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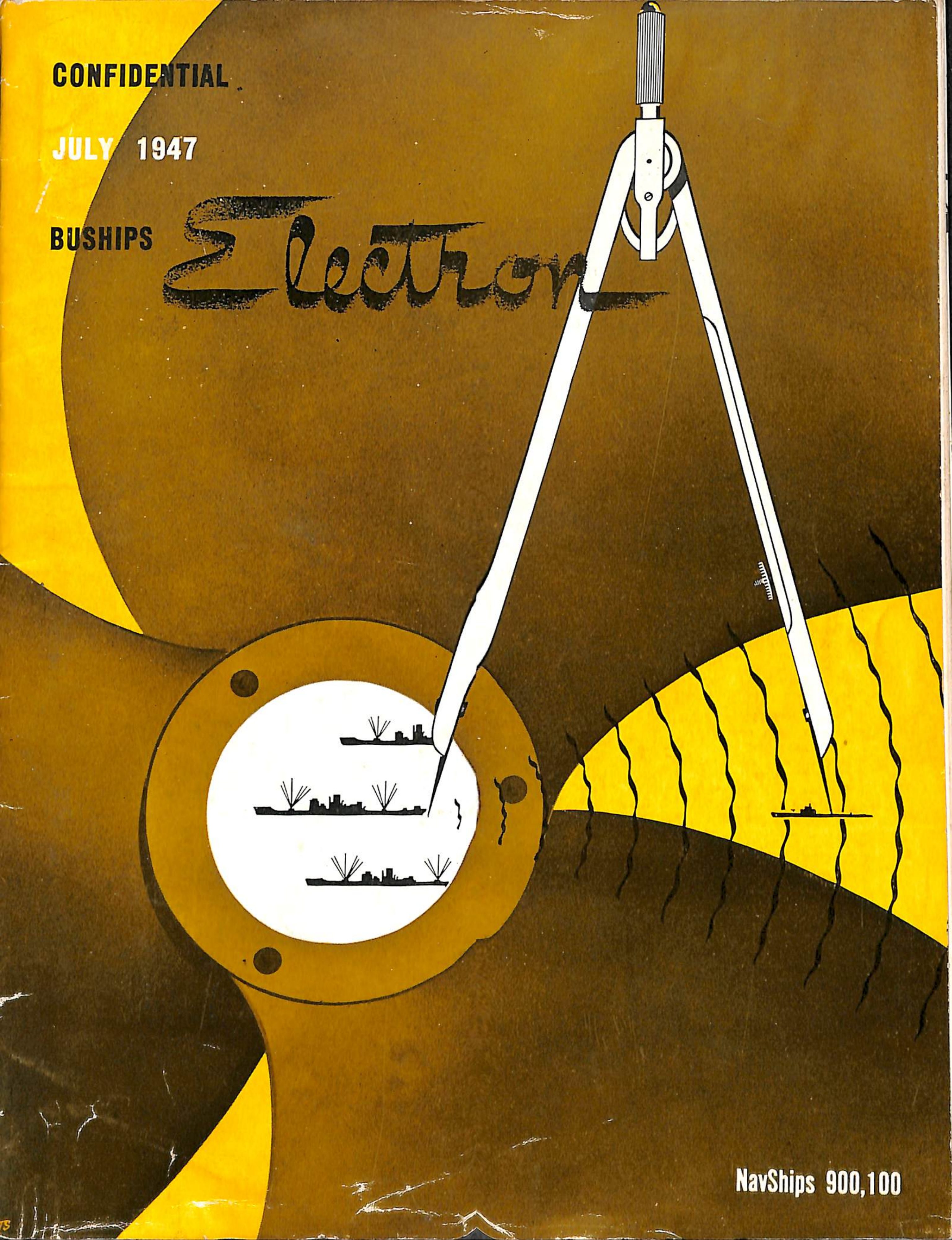
JULY 1947

BUSHIPS Electron



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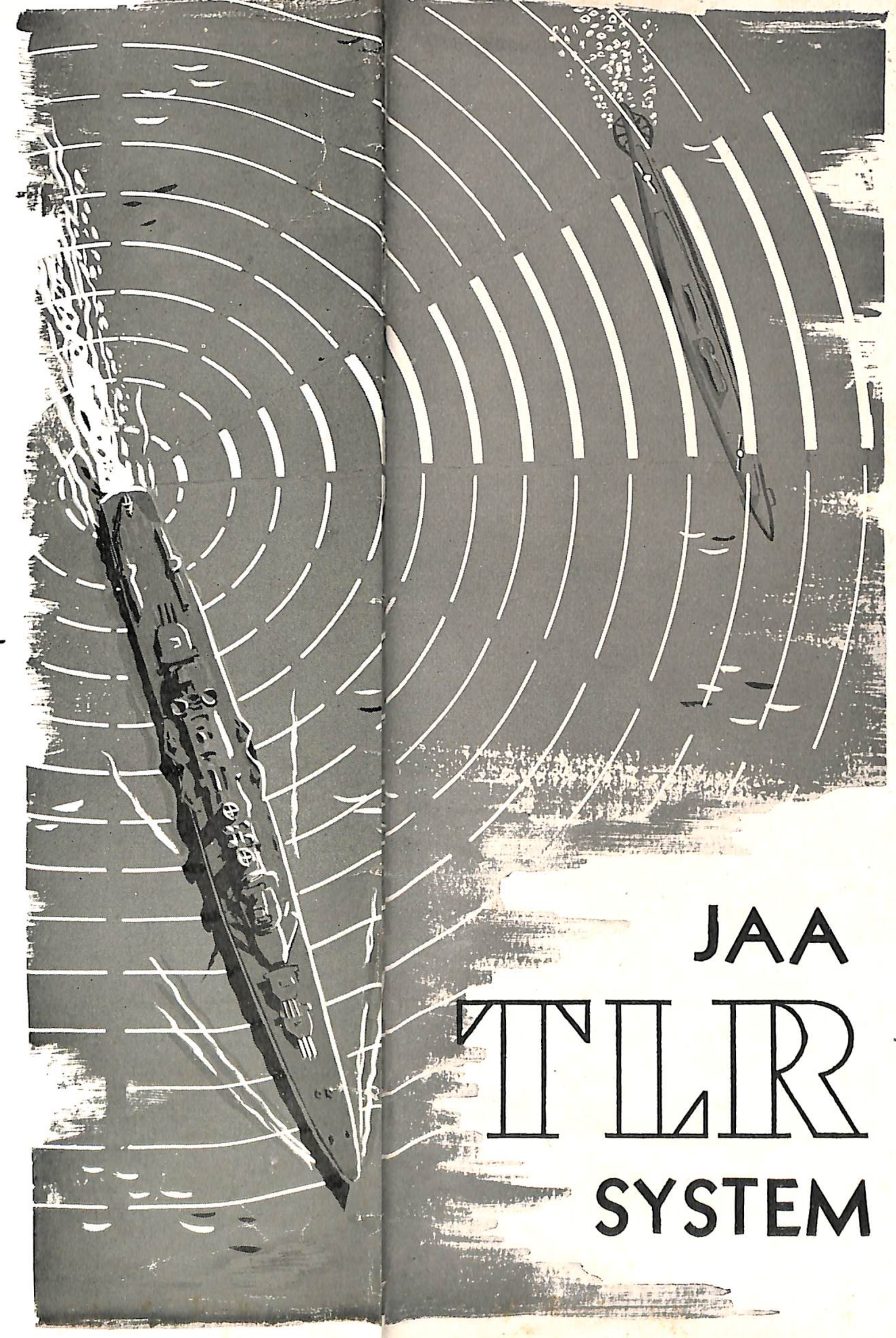


JAA TLR SYSTEM

JAA TRIANGULATION-LISTENING-RANGING SYSTEM

The Model JAA submarine sonar equipment for triangulation, listening and ranging (TLR) was designed to meet the possibility for a listening ranging equipment that could be used both in preparing and evading attack while a submarine was submerged. This equipment determines the range and bearing from a submarine to a beam (±60°) target by utilizing the sound energy generated by the target. The system consists essentially of a system for triangulating from a baseline on the deck of a submarine, at the ends of which are located two hydrophones having highly directional sonic listening characteristics. Relative forward and after bearings from these hydrophones are fed to a computer (triangle solver) which computes the range of the target from the bearings and the known length of the baseline, and drives a range motor to print a trace of range-rate on an associated recorder.

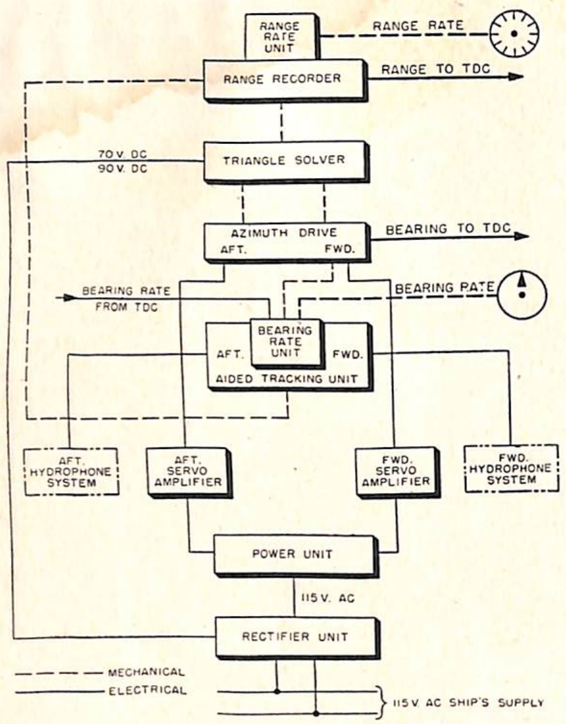
The major units of the Model JAA equipment are:

2 magnetostriction line-hydrophones
1 forward training mechanism
1 after training mechanism
2 preamplifiers
2 RLI bearing-deviation indicators
1 sonic amplifier and control panel
1 computer (mechanical)
1 noise source
2 noise-source transducers
1 intercommunication system

The important components of the complete system are shown in block diagram form in figure 2. The upper center section of the diagram shows the four sections of the Computer: the Aided-Tracking Unit, the Azimuth Drive Unit, the Triangle Solver, and the Range Recorder. On either side are shown the hydrophone training systems.

MAJOR UNITS

Magnetostriction Line-Hydrophones: The two hydrophones used in this equipment are of the straight untapered 5-foot permanent-magnet magnetostriction type, made up of ten toroidally-wound sections. They are plastic filled, and are covered with neoprene rubber compound. They are mounted on baffles which consist of a streamlined stainless steel fairing covered with a rubber blanket.



SPERRY COMPUTER-BLOCK DIAGRAM

FIGURE 2—*Block diagram of the complete Model JAA system showing the major connections.*

Training Mechanisms: The training mechanisms are located in the forward and after torpedo rooms. They are too similar to those of the Model WFA-series topside units to warrant further comment here.

RLI Bearing-Deviation Indicators and Preamplifiers: Sounds generated by a target are picked up by the split hydrophones. These signals induce

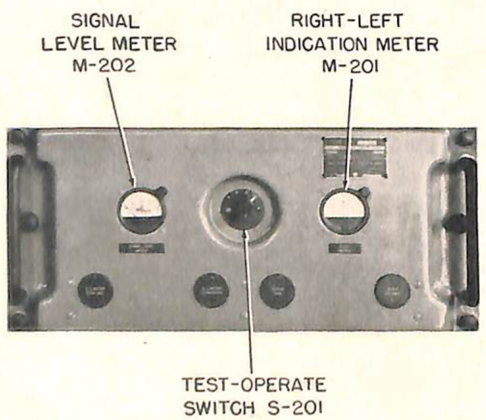
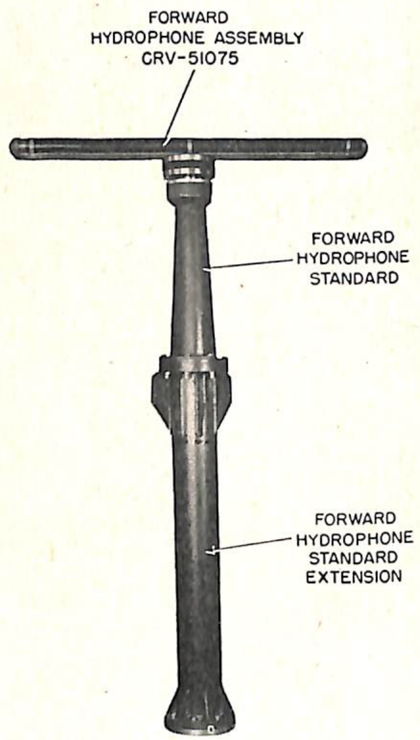


FIGURE 3—*Right-left indicating bearing deviation indicator main unit.*

voltages in each half of the hydrophone which are equal in amplitude but differ in phase, unless the sound source is in a plane at right angles to the hydrophone. The halves of the hydrophone are connected to a pair of input transformers and associated preamplifiers in such a manner that one preamplifier receives the vector sum of the voltages generated in the two sections of the hydrophone, and the other preamplifier receives the vector difference. When the hydrophone is trained on the target, no difference voltage is generated, and the sum voltage is equal in amplitude to the sum of the two voltages in the two halves of the hydrophone. When it is trained slightly off the target, a



Forward hydrophone assembly, standard, and extension.

difference voltage is generated which is displaced 90 electrical degrees, either leading or lagging the sum voltage depending upon whether the target bears to the right or left of the hydrophone.

These sum and difference signals, displaced 90° in phase, are fed to the RLI unit proper (see figure 3). This is a two-channel system, one being called the *sum* channel and the other the *difference* channel, both being identical up to the last stage. In the input of each channel there is a 500-16,000-cycle band-pass filter followed by three stages of pentode amplification using varistors in an automatic-volume-control circuit.

