inches or centimeters. The instrument is adaptable to very rapid displacement changes; detection of these changes is limited only by the response of the amplifier and by the energizing frequency applied to the probe.

Results of the NBS investigation show quantitatively the change in mutual inductance between two coils when a conducting plate moves toward or away from the coils; see figure 3. The change in mutual inductance can be calculated by use of the theory of images whereby the conducting plate is replaced by an "image coil" that has the same effect as the plate on the mutual inductance between the two coils. Thus a system of three coils is substituted for the system of two coils and plate. The equivalence of electrical and magnetic effects between the two systems allows the use of the image coil in mathematical analysis of the flux-linkage variations. One of the assumptions in this analysis is that the plate is perfectly conducting; in practice, however, plate conductivity is finite. Although detailed studies of conducting plates with finite conductivity have not yet been made, preliminary investigations indicate that if a suffi-

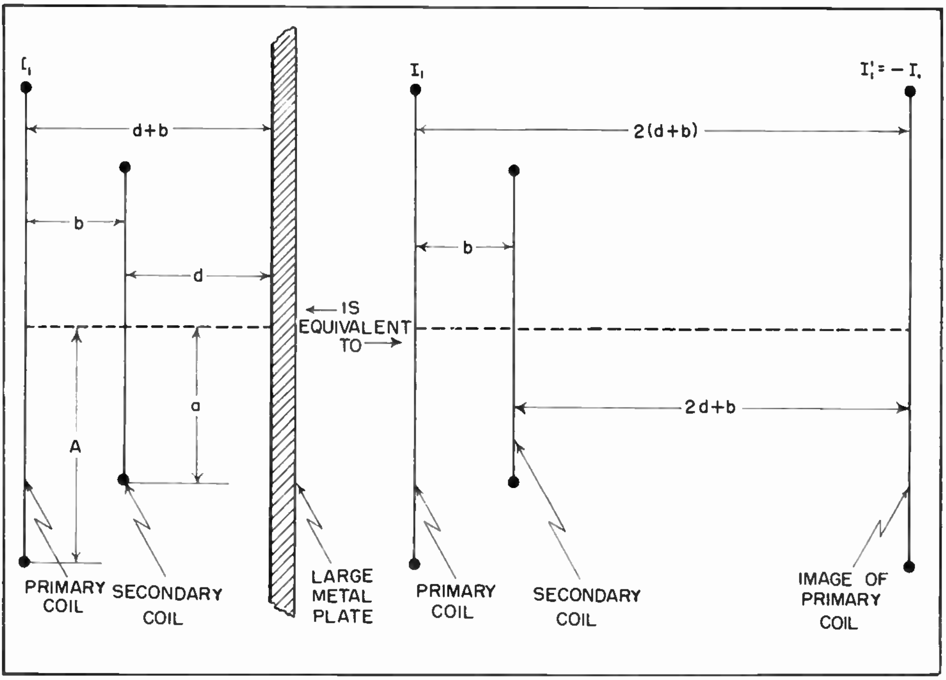


Figure 3. Diagram Demonstrating Theory of Images Used in the Design Analysis of the NBS Mutual-Inductance Transducers with Highly Conducting Reference Plates. At left is the system of two coils and plate; at right is the equivalent system of three coils, where the reference plate is replaced by the image of the primary coil.

ciently high frequency is used, in most applications the effect reduces the instrument's sensitivity by only a negligible amount.

From the analysis made so far, the following design recommendations can be specified:

1. The reference plate should be as nearly a perfect conductor as practicable.
2. The primary or exciting coil should be larger than the secondary coil, to permit greater heat dissipation.
3. If it is not possible for the primary coil to be coplanar with the secondary coil, then the primary coil should be the farther from the plate.
4. The excitation frequency should be as high as possible, provided that the instabilities of resonance are avoided. Although it is true that operation at resonance will greatly enhance the sensitivity, a high degree of sensitivity is not usually a ruling consideration in probe design.
5. The leads to the primary coil and to the secondary coil should be shielded from each other, or should be fixed with respect to each other.
6. The number of ampere-turns on the primary should be as large as possible.
7. The number of turns on the secondary should be as large as possible, provided that resonance effects are avoided.
8. The ratio of the secondary coil radius to the primary coil radius should be as large as possible.
9. The primary coil should be as large as possible. However, for linear response with displacement, it should not be larger than the reference plate.

All of these recommendations refer to probes designed for static measurements. However, no error results from using static considerations when making measurements on vibrating reference plates if the highest mechanical frequency is less than the electrical frequency.

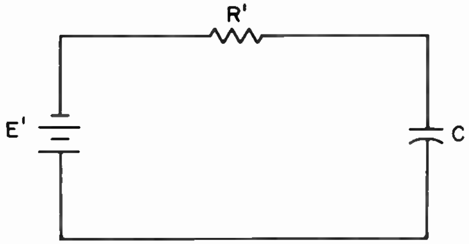
Another aspect of the investigation has been the application of electrodynamic similitude to reduce the amount of experimental work required for the design and construction of probes. Electrodynamic similitude is a method of changing design parameters of a given dimension (such as length or plate conductivity) by a scale factor so that the original output voltage can be maintained by properly altering all parameters of other dimensions. Scaling thus permits a probe of convenient size to be used for experiments, instead of one which is too large or too small for ease of handling or fabrication.

Solution to March-April "What's Your Answer?"

Consideration of the original figure discloses that the final voltage across the capacitor will be 20 volts, a value which can be obtained as follows: the charged capacitor will appear as an open circuit and will impose no loading on R_2 or the source, and the voltage across R_2 (and, therefore, across C) will be determined by simple voltage-divider action. Thus:

$$\frac{E_{R_2}}{E} = \frac{R_2}{R_1 + R_2} = \frac{100K}{500K} = \frac{20}{100}$$

The time required to charge C can be found most easily by transforming E, R_1, and R_2 of the original circuit into an equivalent circuit, by means of Thevenin's theorem. Redrawing the original circuit gives the circuit below, where $E' = \dfrac{ER_2}{R_1 + R_2}$ and $R' = \dfrac{R_1R_2}{R_1 + R_2}$.



