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FRONT COVER—The illustration this month is the schematic diagram of the instantaneous lines of electric force in the plane of a dipole located in free space.

BUSHIPS Electron

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BUREAU OF SHIPS — NAVY DEPARTMENT

MEASUREMENT OF ANTENNA CHARACTERISTICS

By R. T. Brackett

■ Invariably it has been the experience of personnel working out of the U. S. Naval Electronics Laboratory that vessels have extended unlimited hospitality and cooperation in the matter of enabling shipboard antenna measurement operations to be conducted in the San Diego area. Shipboard personnel have indeed shown a lively interest in the nature and objective of these operations.

The novelty and uniqueness of the work, however, often lead to uncertainty as how best to render assistance to the Laboratory, and to what extent the ship's work may be carried on without hampering the operations.

It is the purpose of this article to give a general description of some of the more common measurement projects, and the assistance desired from a vessel's personnel when Laboratory personnel board the vessel to conduct these measurements. Actually, the operations vary from one occasion to another, specific instructions being prepared in each case. It is believed, however, that a few words on the measurement technique will be a help to the shipboard personnel.

ANTENNA SURVEY

The project officer or engineer heading the field survey party often is the first to request access to the vessel. This group, from the Systems Engineering Planning Section, sketch the antenna system installation and nearby portions of the vessel for the information of draftsmen in the Planning Section.

This information is required in order to check or to modify and correct the available drawings of the vessel, and to facilitate construction of scale models for laboratory measurements. Ultimately, the sketches go into a file of prevailing antenna installation practices maintained by the Navy Electronics Laboratory for information and record.

The survey operation employs a combination of photographic and sketching techniques. Calibrated

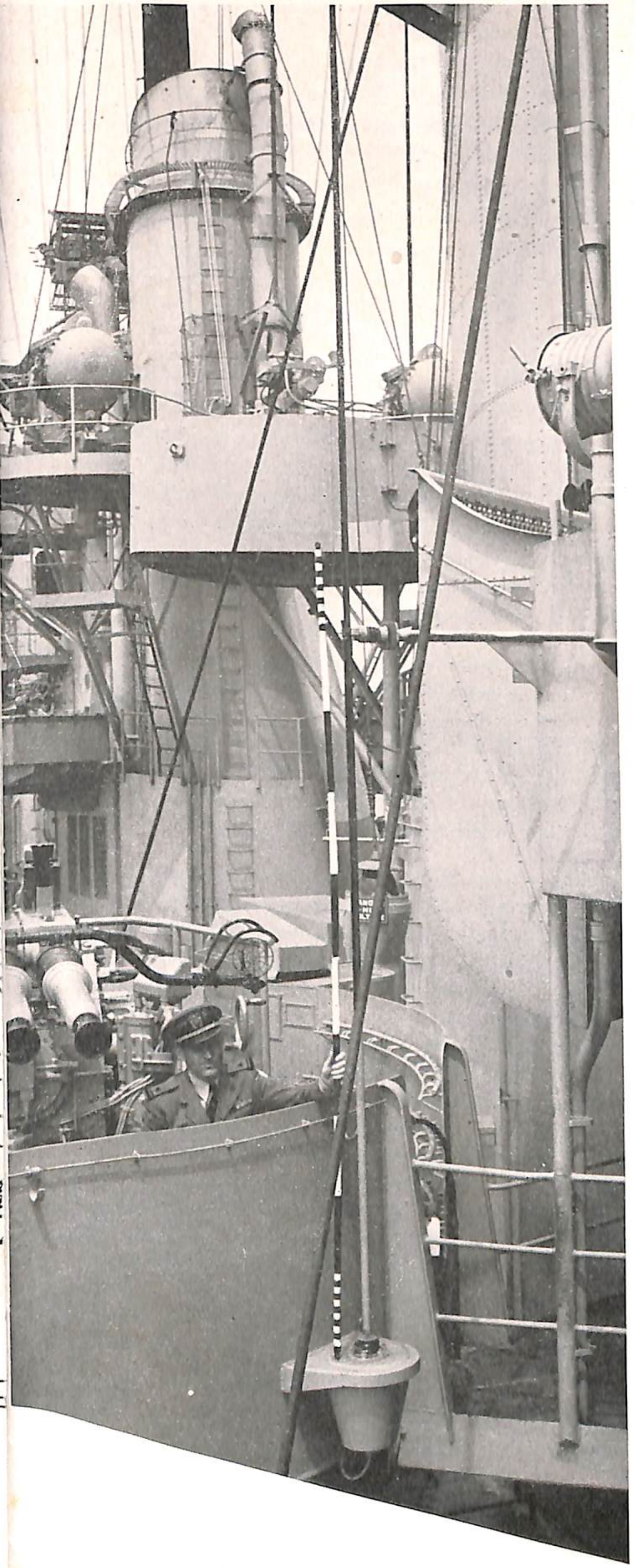


Figure 1—*Establishing the scale in photography for sketching purposes later.*

rods introduced into the photograph establish scales by which distance may be subsequently determined. At the same time careful notes and tape measurements are recorded, and the routing of all antenna distribution lines is carefully diagrammed.

For this operation, the vessel is requested to supply two or three radio technicians who are familiar with the installation. It is desired, though not absolutely necessary, that the vessel be moored. Ship's work may be carried on as usual.

When the antenna installation survey has been completed other groups may visit the vessel to begin electrical measurements. The three most common of such operations will be described briefly.

RADIO NOISE MEASUREMENTS

The Systems Engineering Radio Noise Interference Section makes radio noise level measurements over a spectrum from 150 kc to 400 Mc, and evaluates the resulting interference to electronic equipments.

The purpose of these measurements is to discover spurious radiations which can hamper the operation of electronic equipments or can be detected by the enemy. Once their origin has been determined, such radiations can usually be suppressed by filtering and shielding, or by corrective features being incorporated into the design of new equipments.

These measurements consist of exploring the vessel with a noise meter. In determining radiated noise levels, the instrument is employed with a calibrated antenna as a field intensity meter. In measuring conducted noise the instrument is used as a radio frequency voltmeter. In tracking down noise sources, it is frequently helpful to use a very small loop antenna as a directional noise field probe.

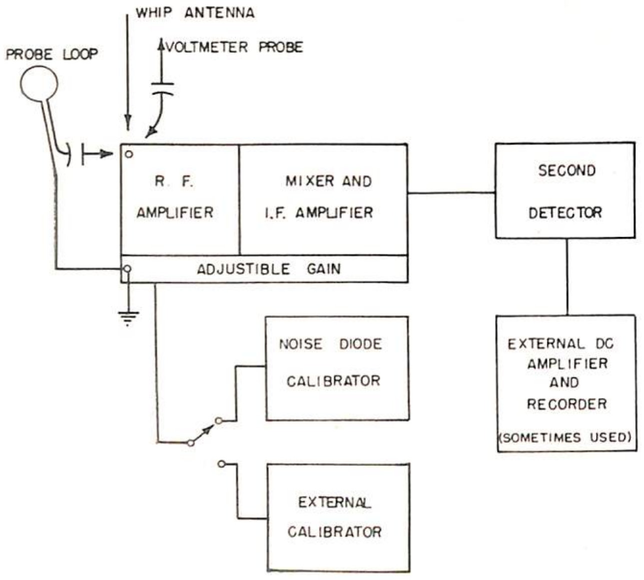


FIGURE 2—*Basic circuit of radio noise and field strength meter. Many refinements are not shown, and the actual circuit is much more complicated than this.*

The radio noise meter is a specially-designed heterodyne receiver with adjustable gain, having calibrated pickup devices and a local signal source for adjusting the instrument to standard gain. A block diagram of one such instrument is shown in figure 2.

To calibrate the meter, the receiver is tuned to the desired frequency and the appropriate detector time constant is selected (according to whether average or peak values are to be determined). The local standard signal is next injected, and the receiver gain adjusted to give standard output. Finally, the local signal is turned off, and the receiver then operates under standard and reproducible conditions.

The particular instrument represented in figure 2 has two types of local signal generators. One is a shot-noise generator housed in the cabinet. The other is an external oscillator with output meter, specially constructed for use with this instrument. The external d-c amplifier was built by the Laboratory. and is not part of the instrument.

The output meter is calibrated to read microvolts directly at the instrument terminals when used with a suitable whip antenna. When the effective length of the antenna is known, the meter readings can easily be converted to field intensity in microvolts per meter. If the antenna is simulated by a voltmeter probe and a small capacitor in series, the instrument may be used as a direct reading microvoltmeter.

The test location should be either remote from other vessels and shore activity (particularly industrial or heavy traffic areas), or else in an area previously evaluated for extraneous noise. There are some restrictions on ship's work during the course of these measurements, but these must be determined at the time the measurements are being made. The ship's electric and electronic equipments must be operated singly and in combinations under controlled conditions to establish various conditions.

The services of the Electronics Officer are required almost continuously. He is asked to establish liaison for the measurement group, to assist in checking over the inventory of equipments so that no potential noise source shall be overlooked, and to secure authorization to operate or secure equipments. Assistance of radio technicians and of electricians is necessary to provide sources of 110 volts a.c. for the measuring equipments, and to identify wiring and cable runs. Assistance of radio operators is required to compile available information on unusual and repetitive interference encountered on different antennas and their connecting trunks, and to measure the conducted interference at the antenna transfer panels. A final interference evaluation of the ship as a unit may require operation at sea.

SOME ELECTRICAL CONSIDERATIONS

Both the Ship Measurement and Antenna Systems Research Sections of the Systems Engineering Department measure ship antenna impedance characteristics. In the December issue of ELECTRON, a brief description was given of the typical antenna impedance characteristic. Figure 2 on page 12 of that issue showed part of one such characteristic obtained by Navy Electronic Laboratory engineers.

The determination of antenna impedance is essential to the design engineer if the radio transmitters and receivers are to be properly designed for the load impedances with which they are to be used. They are also of interest to the installation and maintenance groups, for one criterion of a good installation is that the impedance characteristic shall be stable, and not greatly influenced by surrounding structures. This last implies that the antennas shall not be intercoupled.

Antenna impedance is also of interest to the radio technician. It is often observed that in setting up a high-frequency transmitter the antenna current is very small. Suppose that this antenna is being excited by a 200-watt transmitter which develops just its rated power, and no more, at all frequencies. Then if I_a is the antenna current and R_a is the antenna resistance,

$$I_a^2 R_a = 200$$

at all frequencies.

Now at the lower frequencies R_a is quite small, about 4 ohms near 3 Mc. Then from the relation

$$I_a^2 \times 4 = 200$$

we find that

$$I_a = 7.08 \text{ amperes}$$

which is a sizable antenna current.

At higher frequencies the antenna resistance increases greatly, to nearly 3000 ohms just below 6 Mc. Then

$$I_a^2 \times 2920 = 200$$

or

$$I_a = 0.257 \text{ ampere}$$

which, although high enough to account for 200 watts antenna power at this frequency, is not enough to produce a readable meter deflection.

The meter reading is not in itself an indication of power, one reason for which can be seen from the above relation. Another reason is that for a given frequency the meter reading varies with respect to its relative position in the antenna system, and also is governed by the length of the trunk or transmission line employed and the parameters of the antenna. Detailed instructions for proper transmitter tuning are contained below under "Transmitter Tuning."

ANTENNA IMPEDANCE MEASUREMENTS

At medium and high frequencies the antenna impedance is measured by a radio-frequency bridge, such as the General Radio Model 916, pictured in figure 3. A greatly simplified diagram of one such equipment is shown in figure 4. It includes the bridge unit itself, a signal generator, E, and a communications receiver used as a detector, D.

When the bridge circuit is balanced there exists no potential difference, F-G, and no signal will be heard in the receiver. However, when the bridge is not balanced, there is a potential difference, and a signal can be heard.

This particular device works on the partial-substitution method, and requires two separate adjustments for balance. A preliminary adjustment is obtained by balancing built-in components of the bridge to convenient initial values. A final adjustment is then made after introduction of the

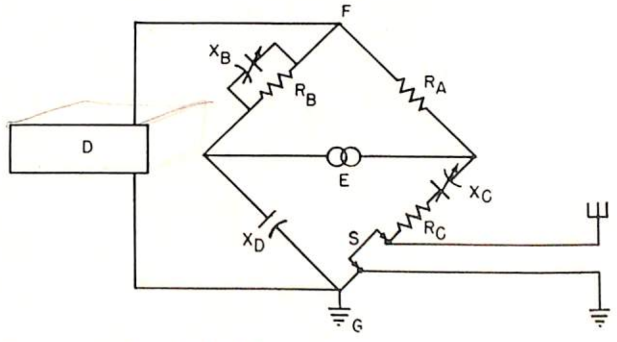


FIGURE 4—*Basic bridge circuit. Many refinements are not shown, and the actual circuit is much more complicated.*

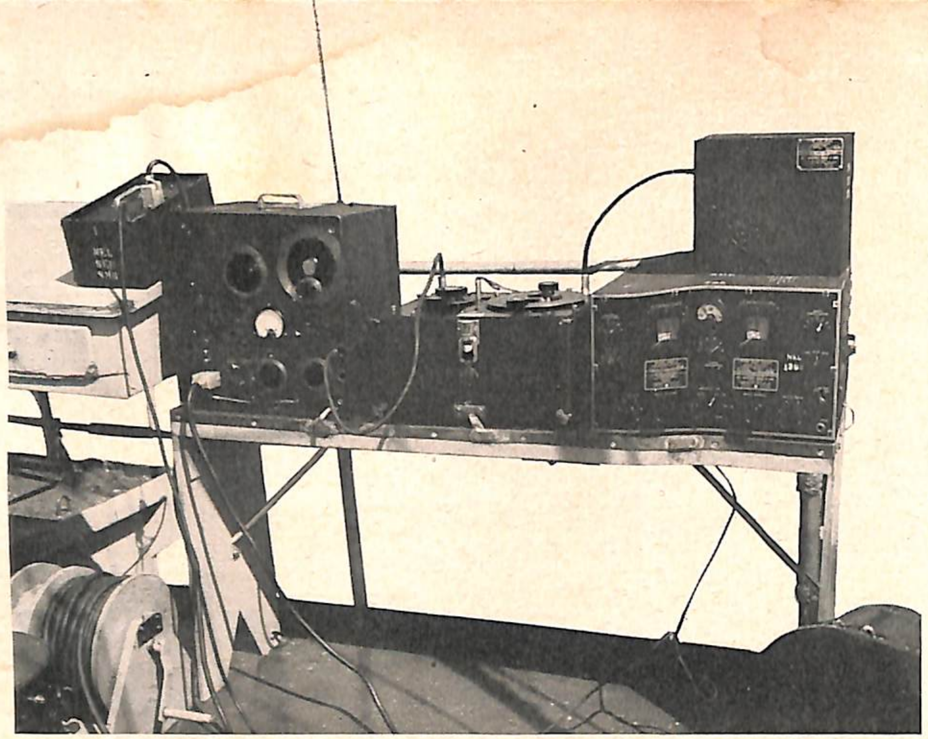


Figure 3—*Measurement of antenna impedance with the radio-frequency bridge. A drop cord and portable reel appear at the lower left. The folding table has a copper-covered top, which is grounded. The signal source with its power-supply are at the left. The bridge unit is in the center, and the detector and speaker are at the right. The antenna under test can be seen behind the signal generator. It connects to the bridge terminal between the two large dials.*

unknown impedance into the bridge circuit. Then the difference between the two adjustments shows the magnitude of the impedance which has been introduced.