After being amplified, the signals are again filtered through a 9-16-kc band-pass filter. The signals are then shifted 45° in the sum channel and 135° in the difference channel (a relative overall shift of 90°) to obtain signals which are either in phase or 180° displaced, depending on whether the hydrophone is pointing to the left or to the right of the target. After both signals are further amplified, the sum signal is passed through a phase inverter in order to obtain two equal signals, one of which is in phase with the original signal, and the other 180° out of phase.

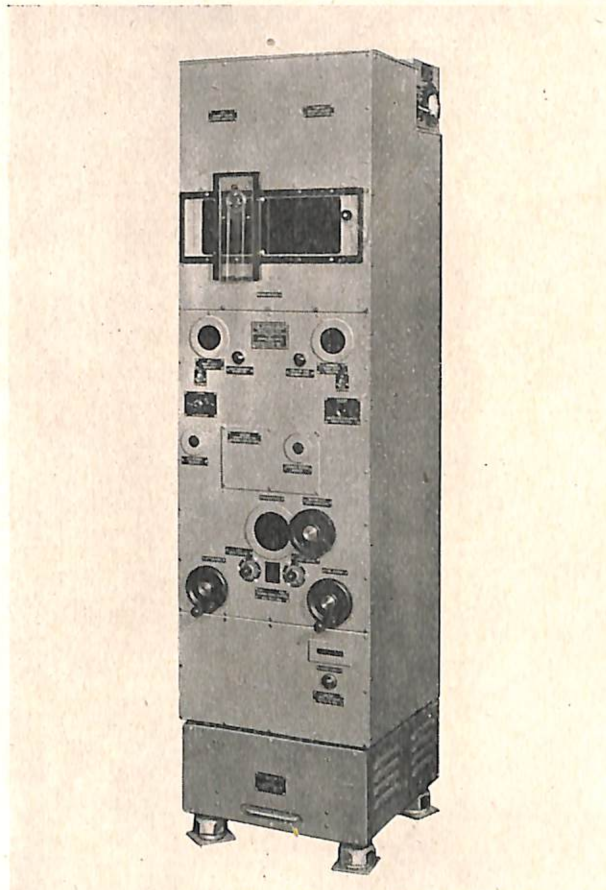


FIGURE 4—*Mechanical computer stack. From top to bottom, in order, are the rectifier unit, range-rate assembly, triangle solver, and power unit.*

The signals from both channels are now fed into a phase-sensitive detector. The action of the detector results in a d-c voltage, the polarity of which depends upon the phase relationship of the sum and difference signals applied. This d-c signal is put through a "chopper" and amplified. A second phase detector converts the chopped a.c. into d.c. which operates a zero-center microammeter, the scale of which is marked RIGHT TRAIN and LEFT TRAIN. When the JAA is operated with its selector switch in the ATF (automatic target following) position, this d-c voltage is fed to servo amplifiers which cause the hydrophones to rotate until the voltage drops to zero as will be described later.

Sonic Amplifier and Control Panel: The sonic amplifier is a three-stage audio amplifier used for listening directly to the target noise in the water. A selector switch enables the operator to choose between 1500-cycle, 3000-cycle and 4500-cycle high-pass filters as an aid in obtaining best target identification and bearing determination. The operating controls are located on the sonic amplifier panel.

Computer (Mechanical): The mechanical computer, shown in figure 4, can add, subtract, multiply and generate sine functions. From the bearing information supplied by the hydrophones and the RLI, the computer determines the range of the target and plots it on a moving-chart recorder. Since this unit is the heart of the JAA system, it will be described in detail later.

Noise Source and Noise Transducers: The noise source is a gas tube followed by an amplifier which amplifies the random noise of the tube. The output of the noise source is fed to two small transducers and is used for testing and lining up the JAA equipment. The transducers *(squealers)* are 10-inch magnetostriction devices mounted near the main hydrophones along the baseline of the ship.

Intercommunication System: The function of the intercommunication system is to provide communication between the maneuvering room, where the main stacks are located, and the conning tower. The unit consists of an audio amplifier, microphones, headsets and loudspeakers.

OPERATION

There are four ways in which the Model JAA system can be operated, these being selected by two four-position selector switches, one for each hydrophone. The markings on the switches read IHT *(independent hand train),* SHT *(synchronous hand train),* ATF *(automatic target following)* and 1066 (1066 is the type number of the computer).

For searching, it is necessary that it be possible to train the two hydrophones independently of each other. This is accomplished by setting the selector switches to the IHT position. The hydrophones are controlled by two typical servo systems: the after hydrophone by a 5G synchro (in the aided-tracking unit of the computer), a 5CT on the training shaft, a servo amplifier and a motor geared to the training shaft; the forward hydrophone by

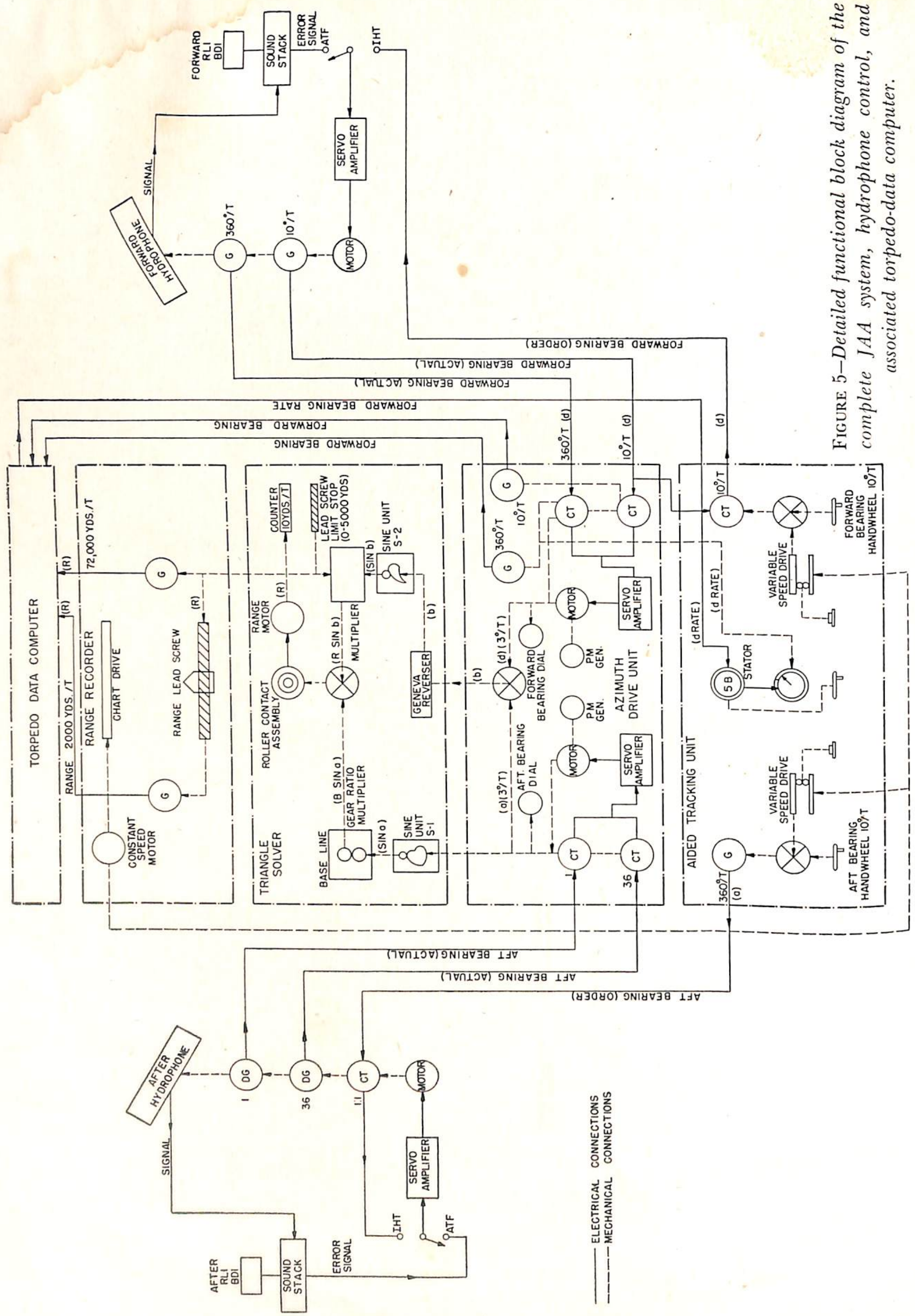


FIGURE 5—*Detailed functional block diagram of the complete JAA system, hydrophone control, and associated torpedo-data computer.*

a 5CT synchro (in the aided-tracking unit of the computer), the lower 5G on the training shaft, a servo amplifier and a motor geared to the training shaft, as shown in figure 5. Both the after 5G and the forward 5CT in the aided-tracking unit can be positioned either by handwheels or a VSD *(variable-speed drive)* or both simultaneously, this being accomplished by the use of a differential on each. The VSD's are used for continuous searching at slow speeds and they obviate the necessity of continually turning the handwheel during search. The forward VSD has another use which will be described later along with the aided-tracking unit of the computer.

Under certain conditions it is desirable to rotate both hydrophones by operating the forward handwheel. This is accomplished by setting the selector switches to the SHT position. When this is done the after handwheel and VSD are inoperative, and the after servo system is controlled by the forward handwheel and the 5CT synchro. The after hydrophone then listens on a line parallel to that of the forward hydrophone.

Automatic target following can be accomplished by turning the selector switches to the ATF position, after the target has been located and both hydrophones trained on it by operating the handwheels in the Aided-Tracking Unit. Under this condition control of the hydrophones is taken over by the sound stack. The servo systems between the handwheels and the hydrophones are electrically disconnected so that turning the handwheels has no effect on the hydrophone bearings. The servo systems are now controlled by the d-c "error voltage" output of the RLI Bearing Deviation Indicator (described previously). As long as the hydrophones remain on target there is no d-c output from the RLI, the servos have no d-c input, and the hydrophones do not turn. When the hydrophones get off target, the RLI feeds a d-c error voltage to the servo systems which causes the hydrophones to rotate until they are on target again.

When the selector switches are in the "1066" position, the training of the hydrophones is controlled from the sound stack in the same manner as just described under ATF, and the Computer is thrown into the circuit. The Computer is not used in any other operating position of the selector switches except this 1066 position.

COMPUTER

Azimuth Drive Unit: This unit, shown in figures 6 and 7, is functionally the first section of the Computer, so it will be discussed first. It is in operation at all times, regardless of whether the hydrophones are being trained by hand, variable-speed drives, or automatically. This is a 1- and 36-speed system for increased data accuracy, but for simplicity of discussion only one speed will be considered.

Geared to the after hydrophone shaft are two 5DG synchros (used as 5G's) in addition to the 5CT required for the actual training, and geared to the forward hydrophone are two 5G synchros, as shown in figure 5. These synchros, being geared

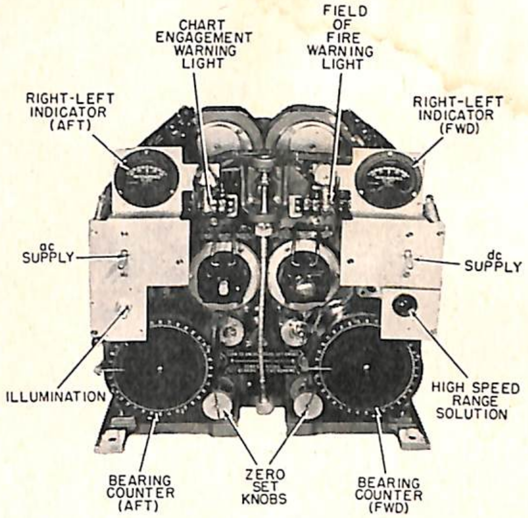


FIGURE 6—*Azimuth drive unit of the computer—front view, covers removed.*

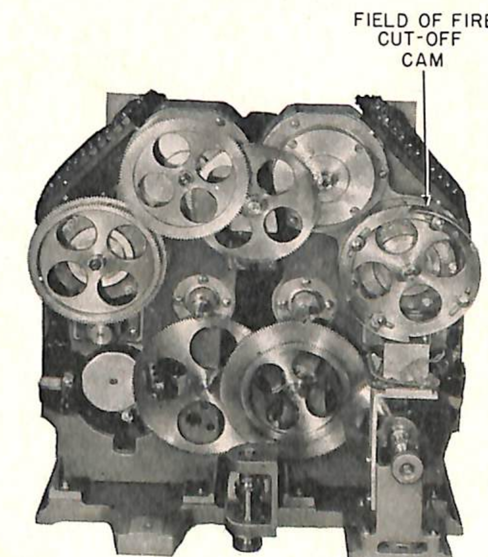


FIGURE 7—*Azimuth drive unit of the computer—rear view, covers removed.*

to the hydrophone shafts, repeat electrically their respective bearings to the synchros of the Azimuth Drive Unit. In this unit the after bearing is indicated on a dial on the left-hand side, and the after synchros (5CT's) are also on the left, one over the other. The forward bearing is indicated on a dial on the right-hand side, and the two forward bearing 5CT synchros are on the right, one over the other. Both after and forward synchros are servo driven, as shown in figure 5, and the rotation of their shafts represents the actual hydrophone angles to be used by the Triangle Solver.