The equivalent voltage is thus seen to be 20 volts (confirming the value obtained above), and the equivalent resistance is 80,000 ohms. The charging time constant is, therefore, 8 x 10^4 x 10^{10}, or 8 microseconds. Assuming that C will charge fully in 5 time constants gives 40 microseconds as the answer to the first question.

THE POLAR IMPEDANCE CHART AND ITS USE

This article describes the construction of the polar impedance chart (Smith Chart) and some typical applications of this chart in performing transmission line computations which are of general interest to communications and electronics personnel.

(Editor's Note: This article is substantially the same as that appearing in the "Civil Aeronautics Administration Course Material" and is reprinted here by permission of that agency.)

INTRODUCTION

THE INPUT IMPEDANCE of a transmission line is the impedance that would be seen looking toward the load if the line were cut. The input impedance of a transmission line that is not terminated in its characteristic impedance varies with line length. If the line is considered to be without loss, the variations in input impedance are repeated every half wavelength. Because of the repetitive nature of the input impedance, it can be plotted as a function of line length and characteristic impedance. The appearance of this plot can be made to take any desired form, one of the most easily used forms being that of the *polar impedance chart* or the *Smith chart* (after Philip H. Smith who first developed this type of display). The polar impedance chart relates, in a graphical manner, the input impedance, characteristic impedance, and SWR of a transmission line. The name *polar impedance chart* is used because the display is completely contained in a circle.

CHART COORDINATES

An impedance may be written in several different forms. To give individual information about the resistive and reactive components, the rectangular form is used. If the impedance value is to be represented by a point on a two-dimensional plot, the rectangular form of expressing the impedance suggests one coordinate for resistive components of all impedances and another coordinate for the reactive components of all impedances. The polar impedance chart is basically, therefore, a two-coordinate system of perpendicularly intersecting circles, one system of circles for resistive components and the other system of circles for reactive components of all impedances.

THE RESISTANCE CIRCLES

Inspection of figure 1 and the polar impedance chart shown in figure 10 will reveal a system of circles all of which are tangent to each other at the bottom of the chart and all of which have their centers on a vertical line. Any one of these circles is the locus of all points representing impedances with the same

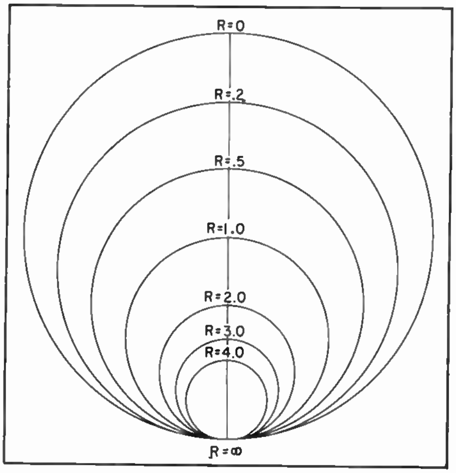


Figure 1. Impedance Chart Showing Only Resistance Circles

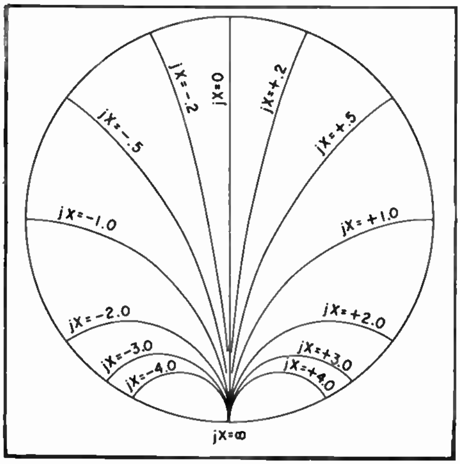


Figure 2. Impedance Chart Showing Only Reactance Circles

resistive components. Any two *different* points on the same resistance circle represent two impedances with the same resistive component but with different reactive components.

THE REACTANCE CIRCLES

Inspection of figure 2 and the impedance chart shown in figure 10 will reveal a second system of circles only certain arcs of which are included on the chart. Each of these arcs intersects each of the resistance circles at right angles. These perpendicularly intersecting arcs of circles are the reactance circles. The positive reactance circles are on the right half of the chart, and the negative reactance circles are on the left half of the chart. Any one reactance circle is the locus of all points representing impedances having the same reactive component. Any two points on a reactance circle represent two impedances with the same reactive component but different resistive components. *Any point on the chart, therefore, represents one and only one impedance value.*

CHART UNITS

It is desirable to use the chart on a variety of problems having different initial conditions. One of the initial conditions that may change from problem to problem is characteristic impedance, Z_0. In order to use the chart in solving transmission line problems involving different values of Z_0, the units used in labeling resistance and reactance circles are in terms of Z_0. Referring to figure 3, consider the following illustration:

If a point on the impedance chart is on a resistance circle of 0.5 and a reactance circle of —1.0, as read on the scales of the chart, this point represents an impedance of 0.5 – j1.0 *in chart units or a normalized value.* To get the actual value of the impedance, the Z_0 of the transmission line must be known. Then the actual impedance value is found by multiplying the impedance in chart units by the characteristic impedance, Z_0. Assume Z_0 in this case to be 50 ohms. The actual impedance is then 50(0.5 – j1.0), or 25 – j50 ohms.

Conversely, if the point representing the impedance 25 – j50 ohms on a 50-ohm line is desired, it is necessary to change the actual impedance value into chart units (or normalize it) by dividing it by Z_0. Thus, in the example above, the chart-unit value of 25 – j50 would be 0.5 – j1.0 if Z_0 is 50 ohms. The point of intersection of the 0.5 resistance circle and the – 1.0 reactance circle would then represent the impedance 25 – j50.

