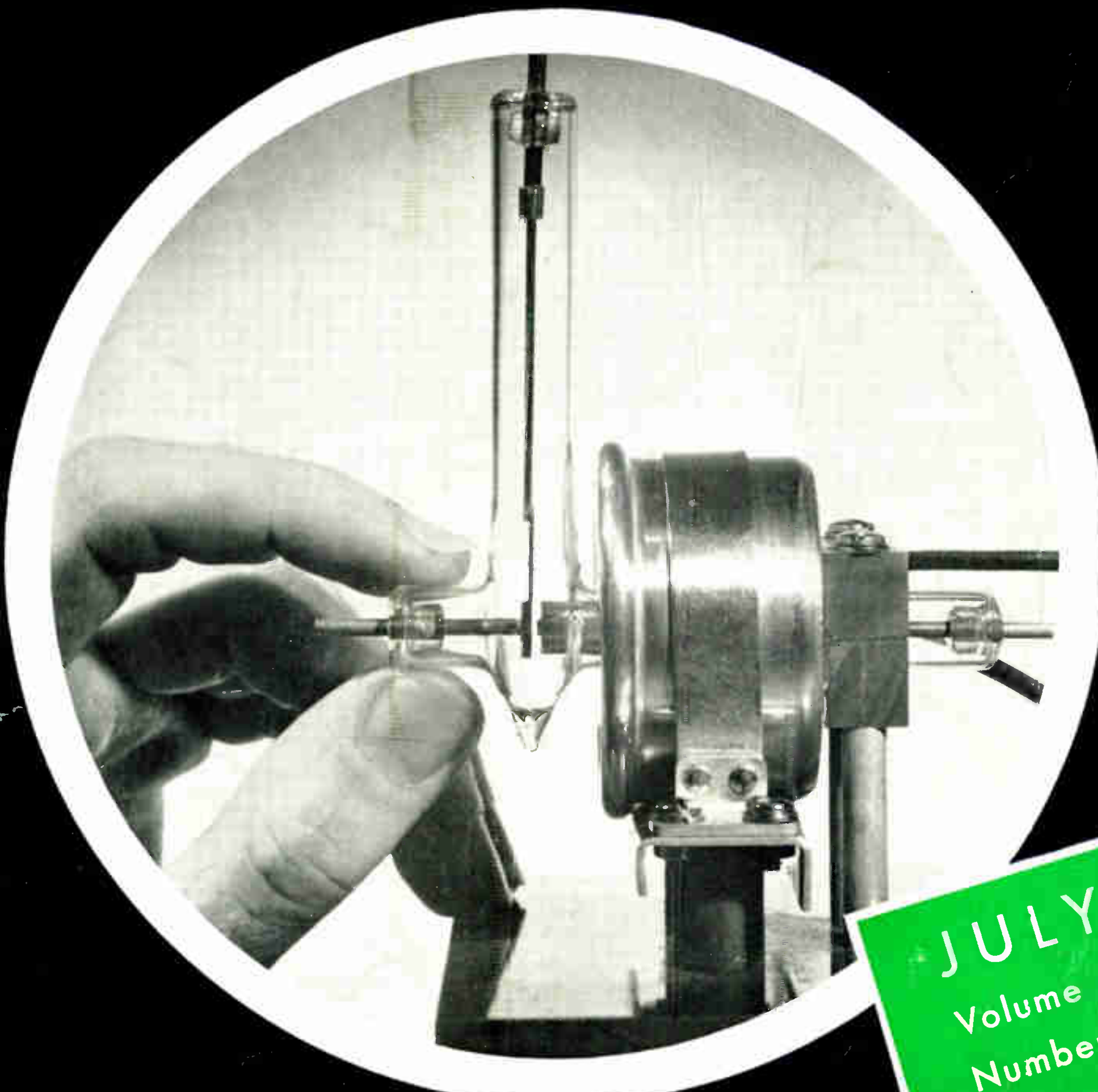
BENDIX RADIO ENGINEER



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IN THIS ISBUE

Page

BUY WAR BONDS

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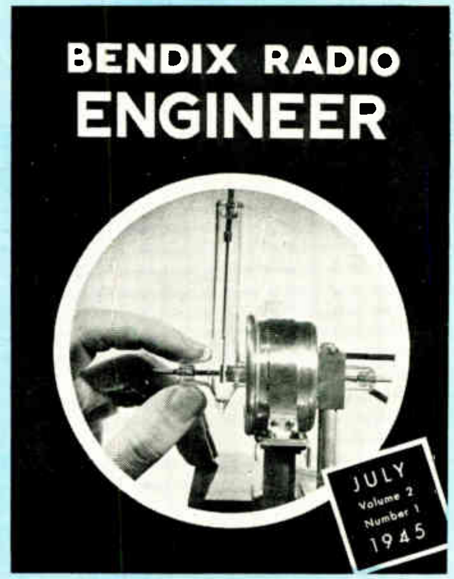


The Cover

A relay is inserted into the energizing coil of a glass type vacuum switch. Switches of this type are fast acting, small, and are unaffected at high altitudes; they have proved very effective as antenna transfer relays in aircraft transmitters. An analysis of their operating characteristics is presented in an article by R. B. Edwards on Page 10. *Photograph by P. K. Morris.*

BENDIX RADIO

The potential fruitfulness of engineering experience is increased inestimably when it is recorded so that it may be shared by others. For even a laboratory observation, published only as an interesting footnote to a scientific investigation, may be all that is required to inspire an association of ideas that leads someone into unexploited fields of research.

ESTIMATING MICROWAVE S/N RATIO

An easy method of predicting the performance of microwave communication circuits.

By A. C. OMBERG
Section Chief
Research and Development

It is interesting to demonstrate how the performance of microwave communication circuits can be predicted without going through laborious calculations of field strengths, antenna currents, microvolt sensitivities and other factors usually considered by radio engineers when working with circuits operating at lower frequencies.

Assume, for instance, that there is a nondirectional radiator sending energy uniformly in all directions. Let the total power of the transmitter be P_T.

At a distance of 1 unit (a foot, or a meter, or a mile) a surface around this antenna would have 4π square units, so the power per square unit must be $\frac{P_T}{4\pi}$. By this reasoning it is apparent that at any distance, R, in feet, the power per square foot is,

$$\frac{P_T}{4\pi R^2}.$$

If a directional antenna is used, the power is effectively increased by the gain of the antenna. If the gain of the transmitting antenna is G_T the power density at any distance, R, becomes,

$$\frac{P_T\,G_T}{4\pi R^2}. \qquad (1)$$

A receiving antenna placed in this field will intercept some of the power. The amount it will intercept depends on its effective pickup area or aperture. A microwave receiving antenna can be thought of as a funnel which scoops in power. The effective area of this funnel is $\frac{\lambda^2}{4\pi}$ for a nondirectional or isotropic antenna. Thus, for a wave length of 1 foot a nondirectional antenna has an effective pickup area of $\frac{1}{4\pi}$ square feet.

If the receiving antenna has an area larger than about $\frac{\lambda^2}{4\pi}$ it becomes directional; that is, it receives better from certain directions. This directional property is often called "gain." The gain of a receiving antenna can be seen to be $4\pi A$, where A is the area expressed in square wavelengths.

Therefore, with a receiving antenna whose area is A_R and which is located a distance R (A_R and R in the same units) from the transmitter, the power intercepted is,

$$\frac{P_T\,G_T\,A_R}{4\pi R^2}.$$

Substituting,

$$G_R = \frac{4\pi A_R}{\lambda^2};$$

hence, power received is, $\frac{P_T\,G_T\,G_R\,\lambda^2}{16\pi^2\,R^2}$. (2)

Figure 1 shows a nondirectional radiator. From this illustration it is easy to see how the transmitted power is "thinned out" as it is spread over larger and larger spheres. The simple fundamental formulas are given and

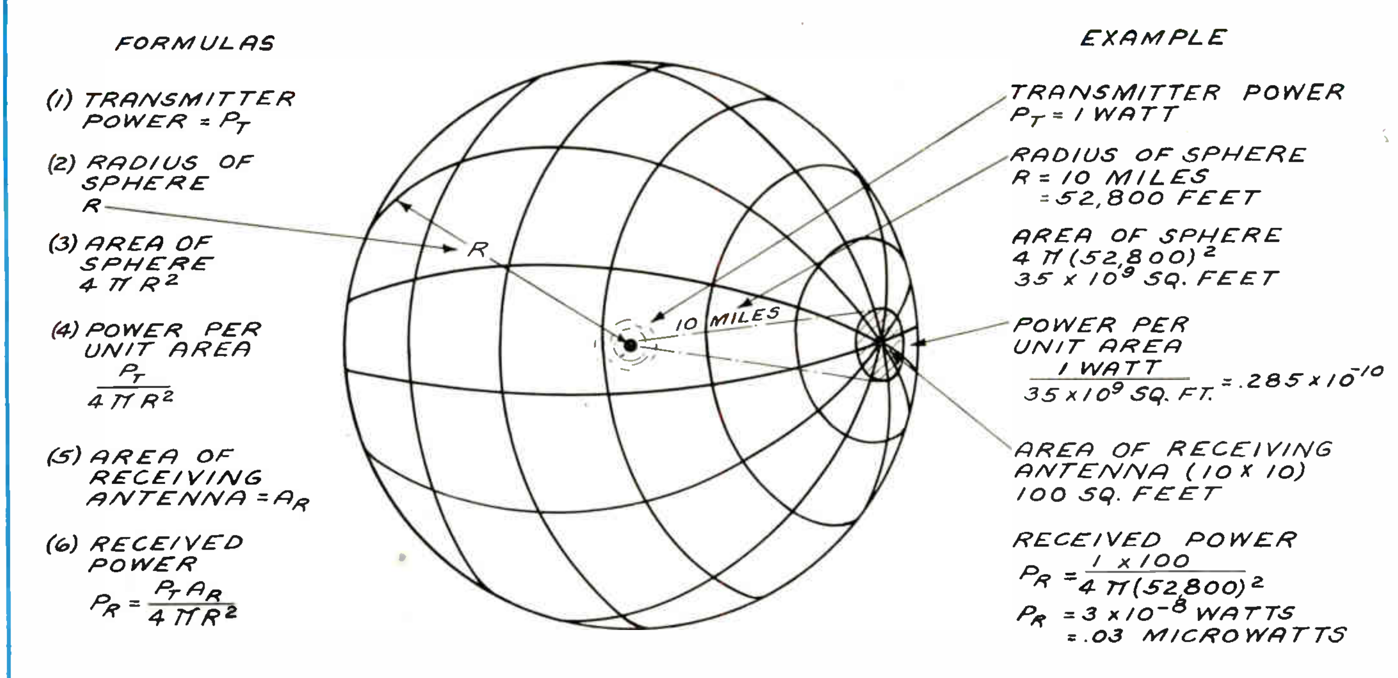


Figure 1—Free space radiation pattern of nondirectional microwave transmitter.

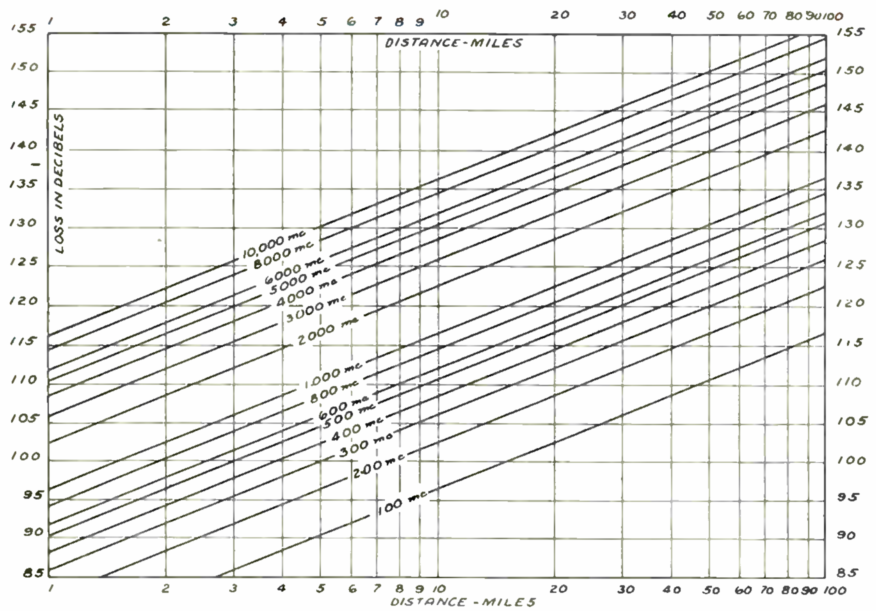


Figure 2—Curves showing circuit losses between two antennas at various distances and frequencies.

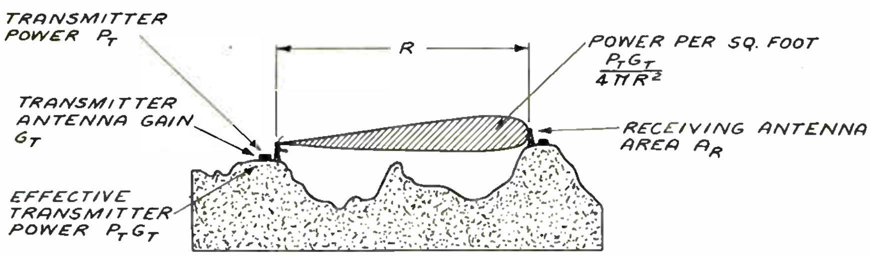


Figure 3—An ideal condition for microwave communication with directional antennas, and an example of power calculations.

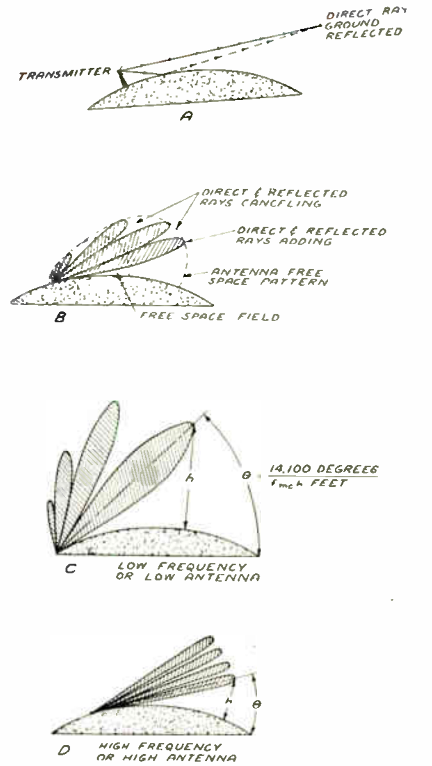


Figure 4—A and B: Radiation striking ground combines with direct rays to increase or cancel strength of free space field, thus dividing energy into lobes. C and D: Number of lobes and height above ground of first lobe depend on transmitter height in wavelengths.

an example computed. In this example, the power per square foot at a distance of 10 miles from a one watt isotropic radiator is shown to be 2.85×10^{-11} watts. Since there are 3.5×10^{10} square feet on the entire surface of the sphere the total power is $2.85 \times 10^{-11} \times 3.5 \times 10^{10}$ or 1 watt total radiated power.

Signal-To-Noise Ratio

The usefulness of this received power is limited by the ever-present thermal noise. The thermal noise in a perfect receiver is known to be KTB watts, where,

K is Boltzman's constant,

T is absolute temperature,

B is the bandwidth in cycles.

Unfortunately, we do not have perfect receivers. Every receiver adds some noise to the rock bottom KTB. The amount of this added noise can be measured, and is expressed in terms of a multiplicative factor $\overline{NF}$ called the *noise figure* of the receiver. The noise power present in a receiver is,

$$\overline{NF} \times KTB$$

A perfect receiver can thus be seen to have an $\overline{NF}$ of 1. A poorer receiver will have a correspondingly higher noise figure.

With the signal power and the noise power derived, it is a simple matter to write the signal-to-noise ratio:

$$\frac{S}{N} = \frac{\text{Signal Power}}{\text{Noise Power}} = \frac{\dfrac{P_T\ G_T\ G_R\ \lambda^2}{16\pi^2\ R^2}}{\overline{NF}\ \ KTB} \qquad (3)$$

or,

$$\frac{S}{N} = \frac{P_T\ G_T\ G_R \left(\dfrac{\lambda}{4\pi R}\right)^2}{\overline{NF}\ KTB}. \qquad (4)$$

In order to facilitate the rapid estimation of circuit performance, formula 3 can be rearranged as follows:

$$(S/N)_{db} = +204_{db_1} + G_{T_{db}} + G_{R_{db}} + P_{T_{db_1}} - \overline{NF}_{db} - B_{db} - A_{TT_{db}}$$

where,

204_{db_1} = db below 1 watt for noise power in 1 cycle,

$G_{T_{db}}$ = transmitting antenna gain in db,

$G_{R_{db}}$ = receiving antenna gain in db,

$P_{T_{db_1}}$ = power of transmitter expressed in db above 1 watt,

$\overline{NF}_{db}$ = noise figure in db,

B_{db} = $10 \log_{10} B$, where B = bandwidth in cycles,

$A_{TT_{db}}$ = $20 \log \dfrac{\lambda}{4\pi R}$

The last factor is the attenuation between two isotropic antennas separated by distance R. The value of $20 \log \lambda/4\pi R$ has been plotted as a function of R in miles and f in megacycles and is shown in figure 2.

To demonstrate how the preceding formula is used to estimate performance, let us consider an example in which we wish to find the signal-to-noise ratio for a 4000 mc circuit of 50 miles. Assume that the following conditions exist: 1) transmitting and receiving antenna gains are 25 db, 2) transmitted power is 10 watts, 3) the receiver has a bandwidth of 100,000 cycles, and 4) the receiver $\overline{NF}$ is 25 db. Then,

$$(S/N)_{db} = 204 + 25 + 25 + 10 - 25 - 50 - 142 = 47 \text{ db}$$

The value of 142 db is found from figure 2 as corresponding to 50 miles and 4000 mc.

Propagation Factors

Since the foregoing considerations all have been based on free space propagation, they hold only as long as the gain of the transmitting antenna is sufficient to produce a beam which can be tilted so as not to strike the ground. This procedure is often practical at microwave frequencies, especially when hilltop to hilltop links are employed. Figure 3 shows a somewhat idealized example of such an installation. Using this illustration,

Received Power (P_R) = Power per sq. ft. × Receiving Antenna Area, or

$$P_R = \frac{P_T\, G_T}{4\pi R^2} \times A_R;$$

$$P_R = \frac{P_T\, G_T\, A_R}{4\pi R^2}.$$

Since,

$$G_R = \frac{4\pi A_R}{\lambda^2},$$

$$A_R = \frac{G_R \lambda^2}{4\pi}.$$

Substituting A_R in the equation for P_R,

$$P_R = \frac{P_T\, G_T\, G_R\, \lambda^2}{4\pi R^2 \times 4\pi}$$

$$= \frac{P_T\, G_T\, G_R\, \lambda^2}{(4\pi R)^2}.$$

Considering a numerical example where,

P_T = 1 watt,

G_T = 100,

G_R = 100,

R = 52,800 feet,

λ = 500 mc = 0.6 meter,

λ^2 = 4 square feet:

$$P_R = \frac{(1)(100)(100)(4)}{35 \times 10^9},$$

$$= 1.1 \times 10^{-6} \text{ watt}.$$

When the radiation strikes the ground, the direct and reflected rays combine either to increase or cancel the strength of the free space field, thereby dividing the energy into lobes. The received power then might be anywhere between zero and 6 db above the value indicated by the foregoing procedure. Figures 4*a* and 4*b* illustrate this process. Figures 4*c* and 4*d* show how the height of the first lobe and the distance between lobes depend on the height above the earth in wavelengths. Thus, at micro-wavelengths a relatively small increase or decrease in the height of either the transmitting or receiving antenna will serve to place the operation in or near the maximum of a lobe, so long as the line-of-sight condition exists.

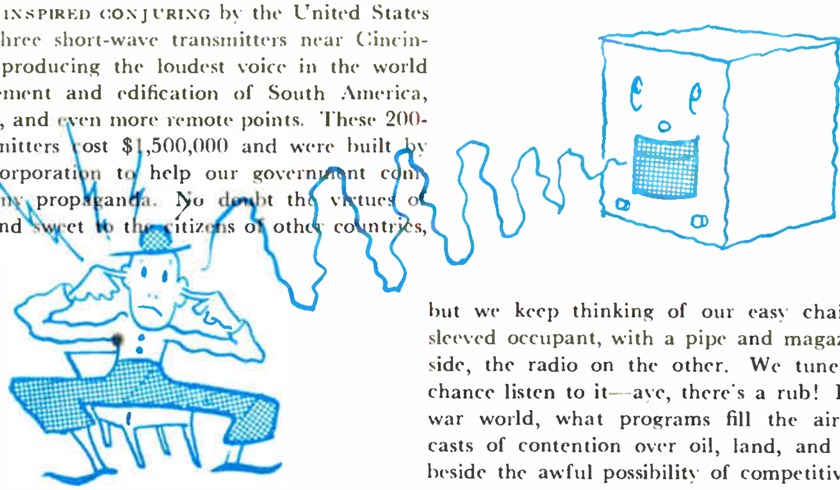
It is then possible to estimate the performance, that is the signal-to-noise ratio, of a circuit to a fair degree of accuracy. To make this estimate it has been shown that only simple, fundamental methods are required.

Arthur C. Omberg

As Chief of the Engineering Research and Development Section, quiet, soft-spoken Arthur C. Omberg directs all Bendix Radio long term product development and electronic research. A native of Memphis, Tennessee, and a typical southerner, he is a graduate of Vanderbilt University, receiving his B. S. in 1932, his M. A. in 1934 and his E. E. degree in 1935. During 1928 and 1929 he was at sea as radio operator for Radiomarine Corporation. As transmitter engineer with WSM at Nashville, Tennessee, between 1932 and 1942, he became widely known in the entire area as a consulting engineer on broadcast station problems and surveys. For a large portion of this time he was also consulting physicist to Vanderbilt Hospital. In July, 1942, he transferred to the Signal Corps as Assistant Chief of the Operational Research Branch.

"Speak Softly—"?

After some inspired conjuring by the United States Government, three short-wave transmitters near Cincinnati are busy producing the loudest voice in the world for the amazement and edification of South America, Europe, Africa, and even more remote points. These 200-kilowatt transmitters cost $1,500,000 and were built by the Crosley Corporation to help our government compete with enemy propaganda. No doubt the virtues of democracy sound sweet to the citizens of other countries,



but we keep thinking of our easy chair and its shirt-sleeved occupant, with a pipe and magazine rack on one side, the radio on the other. We tune the radio, perchance listen to it—aye, there's a rub! For in that post-war world, what programs fill the air! Present forecasts of contention over oil, land, and air routes, fade beside the awful possibility of competitive nations trying to outshout each other.

BENDIX ENGINEERING ORGANIZATION

By W. L. WEBB
Director of Engineering and Research

W. L. Webb

THERE ARE AS MANY WAYS of organizing an Engineering Department as there are persons in it; but regardless of the form of the organization, it must accomplish certain prime objectives. This discussion will be confined to the requirements at Bendix Radio, where the following basic objectives have been established for the Engineering group:

1) By continuous observation and investigation, it must keep abreast of the field in which the products of the Company are used, in order to develop new products which will be ahead of those of competitors.

2) It must continuously develop and design a complete line of products for the market or markets in which the Company is interested.

3) It must render engineering service to the customers and, by continuous contact with those customers, be aware of their requirements, troubles, and problems.

4) It must provide complete engineering service to the factory and associated factory departments, by furnishing the necessary information for manufacturing, purchasing, and testing of the equipment in accordance with the requirements of the customer and the quality standards of the Company. Service on all the technical problems must be given by personal contact.

Although these could be elaborated on and others added, basically they are our prime objectives. The writer has often stated that an Engineering head, or project engineer, is a slave to three masters; namely, the customer, the factory and the personnel under him. He must be constantly aware of the needs and problems of all three and keep all of them satisfied.

A review of our past problems and organization is worthwhile before discussing the changes that have occurred in our product requirements, and the necessity for engineering organization changes to facilitate design of better and more diversified products at less cost and in less time.

For any particular product, the design must meet the customers' requirements; it must be manufacturable with our factory facilities at the lowest possible cost; and the amount of engineering time and money expended must be consistent with the demand for the product. In other words, it is not good business to spend $25,000 and one year to design a product and then find that not over 200 units per year can be sold for $250 each. It must be emphasized that "time is money" in the fast moving aviation and radio industry; that a product which has a good market and is profitable today, may be worthless a few months from now.

In the early years of Bendix Radio, the project engineer was required to do everything, with very little technical or clerical assistance available. He designed equipment, contacted customers, directed factory personnel, directed draftsmen, selected, tested and designed components, made decisions regarding rivets, bearings, screws, alloys and other standard mechanical components, prepared parts lists, and ordered material. As the organization expanded under wartime conditions and larger quantities of a given product were manufactured, the equipment project engineer became more concerned with the problems of production follow-up and routine work than with development work.

Specialization With Growth

When a reasonably large staff of engineers (100 or more) had been built up, however, it became economically justifiable to have specialists in certain fields, such as transformers, standard electrical components, standard mechanical components and specialized measurements. These specialists assist us in achieving our objective by conserving the time and effort of design engineers, and by helping to obtain standardization. It certainly is not worthwhile for each project engineer to make his own tests on resistors, tube sockets, relays, capacitors, switches, or other common components, when a number of engineers can and should use identical components. Neither is it sound for each design engineer to make his own investigation and selections of hardware, greases, paint finishes, plating, ball bearings, alloys, type of casting or other standard parts; first, because he is not an expert on these problems, and second, because he should be spending his time on the development of the over-all equipment. Moreover, each engineering section formerly selected its own particular grease or rivet, or ball bearing, and chaos resulted in the factory, because separate specifications and drawings existed for several greases or ball bearings or other parts and each had to be purchased and stocked separately, when actually all are used in similar or identical applications. The above examples actually did exist in our plant and still do in some cases.

Specifically our Mechanical Engineering Section and Mechanical Standards Committee have reduced the number of standard hardware drawings from 225 to 28 with no sacrifice in design. Similar results have been attained by the Electrical Components Section working with the Electrical Standards Committee. The number of parts that have been standardized are too numerous to mention, but they include capacitors, resistors, rivets, screws, nuts, ball bearings, alloys and hook-up wire. More progress in this direction will be made, for both of these groups have been functioning less than a year.

Recently our Measurements and Standards Laboratory was organized for the purpose of supplying design engineers with meters and instruments of established accuracy, specialized measurement service, and meter and instrument maintenance and calibration. Previously each design laboratory operated and maintained its own laboratory instruments, whether a 0.1% bridge or a 20% ohmmeter. It is the intent now that each design laboratory possess instruments that are peculiar to its own work and which its personnel uses regularly. However, highly precise standards, bridges, and meters that are used only occasionally by a given engineering group and are difficult to operate, are permanently set up and ready for use in the measurements laboratory for the convenience of engineering personnel. Qualified engineers can use these set-ups themselves or competent technicians are available to make the measurements, give the answers and specify the accuracy of the measurement. This Section will soon be located in new, larger quarters, where precision equipment can be properly set up and used.