In figure 8, the triangle to be solved, angle a is the after hydrophone bearing, angle b is the target angle, angle d is the forward hydrophone bearing, side B is the baseline, and side R is the range from the forward hydrophone to the target. It should be noted that side R has been chosen arbitrarily as the range to be used, but side C represents the range from the after hydrophone to the target and could be used equally well. First we solve for angle b, the target angle:

$a + b + c = 180°$ (three angles of a triangle $= 180°$)

$a + b = 180° - c$

and $c + d = 180°$ (they form a straight line)

$d = 180° - c$

therefore $a + b = d$

and $b = d - a$

in other words, the target angle equals the foreward bearing minus the after bearing.

The after bearing is coupled directly from the Azimuth Drive Unit to the Triangle Solver by means of a flexible shaft, and is also sent into one side of a differential in the Azimuth Drive Unit. The forward bearing is sent into the other side of the differential. The differential subtracts the after bearing from the forward bearing, so that its output is angle b, the target angle. This output is fed by flexible shaft to the Triangle Solver.

The two remaining 5G synchros of the Azimuth-Drive Unit are located at the top of the unit. Their function is to feed the forward bearing to the TDC (torpedo data computer). Their positions represent the actual instantaneous forward bearing, and their rate of rotation represents the rate of change of forward bearing. This forward-bearing rate-of-change is fed by a flexible shaft to the Aided-Tracking Unit and used there in a way to be described later.

Triangle Solver: The Triangle Solver portion of the Computer determines the range of a target

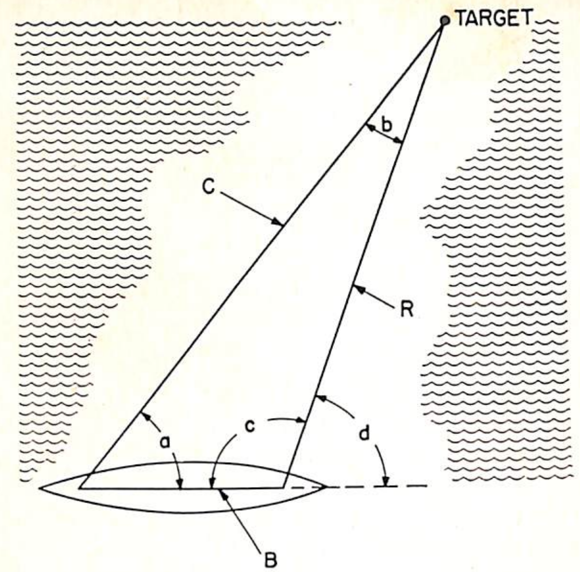


FIGURE 8—*Typical triangle to be solved by the computer. Angle a is the after hydrophone bearing, angle d the forward bearing, angle b the target angle, side B the baseline, and side R the range line from the forward hydrophone to the target.*

by utilizing the law of plane trigonometry known as "the law of sines" which states that, if one side and any two angles of a plane triangle are known, the other can be determined from the relationship (see figure 8):

$$\frac{B}{\sin b} = \frac{R}{\sin a} = \frac{C}{\sin c}$$

$$\frac{B}{\sin b} = \frac{R}{\sin a} \quad \text{(using the first two terms)}$$

or $B \sin a = R \sin b$

In this equation the only unknown is R, since B is the fixed distance between the hydrophones, and the after bearing angle a and the target angle b are fed to the Triangle Solver from the Azimuth Drive Unit. The purpose of the Triangle Solver is to set up the two sides of the equation and balance them mechanically, getting R in some measurable form in the process.

First the heart-shaped cam of sine unit S-1 is rotated in accordance with the after angle, as shown in figure 5. This cam is cut so that the motion of its follower corresponds to the sine of the angle to which the cam is driven. The output of S-1, therefore, is sin a, and this is fed to a multiplier which multiplies it by B. Since B (the baseline) is fixed for a particular ship, the multiplication is done by simple gearing, the output of the multiplier being $B \sin a$, one side of the equation we are solving.

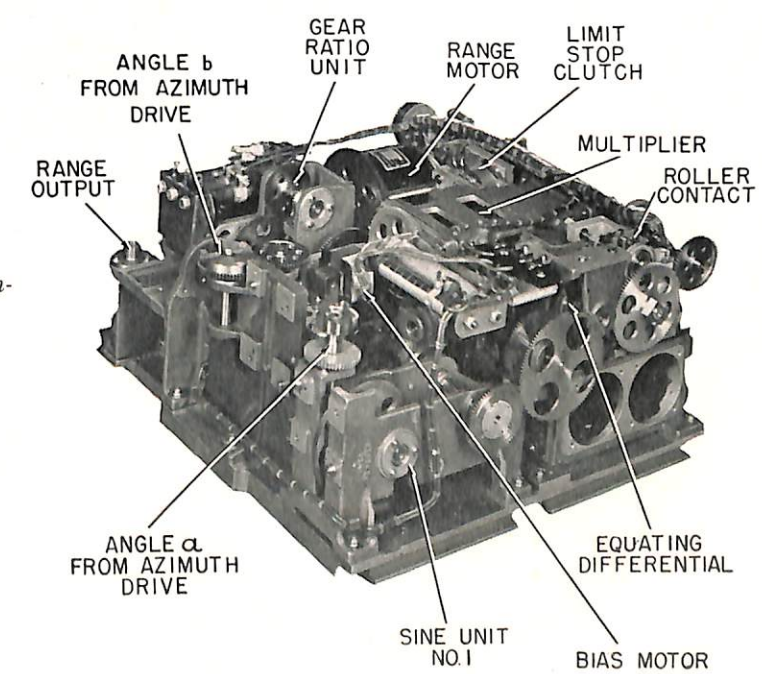
Similarly, the cam of sine unit S-2 is rotated in accordance with the target angle, the follower's motion being proportional to the sine of the angle, the output of S-2 being sin b. This cam looks like only half a heart, and in order to get a complete sine cycle its motion must be reversed after it has rotated through 90°. This is necessary because the target angles are so small that, in order to provide sufficient accuracy in the cam, the rise per degree must be much larger than for the after-angle cam. In order to limit the size of this cam, it is cut to represent only half of the sine function, and its motion is reversed to obtain the other half. Actually, in order to expand the scale still further, the cam is cut to represent $1 - \sin b$, and the output juggled to give simply sin b. The reversal is accomplished by a Geneva intermittent sprocket mechanism which shifts a clutch after a certain number of revolutions.

This sin-b output of sine unit S-2 is fed to the right-hand multiplier of figure 5. The other input to the multiplier is the unknown quantity R (range), so that the output of the multiplier is proportional to $R \sin b$, the other side of the equation to be solved. Since both of the inputs to this multiplier are variables, it cannot be a simple gear-ratio-type of multiplier.

The final solution of the equation is obtained by feeding the output of the left-hand multiplier into one side of a differential, and the output of the other multiplier into the other side, in such a manner that the motions are opposing. If these quantities are equal ($B \sin a = R \sin b$), the differential spider will not rotate. The spider is mechanically connected to a roller contact assembly so that, whenever it does turn, a contact is made and power is supplied to the range motor.

The quantity $B \sin a$ is always being supplied to the differential by the left-hand multiplier, but the output of the right-hand multiplier, at this time, is only sin b. Since sin b does not equal B sin a, the differential spider will turn, thereby upsetting the roller contact assembly and applying power to the range motor. The motor will then run until the contact assembly is restored and its power is cut off, which means that the two inputs to the differential have been made equal. To do this, the range motor has had to supply R to the right-hand multiplier (which has supplied $R \sin b$ to the differential) and, therefore, the rotation of the range motor's shaft is proportional to R—the needle we have been looking for in this haystack!

The range motor also turns a counter which indicates the range directly. The multiplier is protected from being driven too far in either direction by a Leadscrew Limit Stop which consists of a leadscrew driven by the motor and a microswitch



Triangle solver of the computer—exposed view showing internal arrangement at each end of the travel. A follower on the lead-screw strikes these switches and cuts the power to the motor at 0- and 5000-yard ranges.

The multiplier required for the two variables (R and sin b) is an interesting device. Consider that two variables X and Y are to be multiplied together. (In this case X is range and Y is sin b.) First the quantities are added together by means of a differential. Then they are subtracted similarly. The results, $(X + Y)$ and $(X - Y)$ are used to rotate two cams. These cams are actually fancy pin cams, and the output of each follower is proportional to the square of the quantity rotating the cam. We have, therefore, as outputs:

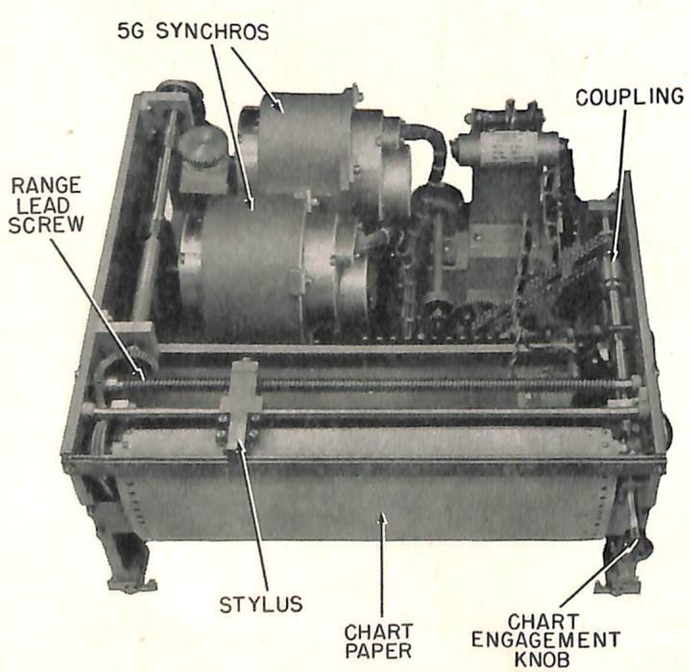
$$(X+Y)^2 = X^2 + Y^2 + 2XY$$
$$(X-Y)^2 = X^2 + Y^2 - 2XY$$

These two equations, represented by shaft rotations, are fed into a differential in such a way that the second equation is subtracted from the first one. The result of this subtraction, $4XY$, is divided by 4 by simple gear ration, leaving us with XY or R sin b, the desired multiplication products.

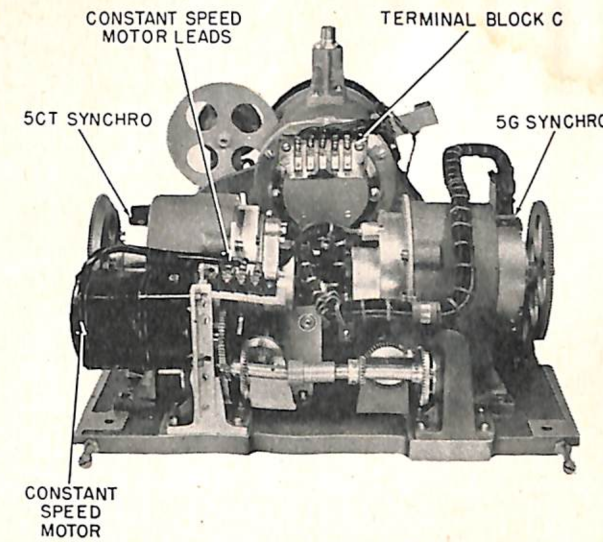
Range Recorder: The Range Recorder (see figure 5) receives the output of the range motor in the Triangle Solver via flexible shaft. A stylus is positioned by a lead screw and thus a continuous trace of range is given. The paper drive speed is maintained at 1-inch per minute by a 1-rpm constant-speed motor. The paper is carried on a roller at the bottom of the unit, is looped up to meet the stylus, and is taken up on another roller in front of the feed roller. Also in the recorder are two 5G synchros which electrically repeat the range to the Torpedo Data Computer.

Aided Tracking Unit: So far the primary function of the Aided Tracking Unit has been described as providing the means for training the hydrophones either by hand or by variable speed drives. The unit performs one other important function, however. If the target is lost temporarily, it is possible to keep the forward hydrophone trained to approximately where the target should be found again, assuming no change of target speed or course. Some of the causes for losing a target could be a ship coming between the hydrophones and the target, the target being lost in own ship's wake during a turn, something going wrong with the sound stack, or similar reasons.

The Azimuth Drive Unit is continually feeding the actual forward bearing to the TDC (torpedo data computer), and the forward bearing rate to the Aided Tracking Unit (see description of the Azimuth Drive Unit). The TDC takes the instantaneous bearings provided and computes a forward bearing rate and repeats it to the 5B synchro of the Aided Tracking Unit (see figure 5). This synchro has a dial with a single index line attached to its rotor, and it will rotate continuously according to the computed forward bearing rate. Outside of this dial is a ring, also with a single index line, and free to turn independently of the synchro.



Exposed view of range recorder unit of the computer, showing major components.



Aided-tracking unit of the computer—rear view showing arrangement of components

This ring is driven by the actual forward bearing rate, which is being received by flexible shaft from the Azimuth Drive Unit. Both dial and ring rotate, and if the computed rate from the TDC is not the same as the actual rate from the Azimuth Drive Unit, the dial and ring will not rotate in synchronism. To facilitate comparing these rates, the 5B synchro can be turned by hand to line up the two indexes, this being accomplished by turning the center handwheel of the unit until these indexes line up.

Now suppose something keeps signals from reaching the hydrophones. This means that the RLI Bearing-Deviation Indicators can supply no error signals to the training servo amplifiers. Control of the hydrophones must then be assumed by the handwheels or variable-speed drives, or the target will be lost. First the selector switches are changed to the SHT position, which throws out the computer and switches control of the after hydrophone to the forward handwheel (as described under *Operation*). The TDC is still sending a computed forward bearing rate which appears on the rotor of the 5B synchro in the Aided Tracking Unit, this rate being based on the latest known data. If the forward variable-speed drive is set so that the ring around the 5B rotor dial rotates in synchronism with the rotor, the two hydrophones will be turning at a rate equal to the computed rate. When the obstructing object has passed on out of the way, the hydrophones will be pointing approximately toward the target rather than off in another quadrant. When the signals become sufficiently strong, the after projector can be trained back to the target, the computer again switched in, and only a minimum of time will have been lost.