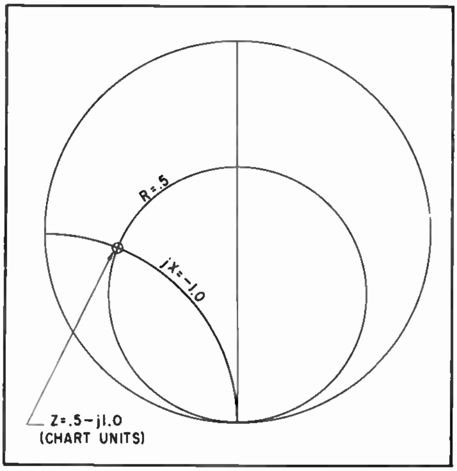


Figure 3. Impedance Chart Showing Location of Impedance Value 0.5–j1.0 (Chart Units)

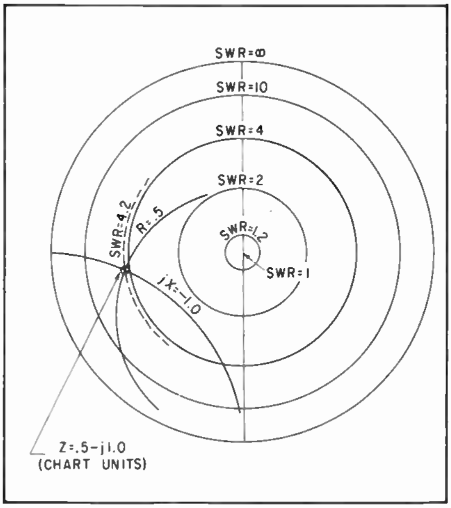


Figure 4. Impedance Chart Showing Standing-Wave-Ratio Circles

STANDING-WAVE-RATIO CIRCLES

The locus of points representing all input impedances of a line that will produce the same SWR on the line is a circle with its center at the exact center of the chart. The system of concentric circles on the chart is therefore SWR circles. Figure 4 shows a few SWR circles. The impedance of the above example, 25 – j50, is found to lie on an SWR circle of 4.2. This indicates that a 50-ohm line with an input impedance of 25—j50 at any point will have an SWR of 4.2. The point in the exact center of the chart represents an SWR of unity, since this point represents an impedance equal to Z_0. The circle forming the outer boundary of the chart is an SWR circle of infinity, since these points represent purely reactive impedances.

WAVE-LENGTH SCALES

The input impedance to a lossless mismatched transmission line varies with the line length and is the same at two points 180° apart. Also the SWR does not vary along the line. Therefore, a physical movement on the line of the point at which input impedance is considered may be represented by a movement of the impedance point on the chart along a constant SWR circle. In going once around the chart on this constant SWR circle, the point representing line impedance has passed through every possible value of the line input impedance, or it has moved the equivalent of 180°. Thus once around the chart represents 180° electrically even though it is 360° physically on the chart. Refer to point P on the chart of figure 5. This is the point which represented the input impedance of a 50-ohm line in the previous example. If the input impedance of the same line were desired at some other point, A, which is 45° toward the generator from P, the point on the chart representing input impedance at P should be moved clockwise (toward the generator) on the constant SWR circle of 4.2 for a distance of 45 electrical degrees, as indicated in figure 5. Note that this 45° electrical distance on the line corresponds to a 90° physical angle on the chart. Likewise, the input impedance at a point B, which is 60° toward the load from P, may be found by moving the impedance point

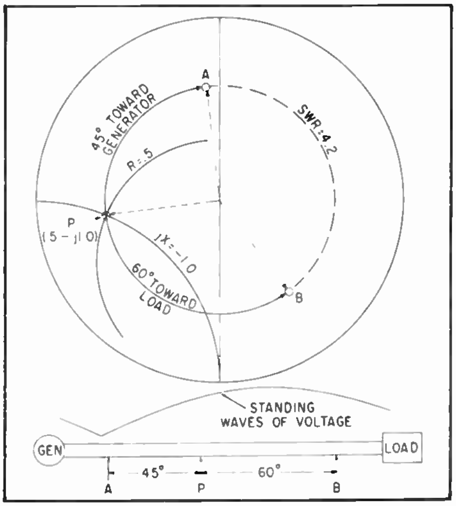


Figure 5. Movement of Impedance Point on Chart to Correspond to Physical Movement of Point Along Line

counterclockwise (toward the load) on the constant SWR circle of 4.2. Note again that this 60° movement on the line is represented by a 120° movement on the chart.

The outer boundary of the chart (figure 10) is calibrated in wave lengths for convenience in measuring off line lengths pertaining to different problems. One set of wave-length scales reads toward the generator, or clockwise, and the other set reads toward the load, or counterclockwise. If line length in electrical degrees is used instead of wave lengths, a protractor may be used, keeping in mind the fact that the chart circumference represents 180°. The scale marked ANGLE OF REFLECTION COEFFICIENT may be adapted to read line length in the absence of a protractor.

VOLTAGE MAXIMUM AND MINIMUM POINTS

The input impedance of a line at a voltage maximum is a pure resistance and is greater than Z_0; actually, $R_{max} = SZ_0$. The bottom half of the pure resistance line (or zero reactance line) represents all such impedances. Thus when a point on the chart representing the input impedance to a line lies on this half of the pure resistance line, a voltage maximum exists on the transmission line at this point. The upper half of the pure resistance line, therefore, represents the presence of a voltage minimum, since a voltage maximum and a voltage minimum are always separated by 90° of line length. The input impedance at a voltage minimum is also pure resistance ($R_{min} = \frac{Z_0}{S}$).

FINDING INPUT IMPEDANCE AT ANY POINT ON THE LINE

The input impedance at any point on a transmission line can be found if the input impedance to the line at some other point is known and if Z_0 and the electrical distance between the known and unknown input impedance points are known. The general procedure, using the chart in figure 10, is to first obtain the chart-unit value of the known input impedance by division by Z_0. Then enter this point on the impedance chart. Note the SWR as read on the SWR scales of the chart. Move the point on the chart on this SWR circle in the appropriate direction and the appropriate amount to locate the point which represents the chart-unit value of the input impedance at the point desired. Change the chart-unit value as read from the chart to actual impedance by multiplying by Z_0. Remember that clockwise rotation on the chart corresponds to a physical movement toward the generator, and that counterclockwise movement corresponds to physical movement toward the load.

EXAMPLES OF PROBLEM SOLUTIONS USING THE IMPEDANCE CHART

EXAMPLE ONE

A 50-ohm line is terminated in an impedance of 30 + j40 ohms. If the line is 60° long, find the value of input impedance.