In making the initial adjustment, the terminals at S are short-circuited by a jumper, and the calibrated reactances X_B and X_C are adjusted until zero signal indication is given by the detector. From the condition for bridge balance,

$$\frac{R_A}{\dfrac{R_B jX_B}{R_B + jX_B}} = \frac{R_C + jX_C}{jX_D}$$

we can derive

$$R_C = \frac{R_A X_D}{X_B}$$

$$X_C = \frac{R_A X_D}{R_B}$$

Actually the dials for X_B and X_C are calibrated to show directly the values R_C and X_C in ohms. The initial values obtained by this preliminary setting are recorded as R_0 and X_0.

Next the jumper at S is removed and the bridge is again balanced by readjusting X_B and X_C. This gives us new values of R_C and X_C, say R_1 and X_1.

Now the change in these values must be that caused by the introduction of the antenna impedance Z_a into the circuit, i. e.,

$$R_a = R_1 - R_0$$
$$X_a = X_1 - X_0$$

It is found, particularly when measuring in the high frequency range, that all leads must be as short as possible, that the generator and detector both must be thoroughly shielded, and that proper grounding conditions must be maintained.

Frequently it happens that the antenna terminals are not conveniently accessible from the position where the bridge can be set up. In such circumstances it has been found advantageous to connect the antenna terminals to the bridge by means of a coaxial cable of suitable length. This in effect transfers the bridge terminals to the antenna location, through a shielded circuit of known and stable characteristics. The measured values then differ considerably from the true values of the unknown, but the latter values may be easily calculated.

Usually no assistance from the vessel is necessary when antenna impedance measurements are to be made at medium or high frequencies. The vessel should be well in the clear, preferably at a buoy. Most ship's work may be carried on as usual, but there are some restrictions upon activities of the Communication Department, since other m-f and h-f antennas within a one-hundred-foot radius should be disconnected during the measurement periods. No radio transmissions at high frequencies or below should be undertaken without warning the measurement party.

ANTENNA RADIATION PATTERN MEASUREMENTS

The Systems Engineering Ship Measurement Section also makes determinations of ship antenna directivity patterns. Directivity is the property by which the antenna functions (as a radiator or a collector) more effectively along some relative bearings than along others. One example was given by figure 3 in last month's article.

The purpose of determining these patterns is twofold. The immediate objective is to acquaint the vessel's personnel with the fact that their antennas are directive and, insofar as possible, to supply specific information which may be of tactical value under favorable circumstances. The ultimate objective is to learn enough about the origin of directivity to permit its reduction or elimination.

The chart, figure 5, shows the measurement range and illustrates the procedure. The area A is the Border Measurement Station at which the Laboratory maintains most of the shore-based equipment employed in these tests. The point B indicates a special marker buoy eight miles west of the beach site A.

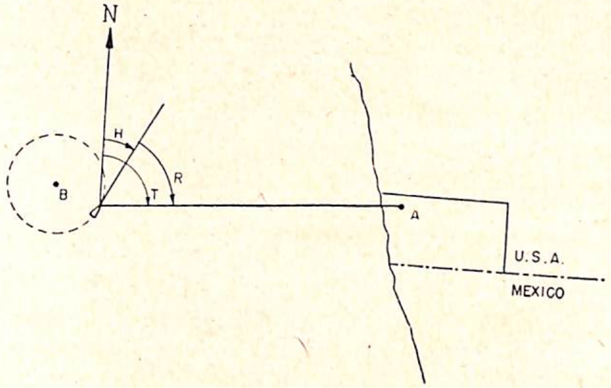


Figure 5—*Border-station and measurement range (not shown to scale). The diameter of the ship's turning-circle should be small in comparison with the distance from A to B, so that neither the true bearing nor the distance of the border station vary appreciably during the turn.*

Previous to the test, if possible, laboratory engineers set up the ship's transmitters on all test frequencies to be employed, adjusting them carefully to standard operating conditions and log settings. This assures some uniformity of operating conditions so that the results may be compared with other tests. Also considerable time is saved in setting up the equipments ahead of time so that more tests can be completed in the available ship time.

Basically the operation is fairly simple. The vessel takes station and turns continuously in a tight circle about the marker buoy. To measure a transmitting antenna, continuous locked key transmissions are made with a short break to mark the ship's heading every thirty degrees. At Border Station, a continuous chart record is made of the field intensity. The breaks appear as pips, easily recognized on the record and are identified from time to time by notations on the chart record.

As recorded, this chart shows how the recorded signal intensity varies with ship's heading. This is quite a valid presentation, but not a very helpful one. Let us look again at figure 5. If we know the ship's heading H and the true bearing T of Border Station, then the bearing of the station relative to the ship's head is

$$R = T - H \text{ or } R = 360 + T - H$$

From this relation we can easily relabel the pips so that the chart record will show how the signal intensity varies with the relative bearing of Border Station. (To anyone who has used an "is-was" this conversion is simple.) In the final representation, the chart record is redrawn on polar coordinates as in figure 3 of last month's article.

Sometimes a radar beacon is set up at Border Station and continuous radar observations are made on this from the ship. The bearing marks are then given at thirty-degree intervals of relative bearing of Border Station.

When a receiving antenna pattern is to be determined the procedure is nearly the same. A transmitter is set up at Border Station on the test frequency, and the received signal voltage is measured by using the noise meter as a microvoltmeter, in conjunction with the d-c amplifier and recorder shown in figure 2.

Usually arrangements are made to copy the vessel's radio schedules ashore, and all radio and radar activity is secured except for the equipments employed in the measurement operations. Laboratory engineers man the equipments, maintain communication with Border Station, and keep all notes, data, and records. Although little ship's work may be carried on during the measurement operations, little assistance is required from the vessel.

TRANSMITTER TUNING

For these operations, the associated transmitting equipments are considered as instruments. Consider now a representative high-frequency transmitting equipment such as the Model TBM or TCK, which have output circuits somewhat like those shown in figure 6. At the beginning, assume that all circuits are detuned, and that the coupling has been set at some fairly low value.

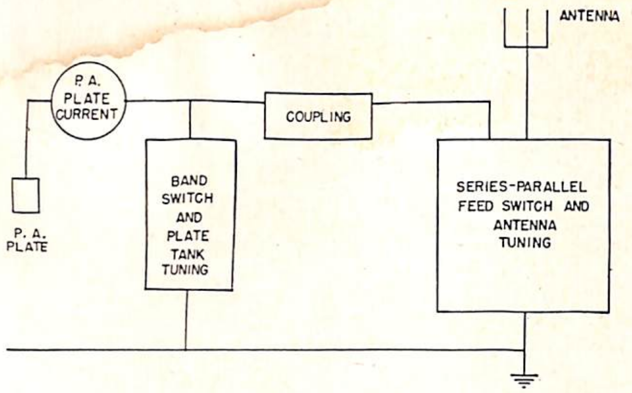


Figure 6—*Representative transmitter r-f system (power-amplifier plate to antenna). Actual circuit details vary, but the diagram shows the characteristic functions of the circuit elements.*

When excitation is applied to the power-amplifier grid, plate current begins to flow. Current flow indicates plate loss in the tube, and the power-amplifier plate begins to heat. The obvious thing is to tune the plate tank to resonance. This yields a minimum plate current, and if the plate has been hot, it will be observed to cool.

Next the antenna is tuned to resonance so that it will draw power from the power-amplifier plate tank. This sometimes produces a readable antenna current, and it always produces a readable increase in power-amplifier plate current. When the antenna is tuned exactly to resonance, the power-amplifier plate tank may become slightly detuned. It is often necessary to retune several times, driving the plate current as high as possible with the antenna tuning and as low as possible with the plate tank tuning.

Now when both tuning adjustments are first realized simultaneously, it will be only coincidence if the load is found to be rated value. This is the value which will give rated power-amplifier plate current *when the plate tank and antenna are correctly tuned,* a value determined by the manufacturer and stated in the instruction book, and often indicated by a red line on the instrument face.

To adjust to this value, the coupling control is moved up (or down) a little to increase (or decrease) the current at the resonance condition. Probably both antenna and power-amplifier plate tank will be slightly detuned. Therefore, these circuits must be retuned, the coupling readjusted, the circuits again retuned, and so on, resonance being preserved while load is increased (or decreased) to its rated value.

RADIO FIELD INTENSITY MEASUREMENTS

The field intensity meter is quite like the interference locating equipment, consisting of a superheterodyne receiver with adjustable gain equipped with a calibrated loop antenna and local calibrating oscillator for introducing a known voltage into the loop. The block diagram of one such instrument, shown in figure 7, may be compared with figure 2.

To measure a field intensity, first the desired signal is tuned in. The gain is then set at a convenient value, and the tuning continued till maximum response is obtained.

Next a large specified attenuation is introduced (sufficient to eliminate the signal); the calibrating oscillator is tuned to the test frequency and adjusted to standard output.

The receiver gain is now adjusted to standard output, the oscillator turned off and the excess attenuation removed from the circuit.

The receiver is now operating under standard and reproducible conditions. By employing a calibration furnished by the manufacturer, the field intensity in microvolts per meter can be determined from the receiver output meter reading.

The field intensity meters used at very high frequencies employ dipole antennas instead of loops.

While the foregoing does not by any means give a complete account of the Systems Engineering Department measuring activities, it does give the reader a fairly good idea of the types of work employed in the investigation of antenna characteristics leading to integrated and engineered antenna systems for naval vessels, and the part played by ships' personnel in these operations.

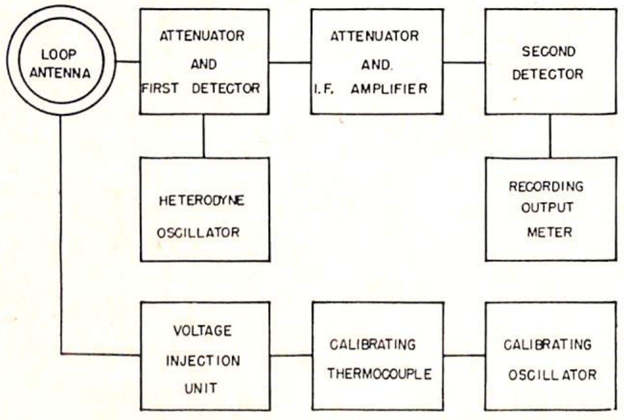


Figure 7—*Basic elements of the field intensity meter. As before, many refinements have been omitted.*

The Decibel

By James M. Bruning *Lieutenant Commander, E-T, USNR*

■ Before the days of radio, electrical transmission of speech could be accomplished only through the use of wires. Wire size and spacing had pronounced effects upon the intensity and quality of the speech transmitted. If wire thickness and spacing were increased, the effectiveness of the "line" was greatly improved. However, the added cost of heavier lines outweighed the advantage of greater effectiveness.

With further increase in the number of lines employed, it became necessary to start the use of cables in which a number of insulated wires were encased in a lead sheath. The situation now existed wherein many lines of widely different construction and effectiveness were in use. It was evident that a standard unit of comparison must be set up to compare the effectiveness of the various lines.

The best all-around line appeared to be 19-gauge cable, having a d-c resistance of 88 ohms per loop mile, and a distributed capacity of 0.054 microfarad per linear mile. This type of line became known as the standard, and a measuring unit known as a "mile of standard cable" was adopted. Before this unit could be used as a yardstick, it was necessary to design a test set or box that could contain several miles of this particular cable.

By connecting together a group of small, fixed resistances and condensers having electrical characteristics equal to those of standard cable, and by bringing out suitable taps, it became possible to construct the desired transmission test set. Movement of panel switches would then select resistance and capacitance values equivalent to any desired number of "standard cable miles." If a new long line circuit were to be tested, the observer's voice was alternately switched through the new line and then the test set. Switches were manipulated until the output sound heard—or measured—was identical, regardless of whether the actual line or the test box was being used. When this condition was obtained, the effectiveness of the line under test was rated as equivalent to the actual number of miles of standard cable set up within the test set. A circuit rated as having a transmission equivalent of "three miles" of standard cable was obviously a higher grade channel than one having an equivalent of "ten miles."

While the system was a great advance in engineering practice, certain disadvantages soon became apparent. Results varied from day to day, and different observers could not agree as to the exact number of "miles" that would be the precise equivalent of a particular line. Investigation disclosed that these discrepancies were related to the average pitch of the speaker's voice, and the hearing ability of the listener to detect small variations in sound intensity. It was obvious that the system was not perfect. In fact, the attenuation constant varied considerably with frequency, and only one test frequency could be used without causing serious errors.