The variable-speed drives are used to control the rotation of the hydrophones. Referring to figure 5, the constant-speed disks are rotated at a constant speed derived from the Recorder paper-feed motor via a flexible shaft. Bearing on each disk is a ball with a second ball directly above it. This top ball makes contact with a roller which is free to rotate, and which presses the balls together and against the surface of the flat constant-speed disk so that the motion of the disk is transmitted through the balls to the roller. The balls are held in position by a carriage which can be positioned along the diameter of the disk and the length of the roller by means of a knob. The speed of rotation of these balls, and hence of the roller, is proportional to their distance from the center of rotation of the disk (where the speed is zero). Hence a variable speed is obtained, and the direction of the roller's rotation can be changed by moving the ball carriage from one side of the center of the constant-speed disk to the other.

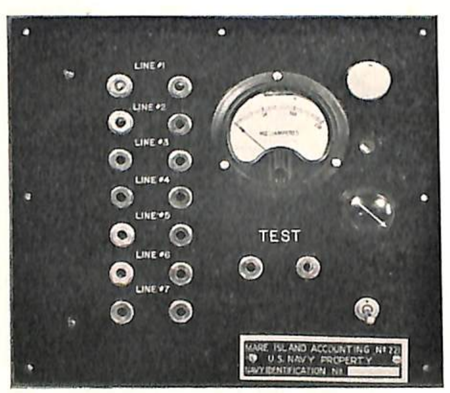
Used differently, the VSD can become an integrator. While this has no bearing on the operation of the Model JAA equipment, it is a point of interest and may be used in some future model. Instead of being positioned by hand, suppose that the ball carriage is displaced from the center of the disk an amount proportional to the rate of change of something (range, for example). If there is no change in range, the ball carriage remains at the center of the disk, and the roller remains stationary. With the ball carriage displaced from the center, however, the roller would turn at a rate proportional to its distance from the center. The angular position of the roller at any instant would then correspond to how much the range had changed, or, in other words, to the integral of the range rate.

TELETYPE TEST PANEL

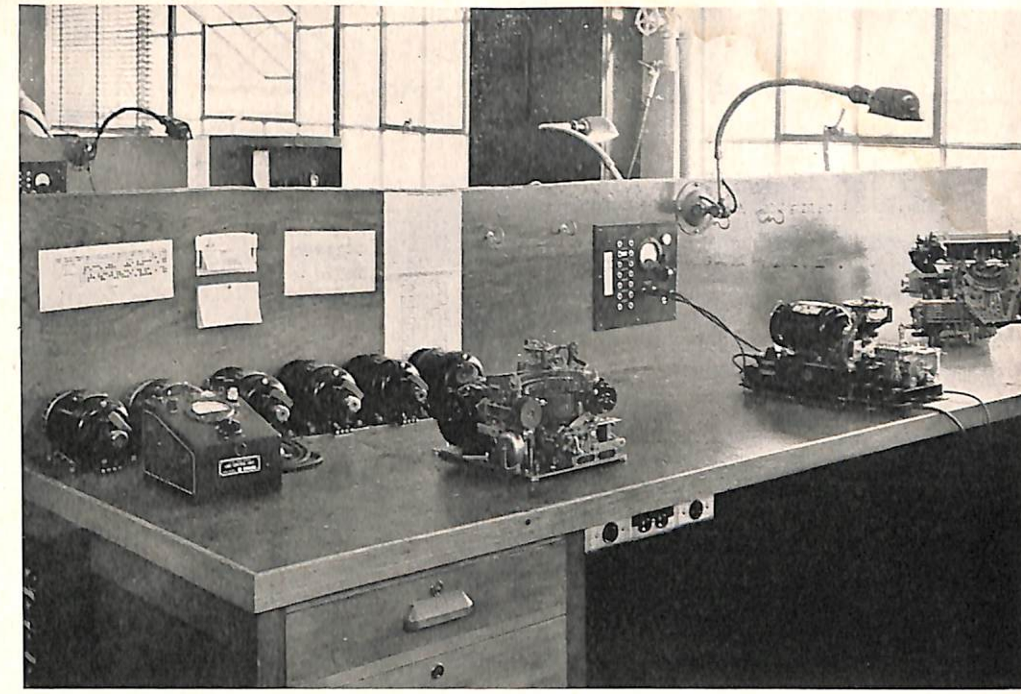
■ The present methods used in the testing and repair of teletype machines are becoming inadequate due to rapid expansion in this field. The most common of these is accomplished by connecting each machine to a teletype transmitter through an arrangement of wires, switches, a rheostat, and meter. It is a good method and covers all the test requirements, but is not adequate for handling the present volume of teletype maintenance activities because only one machine can be tested at a time. Some of the larger activities, finding it practically impossible to carry on efficient maintenance by this method, turned to on their own and set up new test methods in an effort to solve the problem. Many of these ideas were very good and will be screened by the Bureau in the near future so that the better ones may be combined to form a new standard set up. However, for the present the Bureau wishes to pass on one of the more practical methods so that all activities may benefit. This method was developed by the Teletype Repair Shop at the Mare Island Naval Shipyard, where it is now in use.

Their method utilizes the same general test procedure as that generally in use, but it replaces the haphazard connection arrangement with a small, compact patch panel containing the rheostat, meter, a power switch, and a series of jacks. When mounted in a work bench and provided with 110-volt d-c power, the panel will permit several machines to be set up on the bench and tested one against the other. All wiring is internal and all test connections for the teletype machines and test equipment are made through the use of plugs and the panel jacks. Where desired, a number of these panels may be used to provide testing facilities for a larger number of machines. In fact the Mare Island shop has panels installed in ten work benches and connected in a series arrangement which, with 7 pairs of line jacks on each panel, will handle seventy machines. Reports indicate that this arrangement cuts testing time approximately fifty percent and results in more efficient maintenance.

Details of the panel are shown in the wiring diagram, which also shows sample test connections. The internal wiring is very simple, consisting of the seven sets of line jacks and a series circuit containing the power switch, milliameter, rheostat and the two test jacks. The line jacks are arranged in sets of two connected in series. When the panel is used as a separate unit there are no external connections required except for 110-volt d-c power, but in an arrangement such as that used at Mare Island it is necessary that the line jacks be connected in series with the corresponding jacks on the other panels as shown in the diagram. The other section of the panel, the series circuit, provides all the requirements of an elementary teletype control circuit. Power is wired permanently into the panel, current can be controlled as desired by means of the meter and rheostat, and the two jacks provide a means for inserting the teletype transmitter and teletype machine into the circuit. This circuit



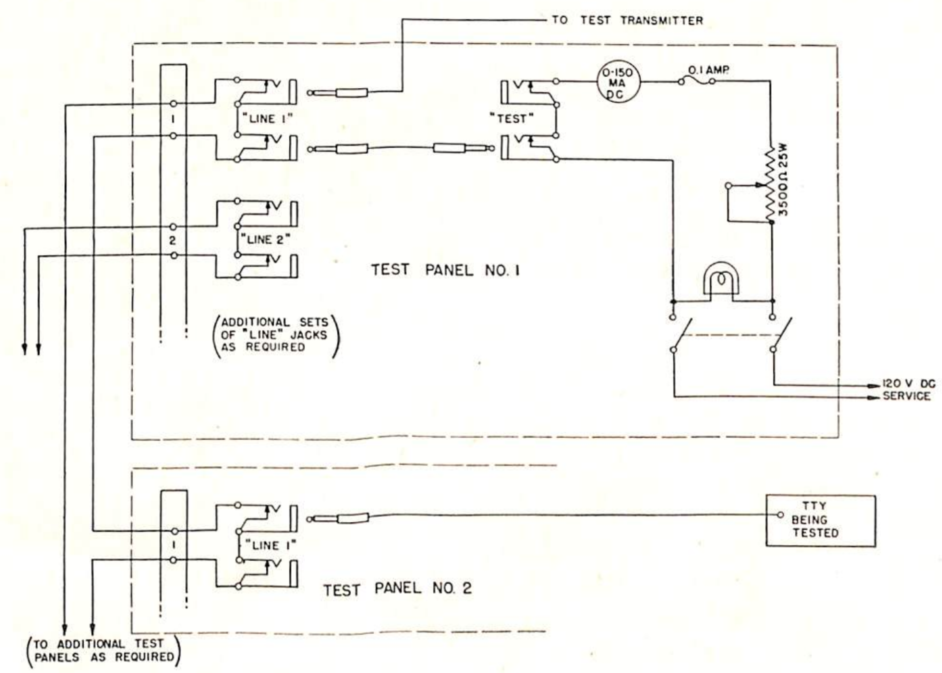
Closeup of one of the TTY test panels which provides 7 tie lines to other work benches.



Mare Island TTY work bench setup for multiple testing of machines.

can also be used to provide power for a maximum of ten machines by inserting a patch cord between one of the local test jacks and a line jack as shown in the diagram.

All in all this test panel seems to be very practical. It has been used to such a good advantage by the originating activity that it should also prove helpful to others. For the benefit of interested activities it is interesting to note that the ten panels at Mare Island were built of salvage material and the entire installation was made at a cost of only ten man days.



Schematic of one of the test panels, showing external wiring and patching required for multiple testing.

MODEL TDY FIELD CHANGES

■ In order to clarify the field change situation for the Model TDY countermeasures equipment, the following list of field changes has been compiled by the Bureau:

#1-TDY—Addition of Start-Stop Resistor.

#2-TDY—Extension of Lower Frequency of TDY with Manual Antenna Mount.

#3-TDY—Installation of Motor-Driven Antenna Mount and Control Indicator.

#4-TDY—Modernization Kit.

#5-TDY—Conversion of Model TDY to TDY-a, and Model TDY-1 to TDY-1a.

#6-TDY—Simplification of Monitor System.

#7-TDY—Tube Injector Modification.

#8-TDY—Replacement of Two Reflectors in TDY-a/TDY-1a Antenna System.

#9-TDY—Relocation of Magnetron Tube Clamp.

#10-TDY—Addition of Remote Antenna R-F Switch in CAPR-10AFJ Antenna Pedestal.

#11-TDY—Replacement of Magnetron Filament Leads.

#12-TDY—Addition of Second Magnetron Seal Blower.

#13-TDY—Installation of Spacer Band for Magnetron Filament Leads.

#14-TDY—Change and Relocation of Bleeder Resistors.

#15-TDY—Replacement of Pump Seal Assembly.

#16-TDY—Improved Conversion of Model TDY to TDY-a, and Model TDY-1 to TDY-1a.

#17-TDY—Cancelled.

#18—TDY—Upper Frequency Kit.

Field changes #1, 2, 3, 4, 6, 7 and 10 are considered by the Bureau as having been completed on all of the affected equipments, and are included in this list for identification only. Electronics Officers should be contacted for the field-change kits required for changes #12 and 15. These changes are within the scope of the ship's force, and the kits include complete detailed instructions and all the parts and material required.

Field changes #5, 8 and 16 require yard availability, and an Electronics Officer should be contacted for their accomplishment. Complete information on changes #9, 11, 13, 14 and 18 is not yet available, but will be disseminated as soon as possible.

MODEL RDG LUBRICATION CHARTS

Lubrication charts for the Model RDG receiving equipment entitled "Lubrication Chart—RDG Equipment" are in the process of being distributed. These charts bear the short title of NavShips 250-970-5.

In view of the small number of Model RDG equipments being distributed, and the limited number of charts available, the initial distribution will be only two copies to each Electronics Officer at various selected shipyards. Only ships having Model RDG equipment aboard should apply to the nearest Electronics Officer for these charts. Electronics Officers should request copies of these charts, when needed, from the Bureau of Ships, Code 253, on Form NavGen 47 using both the long and short title of the charts.

"—and then I replaced the klystron and adjusted the cavity."

SR-3 AND SR-6 WAVEGUIDE AND FITTINGS

In order to prevent the use of excess waveguide and accessories with the Models SR-3 and SR-6 radar equipments, installation activities are cautioned to use no more than the amounts supplied with the equipments. Transmission line (waveguide and fittings) is furnished with the Models SR-3 and SR-6 as follows:

	SR-3	*SR-6*
Waveguide (RG-69/U)	100 ft. in ten 10-ft. sections	100 ft. in ten 10-ft. sections
Flanges	25 pr. (25 male and 25 female)	15 pr. (15 male and 15 female)
Elbows	5 90° E-bends; 5 90° H-bends; 5 45° E-bends; 4 45° H-bends.	5 90° E-bends; 5 90° H-bends

In addition, all necessary gaskets, nuts, bolts and lockwashers are furnished. Any material not used in the installation should be returned to the Naval shipyard stock, since the Bureau of Ships is not planning to furnish transmission line spares at this time.

BATHYTHERMOGRAPH BLISTER

Recent failure reports received in the Bureau of Ships indicate that recurrent derangements of the Model OCN submarine bathythermograph are resulting from faulty installation of the CTB-10599 temperature unit, in both the upper and lower mounting positions. It appears that during installation, the four 1″ 3/8-24 mounting bolts (part No. A-220) are either broken or lost, and standard steel bolts substituted for them. These steel bolts soon erode due to oxidation and electrolytic action, allowing the temperature blister to loosen or fall off. This breaks the small capillary tube and renders the bathythermograph useless.