Solution (refer to figure 6):

1. Change the terminating impedance to chart units by dividing by Z_0. Thus Z_R is 0.6 + j0.8 in chart units.

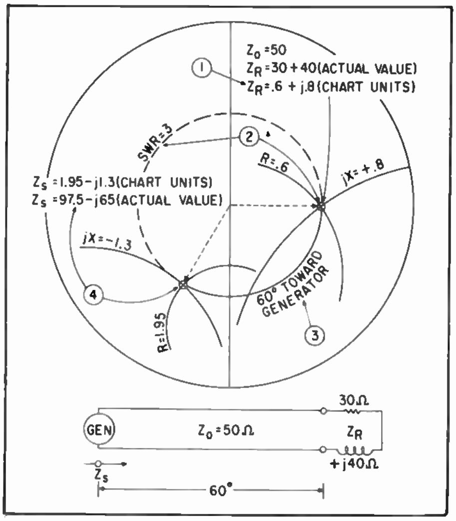


Figure 6. Illustration of the Steps in Solving the Problem of Example One

2. Locate this impedance as a point on the chart on the SWR circle of 3.

3. Move the point along this SWR circle toward the generator (clockwise) for an electrical distance of 60°

4. Read the chart-unit input impedance value at this point on the line as 1.95 – j1.30. Find the actual value of the impedance by multiplying by 50, the Z_0 of the line. Thus Z_s at 60° is 97.5 – j65.0.

EXAMPLE TWO

A 100-ohm line has a standing-wave ratio of 4. A voltage minimum exists 130° from the load. Find the value of load impedance.

Solution (refer to figure 7):

1. Locate the point on the chart representing the input impedance of the line at the voltage minimum. This will be the intersection of the SWR circle of 4 and the top half of the pure resistance line.

2. Move counterclockwise on this SWR circle (toward the load) for an electrical distance of 130°. Read the chart-unit value of impedance at the load of 0.56 + j1.03.

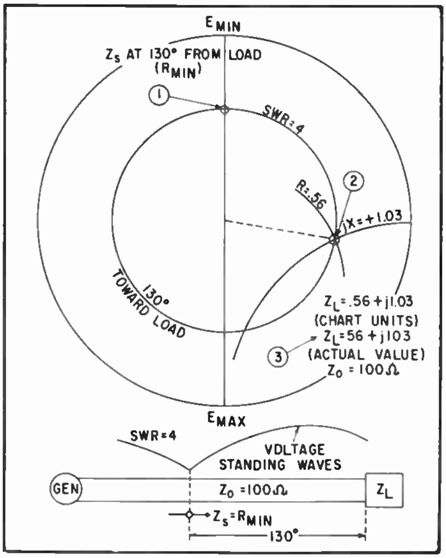


Figure 7. Illustration of the Steps in Solving the Problem of Example Two

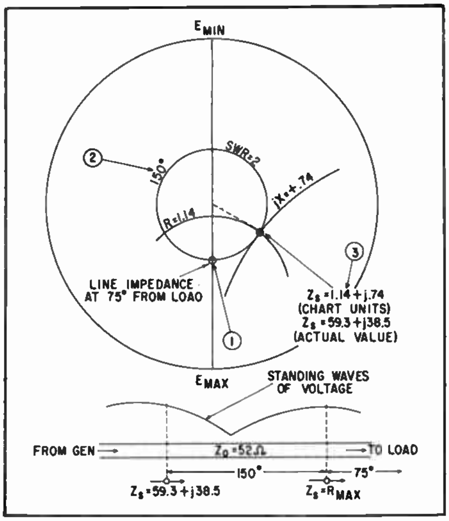


Figure 8. Illustration of the Steps in Solving the Problem of Example Three

3. Multiply this value by Z_0 (100 ohms) to get the actual value of the load impedance: 56 + j103 ohms.

EXAMPLE THREE

A 52-ohm line has an SWR of 2 and a voltage maximum at a point 75° from the load. Find the value of input impedance at a point 225° from the load.

Solution (refer to figure 8):

1. Find the point on the chart representing the input impedance to the line at the voltage maximum. This will be the intersection of the SWR circle of 2 and the bottom half of the pure resistance line.

2. Move this point clockwise (toward the generator) on this SWR circle for an electrical distance of 150° (the difference between 225° and 75°).

3. Read the chart-unit value of the input impedance as 1.14 + j0.74. Multiplying this value by Z_0 (52 ohms) gives 59.3 + j38.5 ohms as the input impedance at the point 225° from the load.

USE OF THE IMPEDANCE CHART IN WORKING WITH ADMITTANCE

The input impedance of a line at a voltage maximum is called R_{max} since it is pure resistance and is greater than Z_o.

The admittance of the line at this point would therefore be a pure conductance and is called G_{min}. Likewise, at a voltage minimum, the input impedance and input admittance are called R_{min} and G_{max}, respectively. When G_{min} and G_{max} are changed to chart units by division by G_0, the characteristic conductance of the line, the points representing them on the chart are on the pure resistance line (or pure conductance line), but in reverse position with respect to the voltage maximum and voltage minimum parts of this line as was found when working with impedance on the chart. Thus to use the chart in problems dealing with admittance, the top half of the pure conductance line represents points of input admittances at a voltage maximum, and the bottom half of this line represents points of input admittances to a line at a voltage minimum. This interchange of the V_{max} and V_{min} parts of the pure resistance line is the only change needed when working with admittance on the chart. Movement along the line is still represented on the chart as a movement of the admittance point on a constant SWR circle. Clockwise rotation represents movement on the line toward the generator, and counterclockwise rotation represents movement on the line toward the load, as was the case when working with impedance. The resistance circles used in working problems in impedance are now considered to be conductance circles when working with admittance, and the reactance circles are now susceptance circles.

It is sometimes convenient to use both admittance and impedance methods in working a transmission line problem. An example of this is the problem of stub matching when the value of load impedance is known. It is possible to do this on the chart and change over at any point in the solution from impedance to admittance, or vice versa, as chart-unit values of input impedance and the corresponding input admittance are always on the same SWR circle and are always physically 180° apart. Thus if either the impedance point or the admittance point is known on the chart, the other can be found by merely extending the line joining the known point with the center of the chart until it intersects the same SWR circle on the opposite side of the chart. This point of intersection is then the other point (the impedance point if the admittance point is known, or the admittance point if the impedance point is known).

