RADIOTRONICS

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SOME NOTES ON FEEDBACK

By F. Langford-Smith.

1. Pre-distortion of signal with negative feedback.

An amplifier with considerable negative feedback is often regarded as one with low distortion. This is not true for the simple case with overall negative voltage feedback from output to input. In this case the distortion of the amplifier itself is not changed by the feedback but the input voltage is pre-distorted in such a way as to produce an almost distortionless output voltage.

This may be illustrated by the example of Fig. 1. The input voltage E_i' is of sine waveform. The output voltage is distorted and rather flat-topped, and hence the voltage fed back (βE_o) has the same shape. The voltage applied to the amplifier input terminals is $E_i = E_i' - \beta E_o$ and is obtained graphically by subtracting the value of βE_o from the corresponding value of E_i'. It will be seen that, in this case, the voltage E_i applied to the input terminals is pre-distorted with a peaked waveform to counteract the flat-topping which occurs in the amplifier.

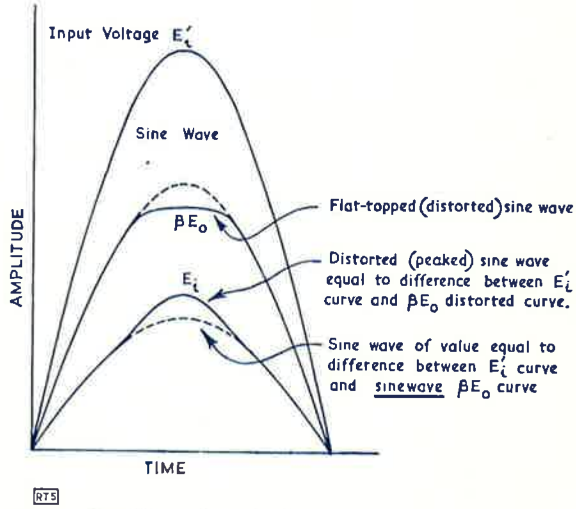


Fig. 1. Pre-distortion of signal by negative feedback. E_i' = sine-wave input voltage, βE_o = fed-back voltage, $E_i = E_i' - \beta E_o$ = voltage applied to amplifier input terminals. The broken-line curves are sinusoidal.

2. The reduction in distortion due to negative feedback.

Rowlands has examined, by a more rigorous method, the reduction due to negative feedback in the harmonic distortion produced by an amplifier. It is generally assumed that, for a given output from the amplifier, the harmonic distortion is reduced by negative feedback to $\frac{1}{1-\beta A}$ of its original value where A is the amplification ratio without feedback and β is the fraction of the output fed back. In cases where the gain without feedback does not vary appreciably up to the maximum power output, this expression for the reduction of the distortion is correct; in other cases the value of A is to be interpreted as the slope of the output voltage versus input voltage curve in the distortion region. Normally, when a feedback amplifier is approaching full output, the slope of the output voltage versus input voltage curve (linearity characteristic) falls off somewhat at one or both ends, resulting in a lessened reduction in harmonic distortion. When such an amplifier is overloaded, a similar but more intensive bending of the linearity characteristic occurs, and in the extreme limit the linearity curve becomes horizontal, A becomes zero and there is no reduction in distortion by the feedback.

* Based on R. O. Rowlands' "Harmonic distortion and negative feedback", Wireless Engineer 30.6 (June, 1953) 133.

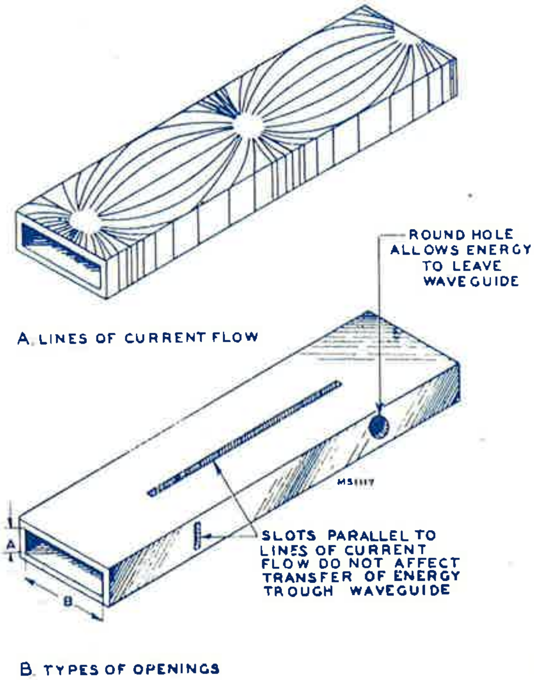
† Roddam, T. "Distortion in negative feedback amplifiers", W.W. 60.4 (April, 1954) 169.