To prevent this type of failure, the Bureau of Ships requests that all yards and repair facilities take corrective action at the earliest availability on any submarine having an OCN installation. The suggested correction is the use of stainless-steel or monel-metal hex-head bolts which may be obtained by the activity or made from 5/8″ or 3/4″ hex stock. Incidentally, lock washers were not furnished for this application by the contractor, and their use is not recommended. Consideration should be given, however, to the careful application of a paint preservative.

CHANGE IN BATHYTHERMOGRAPH ALLOWANCE

The Chief of Naval Operations has informed the Bureau of Ships that bathythermograph equipment is not required by CA and CL division flagships, but is required by carriers attached to Anti-Submarine Warfare (ASW) Hunter-Killer Groups. Accordingly, installation and electronic supply activities are advised that the changes listed in the accompanying table will be incorporated in the next revision of the electronic equipment allowance lists. These changes are published here as advance information and for guidance in planning new installations pending formal promulgation by Shipalts or letter as appropriate.

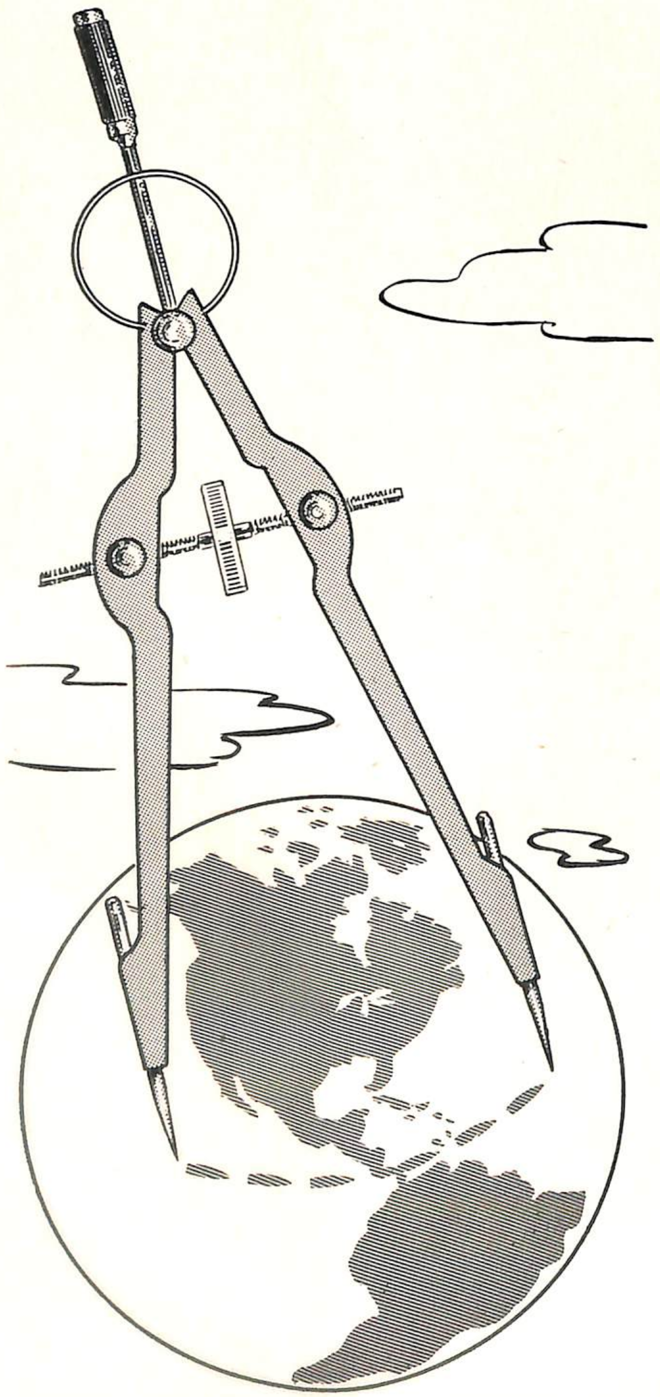
Type	*Page*	*Change*
CA Heavy Cruisers (division flagships)	6	Delete B/T equipment
CL Light Cruisers (6000 tons "AA")	5	Delete B/T equipment
CL Light Cruisers (10,000-ton division flagships)	6	Delete B/T equipment
CV Aircraft Carriers	6	Change footnote No. 5 to read "If assigned ASW Hunter-Killer Group" in lieu of "Carrier Division Flagships."
CVE Escort Aircraft Carriers	4	Change footnote No. 5 to read "If assigned ASW Hunter-Killer Group" in lieu of "Carrier Division Flagships".
CVL Small Aircraft Carriers	6	Change footnote No. 5 to read "If assigned ASW Hunter-Killer Group" in lieu of "Carrier Division Flagships."

ERI OR IFF ? ?

The Committee on Nomenclature and Terminology for Joint Air Defense, which is a subcommittee of the Joint Army-Navy Communications Board, has recently ruled on the correct terminology for the equipment and field which we now identify by the letters "IFF" standing for "Identification, Friend or Foe." The ruling states that the actual equipments used for identification purposes, both present and future, shall continue to be called "IFF equipments," such as the Mark-3 IFF System, but the field (broad, general aspects) shall be known as "ERI," Electronic Recognition and Identification. All Naval activities concerned should note this change in terminology.

Calculating Great-Circle Bearings . . . . . .

By Lt. Comdr. I. L. McNally, USN, Bureau of Ships



■ The problem of determining great-circle bearings between two points on the earth's surface presents itself to the electronics technician in the orientation of directional antennas. It is the purpose of this article to demonstrate a method by which the correct azimuth of a directional antenna may be calculated by the use of simple trigonometry. All of the required functions may be found in any standard trigonometric table and, if care is exercised in the calculations, the results will be accurate to a fraction of a degree.

Calculations involving only plane trigonometry are sufficiently accurate up to ten degrees on the earth's surface. Great-circle paths over distances up to 500 nautical miles do not deviate from the rhumb line by over one-quarter of a mile.

EXAMPLE 1:

Determine the true bearing from Cavite to San Francisco and from San Francisco to Cavite. The geographical positions of the two stations are:

San Francisco	Lat. 38° 05′ 50″ N,	Long. 122° 16′ 42″ W
Cavite	Lat. 14° 29′ 37″ N,	Long. 120° 54′ 07″ E

Always draw a sketch of the problem and label the points as shown in figure 1. The station closest to the North Pole is always designated B.

A little care must be exercised in determining the difference of longitude (DL_o) if the stations are located on either side of the date line or the prime meridian. If the latitude is south, it is given a negative sign, in which case the addition or subtraction must be done algebraically.

Prepare a work sheet as follows:

L_a = latitude of point A = 14° 29′ 37″

L_b = latitude of point B = 38° 05′ 50″

DL_o = difference of longitude = 116° 49′ 11″

X = half difference of longitude = 58° 24′ 35.5″

Y = half sum of latitudes

$$= \frac{L_b + L_a}{2} = 26° \; 17' \; 43.5''$$

Z = half difference of latitudes

$$= \frac{L_b - L_a}{2} = 11° \; 48' \; 06.5''$$

Listing and looking up the trigonometric functions,

X = 58° 24′ 35.5″ $\quad \cot X = 0.6147$

Y = 26° 17′ 43.5″ $\quad \sin Y = 0.4430 \quad \cos Y = 0.8965$

Z = 11° 48′ 06.5″ $\quad \sin Z = 0.2046 \quad \cos Z = 0.9788$

Two new angles, V and W, (stepping stones to the answer) must now be calculated from the following formulas by substitution of the values listed above.

$$\tan V = \frac{\cos Z \cot X}{\sin Y} = \frac{.9788 \times .6147}{.4430} = 1.3582$$

$$\tan W = \frac{\sin Z \cot X}{\cos Y} = \frac{.2046 \times .6147}{.8965} = .1403$$

V = 53° 38.2′ $\qquad W$ = 7° 59.3′

angle $A = V - W$ = 45° 38.9′ true

angle $B = V + W$ = 61° 37.5′

To express angle B as a *true* bearing, measured from North in a clockwise direction, subtract from 360°, or angle B = 360° − 61° 37.5′ = 198° 22.5′ true.

If the great-circle distance is desired, the following formula may be employed:

$$d = 120 \; arc \tan \left[\frac{(\sin V \tan Z)}{\sin W}\right] \text{ nautical miles}$$

$\sin V = 0.8053$
$\tan Z = 0.2089$
$\sin W = 0.1390$

$$arc \tan \frac{(.8053 \times .2089)}{.1390} = arc \tan 1.2103 = 50.42°$$

d = 120 × 50.42 = 6050 nautical miles.

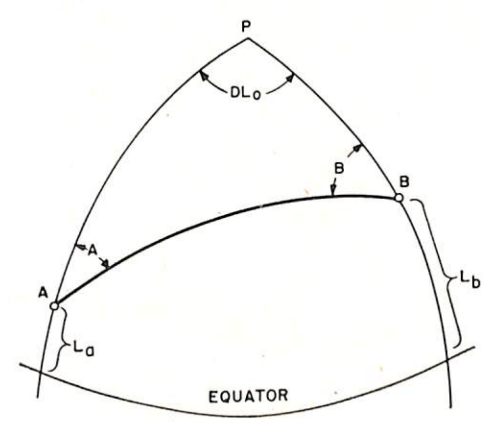


FIGURE 1—*Proper form of working drawing for problems in which points A and B are both in the Northern Hemisphere.*

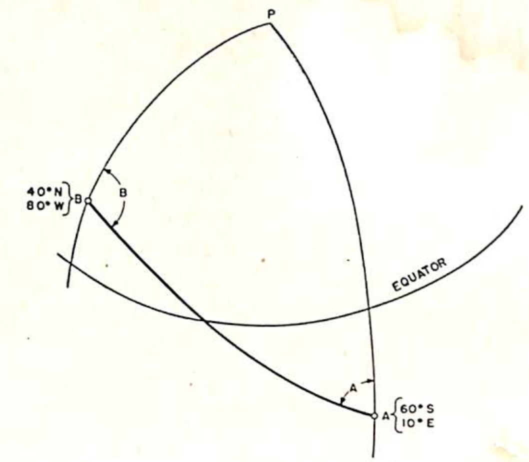


FIGURE 2—*Working sketch for Northern and Southern Hemisphere problem.*

EXAMPLE 2:

In this example points A and B are located on opposite sides of the equator, as shown in figure 2.

A = 60° S, 10° E $\qquad B$ = 40° N, 80° W

L_a = 60° S = (−60°)

L_b = 40° N

DL_o = 90°

X = 45°

$$Y = \frac{40 + (-60)}{2} = -10°$$

$$Z = \frac{40 - (-60)}{2} = 50°$$

Disregard algebraic signs and look up functions:

X = 45° $\quad \cot X = 1.000$

Y = 10° $\quad \sin Y = 0.1736 \quad \cos Y = 0.9848$

Z = 50° $\quad \sin Z = 0.766 \quad \cos Z = 0.6428$

$$\tan V = \frac{.6428 \times 1.}{.1736} = 3.703$$

$$\tan W = \frac{.766 \times 1}{.9848} = 0.779$$

V = 74.9° $\qquad W$ = 37.9°

$A = V - W$ = 37° = 323° true

$B = V + W$ = 112.8° true.

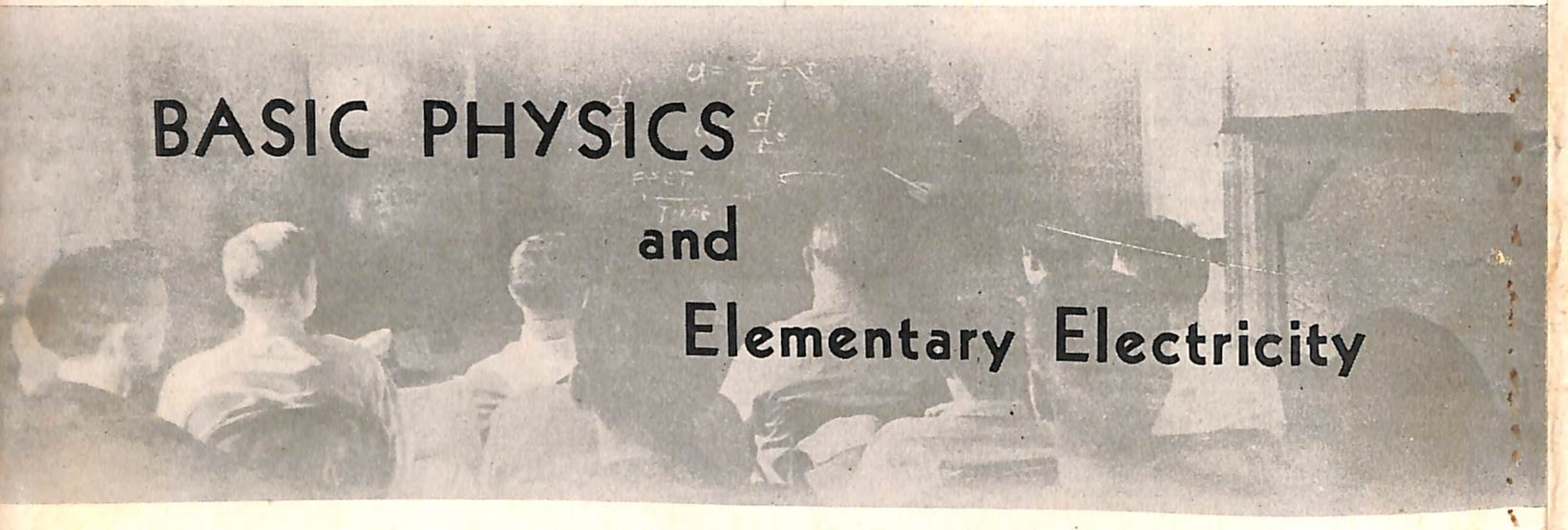
$A = V - W$ = 37° = 323° true

The intensive nature of the curriculum for ETM training has created an urgent need for a text fitted to the curriculum. The Standards and Curriculum Division of the Bureau of Naval Personnel has undertaken the preparation of such a text.