EXAMPLE FOUR:

The SWR on a certain line is 4 and a voltage maximum exists at a point 30° from the load. Find the distance from the load to the point nearest the load where the input admittance to the line has a conductance component equal to G_0, the characteristic conductance of the line.

Solution (refer to figure 9):

1. Find the point on the chart which represents the chart-unit value of input admittance of the line at the voltage maximum. This point will be the inter-

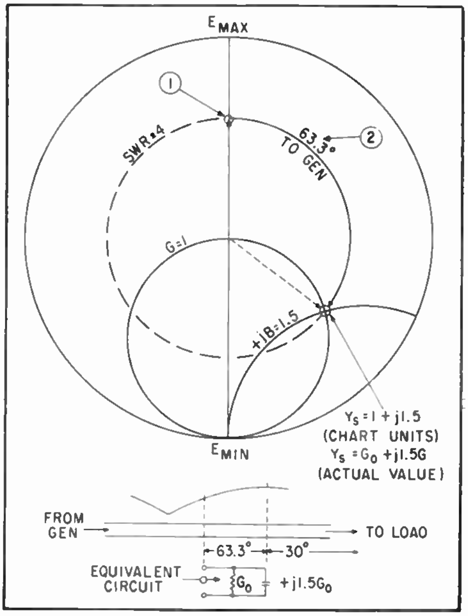


Figure 9. Illustration of the Steps in Solving the Problem of Example Four

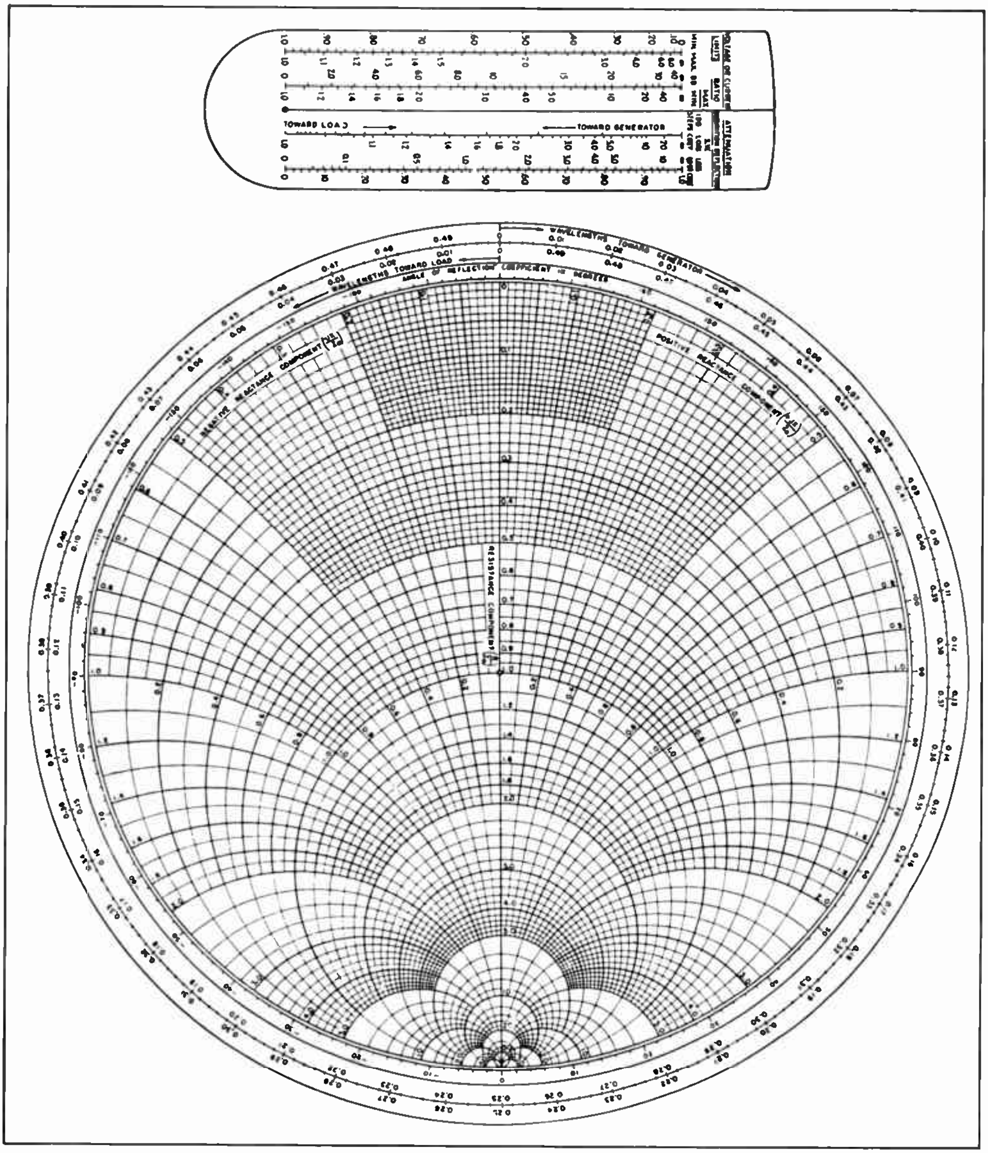


Figure 10. Complete Smith Chart

section of the SWR circle of 4 and the top half of the pure conductance line.

2. Move on this SWR circle toward the generator (clockwise) until intersecting the unity conductance circle. At this point the chart-unit value of the input admittance is 1.0 + j1.5, or the conductance component is equal to G_0 and the susceptance component is equal to $1.5G_0$. Read the distance traveled along the SWR circle as 63.3° from the voltage maximum. Thus the distance to the load from the point found to have an admittance of $G_0 + j1.5G_0$ is 30° + 63.3°, or 93.3°.

RADIO LOCATION OF UNDERGROUND CABLES AND PIPES

by George W. Spooner
Philco TechRep Field Engineer

The task of accurately locating buried pipes or cables may be considerably simplified by the application of radio location methods and devices. This article describes the principles of this method of radio locating and indicates both its good and bad features.