The Technical Publications Section also is intended to help us accomplish our objectives by relieving the engineer of the detail work of instruction book preparation, and in many cases relieving him entirely of responsibility for instruction manuals. This section constantly strives to produce better instruction books, and to have them ready when the equipment is shipped. Important to the success of a product is a well-written and well-illustrated instruction manual, which contains the necessary technical information in a form easily understood and easily found for reference. Even more important, it must be ready to ship with the equipment. If the above is accomplished with the minimum of effort on the part of design engineers, our objectives are more nearly reached.

The design engineer has also been relieved of as much clerical work as possible, by having all routine clerical work done in the Engineering Service Section. Here all parts lists are made from information on drawings, change orders are processed and distributed, references are maintained, tracing files are handled, blueprint service is given, routine tracing is done, sets of drawings for Government requirements are prepared and handled, manufacturing releases are processed, a technical library is operated, drafting standards are set up, and other clerical or routine drafting service is given. There was a time when the design engineer even prepared and typed his own parts lists.

The Transformer Engineering Section designs and develops all audio and power transformers and reactors. The equipment designer needs only to make known his electrical requirements and space limitations in informal discussion, and this group designs the units and supplies models. Preparation of manufacturing information and production follow-up of components also are handled by this Section, without further load on the project engineers.

Experimental Engineering exists only to render service to the design engineer in the construction and assembly of his models. It is operated as informally as possible, and a minimum of paper work is required to get any kind of model work done. In addition, each laboratory has its own hand tools and certain number of machine tools, so that the engineer can do some of his own model work if he desires, or he can have one of the competent model makers available in each laboratory do the short jobs for him without sketches or drawings.

Our entire engineering organization is directed toward the accomplishment of primary objectives by relieving the design engineer of as much routine as possible, permitting all of his thoughts and efforts to be directed toward product development. It is our belief that our design engineers are the greatest single factor in determining our success, and everything possible must be done to give them assistance in order that their mental attitude is conducive to constructive thinking, and maximum time is spent on the design of the products for which they are responsible.

Policy Pays Dividends

This policy results in over-all savings to the Division, because our largest engineering cost is engineering salary. Everything in the way of service or facility that can be provided the engineer, will pay dividends by increasing his design output. Competent specialists and routine workers can always be obtained at going rates and their output can be measured. On the other hand, really capable engineers, who must do creative thinking in order that the Division can be operated profitably, cannot be always obtained.

The fast moving aviation and radio industries obsolete equipment in from one to five years. It has been learned by experience that any firm in the industry must do a certain amount of long term product development or research, or it will soon find that other firms have all of the new products. It has also been learned that an engineer loaded with production problems and urgent design schedules, does not have adequate opportunity to give constructive thought to new products. In addition, he is often too aware of production and field difficulties to bring himself to suggest the "impossible." Every effort is being made in the engineering design sections to assign Junior Engineers to the project, during its early stages, so that they can handle the production follow-up, leaving the project engineer free to go ahead with new work.

Developments for which we have an immediate market, or for which we are reasonably certain a successful design can be completed in a known length of time are usually handled in our regular engineering design sections. Long term development projects which might not result in an immediately salable product, but for which we know a market can be created, are usually assigned to the Research and Development Section. When this group develops a new product and completes a working model, and it is apparent that it will sell and is practical from a manufacturing standpoint, it is turned over to one of the design engineering groups for production design and drafting. This is necessary because it is not intended that experienced product designers or draftsmen will be a part of the Research group. We will look to it for our inventions and patent output.

Future Possibilities

At this point, it is my desire to inject some thoughts on the future for the Engineering personnel. In the past, most of our products could be divided into receivers, transmitters, or other particular equipments. The trend of the industry now is to require the development of integrated communication or navigation systems. Often the transmitter, receiver, control circuits, and so forth, are built into a common unit. In some cases the antenna may be an integral part of the unit. Moreover, our field is becoming more diversified. In addition to commercial and military aviation products, we are undertaking the development of railroad radio communication equipment, personal airplane radio, broadcast receivers, television, and marine communication and navigation equipment. It is doubtful if our receiver, transmitter and radar sections should any longer be separate groups; perhaps we should have the division made by type of application, such as railroad, military aviation, commercial aviation, personal airplane, marine products, and consumer product. Further, perhaps we should not have separate laboratory and testing facilities, but rather a single laboratory for all major experimental and testing work for all special products, not including consumer products. In addition, our organization must be extremely flexible, so that we can assign engineers to the most urgent and important projects, and not allow departmental lines to keep one section overloaded and another underloaded. This is the most important point of all, because our development load shifts from time to time and we must be able to assign the best qualified engineers and technicians to the projects on which our future sales depend.

Another point that needs a lot of thought is our conversion from wartime conditions to peacetime conditions. In the aviation field, we have had what can be called mass production. We have manufactured aviation products at rates of from 1000 to 6000 per month. Design for this type of production requires entirely different thinking from the design for a total production of from 10 to 100 units. Less money can be spent in preparing perfect and carefully checked drawings, testing and selection of components, and processing of over-all design. In other words, it is often more economical and better business to release a design that is only 90% accurate and take care of the troubles in the factory, and even in the field, than it is to spend the time and money to make the design 98% or 100% accurate. We must learn to "gamble" more on our design, take chances with troubles; that last 2 to 10% perfection is the most difficult to attain and requires a disproportional share of the total time and money. Work must be done quickly and at less engineering cost.

(Continued on page 36.)

AUTOMATIC GAIN CONTROL

Several improved automatic gain control systems for compact mobile and portable receivers.

By THOMAS G. ARNOLD, Jr.
Receiver Engineering

THE IMPORTANCE OF an automatic gain control system that holds the output level of a receiver relatively constant over a wide range of input signals is well known to designers of home and communications receivers. The trend toward compactness, particularly in aircraft and other mobile and portable services, however, imposes limitations on components and power consumption. It has, therefore, become increasingly difficult to design systems whose characteristics approach the degree of flatness obtained by using a separate intermediate frequency A. G. C. amplifier, or a d-c amplifier for stepping up voltages developed by an A. G. C. rectifier.

Ordinarily, an intermediate frequency A. G. C. amplifier necessitates the use of an extra tube and i-f transformer, plus associated resistors and capacitors. The conventional d-c amplifier, on the other hand, requires either that the cathodes of the tubes which it controls be placed at a relatively high d-c potential, or that a source of negative voltage be provided for the amplifier itself. In compact receivers, both may prove impracticable.

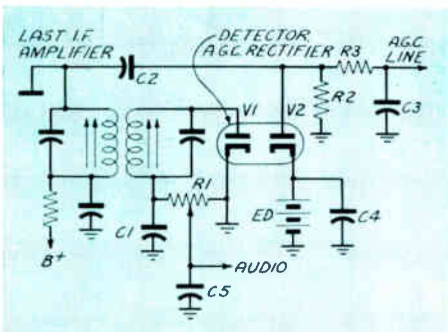


Figure 1—Conventional second detector-A. G. C. Rectifier System.

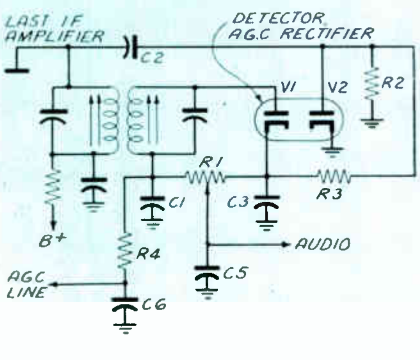


Figure 2—Series Simple A. G. C. System.

Delayed A. G. C. Preferred

Delayed A. G. C. action is preferred to simple A. G. C. in today's amplitude modulated receivers for all types of service, because it has two distinct advantages:

1) Receiver gain is maximum for weak signals, with A. G. C. action starting at some predetermined signal level and holding the output relatively constant. The degree of constancy is determined largely by the effectiveness of the system in developing A. G. C. voltage, and the number of amplifier stages it controls.

2) There is less increase in receiver output as the input signal rises beyond the point where delay is overcome.

Several delayed A. G. C. systems have been developed which use a minimum number of parts, and yet permit less rise above the knee of the desired output curve than the ordinary diode delayed rectifier. Of those to be described, none require a negative power supply voltage, nor do the cathodes of the controlled amplifier tubes have to be raised above the usual biasing potential. Only an additional dual purpose tube, with associated resistors and capacitors, is needed. The results obtained with each system will be compared to those obtained with the familiar twin diode second detector-A. G. C. rectifier.

Series System Design

Figure 1 is a diagram of a conventional system. Diode V1 is the second detector, and audio intelligence is developed across the load impedance resistor R1 and capacitors C1 and C5. Diode V2, the A. G. C. rectifier, is coupled to the primary of the last i-f transformer through C2, while the rectified signal voltage appears across load resistor R2. Alternating components are removed by filter circuit R3-C3, leaving almost pure direct current to be applied to the r-f and i-f stages. Delay is provided by raising the cathode potential through voltage source E_D so that no rectification occurs until the biasing voltage is exceeded by the peak r-f voltage on the plate of V2.

A modification of this system is shown in figure 2. Here the output of filter circuit R3-C3 is connected to the cathode of detector tube V1. Capacitor C3 places the cathode at ground potential for both radio and audio frequencies. A. G. C. voltage is taken from the transformer side of load resistor R1 through filter R4-C6. In addition to the audio voltage, a d-c potential, negative with respect to the cathode of V1, appears across resistor R1, and is proportional to the r-f voltage across the secondary of the last i-f transformer. Therefore, the A. G. C. line has a negative voltage that is the sum of the voltages on R1 and R2, and exceeds the peak r-f potential at the output of the last i-f amplifier if proper constants are used.

In figure 3, the A. G. C. voltages developed by a simple conventional system

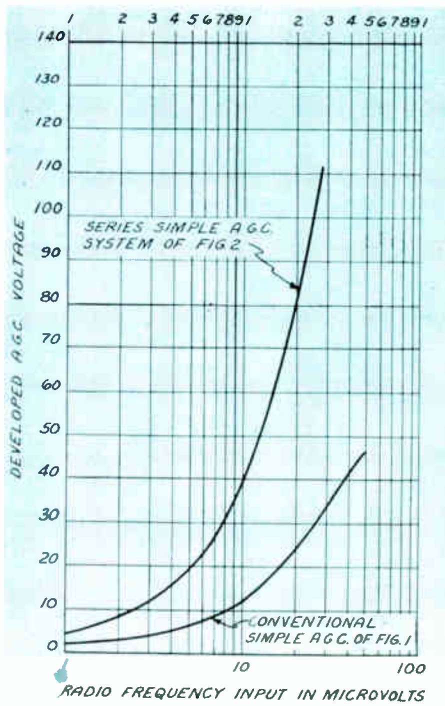


Figure 3—Comparison of A.G.C. bias voltage developed by systems of figures 1 and 2. Bias was not applied to preceding amplifier tubes when readings were made.

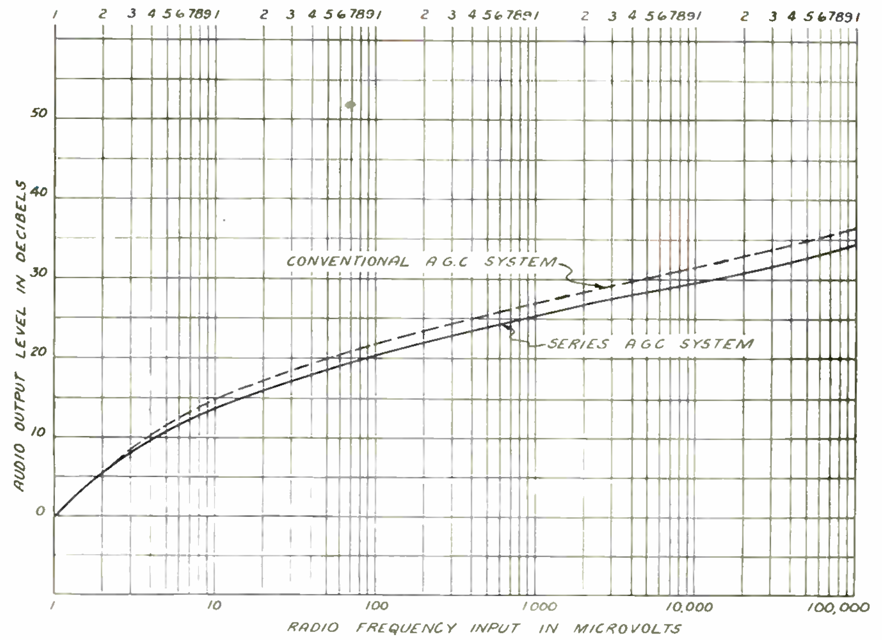


Figure 4—Comparison of A. G. C. characteristics of figures 1 and 2 when bias voltage is applied to amplifier grids.

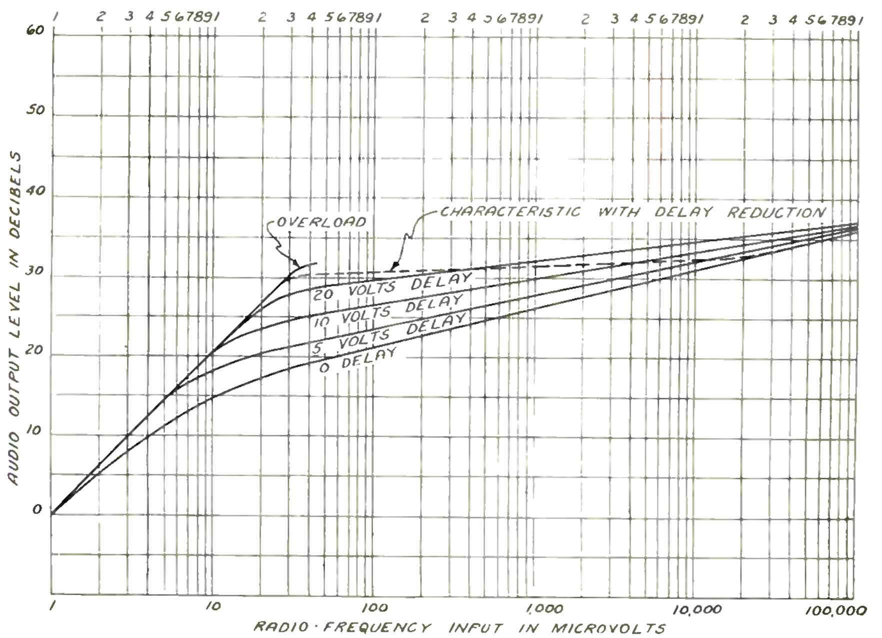


Figure 5—Curves showing improvement in A. G. C. action with delay reduction.

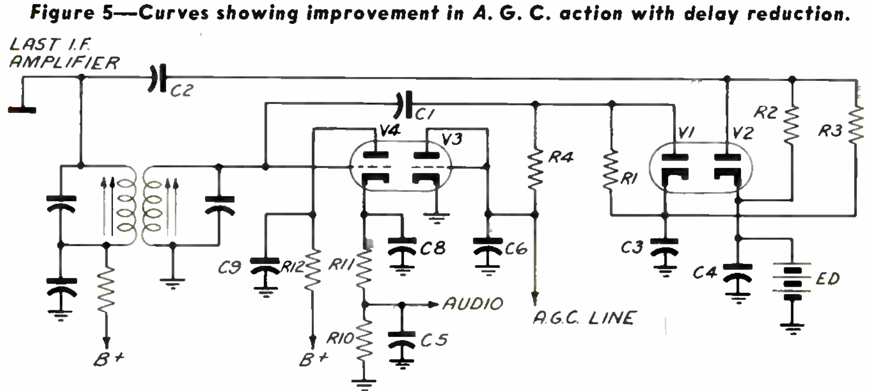


Figure 6—Series delayed A. G. C. system.

and the modified series system are compared. The curves were obtained with a receiver having an intermediate frequency of 1630 kc. Its two i-f stages are preceded by an r-f stage and mixer, but the A. G. C. voltage was not applied to the amplifier stages when the readings were made.

When the r-f amplifier, the mixer, and the first i-f amplifier are biased by the voltage of the modified system, however, the A. G. C. voltage exceeds that of the conventional system by very little as shown in figure 4. Small improvement in characteristic is obtained with the simple series system in receivers having several controlled stages, because the higher the initial A. G. C. voltage applied to the grids of the r-f amplifier, mixer, and first i-f amplifier, the greater is the reduction in gain of these tubes. The consequent decrease in voltage input to the A. G. C. rectifier system reduces A. G. C. output by a corresponding amount. This leveling action of the higher initial voltage precludes a proportional increase in A. G. C. effectiveness with the series system.

Series Delay System

If, however, the A. G. C. system is further modified so that a delay voltage that is a relatively large fraction of the A. G. C. voltage developed on moderately strong signals is applied, the series system gives not only an over-all improvement in the flatness of the input versus output characteristic, but also sharpens the knee of the A. G. C. curve.

In a delayed A. G. C. system, the maximum available control voltage is reduced by an amount that is almost equal to the delay voltage. Therefore, when the delay voltage decreases as the signal strength increases beyond the value at the knee of the A. G. C. curve, receiver output is more nearly constant. Figure 5 shows a family of curves in which input is plotted against output for various delay voltages from zero (simple A. G. C.) to a value high enough that overload occurs in one of the circuits, thus establishing the maximum output level. The characteristic indicated by the dash line results when the delay voltage is reduced as the signal increases.

The delayed series A. G. C. system shown in figure 6 is based on the principle of delay reduction. Diodes V1 and V2 are both A. G. C. rectifiers, V1 being coupled to the secondary of the last i-f transformer, and V2 to the primary. The cathode of V2 is raised to the desired delay potential, E_D by using a battery as shown, or with a voltage divider on the high voltage circuit, or by tapping any other convenient voltage source.

As in the circuit of figure 2, the voltage developed across R2 because of signal rectification is applied to the cathode of V1 through filter R3-C3. Voltage across R1, which also results from signal rectification, adds to that across R2 and to E_D to give the net A. G. C. voltage. To prevent E_D from placing a positive voltage on the A. G. C. line in the absence of a signal or at low signal levels, V3, whose grid and plate are connected, is tied between the line and ground. V3 then conducts until sufficient signal voltage is applied to the system to cause the negative voltage developed across load resistors R1 and R2 to exceed the positive potential of E_D.

Because of the contact potential of V3 during conduction, a small negative voltage appears on the A. G. C. line regardless of signal strength. This may be removed by returning the cathode of V3 to a positive potential approximately equal to the contact potential. A tap on the E_D source is a convenient means of obtaining this positive potential.

V4 is an infinite impedance detector used for the recovery of audio signals. It does not load the last i-f transformer, and consequently does not reduce the available A. G. C. voltage recovery. Diode V1 could be used as a combination audio and A. G. C. rectifier as it is in the circuit of figure 2, were it not for the fact that, with V3 tied to the A. G. C. line, current flows through R1 because of the delay potential E_D. The current through R1 develops a biasing voltage on the plate of diode V1, thereby preventing detection of weak signals and causing distortion of strong ones.

Figure 7 shows a comparison of the A. G. C. characteristics of the series delayed system and the conventional delayed system (figure 1) when the knees of both are at approximately the same signal level.

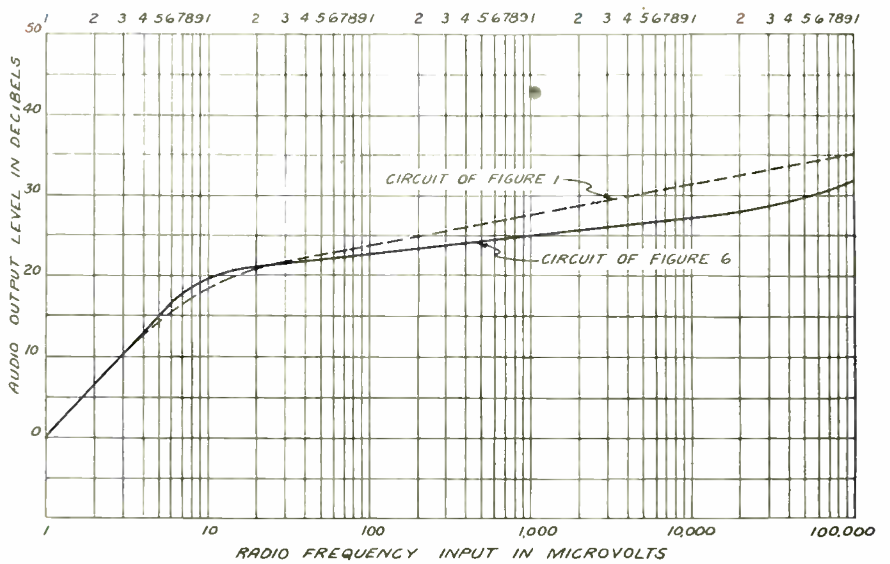


Figure 7—A. G. C. characteristic of circuit in figure 6 compared with that of conventional circuit of figure 1.

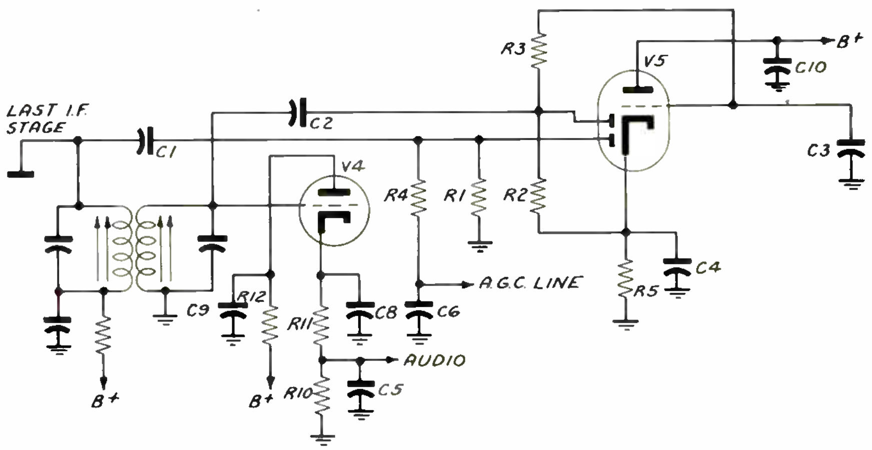


Figure 8—Delay reduction system.

Direct Delay Reduction

The reduction of delay voltage with increase of signal strength can be accomplished directly with the circuit shown in figure 8. Again an infinite impedance detector, V4, is used, and one diode plate of a duo-diode triode, V5, is coupled to the primary of the last i-f transformer through capacitor C1. A. G. C. voltage is developed across load resistor R1, and is filtered by R4 and C6. The second diode plate of V5 is connected to the secondary of the final i-f transformer through coupling capacitor C2. This diode, which is tied to the cathode of V5 through load resistor R2, is the delay reducing rectifier. The high potential side of resistor R2 is coupled to the grid of V5 through filter resistor R3, and the grid is placed at audio and radio frequency ground potential by capacitor C3.

A. G. C. delay voltage is developed across resistor R5 because of the d-c plate

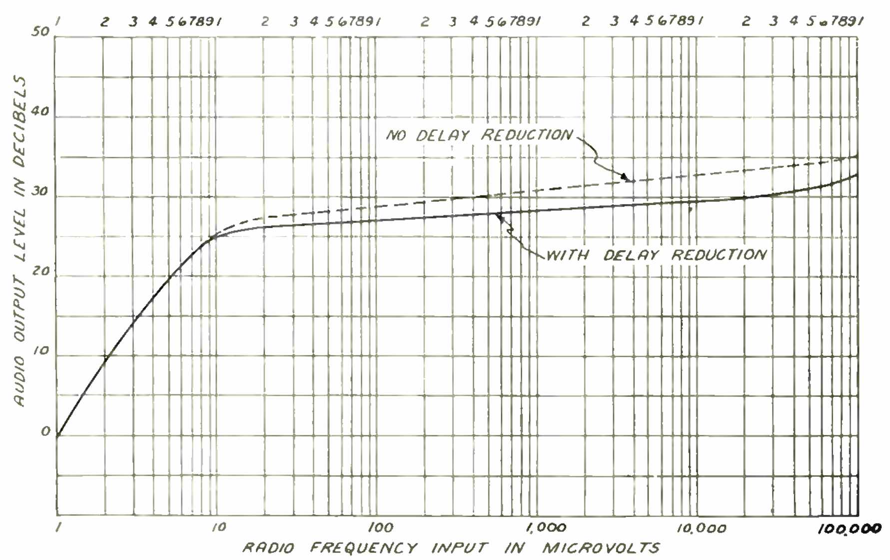


Figure 9—Characteristics of circuit of figure 8 with and without delay reduction.

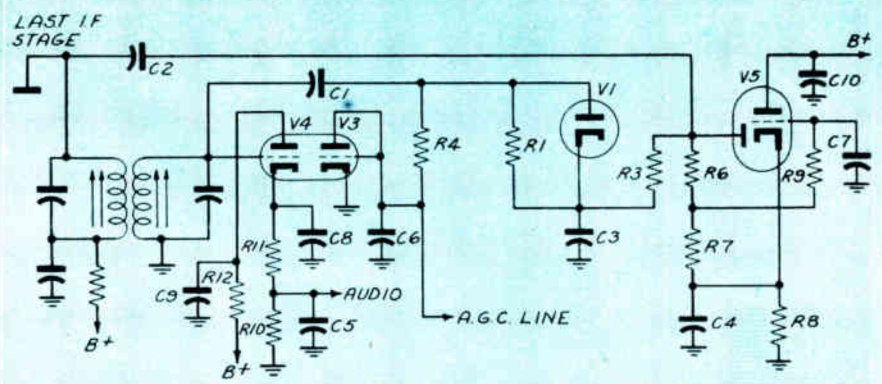


Figure 10—Series delay reducing A. G. C. System.

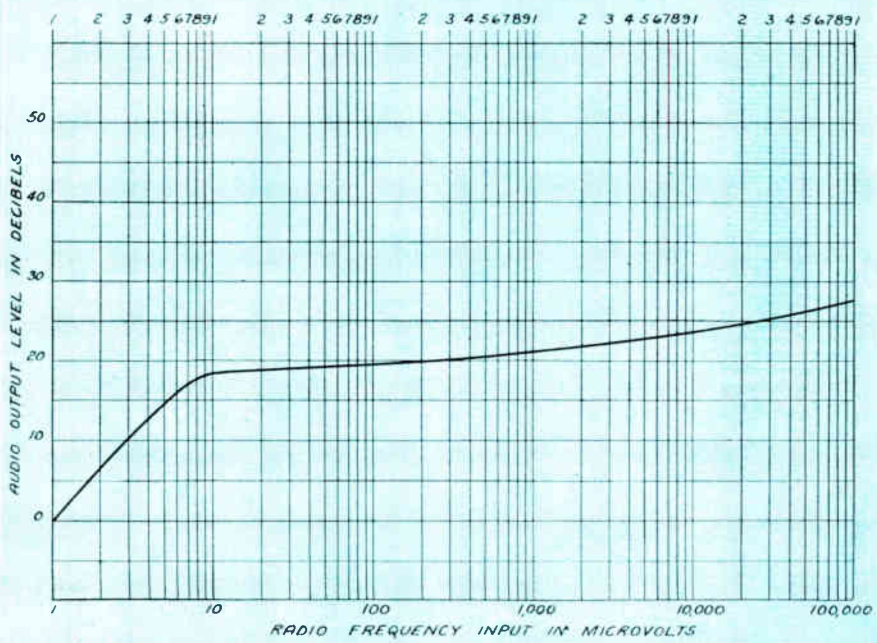


Figure 11—A. G. C. characteristic of series delay reducing system.

current flowing through it, and capacitor C4 puts the cathode at a-c ground potential. Since the A. G. C. diode plate is returned to ground, no d-c voltage appears across load resistor R1 until the peak voltage on the plate exceeds the voltage across R5. Then, with continued rise in signal strength, A. G. C. voltage is developed, and the potential increases across the delay-reducing diode load R2. This increase applies more bias to the grid of V5, thus reducing its plate current and the delay voltage across resistor R5. Figure 9 shows the A. G. C. characteristics of the circuit of figure 8 with and without delay reduction.