Since considerable time will be required to complete the full text, the urgent need for electronics instruction material prompts this printing of individual assignments of the text in the ELECTRON. *These assignments will serve as a refresher course for rated technicians and as preparatory work for strikers. There are no restrictions on the reproduction by Naval activities of this unclassified material for training purposes. Constructive criticism of the course material is desired and should be forwarded to the Bureau of Naval Personnel, attention Pers-41.*

A number of test questions will be included at the end of each assignment. The questions are designed to encourage individual thinking and to test the understanding of the completed assignment. Answers to test problems will be included with a subsequent assignment.

The first course of instruction will deal with basic physics and elementary electricity. A companion course, not yet started, will deal with the mathematics essential to an understanding of electrical and electronic circuits.



BASIC PHYSICS and Elementary Electricity

CHAPTER I – MEASUREMENT

■ All the engineering sciences are based upon the fundamental principles of physics. Physics is concerned with the basic concepts of matter, energy, and measurement. Instruction in physics in a course of this type must necessarily be limited, but the student will bear in mind that so-called advanced engineering is little more than a wider application of basic physical principles.

Instruction in physics may be broadly classified as qualitative and quantitative. *Qualitative* knowledge provides the necessary "know why," whereas *quantitative* knowledge provides the "know how." When the time available for instruction is limited, it is customary to curtail qualitative instruction. This practice has two major disadvantages: first, the greater the limitation on qualitative instruction the greater will be the dependence placed upon the student's memory; second, lacking qualitative knowledge, the ultimate engineering level to which the student may aspire is limited. Once adequate qualitative knowledge is acquired the engineer tends to become self-sufficient, new developments being mastered by self-study methods. The desirability of placing maximum emphasis on qualitative instruction is evident in the old adage, "the man who knows how may always have a job, but the man who knows *why* will always be his boss." Mathematics is the primary tool by which qualitative knowledge is converted to quantative knowledge. The statement "an electromotive force is that force which establishes an electric current in a circuit" is qualitative in that it simply defines what an electric force accomplishes. The statement "the current in a resistive circuit varies directly as the applied electromotive force" is a quantitative statement. In a mathematical way it indicates that if the electromotive force applied to a circuit is doubled the current in the circuit should be doubled. However, the second statement has little meaning without the first; for there is nothing in the second that describes the nature of an electromotive force. In other words, qualitative instruction is required in order to give meaning to quantitative methods, one form of instruction complementing the other.

SCIENTIFIC MEASUREMENT

It is impractical to discuss the concepts of physics without some idea of the systems of measurement in common use. Measurement itself is a vitally important subject for the engineering student. Engineering theory is substantiated by experiment and measurement. The qualitative knowledge of the scholar becomes the quantitative knowledge of the engineer through measurement. It is quite possible to be thoroughly conversant with the principles of a subject and yet be incapable of performing routine measurements on a specific equipment.

By international agreement the *metric system* of measurement has been adopted for all scientific measurements. The great advantage of the metric system is its decimal nature. Shifting from larger to smaller or smaller to larger units is accomplished by the simple process of shifting the decimal point.

1 kilometer	=	1000 meters
1 meter	=	100.0 centimeters
1 centimeter	=	10.00 millimeters
1 millimeter	=	1000 microns

In the United States and Great Britain the so-called English system of measurement is used in domestic commerce. The fundamental units of this system are the foot, the pound, and the second. Engineers usually refer to it as the F.P.S. system. The student will be familiar with this system from everyday usage.

In the metric system the fundamental units are the meter, the kilogram, and the second. However, when science adopted the metric system, the centimeter, the gram, and the second were adopted as the fundamental units of length, mass, and time. This scientific system was called the C.G.S. system. Here the centimeter represents 100th of a meter, and the gram 1000th of a kilogram. At the time the C.G.S. system was adopted electrical science was in its infancy. The word "electronics" had not yet been coined. As electrical and electronics knowledge increased, clear definition of electrical and magnetic units became necessary. In 1935 the International Electrotechnical Commission adopted the M.K.S. *(meter-kilogram-second)* system for all scientific work. It has been proposed that a fourth fundamental unit, the ohm, be adopted in order to facilitate duplication of certain electrical standards. If this is done, the M.K.S. system will then become the M.K.O.S. system.

Most of the confusion that now exists in scientific measurement is the result of shifting from the C.G.S. to the M.K.S. system. Older engineering texts were committed to the C.G.S. system. More modern texts are using M.K.S. units. In this course emphasis will be placed upon M.K.S. units with certain C.G.S. units being defined to give the student a working knowledge of that system.

FUNDAMENTAL UNITS OF MEASUREMENT

All units may be classified as either fundamental or derived. The fundamental units are the units of length, mass, and time. All other units are capable of definition in terms of these fundamental units. In the M.K.S. system the fundamental units are the meter, the kilogram, and the second. The original definitions of the fundamental units were intended to meet certain broad specifications. They were to be simple and hence easily understood. They should permit establishing standards that could be easily maintained and duplicated. They should apply anywhere in the universe, would not change over long periods of time, and could not readily be altered by any action of man. In the final analysis no unit met all of these specifications.

Unit of Length: The fundamental unit of length, the meter, was originally intended to be one ten-millionth of the distance, measured along the surface of the earth, from the equator to the north pole.

More accurate measurements have disclosed that this distance is 10,000,880 instead of 10,000,000 meters as originally measured. Today the standard meter is represented by the distance between two parallel lines, at 0° Centigrade, on a bar of platinum-iridium alloy stored in the vaults of the International Bureau of Weights and Measures near Paris, France. Two copies of the standard meter, called the National Prototypes, are held in the U. S. Bureau of Standards. Copies of these prototypes are available to industry and institutions needing them for calibration purposes. Congress has legally defined the standard yard as $\frac{3600}{3937}$ of a standard meter.

1 meter	=	39.37 inches
1 foot	=	0.3048 meter
	=	30.48 centimeters
1 inch	=	2.54 centimeters

Unit of Mass: The standard unit of mass in the metric system is the kilogram. Although mass and weight are different properties of matter, it is possible to define one in terms of the other. It was

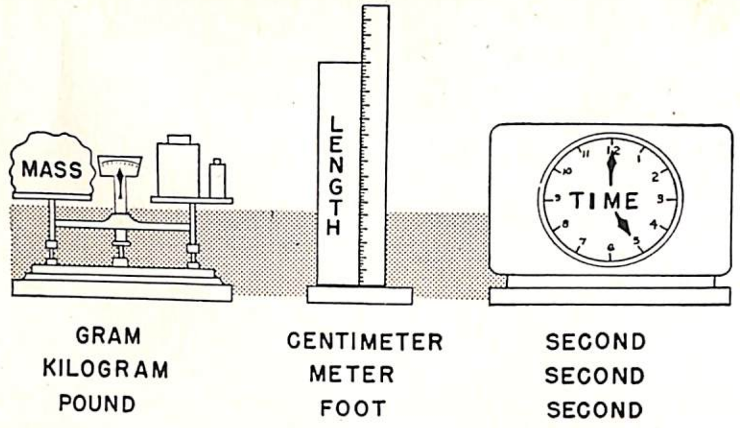


FIGURE 1—*Fundamental units of mass, length, and time.*

originally intended that 1000 cubic centimeters of water, at the temperature of maximum density 3.98° Centigrade, should represent the standard kilogram weight. The discovery of heavy water indicated that equal quantities of water did not always weigh exactly the same, so today the standard kilogram weight is a cylinder of platinum-iridium alloy maintained in the International Bureau of Weights and Measures. Two National Prototypes are maintained in the U. S. Bureau of Standards. Congress has legally defined the avoirdupois pound as $\frac{1}{2.2046}$ of a standard kilogram weight.

1 kilogram	= 2.2046 pound
1 ounce	= 28.35 grams

For all practical purposes one cubic centimeter of water weighs one gram.

Unit of Time: The fundamental unit of time, the second, is the same in all measuring systems. It is defined as $\frac{1}{86{,}400}$ of a mean solar day, a duration of time exactly equal to 24 hours or 86,400 seconds. It is known that tidal friction is gradually decreasing the speed of rotation of the earth so that the mean solar day will gradually increase but it will be several million years before this change becomes important.

The standard second is made available throughout the world by means of radio time signals. A master clock, maintained at the Naval Observatory in Washington, D. C., is regulated by suitable astronomical observations. When this clock is used to modulate a radio transmitter, the duration of time between second ticks is exactly one standard second.

METRIC TABLES

Metric tables of measures will not be included in this text, as they are available in a variety of technical publications. As a last resort reference may be made to the tables listed under the word "metric" in any college standard dictionary. There is little necessity for the student to memorize such tables, but it is important to memorize the various prefixes used to indicate the different magnitudes of metric units. The most important of these prefixes are listed here.

Prefix	*Multiplying Factor Indicated by Prefix*	*Example*	
mega (or meg)	one million	1 megohm	= 1,000,000 ohms
kilo	one thousand	1 kilocycle	= 1,000 cycles
hecto	one hundred	1 hectoliter	= 100 liters
deca (or deka)	ten	1 decameter	= 10 meters
deci	one-tenth	1 decibel	= 0.1 bel
centi	one-hundredth	1 centimeter	= 0.01 meter
milli	one-thousandth	1 milliampere	= 0.001 ampere
micro	one-millionth	1 microvolt	= 0.000001 volt

THE LANGUAGE OF PHYSICS

In the early stages of physics training, the student is primarily concerned with learning the language or the vocabulary of the subject. New words are constantly being introduced, and it is important to learn their exact meaning. In some cases a new word will be defined, then this word will be used to define a second engineering term. Failure to understand the first will make it impossible to understand the second. It is therefore important to place emphasis on learning the exact meaning of each engineering term as soon as it is met.

In the following pages some of the most common words peculiar to physics will be defined. Only those considered of maximum importance to an understanding of electrical principles will be discussed. In presenting the words, an attempt will be made to define them qualitatively and then quantitatively so that the student may get some idea of how derived units are obtained from the fundamental units of length, mass, and time.

Length: Length is the extent of space or distance between points along a prescribed path. In measuring length it is usually assumed that the measurement is made along a straight line; that is, along a path that represents the shortest distance between two points. However, length may be measured along a curved line: the circumference of a circle is measured in units of length. (The student may think of a curved line as a very large number of very short straight lines joined end to end.)

When more than one dimension of length is involved in a measurement, it is customary to use certain words to describe each dimension. In stating the dimensions of a rectangular box the greatest dimension is usually referred to as the length, the next greatest the width, and the shortest dimension the depth or thickness. Thus the statement that a box has dimensions $3 \times 2 \times 1$ (read 3 by 2 by 1) meters means the box is three meters long, two meters wide, and one meter deep.

The fundamental unit of length (a distance) in the M.K.S. system is the meter, in the C.G.S. system the centimeter, and in the F.P.S. system the foot. The centimeter is one one-hundredth of a meter, and the foot is about 0.305 meter. One meter is about 3.28 feet.

Area: Area is defined as the extent of surface. Unit area is a square, one unit long and one unit wide. A square centimeter is the area enclosed by a square measuring one centimeter on a side. When the statement is made that a surface has an area of 16 square centimeters, it means that sixteen unit squares would just cover the surface. It also means sixteen unit squares would cover an area equal to that of a given surface no matter how the squares are arranged. Therefore an area of 16 cm^2 could apply to any number of differently shaped surfaces, for area does not define shape. Thus 16 cm^2 describes the area of a circle 4.51 cm in diameter, the area of a square 4 cm on a side, the area of a rectangle 2×8 cm, 16×1 cm, or 5×3.2 cm, etc. See figure 2.

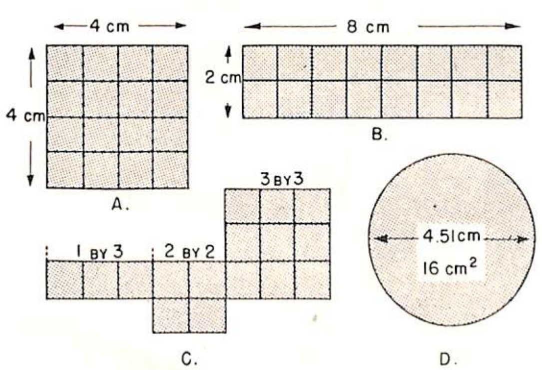


FIGURE 2—*Four different shapes, all of the same area.*

It is evident that to measure area we must make at least two measurements of length. In the case of a square or rectangle,

$$\text{Area} = \text{length} \times \text{width}$$
$$A = LW$$

where A will be in *square* units when L and W are expressed in units of *length*. The unit of area is a derived unit based upon the product of two measures of length. The idea of "square unit" comes from the fact that a product like "length times length" is called "length squared" in mathematics.

More involved measurements are necessary in order to determine the area of irregular surfaces. The area of figure 2c can be found by adding the areas of its parts. Thus

$$A = (3 \times 3) + (2 \times 2) + (3 \times 1) = 16 \text{ cm}^2.$$

The area of many small irregular surfaces, even those bounded by curved lines, may often be estimated to a fair degree of accuracy by laying the surface off in unit squares or by dividing the surface into a number of regular parts, the area of which can be calculated individually, and then added. The area of any surface is equal to the sum of the areas of its parts.

The unit of area in the M.K.S. system is the square meter (abbreviated m^2), in the C.G.S. system the square centimeter (cm^2), and in the F.P.S. system the square foot (ft^2). What is the multiplying constant to convert square meters to square centimeters?