IT IS OFTEN necessary that a buried cable or pipe be located with sufficient accuracy to allow excavation to proceed in the vicinity without incurring damage to the cable or pipe.

Any metal object of appreciable size buried at depths up to 8 feet or more may be easily and fairly accurately located by what is known as the high-frequency (or radio) method of detection. The available commercial detectors operate on a principle which is similar to that of military type mine detectors. However, the commercial detectors are specifically designed for the location of buried pipes or cables, and are therefore more efficient for this particular application.

The equipment consists of a transmitter and receiver which operate in the frequency range between 130 kc and 1 mc. (The equipment used by the author for these tests operated on a frequency of approximately 1 megacycle.) The signal is radiated from a loop antenna which is built around the transmitter case, and which is oriented perpendicular to the ground when in use. The receiver is mechanically attached to the transmitter by a bar approximately 3 feet long, and is thus held rigidly in position with respect to the transmitter. The receiver antenna is also a loop which is built around the receiver case. In operation this loop is oriented parallel to the ground, and is thus in a null position with respect to the transmitted signal field. Figure 1 shows the equipment ready for operation. The equipment operates on the principle that any metal in the vicinity of a transmitted signal will distort the radiated field pattern. The receiver loop, which is then no longer in the null position, will provide a signal output. The received signal will be both aurally indicated in the earphones and visually indicated by a meter provided on the receiver panel. Figure 2 (left) shows the field without a buried object, and figure 2 (right) shows the distorted field when a buried cable is encountered.

The effect of ordinary soil without buried objects is such that there is always a slight warping of the field. In order to compensate for this, the receiver loop antenna is tilted slightly with an adjusting knob to obtain a true null setting under particular conditions of

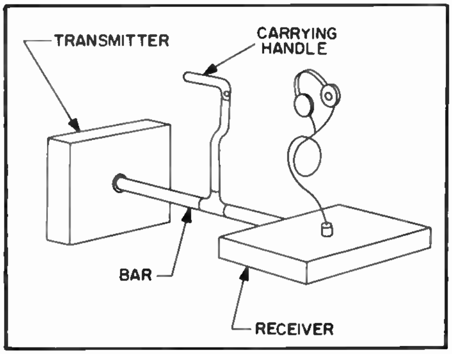


Figure 1. Line Drawing Illustrating Relative Orientation of Transmitter and Receiver

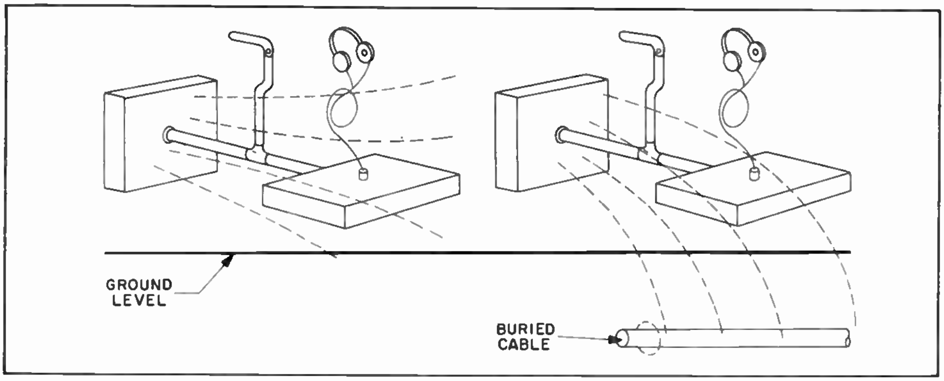


Figure 2. Transmitter Field without (Left) and with (Right) Object Which Causes Distortion

moisture content and type of soil. In actual operation, the adjustment is then turned slightly so that a very weak signal is heard. Any buried object will then be indicated by an increase in signal and a change in pitch. The signal level will be maximum when the transmitter is directly over the buried object, and by decreasing the volume with the volume control provided, it is possible to find the exact location of the object. If the buried object is a pipe or cable, the greatest signal strength will occur when the transmitter loop is directly above the object and is oriented parallel to the run of the cable or pipe. On the other hand, if the object is round or square (such as a manhole cover) orientation of the transmitter has no effect.

Small buried objects will give only a weak indication which will soon be passed over, whereas a buried pipe or cable will give a good indication for several feet on each side. Figure 3 shows a graph of relative signal strength as a buried cable is approached and passed at right angles to its run. This particular cable was approximately 1 inch in diameter, and was buried at a depth of approximately 30 inches.

Smaller cables or pipes may be found at considerable depths, depending upon the proficiency of the operator. Experience is a necessary factor in the understanding and interpretation of the indications.

Once a buried cable has been located, it is often desirable to trace its run. There are two methods for doing this in the field. The first requires that the operator find the position and orientation of the equipment which gives maximum signal. This condition will exist when the transmitter is directly over the cable and oriented in a direction parallel to its run. The operator then carries the equipment slowly in the direction of the cable run. As long as the transmitter is directly over the cable, maximum signal will be indicated. It should be noted that if the cable depth varies, there will be a change in signal strength but the maximum will still be directly over its run.

In the second method, the transmitter and receiver are separated. The transmitter is then placed on the ground directly over the cable. It should stand upright and at right angles to the apparent run of the cable. The receiver is then held face up and level at waist height and moved slowly in the apparent direction of the cable run. A signal

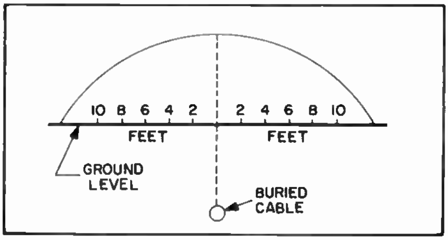


Figure 3. Plot of Relative Meter Indication Versus Horizontal Distance from Object

will be indicated when the receiver is anywhere near directly over the cable. When it is exactly over the cable, there will be a very sharp null. Using this null, the cable may be followed for a distance of 100 to 500 feet without moving the transmitter. The maximum distance in this case is dependent upon the depth of the cable.