The delay reducing feature can be incorporated in the circuit of figure 6 by using a diode-triode as a combination delay reducer and A. G. C. rectifier, and by incorporating an additional diode, V1 (figure 10), as a second A. G. C. rectifier. The characteristic curve obtained with this system is shown in figure 11.

A circuit similar to the system of figure 2 was designed by the author for a vhf communications receiver. In this case, it was not necessary to resort to a separate audio detector, because the detector load was small compared to the resistance of the filter systems. Consequently, the small voltage developed across the former because of the A. G. C. line-to-ground diode was overcome by amplified r-f grid circuit noise, and there was no apparent detector bias on weak signals.

The A. G. C. systems which have been described are probably best suited for mobile and portable receivers where power consumption and the number of large components must be held to a minimum. All but the last circuit can be incorporated in a receiver by providing only filament power for one tube and a few milliamperes of plate current, in addition to the power required by the conventional signal diode-A. G. C. diode system.

Thomas G. Arnold, Jr.

An avid interest in all phases of radio receiver development keeps affable, ingenious Tom Arnold close to the grind not only in the Bendix Radio Receiver Laboratory but also in his home workshop. During high school days in his native Pittsburgh, he built his own radio station (W8NWA) which he operated until amateurs were taken off the air. He received his B.S. in Electrical Engineering at Carnegie Institute of Technology in 1942, and during one summer vacation worked with a switch and signal company long enough to get some knowledge about railroad signal circuits and to decide he still preferred radio. He became associated with Bendix Radio immediately after graduation, as supervisor of instruction on airborne vhf equipment for the Signal Corps Training School. Beginning June, 1943, he became junior project engineer on the modification of the well-known King George receiver. More recently, as assistant project engineer, he designed a noise limiter for use on vhf receivers. He is currently engaged in making comparison tests for the Signal Corps in collaboration with Transmitter Engineering, on the relative merits of FM and AM for vhf aircraft communication.

Books Received

Soul Of Amber, by Alfred Still. Murray Hill Books, Inc. 259 pages. Price $2.50. History of the development of electrical knowledge.

Electrical Drafting, by D. Walter Van Gieson. McGraw-Hill Book Company. 128 pages. Price $1.50. Helpful information for all types of electrical drafting including communications.

Introduction To Practical Radio, by D. J. Tucker. The Macmillan Company. 270 pages. Price $3.00. A very good basic text with review questions.

VACUUM RELAYS AND SWITCHES

An analysis of glass type vacuum switches to determine their operating characteristics at radio frequencies.

By R. B. EDWARDS
Assistant Section Chief
Transmitter Engineering

LIGHTWEIGHT, FAST ACTING vacuum type glass switches, whose operation is unaffected at high altitudes, make ideal antenna transfer relays and are used in several Bendix aircraft transmitters and antenna loading units. These units operate at frequencies from 300 kc to 18 mc and subject the relays to peak potentials as high as 20,000 volts.

Because these vacuum switches have proved so effective, a series of experiments was recently conducted to determine the feasibility of using them in other applications where a radio circuit is interrupted without cutting off the r-f source.

The information obtained from these tests and subsequent calculations should prove useful to those who contemplate using vacuum relays for such services as keying antennas, modulating antennas, or transferring from one antenna to another.

The wave shape of a keyed circuit is quite important and the time required to break the r-f arc has a definite effect on the shape of the wave as well as the speed at which the circuit can be keyed.

A portion of this test was devoted to the determination of the time required to break an r-f arc with a vacuum relay. Circuits were designed to produce an oscilloscope pattern of the r-f voltage built up across the relay contacts as the armature moved from the unenergized to the energized position. A formula was then derived for computing the distance the moving contact opens in a given time interval.

Test Circuits

The first requirement for a measurable pattern on the oscilloscope screen is a horizontal sweep which starts simultaneously with the opening of the switch contact, while an r-f potential is applied across the contacts. The second requirement is the presence of a timing wave of known frequency in the pattern.

An R-C timing circuit in the grid of a small triode is employed to start and to control the speed of the horizontal sweep. This R-C circuit is triggered by a key which also controls the relay energizing coil. Capacitor CT and resistor RT (figure 1) are inserted before synchronizing operations to form part of a vertical sweep, which times the start of the horizontal sweep coincident with the opening of the relay contacts. The vertical sweep voltage during synchronization is developed by CT charging through RT from the 250-volt power source, after the contacts open. During initial synchronizing adjustments, the connections marked "A" and "D" are opened to break the connection to the r-f load circuit, and to provide a higher potential on CT. Connection "B" is closed to connect the vertical plate of the oscilloscope directly to CT. When synchronization is completed, both CT and RT are removed, "A" and "D" are closed and connection "B" is broken. This operation provides for application of r-f voltage through the dummy load from the antenna loading unit in which the relay is used.

The vertical sweep starts when the relay contacts begin to open, and the horizontal sweep is timed to start in synchronism with the vertical sweep (see figures 6, 7 and 8).

Two separate circuits in the plate of the sweep tube were used, because one produced a complete pattern which covered only 50% of the screen, whereas the other covered the entire screen but left a small blank space at the start of the sweep. Data obtained by using both circuits gave a complete picture of the action taking place.

Both systems are shown in figure 1 which is a complete circuit diagram. Figures 2 and 3 are simplified schematics of Systems #1 and #2, respectively. A description of the operation of both systems follows.

System #1 (figure 2) uses a 250-volt power supply and a one megohm load resistor (R3). The horizontal plates of the scope are connected across this resistor; the vertical plates are connected between the 250-volt supply and ground through R4. The 6J5 tube is biased beyond cutoff by the 135-volt battery in series with its grid, and the spot remains near the center of the screen. When the key is closed, the 135-volt bias is removed, and the negatively charged capacitor (C1) discharges through resistor (R1) to ground. Closing the key also connects the negative end of the battery to ground, thus providing a path for current from the battery to flow through the relay coil which becomes energized and causes the moving contact to operate. The

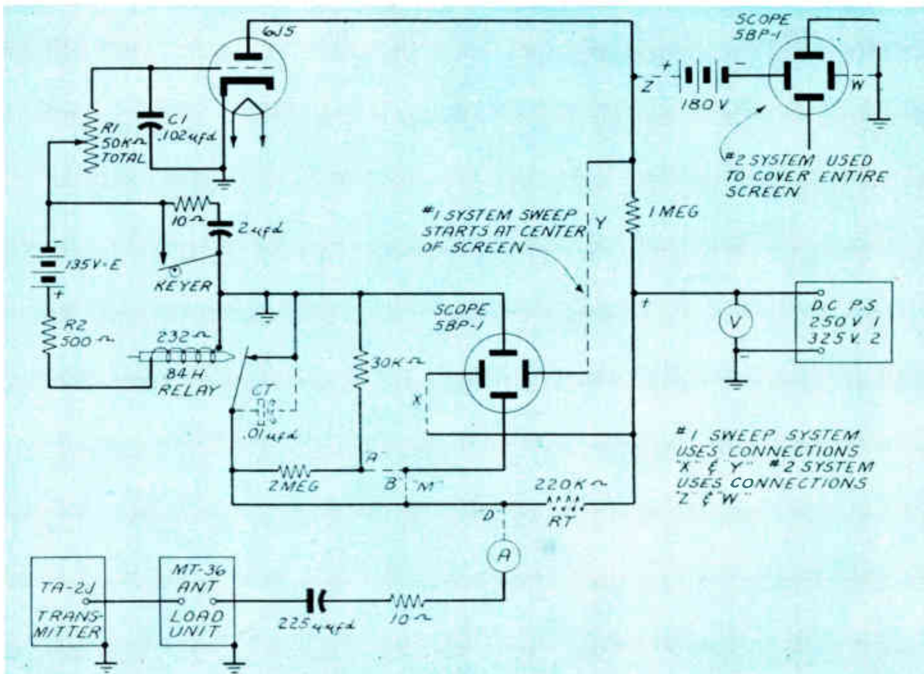


Figure 1—Complete circuit used to time start of horizontal sweep and to study r-f arc in relay.

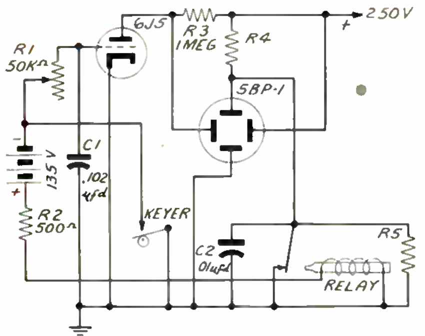


Figure 2—Simplified schematic diagram of sweep circuit No. 1.

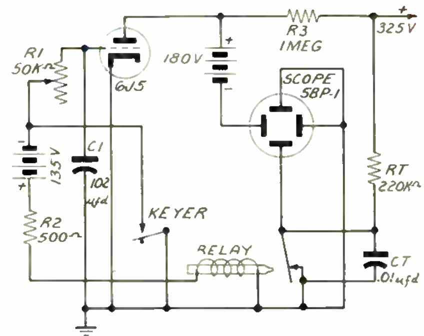


Figure 3—Simplified schematic diagram of sweep circuit No. 2.

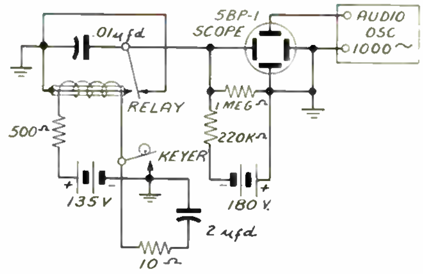


Figure 4—1000 cycle circuit used to time travel of relay armature from unenergized position to closed position.

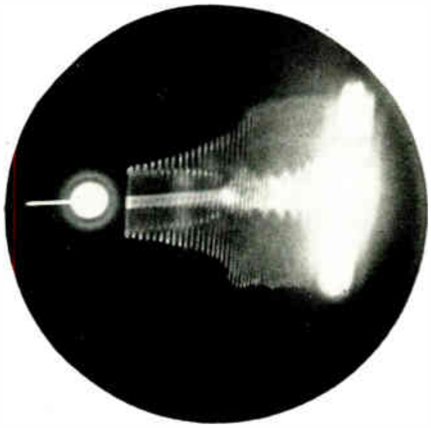


Figure 5—Scope pattern of voltage built up across opening vacuum switch contacts.

time required by C1 to discharge to the point where the tube starts to conduct is made equal to the time lag of the coil energizing current by adjustment of R1. Thus synchronization is accomplished.

System #2 (figure 3) employs similar principles but, because of a different power circuit, produces a pattern which covers the entire scope screen. In this circuit, a 325-volt supply is connected so that it is opposed by a 180-volt battery. As in System #1, while the key is open, the 6J5 tube is biased beyond cutoff and no current flows in its plate circuit. Capacitor C1 is negatively charged as before. One horizontal plate of the scope is at a positive potential equal to the difference between the bucking power supplies (325 – 180 = 145 volts). This positive potential causes the spot to move to the left. When the key is closed, the same action as before takes place in the grid circuit of the tube and in the energizing relay coil. However, when the tube starts to conduct as capacitor C1 discharges and removes the high grid bias, the IR drop across the plate load resistor becomes quite high. The 180-volt battery then takes control of the spot, which moves to the right as the 145-volt potential on the horizontal plate is reduced. This system produced nearly 100% screen coverage and was used to obtain all photographs except figure 9.

The simple circuit in figure 4 provides a 1000 cycle wave on the screen to time the relay armature travel from the instant the contact opens until it closes in the energized position. A 180-volt battery is used in conjunction with a 220,000 ohm charging resistor and a 0.01 μfd capacitor. When the contacts in the unenergized position open, the horizontal sweep starts and is controlled by the voltage developed across the capacitor. The sweep stops instantly when the contacts close in the energized position. See figure 10 for photograph of the resulting pattern.

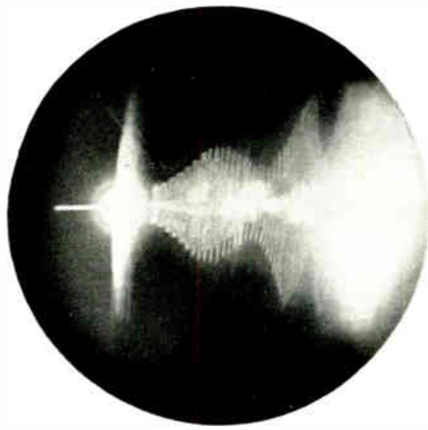


Figure 6—Pattern of voltage built up across opening vacuum switch contacts when 1000 cycle modulation is applied to the 314 kc carrier. Elongated flash across starting spot at left is the return sweep.

Results of Tests

After synchronization of the horizontal sweep with the opening of the relay was obtained (see figure 7), the patterns in figures 5 and 6 were photographed. Figure 5 shows the build-up of the r-f voltage across the opening contacts. The arc formed approximately 200 microseconds after the relay contacts started to open, and was extinguished after approximately 1310 microseconds. The 200 microsecond interval results partly from the comparatively high capacity across the contacts during the first portion of travel. Timing was accomplished by the visible 18 kc modulation of the carrier because of a convenient parasitic oscillation in the final amplifier of the particular transmitter used for the tests. Figure 6 was photographed under similar conditions, but with the addition of a 1000 cycle modulation to provide a means of calibrating the 18 kc modulation on the screen.

The photographs in figures 5 and 6 were made using sweep System #2. It can be seen that the horizontal sweep line, from the spot to the start of the voltage build-up, is missing. When a similar pattern was observed using System #1, the line was complete but the pattern was compressed to about half-size, so that individual cycles of the 18 kc timing wave could not be counted. It appears that stray r-f voltage may have been picked up in the horizontal sweep circuit when System #2 was used and that this stray voltage destroyed the start of the line in figures 5 and 6. In order to get enough r-f voltage to produce a clear pattern on the scope, some inductive coupling was used at "M" in figure 1. It was secured by running parallel leads very close together for a distance of a foot.

R-f voltage across the open relay contacts was about 1000 volts peak at 314 kc.

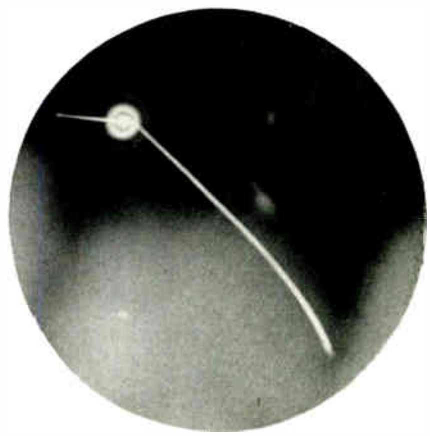


Figure 7—Horizontal sweep starting at the same time the switch contacts open.

This value is considerably lower than that usually encountered by changeover relays at frequencies between 300 and 600 kc in the 100 watt transmitter and antenna loading unit used in these tests. However this voltage would be about the maximum that should be applied when using the relay to key a steadily energized r-f circuit. The current in the relay contacts was 1.7 amperes before the contacts were opened. The dummy load on the antenna loading unit consisted of a 225 $\mu\mu$f, 20,000 volt mica capacitor in series with a 10 ohm, 100 watt carbon resistor.

The total relay armature travel time was obtained from the pattern shown in figure 10. From measurements of the 1000 cycle wave, this time was estimated to be 3105 microseconds.

The inductance and a-c resistance of the relay coil winding were measured at 120 volts, 60 cycles. Two resistors of different values were used in series with the coil. Voltages across the coil, the resistor, and the line were measured and the following data obtained:

Series resistor	*Voltage across resistor*
800Ω	88v
308.3Ω	59v

Voltage across coil	*Line voltage*
46v	122v
75v	121v

The inductive reactance and a-c resistance of the winding were calculated graphically from these data. They proved to be 0.846 henry and 235 ohms for the 800 ohm series resistor with 0.116 ampere current. When the series resistor was changed to 308.3 ohms, the current increased to 0.193 ampere, the calculated inductance was 0.834 henry, and the calculated resistance was 230 ohms. Averages of these values give 0.84 henry and 232 ohms which figures were used in calculating the start of the relay opening time.

Other measurements made on the relay and circuit components were:

1) Contact diameter (for calculating capacity) = 2.090 inches,

2) D-c resistance of coil winding = 130 ohms,

3) Distance between contacts in unenergized position = 0.025 inch, and

4) Minimum current to close relay = 0.100 ampere.

Normal operating voltages for the relay coil are 25 to 28 volts. A 500 ohm series resistor used in the tests gives a current of 0.214 ampere which is equivalent to operation at 27.8 volts.

Calculating Opening Time

Using the values in figure 1 of C1 = 0.102 µfd, R1 = 18,000 ohms (the adjusted value of R1), V_o = 135 volts (the grid voltage on the 6J5 across C1 before the key was closed), and V = 19.5 volts (the potential at which the 6J5 tube starts to conduct and the sweep starts) in the formula

$$V = V_o \varepsilon^{-\frac{t}{R1C1}}, \qquad (1)$$

the calculated time is computed to be 3540 microseconds.

The relay current at the time the contacts started to open was calculated as follows:

Since the relay current is

$$i = \frac{E}{R}\left(1 - \varepsilon^{\frac{-Rt}{L}}\right) \qquad (2)$$

at any time t, when

i = relay coil current in amperes,

E = battery voltage (135 volts),

R = sum of coil a-c resistance and series resistor = 232 + 500 = 732 ohms,

L = inductance of coil = 0.84 henry,

t = elapsed time after key is closed = 3.54×10^{-3} seconds, and

ε = 2.718 (base of natural log);

we get 0.176 ampere for the current at the time the relay started to open. The measured d-c current required to barely close the relay contacts was only 0.1 ampere. However the eddy current in the steel case of the coil reduces the flux density considerably while the coil current is changing (i.e., while $\frac{di}{dt}$ is appreciable).

Time-Distance Formula

A formula for computing the distance traveled by the moving relay contact in a given elapsed time was derived. The derivation demonstrates the effect of current build-up in the coil on the acceleration and travel of the armature at a given instant, and provides a comparison for a simplified formula which uses an average value of acceleration. The derived formula also provides a means for closely approximating the armature travel and contact opening at the time the arc is broken.

The following assumptions, based upon the physical construction of the relay, were used:

1) Since the air gap is large even in the closed position, the flux is assumed to be directly proportional to the current in the winding;

2) Because the armature travel is quite small compared to the spring length, it is assumed the force of the spring is constant for the duration of armature travel;

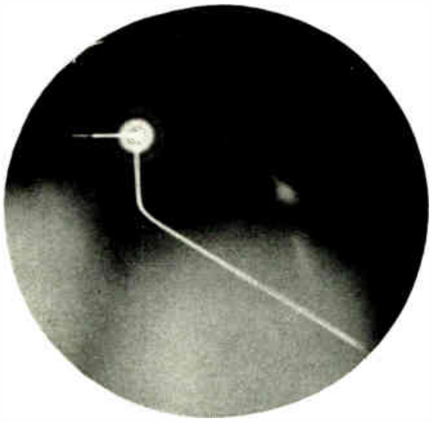


Figure 8—Horizontal sweep starting after the vertical sweep.

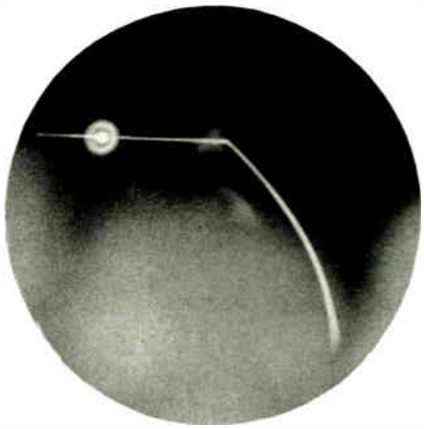


Figure 9—Horizontal sweep starting before the vertical sweep.

Figure 10—Pattern when 1000 cycle wave is used to time travel of switch armature from the unenergized position to the closed position.

3) The inductance and resistance of the coil are assumed constant and of the same values measured at 60 cycles (i.e., 0.84 henry and 232 ohms). This assumption is based upon the fact that the current in the winding changes during the travel of the armature and $\frac{di}{dt}$ will be comparatively high. If $\frac{di}{dt}$ is appreciable, hysteresis and eddy current losses will compare with the values at 60 cycles.

From assumption #1, it may be stated that the magnetic force (because of the relay winding on the armature) at any time t is

$$F = Ki^2, \tag{3}$$

where

K = a constant, and

i = current at time t.

This comes from the formula

$$F = \frac{B^2A}{8\pi}, \tag{4}$$

where

A = area of magnetic path, and

B = flux density;

or

$$F = B^2C, \tag{5}$$

where

C = a constant.

Also,

$$i = DB \text{ (from assumption \#1)}, \tag{6}$$

where

D = a constant.

Accordingly, since in equation 3

$$F = Ki^2,$$

and, from assumption #2, the force of the armature spring is a constant F_1, then the accelerating force acting on the armature is

$$Ki^2 - F_1.$$

From Newton's law of motion, F = Ma. Therefore it can be stated

$$Ki^2 - F_1 = Ma, \tag{7}$$

where

M = the effective armature mass, and

a = acceleration at any time t.

From equation 1,

$$i = \frac{E}{R}\left(1 - \varepsilon^{\frac{-Rt}{L}}\right),$$

and

$$a = \frac{d^2s}{dt^2},$$

where

s = distance traveled by the armature in time t.

Therefore,

$$K\frac{E^2}{R^2}\left(1 - \varepsilon^{\frac{-Rt}{L}}\right)^2 - F_1 = M\frac{d^2s}{dt^2}. \tag{8}$$

F_1 may be evaluated in terms of K from the known fact that i = 0.176 ampere when the relay contacts start to open, and at this time $\frac{d^2s}{dt^2}$ would be zero.

Substituting we get $F_1 = 0.031$.

Equation 8 may then be written

$$\frac{d^2s}{dt^2} = K_1\left[\frac{E^2}{R^2}\left(1 - \varepsilon^{-\frac{Rt}{L}}\right)^2 - .031\right] \tag{9}$$

where

$$K_1 = \frac{K}{M}.$$

The integration and thus the solution of (8) give the following equation:

$$S = K_1\left[\frac{E^2}{R^2}\left(\frac{t^2}{2} - 2\frac{L^2}{R^2}\varepsilon^{-\frac{Rt}{L}} + \frac{L^2}{4R^2}\varepsilon^{-\frac{2Rt}{L}}\right) - .031\frac{t^2}{2} + K_2t + K_3\right], \tag{10}$$

where K_2 and K_3 are constants of integration.

Since R, E and L are known from the test data, K_2 can be evaluated from the fact that $\frac{ds}{dt} = 0$, when t equals 3540 microseconds (the time at which the relay contacts start to open after the key is closed). K_3 can be evaluated (after K_2 has been found) from the fact that S = 0, when t = 3540 microseconds. To evaluate K_1, make s = .025 inch when t = 6645 microseconds (6645 microseconds = 3540 microseconds + 3105 microseconds = total time required to close relay).

The total measured contact opening was 0.025 inch. Substituting all known values, equation 10 becomes

$$s = 3079 \times 10^6\left[.03402\left(\frac{t^2}{2} - 2.634 \times 10^{-6}\varepsilon^{-871.5t} + .3292 \times 10^{-6}\varepsilon^{-1731t}\right) - .031\frac{t^2}{2} - 14.26 \times 10^{-6}t + .03562 \times 10^{-6}\right]. \tag{11}$$

If we use the experimentally determined time of 1310 microseconds in figure 4, t = 1310 + 3540 = 4850 microseconds and s is found to be 0.002 inch, which is the distance the contacts have opened when the arc is quenched. This formula becomes unwieldy when t is small because the constants and terms must be carried to eight significant figures for accurate results. In such cases, it will be found convenient to assume a constant average acceleration. The average acceleration will be larger than the actual value for small and medium intervals of time. When using an average acceleration we should use the well-known formula

$$S = \tfrac{1}{2}at^2. \tag{12}$$

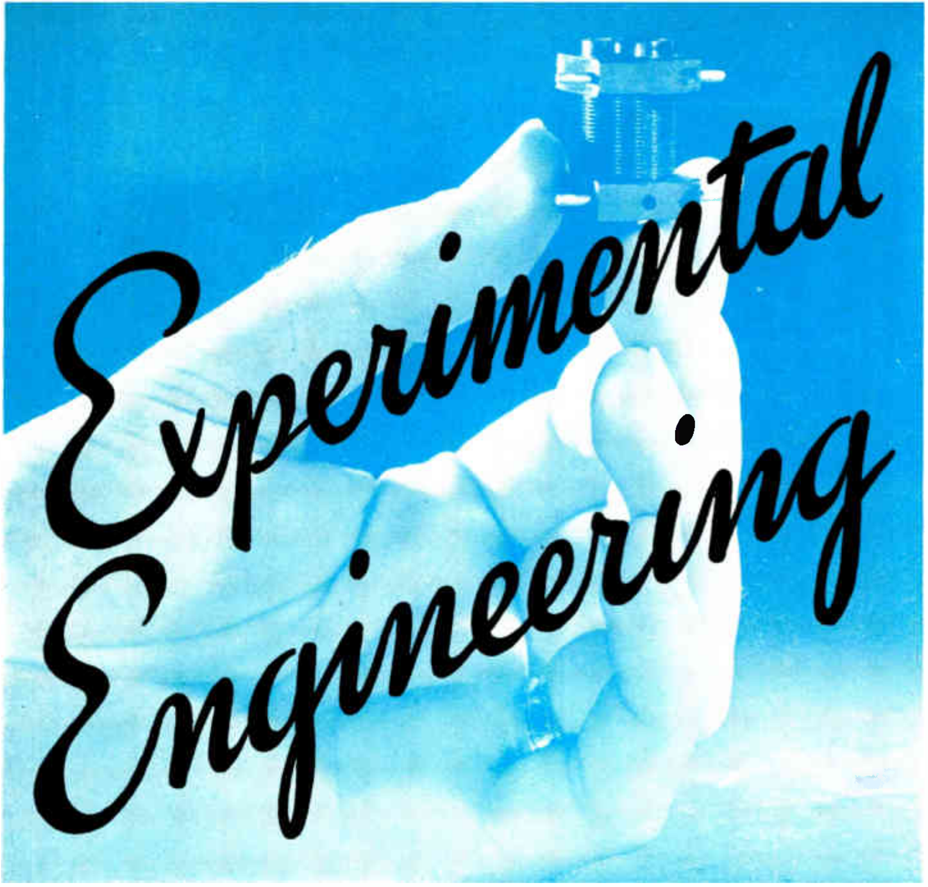
For example, when s = .025 inch, t = 3105 microsecond, and the average acceleration is $a = 5.19 \times 10^{-9}$ inch per microsecond, per microsecond.