This treatment has been extended by a subsequent article in the Wireless World† to cover the design of feedback amplifiers. At some later date it is hoped to follow up this important subject by a further article in Radiotronics.

Wave Guide Application

Wave Guide Coupling

Current flow through a waveguide is determined by the distribution of the magnetic and electric fields set up by the wave. For a certain distribution, the current circulates around the waveguide as shown. A narrow slit may be cut down the wide part of a waveguide and not cause attenuation or reflections. This is due to the fact that the potential across the slot is zero. For the same reason, a slot may be cut on the narrow side perpendicular to the line of propagation. Another type of opening in the waveguide is the circular hole on the narrow side such as is used to couple energy from the waveguide. Across this type of opening there is a potential difference causing energy to be propagated.



EFFECT OF OPENINGS IN WAVEGUIDE

Slotted Section Energy can be removed from or coupled into a waveguide by inserting a probe in a slotted section of waveguide. In general, the energy coupled out of or into the line depends on the position of the probe along the line, the depth of the probe within the line, and the orientation of the probe with respect to the axis of the line. When this type of coupling is used for test purposes it can be seen that the probe is receptive to reflected energy within the line as to the direct energy being transmitted through the line. Obviously, this fact will complicate measurements and may result in incorrect data. Further, since it is difficult to re-establish the exact position of the probe it cannot be determined exactly whether variations in measurements are caused by changes in the r-f system itself or in the positioning of the probe.

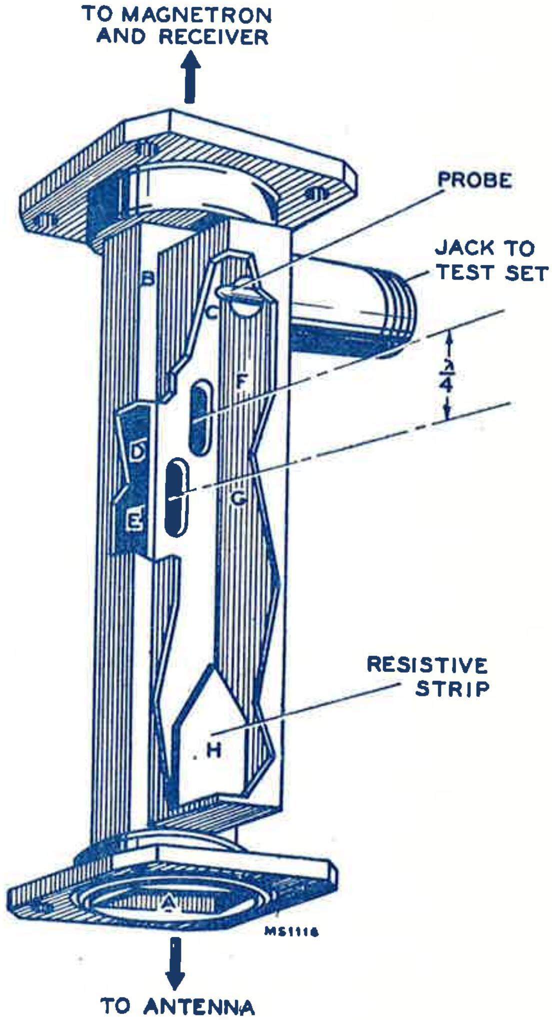
Test Antenna For test purposes, another method of sampling transmitter energy that is being transmitted along a transmission line is the use of a test antenna located within the radiation pattern of the antenna load. The position and orientation of the test antenna must be fixed in such a way that it can be reestablished at will. The initial position of the test antenna is influenced by the surrounding objects which through the reflection of energy, tends to add variables in any measurements obtained. Since it is difficult to obtain the same coupling conditions each time comparative data is taken, the test antenna method of transmission measurement is limited in accuracy.

Directional Coupler A third method of coupling energy for test purposes is with the directional coupler. This method is much preferred to those previously mentioned chiefly for its greater convenience of use, stability, freedom from the effects of reflected energy and ease of calibration.