Volume: Volume is the extent of space enclosed within the boundary surfaces of a body. To determine the volume of a regular body, at least three measurements of length are required:

$$\text{Volume} = \text{length} \times \text{width} \times \text{depth}$$
$$V = LWD$$

Volume is said to have dimensions of "length cubed" because it is the product of three factors of length. The unit of volume is a cube having

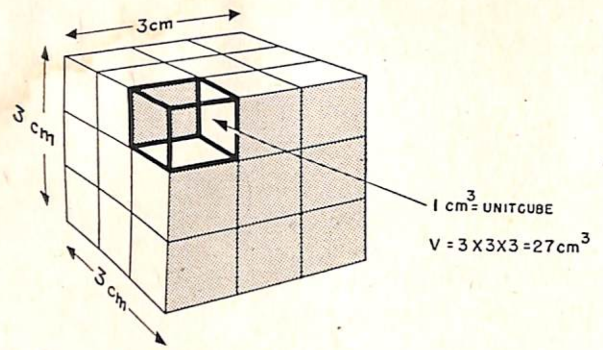


FIGURE 3—*The unit of volume is a cube with sides of unit length.*

sides of unit length. See figure 3. Considerable ingenuity is often needed to measure the volume of irregular bodies. Sometimes it is practical to divide the given body into a series of regular shaped parts and then apply the rule that the total volume is equal to the sum of the volumes of all the individual parts. Figure 4 demonstrates another method of measuring the volume of comparatively small irregular bodies. The volume of water displaced by the body when submerged in water is equal to the volume of the body.

The unit of volume in the M.K.S. system is the cubic meter (m^3), in the C.G.S. system the cubic centimeter (cm^3), and in the F.P.S. system the cubic foot (ft^3).

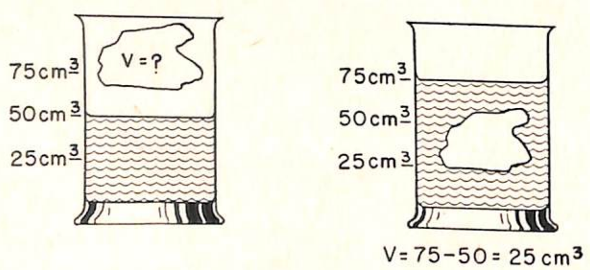


FIGURE 4—*Measuring the volume of an irregularly-shaped object by measuring the volume of liquid it displaces.*

Velocity: The dictionary may define "speed" and "velocity" as the "rate of motion," but to the engineer there is a definite difference in the meaning of the two words. The speed of an object simply states how rapidly the body is moving without any indication of the direction in which it is moving. To the mathematician, speed is a *scalar* quantity; that is, one that indicates only magnitude or size. But velocity is a *vector* quantity; that is, one that indicates both magnitude and direction. A body may move at constant speed and yet any selected point on the body may be moving at a variable velocity. A wheel may roll along the surface of the earth at constant speed but any point on the rim of the wheel will have a variable velocity because the direction in which the point moves constantly changes.

The word "rate" always implies a ratio. Unit velocity is a unit ratio involving the fundamental units of distance (length) and time.

$$\text{Unit velocity} = \text{distance per unit time} = \frac{\text{distance}}{\text{time}}$$

$$v = \frac{d}{t}$$

In the M.K.S. system the unit of velocity is the meter per second, in the C.G.S. system the unit is the centimeter per second and in the F.P.S. system the foot per second. These may be written m/s, cm/s, and ft/s, respectively.
Other units of velocity are miles per hour, revolutions per minute, etc. These units are also used in measuring speed.

Acceleration: Acceleration is defined as the rate of change of velocity. Acceleration is said to be uniform when the change in velocity per unit time is a constant. Non-uniform acceleration exists when the rate of change of velocity is variable. Acceleration is said to be positive when the velocity is increasing and negative when it decreases.

Unit acceleration is represented by unit change in velocity in unit time. If a body is moving at a velocity of ten feet per second and each second the velocity increases by 2 feet, then the acceleration is two feet per second per second. This is usually written 2 ft/sec^2. If the velocity is decreasing at the rate of 2 feet per second the acceleration is $-2ft/sec^2$.

$$\text{Acceleration} = \frac{\text{velocity}}{\text{time}}$$

$$a = \frac{v}{t}$$

Since $v = \frac{d}{t}$,

then in terms of fundamental units

$$a = \frac{d}{t} \div t$$

$$a = \frac{d}{t^2}$$

Unit acceleration in the M.K.S. system is the meter per second squared, in the C.G.S. system the centimeter per second squared, and in the F.P.S. system the foot per second squared.

In physics an important example of acceleration is that caused by gravity acting upon a free-falling body. Any body falling in a vacuum toward the earth accelerates at a constant rate. This rate varies slightly with the distance of the body from the center of the earth and at various points over the surface of the earth, but in physics this variation is usually neglected and the acceleration caused by gravity is taken as 9.80 meters per second squared, equivalent to 32.2 ft/sec^2. Let us neglect the effects of air resistance; then if a body starts from rest and falls toward the earth, at the end of the first second it will have a velocity of 9.80 m/sec, at the end of the second second the velocity will be 9.80 + 9.80 or 19.60 m/sec, at the end of the third second 19.60 + 9.80 or 29.40 m/sec, etc. Each second of fall increases the velocity of the body by 9.80 m/sec. If the body is thrown upward against the force of gravity, the velocity would decrease uniformly at the rate of 9.80 m/sec. The constant of gravitational acceleration is represented by the symbol g.

$$g = 9.80 \text{ m/sec}^2 = 980 \text{ cm/sec}^2 = 32.2 \text{ ft/sec}^2.$$

When acceleration is uniform, it may be calculated by measuring the velocity at the beginning and end of a known time interval.

$$\text{Acceleration} = \frac{(\text{final velocity}) - (\text{initial velocity})}{(\text{duration of time interval})}$$

For example, if a car is moving at 45 mph at the instant the brakes are applied and three seconds later the velocity has decreased to 30 mph, the acceleration is

$$a = \frac{30 - 45}{3} = -5 \text{ miles/hour/second.}$$

When the acceleration is non-uniform, this formula yields the average, or mean acceleration. In the example above, if the speed of the car decreased to 35 mph at the end of the first second and then to 30 mph in the second and third seconds the average acceleration would still be −5 miles/hour/second.

The final velocity of a uniformly accelerating body may be calculated from

$$v_f = v_i + at$$

where v_f is the final velocity, v_i the initial velocity, a the average acceleration during the time interval t. The average velocity of a uniformly accelerating body over a given time interval is

$$v = \frac{v_i + v_f}{2}.$$

When the average velocity is known, the distance through which a body moves in a given time t is

$$d = v_a t.$$

An automobile moving at 30 mph accelerates at the rate of 5 m/h/sec for six seconds. Through what distance will the car move in this time interval?

$$v_f = 30 + (5 \times 6) = 60 \text{ mph}$$

$$v = \frac{30 + 60}{2} = 45 \text{ mph}$$

$$6 \text{ sec} = 1/600 \text{ hour}$$

$$d = 45 \times 1/600 = \frac{3}{40} \text{ mile} = 396 \text{ ft.}$$

Mass: Mass was defined by physicists, many, many years ago, as a measure of the quantity of matter contained in a body. This definition leads to the logical conclusion that mass should be a constant for any given body. A gallon measure should hold a gallon of water on the earth, the moon, or anywhere in the universe. After formulating this qualitative definition, scientists were at a loss for many years as to how it could be placed in quantitative form. It was the work of Sir Isaac Newton that eventually solved the problem. The quantitative relations which he established give a basic understanding of the words mass, force, and weight. The student must grasp these quantitative relations because from them are derived the fundamental concepts of electromotive force, electrical work, energy, and power.

Force: In order to define mass quantitatively, it is first necessary to define the meaning of "force." First impressions of force come from muscular effort. Intuition tells us that muscular force may be used to change the direction of motion of a body. A baseball player realizes intuitively that greater force is required to throw a baseball from first to third than from first to second base. The same intuition tells us that more effort or force is required to move a large body a given distance than to move a smaller one of the same material through the same distance. Therefore the quantity of matter in a given body determines the force needed to move it through a given distance. It is easier (that is, less force is required) to stop a thrown baseball than a rifle bullet, although the baseball may contain several times more matter than the bullet. Hence the velocity of a body must also have some control over the force required to change the motion of the body. These relatively simple ideas led Newton to believe that force, mass, and velocity were related in some definite manner. As a starting point he defined force as *an action exerted by one body on another tending to change the state of motion of the body acted upon.* Note particularly that

Newton did not say that applying a force always resulted in a change in motion. Lifting an object is equivalent to applying a force that changes the direction of motion of the object lifted. However, if the body is sufficiently heavy that the applied force cannot move it, then the force simply *tends* to change the direction of motion.

Anyone stepping from a moving vehicle notes that his body tends to continue in motion in the direction of the vehicle. Similarly it is much easier to step aboard a moving vehicle if a person is moving in the same direction and at the same speed as the vehicle. Analyzing experiences of this type led Newton to formulate his first law of motion which states that *every body continues in a state of rest or uniform motion unless the application of some external force compels a change in that state.* An important property of matter becomes evident from this law. It is called *inertia* and is defined as *that property of matter by virtue of which it tends to remain at rest or in uniform motion unless external forces are operating upon it.* In the study of electricity it will be found that the electrical property called inductance is nothing more than the inertia of the electrical circuit which acts to oppose any change in current flowing in the circuit.

By a series of simple experiments and observations Newton noted that application of a known force to a given body would impart a given velocity to the body. If the mass of the body were increased, the same force would impart a lower velocity. If the mass was decreased, a higher velocity would result. A body in motion then possesses a property that does not exist when the body is at rest. He called this property *momentum* and on the basis of experiment established the relation

$$\text{momentum} = \text{mass} \times \text{velocity}$$
$$M = mv.$$

Since velocity is measured in terms of unit length (distance) per unit time, then the fundamental dimensions of momentum are

$$M = \frac{md}{t}.$$

In the M.K.S. system the unit of momentum would be the kilogram-meter per second.

When the motor of an automobile exerts a driving force upon the car, the force acts to accelerate the movement of the car. In moving, the car must overcome the opposing forces of friction—friction in the driving system of the car, the frictional resistance of the air, and the resistance offered by the road over which the car moves. These opposing forces all increase as the velocity of the car increases. When the applied forces exceed the opposing forces, part of the applied force is cancelled in overcoming the opposing forces; the remainder, called the net or effective force, is utilized in accelerating the forward motion of the car. Since the opposing forces increase with velocity, a final velocity will eventually be attained for any given applied force. When the opposing forces have built up to a point where they just equal the applied force, the effective force is zero, the velocity is constant, and the acceleration is zero. The forces are then said to be in equilibrium.

Considering only the effective force acting on a body, it can be shown that the greater the mass of a body the less will be the acceleration imparted by a given force. If the applied force is constant, doubling the mass of a body will halve the acceleration, and halving the mass will double the acceleration. From these conditions Newton formulated his second law of motion which states that *the effective force acting upon a body is directly proportional to both the mass of the body and the acceleration produced by the force.* Note that this law gives a quantitative definition of a force. It is the basis of several important electrical principles.

$$\text{force} = \text{mass} \times \text{acceleration}$$
$$F = ma$$

Dimensionally, $F = \dfrac{md}{t^2}$.

Unit force is that force which will impart unit acceleration to unit mass. In the M.K.S. system this unit is called, appropriately enough, the *newton.* A newton is that force which will impart an acceleration of one meter per second per second to a mass of one kilogram. In the C.G.S. system the unit of force is called the *dyne* and is that force which will impart an acceleration of one centimeter per second per second to a mass of one gram.

The importance of Newton's work in quantitatively defining force is that it yields a useable definition of mass.

$$F = ma$$

$$m = \frac{F}{a}$$

Force and acceleration are quantities easily measured. Unit mass can now be defined. One kilogram of mass is that mass which will be accelerated one meter per second per second by applying an effective force of one newton.

Newton's third and final law of motion states that *for every action upon a body there is an equal and opposite reaction.* In essence this third law of motion means that Body *A* cannot exert a force on Body *B* unless Body *B* pushes back against Body *A* with an equal force. A sheet of paper cannot stop a rifle bullet because it is incapable of exerting an opposing force equal to the force of impact of the bullet. A force is utilized or expended by pitting it against an equal and opposite force.

Weight: An attempt has been made up to this point to explain mass and force without reference to weight s6 as to avoid confusing the student. Weight is a property of matter and is defined as a measure of the force of gravity acting upon the mass of a body. Weight is a measure of force, the force of gravity, acting upon a given body. In an earlier paragraph the gravitational constant *g* was defined, although it was stated that *g* was not strictly a constant. The rate at which a free-falling body accelerates under the influence of gravity varies with the distance of the body from the center of the earth. The value of *g* at sea level is greater than on a high mountain top. To some extent the density of the earth's crust causes the gravitational constant to vary slightly, the value of *g* being greater over areas of high density. Since weight is a measure of the force of gravity acting upon the mass of a body, the weight of the body will vary in accordance with the variation in the value of *g*. The primary difference between mass and weight is that mass is a constant (independent of gravity) whereas weight may vary, although it is customary to consider weight a constant.

Although the force of gravity varies at different points on the earth's surface and at different altitudes, the range of variation is not very great. A mass that weighs 2000 pounds at sea level will weigh about 1999 pounds at an altitude of one mile above sea level. Since the radius of the earth is slightly less at the poles than at the equator, the value of *g* will be somewhat less at the equator than at the poles. It varies from about 9.832 m/sec² at the poles to 9.7799 m/sec² at the equator, both these values being for sea level. Since weight is an important property of matter in commerce, Congress has fixed the legal value of *g* at 9.80665 m/sec², and weight measuring devices are calibrated in terms of this value.