(Continued on page 36)

R. B. Edwards

THOUGH COVERING a relatively brief span of years, it's quite a stride, and in the good American tradition, from Bob Edwards, the hustling boy who peddled newspapers and delivered bundles in a little Montana town, to Bob Edwards, designer of aircraft radio equipment. He was born in St. Louis, and was awarded a Bachelor's degree in Electrical Engineering at Montana State College at Bozeman in 1930. Following graduation, he joined the technical staff of Bell Telephone Laboratories, where he was engaged in design and development of short wave transmitters for transoceanic telephone service. In 1932, he returned to Montana State to earn his Master's degree. Immediately entering the service of the Montana Power Company, he advanced from operator's helper to design electrician for carrier current communication systems. His connection with Bendix Radio began in 1937 at the Chicago plant. Transferred to Baltimore in 1938, he was placed in charge of the Service Department in 1939, but soon returned to the Engineering Department as project engineer. He has since been in charge of several well-known Bendix products, and worked on the transmitter section of the first radar set constructed here. He is now Assistant Section Chief of Transmitter Engineering, and coordinator on the railroad radio project.

Experimental Engineering



Small molded phenolic coil form with a wall thickness of 0.010 inch made in Experimental Engineering after outside manufacturers were unable to produce.

WANT TO SHOOT PAR GOLF this summer? Redecorating your house and in need of advice? Are aphids swarming in your flower garden? Does your watch need repairing, or your horse need shoeing?

A far cry from experimental engineering in the radio industry? Not at Bendix Radio! Personnel in the Experimental Engineering Section of the Engineering Department can answer these questions.

If you are a Bendix old-timer, you call the section "Model Shop." But in the departmental listing, it is "Experimental Engineering." Neither title completely explains what goes on here. No brief designation could encompass such operations as testing new plastics, making tiny filaments and grids for special tubes, engraving dials 3 feet in diameter within 15 seconds accuracy, forming ribs on large antennas, welding chassis for airborne and ground equipments, hardening and heat treating tools, and machining intricate wave guides.

Special Training Program

In the hectic early days of the war, Bendix Radio was faced with finding skilled people for highly specialized jobs in this section, as in others. The first difficulties were overcome but, by mid-1943, the situation became critical in Experimental Engineering. A special training program, set up at a nearby school, provided shop facilities for night training during school terms, and full daytime training during summer vacations. Experimental Engineering supplied instructors and precision tools. Equipment duplicating much of that in the section supplemented the school's machines. Trainees were selected by their high ratings on mechanical aptitude tests. Actual production work was sent from the section to the school and these people trained, not on models, but by making working parts for units from simple blueprints. Thus, from the beginning, they helped meet production schedules on equipments to be used and those showing special mechanical ability were taken into the section.

Housewives, farmers, auto mechanics, sign painters, boys and girls just out of school, blacksmiths, watch makers, paper hangers, a commercial artist, a professional golfer, and a gardener acquired new titles and new skills. They were soon listed as skilled and semi-skilled mechanics, sheet metal workers, electric-arc, acetylene and hydrogen welders, electroplaters, assemblers, plastic workers, and tool and die makers. Through these war years, the section has maintained the largest staff in Engineering. Exacting work and multiple demands keep two shifts running constantly. Today, these people think in terms of gauges and gadgets, not gardens and golf, and the questions they hear are: Can you copper plate this part to a rigid specification? What about a distinctive design for this control knob? Can this part be cast? What about shielding?

Primarily set up to build the mechanical parts for experimental and development models of the latest radio engineering designs, the section has grown in complexity of operations until a difficult project seems run-of-the-mill. Since the difficult and exacting project is commonplace at Bendix Radio, the radio engineer scarcely realizes the section is unique.

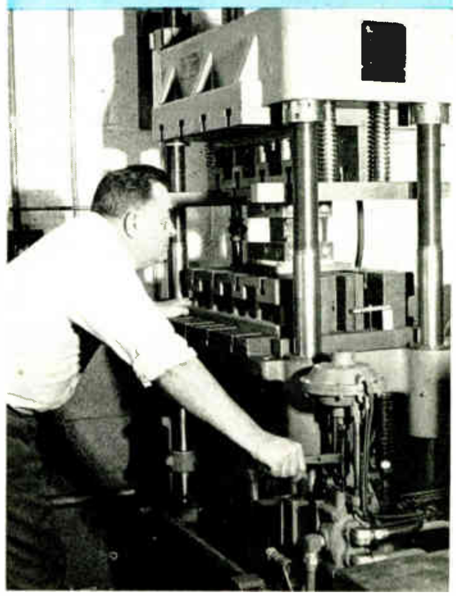
Not so with visitors—they are impressed by the diversity of operations and equipment. In most organizations, plastics, plating, and laboratory testing are separate departments. Nor is production asked of the usual model shop. Here, these processes are merged into one section and even production is undertaken in emergencies.

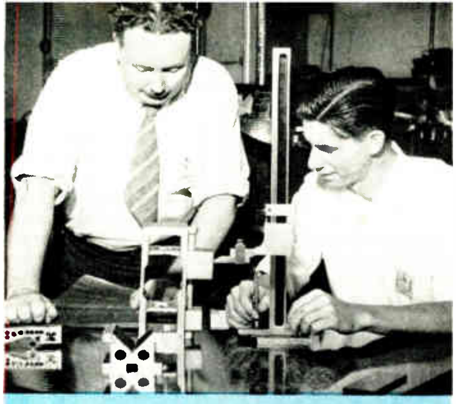
When Receiver Engineering needed a very thin molded phenolic coil form for a special compass design, they submitted the specifications to one manufacturer who said, "Impossible!" A second manufacturer echoed the first, so Experimental Engineering personnel set to work making a coil form threaded inside and out and with tapering walls 0.020 inch thick. Part of one wall had a keyway which brought the wall at that spot to 0.010 inch. With a model perfected, the section went into production and turned out hundreds of the forms.

In another emergency, some 5000 coil forms for a transmitter-receiver project rolled from the section. No outside manufacturer could promise delivery in sufficient quantity in the time allotted, and each unit needed twelve forms. Again, the section went into production and the equipments went out on schedule.

Section Chief G. A. Exley tries to outguess engineers and to stock new products

Plastic molding dies in the Stokes Press being checked by Ed Miller.





G. A. Exley, Section Chief, and Bill Britton checking dimensions on a casting with a vernier height gage.

and difficult-to-find items. Various kinds, shapes and thicknesses of metals, plastics and small machined parts are kept in stock, but the radio engineer sometimes wants the unusual. For instance, requests come in for Kovar, for stainless steel tubing, or for invar, a metal with no coefficient of expansion—all difficult to procure quickly. Once, a special sheet plastic was requested but the Navy had commandeered all available supplies. The manufacturer obligingly supplied a sheet from company samples.

Rubber masters, or blankets, for metal working are important to the aviation industry. So important, in fact, that Douglas Aircraft says engineering in this industry has been revolutionized by the process and that it made possible the tremendous wartime production of aircraft with a saving of millions of man-hours.

Experimental Engineering uses the same technique in extruding metals for radio equipment. Mr. Exley agrees that the rubber blanket process saves time and money, and assures perfect surfaces on chassis where durability and beauty are desired.

While the aircraft industry uses presses up to 5000-ton capacity, such a machine as the section's 100-ton Cincinnati Brake gives sufficient pressure for radio work. Acting on the hydraulic principle that pressure reacts equally in all directions, a semi-fluid solid such as rubber is used as a blanket because of its flowing tendencies. Confining it by an enclosure, or channel box, assures that only the desired area will be extruded. The die is fixed in position on the brake with the metal to be shaped placed on top. A rubber blanket goes on over the metal and a sheet of steel is laid over the rubber pad. A foot pedal having a friction clutch starts the brake's carriage down. The pressure hits the steel first. This presses on the rubber which, in turn, presses on the metal. The flexible rubber literally flows over the die and the result is level and uniform surfaces. Only the finest natural rubber is used to make the blankets and the dies are usually masonite or bakelite. However, for quantity production, hard steel dies are used.

Proud of Variable Capacitor

Just as each design section is proudest of some one project, Experimental Engineering is justly proud of one achievement. A design laboratory needed a large twenty-stator variable capacitor with the rotor engaging the stators only at intervals. Each stator had to be shaped from one piece of metal, with four notches, or slots, in the outside diameter and a half-moon shaped center curving in a parabola, accurate within 0.002 inch. A noted research concern, commissioned to produce them, consulted experts in this field and bought special equipment costing several thousands of dollars. But, after much work, the result was inadequate production and stators not accurate within the allowed tolerance. With existing equipment, Experimental Engineering then attempted the job and produced stators which, when checked on a shadowgraph, were shown to be accurate to a much greater degree than the allowed tolerance.

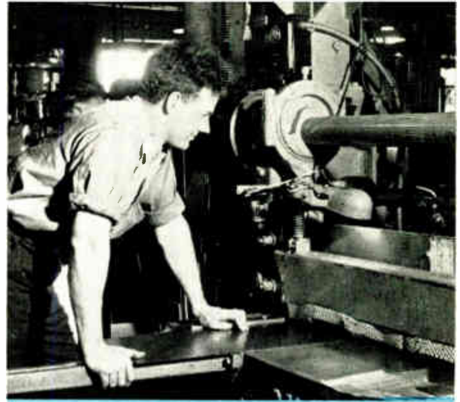
Mechanical shops of this kind seldom install large machines for relatively small jobs and small lots. This means that improvised methods are sometimes necessary, such as machining castings on a milling machine rather than on a boring mill. One equipment demanded a base casting of cast iron 12 inches wide and 26 to 28 inches long, with a spindle in the center jutting up 6 inches. Normally, a 42-inch boring mill would be used but, in this instance, the work was fastened on a spindle of a medium-sized milling machine. With the tools fastened on the table of the machine, the milling machine became a horizontal boring machine and a professional job resulted.

A Story in Plastics

Plastic work done in the section is a story in itself. Qualifications, such as water repellency, strength, and dielectric properties, of dozens of plastics are kept on file. New plastics are added as they reach the market, and one unusual liquid plastic is currently under consideration. Allegedly, it can be cast, or molded without pressure with one-half the normal heat.

Plastic forms are molded, with up to 100-ton pressure, on a Stokes Automatic Molding Press. Plastic powder, weighed in advance in predetermined amounts for each form, is kept in separate envelopes. Craftsmen in the section fashion the molds in two parts from hard or soft steel, depending on the quantity to be run. The bottom half of the two-section mold clamps into the lower part of the press and the other half fastens into the upper part.

Varying degrees of heat are necessary in molding different plastics. On the Stokes



E. L. Langford shearing a sheet of metal on the Niagara Shear.

Press, a gas-fired high-pressure boiler, which goes to 150 pounds pressure, supplies this heat. Live steam runs from this boiler through ducts around the mold's two sections. An automatic valve holds to a preset pressure and a meter scale registers this pressure as it mounts. When the mold reaches the desired temperature, the contents of one envelope are poured into the lower half. Pressing a button starts the bottom section moving upward to clamp against the stationary upper portion. Near the juncture with the upper section, the mechanism drops the bottom mold for an instant to allow gases to escape, then closes with a rush. The powder is subjected to increasing temperature as the steam pressure rises.

At a certain temperature, a molecular change takes place and the powder liquefies. Liquid only a few seconds, the plastic then solidifies and a curing time—varying according to volume, or bulk, and the kind of plastic—requires several minutes while the molds are still joined. An automatic control, or timer, then releases the mechanism and the hot plastic form is lifted out with asbestos gloves. If necessary, a buffing process removes flashes or ridges. Often, the forms have smooth, perfect surfaces and buffing is unnecessary.

Seeming Disorder Misleading

The constant din in this noisiest of all Engineering sections, plays havoc with acoustics and the interplant sound system in the section. Special ovens and boilers upset the air conditioning system. Expanding facilities and equipment in nonexpanding quarters add to a seeming disorder. Blueprints may dribble in singly as a new project starts, or all prints for a complete project may come in at once marked "rush." Sometimes, instead of a detailed blueprint, a rough sketch is received with "use your own judgment, but rush!" penciled on it. All this contributes to the heterogeneous collection of jobs underway. But out of this maze of projects, tightly packed personnel and machines, come designs attesting to skillful planning and skilled workmanship.

TRANSMISSION LINE CHARTS

Derivation and application of impedance and admittance charts used to solve transmission line problems. Background material was presented in a previous article.

By Lt. H. T. STRANDRUD
U. S. Signal Corps

A PROPER MATCH OF impedances is important in transmission lines operated at high frequencies. Methods of obtaining a proper impedance match can be readily analyzed graphically by means of impedance or admittance charts. It is the purpose of this article to describe the derivation of such charts, and to explain their use.

At high frequencies, losses usually have a negligible effect on the characteristics of transmission lines. In this article it is assumed that line losses are negligible; the charts described are based on a lossless line.

Line Terminated in Pure Resistance

As a convenient approach to the impedance chart, first consider a line terminated in a pure resistance load, R_R (figure 1). Using the notation from the preceding article,* the impedance, Z, seen looking towards the receiving end of the line from a distance x is

$$Z = Z_o \frac{\dfrac{R_R}{Z_o} + j\tan\beta x}{1 + j\dfrac{R_R}{Z_o}\tan\beta x}. \qquad (70)$$

where

Z_o = characteristic impedance of the line,

R_R = terminating resistance,

βx = number of radius of phase shift in length of line x.

Equation 70 is another form of equation 57† in which R_R has replaced the more general term Z_R, and βl has been replaced by βx since we wish to consider impedance at all points along the line.

Although the load is a pure resistance, the impedance Z measured at various points along the line will in general be complex. Writing resistance and reactance components of Z as

$$Z = R + jX \qquad (71)$$

and dividing both sides by Z_o, equation 70 becomes,

$$\frac{Z}{Z_o} = \frac{R}{Z_o} + j\frac{X}{Z_o} = \frac{\dfrac{R_R}{Z_o} + j\tan\beta x}{1 + j\dfrac{R_R}{Z_o}\tan\beta x}. \qquad (72)$$

*"Transmission Line Theory," April, 1945.

† All equation numbers below 70 refer to the preceding article of this series, "Transmission Line Theory," April, 1945.

In equation 72, from which the impedance chart will be derived, all quantities are expressed as per unit values, or fractions based on Z_o. This permits a single chart to apply to any transmission line regardless of the value of Z_o.

The impedance chart is a plot on rectangular coordinates of per unit impedance values calculated from equation 72. For example, assume that the per unit load resistance,

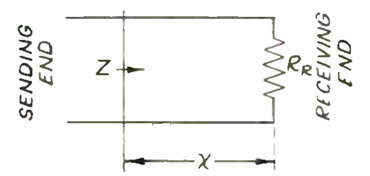


Figure 1—Transmission line terminated in pure resistance.

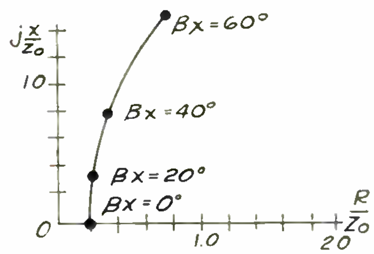


Figure 2—Per unit impedance curve for line terminated in resistance 0.2 times Z_o.

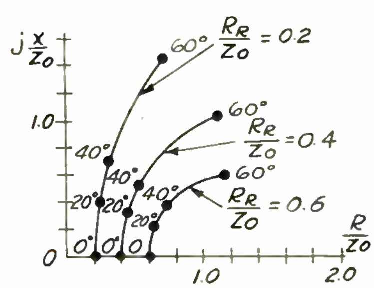


Figure 3—Per unit impedance curves for various terminating resistances.

$\frac{R_R}{Z_o}$, is 0.2. Then values of per unit impedance, $\frac{Z}{Z_o}$, are as follows: For $\beta x = 0°$,

$$\frac{Z}{Z_o} = \frac{R}{Z_o} + j\frac{X}{Z_o} = \frac{0.2 + j\tan 0°}{1 + j\,0.2\tan 0°} = 0.2 + j0. \qquad (73)$$

For $\beta x = 20°$,

$$\frac{Z}{Z_o} = \frac{R}{Z_o} + j\frac{X}{Z_o} = \frac{0.2 + j\tan 20°}{1 + j\,0.2\tan 20°} \qquad (74)$$

$$= 0.23 + j\,0.34.$$

For $\beta x = 40°$,

$$\frac{Z}{Z_o} = \frac{R}{Z_o} + j\frac{X}{Z_o} = \frac{0.2 + j\tan 40°}{1 + j\,0.2\tan 40°} \qquad (75)$$

$$= 0.34 + j\,0.78.$$

For $\beta x = 60°$,

$$\frac{Z}{Z_o} = \frac{R}{Z_o} + j\frac{X}{Z_o} = \frac{0.2 + j\tan 60°}{1 + j\,0.2\tan 60°} \qquad (76)$$

$$= 0.71 + j\,1.47.$$

Plot these values of per unit impedance with $\frac{R}{Z_o}$ measured along the horizontal axis and $j\frac{X}{Z_o}$ measured along the vertical axis (figure 2).

The resulting curve gives the per unit impedance at any angle βx from the receiving end of a line terminated in a resistance of 0.2 times Z_o.

Similar curves can be plotted for other values of per unit load resistance $\frac{R_R}{Z_o}$. Figure 3 shows such curves for the cases $\frac{R_R}{Z_o} = 0.2$, 0.4, and 0.6. If the curves are carried farther, they will be found to close on themselves when $\beta x = 180°$ and then repeat. By means of such calculations the entire impedance chart could be constructed.

Equations of Circles

A more practical method of constructing the impedance chart is to obtain the equations of the curves and then use a geometrical construction. The equations of the curves plotted in figure 3 can be obtained from equation 72. Each curve is identified by a value of $\frac{R_R}{Z_o}$ only, and represents a relation (between the

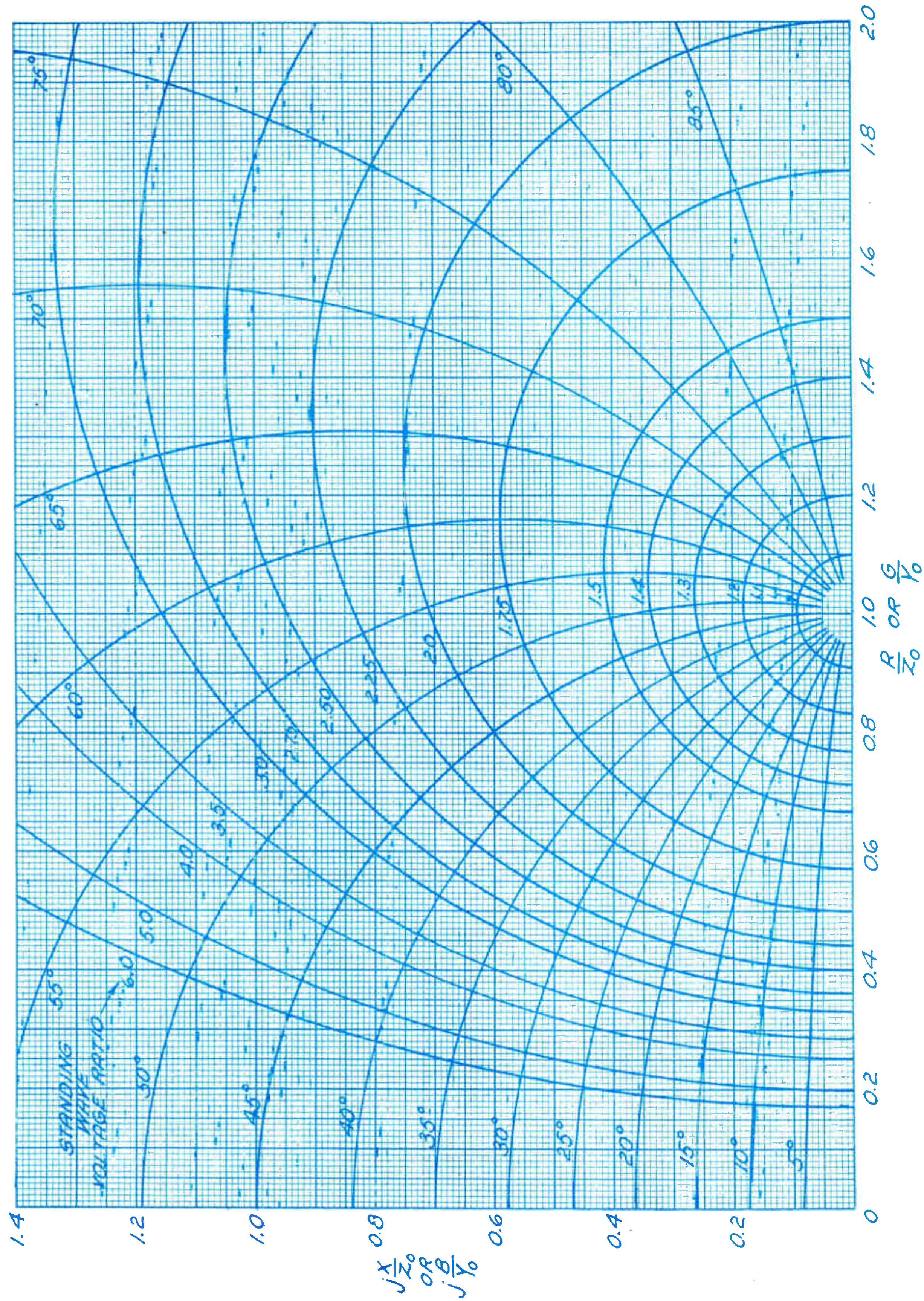


Figure 4—Transmission line chart.

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coordinates $\frac{R}{Z_0}$ and $\frac{X}{Z_0}$) which contains $\frac{R_R}{Z_0}$ but not βx. This relation is obtained from equation 72 as follows.

For a shorter notation, set

$$\frac{R}{Z_0} = a,\ \frac{X}{Z_0} = b,\ \frac{R_R}{Z_0} = A,\ \tan \beta x = B \qquad (77)$$

(Note that a, b, A, and B are all real numbers.) Equation 72 then becomes,

$$a + jb = \frac{A + jB}{1 + jAB}. \qquad (78)$$

Clear of fractions:

$$a + jb + jaAB - bAB = A + jB \quad (79)$$

Equate real terms and imaginary terms:

$$a - bAB = A; \qquad (80)$$

$$b + aAB = B. \qquad (81)$$

From equation 81,

$$B = \frac{b}{1 - aA}. \qquad (82)$$

Substituting in equation 80,

$$a - bA\left(\frac{b}{1 - aA}\right) = A, \qquad (83)$$

$$a - a^2A - Ab^2 = A - aA^2,$$

$$a^2 - a\left(\frac{1}{A} + A\right) + b^2 = -1. \quad (84)$$

Completing the square,

$$\left[a - \frac{1}{2}\left(\frac{1}{A} + A\right)\right]^2 + b^2 \qquad (85)$$

$$= -1 + \frac{1}{4}\left(\frac{1}{A} + A\right)^2.$$

This is the equation of a family of circles with radius

$$\sqrt{-1 + \frac{1}{4}\left(\frac{1}{A} + A\right)^2} = \frac{1}{2}\left(\frac{1}{A} - A\right), \ (86)$$

and center at

$$\left[\frac{1}{2}\left(\frac{1}{A} + A\right), 0\right]. \qquad (87)$$

From these values of radius and location of center, the entire family of circles which is partly shown in figure 3 can be constructed. (See figure 4.)

In figure 3, a curve can be drawn through all points labeled 20°, and other curves through the 40° points, the 60° points, or points representing any particular constant value of βx. These constant-angle curves form another family, the equation for which involves βx but not $\frac{R_R}{Z_0}$. To find the equation of this second family of curves, eliminate A from equations (80) and (81). From equation (80),

$$A = \frac{a}{1 + bB}. \qquad (88)$$

Substitute in equation 81:

$$b + a\left(\frac{a}{1 + bB}\right)B = B; \qquad (89)$$

$$b + b^2B + a^2B = B + bB^2;$$

$$a^2 + b\left(\frac{1}{B} - B\right) + b^2 = 1 \qquad (90)$$

Completing the square,

$$a^2 + \left[b + \frac{1}{2}\left(\frac{1}{B} - B\right)\right]^2 \qquad (91)$$

$$= 1 + \frac{1}{4}\left(\frac{1}{B} - B\right)^2.$$

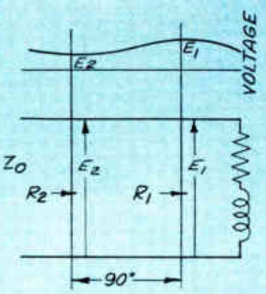


Figure 5—Standing wave of voltage on transmission line.

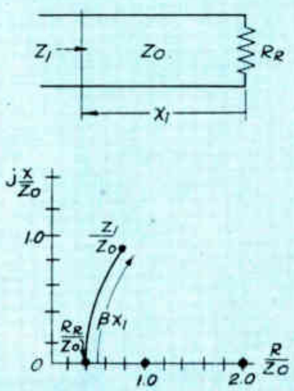


Figure 6—Use of impedance chart for line terminated in pure resistance.

This is the equation of a family of circles with radius

$$(75)\ \sqrt{1 + \frac{1}{4}\left(\frac{1}{B} - B\right)^2} = \frac{1}{2}\left(\frac{1}{B} + B\right), \quad (92)$$

and center at

$$(76)\ \left[0, -\frac{1}{2}\left(\frac{1}{B} - B\right)\right]. \qquad (93)$$

From these values of radius and location of center, the constant-angle circles on the transmission line chart can be constructed.

Figure 4 is a chart with both families of circles drawn by means of the above expressions for radius and location of center. Since the chart is symmetrical, only the half showing positive reactances is drawn. Problems involving the negative-reactance half of the chart can be solved by considering the half shown to be a mirror image of the missing half.

Shown on figure 4 for each circle is the standing wave voltage ratio or ratio of maximum to minimum voltage along the line. This ratio can be found once the per unit load resistance is known.

The two points where each circle crosses the horizontal axis represent points at which line impedance is a pure resistance. As shown by figure 4, these points are 90° apart. Let R_1 be the larger of the two resistances and E_1 the corresponding line voltage. Also, let R_2 be the smaller resistance and E_2 the corresponding voltage as shown in figure 5. Since power loss along the line is assumed to be zero, there is equal power at the two points. Hence,

$$\frac{E_1^2}{R_1} = \frac{E_2^2}{R_2}. \qquad (94)$$

Since the points are 90° apart, equation 64 may be applied to give

$$R_2 = \frac{Z_0^2}{R_1} \qquad (95)$$

Then

$$\frac{E_1}{E_2} = \sqrt{\frac{R_1}{R_2}} = \sqrt{\frac{R_1}{(Z_0^2/R_1)}} = \frac{R_1}{Z_0}. \qquad (96)$$

Thus, the standing wave voltage ratio, E_1/E_2, is equal to the per unit resistance at a point where line impedance is the larger of its two pure resistance values. The ratio marked on each circle is then simply the coordinate of its right-hand intersection with the horizontal axis.