(A) *Physical characteristics.* The coupler consists of a section of main waveguide on the narrow dimensions of which is mounted an auxiliary piece of waveguide closed at both ends and having the same cross-sectional dimensions. The auxiliary guide is closed at both sides. In the common faces of the two guides are two coupling holes, spaced one-fourth wave length apart. A coaxial, type N connector is attached at the center of the wide dimensions of the auxiliary line, between the coupling holes and the shorted end of the line. The center conductor of this coaxial line extends into the guide. The other end of the auxiliary guide is terminated by a thin strip of absorbing material to prevent reflections.

Reprinted with acknowledgements to R.C.A.

(B) *Electrical characteristics.* The energy from the line is coupled inductively through the two holes. Since they are on opposite sides of the center line of the main waveguide, where the directions of the magnetic flux lines are opposite, there is a 180 degree phase difference in all the energy coupled through the two holes. In addition, the slots are a quarter-wave length apart. The transmitted energy flows in path BDFC and in path BEGC. There is a half wave length difference in these paths which gives an additional 180 degree phase shift to the energy arriving at point C. This phase shift combined with the original 180 degree phase shift occurring as the energy is coupled through the slots causes a total phase shift of 360 degrees so that the energy arrives at the probe in phase and is conducted through a coaxial cable to the test set. The transmitted energy which takes the path BDFH and BEGH cancel out at H. As these paths are equal the energy from point B arrives 180 degrees out of phase at point H and cancellation occurs. For any energy that is reflected in the main waveguide it can be seen that cancellation would occur at point C and absorption in the form of heat would take place at point H. Therefore, the reflected energy from any impedance mismatches has no effect on the transmitted power measurements.

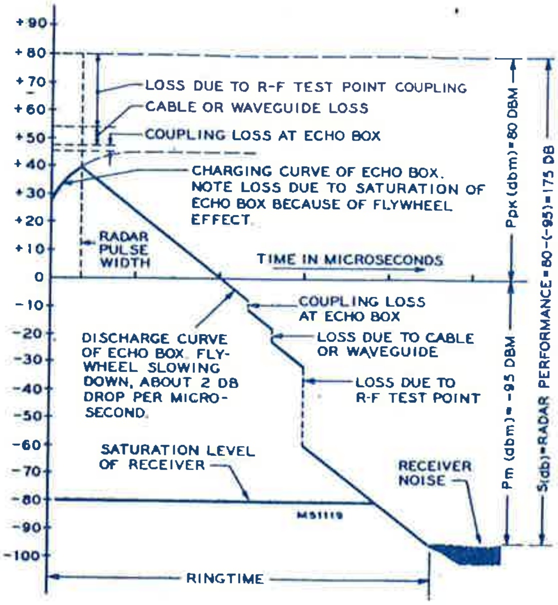


DIRECTIONAL COUPLER

Test Equipment and Analysis

Echo Boxes An echo box is a test device used extensively in checking the performance of UHF equipment. It is a cavity whose resonant frequency is dependent on its dimensions. In normal use, the echo box is excited with a portion of the power from the main transmitted pulse and then the energy stored in the echo box is measured in "ring time." Ring time is the elapsed time from the main transmitted pulse to the time when the echo box energy output falls to a point to equal the noise level of the receiver. Note that the echo box receives power which is proportional to the peak power transmitted Ppk and is measured relative to the sensitivity of a receiver Pm. This is the same as saying that the observed ring time is proportional to the overall performance of the transmitter and receiver characteristics.

1. *Theory* The functioning of an echo box is described with reference to the graph of a typical echo box charge and discharge characteristics. Assume the echo box is excited by a transmitter pulse with a peak power of 80 dbm. The peak power supplied to the echo box is attenuated because of the losses resulting from three distinct causes. These are the loss due to the r-f test point, the loss in the cable or waveguide connecting to the echo box, and the coupling loss at the echo box itself. Assuming, as shown, that these combined losses cause a total loss in signal power of 35 db, the net power available at the echo box is approximately 45 dbm. This amount of energy is capable of being stored in the echo box because it is being reflected back and forth constantly oscillating. Because of



ECHO BOX CHARGE AND DISCHARGE CHARACTERISTICS

what is termed the flywheel effect, a definite length of time is required for the energy within the box to build up to its maximum value. Thus, as shown, the radar pulse may come to an end before the echo box charging curve has reached the maximum value of 45 dbm. After the transmitted pulse ends, the echo box continues to oscillate and this energy is fed back to the receiver. Now the flywheel effect operates to make the echo box discharge its energy slowly, about 2 db drop during each microsecond. The same losses are present during the discharge process as during the charge. On the graph it is assumed that the saturation level of the receiver is –80 dbm. As long as the energy fed back to the receiver is greater than this value, the receiver is saturated. The point at which the edge disappears into the receiver noise (–95 dbm), is the minimum discernible signal level Pm (dbm). The ringtime is shown as the length of time between the start of the transmitter pulse and the point at which the signal fades into the receiver noise. Performance figure S (db) is shown equal to the algebraic difference or numerical sum of P pk (dbm) and P m (dbm). If either of these two values is increased, the length of time required for the echo box signal to disappear into the receiver noise level (that is, the ringtime) also increases.