With this equipment it is possible to determine the depth of a cable with reasonable accuracy. Using the equipment in the same way as in the second method above, the null directly over the cable is found, and this is marked on the ground. The receiver loop is then rotated clockwise to a 45-degree angle. (Some equipments have a depth gauge which indicates this angle.) With the receiver loop held at the 45-degree angle, it is moved from side to side at right angles to the run of the cable until another null is found. This spot is also marked on the ground. As can be seen from figure 4, the distance between the two marks on the ground is then equal to the depth of the cable.

This type of equipment has been found to be highly efficient in the location of buried cables or pipes, and, with practice and experience, an operator can become highly proficient in its use. The equipment will not find a buried coin or small object, but when used within its limitations, it produces excellent results. It is battery-operated and uses vacuum tubes of low current drain, to ensure long battery life. On some makes of equipment, a switch and meter are also provided on the panel for checking the condition of the batteries whenever the equipment is to be used.

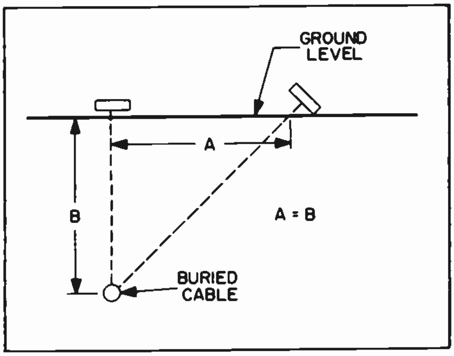


Figure 4. Method of Determining Depth of Buried Object

During tests, it was noted that overhead power lines have no apparent effect on the operation of the set, and it can thus be operated successfully in the vicinity of such lines.

QUALITY CONTROL OF VACUUM TUBES

by Walter Gilbert, Philco Accessories Division,
and Stan Rosen, Philco Service Division

(Editor's Note: This article was written by the authors in conjunction with the Electronics Education Unit of the Philco Service Division, and originally appeared in the February, 1957, issue of the Philco Electronic Supervisor.)

NEW AND MODIFIED type circuits are constantly being designed and developed in the electronics industry. For this reason, the type of tube to be used with these circuits must also be redesigned or improved to meet its new application. Also, the tube manufacturer is always improving upon the type tube in general use, as may be seen by looking through a tube manual.

In this effort to produce newer and better type tubes, the methods of checking the quality and efficiency of these tubes must also be improved upon. To help in preventing tube failure, practically all tubes are put through static life and dynamic life tests as they are produced, in order to check each particular tube under actual working conditions. By the use of these methods, defective or faulty tubes are detected, thereby satisfactorily controlling the quality of the tubes.

However, in some instances these tests cannot fully determine the true efficiency of certain types of tubes. Furthermore, these tests cannot indicate how well these tubes will function after lengthy periods of operation. For this reason, more extensive tests have been devised.

The "beam power pentode" is a good example of a particular type of tube which requires more extensive testing. In television, this type is usually employed as the horizontal output tube because of its high efficiency. In the past, however, a major fault with this type was overheating, which in turn caused short life. Many methods were investigated in an effort to minimize this heating effect, and the most satisfactory method to be derived was the placing of "radiators" within the tube to help in dissipating the heat. Figure 1 illustrates three types of radiators used.

Through further testing, the cause of this overheating was determined. It was found that if the grids within the tube are not properly aligned (screen grid alignment is particularly critical), the tube will draw excessive screen current, thus effectively stealing power from the plate circuit. Such a condition is aggravated by the fact that as the screen grid is overheated by the excessive flow of current, it becomes further misaligned, with complete failure as the end result.

For some time now, a completely new type of test, developed by Philco, has been used. This test determines the dynamic ratio of the plate current to the screen current, and is the most accurate and effective method yet to be devised. Figure 2 is a block diagram of the test setup for this measurement.

The entire test is comparatively simple, and is accomplished as follows: The cathode is maintained at ground potential, and a 100-volt peak-to-peak sawtooth signal at a frequency of 15,750 cps is applied to the grid, which is biased at zero volts. Plate voltage is approximately one and a half to three times lower than the voltage on the screen. Ammeters are placed in both the plate and screen circuits, to indicate the quality of the tubes. Under test, the tube is subjected to these extreme voltage conditions for only 3 minutes. The short time is important, since if this condition were maintained for any length of time, the tube would definitely burn out.

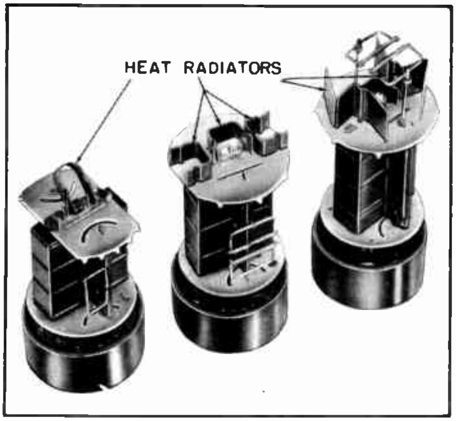


Figure 1. Three Different Types of Heat Radiators Which Minimize Overheating

To obtain the dynamic ratio, the plate and screen currents are checked after 30 seconds of operation, and the ratio of the two readings is computed. Another ratio is obtained after 3 minutes of operation and, providing these two ratios indicate only a slight change, the tube should give satisfactory operation.

The results obtained from a dynamic ratio test of two "beam pentodes," together with the interpretation of the results, are as follows: The first tube, checked after 30 seconds, had a plate current of 252 ma and a screen current of 18.2 ma, making the first ratio 13.3. This same tube checked again after 3 minutes operation had 255 ma in the plate circuit and 19.5 ma in the screen circuit, thus changing the ratio to 13.1. Since the change in ratio is small, this tube will provide normal service. The second tube, when measured after 30 seconds, also checked normal with 265 ma plate current and 19.5 ma screen current, giving a ratio of 13.6. However, after 3 minutes operation, the plate current had dropped to 190 ma, while the screen current had risen to 28 ma. This big change in plate and screen currents drastically reduced the ratio to 6.8, indicating that this particular tube was slumping and would not give satisfactory service. Such a tube is therefore rejected.