A new unit known as the "Transmission Unit" or "TU" was next adopted. This unit was essentially the same mile of standard cable, with the added qualification that the frequency being measured must be 800 cycles. A meter was substituted for the listener's ear at the far end of the circuit, and precision results could now be obtained. Further research indicated that the essential range of frequencies needed to carry commercial intelligibility was roughly from 300 to 3000 cycles per second. An 800-cycle test was not sufficiently representative. The higher frequency of 890 cycles was tried with good results, and finally the test frequency of 1000 cycles was adopted as the standard. A condition had now been reached where measurements were actually made at 1000 cycles, but the unit used was still the standard cable mile at 800 cycles. It was time for a further refinement of the unit yardstick.

Experimenters had noticed that a volume or intensity change of about 20% was just noticeable to the average listener. The addition of one mile of standard cable to a circuit under test caused a loss of about 20% in intensity. If the science of mathematics could relate these two facts in such manner that computations could readily be made, then the basis for a natural unit of measurement was at hand. Ear response is essentially logarithmic. Logarithms make it possible to substitute simple addition and subtraction for multiplication and division. So the desired unit should operate on a logarithmic basis.

The new unit was worked out and adopted. It was called the db. The full name of db is "decibel." The first syllable means one-tenth, and the last syllable is taken from the name of the inventor of the telephone, Alexander G. Bell. The decibel is a small unit. The larger unit is called the bel. It is ten times as great as the db, and is of use in certain computations which will be illustrated later. Let us investigate this db unit, and see what it is and how it can be used.

The db is simply a "yardstick." There are many kinds of yardsticks. Automobile engineers use "horsepower"; bankers use "dollars"; food experts use "calories." In each case the units involved are used to measure something. That is the function of the decibel in electrical engineering.

A car owner is interested in the number of miles per gallon obtained from his machine. He is talking "efficiency." He desires to get the most out of what is put in. Efficiency is merely the ratio of output to input.

If only 1% of the voice power put into a transmission line is received at the terminal, the efficiency of the circuit is 1%. If 90/100 of applied electric power is successfully transmitted through a line, then that particular line is 90% efficient.

The unit for measuring efficiency of a transmission line or circuit could well be "percent." However, one or two percent changes in power are not readily noticed by the human ear. A worthwhile unit for measuring speech power should be one that measures increments which are evident to normal listeners.

The old "mile of standard cable" and the later "TU" both met this requirement. In each case a ratio appeared between input and output. This ratio was a natural one, lending itself readily to audible measurement of incremental changes in audible power. A very slight change in the numerical value of this highly natural ratio resulted in a percentage figure that allows mathematical computations to be handled with ease. This new ratio expressed in percent came out to be 79%—or 79.4% to be more exact. Note that 79.4 percent (0.794) cubed will equal 50%. Also, 79.4 percent multiplied by itself ten times will equal 0.10 or 10%.

Obviously, if a circuit is less than 100% efficient, there has been a loss of power along it. If 79% of the total electric power put into a circuit arrives at some other point, that circuit would be 79% efficient, or 1 db efficient in engineering parlance. However, if an amplifier is connected to a circuit, power is added. When amplification takes place, it may occur that the *input* is only 79% of the *output*.

To differentiate, one could say the circuit is minus 1 db efficient when the output is 79% of the input, and a loss has occurred. When the input is 79% of the output, as a result of amplification, one could say the circuit is plus 1 db efficient, and a gain has occurred. Note that if a circuit is plus 1 db efficient, the output is 1/79% or 1/0.79 or 126% of the input. We then have the situation where, if we hold to our fundamental idea of efficiency (how much of input becomes useful output), then 1 db change in level may correspond to an output of either 79% or 126%. To differentiate between the two, we simply say "1 db loss" or "1 db gain."

If a line or instrument is 50% efficient (79% × 79% × 79%), the engineer says there has been a loss of 3 db. Here the 3 indicates the number of times 79% is used as a term in multiplying. If there is a 25 db gain, 126% (1.26) must be multiplied by itself 25 times.

The reason for measuring efficiency in terms of db's rather than percent now becomes clear. It is easier to add small numbers than to multiply large ones. (The science of logarithms is based upon this principle.) For example, if three equipments are respectively 79%, 63%, and 50% efficient, the overall efficiency is 0.79 × 0.63 × 0.50 or 25%. However, if efficiency is expressed in db's, the total efficiency is found by simple addition. In the above example, the engineer says the three equipments have individual losses of 1 db, 2 db and 3 db, so the total loss is 6 db.

Note again, that db's, plus or minus, are added algebraically, whereas percentages are always multiplied. If one is accustomed to the term and hears it frequently, the 6 db loss means just as much as to know that the efficiency is 25%.

The decibel, then, is a term used for expressing the ratio between two quantities of either electrical or sound energy.

To express the ratio of one power to another in circuits of equal impedance, the following formulae are used.

$$\text{db} = 10 \times \log_{10} \frac{P_{\text{out}}}{P_{\text{in}}} \quad \text{or} \quad \log_{10} \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{\text{db}}{10}$$

Now, *power* is proportional to either I^2 or E^2. To express *current* or *voltage* ratios, we must multiply the logarithm of the ratio by 2. This follows, because to square a number, we multiply its log by 2.

Thus, to express the ratio of current to current or voltage to voltage in circuits of equal impedance, we use the formulae:

$$\text{db} = 20 \times \log_{10} \frac{E_{\text{out}}}{E_{\text{in}}} \quad \text{or} \quad \text{db} = 20 \times \log \frac{I_{\text{out}}}{I_{\text{in}}}$$

ZERO REFERENCE LEVEL

Before proceeding with actual examples of db usage, it is necessary to understand the concept of the zero reference level. Zero *level* is not the same as zero *power*. It is merely a starting or reference point, having a very low but definite amount of power, and to which other powers may be compared. For convenience in comparing circuit efficiencies, this starting point was agreed upon as being the zero level. Any power, voltage or current can be compared with the zero level. All powers above the reference level are designated as plus quantities, and powers smaller than the reference level are designated as minus quantities.

Unfortunately, various industries adopted different standards for their zero levels. Conversions from one level to another can be made by taking away or adding the necessary amount of units from the scale in question; then these conversions are compared to the six-milliwatt, 600-ohm standard.

Power levels in use:

Industry	*Zero db level*
Standard agreement (used by the Navy)	6.0 milliwatts into 600 ohm load.
Radio broadcast (volume unit)	1.0 milliwatts into 600 ohm load.
Telephone system	2.4 milliwatts into 600 ohm load.
Sound pictures	6.0 milliwatts into 600 ohm load.

ILLUSTRATIVE EXAMPLES

The following examples are worked out in detail to illustrate the method of attacking any particular problem.

To find db with respect to zero level for power outputs above zero reference level.

An amplifier delivers 3 watts. How much is this expressed in db above zero level?

$$\text{db} = 10 \log \frac{P_o}{P_i}$$

$$\text{db} = 10 \log \frac{3}{0.006} = 10 \log 500$$

$$\log 500 = 2.69$$

$$\text{db} = 10 \times 2.69 \qquad = 26.9 \text{ db}$$

To find db with respect to zero level for power outputs below zero reference level.

An amplifier has an output of 5 milliwatts. How much is this in db above zero level?

$$\text{db} = 10 \log \frac{P_o}{P_i}$$

$$\frac{P_o}{P_i} = \frac{0.005}{0.006} = 0.83$$

$$\log 0.83 = 9.9 - 10$$

$$\text{db} = 10\ (9.9 - 10) = 99 - 100$$

$$\text{db} = -1$$

Db loss or gain.

(a) A certain frequency is attenuated so that power output at this frequency drops from 12 to 9 watts. What is the loss in db?

$$\frac{P_o}{P_i} = \frac{9}{12} = 0.75$$

$$\log 0.75 = 9.8 - 10$$

$$\text{db} = 10\ (9.8 - 10) = 98 - 100$$

$$\text{db} = -2$$

The signal is said to suffer a 2 db *loss*, since the db is negative.

(b) An amplifier has 0.2-watt input and 12 watts output. If equal impedances are assumed, find the gain in db.

$$\frac{P_o}{P_i} = \frac{12}{0.2} = 60$$

$$\log 60 = 1.77$$

$$\text{db} = 10 \times 1.77 = 17.7 \text{ db}$$

The amplifier is said to have a *gain* of 17.7 db because the db is positive.

Converting db to power.

$$\text{db} = 10 \log \frac{P_o}{P_i}$$

$$\frac{\text{db}}{10} = \log \frac{P_o}{P_i}$$

Note that the term $\frac{\text{db}}{10}$ is a logarithm, the antilog of which is $\frac{P_o}{P_i}$.

$$\text{antilog}\ \frac{db}{10} = \frac{P_o}{P_i}$$

$$P_o = P_i \times \text{antilog}\ \frac{db}{10}$$

A microphone has an output level of –40 db with respect to the reference level. Express this in watts.

$$db = 10\ \log \frac{P_o}{P_i}$$

$$-40 = 10\ \log \frac{P_o}{0.006}$$

$$\frac{-40}{10} = \log\ \frac{P_o}{0.006}$$

$$-4 = \log\ \frac{P_o}{0.006}$$

The term –4 is a logarithm, the antilog of which is 10^{-4}, or 0.0001.

$$0.0001 = \frac{P_o}{0.006}$$

$$P_o = 0.0001 \times 0.006 = 0.000{,}000{,}6$$

$$= 0.6\ \text{microwatt}$$

In converting minus db to watts, it is often convenient to take advantage of a fundamental rule of the algebra of logarithms.

$$db = 10\ \log \frac{P_o}{P_i}$$

$$-db = 10\ \log \frac{P_i}{P_o}$$

(a) A microphone has an output level of –74 db. What is this level in watts?

$$\frac{-74}{10} = \log \frac{P_o}{0.006}$$

$$\frac{74}{10} = \log \frac{0.006}{P_o}$$

$$7.4 = \log 2.52 \times 10^7$$

$$P_o = \frac{0.006}{2.52 \times 10^7}$$

$$= 0.000{,}000{,}000{,}238\ \text{watt}$$

(b) A microphone has an output level of –17.3 db. How many watts does this represent?

$$1.73 = \log \frac{0.006}{P_o}$$

$$P_0 = 0.11\ \text{milliwatt}$$

MAINTENANCE OF STAND-OFF INSULATORS

Chapter 67 of the Bureau of Ships Manual calls for periodic inspection and cleaning of antenna insulators. The recommended intervals between inspections and cleanings are the maximum permissible under ideal conditions. Article 67-151 says that antenna insulators should be cleaned more frequently than recommended when conditions are such that dirt deposits accumulate rapidly. Failure to comply with this will result in inefficient operation, as proven by reports received from the fleet. Frequent visual inspections should be made to detect damage, fouling and other readily detectable conditions which affect antenna efficiency; frequent resistance checks should be made with a megger to determine resistance-to-ground conditions.

All stand-off insulators should be cleaned at least once a month, and more often if conditions warrant. This cleaning should be thorough, with nothing left to chance. Several rinsings should be used to remove accumulated dirt and salt water deposits.

After each cleaning, a coating of Dow-Corning Compound No. 4 should be applied to the entire surface of the insulator. This compound is a jelly-like silicone material and can be applied with a clean lint-free cloth, taking care that the entire insulator surface is covered with a thin film. Water droplets will run off this film, thus allowing less opportunity for salt to deposit and for dirt particles to adhere to the insulator. Dow-Corning Compound No. 4 is available from all Electronics Supply Offices, and a supply should be carried aboard all vessels for this purpose.

DATA CARDS VS. FAILURE REPORTS

Material Engineering, the unit whose responsibility it is to handle the Failure Reports received by the Bureau, is quite perturbed over the recent receipt of a number of Officers' Data Cards (NAVPERS 340).

"Yes," says Material Engineering, "these data cards are similar in size and appearance to the Failure Report forms but we are quite certain that BuPers would be much happier to receive them than we are."

Officers' Data Cards can in no way be interpreted as pertaining to electronic equipment—or failures. Please, let us not further add to the encumbrances of Material Engineering!

BATHYTHERMOGRAPH NOTES

GLASS SLIDES

■ The deplorable condition in which bathythermograph glass slides have been reaching the Hydrographic Office has been brought to the attention of the Bureau of Ships both by calls from the Hydrographic Office and by excessive requests from the field for material. It seems that the glass slides after being removed from the bathythermograph and rinsed in plain water are subjected to an overdose of thick lacquer and then put in slide boxes with no sheets for protection. As a result the excess lacquer cements the slides to the bottoms of the boxes from which they can be removed only by demolishing the boxes and in some cases by breaking a considerable number of the slides. In addition, the trace is barely readable due to the thick, obscuring coat of lacquer.

The instruction books state that the slides are to be placed in the boxes to dry while they are still wet, in an effort to prevent the absorbed moisture of the air from rendering the slides entirely opaque. They neglect to mention, however, the pitfalls attendant to such an operation. Accordingly, the following procedure is recommended to avoid difficulty and to prevent broken or spoiled slides:

1—Examine each new box of glass slides to see that each slide is smoked properly. If any are improperly smoked or scratched, wipe them off with a paper towel or rag and resmoke them.

2—Remove only one slide at a time from the box, insert in the B/T holder, and press firmly in to the stop pin. The bevelled corner of the glass slide is inserted first, and is forward with respect to the B/T shell. With the slide inserted in this manner, the smoked side is in the proper position to receive the temperature and pressure indications.

3—To remove the slide from the holder, insert a small screwdriver, stiff wire or rod through the hole opposite the slide and push the glass out slowly. When it is almost free, grasp edgewise with fingers and rinse it in fresh water by dipping and sloshing.

4—Label the slide with dry pen or scratch awl as described in the instruction books:

First line—Slide number (to run consecutively between ports) and time (GCT).

Second line—Date (month, day and year with month in roman numerals).

Third line—Latitude and longitude to nearest whole degree (note that the bathythermograph log sheet should have the latitude and longitude entered to the nearest minute).

Fourth line—Serial number of the bathythermograph.

5—Air-dry the slide as much as time permits and then dip it into a very thin lacquer solution. This solution should be thinned to little more than the viscosity of water.