Use of Impedance Chart

For a line terminated in a pure resistance, the chart of figure 4 gives directly the impedance from any point along the line to the receiving end. This use of the chart is shown in figure 6, where a line with a characteristic impedance Z_0 is terminated in a load R_R. To find the impedance seen looking toward the load at a distance X_1 from the load, start at point $\frac{R_R}{Z_0}$. Follow clockwise along the circle which passes through this point a distance βx_1 degrees to a point on the constant-angle circle for βx_1 degrees. The value $\frac{Z_1}{Z_0}$ read from the chart at this second point is the per unit impedance when looking toward the load R_R from a distance x_1.

To extend the use of the chart to a line terminated in a complex impedance, consider the complex impedance to be replaced by an equivalent length of line with resistance termination. This is shown in figure 7 for a line of characteristic impedance Z_0 terminated in a load Z_1.

To find the impedance when looking toward the load from a distance x_2, start at the point

$\frac{Z_1}{Z_o}$ and proceed clockwise a distance βx_2 degrees to a point on the constant-angle circle for $(\beta x_1 + \beta x_2)$ degrees. The value $\frac{Z_2}{Z_o}$ read from the chart at this point is the per unit impedance seen looking toward an equivalent pure resistance termination from a distance $(x_1 + x_2)$. $\frac{Z_2}{Z_o}$ is also the per unit impedance seen looking toward the load Z_1 from a distance x_2. Hence, when the load is a complex impedance, distances along the line are measured as differences between values marked on the constant-angle circles.

The use of the impedance chart is summarized in the following rule:

To find per unit impedance looking towards load, start at point representing load and proceed clockwise on chart for the proper number of degrees.

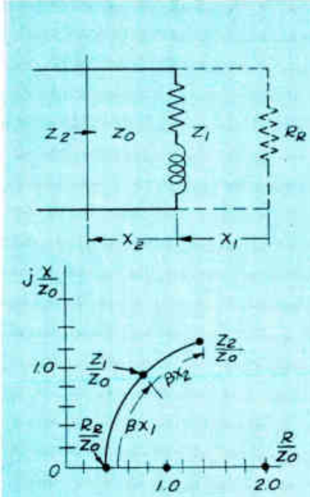


Figure 7—Use of impedance chart for line terminated in complex impedance.

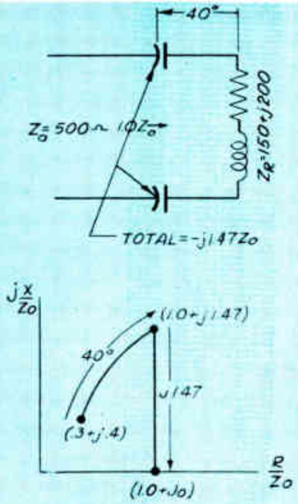


Figure 8—Example of use of impedance chart.

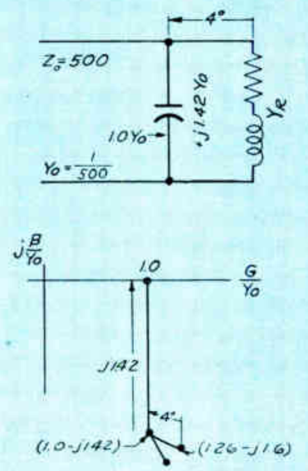


Figure 9—Example of use of admittance chart.

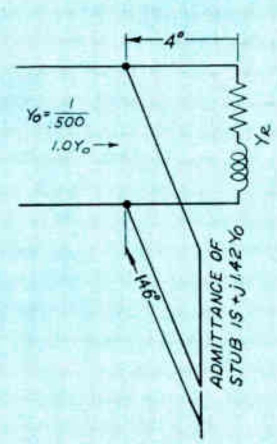


Figure 10—Matching with single stub.

Example of Use of Impedance Chart

As a simple example of the use of the impedance chart, consider a transmission line with $Z_o = 500$ ohms, terminated in an impedance of $Z_R = 150 + j\,200$ ohms (figure 8). To permit operation of the line without standing waves of voltage it is necessary to match this load to the line, or, in other words, to add matching reactances which will make the line see 500 ohms pure resistance.

Here the per unit load impedance is

$$\frac{Z_R}{Z_o} = \frac{150 + j\,200}{500} = .3 + j\,.4. \tag{97}$$

Start at $(.3 + j\,.4)$ on the chart and proceed clockwise to the vertical line through the point $(1.0 + j\,0)$. It is 40 degrees to the point $(1.0 + j\,1.47)$. Hence, at a point 40 degrees from the load, the per unit line impedance is $1.0 + j\,1.47$. If at this point a per unit reactance of $-j\,1.47$ is added, the resultant per unit impedance seen by the line will be $1.0 + j\,0$ which represents a pure resistance of 500 ohms. The reactance could be added simply by inserting a total capacitive reactance of $1.47\,Z_o = 735$ ohms in series with the line as shown in figure 8. In practice, however, tuning stubs (discussed in following paragraphs) are usually used instead of lumped reactances.

Admittance Chart

Admittance charts are more often used in practice than are impedance charts, because most matching reactances are placed in parallel with the line rather than in series. As discussed below, the admittance chart is geometrically the same as the impedance chart, and figure 4 can be used for either.

Define,

$$Y_o = \frac{1}{Z_o} = \text{characteristic admittance of line.} \tag{98}$$

$$Y_R = \frac{1}{Z_R} = \text{admittance of load,} \tag{99}$$

$$Y = \frac{1}{Z} = \text{admittance seen at distance } \beta x \text{ from load.} \tag{100}$$

$$Y = G + jB = \text{conductance and susceptance components of } Y. \tag{101}$$

Substitute equations 98, 99, and 100 in 70:

$$\frac{1}{Y} = \frac{1}{Y_o}\,\frac{\frac{Y_o}{Y_R} + j\tan\beta x}{1 + j\frac{Y_o}{Y_R}\tan\beta x}. \tag{102}$$

or

$$Y = Y_o\,\frac{\frac{Y_R}{Y_o} + j\tan\beta x}{1 + j\frac{Y_R}{Y_o}\tan\beta x}. \tag{103}$$

Equation 103 has the same form as equation 70. Hence the admittance chart derived from 103 will have the same form and will be used in the same manner as the impedance chart that was derived from 70.

The use of the admittance chart is summarized in the following rule:

To find per unit admittance looking towards load, start at the point representing load and proceed clockwise on chart for the proper number of degrees.

Open wire lines are often matched by means of a single parallel stub of variable length and position. For instance, consider an example:

The characteristic admittance of the line is

$Y_o = \frac{1}{500}$, load admittance is Y_R

$= .00252 - j.0032.$

$$\frac{Y_R}{Y_o} = 1.26 - j\,1.60. \tag{104}$$

Start at $(1.26 - j1.60)$ on the chart (figure 9) and proceed clockwise to the vertical line through the point $(1.0 + j\,0)$. It is 4 degrees to the point $(1.0 - j\,1.42)$. If a per unit susceptance of $+j\,1.42$ is added at this point, the resultant will be $1.0 + j0$ and the line will see its characteristic admittance. Hence the line can be matched by adding a susceptance of $+j\,1.42\,Y_o$ in parallel with the line at a point 4 degrees from the load. A capacitor could be used as shown in figure 9.

If 4 degrees of line is so short as to be in-convenient to work with, 180 degrees may be added. This corresponds on the chart to traveling once around the circle before stopping at point (1.0 + j 1.42).

A short-circuited line, or stub (figure 10), is commonly used instead of the capacitor shown in figure 9. The required length of stub can be calculated by means of equation 58, or, more conveniently, by means of the admittance chart.

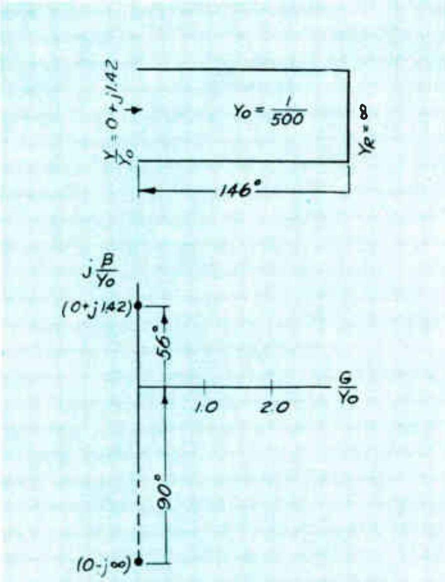


Figure 11—Use of chart to determine stub length.

To find the length of the stub from the admittance chart, use the general rule given above for use of the admittance chart. See figure 11. Here the load impedance is zero, or load admittance is infinite. Hence the point at $-\infty$ on the vertical axis may be taken to represent the load. It is required to travel clockwise on a circle (here the vertical axis, a circle of infinite radius) to the point (0 + j 1.42). As shown in figure 11, this requires a total of 90 + 56 = 146 degrees.

Matching with Two Stubs

On a coaxial line, position of a stub along the line cannot readily be varied. For this reason, two stubs of fixed position and adjustable length are generally used.

To demonstrate the principles involved, assume that the line discussed in the preceding examples is to be matched to its load by means of two adjustable short-circuited stubs at fixed distances of 30 degrees and 120 degrees, respectively, from the load. See figure 12.

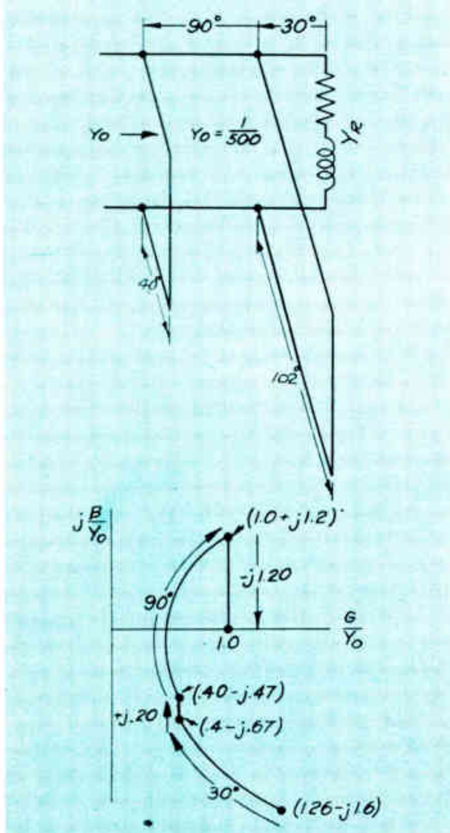


Figure 12—Matching with two stubs.

As before, the per unit load admittance is 1.26 − j 1.60. From this point, it is necessary to travel 30 degrees clockwise, add a susceptance, travel 90 degrees clockwise, and add a second susceptance to arrive at the point (1.0 + j 0) for a matched line. The initial 30-degree travel brings us to the point (.40 − j .67). Vertical lines are next drawn through this point and through the point (1.0 + j 0). It is then necessary by means of a cut and try process to find a circle upon which the distance between these two vertical lines is 90 degrees. The solution, shown in figure 12, is a circle through the points (.40 − j .47) and (1.0 + j 1.20).

Per unit stub susceptances required to be added at the two points (figure 12) are + j .20 for the stub 30 degrees from the load, and − j 1.20 for the other stub. Stub lengths, found from the admittance chart by the method previously described, are 102 degrees and 40 degrees, respectively.

Matching Generator to Line

As a final example of the use of the admittance chart, consider a generator of internal admittance Z_G = 150 + j 200 ohms (figure 13) which it is desired to match, for maximum

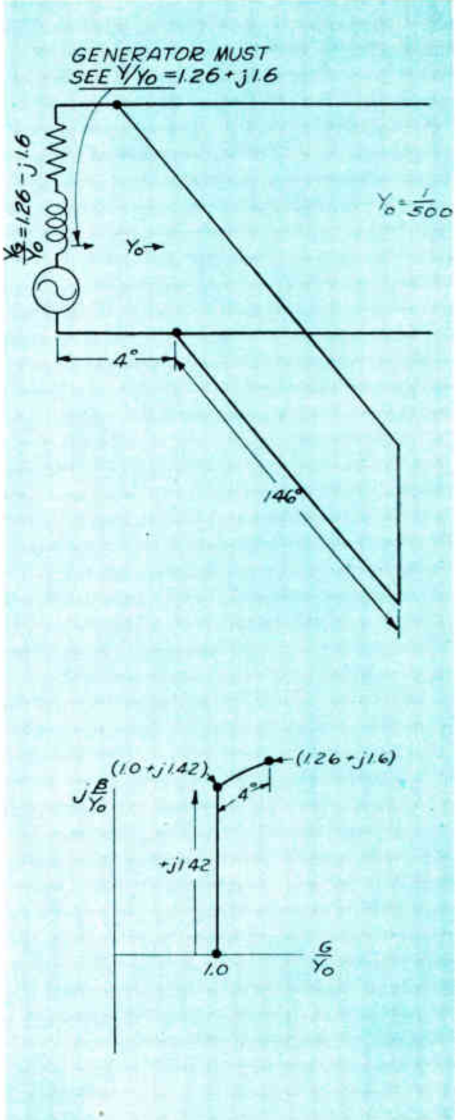


Figure 13—Matching a generator to a line.

power transfer, to a line with Z_o = 500 ohms. A single stub will be used. For a match, the admittance at the generator terminals must be the conjugate of the internal admittance of the generator. Per unit generator admittance is $\frac{Y_G}{Y_o}$ = 1.26 − j 1.60. Hence the per unit admittance at the generator terminals must be 1.26 + j 1.60.

Here the load is the transmission line, for which $\frac{Y_R}{Y_o}$ = 1.0 + j 0. Starting at point (1.0 + j 0) it is necessary to add a susceptance and then travel clockwise to point (1.26 + j 1.60). As shown in figure 13, a stub of susceptance + j 1.42 placed 4 degrees from the generator will fit these requirements. As before, the length of the stub is 146 degrees.

Flying Pickup

By CECILIA MUTH
Technical Publications

EARLY IN THE MORNING at the Pittsburgh County Airport a Stinson SR-10C is wheeled up in front of the Administration Building preparatory to a flight in the unique mail service of All American Aviation.

Close by, in the operations room of the company, there is a buzz of activity as a teletype brings in weather reports to the chief dispatcher, a radio operator sends out departure and arrival times, and pilots wander in and out in an effort to keep up with flight plans while supervising the loading of their planes. The operations room is the hub of the thriving air pickup service which flies the mail twice each day on five routes leading out of Pittsburgh like spokes of a wheel to small communities not served directly by the trunk lines.

This section of the country, once known as the graveyard of aviation, was deliberately chosen as the laboratory area for pickup service. A pilot explained why. Smoke around Pittsburgh, frequent fogs in the valleys, heavy winter weather throughout the mountainous terrain—if these hazards were overcome the service would merit recognition. The Post Office Department itself had made the choice when bids were first sought for the operation of two experimental air mail pickup routes.

Alone in the Field

All American Aviation, founded by the late Richard C. DuPont, famous glider pilot, was the only bidder, and was awarded the contract. In the six years of its existence it has been the only company in the field.

Thumbing a ride on one of All American's planes is as complicated as Ibn Saud's visit to a U. S. cruiser: Washington officials must approve, the weather must be beneficent, a special seat must be installed in the plane, and the pilot must be notified. But these difficulties are forgotten when, at 8:15, flight number 8 takes off for Williamsport, 202 miles to the northeast. Other sturdy little red ships, powered by single 260 horsepower Lycoming engines, are already under way. Still others are to follow, for the morning schedule includes flights to Jamestown, N. Y., to Philadelphia by way of Wilmington, and two routes to Huntington, W. Va., one via Charleston and the other through the Ohio Valley.

An extra headset, thoughtfully provided by the pilot, Captain M. W. Lossing, made it possible to be in on all radio conversations right from the start. Routine messages exchanged between the pilot and control operator served to test out the equipment, a familiar Bendix Radio TA-6 Transmitter and RA-10 Receiver, operating on the AAA day frequency of 5582.5 kc. Transmission was reported loud and clear. On the receiving end, the volume from the 250 watt ground station seemed thunderous.

Pickup at 120 MPH

"Here we go," announced the pilot. Running true to form, Pitcairn, 11 miles out, was shrouded in smoke. The plane circled in among the hills, banked sharply, and made a dip deep enough to cause momentary and unnecessary apprehension. At 120 miles an hour the plane flew straight at the side of the hill, leveling off when only 15 feet above the ground to make contact with the ground equipment. There is only a faint "snick," then a sharp rise, and it's all over, with no jar, no jolt, no discomfort.

This is what happens. A mail container on the ground is placed between two twelve-foot poles, spaced twenty feet apart. A loop of rope is threaded through a "U" bolt on the container and through light, tension-released clips at the top of the poles. With uncanny accuracy, and with depth perception that leaves one marveling, the pilot spots the rig that resembles a tall clothes line, snags the horizontal stretch of rope with a hook at the end of a 12-foot arm beneath the plane, and pulls away to a quick climb to clear all obstructions and prevent the dangling burden from striking the ground. It all happens in a flash—a minute and a half, to be exact—with smoothness and precision. Honors are pretty evenly divided between the ingenious equipment and the skillful and practiced techniques of the pilot and pickup man.

Like the other pilots, Captain Lossing was modest, good-humored, confident, keen, business-like. They are all sold on the pickup service; even those with pre-war experience in transoceanic flying, and wartime records in the Air Transport Command, insist that such assignments are monotonous by comparison. Because of conditions peculiar to this operation, they must be men of proved judgment, who can make up their minds in a hurry, who know what to do in an emergency.

"One of the boys got himself mentioned in the Congressional Record," the pilot remarked between pickups at Vandergrift and Indiana. "He was flying down the Ohio Valley early one morning and noticed flames coming out of a farm house on the outskirts of one of the towns. He radioed the Pittsburgh station, giving the exact location. Pittsburgh immediately phoned the local fire department. They sent out apparatus, and the house, which happened to be unoccupied at the time, was saved." Good old TA-6!

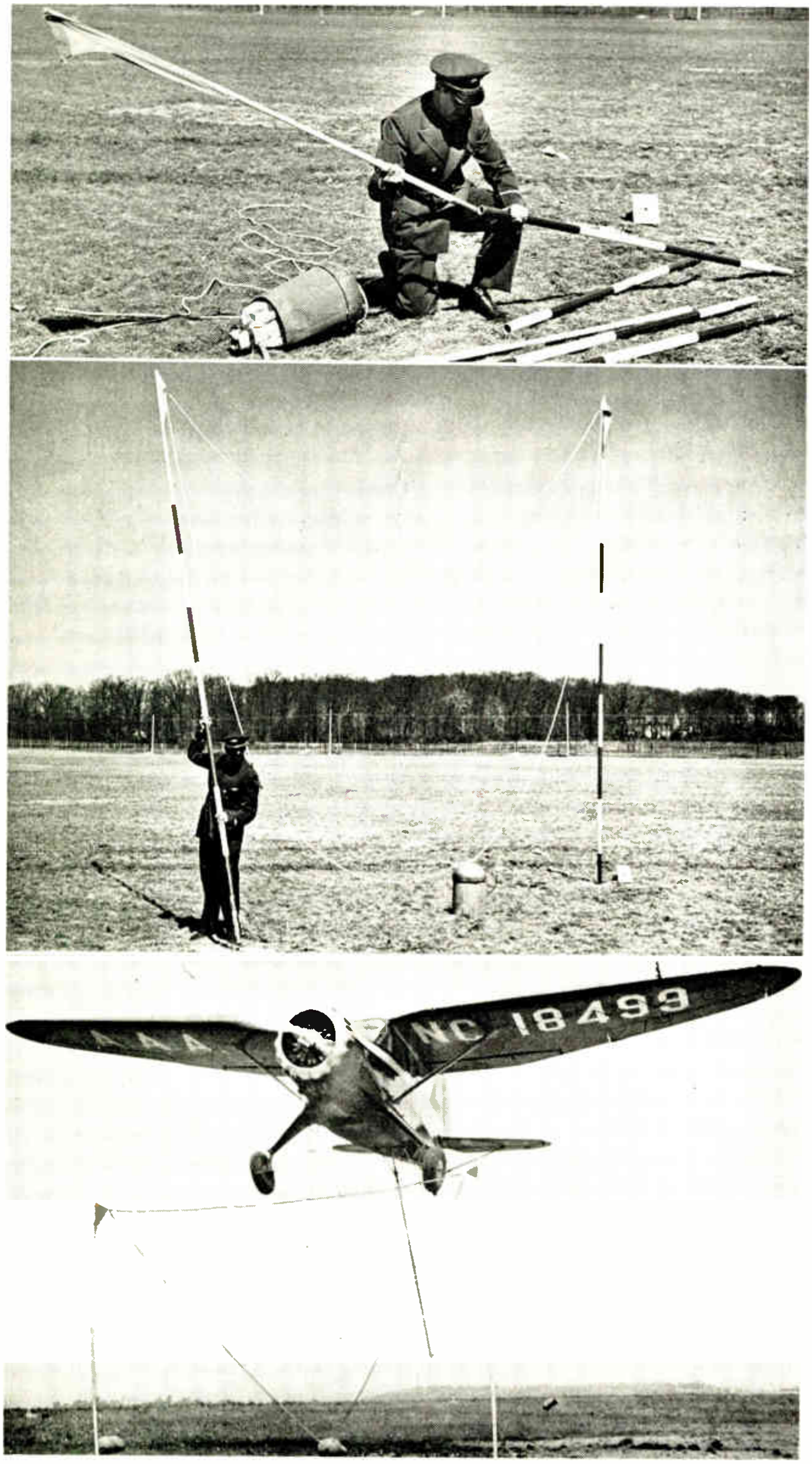
Contact Flying

The plane is equipped with the transmitter which, in addition to the company frequency, also tunes to the national contact frequency for commercial aircraft on 3117.5 kc, with a receiver which tunes the company fixed frequency, the broadcast band and the range, and with a Bendix Radio Loop MN-24. Nevertheless, authorization to fly by instrument is limited to strict emergencies. Flights are made by contact, in daylight hours only, without the use of navigational aids. The CAA license permits routine operation with a 500-foot ceiling and one mile visibility. So, as the pilot points out, it's that barn on the side of the hill, the school with the concrete trim, the river, the highway, the coal mine at the crest of the mountain, and other familiar landmarks, which keep him on his course. Because he rarely flies more than 500 feet above the ground, there is ample opportunity to view the landscape and check his location.

Conversation is interrupted about every half hour to permit a radio report to the Pittsburgh operator, to give location, altitude, and estimated time of arrival at the next station. Most of the time the 15 watt transmitter carries through to the ground station at Pittsburgh without difficulty. When the plane operates below the level of the surrounding terrain or under unusual atmospheric conditions, however, messages may not get through. A trailing antenna would help, instead of the 36-foot straight wire antenna, but with two ropes already dangling at pickup time, another trailing line could easily become fouled. What their communications chief really would like to have is the four-channel, 50 watt transmitter section of the Bendix Radio RTA-1B, inasmuch as weight considerations rule out installation of the complete transmitter-receiver equipment. This he knows would do the trick.

Pickup Man Kept Busy

While in the air, the flight mechanic works in the center of the plane. He is the



Photos courtesy All American Aviation.

Top: Messenger assembles portable ground station equipment prior to arrival of pickup plane.

Center: Ground station erected for pickup. Loop of nylon rope is threaded through sails at top of sectional poles and through "U" bolt in container which rests on ground.

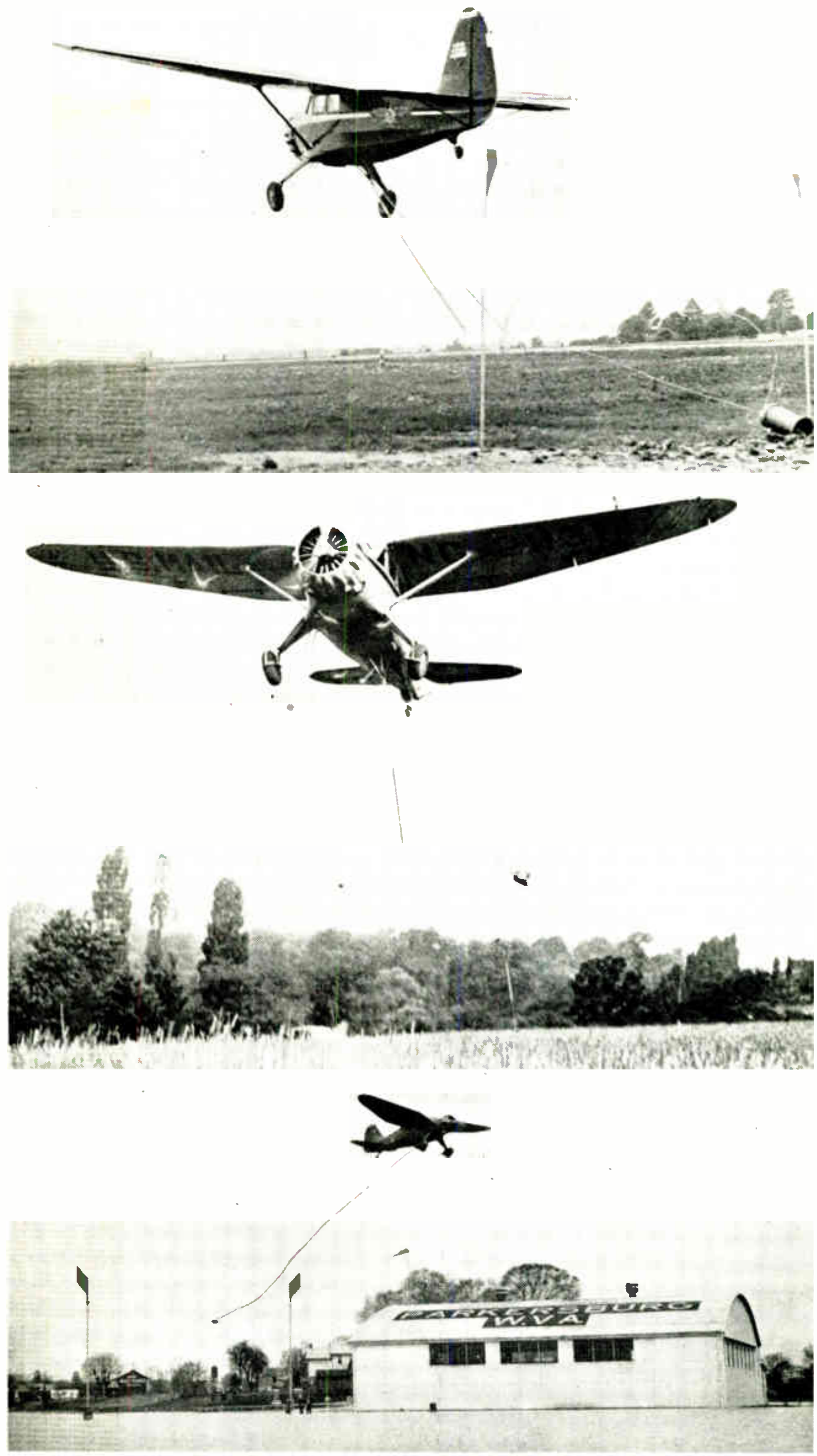
Bottom: Plane arrives at pickup station. Retractable wooden arm is in position to contact rope to which mail container is attached. Incoming mail container released from plane is in background.

pickup man, in the sense that he manipulates the special gear from a seat beside the two-foot hatch which is opened up during pickup operations. And when on a close schedule a series of pickups is made at four or five minute intervals, roller-coaster fashion, he is a very busy man indeed. He brings in the container, unloads it, assorts the pouches in nearby storage bins, records on company and Post Office charts the number and weight of the pouches, and fills the container for delivery at the next station.