From the tests mentioned above, it can be seen that there is a constant striving to maintain and improve the present high quality of vacuum tubes. This fact is evidenced by the presence of suffix letters in many tube type numbers, and also by the development of new tubes to perform the same function as older type tubes.

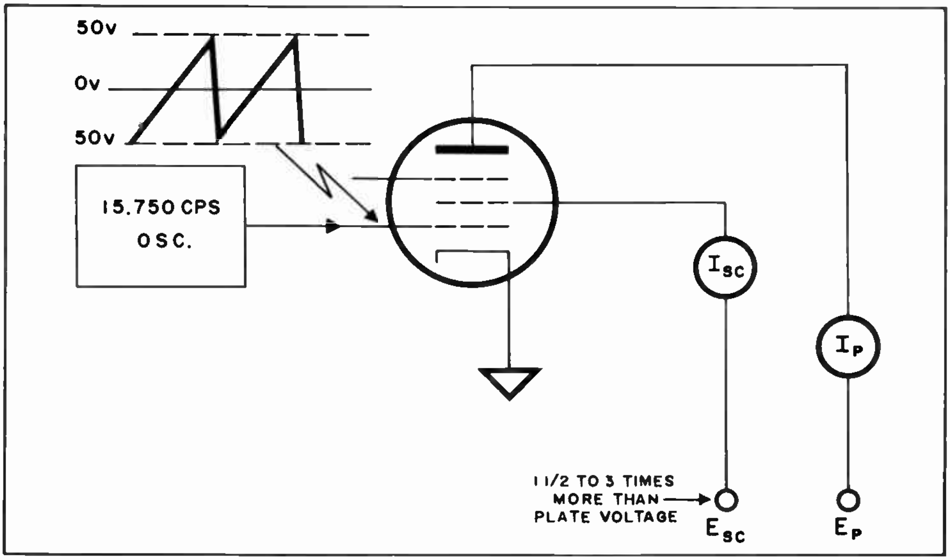


Figure 2. Test Setup Used to Determine Dynamic Ratio of Plate Current to Screen Current

The following problem was posed by M/Sgt. David A. Berger, and is concerned with a trouble appearing in the AN/APN-9 Loran equipment.

"Could you advise me as to how to correct the malfunction shown in the figure below. *(Editor's Note: The photograph enclosed with the request has been replaced by the drawing in the figure below for the sake of clarity.)* The equipment is the Receiver-Indicator R-65/APN-9, and the presentation illustrated appears with the controls in the following positions:

Function Switch—set to position 5
Coarse Delay—set fully counterclockwise
Fine Delay—set fully clockwise
PRR (Pulse Repetition Rate)—set to 'High'

I have come across a number of sets in which this same trouble is apparent."

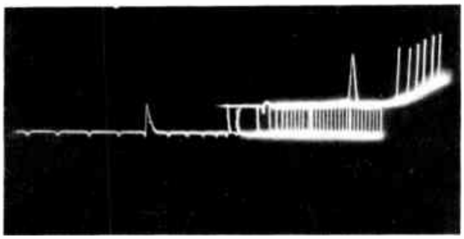


Illustration of Incorrect Indicator Presentation

The information given indicates that the trouble is apparent only on position 5 of the function switch, and provides no indication of what effect, if any, the delay setting has. It would be of great help in pinpointing the trouble if more information could be obtained. However, from the information given, it appears that the d-c horizontal positioning voltage is not present during the time of the upper trace, and that the vertical separation voltage is insufficient. A check on the waveforms at the deflection plates (both horizontal and vertical) would be logical. The shield grounds on the deflection plate leads should also be checked. These suggestions merely provide a starting point, of course, and do not locate the trouble.

Since the trouble is apparent on a number of equipments, other readers may have come across it. If so, let us know, in order that we may forward the information to Sgt. Berger.

TECHNICAL SKETCH OF GEORGE BOOLE (1815–1864)

EDUCATION

George Boole was born at Lincoln, England, the son of a poor storekeeper. Lack of money for an adequate education forced Boole to self-education. In this field he did an admirable job of learning Greek and Latin. Boole's early mathematical training was obtained from his father, and at sixteen Boole took a job as an assistant teacher in a nearby school. Boole continued his studies and was quite successful in the field of logic, as evidenced by the following.

MAJOR SCIENTIFIC CONTRIBUTION

Boole's most important scientific contribution was the formulation of a scheme for the solving of problems in the field of logic by the use of authentic mathematics. In honor of Boole this inspired scheme is called Boolean algebra.

Boolean algebra consists of systematic rules for the handling of the connectives *or, and, not.* Modern applications of this algebra to electronics fall in the field of data and information handling systems, for example, the design of computer circuits.

Boolean algebra may be used to reduce the number of operations to accomplish a certain desired result to a minimum. For example, a complicated relay and switching arrangement having redundant operations can be redesigned, by application of Boolean algebra, into an efficient system having a minimum of operations.

In Boolean algebra, the symbols of operation are separated and treated as objects of calculation. A crude example is given in the following statement, which may be set up in symbolic form.

If a certain switch is closed or if a certain bypass contact is not closed, a given relay will energize.

Let the condition *if a certain switch is closed* = A.
Let the condition *if a certain bypass contact is closed* = B.
Let the condition *a given relay will energize* = C.

Stated in Boolean algebra, the statement then becomes:

$$A \cup \bar{B} = C$$

where $\cup$ is used to symbolize "or," and the line over B represents negation of B.

PROFESSIONAL CAREER

Boole was a teacher in the equivalent of our public elementary schools for about four years. At twenty he opened his own school and further pursued the teaching of elementary students for about fourteen years.

Several papers by Boole appeared in the *Cambridge Mathematical Journal,* and following the publishing of the *Mathematical Analysis of Logic* (a pamphlet), he was appointed Professor of Mathematics, Queens College, Cork, Ireland.

PUBLISHED WORKS

1. *Mathematical Analysis of Logic,* in 1847.
2. *An Investigation of the Laws of Thought on Which Are Founded the Mathematical Theories of Logic and Probabilities,* in 1854. (This is Boole's master work.)
3. *Treatise on Differential Equations,* in 1859.
4. Treatise on the *Calculus of Finite Differences,* in 1860.

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