6—Drain or shake off any excess lacquer and place the slide in the box. *Be sure that the bottom of the box is covered with two or more layers of paper to prevent the slide from sticking.* Close the top of the box. *Warm air should not be used for drying* since it encourages the collection of moisture on the lacquered surface causing it to turn milky and become opaque.

7—When the box becomes full, or on completion of the voyage, pack the slides so as to prevent breakage (preferably in their box), and ship them, together with their filled-in log sheets and associated data, to

The Hydrographer
Hydrographic Office
Navy Department
Washington 25, D. C.

Heretofore, slides were addressed to two different activities, one on the east coast and one on the west. The address given above is the correct address; the change was made in order to coordinate fully the work involved in obtaining slide data.

Note: If a slide is to be used in the viewer before lacquering, handle it carefully to prevent scratching the smoked surface or breaking the glass. Also note that the serial number of the grid used must correspond to the serial number of the bathythermograph.

If purchased from a contractor, the cost of accessory materials for preparing and handling the slides is exorbitant. Accordingly, some substitutes that can be prepared from standard stock and ordinarily-junked items are described as follows:

A—Fixative.

Item	*Stock No.*	*Quantity*	*Description*
211	52-L-420	qt. can	clear lacquer
387	52-T-500	qt. can	lacquer thinner
388	52-T-520	gal. can	lacquer thinner

B—Smoking Lamp. A lamp can be made from an empty shoe polish tin with a folded piece of blotter for a wick. Melted candle, paraffin wax or domestic ceresin wax is poured around the blotter and allowed to harden. A folded edge of the blotter should protrude above the level of the wax.

C—Tweezers. Tweezers can be made from wire, or acquired in the form of a surveyed rusty instrument from the medical department. Short pieces of neoprene spaghetti serve as excellent tweezer-tip coverings.

D—Dipping Jar. The jar can be any empty peanut butter or pickle jar having a tight-fitting cover. The lacquer solution is kept thin by the addition of lacquer thinner from time to time.

E—Push Rod. This can be a small screwdriver, wire or punch such that the blade end fits the hole opposite the slide in the holder.

F—Thermometers. A broken thermometer can be replaced by a standard water thermometer ranging from −5° or −15°F to 120° or 130°F, enclosed in a galvanized metal case with rubber buffers (item No. 466, Standard Stock No. 18-T-3170).

Slide and log sheet discrepancies like the following indicate lack of care and knowledge of the instruction books:

a—Thermometer temperatures on log sheet do not agree with the bathythermograph temperatures within 0.2 degree because heated injection water was used or the temperature of the bucket water was taken some time before or after making the slide.

b—The necessary slide information was lettered in over the trace making it unreadable. (Extensive scratching indicates rough handling.)

c—Slides received without any lacquer coating. This condition rendered the slides absolutely useless.

B/T CARDS

Instead of dipping the submarine bathythermograph card as is done with glass slides, it is suggested that the fixative be sprayed on using a small fly sprayer, an atomizer, or a sprayer powered by breathing through a tube or stem such as artists use. This is an alternate method and is useful where a large can or jar is not available for a dipping pot. After dipping or spraying, and drying, the cards should be assembled in order after each cruise (port to port), or when a sufficient number have been obtained, and shipped to the same address, given above, to which glass slides are sent.

Be sure the cards are completely filled out before shipping. It is recommended that any unusual conditions attendant to the time and trace obtained be entered on the back of the card for the use of the Hydrographic Office in averaging the readings for an area.

REPAIRS

The attention of all personnel concerned with bathythermograph repairs is invited to the fact that a renewed contract, NObs-2325, effective for this fiscal year and replacing the old cancelled contract, has been let to the Bristol Company.

U-H-F CRYSTALS—CORRECTION

The last issue of ELECTRON carried an article on page 22 entitled "U-H-F Crystals." In the article was set forth the procedure for obtaining sets of u-h-f crystals in order to complete allowances. According to information received in the Bureau, many ships and activities have misinterpreted the article, believing that it applied to individual crystals which have failed or are missing rather than to complete sets. As a result, Electronics Officers are receiving numerous requests for replacement crystals which they cannot fill.

To obtain individual replacement crystals, submit requisitions to the U. S. Naval Gun Factory, Washington, D. C., or to the Ships Supply Depot, Oakland, Calif. Copies of all requests should be sent to Code 955 of the Bureau of Ships, Washington, D. C.

New Books

■ The following listed instruction books have been issued since the December issue of ELECTRON went to press. For a complete list of instruction books distributed since October 1, 1945, see the December issue.

Model	*Short Title*	*Edition*
AN/GMQ-2	NavShips 900,944 (A)	Final
AN/MPN-1A	NavShips 98,025	Field Ch. #2
AN/MPN-1A	NavShips 316 (A)	Ch. #2 and #3 to 1B
AN/PPN-8 (XN-21)	NavShips 900,978	Maintenance Handbook
AN/SPX-2 (XN-21)	NavShips 900,966	Final
AN/TPS-1B	NavShips 40-46	Field Ch. #4
AN/TPS-1B	NavShips 28-45	Field Ch. #5
AN/TPS-1B	NavShips 98,064	Field Ch. #7
AN/UPA-11 (XN-21)	NavShips 900,964	Final
AS-294 (XN-21) / UP	NavShips 900,964	Final
AS-295 (XN-21) / UP	NavShips 900,964	Final
DBF	NavShips 900,929	Final
DBF-1	NavShips 900,959	Final
FRF	NavShips 98,027	Field Ch. #1
KS15206 (for AN/FGC 1A, 1B)	NavShips 91,024	Final
MA-126-E	NavShips 91,008	Commercial
QHB	NavShips 900,976	Preliminary
QXA	NavShips 900,903	Final
SP-1M	NavShips 900,560	Final
SR/SRa	NavShips 900,946	Final
SR-6	NavShips 900,989	InsMat Apprvd
SR-6	NavShips 900,989.1	Installation Handbook
SR-6	NavShips 900,989.2	Operators Handbook
SR-6	NavShips 900,989.3	Maintenance Handbook
SR-6	NavShips 900,989.4	Spare Parts
TBC-3	NavShips 900,855	Final
TDZ	NavShips 900,809	Final
TS-295/UP	Ships 311 (A)	Final
TS-324	NavShips 91,006	Final
TS-535/U	NavShips 900,839	Final
TS-587/U	NavShips 900,990	Final
TS-587A/U	NavShips 900,990	Final
*X-SO-5	NavShips 900,970	Final
*X-SO-5	NavShips 900,970.2	Operators Handbook
X-VK	NavShips 900,993	Final
CV-49992 (for OE)	NavShips 900,781 (A)	Final
COL-50308-A (for TDO)	NavShips 900,973	Final
CQA-51080	NavShips 900,735 (A)	Final
CTD-53518 (for MAR/RDR)	NavShips 900,998	Final
CRV-55AHP-1	NavShips 900,827	Ch. #2 to IB
CRV-55AHP-1	NavShips 900,827.4	Spare Parts
CRP-60ACZ-1	NavShips 900,983	InsMat Apprvd
CQ-60139	NavShips 900,735 (A)	Final
CARJ-66AMX	NavShips 900,947	Final
Mod. 14 Teletype Transm. Distrib.	NavShips 98,018	Commercial

* Available in limited quantities.

SONOBUOY FREQUENCIES CHANGED

In the *List of Naval Electronic Equipment*, NavShips 900,123, the operating frequency band for the model AN/SSQ-1 directional, and AN/SSQ-2 non-directional listening sonobuoys, and the model AN/ARR-26 radio receiving equipment used with them, is given as 60-80 Mc. Since that list was published, the frequency band has been upped to the range of 162-172 Mc. The change was made before the delivery of any of these models to the field, so that all equipments supplied will be adjusted to operate in the new band.

"Resonance, b'God!"

FEWER LOUDSPEAKERS IN CONGESTED SPACES

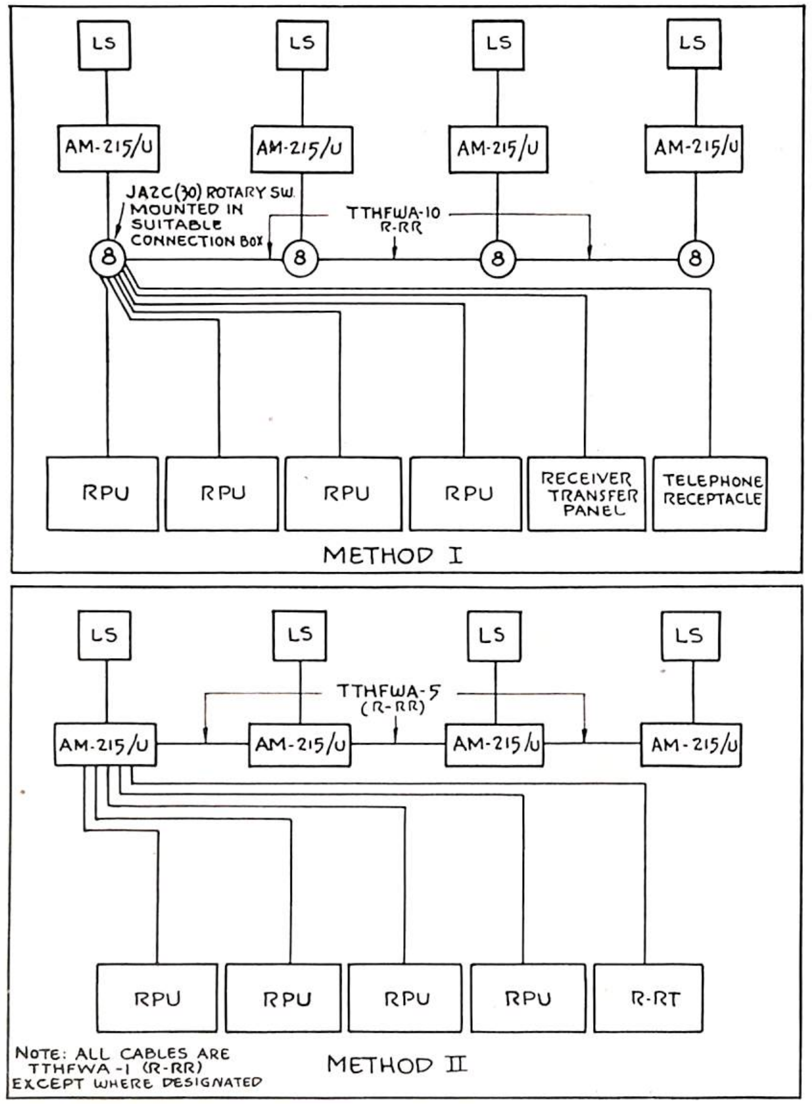
■ In order to eliminate a portion of the confusing noise in the Pilot House, Combat Information Center, and other spaces aboard ship, the Bureau of Ships plans in future installations to limit the number of communication loudspeakers to a maximum of four in any one station. This total will not include intercommunications speakers, or speakers built into remote control units or equipment such as the type -23270 TCS remote control units, or that in the MBF.

In order to gain maximum flexibility with a minimum number of loudspeakers, selective monitoring should be provided. This may be accomplished by two methods, illustrated in figure 1, as follows:

1—When six or more voice circuits are utilized, connecting one type JA2C (30) rotary switch (Bureau drawing 9000 S6503-73437) between each speaker-amplifier (type -49546 loudspeaker and type AM-215/U amplifier) and each voice remote-control unit or radiotelephone receptacle. Additional circuits may also be connected directly to the receiver transfer-panel in the radio room.

2—When five or fewer voice circuits are utilized, employing the selector switch in the type AM-215/U amplifier unit in lieu of the type JA2C (30) rotary switch. This arrangement will permit selection of any desired receiving circuit at the loudspeaker.

The JA2C (30) switch is not supplied in any sort of containing box or enclosure, so a suitable one must be provided. Where operational necessities permit doing so, switches may be installed for greater convenience in a single box in groups of four or less.



Type of Approach	Last Month	To Date
Practice Landings	5,964	71,376
Landings Under Instrument Conditions	301	3,764

U-H-F COMPONENT FAILURES

Failure report cards being received by the Bureau indicate a rapidly increasing number of defective component parts in u-h-f transmitting and receiving equipment. One reason, naturally, is that u-h-f equipment is now being used more than at any time since the beginning of the program. This point loses its importance, however, when upon tabulation of the cards it is found that approximately one-third of the failures are in equipments undergoing pre-installation tests.

In the opinion of the Bureau, a large majority of the failures are the result of defective material or workmanship rather than improper design, as only a small percentage of failures are repetitious. At the present rate of failures it can readily be seen that equipment and stock spares will soon be depleted.

Practically all u-h-f equipments are still within their guaranteed period. The contractual guarantee which is found in the front section of each instruction book clearly describes the condition of guarantee. This is, briefly, that all parts and spare parts except vacuum tubes will be replaced by the contractor if they fail within a service period of one year, providing that failure occurs within two years of the time of acceptance by the navy.

The Bureau desires that at monthly intervals all u-h-f component failures be packaged and returned to the Inspector of Naval Material, in care of the respective contractor, if the equipment involved is still covered by its contractual guarantee. A duplicate of the failure report card submitted to the Bureau should accompany each part.

No parts should be returned from equipment which is no longer covered by the contractual guarantee. In many instances it may be difficult to determine whether an equipment is still within the guarantee period, but for any equipment it may be assumed that the date of acceptance is the same as the date of shipment by the contractor. If this date is not known, it may be obtained from the Bureau of Ships, Code 960.

SUMMARY REPORTS OF TTY EQUIPMENT

From time to time the Bureau has been receiving summary reports of teletype equipment installed in ships. These reports are submitted each time in compliance with BuShips pilot letter, serial R-977-196 over EN28/A2-11, dated December, 1945.

This letter requests "a uniform tabular summary of all navy-owned teletypewriter equipment be included in the quarterly reports submitted in accordance with reference (b), (c) and (d)".

Unfortunately the above excerpt has been misconstrued many times by ships to mean that shipboard teletype equipment should be reported; whereas, references (b), (c) and (d) refer solely to teletype equipment installed at *shore* activities. Preparation of this report by ships duplicates a portion of the current Electronic Inventory Report and therefore has no intrinsic value.