2. *Uses* In addition to indicating performance, the echo box serves several other functions which make it useful in aligning and maintaining UHF equipment.

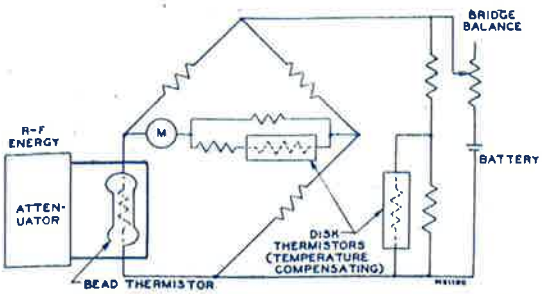
(A) The echo box may be used to isolate the source of trouble in r-f components. Most echo boxes are equipped with an auxiliary microammeter. Energy is coupled from the echo box to a crystal rectifier and the meter is connected to measure the rectified crystal current. Since meter deflection is a measure of transmitter power output, abnormally low or erratic meter readings suggest trouble in the transmitting system. A low ringtime, with normal meter reading, indicates trouble in the receiving system.

(B) Because of its high Q, the echo box makes an excellent wavemeter if its tuning dial is calibrated. Tuning of the echo box to the nominal transmitter frequency is indicated by maximum meter indication. During this process, the transmitter spectrum may also be determined. Because of its very narrow bandpass, the echo box responds to only a narrow portion of the transmitter spectrum at a time. If the echo box is tuned slowly through the region of resonance, the echo box meter deflection will follow the transmitter spectrum.

(C) The echo box can also be connected to the local oscillator of the receiver to measure the frequency of the oscillator. When the echo box is used in this manner, precautions should be taken that it does not "pull" the frequency of the oscillator. To prevent this from occurring, a long length of test cable or several joined lengths, should be used so that there is considerable attenuation between the local oscillator and the echo box.

3. *Limitations* Shown below is the general charge and discharge characteristics of the echo box, as well as the various losses that are encountered when using the echo box with a radar set. There are, however, three other factors which will affect the ringtime. These are temperature, frequency, and humidity. Technical manuals for echo boxes suitable for accurate performance measurements sometimes include data for correcting ringtime for frequency, temperature, and humidity. In most cases the effect of humidity on ringtime is small. Therefore, the accuracy of this method of performance measurement is only as good as the accuracy to which the effect of the other factors is known, and the accuracy to which the ringtime is measured. Only a few of the existing echo boxes are provided with the necessary data. There-

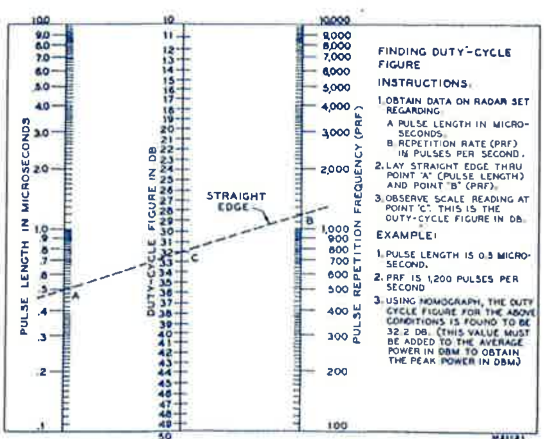
fore the use of the echo box for performance measurements which are accurate within ±2db is limited.