Punxsutawney was fading in the distance as flight mechanic Cecil Lingar worked at the open hatchway preparing for the pickup at Dubois. Between the hatch and the pilot's seat is the pickup unit, an electrically operated winch equipped with a shock absorbing device. On this winch is wound about 100 feet of ⅜ inch nylon rope with a heavy brass hook at the end. He takes the hook and places it into a metal groove on the near end of the contact arm, a hickory pole 2½ inches in diameter and 12 feet long, which extends at a 45 degree angle beneath the plane for the pickup, and immediately after is retracted flat against the plane by a hydraulic cylinder. The hook slides down to the free end of the arm where it is caught and held by a spring retainer.

At the moment of the pickup, the contact arm, somewhere along its length, strikes the loop of rope stretched between the two poles on the ground at the field station, and pulls it free from the springs which secure it to the poles. The ground rope, now trailing the loaded container, rides down the arm into the brass hook. This weight jerks the hook loose from its spring fastening on the contact arm, and now the entire loop of rope bearing the mail container flies free behind the plane. The moment the weight is applied to the hook, the winch begins feeding out the rope from the plane, just as a fisherman lets his quarry run with the line, and for the same reason. After the split second required to accelerate the burden to the speed of the plane—the length of the payout varying with the weight of the burden and the speed at which it is picked up—the winch automatically brakes, reverses the action, and reels the container into the open hatch. If, on opening the container, the pickup man sees a frightened field mouse escape to freedom, he realizes this is just a gallant messenger's gesture toward preventing his life from becoming humdrum!

Delivery of the mail occurs just in advance of the pickup by means of a separate rope which the flight mechanic lets out through the hatch. At a distance of several hundred feet from the station, the pilot pulls a hand trip on the instrument board, and the container with the 60-foot loop of rope still attached falls to the ground and rolls



Photos courtesy All American Aviation.

Top: Ground rope is snagged and freed from poles, and plane begins immediate pull-up to clear all obstructions.

Center: Reel inside of plane has been set in motion by weight of container and pays out additional length of rope to absorb shock of sudden contact.

Bottom: Pickup at flooded air field. Retractable arm already is drawn back to the body of the plane, and trailing rope is nearing full length of payout before action is automatically reversed and container reeled into plane.

with incredible exactness to within a few feet of the station.

"Watch that dog," the pilot was saying, as the plane approached the Dubois station. "I'll tell you a story about him." A large collie was running up and down the field barking vigorously. It seems that in the early days of pickup operations, a delivery container released from a plane struck the dog, and the owner hurried out to pick him up for dead. He wasn't dead. He wasn't even badly injured. But he definitely harbored a deep-seated grudge. Ever since the day of his injury, at the first sound of the Stinson motor in the distance, he races wildly around the field, and continues to do so the entire time the plane is in the vicinity. All other planes pass over unnoticed, but he never fails to meet the pickup, and the pilot would be disappointed if he did.

Once in the plane, the container for the transfer of mail and express was opened.

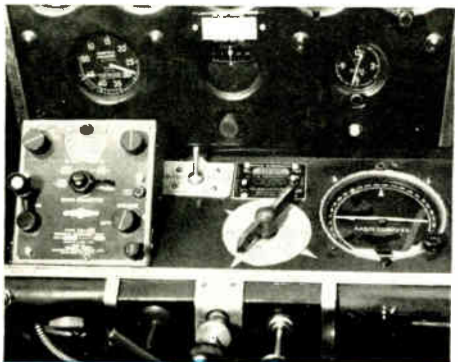


Photo by Robert Taylor, All American Aviation.

Partial view of instrument panel on an All American Aviation Stinson SR-10C, showing Bendix Radio Remote Control Unit and Bendix Radio Azimuth Indicator.

It is shaped like an elongated bell 20 inches high and 1 foot in diameter, and made of heavy rubber with reinforced fibre dome. The flared edge offsets any tendency to spin as the container is drawn through the air at high speed. A stout canvas bag, opening at the bottom, and authorized by the CAA to carry 60 pounds picked up at 150 mph or 90 pounds at 110 mph, is riveted firmly inside the dome. Mail pouches, especially designed by the Post Office, are placed inside this container marked for each specific destination, so the flight mechanic assorts only pouches and handles no loose mail. Express packages, to fit into the container, are restricted in size to 8x8x17 inches and in weight to 35 pounds per pickup.

An Elastic Rope

The nylon rope used in the pickup is an important contribution by AAA scientists. A bit of simple figuring shows that an airplane traveling 120 mph, moves 17.6 feet in a tenth of a second. Ordinary rope could not survive the strain of such an impact. Because drawn nylon is not only strong but also elastic enough to stretch 40% of its length, it can absorb a portion of the shock, and will do the job. Even gliders can be picked up with a 250-foot nylon leader plus a steel cable of much greater length. By the use of this combination in conjunction with a larger winch the weight that can be picked up is theoretically unlimited.

Ground Rig Easily Assembled

Flying over the dense mountain section, at a 2500-foot altitude, but still only 500 feet above the treetops and close in to the ridge, the pilot volunteers, "Look over there at the deer." Sure enough, plenty of them. Clearfield, Phillipsburg, and there's Penn State! Lots of mail, as always, at busy State College.

Bellefonte looms in the foreground, the town which fishermen remember for its famous trout stream and radio historians as the center of early telephony and beacon station experiments. This seems an appropriate time to concentrate on the ground operation. It has already become apparent that in towns where there is no local airport the pickup station is located at almost any point providing sufficient clearance, a pasture, a public park, a playground. At the scheduled time for the pickup, the messenger, a company employee, arrives at the station with the mail which he places in the container, fastening it with a leather strap. He inserts the metal section of the poles into permanent sockets in the ground. The upper section is made of wood with small orange-colored pennants at the top to be more easily seen from the air. Adjusting the 60-foot rope through the clips at the tips of the pennants and through a "U" bolt in the nose of the container, he leaves the container on the ground between the poles. In less than five minutes the stage is set. When the pickup has been made, he dismantles the equipment, places it in a box on the field, and leaves to deliver the mail to the local Post Office and the air express to the Railway Express Agency.

The automobile of each of the pickup messengers is equipped with a specially designed crystal controlled receiver, tuned to the company frequency. In advance of the flight he listens in for a report on flight conditions and possible schedule changes. He may hear something like this: "Flights 4, 6, 11, routine. Flight 7, stand by for further announcement." Then, somewhat later: "Flight 7 proceeding on time. Passing Pitcairn; low ceiling." The Pitcairn messenger is thus saved an unnecessary trip to the station.

Lock Haven, Jersey Shore, and then the terminal at Williamsport, where the plane landed promptly on schedule at 10:06. Despite the fact that there were eleven pickups at intervals of five to twenty minutes, a schedule of 110 mph had been maintained between the two terminals. The messenger was on hand at the airport, mail containers were exchanged, the plane was refueled, and at 10:21 the return trip began. "This is fun," was the reporter's unorthodox reaction right in the midst of a professional assignment on this strictly business run.

Strongly Entrenched

Between pickups one learns some of the interesting details about the pickup business, especially its record on speeding the mail. The company conducted an experiment with a hundred pairs of air mail letters sent to

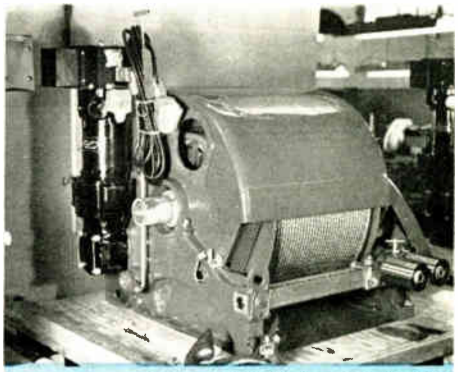


Photo courtesy All American Aviation.

Pickup unit located behind pilot's seat, with close-up view of heavy brass hook which makes contact with ground station rope.

the other through the usual channels. The average time saved by pickup was 10 hours, 20 minutes. On short hauls the comparison favors pickup very strongly. A correspondent, for example, could send a letter in the morning to a destination within the limits of a particular route, and easily receive a reply in the afternoon. That is pretty special service.

Statistics show that the quantity of mail handled by pickup has had an impressive growth. The official count of the Post Office Department for August 1943, a peak month, discloses that 1,648,355 pieces of mail were handled. In not a few of the small towns the per capita use of air mail is greater than in New York. A strong consideration favorable to the pickup service is that on the basis of the rate of compensation fixed for each of six cities in different sections of the country, one of each pair by pickup, and the postal authorities by the CAB—50.26 cents per airplane mile flown on schedules designated by the Postmaster General—pickup has outgrown the subsidy stage and is already realizing a substantial profit for the Department.

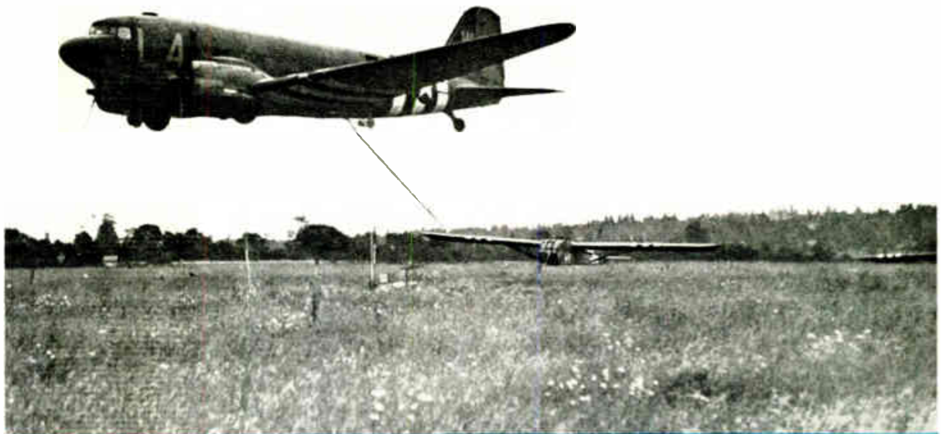
Emergency Services

"We have a grandstand view of floods," the pilot pointed out. "In some of the towns in the Ohio Valley we give the only mail service they get when highways and tracks are under water." He explained that in the flood of 1939, a messenger in a rowboat erected the Parkersburg pickup station, while the pilot dropped the container on a hillside and medical supplies and food to isolated families wherever they happened to be marooned. Usually, though, the station itself is moved to higher ground.

Even during the winter the pickup really gives a good account of itself. When a 28-inch snow grounded all commercial planes and closed the Pittsburgh airport for more than a week, a few of the AAA planes were forced down the day of the big storm at airfields along the routes; but the following day, all pilots resumed their routes on schedule time from the stations where they had landed, and continued to operate their daily flights. Messengers used snowshoes to reach the stations when even the local thoroughfares discouraged the use of an automobile.

For emergency service on the flights a repair truck equipped with tools and hoists, is kept in readiness to make all engine repairs or even replace an entire engine at any point where shop facilities are not available. It is fitted with radio receiver and transmitter so the crew can get in contact with the home operator in case the radio set on the plane under repair is damaged.

It is not surprising in view of AAA's excellent safety record that combination passenger and pickup operation is being seriously considered. Under such an arrangement, landings would be made only at airfields along the route where there are passengers to be taken aboard or discharged. CAB is also considering 25 applications for air pickup from other companies in all sections of the country, which would extend the service from the present 1568 miles to a total of 75,908. Artists of the Feeder Airlines Association have prepared a sketch for the typical aircraft for dual passenger and mail service as a guide to the industry in converting such planes as the Lockheed Lodestar and the Douglas DC-2 for the heavier runs, and the twin engine Beech for the lighter hauls. Designers look forward to a 500 mile range, a cruising speed of 175 mph, a pickup of 200 pounds capacity, greatly increased cargo and mail capacity, accommodations for 12 passengers, and a co-pilot as well as a pilot. Radio equipment will be installed to meet requirements for night and instrument flights. In fact, the use of improved radio aids now under military restriction is foreseen to permit pickups under instrument conditions when the pilot cannot see either the ground or the station.



Official U.S.A.A.F. Photo.

Pickup method of launching gliders has been used successfully in both theatres of war where supplies and troops have been landed or wounded men must be evacuated in areas too small for take-off of a plane with glider attached. Photograph shows a plane which participated in "D" day operations as it approaches a ground station erected on a field in France to launch a CG-4 glider.

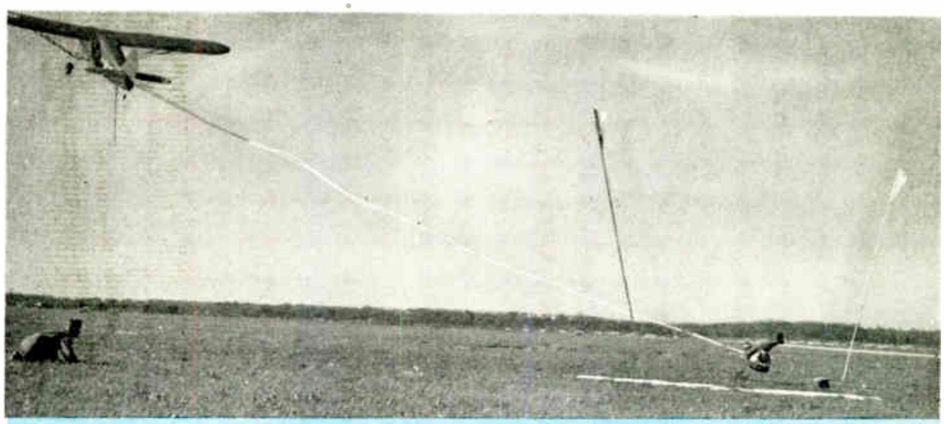


Photo courtesy Air Technical Service Command.

Pickup of a man by a plane in flight, using AAA techniques, has been developed by the Air Technical Service Command and Army Air Force at Wright Field, Ohio, for rescuing stranded fliers, prisoners, or espionage agents. The man wears a variation of parachute harness.

Pittsburgh Again

Almost four hours after the take-off, the plane was nearing the end of the trip. Suddenly the pilot said: "Why don't you make the radio report from Vandergrift?" Though I was much impressed with the competence of the pilots, the maneuverability of the little ships, and the efficiency of the service, this final gesture of mine was hardly an impressive one. I found myself with mike in hand speaking in a halting, timid voice which even I didn't recognize. "AAA Flight 7 calling Pittsburgh." On receiving the booming reply, "Go ahead Flight 7," I feebly gave the routine information. In a few moments the Pittsburgh operator came back with the comment: "What's the matter, Lossing, getting tired?"

AIRCRAFT RADIO SHOCKMOUNTING

Design information that will help the engineer select the best available mounting unit for a particular application.

By J. H. BEST
Mechanical Engineering

MOUNTING UNITS HAVE BEEN USED to reduce shock and vibration damage to aircraft radio for years, but most types in use were designed to isolate vibration originating in such mounted equipment as motors and punchpresses, and the manufacturer's literature is presented accordingly. Only recently has there been any attempt to design units primarily intended for aircraft instruments.

Actual design of shockmounts is a specialized procedure, but the aircraft instrument engineer should have sufficient understanding of the problem to permit him properly to apply the improved mounts that are now becoming available. This article summarizes the information that he must have in order to do so.

Functions of Shockmounts

What is a shockmount supposed to do and under what conditions does it function? It must, first of all, support an instrument so that it at no time hits surrounding objects, and so that there is no failure of equipment even in a 9G pullout. It must reduce destructive shocks, and the transmission of vibration present in the quietest of today's planes.

Let us cover these functions in more detail. Slowly applied centrifugal forces result from aerial acrobatics and may be in any direction, although normally they are perpendicular to the surface of the wings. Military specifications require that mounting units have the ability to withstand 10G's vertically and 7½G's horizontally. While these figures may seem high for normal commercial and private flying, there is the possibility of a mounting unit breaking loose in a crash and of both it and the equipment it supports becoming projectiles. Therefore, maximum structural strength of an assembly should be the objective of the designer.

Barring accidents, landing shocks in heavy aircraft are low. A typical value is ½G in a normal landing of a B-29. The writer has found no data on the landings of light planes—with or without students at the controls—or on light planes taxiing over rough fields. However, road shocks up to 3G have been recorded in tanks and we can safely assume that aircraft ground shocks are no greater. In addition to vertical shocks, horizontal shocks may be caused by assisted take-offs or carrier landings. It is known that a horizontal force of from 3½ to 4G has caused failure of an airplane's structure in test landings, so 3G also may be taken as the greatest probable horizontal force in normal operation.

All of these shocks have a relatively low frequency and large amplitude. Large shock forces of high frequency and small amplitude occur in military airplanes when their armament is fired. For example, the firing of the heaviest weapon used in a medium bomber (75 mm) produces a 9G acceleration in secondary structural members (at the radio operator's station) at a frequency of about 1/100 of a second, and an amplitude of 1/32 of an inch.

Shockmounts do not isolate or reduce slowly applied forces and low frequency shocks. Their function is to isolate high frequency shocks and vibration. Since a high frequency shock can be considered a half cycle of vibration, the remainder of this article is limited to vibration isolation.

Vibration Isolation

Vibration in normal flight is primarily caused by the engines and propellers. In certain applications, adjacent rotating equipment may be an exciting factor, and high speeds may cause aircraft surfaces to flutter. This vibration is transmitted from its source to the instruments through structural members, which have a natural frequency of vibration. The members vibrate at the exciting speed, or at a harmonic or subharmonic of the exciting speed, if this happens to be near the natural frequency of the structural member. Data from several sources show normal vibration to consist of a number of frequencies, that at the engine speed, in general, having the largest amplitude.

Direction of vibration depends primarily on the arrangement of the airframe. For example, one strut may have a 0.015 inch horizontal motion at 1800 rpm, and another a 0.005 inch vertical motion at 3600 rpm. The resulting transmitted motion is extremely complex, even without considering the engine beat in multi-engined ships. Therefore, vibration components in all directions at all destructive frequencies must be allowed for in the design of a mount for general use.

Amplitudes of vibration of the relatively stiff structural members to which instruments should be mounted are considerably less than the amplitudes of light panels, and windows for instance. At cruising speed, about 1/64 of an inch is the total excursion of secondary structural members at the radio operator's station of a B-29, a comparatively quiet plane. Some panels of light bombers, on the other hand, may exceed 1/16 of an inch excursion. No data is available on amplitudes when aircraft is damaged in combat, but mounting equipment tested for 1/16 of an inch total excursion has consistently kept the radio equipment operative in such cases.

Although most instrument components are now tested for failure by vibrating them at large amplitudes for a short time within the range of the engine speed, there is apparently no information available on the life of such fragile components as radio tubes over long periods of service. Tube life, however, is often reported unsatisfactory by the airlines. But until comparative tests are made on mounts offering various degrees of isolation and having varying isolation frequency ranges, we shall not know just what the economical range and degree of isolation are. Meanwhile, we can only play safe and design for the greatest isolation and range possible when the equipment is fragile enough to warrant it. Military specifications now call for at least 65% isolation of vibration in all directions at engine speeds (1800 to 2000 rpm).

Factors Ordinarily Considered

Let us now consider the selection and location of mounting units. The general theory of vibration isolation by spring mounting is well known, but for convenience the fundamental formulas used in common aircraft instrument applications are given. Perhaps it should first be mentioned that actual performance of commercial mounts is very close to the computed theoretical values, although the usual computation neglects friction. Moreover, units which perform satisfactorily under test conditions (simple harmonic motion) perform well under the more complex vibration of service conditions.

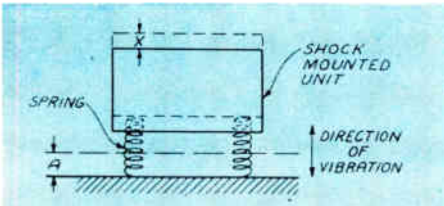


Figure 1—Simplified drawing of usual method of mounting radio equipment with vibration applied vertically.

Figure 1 represents a unit mounted on equal springs, equally loaded, with vibration applied in the direction of the axis of the springs. The body moves only in the direction of the axis of the springs. To calculate the performance of this unit, proceed from the differential force-acceleration equation

$$\frac{W}{4G}\,\frac{d^2x}{dt^2} = \frac{Kx}{4},$$

where:

W = weight of mounted equipment,

x = amplitude of vibration of spring supported mass,

G = acceleration caused by gravity, and

K = pounds per inch deflection (spring constant).

Taking $x = A \sin 2\pi Ft$ we get the following solution:

Resonant frequency (F_N) equals

$$\frac{\sqrt{G}}{2\pi}\sqrt{\frac{K}{W}} = 3.12\sqrt{\frac{1}{\Delta}}, \text{ and}$$

Per cent transmission (or amplification) equals

$$\frac{1}{\dfrac{F^2}{F_N^2} - 1},$$

where

A = amplitude of applied simple harmonic motion,

F = frequency of applied vibration, and

Δ = Static deflection of spring supported mass.

These relations are shown graphically in figure 2. From this set of curves (which is published by most mount manufacturers), and from the load-deflection curve published for the mount selected, the performance of the unit can be determined.

Unfortunately, however, it is not usually feasible to meet the conditions upon which the curves of figure 2 are based. In the first place, the mounting unit designs used in the past differ considerably in vertical and horizontal properties. But aircraft vibration is as serious horizontally as it is vertically, so mount assemblies should be non-directional. Secondly, in the unit illustrated the mounts are located symmetrically around the center of gravity, and the vibration does not apply any torque to the equipment. In the usual case where the mounts are between the instrument and a shelf, the center of gravity cannot be so located in respect to the springs which isolate horizontal vibration. With the consequent off-center loading, a second resonant frequency, the torsional mode, is present. This frequency is higher than the centrally loaded resonant frequency and, with the usual type of mount conventionally located, is likely to be very near engine speed.

Additional Factors Necessary

No formulas were found in the available literature for handling the torsional mode of vibration, so a solution was worked out.

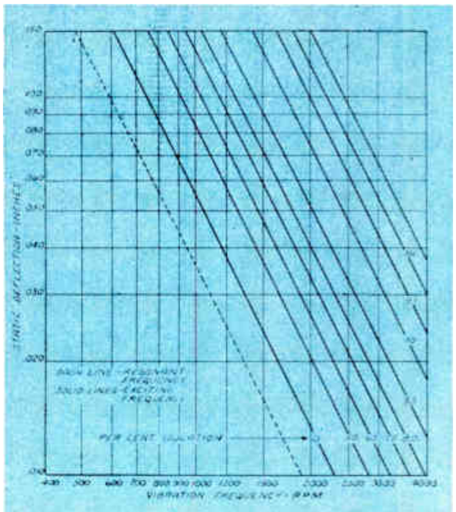


Figure 2—Vibration reduction by spring mounting. Dash line represents the relation between resonant frequency and static deflection. Solid lines represent the isolation obtainable over a range of applied frequencies for all common values of static deflection.

Figure 3 is a simplified drawing of the mounting application to be analyzed. The supporting surface is vibrating horizontally, and as a result the unit both rotates and vibrates lineally. Only one of the four identical and equally loaded shockmounts is shown and analyzed, and is represented schematically as two springs.

If we assume that motion starts from rest, that friction is negligible, and that the amplitude is sufficiently restricted so that the center of gravity has negligible vertical motion, the differential force and moment equations of the mounted mass are as follows:

$$O = \frac{M}{4}\,\frac{d^2x}{dt^2} + (x + \Psi H)K_H + (-A)\,K_H \text{ sine } \omega t;$$

$$O = \frac{I}{4}\,\frac{d^2\Psi}{dt^2} + H\,(x + \Psi H)\,K_H + \frac{L}{2}(K_V)\,\Psi\,\frac{L}{2} + (-A)\,HK_H \text{ sine } \omega t,$$

where

M = mass of body $\left(\frac{\text{weight}}{G}\right)$.

I = moment of inertia of the mass $\left(\frac{I_o}{G}\right)$.

H = distance from center of gravity to plane of shockmounts,

L = distance between shockmounts,

K_V = vertical spring constant of shockmounts,

K_H = horizontal spring constant of shockmounts,

A = amplitude of applied vibration.

ω = frequency of applied vibration = $2\pi f$.

x = lineal movement of body at time t, and

Ψ = angular movement of body at time t.

These conditions are satisfied by sine functions (with zero integration constants) which can be divided out. The resulting equations, regrouped and transformed algebraically, give the ratio of the lineal vibration of the mounted unit to the vibration of the supporting surface, and also a similar ratio for induced rotation:

$$\frac{X\ (\text{max.})}{A} = \frac{\left(HK_H^2 + \frac{I\omega^2}{4}K_H - H^2K^2_H - \left(\frac{L}{2}\right)^2 K_HK_V\right)}{\frac{MI}{16}\omega^4 - \left[\left(H^2K_H + \left(\frac{L}{2}\right)^2K_V\right)\frac{M}{4} + \frac{IK_H}{4}\right]\omega^2 + K_H\,K_V\left(\frac{L}{2}\right)^2};$$

$$\frac{\Psi\ (\text{max})}{A} = \frac{-\frac{M}{4}\,\omega^2\,K_H\,H}{\frac{MI}{16}\omega^4 - \left[\left(H^2K_H + \left(\frac{L}{2}\right)^2K_V\right)\frac{M}{4} + \frac{IK_H}{4}\right]\omega^2 + K_H\,K_V\left(\frac{L}{2}\right)^2}.$$

In practice, we are interested in the resultant of these lineal and rotational mo-

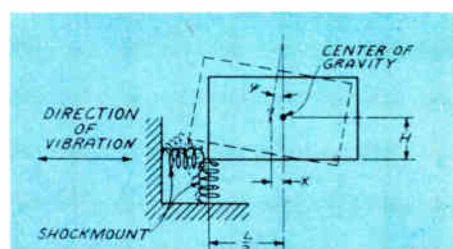


Figure 3—Schematic drawing of usual method of mounting radio equipment with vibration applied horizontally.