In view of the foregoing, ship reports showing teletype equipment only are no longer required.

NEW ISSUE DATES FOR MAINTENANCE BULLETINS

Starting 1 January, 1948, the Communication Equipment Maintenance Bulletin, the Radar Maintenance Bulletin, and the Sonar Bulletin will be published at quarterly intervals, once every three months. In consideration of the fact that items of very high urgency may be promulgated in the Radio Installation Bulletin, the BuShips ELECTRON, or by individual letter, it is felt that no great hardship will be incurred in this change.

CHANGE TO STANDARD DISTRIBUTION LIST

Effective 29 August, 1947, the distribution list for Electronics Officers, Electronics Supply Officers, and GCA Units will be designated "Special List No. 14" of the Standard Navy Distribution List instead of "Special List No. 4" as formerly.

MAR OSCILLATOR CIRCUIT

An interesting oscillator circuit was devised for the MAR which has been dubbed the "crystal saver". Instead of the MAR requiring two different sets of crystals, one for the receiver and one for the transmitter, only one set is needed, plus a fixed crystal in the frequency-multiplier section.

A portion of the output of the second tripler is fed to another tripler tube in the receiver section to provide the heterodyning frequency, which when mixed with the received signal results in the 30.2 mc i-f frequency. The balance of the output of the second tripler in the multiplier section is fed to the converter tube in the transmitter section. The 10.066 mc fundamental frequency of the fixed oscillator referred to above is also coupled to the converter tube resulting in two side-band frequencies equal to the sum and difference of the two frequencies. The lower frequency is selected by the plate tuning elements which, after being tripled, is found to be 30.2 mc (receiver i-f) lower than the heterodyning frequency in the receiver.

SPARE PARTS FOR LOUDSPEAKERS

Inquiries have been received by the Bureau of Ships regarding spare parts for the type -49546 loudspeaker. Neither equipment spares, stock spares, nor spare parts stored on tenders have been provided for this equipment. In the event of failure such that the unit cannot be repaired using parts from local stocks, the speaker should be replaced with a new unit at the first opportunity.

WHAT IS "RADIAC"?

RADIAC is a descriptive term, like RADAR, SONAR, HERALD, and others, which has been approved by the Joint Research and Development Board to apply to a new branch of electronics. It is a pronounceable word derived from the description, RAdiological Detection, Indicating And Computing equipment.

Watch BuShips ELECTRON for an article concerning this new equipment.

MICROFILM COPIES OF DRAWINGS

The Bureau of Ships has recently announced that microfilm copies of Electronics Division manufacturing and installation drawings of many equipments are now available. Microfilm copies of drawings of the following equipments can be obtained by submitting a request to the Bureau of Ships, Code 932Bi, Nomenclature Control.

AN/APN-9/DBS
AN/APS-4/AN/APS-4a
AN/APS-6/AN/APS-6a
AN/APS-30 T1
AN/GPN-2
AN/MPN-1a
AN/TPS-1b
AN/APM-3
AS-354/MPN-1a Replacement Search Antenna
ASB-3/-6/-7
C-427/GR
CG-10AEX and CG-10AFT Speed and Course Computors
CAKB-10631 Auto Air Dryer
CAOR-53212-a Discriminator
CAOR-62142 Voltage Divider Probe
CG-35ABL Power Osc.
CGB-23455 and CGP-47410 Remote Antenna Tuner
CRV-50254 Speech Amplifier for TBL-2
CRV-55AHP-1 Range Indicator
CEXB/CXEC
CXEQ
CXKR
DAS
DAS-4
DBF-1
DBN
DBS (AN/APN-9)
FRA
GO-9 and Modification Kits
GP-6/-7 Power Control
JT
MBF
MBM
OAX-1
OBO
OCF
OCR-1
PM
QAA
QBH
QCU/1
QFN
QGB
QJB
RAK Series F. C. No. 4
RBM Series
RDJ-1
SA-3/SD-5 PPI
SB-74/G Patch Cord Panel
SC/SK Antenna Assembly
SC-3
SC-4
SC-5
SJ-1
SL-1
SP-1M
SP-1M Speed and Course Computer
SR
SR-2
ST
TAB-5/-6/-7
TAJ Series
TBA-4/-5/-9/-11/-12/-13
TBC-4/-5
TBK Series
TBK-17/-19
TBL Series
TBL-8
TBM Series
TBU Series
TBW Series
TBX Series
TCE-1/-2
TCG-1/-2
TCJ/-1
TCK/-1
TDE/-1/-2
TDQ
TDZ
TS-148/UP
TS-268/U
TS-358/U
TS-45/A
UG-340/U Adapter
X-DBH
ZM-1/U Ohmmeter

SUBMARINE ANTENNA INSULATORS

Reports received in the Bureau of Ships indicate that the navy type –61276-A antenna entrance insulator is not always installed properly in submarines. Bureau of Ships Drawing No. RE 61 F 341A provides the proper step-by-step procedure for installing this insulator. Close adherence to this procedure will assure a water- and pressure-tight installation. Copies of this drawing may be obtained by requesting them from the Bureau of Ships, Code 982, Washington 25, D.C.

Electrostatic Units

BASIC PHYSICS

Part-7

■ Electrical units which are based upon C.G.S. units and upon the definition of a unit electric charge are part of the *electrostatic system,* while those based upon the definition of a unit magnetic pole belong to the *electromagnetic system.* Only the more important electrostatic units will be discussed in this chapter.

When the unit electric charge was first defined, the C.G.S. system was standard in all scientific work. For that reason the absolute electrical units are usually defined in terms of the fundamental units (gram, centimeter, and second).

Practical electrical units are simply multiples or submultiples of the absolute units. One of the strongest reasons for the adoption of the M.K.S. system is that the practical electrical units fit into it naturally.

Charles Coulomb, French physicist and mathematician, formulated the basic law of electric charges which may be used for defining the unit electric charge. Using a torsion balance, Coulomb measured the force of repulsion between equal charges of like polarity. He found that *the electric force between two charges varied directly as the magnitude of the charges and inversely as the square of the distance between them.* This law holds if the volume of space occupied by the charges is small compared to the distance between

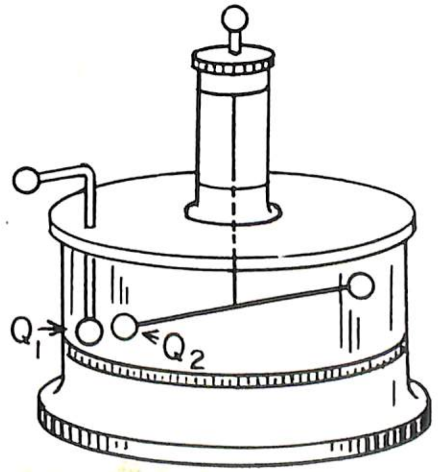


FIGURE 1—*Torsion balance.*

them. Such charges are often referred to as *point charges,* implying that they occupy negligible volumes.

Measuring the force between two charges first in air and then in a vacuum indicates that the medium surrounding the charge affects the electric force. The new factor is called the "dielectric constant" of the medium. The dielectric constant of a vacuum is equal to unity, while for air at normal temperature and pressure it is about 1.000586, which, for practical calculations, may be taken as 1.000. The unit charge is defined in terms of the force it will exert on an identical charge in a vacuum.

Coulomb's Law is expressed in mathematical form by

$$F = \frac{Q_1Q_2}{kd^2}$$

where F represents the electric force exerted between the two charges Q_1 and Q_2 when separated by a distance d. The dielectric constant of the medium is represented by the symbol k. In this chapter it will be assumed that $k = 1$, in which case Coulomb's law becomes

$$F = \frac{Q_1Q_2}{d^2}$$

from which

$$Q_1Q_2 = Fd^2.$$

If both Q_1 and Q_2 are unit charges, then $Q_1Q_2 = 1 \times 1 = 1$, and the unit charge may be defined in any system of units as

Unit charge = Unit force × (unit distance)².

The *electrostatic unit of charge* is defined in C.G.S. units. *The unit electrostatic charge is that positive charge which, in a vacuum and at a distance of 1 centimeter, repels an identical charge with a force of 1 dyne.* An electric charge may exert a force of attraction as well as one of repulsion. To avoid confusion, it is necessary to arbitrarily assign *positive polarity* to a unit charge.

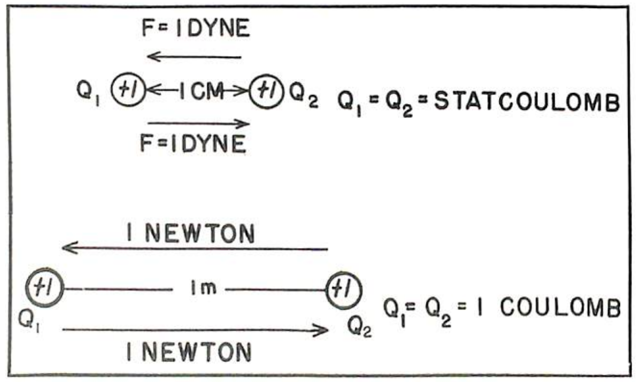


FIGURE 2—*Unit charges.*

The electrostatic unit charge is called a *statcoulomb,* the prefix "stat" being used with all units of this system, for which the abbreviation *esu,* meaning electrostatic unit, is used. The term "esu" sometimes is used to mean *statcoulomb.* The statcoulomb is a rather small charge and is not used in practical work.

The practical unit of charge in the M.K.S. system is the *coulomb. Two positive charges, each having a magnitude of 1 coulomb, will repel one another with a force of 1 newton at a distance of 1 meter.* The coulomb is a rather large unit compared to the statcoulomb.

1 coulomb = 3 × 10⁹ statcoulombs.

The proton and electron represent the smallest possible electric charges. Both particles have charges of equal magnitude but of opposite polarity. The charge of an electron is often referred to as an elementary charge.

Charge of electron $= e = -4.77 \times 10^{-10}$ *statcoulomb* $= -1.59 \times 10^{-19}$ *coulomb.*

Charge of proton $= +4.77 \times 10^{-10}$ *statcoulomb* $= +1.59 \times 10^{-19}$ *coulomb.*

In practical work it may be assumed that a positive charge of 1 coulomb constitutes a deficiency of 10^{19} electrons, a similar negative charge, an excess of 10^{19} electrons.

If Coulomb's law is applied to a normal hydrogen atom, some idea of the magnitude of the electrical forces exerted by protons and electrons may be obtained. The following statistics apply to a normal H atom.

Mass of proton $= 1.66 \times 10^{-24}$ gm.
Mass of electron $= 8.99 \times 10^{-28}$ gm.
Diameter of electron orbit $= 1 \times 10^{-8}$ cm.
Distance between electron and proton = radius of orbit $= 0.5 \times 10^{-8}$ cm.

Charge of electron = charge of proton $= 4.77 \times 10^{-10}$ esu.

$$F = \frac{Q_1Q_2}{d^2} = \frac{(4.77 \times 10^{-10})\,(4.77 \times 10^{-10})}{(0.5 \times 10^{-8})^2} = 0.0091 \text{ dyne.}$$

Although a force of 0.0091 dyne may seem to be negligible, when the extremely small mass of the electron and proton is considered it is actually a force of enormous magnitude. By contrast the force of gravitational attraction between proton and electron in a normal H atom is of the order of 10^{-42} dyne. This is infinitesimal when compared to the electrical force. Large quantities of electrical energy may be carried by small conductors simply because protons and electrons are capable of exerting electric forces all out of proportion to their mass.

THE ELECTRIC FIELD

Theoretically an electric charge is capable of exerting a force on other charges in all directions extending to infinite distances. Practically, because the force varies inversely as the square of the distance from the charge, the electric force may be assumed to be concentrated in the space immediately surrounding the charge. *That space in which the electric force exerted by a charge on other charges is perceptible is said to contain the electric field of the charge.* Michael Faraday, English physicist and chemist, formulated the basic concepts of an electric field by which it is possible to evaluate the electric field at any point in space with reference to a given charge or group of charges. (These concepts may appear to be quite complicated, but a working knowledge of them is essential if electric forces in space are to be understood.)

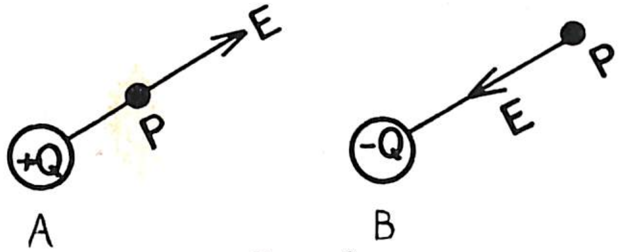


FIGURE 3.

The definition of the unit electric force must be such that it will permit evaluation of the effective force at any point in an electric field. Charges of like polarity repel, charges of unlike polarity attract. In order to evaluate the electric force of one or more charges at some point in the field of another charge, it is necessary to assume that the charges are anchored or fixed in space. It will also be helpful to know (see figure 3) that the force exerted by a charge of +Q on another positive charge located at a point P is directed along the straight line QP joining the positions of the two charges, and points in the direction E as shown in 3 (a); this also holds for a charge of –Q except that the force is directed in the opposite direction (figure 3b).

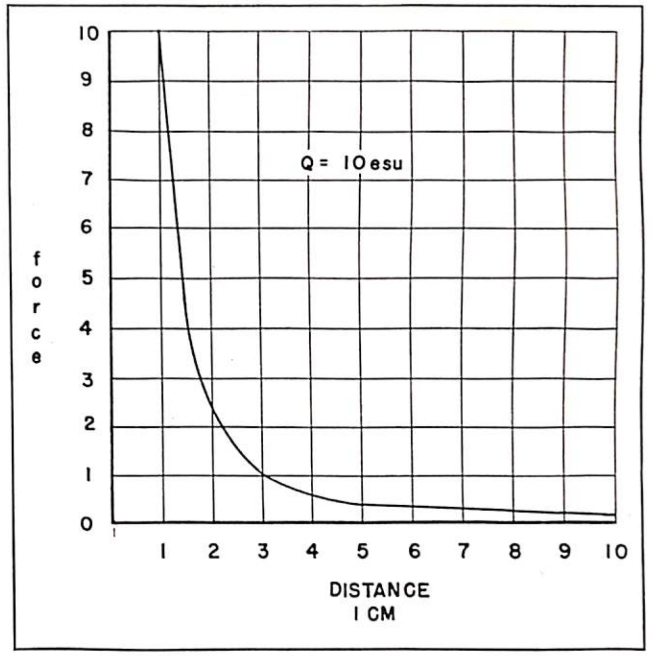


FIGURE 4—*Inverse square-law variation of field of a point charge.*

To understand Faraday's concept of an electric field, it is necessary to grasp the idea that an electric force varies inversely as the square of the distance from the charge. Figure 4 is a curve showing how the electric force exerted by a charge of 10 esu on another charge varies as the distance from the charge increases.