The quantitative relation between weight, mass, and *g* is given by

$$W = mg$$

Confusion results from the fact that mass and weight are measured in units that have the same name. A mass of one kilogram weighs 9.80 kilograms, a mass of one gram weighs 980 grams, a mass of one pound weighs 32.2 pounds. To avoid confusion, it is customary to use the word "mass" to indicate that the measurement does not involve the force of gravity, and the words "force" or "weight" to indicate that the constant *g* is involved. A "pound force" is the force exerted by gravity on a pound weight. Measurements that are independent of gravity are called *absolute* values. Those dependent upon the force of gravity are called *gravitational* values.

Gravitational Units: The fact that

$$W = mg$$

from which

$$m = \frac{W}{g}$$

has led to a system of units based upon the gravitational constant *g*. Absolute units are based upon the relation

$$m = \frac{F}{a}.$$

It is interesting to note that W/g is a constant, although both *W* and *g* may vary. The variation is always such that weight divided by *g* yields the same quotient. To avoid confusion, the gravitational units will not be defined here. When necessary to clarify future discussions, they will be defined at the appropriate point in the text.

Law of Universal Gravitation: Newton's law of universal gravitation is of general interest because it is very similar to two laws in electrical engineering that form the basis of the electromagnetic and electrostatic systems of units. Newton reasoned that every body in the universe attracted every other body with a force directly proportional to the masses of the bodies and inversely proportional to the square of the distance between them.

$$F = \frac{km_1m_2}{d^2}$$

where *F* is the force of attraction, m_1 and m_2 the respective masses of the bodies, *d* the distance between them, and *k* the constant of proportionality whose value depends upon the units in which the other values are measured. If m_1 is the mass of the earth and *d* the radius of the earth, then

$$g = \frac{km_1}{d^2}.$$

Since *k* and m_1 are constants, if the radius of the earth is constant then *g* is the constant of gravitational attraction. This leads to the quantitative definition of weight

$$F = W = m_2 g.$$

PROPORTIONALITY CONSTANT

The so-called constant of proportionality, usually represented by the symbol k, is a part of all engineering formulas; however, it is customary to omit writing it when the value of k is unity. The student will have little difficulty in visualizing the nature of k if he remembers that the value of k is dependent upon the units in which other terms of the formula are measured. Consider the statement "the area of a rectangle is directly proportional to the length and width of the rectangle." This statement is true regardless of the units in which the area, width, and length are measured. It is symbolized as

$$A \propto LW$$

where the symbol $\propto$ is read "varies as." This is a statement of proportionality which becomes an equation by introducing the constant of proportionality,

$$A = kLW.$$

The value of k will depend upon the units in which A, L, and W are expressed. This is a general formula that applies in all cases. When written

$$A = LW$$

it is a special formula that is true only when A, L, and W are expressed in units such that $k = 1$. For example, if L and W are in feet and A in square feet, then k equals unity because the unit of area, the square foot, is measured in feet—the same unit that is used to measure L and W. However, if A is expressed in square yards and L and W in feet, the value of k is no longer unity. Multiplying L feet by W feet yields a product LW square *feet.* Since one square yard is equal to 9 square feet, the product LW square feet is nine times too large for the value of A in square yards.

To convert square feet to square yards it is necessary to divide by nine or perform the equivalent operation of multiplying by one-ninth.

$$A \text{ yd}^2 = \frac{L \text{ ft} \times W \text{ ft}}{9 \text{ ft}^2} = \frac{LW \text{ ft}^2}{9 \text{ ft}^2} = \frac{LW}{9} = \frac{1}{9} LW$$

Since $A = kLW$,

then $k = \dfrac{1}{9}.$

This value of k is not so obvious when one-ninth is expressed as a decimal value—

$$A = 0.111\ LW$$

which would yield a value for A accurate only to three significant figures.

In establishing a system of measurement, the fundamental idea is to develop units so that in basic formulas the value of k is equal to unity. However, in many derived formulas, or when shifting from one system to another, or when using mixed units, the value of k frequently is greater or less than unity. This often results in odd numerical constants appearing in the formulas. It should be noted that k is an abstract number and does not involve any particular unit of measurement. The engineer views the formula $A = kLW$ as a general formula true in all cases, whereas $A = LW$ is a special case in which the units used are such as to make $k = 1$.

TEST QUESTIONS

1. (a) 1.7 decameters = ... centimeters
   (b) 2.5 amperes = ... milliamperes
   (c) 5,200,000 ohms = ... megohms
   (d) 310 microvolts = ... volts
   (e) 40 megacycles = ... kilocycles

2. (a) 6.28 feet = ... meters
   (b) 25 cm = ... inches
   (c) 27 ft² = ... square meters
   (d) 1000 cm³ = ... cubic inches
   (e) 46 ounces = ... kilograms

3. A body has a present velocity of 12 ft/sec. In 10 seconds it has a velocity of 7 ft/sec. What is the mean acceleration?

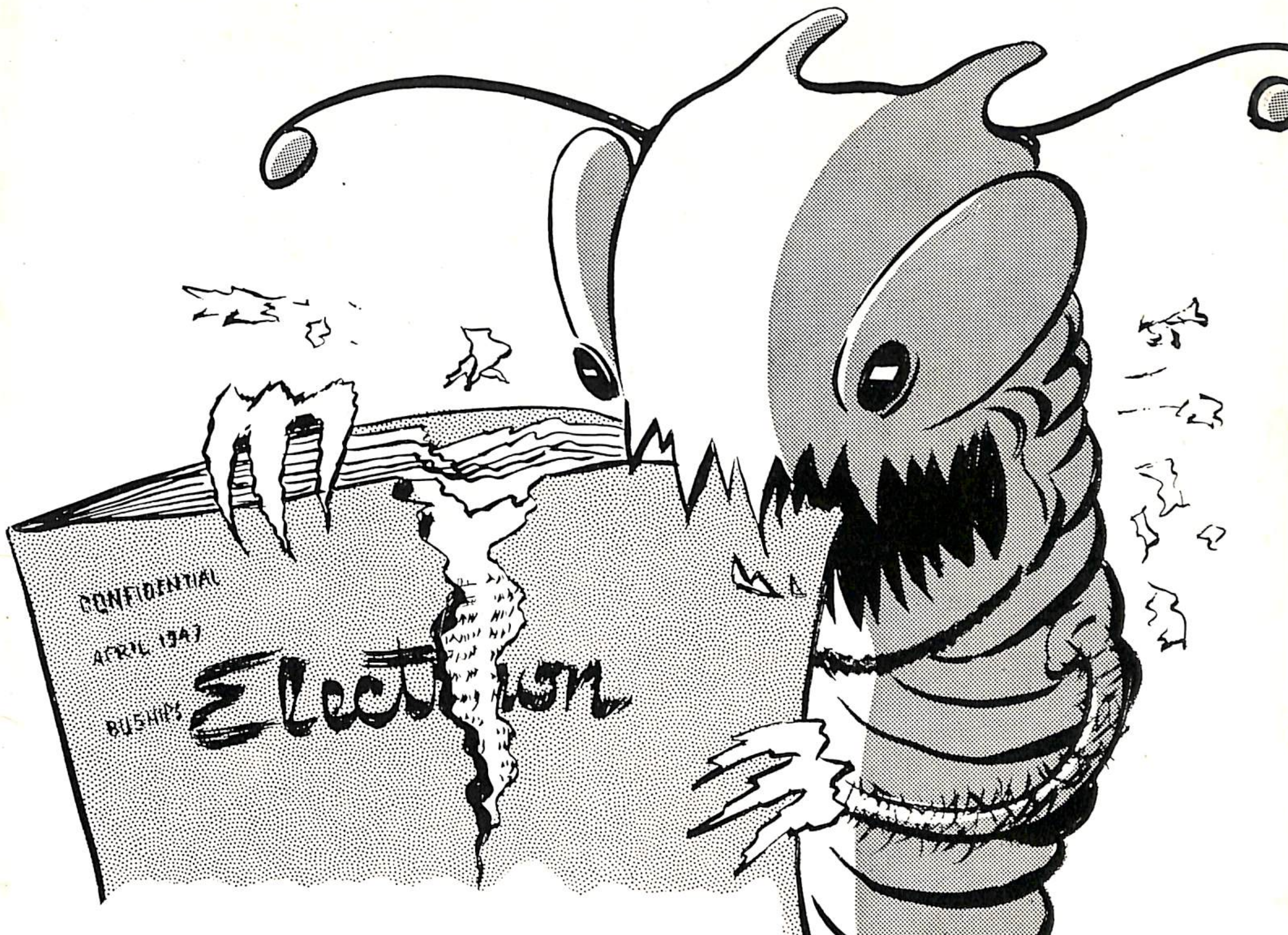
4. A body starting from rest and having uniform acceleration moves in the fourth second through a distance of 112 feet. What is the acceleration in meters per second squared? Through what distance in meters does the body move in the third second?

5. A body having a mass of 4 kg is moving at the rate of 8 m/sec. At this instant a force begins to act upon the body in the direction of motion and at the end of 20 seconds the velocity has increased to 24 m/sec. Determine the magnitude of the effective force.

6. A gram weight is equal to what force in dynes?

7. A spring balance is carried in a balloon that is ascending vertically. What is the vertical acceleration in feet/sec² of the balloon if an 8-ounce weight causes the balance to read 9 ounces? $g = 32$.

DON'T BE A TERMITE!



The termite above is going through this copy of ELECTRON without learning anything.

There is a tendency—we are all human—to read only the articles applying to pet equipments. This reduces the usefulness of the magazine. Why do that? This is your magazine. By reading and understanding every article you can gain for yourself a well-rounded understanding of the principles involved in many different types of electronic equipment.

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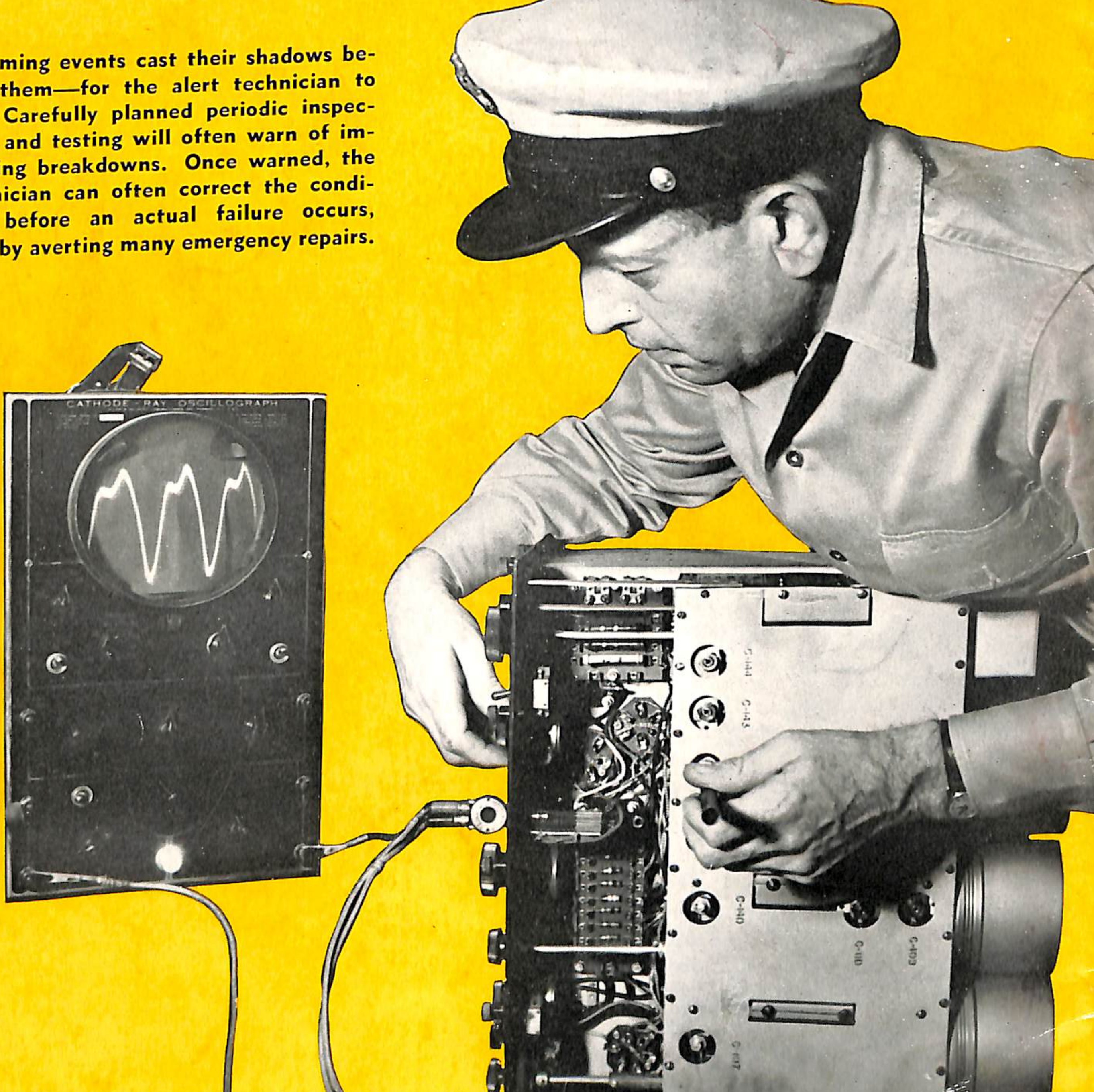

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