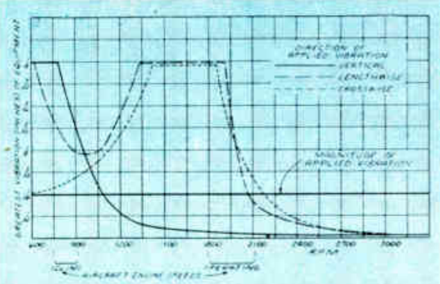


Figure 4—Vibration test performance of radio equipment mounted on conventional corner-located vertical shear type mounts. Solid line represents unit vibration when test table is vibrated vertically. Dash line represents unit vibration when the test table is vibrated horizontally, lengthwise, and crosswise to the unit.

tions, and friction measurably affects the results. Therefore, the equations are too cumbersome and inaccurate to be useful. However, the resonant frequencies are those at which the denominators equal zero. The accuracy of their determination is not affected by friction, and by knowing them we can estimate performance without further mathematical gymnastics.

Therefore, equating the denominator to zero, transposing to more convenient terms, and applying the general formula for the solution of quadratics, we derive the following formula for the higher of the two resonant frequencies:

$$F = 3.12 \sqrt{\frac{B + \sqrt{B^2 - 4C}}{2}},$$

where

$$B = \frac{D\left(\frac{L}{2}\right)^2 + H^2 + R^2}{D\Delta_V R^2},$$

$$C = \frac{\left(\frac{L}{2}\right)^2}{D\Delta_V^2\, R^2},$$

L = distance between mounting units,

H = distance from center of gravity to mounting units,

Δ_V = vertical static deflection,

$D\Delta_V$ = horizontal static deflection, and

R = Radius of gyrations $= \sqrt{\frac{I}{M}}$.

Exact isolation curves for general applications, such as those shown in figure 2 cannot be given for off-center loading, since the shape of the curve in any application is a function of the constants of the instrument to be mounted. Working the curves out for any particular application is generally too long a job to be worthwhile. However, for the same ratio between resonant frequency and applied frequency, the per cent isolation is greater for off-center loading than the isolation shown in figure 2, so these curves can be used safely for estimating performance.

Inspection of the preceding formula shows a number of interesting relations. Let us examine the B term, since it is obvious, after working a few practical solutions, that this is the more important, although the C term is not negligible.

Take the constants of the instrument first. H (distance from mount to center of gravity) appears in the second power. In other words, the designer should keep the center of gravity as low as possible, a fact which is fairly obvious without recourse to mathematics. Then consider the inertia-mass ratio (R). In the numerator it is added, while in the denominator it is a multiplier. For low resonant frequencies, therefore, this ratio should be as large as possible. The instrument designer can affect this ratio somewhat by proper placement of heavy components. The ideal layout would be one in which the weight is concentrated equally at the corners. Although this layout is obviously not practical, it is worthwhile to consider placing the components for high moment of inertia about the longest axis.

The other quantities in the B term concern the selection and placement of the mounting unit. The product $D\Delta_V$ is the horizontal static deflection of the mounted instrument. This is in the denominator and therefore should be as large as possible. Mounts having large horizontal static deflection can be used without excessive movement of the equipment. Horizontal motion may be stopped by snubbers at a deflection less than the deflection caused by gravity. Vibration isolation, however, ceases when the mounting surface is tipped from the horizontal, and snubbing begins. Shock absorption is also sacrificed. Balancing these considerations is a problem for the mounting unit designer, but the instrument designer should be aware of them in order to make the best selection for his application.

From the term $D\left(\frac{L}{2}\right)^2$, we see that the center-to-center placement distance of the

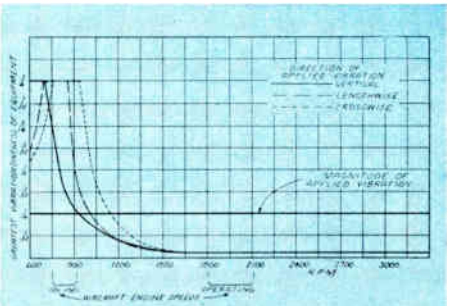


Figure 5—Vibration test performance of same equipment on the same mounts, relocated and modified for greater horizontal static deflection.

J. H. Best

AFTER SERVING as Bendix Radio project manager on the "Queen" ground station equipment, until its completion—an assignment involving close contacts with the Engineering Department—J. H. Best decided to "hop the fence" and throw in his lot with engineering. His prior experience had been in production control at Sperry Gyroscope, as assembly foreman at Permuttit Company and in various production capacities and tool design at Bendix Radio. Massachusetts Institute of Technology had awarded him a B.S. in Industrial Engineering in 1935, however, and he had been elected to the Tau Beta Pi, so the shift was a perfectly logical one. He attended public schools in New York State, completing his college preparatory at Phillips Academy, Andover, Massachusetts, in 1931. For the last six months in the Mechanical Engineering Section, he has been project engineer on vibration isolation problems encountered in the construction of aircraft radio equipment.

mounts is an important factor. The degree of importance is determined by the constants of the unit, and can be found only after these constants are known. Placement, of course, should be symmetrical with the center of gravity The instrument designer should note that decreasing the center-to-center distance to lower the resonant frequency of relatively tall units, increases the possible static and shock forces at the mount. Separate snubbers may be placed at the corners to take care of these forces.

Advantage in New Design

The increased vibration isolation which can be obtained from the modified mounting units over that obtained from conventional mounts is shown in figures 4 and 5. Mounting units having the improved properties described are not yet commercially available for application by the equipment designer, although one company is now supplying complete assemblies.

Cross Sections

Solve Stenciling Problem in Labs

UPON RECEIPT OF the current Army specification on transformers, requiring that identification schematics be imprinted on all transformer cans, H. J. Oosterling, Transformer Section Chief, found that the use of regular type stencils and rubber stamps was unsatisfactory; that steel stamps are impractical because they place the cost out of line; and that to attach name plates and keep them in place presents many difficult problems.

In collaboration with R. J. Streb, Section Chief of Mechanical Engineering, experiments with different types of stencils resulted in finding one effective for use on black painted surfaces. Units treated by this process have been subjected to the Navy five-cycle salt immersion test and to 2000 hours of humidity tests without deterioration. The plan of dividing lengthy schematics has been adopted so that information is continued on two or even three surfaces. Samples on 14 units have recently been submitted to the Signal Corps for approval. Tests are now under way to determine whether a black imprint on plain tin surfaces applied by the same method will adhere strongly enough to prevent chipping off.

In order to obtain surface for soldering terminals to transformer cans, the two sections conducted investigations and set up facilities at Bendix for fusing tin plate. In this process, the parts to be fused are placed in a wire basket and immersed in 500°F Crisco for one minute. The original dull, harsh finish comes out shiny and smooth, and presents a perfect surface for soldering joints. The flawless electro-plating job required is done in plating tanks under the direction of chemists from the Mechanical Engineering Section.

Add New Models To Compass Line

PRODUCTION FOLLOW-UP on Radio Compass MN-26, and development of new models are continuing in the Receiver Laboratory, with W. G. Yates acting as project engineer on the entire line.

A number of installations of the MN-26HB, completed in Receiver Engineering according to a design drawn up by R. F. Hoover and R. L. Daniel, Sales Engineers, have been made, and other units are in production. This model can be operated either as a left-right or automatic compass, the changeover requiring only a few connection adjustments in the junction box.

The MN-26LB is a three band left-right compass, two bands of which are used for compass and communication, and one for communication only. A new arrangement of r-f units, originally designed by Vernon Moore, Receiver Engineering, permits adjustments of trimmer and inductance screws from the top and front of the equipment without removing the cans. This simplifies alignment both in production and in the field. To effect this change, coils inside the cans were rearranged, with the added advantage that undesired coupling between the coils was reduced, thus further minimizing tuning error in the compass. All future MN-26 Radio Compasses will use the new can design. Earlier compasses on which the change is made, will be identified by means of a "-2" added to the former nomenclature.

The MN-26F is an automatic compass in which the new r-f cans have been incorporated. This model introduces a new frequency range: 200-410 kc for Band 1; 850-1750 kc for Band 2; 2.8-5.8 mc for Band 3. Like the LB model, compass action is restricted to Bands 1 and 2. All three bands are used for communication.

The MN-26UA, soon to be released, is the same as the HB except that it operates from 28v instead of 14v.

Changes Made In Engineering Setup

W. L. WEBB, FORMERLY CHIEF ENGINEER, has been made Director of Engineering and Research in a reorganization of the Engineering Department. A. E. Abel, formerly Chief of the Microwave Section, was named Chief Engineer of all military, aviation, railroad and radar products. Mr. Abel has been associated with Bendix Radio since 1937, as Transmitter Engineer in the Washington plant and as Section Chief first of Transmitter and then of Microwave Engineering. Before coming to Bendix he was Research Assistant in Rails Investigation at the University of Illinois, and spent several years with the Radio Corporation of America. R. K. Frazier is the newly appointed Section Chief of Microwave Engineering.

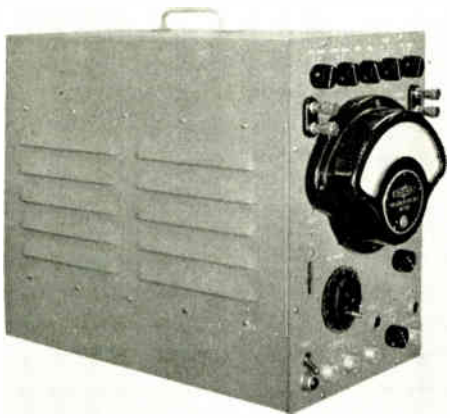
H. M. Detrick comes to Bendix Radio as Chief Engineer of the Broadcast Receiver Section after twenty years of experience in the design field. As Assistant Chief Engineer at the Silver Marshal Company, Chief Engineer of McMurdo Silver, Incorporated, Vice President and Chief Engineer of Hallicrafters Corporation, Chief Engineer of Clough-Brengle Company, the Stewart-Warner home radio receiver division and of General Instrument Company, Mr. Detrick has made many contributions to radio receiver design, and has acquired broad experience in practically all phases of the radio manufacturing business.

In his new capacity Mr. Detrick is in charge of the development of receivers for home use, and has in preparation designs for a full line of table models, console combinations, portables and farm receivers which will be ready when civilian production begins.

Phase, Frequency Meter Completed

DR. HAROLD GOLDBERG, of the Research and Development Section, has recently completed an audio and r-f phase and frequency meter which covers an audio range of 20 to 5000 cps and a radio frequency range of 200 kc to 10 mc. It is direct reading on both ranges, on two alternate scales, 0° to 360° and +180° to +180°, graduated every 5 degrees. Phase reading is independent of frequency on the audio range.

All phase measurements are actually made in the audio portion of the circuit and are accomplished by generating a current pulse of constant amplitude, the width



Audio and r-f phase and frequency meter.

of which is proportional to the phase difference. Radio frequency phase measurements are made by heterodyning the radio frequency input down to the audio range.

A notable feature is the simple operation whereby the audio portion of the equipment is converted to a direct reading frequency meter covering the range from 0 to 3600 cps.

The instrument operates from 105-125 volt, 60 cycle, 140 watt power supply. The d-c supply is electronically regulated. R-f input is either through a coaxial fitting which terminates the coaxial line in its characteristic impedance, or through a pair of high impedance probes which couple to the phase meter by means of coaxial lines.

The equipment is self-calibrating on phase, but frequency calibration requires an external oscillator.

Preliminary tests indicate that under conditions of proper operation an accuracy of better than ±2% of full scale may be expected on both phase and frequency readings.

Iron Core Loops Reduce Air Drag

INVESTIGATIONS CONDUCTED BY G. O. Essex, Receiver Engineer, with Kearfott Engineering Company cooperating on problems of mechanical design, have led to the development of an iron core loop, which has an air drag of less than 2½ pounds at 250 mph, and at lower frequencies has a sensitivity equal to present air core loops.

A unique feature of the new loop assembly is hermetic sealing which need not be disturbed even when making compensator adjustments. After assembly, the complete unit is exhausted, then filled with an inert gas at approximately one-half the atmospheric pressure, and sealed. This prevents accumulation of moisture and oxidization of bearing surfaces. Captive screws are located on the outside of the unit so that correction may be applied to the compensator through sealed metal bellows.

The loop antenna proper is housed in a 3/16 inch special glass dome. The rim of the dome is surfaced with metal so that it may be soldered to a metal baseplate. When installed in the air stream of an aircraft, the loop section is covered with a streamlined housing, which is approximately 16¾ inches long, 6 inches high at its peak, and 5½ inches wide at the base, tapering toward the top. If the loop is installed under an existing streamline blister on the plane or inside of a nonmetal aircraft, the housing may be eliminated.

The loop drive motor, gear train, autosyn transmitter, slip rings, bearings and compensator, located on the opposite side of the base plate and inside the plane, are hermetically sealed in brass with overlapping soldered joints. All leads are brought out through glass sealed terminals.

The entire assembly weighs approximately ten pounds.

Plan N. Y. Show Of Rail Paintings

"RAILROADING IN AMERICA," a series of 20 water colors selected from those painted by John M. Sitton of the Technical Publications staff for Bendix as part of its railroad radio program, will be placed on exhibition at the Grand Central Art Galleries in New York sometime in the early fall. The exhibit is to be sponsored by the Bendix Aviation Corporation.

One of the large galleries of the Grand Central will be devoted to the paintings, which show railroading throughout the country—from the Great Lakes to the swamplands of Florida, and from the harbor of New York to the deserts and high Sierras of the West. The water colors were painted by Sitton during the early part of the year. Cooperating in the project were the Baltimore and Ohio; the Jacksonville Terminal Company; the Atchison, Topeka and Santa Fe; the Denver and Rio Grande Western; the Chicago, Burlington and Quincy; the Southern Pacific; the Chicago, Milwaukee, St. Paul, and Pacific; and the Pere Marquette.

The two-week exhibit will be preceded by a preview to which railroad officials, government officials, and other interested persons will be invited.

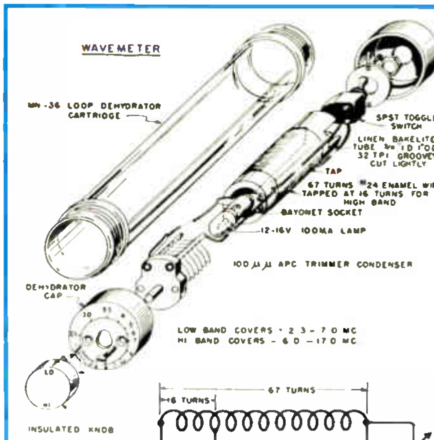
Bendix Units In Diesel Exhibit

A NEW DIESEL LOCOMOTIVE, equipped with a Bendix Radio communications system, is now making a tour of all the railroads in the country as an exhibit of the latest in Diesel equipment. The Electromotive Corporation of LaGrange, Illinois, designed the locomotive which is made up of two 2700 hp units. L. B. Gilmer, sales engineering, was in charge of the installation.

Publish Booklet On RTA Tuning

ON HIS RETURN FROM a visit to a number of ATC bases throughout the country, J. W. Scalbom of the Service Department prepared a handbook of instructions to aid inexperienced operators in tuning the RTA-1B transmitter. Donal G. Erskine and the staff of Technical Publications assisted with the layout.

Generously illustrated, this booklet gives a simple, step by step description of the tuning process. Blank tables are provided for recording tuning data, including the relative positions of antenna and plate rollers in the output coil, for each channel in the



Easily built wavemeter for RTA-1B.

transmitter. Data thus prepared for a certain type of airplane can be retained for future reference when tuning is again required for the same type of plane. The handbook is available without cost, singly or in quantity, by applying to W. L. Cunningham, head of the Service Department.

The wavemeter used by Scalbom for tuning purposes (see illustration) was made by him from materials readily available to Army personnel, and can easily be duplicated. The container, for example, is a dehydrator cartridge from an automatic loop.

Gives Talks On Quality Control

ANALYSIS OF THE RESULTS of nine months' trial of a statistical method of quality control in Bendix Radio inspection and production procedures, has furnished basic material for several lectures delivered by Dr. S. B. Littauer of the Engineering Research and Development Section. On invitation of the War Production Board he has spoken at Temple University, and again at Princeton University as the guest of the Princeton Quality Control Group. He also addressed the Materials Committee of the Bendix Aviation Corporation.

As a means of facilitating application of the new statistical method, which has more than doubled the quality level of a number of products while reducing inspection to one-fifth of the previous requirement, Dr. Littauer has also cooperated with B. L. Sander, Administrative Assistant of the Test and Inspection Department, in organizing training courses for inspection and production personnel.

General Colton And Staff Visit Plant

MAJOR GENERAL Roger B. Colton, Communication Officer of the AAF in charge of all electronic and radar communication procurement and engineering, made an official visit to the Bendix Radio Towson Plant in the latter part of May, to review the production schedules and development projects.

Accompanied by his staff, General Colton conferred with W. L. Webb, Director of Engineering and Research, J. W. Hammond, Communications Radio Sales Manager, and E. K. Foster, Factory Manager, and made an inspection tour of the plant.

They were later guests at a special luncheon in the plant cafeteria.

Plan Equipment For Small Planes

A DEVELOPMENT PROGRAM FOR light aircraft radio to be used in personal planes has recently been inaugurated at Bendix Radio, and a separate engineering and sales organization set up. George Myrick, formerly Marketing Director for Bendix Radio and at one time administrative consultant to the CAA, is sales manager for the new Flightweight equipment, and Charles F. Luscombe is sales engineer. Luscombe was previously connected with the Service and Parts Department as domestic and foreign field representative in Europe and the Pacific war areas. Vernon Moore, of Receiver Engineering, is in charge of development engineering.

Four types of equipment are planned. The first is a range and broadcast receiver to be used in combination with a vhf transmitter-receiver, operating from a 12v d-c vibrator power supply. Loop reception for auxiliary direction finding is provided for in the former equipment. The crystal controlled vhf transmitter and receiver may be independently set at any one frequency on a 118 to 122 mc band.

The second type of equipment is a portable combination broadcast and range receiver. Operation may be from either a dry battery or 115v a-c or d-c. Design includes a built-in speaker and a self-contained miniature headphone. A loop, built into the case, permits simple direction finding.

The third type of equipment is a single band range receiver operating from a 12v battery. Development of miniature sets is also envisioned to take full advantage of all possible size and weight reductions.

The Sales Department has acquired a Stinson Voyager with a 90 hp Franklin engine which will eventually be used in the eastern part of the country for demonstration purposes, but has meanwhile been loaned to the Engineering Department for flight testing the radio equipment in the new Bendix Flightweight line. Previously operated by the Civil Air Patrol in anti-submarine observation duty off the east coast, the ship had been equipped with a rack for 100-pound bomb. Refinishing is being done in an effective black and white color combination with insignia designed by Donal G. Erskine, General Engineering artist.

PANAGRA Installation Outlined

IN THE OFFICE of V. M. La Pierre, Superintendent of Communications for Pan American-Grace Airways, at Limatambo Airport, Lima, Peru, final plans were outlined for PANAGRA installation of Bendix Radio dual automatic compass and RA-2 Receiver. Shown in the photograph are, left to right, R. V. Bruland, PANAGRA project engineer; Don Pomeroy, Bendix Radio South American representative; Mr. La Pierre, holding MN-42B Dual Azimuth Indicator; and Bob Daniel, Bendix Radio Sales Engineer who collaborated with company engineers in the first installation. On completion of subsequent installations in the 19 DC-3A's, PANAGRA flights will be made with 100% Bendix Radio equipment. Map shows route covering eight South American countries over which Bendix Radio equipment flies in PANAGRA planes.

The editorial and art staff of the Technical Publications Section is preparing an illustrated pamphlet to be circulated among aviation committees throughout the country, aircraft manufacturers, and fixed base operators, describing the advantage obtained from radio in private flying.

New Posts For Bendix Engineers

H. L. Spencer was elected Vice Chairman of the Baltimore Section IRE at the June meeting of the group. Other officers named at this time were Ralph N. Harmon, Chairman, and Fred W. Fischer, Secretary-Treasurer, both of Westinghouse Electric and Manufacturing Company.

W. A. Willis, member of Bendix Aviation Materials Committee, has been appointed Chairman of the Materials Standards Sub-Committee of Bendix Aviation Corporation, replacing H. L. Spencer who recently resigned.

W. L. Webb has recently been elected a Director of the Engineers Club of Baltimore. He represents the Baltimore Section of the IRE.

P. B. Tanner (left), and J. B. Gale (right), Manager of Training, with Emiliano Ruiz Diaz of Paraguay and Sze Fu Chen of China who are receiving practical technical training at Bendix Radio, were among those honored by the International Training Administration at a testimonial dinner.

Audio Amplifier Built for DC-4's

S. R. Fund of the Receiver Laboratory has developed a multi-channel audio amplifier with remote control, following the preliminary design prepared by R. L. Daniel, Sales Engineer, in collaboration with Aeronautical Radio, Incorporated. The new unit, for use in DC-4 type planes, makes it possible for any member of an airplane crew to select a receiver or a number of receivers without interfering with the reception of other crew members by introducing unwanted interconnections. The undesired output from any channel, resulting from coupling from any other channel, is held at least 50 db below the selected channel. Increased flexibility in operation is thus obtained. Vibration problems are solved by locating the new amplifiers in the radio rack instead of providing individual units in each jack box.

Six amplifiers, four for receiver output and two for crew interphone, and a 200-volt dynamotor, are mounted in a Standard Aircraft Radio Case (SARC, which replaces ATR), 19 inches long, built so that all connections are made at a 32-contact plug in the rear of the unit. The plug is engaged when the unit is placed on its shockmount.

Operation from either 14 or 28 volt d-c supply is provided by exchanging dynamotors to conform with the power supply of the plane in which it is to be used. Required jumper connections are available in the disconnect plug.

The amplifier sections have a minimum over-all gain of 40 db at 1000 cycles, with fidelity such that the audio output remains within 4 db from 300 to 3000 cycles. Distortion measured at 1000 cycles and 50 mw output does not exceed 3%. A 12A6 tube was chosen because it was found to give the necessary gain with a minimum of distortion.

Honor Technicians Trained At Bendix

Emiliano Ruiz Diaz of Paraguay and Sze Fu Chen of China, who, since last April, have been receiving their practical radio training at Bendix Radio, were among the ten guests of honor at a testimonial dinner given by the International Training Administration. These ten technicians, in this country under an arrangement between the Brazilian, Paraguayan, Chinese and Turkish Governments and our own International Training Administration, are working in several Baltimore industrial plants to obtain instruction and experience in their chosen fields.

Ruiz Diaz holds a degree in Electrical Engineering from the National University at Asunción, where he majored in navigation and radio. He came to this country on a government scholarship, and arrangements were made through the office of the International Training Administration by P. B. Tanner, Manager of Engineering Sales at Bendix Radio, to introduce him to Bendix methods of manufacture and maintenance.

Sze, also a graduate Electrical Engineer, received his degree at the American College in Chungking, specializing in radio and communication. After working for several years as radio repairman and on radio installations, he spent two years with the ATC in the service of the Chinese Government established in India, and was finally sent to this country by his government specifically to learn maintenance methods on aircraft radio equipment.

Their Bendix Radio training has taken them first through the engineering training tour of the Towson Plant, under the direction of O. L. Peterson, Personnel Coordinator of the Engineering Department, then, successively, into the Production Standards Department to become familiar with the activities of the processing, production methods and time study groups; into manufacturing, assembly, inspection and test departments; and finally through a period of actual experience in trouble shooting and repairing in the Service Department.

Sze, after additional experience in other industrial plants, will return to his native country to take charge of the maintenance of aircraft radio equipment for the Chinese Government. Ruiz Diaz plans to establish himself in private business in Paraguay in the field of radio servicing, especially aircraft radio, for which few qualified engineers are at present available.

ENGINEERS on the GO

RMA Capacitor Committee meetings in New York and Philadelphia were attended by H. A. Cook, who also went to a wire specifications meeting at Fort Monmouth, N. J., and investigated new parts at Resistor Instrument, Little Falls, N. Y.; I. T. E. Circuit Breaker at Philadelphia; Erie Resistor Company at Erie, Pa.; Weston and Westinghouse at Newark, N. J.; Telex Products in New York; and Aerovox Corporation at New Bedford, Mass.

A crystal frequency indicator was discussed by P. G. Click at the Bureau of Ships in Washington.

The operation of a high frequency amplifier was demonstrated at Red Bank, N. J., by H. M. Huckleberry and R. S. Leister. Huckleberry then went to Continental Electric at Newark, N. J.

Proposed transformer specifications were the subject of a transformer conference held at the Signal Corps Inspection Office at Newark, N. J. A. J. Rohner and H. J. Oosterling attended, with manufacturers and all branches of the armed services represented. Oosterling, official representative of Bendix Radio, was selected as alternate on the manufacturers' committee. Oosterling and E. S. Oakes also attended a transformer conference at Hudson American Corporation in Brooklyn, N. Y.

Films of Bendix equipment were reviewed at the Pentagon in Washington by O. L. Peterson and Capt. A. B. Gittelman.

F. M. Hoeprich, Bendix engineering representative to Transmitter Equipment Company in New York, made several trips there for engineering conferences.

New equipment was tested at Fort Monroe, Va., and at Fort Hancock, N. J., by A. R. Keskinen, R. J. Davis, and W. Tuddenham.

"Aircraft Electronic Avigation Devices" was the subject of a talk delivered at the Curtiss-Wright Engineering Forum at Buffalo by Dr. S. B. Littauer.

A Bendix Aviation Drafting Standards meeting in New York was attended by L. T. Bard, who also visited Remington Rand's Microfilm Laboratories and the Microstat Corporation.

D. Garrison flew to General Mills, Incorporated, at Minneapolis.

A license for a television station was discussed by D. C. Hierath at the Federal Communications Commission in Washington.

Projects originating in his section were the subjects of visits by W. H. Sims, Jr., to Hudson American Corporation in Brooklyn; Robinson Aviation in New York; Multi-Products in Newark; and Allied Control in New York.

W. A. Willis attended a Bendix Aviation Materials Committee meeting in New York.

Danly Machine Specialty Company in Chicago was visited by W. E. Bartles, who discussed the building of special parts for a new equipment with engineers there.

Various projects under way necessitated trips by N. Raymond to Wright Field, Sparks-Withington at Jackson, Mich., and Colonial Radio at Buffalo, N. Y.

V. Moore attended an S. A. E. meeting in Dayton, Ohio, and went to Washington concerning radio installations on private planes.

A new control panel was discussed by R. V. Lindner at Hudson American Corporation in Brooklyn.

G. R. White discussed the standardization of Q meters at Boonton Radio Corporation in New York.

A. C. Omberg visited Wright Field and, with W. H. Sims, Jr., went to the State Department preparatory to going overseas as technical observers.

L. R. Yates conferred with officials at Airadio, Incorporated, at Stamford, Conn.

H. Walker attended a conference at Wright Field, Dayton, Ohio.

A tooling project was discussed at Hudson American Corporation in Brooklyn by J. R. Mason. Mason also went to Multi-Products in Newark, N. J., concerning a motor drive.

A quality control conference at Princeton, N. J., was attended by A. C. Omberg and Dr. S. B. Littauer. They also visited the quality control group at Temple University in Philadelphia, and attended an engineering conference at the Eclipse-Pioneer Division at Teterboro, N. J., concerning the dual radio magnetic indicator.

Hazeltine Electronics Corporation in New York was visited by W. E. Monroe, Jr., S. Larick, and A. E. Abel.