At a distance of 1 cm, the force has a magnitude of 10 units. At 2 cms it is only one-fourth as great. At a distance of 10 cm the force has decreased to $\frac{1}{10^2} \times 10$ or 0.1 unit. It can be said that, if a charge of 10 esu is placed at the center of a sphere 10 cm in radius, practically all of the electric field would be contained within the sphere. Theoretically, the field occupies all space; practically, it is confined to the immediate vicinity of the charge.

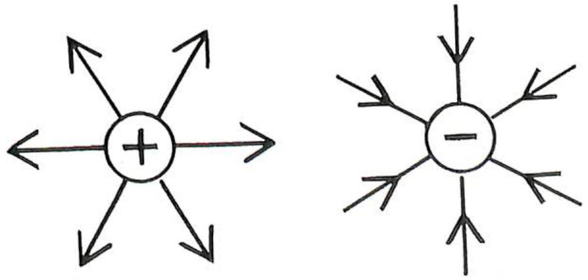


FIGURE 5—*Fields of isolated charges.*

Faraday visualized a unit electric charge as generating a certain number of tubes of force extending in all directions from the charge. These tubes are represented by uniformly spaced lines called, variously: electric lines, electric flux, dielectric lines, etc.

By making certain fundamental assumptions and by giving his imaginary electric lines certain inherent properties, Faraday was able to visualize an element of an electric field at any point and could then formulate the concepts by which the electric force at that point could be calculated. It is difficult to visualize a force as existing unless something tangible is provided against which the force may operate. *An electric field is measured by evaluating the force at every point throughout the field that would be exerted on a unit positive charge at that point, assuming that the field is not distorted by the unit charge.*

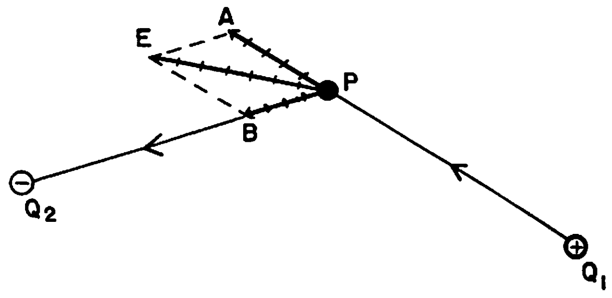


FIGURE 6.

An important property of an electric line of force is direction. Every electric line is understood to originate upon a positive charge and terminate upon a negative charge. The direction of a line of force is always away from a positive charge and toward a negative charge. When the charges are not indicated, arrowheads may be used to indicate the direction of the electric lines. In the case of an isolated charge, the electric lines point either directly toward or directly away from the charge, depending upon whether the charge is of negative or positive polarity. When the field depicts the combined force of two or more charges, the lines of force may be curved instead of straight, in which case the arrows may not point directly toward or away from the charge. In either case, *the direction of a line of force at any point in space is the direction in which a unit positive charge would tend to move if placed at that point.* Defined in this way, an electric line may be thought of as describing one of an infinite number of possible paths which a unit charge may follow in moving from a positive to a negative charge.

Another important property of lines of force is *penetrability.* An infinite number of electric lines can occupy the same space at the same time. Just as any number of guns can be brought to bear upon the same target, any number of electric forces may be brought to bear upon a given point in space. If all the forces acting upon a point are in equilibrium, the point shows no tendency to move, indicating the *effective force* at that point is zero. If the forces are unbalanced, the effective force is greater than zero, and the positive charge will tend to move in a direction determined by the *vector sum of the individual forces acting at the point.* When forces are added vectorially, direction as well as magnitude must be taken into account.

When several electric forces are acting upon a point, the effective force is defined as that force which could be substituted for all the given forces and produce exactly the same effect on the point. This definition becomes clear when reference is made to figure 6. Force A generated by charge Q_1 acts on P tending to move it in the direction PA. Force B generated by Q_2 tends to move P in the direction PB. It should be evident that P would tend to move in a direction somewhere between PA and PB. If A is the greater force, P tends to move more nearly in the direction PA. If B is the greater force, P tends to move more nearly in the direction PB.

The effective force acting at P can be evaluated geometrically. Let the force exerted by Q_1 have a magnitude of five units and that exerted by Q_2 four units. Draw PA five units long and PB four units long. Draw AE parallel to PB. Draw BE parallel to PA. This forms a parallelogram $PAEBP$. A diagonal of this parallelogram drawn from point P represents both the magnitude (approximately seven units) and direction of the *effective* force acting upon P. Forces PA and PB may be discarded by substituting a force of approximately seven units acting in the direction PE. In mathematics, PE is called the *resultant* of the forces PA and PB. It should be evident that any number of forces acting at P could be combined, two at a time, until all the forces are reduced to a single effective force.

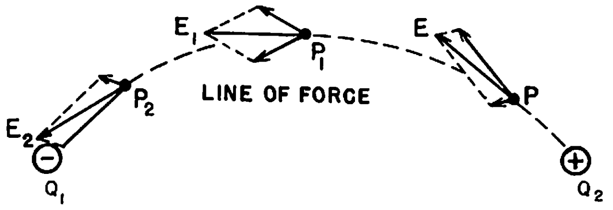


FIGURE 7.

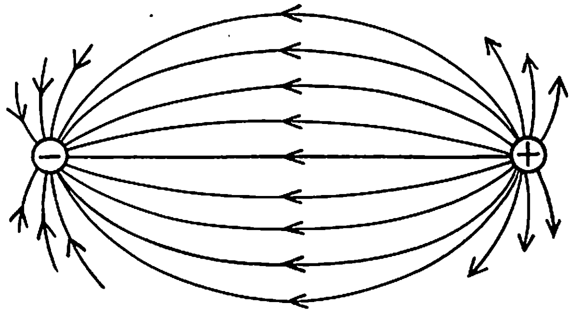


FIGURE 8—*Electric field of two unlike charges.*

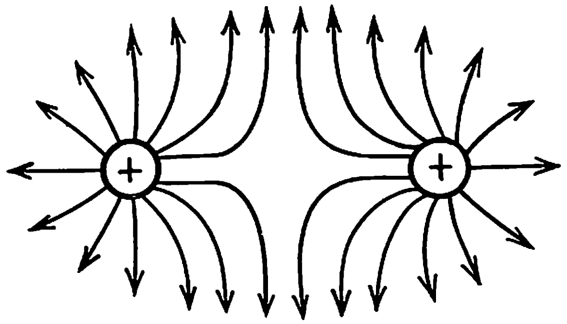


FIGURE 9—*Electric field of two like charges.*

Field Between Unlike Charges. Q_1 and Q_2 in figure 7 are charges of equal magnitude but opposite polarity. At point P, Q_2 exerts a greater force of repulsion than the force of attraction exerted by Q_1, since the distance of P from Q_2 is less than that from P to Q_1. The effective force at P is represented by PE. At point P_1, equidistant from both charges, the two component forces are equal and produce an effective force P_1E_1. At P_2 the force exerted by Q_1 predominates over that exerted by Q_2, producing the resultant force P_2E_2. Any number of additional points could be plotted along the path $Q_2PP_1P_2Q_1$, and a line drawn through these points would at every point indicate the direction in which a unit charge would tend to move if placed upon that line. Hence the path $Q_2PP_1P_2Q_1$ describes an electric line of force. Any number of such composite paths could be plotted until a pattern of the electric field between two unlike charges, similar to that in figure 8, is obtained. The student should note that when two or more charges are acting in a given space, the electric field is composed of curved lines. Only one straight line exists in the field of two unlike charges and that line represents the shortest distance between the charges.

Figure 9 shows the field between two positive charges. Reverse the direction of the lines and the same figure would indicate the field between two negative charges. Such fields are plotted in exactly the same manner as that used in determining the field between unlike charges. Greatest interest in electrical work centers in the field between unlike charges, because moving elementary charges from one point to another in an electrical circuit usually generates an electrical difference of potential.

Careful study of figures 8 and 9 reveals some additional properties of electric lines. Between unlike charges, the lines act like tight rubber bands tending to draw the charges together. Between like charges the lines act like rubber under compression, developing strains that tend to push the charges apart. Another characteristic of electric lines is that they seem to repel each other, which tends to distribute the lines uniformly in the medium surrounding the charges. When the medium is nonuniform, the dielectric constant enters the picture and the lines tend to bunch more in one medium than another.

Field Intensity. Coulomb's law indicates that a unit charge will exert a unit force at a unit distance. Faraday visualized a unit charge at the center of a sphere of unit radius. The surface area of a sphere of radius r is given by

$$A = 4\pi r^2$$

The area of a sphere one centimeter in radius is $4\ \pi\text{cm}^2$. Faraday then made the assumption that a unit charge generated 4π lines of force uniformly distributed in all directions outward from the charge. Under these conditions, one line of force would pass through each square centimeter of surface area of a unit sphere. *One line of force per*

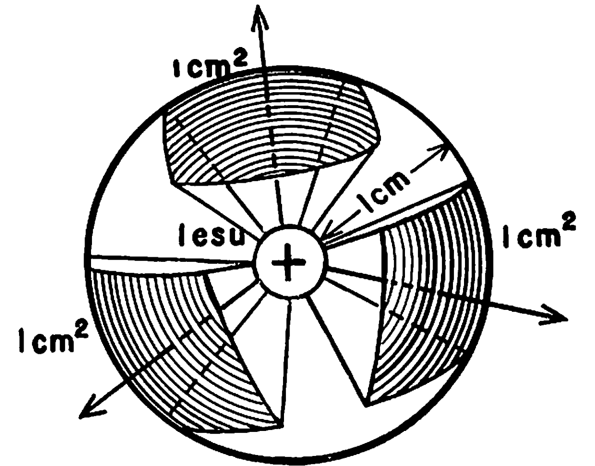


FIGURE 10—*Evaluation of unit field intensity.*

square centimeter constitutes a unit electric field intensity. By Coulomb's law, however, a unit charge exerts a force of one dyne at a distance of one centimeter. Therefore, a field intensity of one line/cm^2 represents an electric force of one dyne/esu.

This concept of field intensity would be of little value if it did not agree with Coulomb's law. Field intensity E at any point in an electric field generated by a charge Q should vary directly as the magnitude of Q and inversely as the square of the distance from Q. Consider first the variation of E with magnitude of Q. If a charge of two esu is placed at the center of a unit sphere, a total of $2 \times 4\pi$ or 8π lines of force will be generated. At a distance of one centimeter, the field intensity will be 2 lines/cm^2. A field intensity of 2 lines/cm^2 is equivalent to a force of 2 dynes. Hence if the magnitude of the charge is doubled, the field intensity at any fixed point is doubled. E varies directly as the magnitude of Q.

Consider now a unit charge placed at the center of a sphere 2 cm in radius. The area of such a sphere is 16π/cm^2. If a unit charge generates 4π/lines, then at a point 2 cm from the charge there will be only one line for each 4 cm^2 of spherical surface. One line for each 4 cm^2 is an intensity only one-fourth that of 1 line/cm^2. At a distance of 2 cm, a unit charge exerts a force of only one-fourth dyne. Electric field intensity, therefore, varies inversely as the square of the distance from the charge. Faraday's concept of field intensity is in complete agreement with Coulomb's law.

The field intensity E at any point in an electric field defines the effective force exerted upon a unit charge placed at that point.

$$E = \frac{Q_1}{d^2}$$

In this equation E, the field intensity, is in dynes/esu; Q_1, the magnitude of the charge that generates the field, is in esu; and d, the distance of the point from Q_1, is in cm. Note that if Q_2 in Coulomb's law represents a unit charge, the equation for field intensity may be derived directly.

If a charge of Q_2 units is placed at P in the field of Q_1, the effective force exerted by Q_1 on the charge of Q_2 units will be Q_2 times greater than the force exerted upon a unit charge. The effective force exerted upon a charge of Q_2 units will then be

$$F = EQ_2.$$

When two or more charges are acting upon the same point in an electric field the resultant field intensity is the vector sum of the individual field intensities generated by the different charges. For example, the field intensity generated at P by charge Q_1 in figure 11 is

$$E_1 = \frac{Q_1}{d_1^2} = \frac{18}{3^2} = \frac{18}{9} = 2 \text{ dynes}$$

Since Q_1 is positive, the direction of E_1 is along the line from P to E_1. The field intensity at P as a result of Q_2 is

$$E_2 = \frac{Q_2}{d_2^2} = \frac{-100}{5^2} = \frac{-100}{25} = -4 \text{ dynes}$$

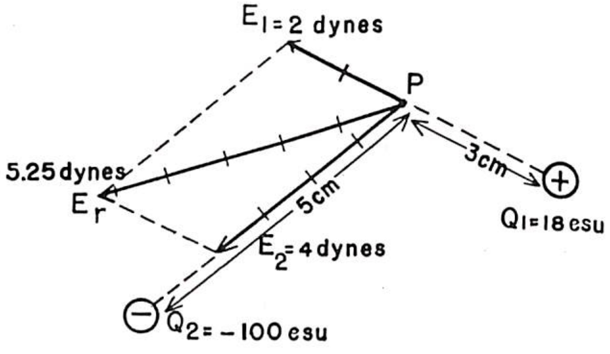


FIGURE 11.

The negative sign simply indicates that the force at P is attractive and will be directed along a line from P to Q_2. Adding the two intensities E_1 and E_2 vectorially yields a resultant intensity E_r of approximately 5.25 dynes in the direction PE_r. In a subsequent section of the course, mathematical methods of adding vectors will be explained. Such methods will yield a greater degree of accuracy than the geometric method used in figure 11.

Electric Potential. Field intensity is a rather cumbersome quantity because it must always be treated as a vector. It will be remembered that Newton defined force primarily to obtain a quantitative definition of work. The work done on a body is independent of the direction in which the body is moved. If a weight of two pounds is moved four feet to the left, 8 ft-lb of work is done. If the weight is now moved four feet to the right, an additional 8 ft-lb of work is done. The total work is 16 ft-lbs, although the body has returned to its original position. The total work done is the sum of the work done by the individual forces acting upon the body. Direction is not a factor in calculating work. If electric charges and forces are analyzed in terms of work, difficulty in working with vector forces is avoided. The concept of field intensity is necessary because work must be defined in terms of force.

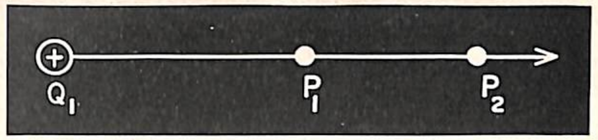


FIGURE 12.

In order to move a unit charge from P_2 to P_1 (figure 12), work must be done against the force of repulsion exerted by Q_1. Conversely, if a unit charge moves from P_1 to P_2 under the impetus of the electric force exerted by Q_1, then Q_1 must do work on the unit charge. *A unit charge at any point in an electric field must possess potential energy because the unit charge cannot be brought to that point unless it does work or has work done upon it.* Theoretically, a unit charge in the field of Q_1 can have zero potential energy only if it is moved an infinite distance from Q_1. *The potential energy of a unit charge at any point in an electric field is called the potential of that point.*

From a quantitative viewpoint the potential of a point in an electric field is the work that must be done upon a unit charge to bring it from a zero potential level to the selected point in the field. Theoretically, the zero potential point is an infinite distance from the charge generating the field. The absolute potential of a point in the field of Q_1 is given by

$$V = \frac{Q_1}{d}$$

where d is the distance of the point from Q_1. V is used as a symbol for work per unit charge because the unit of potential in the C.G.S. system is the statvolt and in the M.K.S. system the volt. The volt is a joule per coulomb because one joule of work is done in moving one coulomb from an infinite distance to a point one meter from a like charge of one coulomb. The relation between volt and statvolt is

$$1 \textit{ statvolt} = 300 \textit{ volts},$$

$$1 \textit{ volt} = \frac{1}{300} \textit{ statvolt}.$$

If V represents the potential (potential energy of a unit charge) at some point in the electric field of a charge Q_1, then, if a charge of Q_2 units is placed at that point, it will have a potential energy of VQ_2 units.

$$V_2 = VQ_2 = \frac{Q_1}{d} \cdot Q_2 = \frac{Q_1 Q_2}{d}$$

where V_2 is the potential energy of Q_2 when it is placed at a point d units from Q_1.

Newton based his idea of work upon mechanical concepts and demonstrated that

$$w = Fd$$

Coulomb's law defines the electric force between two charges as

$$F = \frac{Q_1 Q_2}{d^2}$$

That the concept of electric potential is in agreement with Newton's definition of work is evident from

$$\textit{Work} = Fd = \frac{Q_1 Q_2}{d^2} \cdot d = \frac{Q_1 Q_2}{d} = V.$$

Field intensity is a measure of the electric force acting upon a unit charge at some point in an electric field. Electric potential is a measure of the work done on a unit charge in bringing it up to some point in an electric field. Since

$$E = \frac{Q_1}{d^2}$$

multiplying both sides by d

$$Ed = \frac{Q_1}{d^2} \cdot d = \frac{Q_1}{d}.$$

But $\qquad V = \dfrac{Q_1}{d}$

Hence $\qquad V = Ed$

The potential V of a point in the field of a charge Q_1 may be defined as the product of the field intensity E at that point and the distance d of the point from Q_1. The principal advantage of V over E in working with electric charges and forces is that V is a scalar quantity, which means that potentials may be added algebraically instead of vectorially.

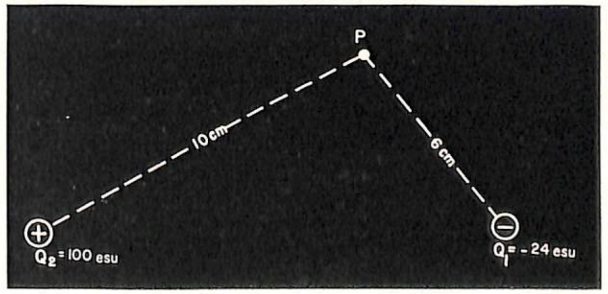


FIGURE 13.

Potential of a Point in a Composite Field. In figure 13, P is a point in the field of charges Q_1 and Q_2. The potential of P as a result of Q_1 is

$$V_1 = \frac{Q_1}{d_1} = \frac{-24}{6} = -4 \textit{ statvolts.}$$

The negative sign indicates a unit charge would accomplish four ergs of work in moving from an infinite distance to P in the field of Q_1.

The potential of P as a result of Q_2 is

$$V_2 = \frac{Q_2}{d_2} = \frac{100}{10} = 10 \textit{ statvolts.}$$

The absolute potential of P resulting from the combined effect of the two fields is

$$V = V_1 + V_2 = -4 + 10 = 6 \textit{ statvolts.}$$

Six ergs of work must be done to move a unit charge from an infinite distance to P in the combined field of Q_1 and Q_2. Actually, a total of ten ergs of work is accomplished, but the work which would have to be done in overcoming the repulsive force of Q_2 on the unit charge is partially counterbalanced by the attractive force of Q_1.

If a charge of Q esu now is placed at P, the potential of the point will be increased Q times. If $Q = 25$ esu, then

$$V_2 = VQ = 6 \times 25 = 150 \textit{ statvolts.}$$

An amount of 150 ergs of work must be done to bring a positive charge of 25 esu to point P.

Equipotential Surfaces. The statement that a unit charge has zero potential only when located an infinite distance from a charge is definitely abstract. A more logical point of reference than an "infinite distance" is necessary if the measurement of potential is to be practical. If a charge is placed at the center of the sphere, every point upon the surface of the sphere will have the same field intensity. This means a second charge could be moved anywhere over the surface of the sphere without encountering any force of opposition, hence no work could be done by or on the charge. Work cannot be done unless the unit charge is moved against some opposing force. *An equipotential surface is one over which a charge may move without gain or loss of potential.*

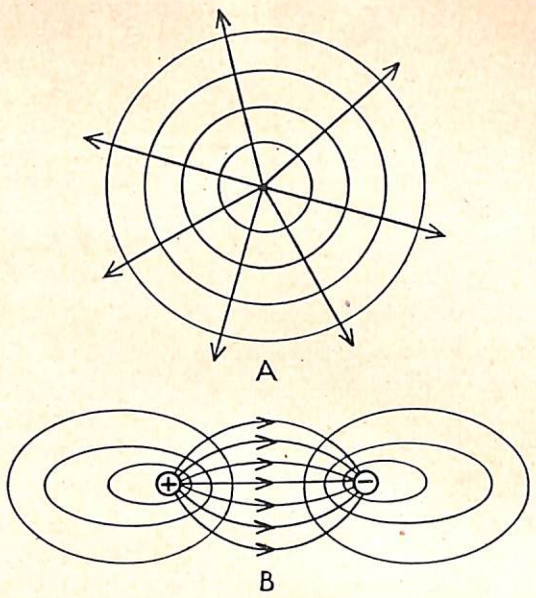


FIGURE 14—*Equipotential lines in field of (A) isolated charge, and (B) two unlike charges.*

An equipotential line is one drawn through all points of the same electric potential in an electric field. The theory that an electron rotates about the atomic nucleus without gain or loss of energy is based upon the fact that the electron orbit is an equipotential path. Figure 14 (a) shows that the equipotential lines about an isolated charge form a series of concentric circles. (Note similarity to electron shells.)

Figure 14 (b) shows the distorted equipotential lines to be found in a composite field of two unlike charges. Even greater distortion is to be expected as the number of charges contributing to the field increases.

Any charged body acts like an equipotential surface because the electric charge always tends to distribute itself in such a way that all points on the body are at the same potential. If this were not true, some points would be subject to a greater electric strain than others, which would force mobile electrons to move until the charge was uniformly distributed and all strains equalized. Figure 15 shows how a charge on a metal sphere distributes itself to form an equipotential surface.

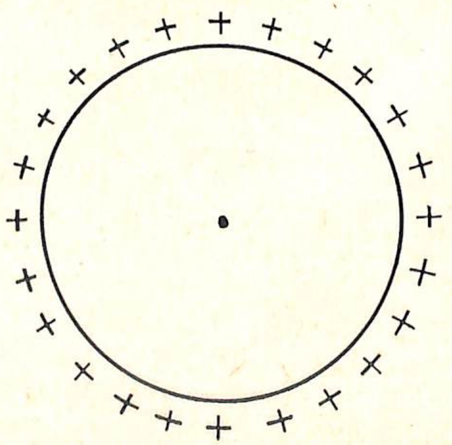


FIGURE 15—*Charged spherical conductor.*

The Earth as an Equipotential Surface. In all electrical and electronic work the earth is the most important equipotential surface. The number of mobile electrons in the earth is so great that the addition or removal of any number within the capacity of man has about the same effect on the earth potential as the removal of a drop of seawater would have upon sea level. The surface of the earth is then a surface of constant potential.

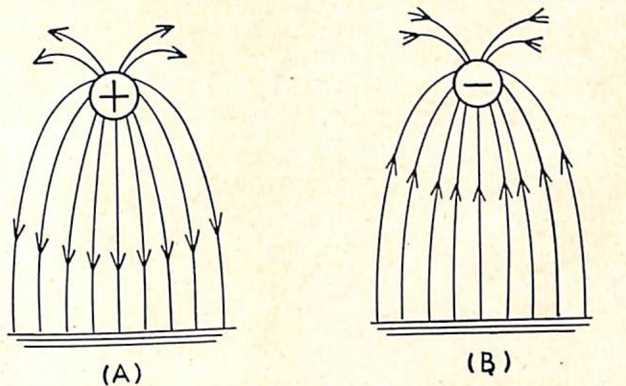


FIGURE 16—*Electric field lines between the earth and (A) a positive charge, and (B) a negative charge.*

A charged body will immediately return to a neutral state if it makes direct electrical contact with the earth. A neutral body has zero electric potential. Electric charges can be induced at some point in the earth, but the induced charge disappears with removal or neutralization of the inducing charge. For all practical purposes the earth represents a surface of zero electric potential. An isolated electric charge in space will generate electric lines which terminate at the earth's surface as shown in figure 16 (a) and (b). Insofar as electrical effects are concerned, any point on the surface of the earth is equivalent to a point an infinite distance from an electric charge.

It should be evident that the earth forms an ideal reference level from which to measure electric potential. The unit potential may now be defined as the work done in moving a unit charge from the surface of the earth to some point P in the field of a charge Q. In the parlance of the engineer, earth potential is called "ground."

Most electrical and electronic circuits are grounded at some point. The drawing symbol ⏚ connected to some point in the circuit indicates that that point is connected to ground or is at ground potential. The absolute potential of any point in the circuit is then the potential of that point in respect to ground.

Difference of Potential. Experience has indicated that the concept of difference of potential offers considerable difficulty. In general the difference of potential between any two points in an electric field, or an electric circuit, is of greater interest than the absolute potential of either point. (The absolute potential of a point is actually the difference in potential between that point and ground when earth is used as the zero reference point.)

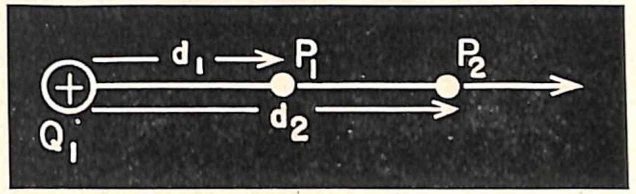


FIGURE 17.

There are two distinct definitions for difference of potential. In figure 17, let P_1 and P_2 represent two points in the field of charge Q_1. Since d_1 is less than d_2 the absolute potential of P_1 must be greater than that of P_2. The work done in moving a unit charge from an infinite distance to P_1 is

$$V_1 = \frac{Q_1}{d_1}$$

and in bringing a similar charge to P_2 is

$$V_2 = \frac{Q_1}{d_2}.$$

The work that must be done to move a unit charge from P_2 to P_1 must then be

$$V = V_1 - V_2 = \frac{Q_1}{d_1} - \frac{Q_2}{d_2}$$

where V represents the difference of potential between P_1 and P_2. One definition of *difference of potential* is the *work done in moving a unit charge from a point of low potential to a point of higher potential.* An electric generator is a device for converting mechanical energy to electrical energy. It accomplishes this function by moving electrical charges against an electric field so as to generate a difference of potential across the output terminals of the machine.

Consider figure 17 from another viewpoint. At P_1 a unit charge has greater potential energy than at P_2. If the electric field of Q_1 forces the unit charge to move from P_1 to P_2, the decrease in potential energy can be accounted for only by having the unit charge accomplish work. In moving from P_1 to P_2 the charge falls through a certain difference of potential or voltage drop. The work done by the unit charge is

$$V = \frac{Q_1}{d_1} - \frac{Q_1}{d_2} = V_1 - V_2$$

which may now be interpreted to mean the *work done by a unit charge in moving from a higher to a lower potential level.* An electric motor is a device for converting electrical energy to mechanical energy. The difference of potential or voltage drop across the input terminals of the motor represents the work done by a unit charge as it moves through the motor from the high- to the low-potential terminal. The only difference in these two definitions of difference of potential is in the direction in which the unit charge moves. In the first case work is done on the charge by an external force to overcome the force of repulsion of Q_1. In the second case the force of repulsion of Q_1 is used to move the unit charge, and in so doing the charge is made to accomplish work. It will be found that the second definition is of greater interest than the first because the number of methods by which electrical energy may be utilized is many times greater than the methods by which it may be generated.