J. P. Shanklin visited the Puget Sound Navy Yard at Bremerton, Wash.

H. M. Huckleberry toured fourteen Army Air Base with communications officers from the Air Transport Command viewing Bendix equipment.

A conference on antennas in Boston, Mass., was attended by R. J. Streb and H. V. Hermansen. Streb went to New York to discuss a new control with officials at American Type Founders and to discuss shockmounts at Robinson Aviation.

W. L. Webb visited the Bartol Research Foundation at Temple University in Philadelphia; the Bureau of Ships Naval Research Laboratories and the State Department in Washington; attended conferences at Wright Field; visited the Columbia Recording Company at Bridgeport, Conn.; then went to the New York office at Rockefeller Center.

Research developments for new equipments were discussed at Massachusetts Institute of Technology by A. R. Keskinen, W. Tuddenham, and M. Hecker.

A new phonograph pickup device and electronic inventions for pianos and phonographs invented by B. F. Miessner were viewed by D. C. Hierath, G. Eltgroth, and H. M. Detrick at Miessner's Morristown, N. J., laboratory.

A CAA meeting in Washington on radio compass equipments was attended by G. O. Essex. Essex and A. A. Hemphill visited Norfolk, Va., concerning radio equipment for a Navy installation.

E. L. Weigel went to the Hudson American Corporation in Brooklyn concerning a control box he engineered. Weigel also attended a conference at Wright Field concerning the same equipment.

D. W. Martin spent a week at the direction finder site of Federal Telephone and Radio Corporation in Newark, N. J., and visited the Bureau of Ships in Washington.

The flux gate compass installation on the Bendix Radio Lodestar at Washington National Airport was inspected by A. C. Omberg, B. Ochterbeck, R. Colvin, G. E. Bevins, and Dr. S. B. Littauer.

Earthbound FLIGHT

The engine roars for the take-off, then settles into a loud drone as the instruments show manifold pressures of 27 inches, propellers synchronized, airspeed of 160 knots and an altitude of 5000 feet. A few minutes later the navigator directs the pilot over the intercom with "At 1500 head 282 degrees magnetic. Estimated time to target 57 minutes." The radioman reports the plane's positions and time of departure over the bomber's transmitter.

At that time, in response to a command over the intercom, the engines die to a whisper, and then are quiet; the pilot crawls from the cockpit, and the navigator and radio operator step from a hut in the corner. Outside, an instructor waits to hold a post mortem on this elementary lesson in flight. One advantage of learning to fly on the ground is that students learn from their mistakes instead of being killed by them. So, in the Special Devices Division of the Bureau of Aeronautics, mockups of regulation Navy equipment are built to simulate flight conditions.

Before this war, classroom training was followed directly by actual training flights. Now that student experience with special devices is sandwiched between the two other types of training, the completed course takes less time and less money. For example, training a bomber pilot in addition to his classroom work, formerly took 60-80 hours of flight at a cost of $350 an hour. Now, with a demonstration panel salvaged from a bomber, some sound effects, and an instructor's control panel, the student pilot can go through the motions of flying all day for about a dollar.

The navigation trainer is a more ambitious project designed to help the navigator, radio operator, and pilot work together as a crew. It has three units—a Link trainer for the pilot, a control board for the instructor, and a hut or cubicle resembling the interior of a Navy patrol bomber and fitted with navigation and radio equipment. One such cubicle has recently been equipped with the Bendix TA-12, RA-10, and MN-26, and is now used at the Naval Air Station in Lake City, Florida. Two prototypes were made by the Navy and tested in the field before being turned over to the Flight Training Research Association for the production of fifty such trainers. The Navy furnishes the gear out of stock, but the contractor builds the cubicle, and assembles the cables, and installs the equipment.

Transmitters feed into dummy antennas. At the control board, the instructor can monitor three or four transmitting frequencies and operate on at least two. He uses a Bendix LM-10 for crystal frequency indication.

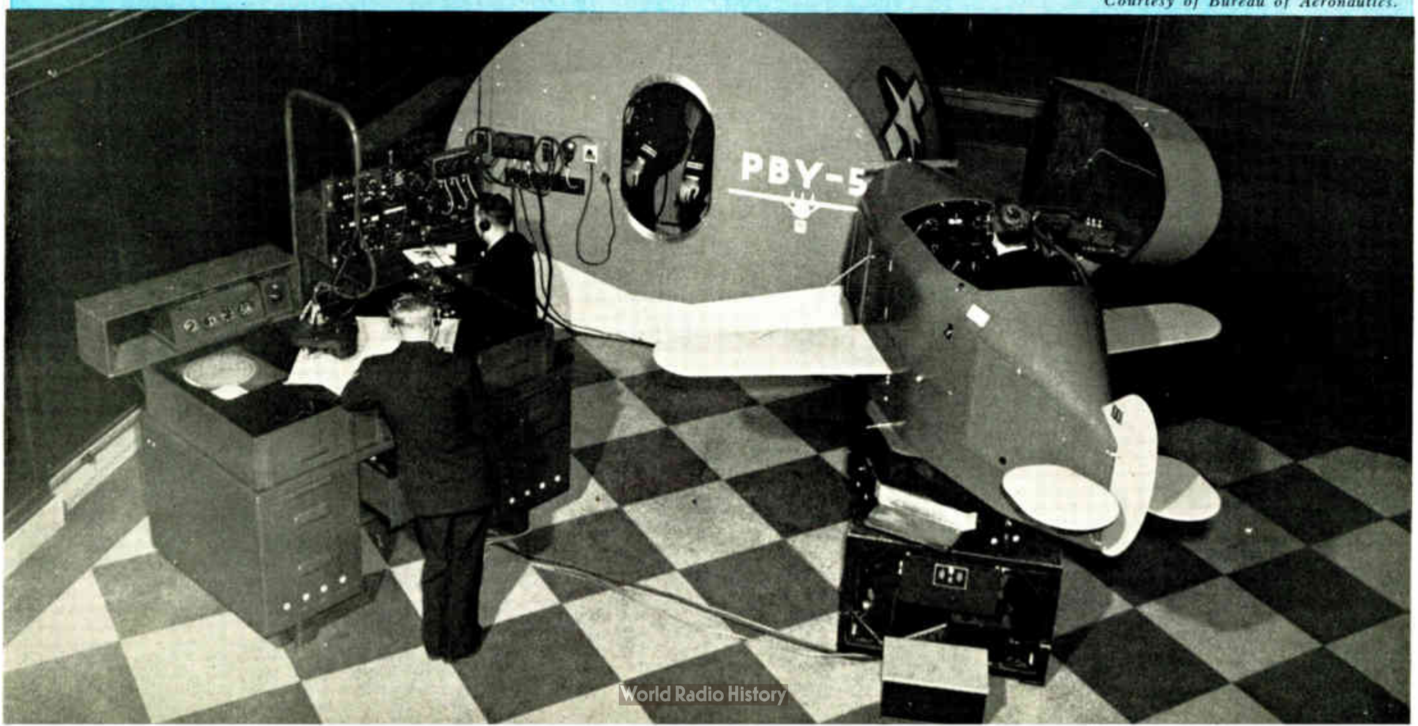
Direction finders in use on these trainers range from the antique DW-1 to the SCR-269, MN-26, and MN-31. Old equipment is still in use since, in spite of top priority, there is some lag between the first delivery of equipment to the Navy and its assignment to training devices. Compass equipment is particularly important because of the radio operator's need for training in taking bearings. Errors, caused by unfamiliarity with equipment, arouse the navigator's distrust; but a crew accustomed to working together in a trainer soon learn how to avoid mistakes, and how to make full use of the direction finding equipment. For navigation, the radio compass in the trainer is accurate within 1 to 1½ degrees—a relatively unimportant error.

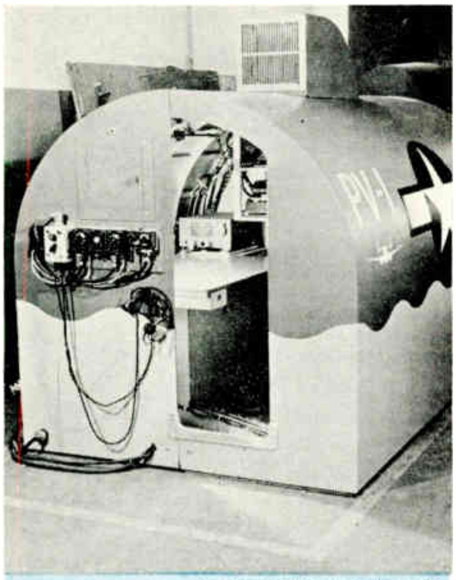
With the growing complexity of naval airplanes and their weapons, the training devices must grow in size and intricacy. The adoption of the F6F fighter two years ago, for instance, resulted in a giant contraption with all the characteristics of the plane. Thyratrons, relays, and servos throughout the equipment provide almost complete electronic control; vacuum control is used only to give the soft feel of the gears. In addition to the instructor's control panel, this equipment is supplemented by a mechanical device which records the details of the flight on a chart at a nearby table.

Not all of the training devices are such awesome machines. Often found in naval recreation rooms is an innocent looking

Complete crew navigation trainer for PBY-5 with instructor's control board at left, cubicle for navigator and radio man in center, and Link trainer for pilot on the right.

Courtesy of Bureau of Aeronautics.





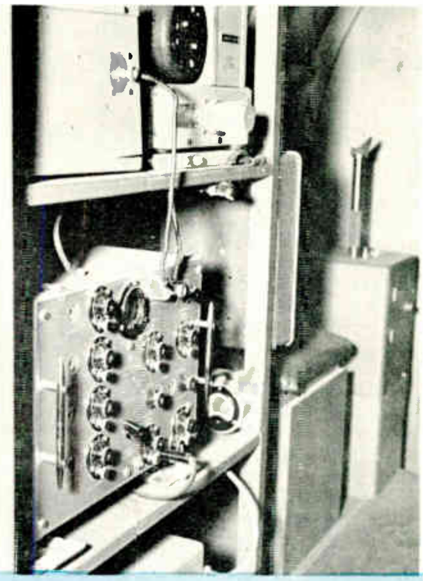
Courtesy of Bureau of Aeronautics

Crew training cubicle for PV-1 with MI-22A Station Box and controls at left of opening, and MN-26 Radio Compass on shelf at right of navigator's station.

adaptation of a pinball machine which drills enlisted men who wish to improve their ratings. With the push of a button, a card flips into sight showing a question and a list of possible answers; the ambitious tyro presses a button with the number of what he hopes is the correct answer. If he muffs it, an embarrassing red sign "INCORRECT" spreads across the light board; if he is right, a golden "CORRECT" shines forth. This mechanical wizard also counts the seconds it took him to indicate the answer, and totes up his score in as baffling a way as any professor ever devised.

Kites also contribute to the training of naval aviators. A target kite emblazoned with a silhouette of a Jap plane flies about 150 feet high at sea, or can be trailed over the countryside by jeep. Its rudder and bridle assembly provides realistic action so easily controlled that its operator can indulge in some ephemeral skywriting.

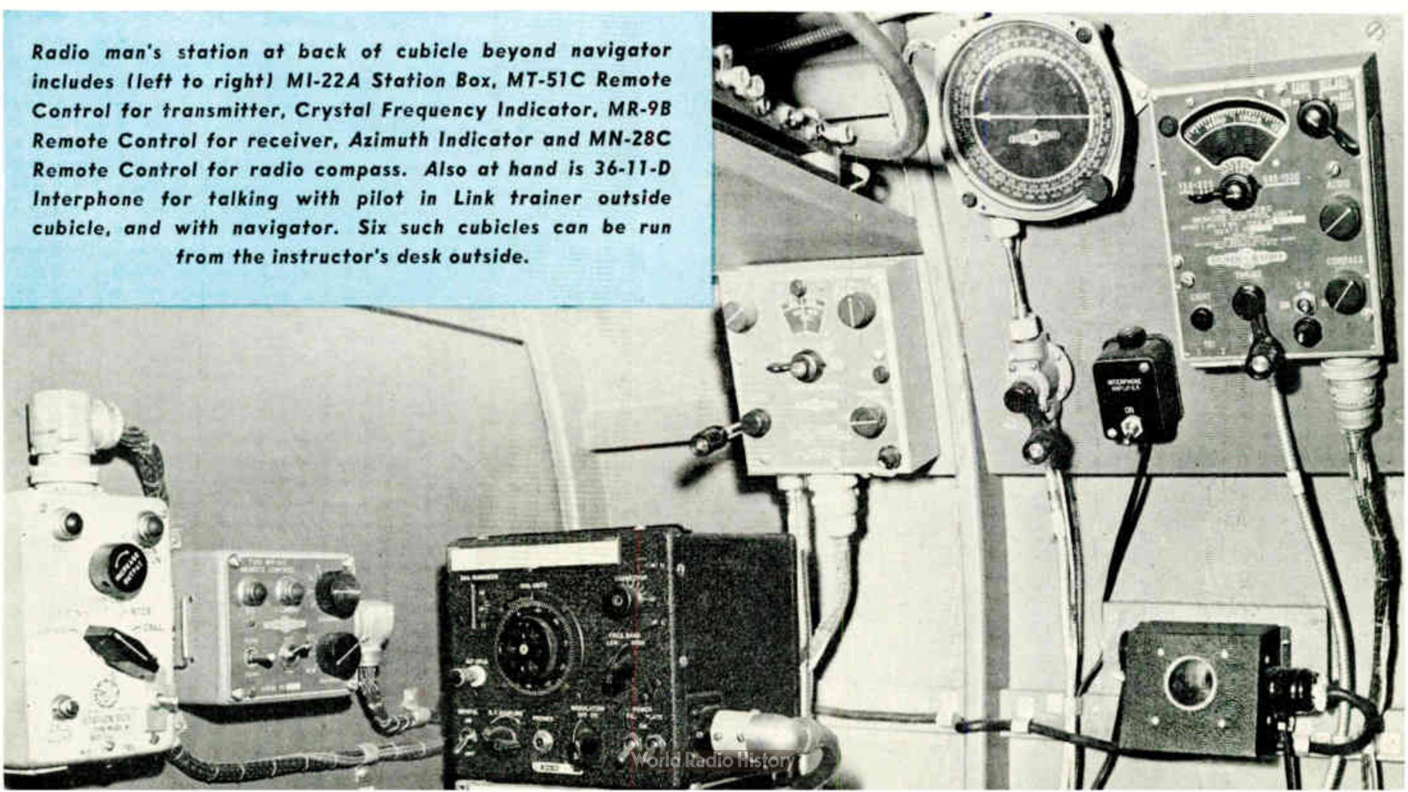
Whatever the atmosphere of game-playing and competition, the devices are carefully planned for efficient training. In gunnery, for instance, the student begins with a range estimation trainer—an oversized coffin-like box with observation sights protruding from the end. Through one of these sights, a student sees an enemy plane in the murky distance which must be calculated. More complicated problems are presented when, under the control of an instructor, the color of the sky changes, and the distance and angle of the plane change. Mastery of ranging is followed by training in turret control at first by sighting a light spot which moves across a screen in an unpredictable pattern. Because the spot is controlled by two irregularly shaped cams moving in opposite directions, its pattern is not repeated until 13 hours have elapsed—long enough to prevent high-powered memory work by the trainees. Next the free gunnery student learns to aim at a moving photograph of a plane on a screen. Training for the fighter pilot comes in a Gunairstructor equipped with moving picture screen, control instruments for the instructor, and a cockpit equipped with controls and sights. In action, the plane roars, the enemy plane flashes across the screen, and the student takes desperate aim. Given only half a minute of ammunition, he soon learns the folly of being trigger happy; he aims carefully before pressing the trigger. Then the rattle of the machine gun reverberates in the hut and—if he is lucky—the elusive plane flashes red for an instant before it goes on playing hard to get.



Behind PV-1 navigator is stored TA-12 Transmitter and (above) MT-53B Antenna Loading Unit and MP-28 BA Power Supply. RA-10 Receiver is not shown in picture.

The difficulty of this lesson, as with most of the other devices, depends on the instructor. Recently a commander just back from the Pacific was given a strenuous workout at the student controls with a lieutenant as instructor. From the cubicle the commander emerged red-faced and awed by the magic of the electrical circuits and the ingenuity of the instructor. Only then was he told that he had met a gambler's fate—the percentage against him was 60-40.

Radio man's station at back of cubicle beyond navigator includes (left to right) MI-22A Station Box, MT-51C Remote Control for transmitter, Crystal Frequency Indicator, MR-9B Remote Control for receiver, Azimuth Indicator and MN-28C Remote Control for radio compass. Also at hand is 36-11-D Interphone for talking with pilot in Link trainer outside cubicle, and with navigator. Six such cubicles can be run from the instructor's desk outside.



MECHANICAL STANDARDS MANUAL

An authentic reference on Bendix Radio mechanical design practices is being prepared by the Mechanical Standards Committee to establish uniform procedure throughout the plant, thus avoiding production snarls and costly salvage. It will resolve differences of opinion among departments and engineering sections into standards acceptable to all.

Standard drafting practices, covering the minimum information required on all drawings, will be established and published in the manual. Suitable instructions are to be provided stating how to specify tolerances and exact dimensioning to insure abnormally close fits and precision workmanship where necessary. As a further aid to the design engineer and draftsman, useful manufacturing and fabricating information will be included, as well as helpful notes on machine shop and mill practices. On the other side of the picture, information will be provided, within practical limits, on all matters related to mechanical design which cannot be included on drawings, such as quality of workmanship expected for various types of manufacture, and fabrication processes generally employed. This information will not, however, be referenced to specific drawings and is not intended in any sense to fix legal boundaries. Routine reference tools of all mechanical design engineers, such as data sheets, reference tables, processing information, and Bendix Radio drafting practices, will be incorporated in the contents, as well as inspection limits on such matters as flatness, squareness, straightness, and parallelism.

Engineering Organization

(Continued from page 5)

On the other hand, in the design of a consumer product, such as broadcast receivers, where production might be between 1000 to 4000 per day, extreme care must be taken with each detail, for a failure in the field or a line shut-down means the return of thousands of sets, or the loss of production of thousands of sets.

We also must find a simpler and faster method of handling the design and manufacture of orders for new equipments in quantities as small as from 5 to 50. It is my opinion that for this type of order we must bypass a great many of our controls. We should assign engineering, production, and test personnel to the job, and allow them to work together as a team, making complete drawings or parts lists unnecessary. Engineering releases could be made informally and no material control would be involved. The group would handle its own requisitions and accumulate material in its assigned area. Thus, Engineering Service, Planning, Material Control, IBM and all other control departments would be bypassed. We must operate in this manner if we are to compete with smaller firms on special products.

Finally, there must be flexibility in our thinking so that our primary objectives can be accomplished, regardless of the necessity for changes in established practices and departmental organization, or in the shifting of facilities and personnel.

VACUUM SWITCHES

(Continued from page 13)

This value is greater than the actual acceleration for small intervals of time (see figure 11).

If we use this value, $s = 28.8 \times 10^{-9}$ inch for 3.333 microseconds (the time for one cycle at 300 kilocycles), the actual distance would be smaller.

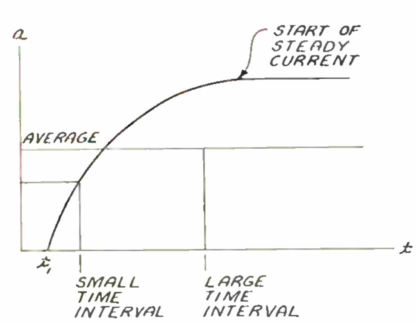


Figure 11—Graph of acceleration build-up with time, as contact opens.

The known interval of time before the arc forms is 200 microseconds after the contacts start to open. The simplified formula gives $s = .1038 \times 10^{-3}$ inch which value is, of course, in error on the larger side. It is apparent therefore that the formula selected should be governed by the accuracy required and the particular interval being sought.

The formula for the capacity between parallel plates is

$$C = \frac{KA}{36\pi d \times 10^5}\ \mu\text{fd},$$

where

K = dielectric constant,

A = plate area in square centimeters,

d = distance in centimeters between plates ($d = 28.8 \times 10^{-9}$ inches $= 7.32 \times 10^{-8}$ cm).

From measurement, the contact diameter was found to be 0.090 inch or 0.228 cm. Therefore,

$$A = (0.114)^2\pi = .040859 \text{ cm.}$$

Substituting the values of K, A and D we get

$$C = .0493\ \mu\text{fd.}$$

From this value of C we can conclude that for a short time after the relay contacts opened, such as the time of one cycle at 300 kc, the contact capacity was too high for the arc to form. A 0.0493 µfd capacity is about 10.8 ohms reactance at 300 kc. At 1.7 ampere, the voltage drop across the contacts under these conditions is about 18.4 volts. Since we know that the actual contact spacing is less than the value used to compute the contact capacity we can be sure that the actual contact capacity would be more than the value given in this discussion.

Let us now consider the contact spacing of 0.1038×10^{-3} inch computed with an assumed average acceleration for the time 200 microseconds. This contact spacing gives a capacity value of 13.7 µµfd, which is too small to influence the arc formation at 314 kc.

Evidently the time of arc voltage drop formation shown in figure 5 is not dependent on the capacity alone, but also on the resistance of the arc. Consideration of the spacing of the contacts at the time the arc was broken (1310 microseconds after opening started) indicates that the computed 0.002 inch spacing gives a capacity of approximately 0.7 µµfd. This capacity is too small to prevent the current from being interrupted even at very high frequencies. At 100 mc, for instance, the capacitive reactance is approximately 2250 ohms. It can be concluded that even though the radio frequency determines when the arc is formed after the relay contacts have opened, it is not likely to influence the time in which the arc is broken, unless the radio frequency is of the order of 50 mc or more. If the frequency is sufficiently high, an arc might not form at all and only capacity current flows after contact separation.

It is hoped that the physical and mathematical data presented here will prove useful to other engineers interested in using vacuum relays in any of the many applications for which they are suitable.

The writer wishes to thank Dr. John W. Hurst of Microwave Engineering for assistance in checking the derivation of the formulas used in this article.

As We heard it

Music Appreciation

Going to a party on one of the islands of the southwest Pacific turned out to be a good stroke of business for Signal Corps troops. One stifling day as they toiled along searching for a break in a telephone line, a messenger from a native chieftain invited them to a local banquet. They accepted the invitation, and went back to their work grumbling at the frequency with which telephone lines had to be repaired on that island. As usual, they found a stretch of wire missing entirely from the line—and no clues, no corpse strangled with wire, not even a footprint.

Having failed as detectives, the GI linemen went off to be the life of the party. The food was plenteous, the girls were lush if not beautiful, and native dancing followed the meal. One jaded observer of the dance turned from the gyrating girls to the musicians who were administering a few hot licks on native instruments. The gleaming strings of a banjo caught his attention and he feigned tourist curiosity in order to confirm his suspicions about the wire. He was right. A pow-wow with native chiefs cut down the Signal Corps repair bill in no time.

Life Abroad

When the American Liberty ship carrying aerial bombs exploded in the Bari harbor shortly before noon April ninth, causing what the Associated Press termed, "one of the major disasters of the war in the Mediterranean theater," J. Walton Colvin, Service Department field representative in that area, was an eye witness. A moment before, he had been within a hundred feet of the scene where suddenly a huge ball of fire and terrific blast hurled people violently into the air, killing hundreds and injuring thousands of servicemen and civilians, seriously damaging harbor installations as well as city buildings, setting fire to hundreds of merchant ships moored nearby, and causing a tidal wave which added to the general horror. Colvin was badly shaken and had his face cut. "The experience can't be described," he wrote. "It was worse than any air raid."

Less calamitous was Colvin's difficulty with his third class mail. He complained loudly that he was not receiving the BENDIX RADIO ENGINEER. Duplicate copies were sent twice, but none reached him. Finally, after a long distance huddle, two copies were sent at the same time—one to Colvin, and the other to the office of the Commanding Officer. It worked like a charm.

Occupational Hazards

Al Parker reports that plane accommodations for radio men on duty are something less than luxury liner style. Once on a trial flight to New York, he was aboard the Standard Oil twin-engine plane on which Bendix radio equipment had just been installed. Before the plane was out of sight of the airport, the cabin grew warm and clouded up with spirals of smoke. The pilot, who had flown this nearly-new plane only eight hours, decided to play safe and circle the field. In the meantime, Al and the co-pilot, growing hotter and hotter, peeled out of their coats and feverishly sought the source of the trouble. It turned out to be simple enough—someone had opened a heat valve and the smoke was burning off the heater surfaces.

Another time he was plagued by more than atmospheric difficulties. He was making tuning adjustments on a TA-6 Transmitter while in flight on a Beech D17S plane owned by the Altoona Aviation Corporation. The transmitter had been placed temporarily on the floor of the cabin where the rear seat had been removed. Al, seated on the floor athwartship just behind the pilot and co-pilot, got down to business. As the plane galloped along at a low altitude, he braced himself with his screwdriver to counteract the bumpy flight and thought of Mother Sill's remedy. Next he felt a slow burn—the TA-6 tubes beside his left hip were warming up. Making all adjustments while looking over his shoulder was rather grim, but the resulting stiff neck convinced him that enough's enough.

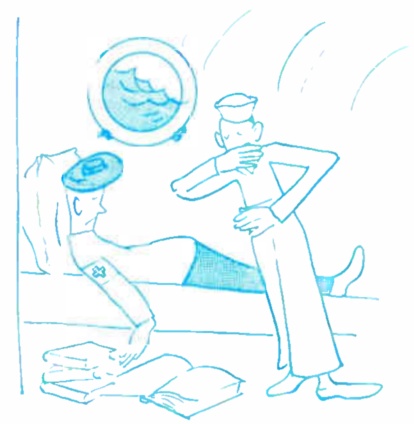
Caribbean Cruise

During a recent trip to Panama on a Navy Aviation Repair Vessel, W. L. Webb did not envy the regular naval personnel who began work at 5:45 A.M. General quarters is sounded at daybreak when all officers and crew dress and go to their battle stations for half an hour of practice in battle routine. Being the Captain's guest brought its own rewards—shooting clay pigeons, for example from a trap set up on deck. When the ship is in port, the Captain has the use of a car with a driver, and a personal "gig" which is a speedboat for his own use.

Rough weather during the first two days of the trip made many of the crew seasick. A Navy doctor on his first trip to sea had been lecturing the officers and men on the theme that seasickness is a mental condition and can be avoided by believing that one will not be seasick. It didn't work. The Navy doctor was confined to his bunk for 24 hours with one of the worst cases of seasickness aboard.

The soda fountain on the ship, which was presented to the officers and crew by Bendix Radio, operates with sufficient profit to give the men free tailor, barber, and laundry service.

Ashore at Panama, Webb practiced his recently acquired Spanish as he went sightseeing among the old churches, Blue Moon Cabarets, and interesting shops.



On the way home, the climate went into reverse. The weather in Panama was delightful as the Navy flying boat lifted and headed north to Miami where it was much warmer. The next day, the plane from Miami stopped briefly at Charleston where it was noticeably warmer, at Norfolk where it was hotter still, and finally landed in Washington—the furnace room of the Americas.

BENDIX RADIO

DIVISION OF BENDIX AVIATION CORPORATION

BALTIMORE, MARYLAND