It is interesting to note that the equation

$$V = \frac{Q_1}{d_1} - \frac{Q_1}{d_2}$$

may be used to show the derivation of the absolute potential of a point. As the distance d_2 increases, $\frac{Q_1}{d_2}$ decreases, so that when d_2 becomes infinitely large, $\frac{Q_1}{d_2}$ becomes negligibly small or approaches zero. When $Q_1/d_2 = 0$, then the absolute potential of P_1 is given by

$$V = \frac{Q_1}{d_1}$$

where d is the distance of P_1 from Q_1.

Relative Polarity. The concept of relative polarity which definitely complicates the idea of difference of potential stems from the fact that the earth is taken as a point of zero potential and there are two kinds of electrical charges, positive and negative.

Q_1, being a positive charge, exerts a repelling force on a unit charge in its field; to do work, the unit charge, therefore, must move away from Q_1. Conversely, $-Q_1$, being a negative charge, exerts a force of attraction on a unit charge in its field; in this case the unit charge must move towards $-Q_1$ to do work.

For example: A positive charge of 100 esu will generate a potential of 20 statvolts at a point 5 cm from the charge. A negative charge of −100 esu will generate a negative potential of −20 statvolts at the same distance. A potential of −20 statvolts does not mean negative potential energy, but rather the direction in which a unit charge must move to accomplish work. The idea is illustrated in figure 18.

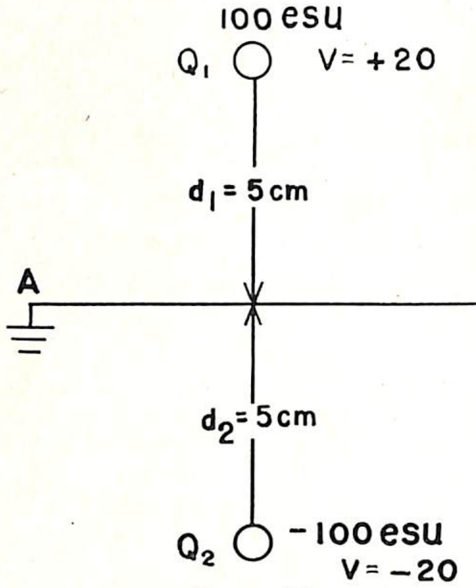


FIGURE 18.

The line AB represents zero or earth potential. AB could be a grounded metal plate between the charges. A unit charge in moving from Q_1 to AB through the distance d_1 does 20 ergs of work under the force exerted by Q_1. The field of Q_1 terminates at line AB. In the movement from AB to Q_2, the force of attraction of Q_2 causes the unit charge to accomplish an additional 20 ergs of work, so the total work done by the unit charge is 20 + 20 or 40 ergs. This means that the unit charge has moved through a potential difference of 40 statvolts. When positive and negative potentials are being considered, the difference of potential represents the *algebraic difference* between the absolute potentials of two points.

$$V = V_1 - V_2$$
$$= 20 - (-20) = 40 \textit{ statvolts.}$$

Shifting the Potential Reference Level. In an earlier chapter special emphasis was placed upon the fact that the potential energy of an elevated body depended upon the reference level from which the height of the body is measured. The potential of any point in an electric field or circuit may be measured with respect to the potential of any other point. A *voltmeter* is a device for measuring difference of electric potential. In a direct-current voltmeter the negative terminal usually represents the point of reference from which potential is measured. If the negative terminal is connected to some point in a circuit, the meter will read the potential difference or voltage drop between that point and the point to which the positive terminal is connected. The meter reading is *with respect to the negative terminal.*

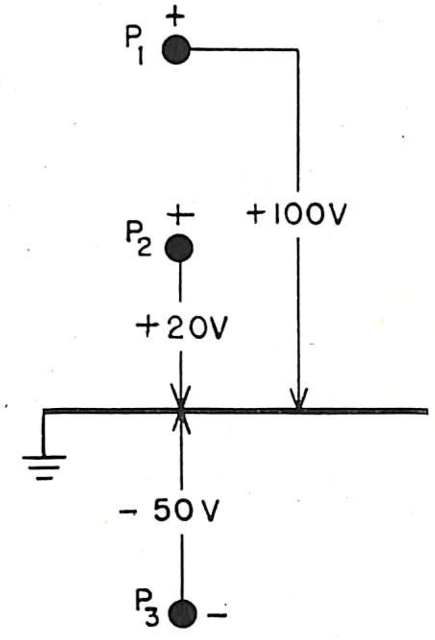


FIGURE 19.

Shifting of reference level is explained in figure 19. The three points have the absolute potentials shown. Let P_1 be the reference level. Then—

P_1 is 100 volts positive with respect to ground.
P_2 is 20 −100 or 80 volts negative with respect to P_1.
P_3 is −50 −100 or 150 volts negative with respect to P_1.

Let P_2 be the reference level. Then—

P_1 is 100 −20 or 80 volts positive with respect to P_2.
P_3 is −50 −20 or 70 volts negative with respect to P_2.
The absolute potential of P_2 is 20 volts positive (with respect to ground).

Let P_3 be the reference level. Then—

P_1 is 100 − (−50) or 150 volts positive with respect to P_3.
P_2 is 20 − (−50) or 70 volts positive with respect to P_3.
The absolute potential of P_3 is −50 volts (with respect to ground).

It should be evident that the *polarity assigned to a difference of potential is relative to the point selected as the reference level.* It is well to remember that if A is positive to B, then B is negative to A.

Familiarity with electrical principles develops a certain looseness of expression with regard to potential difference. An engineer might say the potential across a certain device is 110 volts. What he usually means is that the high potential end of the device is 110 volts positive with respect to the low potential end. Another expression is that point A is 40 volts positive. This can have a dual meaning. It usually means 40 volts positive with respect to ground. It may also mean 40 volts positive with respect to the lowest potential point in the circuit. In electronic circuits a great many points may have negative absolute potentials. Such points are said to be "below ground." A point 40 volts positive with respect to a point that is 10 volts negative is 30 volts positive with respect to ground.

Potential Gradient. Potential gradient will be discussed only briefly at this point. In a later chapter where it is important to an understanding of certain electrical and electronic phenomena, a more extended discussion will be given.

Potential gradient expresses the relation between field intensity and difference of potential. *Field intensity* describes the force exerted on a unit charge at some point in a field, whereas *potential difference* represents the work done in moving a unit charge from one point to another in the field.

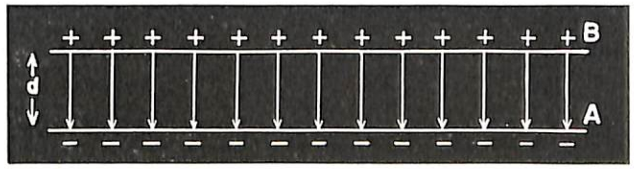


FIGURE 20—*Electric field lines between plates of a charged condenser.*

In figure 20, A and B are two metal plates separated by air. When electrons are removed from B and added to A, a potential difference is established across the plates, with B at a higher potential (positive) than A. If the area of the plates is large compared to d, the distance of separation, the electric field between the plates will be uniform. (A slight non-uniformity exists at the edge of the plates.) A uniform field is one in which the field intensity is the same at all points in the field. A charge moving from A to B will be subject to a constant force given by

$$F = QE.$$

The work done by Q in moving from A to B is

$$w = Fd = QEd.$$

But work is also defined as the product of Q and the difference of potential through which it moves or

$$w = QV$$

Hence $QEd = QV$

Dividing by Qd

$$E = \frac{V}{d}.$$

The quantity $\frac{V}{d}$ represents the *potential difference or voltage drop per unit distance,* and is called the potential gradient of the field. When the field is uniform, the potential gradient is a constant; that is, a charge moving directly from A to B would fall through the same voltage drop from each centimeter of movement, regardless of the distance from either plate.

The potential gradient is not a constant in a non-uniform field. Figure 4 shows that field intensity decreases inversely as the square of the distance from a charge. In a non-uniform field, the *potential gradient at any point is defined as the rate of change of potential at that point.* Figure 4 indicates that the potential gradient will increase with the magnitude of the charge generating the field, and also will increase with a decrease in the distance from the charge. In figure 4 the slope or steepness of the curve is a measure of the potential gradient. How this rate is calculated will be discussed in a later chapter.

Potential gradient is important wherever high potentials are encountered. A charge of large magnitude concentrated into a small volume of space will develop a very high potential gradient in the immediate vicinity of the charge. The electric strain or potential drop across the atoms in the medium surrounding the charge may be sufficient to tear electrons from their orbits. When this occurs, the medium becomes a conductor instead of an insulator. A lightning discharge is a typical example of what occurs when the potential gradient between the earth and a cloud exceeds the critical potential gradient at which the intervening air breaks down or becomes a conductor. Between broad surfaces dry air will break down when the potential gradient approaches 30,000 volts per inch. Between needle points (highly concentrated charges) air will break down at a much lower potential gradient.

EXERCISES, PART 7

Test Questions:

1. A positive charge of 1 coulomb is located at a distance of 1 cm from a negative charge of identical magnitude. Determine the force of attraction between the two charges in metric tons. Note: 1 metric ton = 1000 kg and 1 kg force = 981,000 dynes.

2. In Problem 1, if the distance between charges is increased to 8000 miles (diameter of the earth) what will be the force of attraction between the charges in dynes?

3. Two charges of equal magnitude exert a force of attraction of 75 dynes at a distance of 3 centimeters. Calculate the magnitude of the charges in coulombs.

4. Calculate the force of gravitational attraction between the nucleus and electron in a normal hydrogen atom. The constant g in the universal gravitation law is 6.67×10^{-8} in the C.G.S. system.

5. Calculate the field intensity in lines/cm^2 at points 5, 10, and 25 centimeters from a point charge of 3×10^{-7} coulombs.

6. If a charge of –50 esu is placed at points 5, 10, and 25 centimeters from a charge of 3×10^{-7} coulombs, calculate the force in dynes that would be exerted on the charge at the different points.

7. Given a charge of 6.3×10^{-9} coulomb. Calculate the absolute potential in volts of a charge of 3 esu located 10 cm from the given charge.

8. The absolute potential of P_1 is –40 volts, and of P_2, 30 volts. If P_3 is 60 volts positive with respect to P_1, what is the potential of P_3 with respect to P_2?

ANSWERS TO TEST QUESTIONS, PART 6

1. 1847 and –1.
2. Attractive. 80.
3. 16/25 = 0.64.
4. (a) 6, (b) 29, (c) 73, (d) 80.
5. Infra-red.

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Methods for Determination of Resistance of Power Sources

By John H. Miller

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■ Periodically it becomes necessary to obtain the value of the effective resistance of a power source, be it a battery, a generator with its associated line, a high-frequency oscillator, or an audio-frequency system feeding a load. A number of methods are available for making such measurement from the classical Mance's method for batteries to the simpler so-called voltage-doubling methods. Perhaps the latter can best be called a resistance-doubling method, and is very generally applicable. The method may be either at constant current or constant voltage, depending upon the problem at hand.

The power source may be considered as a fixed voltage, E, in series with a resistance, R_s, whose value is to be determined. Connect a decade box, R, and a suitable milliammeter in series with the source as shown in figure 1. The decade box is then adjusted to a value, R_1, so that a substantial indication is obtained on the milliammeter. Then readjust this resistance to a value, R_2, to give a second current reading of exactly one-half the previous reading. Then the source resistance, $R_s = R_2 - 2R_1$. Actually the resistance of the milliammeter is a part of R_1 and R_2, but may be neglected if small in comparison as is usually the case. If the circuit constants and parameters are such that R_1 can be zero and the meter resistance is negligible, obviously $R_s = R_2$. Where the source resistance is low and short circuit currents cannot be drawn, R_1 values will be found to be necessary but should be maintained at the lowest possible value and also, in these cases, it may be advisable to consider the instrument resistance R_m, in which case $R_s = R_2 - 2R_1 - R_m$. The method is rigorous provided that the circuit constants are linear and, further, for a-c circuits, provided that the impedance does not differ from the resistance by an appreciable amount.

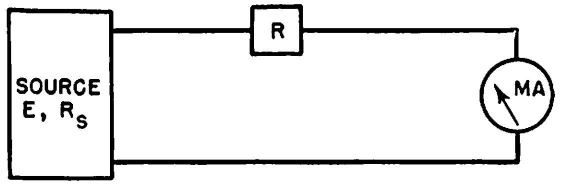

FIGURE 1—*Circuit for determining the resistance of a power source by resistance-doubling method.*

Where non-linear circuits are used, as in rectifier networks, instead of halving the current the voltage can be doubled to maintain the current in the second condition to the same value, whereupon the same equations apply. This arrangement is suitable where an audio-frequency power source is available with an attenuation system or some other voltage control and will give directly the source resistance which can usually be interpreted as impedance at audio frequencies.

The same general method is used for taking the resistance of a rectifier meter such as a VU meter. Figure 2 shows a variable power source, usually 1000 cycles, with voltage control and an accurate voltmeter, V. With a decade box, R, set initially at zero, the rectifier-type instrument, M, is adjusted to read the point at which the equivalent resistance value is to be taken. The voltage is then doubled and the decade box adjusted to give the same reading on the instrument. By definition, then, the resistance of the instrument including its non-linear rectifier is equal to the resistance of the decade box. Through the use of this method the effective resistance of the instrument can be taken at any scale point.

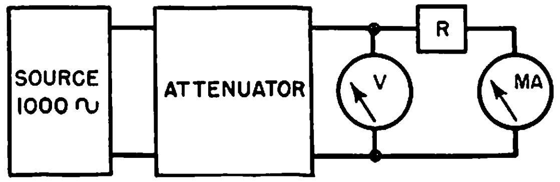

FIGURE 2—*Voltage-doubling method for determining the resistance of non-linear circuits.*

It must be noted that a single figure representing the resistance of a non-linear resistive element is an anomaly and the single value of resistance can be given only if suitably defined. In the practical sense, these resistance values are quite useful in analyzing rectifier meters and, in general, the values obtained by this method probably represent a preferred mean value for any type of non-linear resistive network.

CAREFUL !!

high voltage is

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