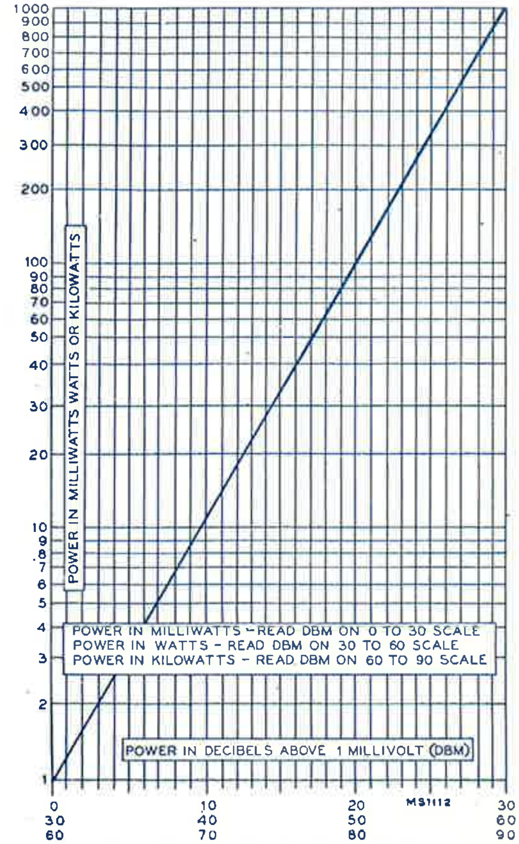
THERMISTOR BRIDGE CIRCUIT FOR POWER MEASUREMENTS

Power Meters The average power output of a microwave transmitter is usually measured with a watt meter. This watt meter may be arranged as a simple, battery operated, bridge circuit, three legs of which are resistors and the fourth leg a bead thermistor. The bead thermistor is a resistive element, the resistance of which varies inversely with the temperature of the thermal bead.

Operation With no r-f voltage applied, a DC voltage is placed across the bridge and adjusted by means of a series variable resistor, until the bridge is balanced. This state of balance is reached due to the fact that as the DC voltage is changed, the current through the bead thermistor is changed, thereby changing its resistance until the ratios of resistances between the legs of the bridge are equal. With r-f energy applied to the thermal bead, its resistance is again changed and the bridge is unbalanced. The amount of unbalance is directly proportional to the r-f energy applied and is indicated by the bridge meter. The meter may be calibrated to read the average r-f power (Pav) either in milliwatts or dbm. In the case of pulse transmitters to convert from average to peak power (Ppk) :—



DETERMINING DUTY-CYCLE FIGURE (EXPRESSED IN DB)



CONVERSION OF POWER TO DBM

Ppk = Pav x D (in milliwatts)

$$\text{Where } D = \text{the duty cycle} = \frac{(i)}{(rd)}$$

r = Pulse repetition rate (Pulses/sec.)
d = Pulse width (sec.)

the peak power output of the transmitter in decibels relative to 1 milliwatt, Ppk (dbm), can be found from the relation—

$$\text{Ppk (dbm)} = 10 \text{ LOG } \frac{\text{Pav (in milliwatts) X D}}{\text{1 MW}}$$

$$= 10 \text{ LOG } \frac{\text{Pav}}{\text{1 MW}} + 10 \text{ LOG D}$$

Therefore:

Ppk (dbm) = Pav (dbm) + D (db)

Where

$$\text{D (db)} = 10 \text{ LOG } \frac{1}{\text{rd}} \text{ (Reference Duty cycle graph)}$$

The above relationship shows that the peak power output of a transmitter in dbm equals the sum of the average power output in dbm and the duty-cycle figure in db. If the value obtained from the power meter is expressed in watts it must be converted to dbm. This can be easily done by use of

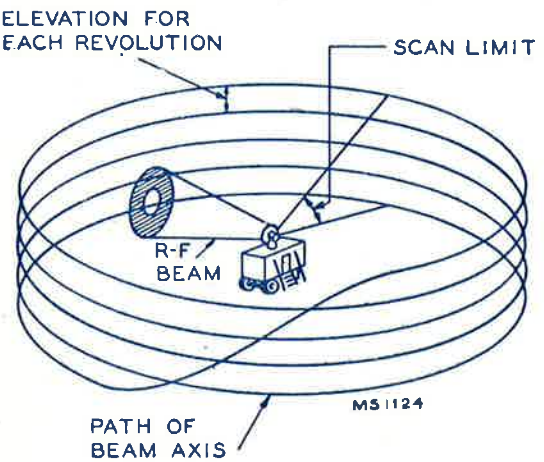
Nutators A nutator is a mechanical or electrical device used in scanning to attain a certain desired antenna coverage pattern. Nutation can be defined as a periodic discontinuity or displacement in a cyclical phenomenon. An example would be the conical rotation of a beam combined with horizontal movement producing periodic displacement in the scanning path.

To discuss types of nutators it will be necessary first to discuss several of the methods now employed in scanning.

Types of Scan

1. Azimuth Scan—refers to continuous scanning in azimuth by a radar beam by rotation of the antenna. Usually for search applications.

2. Sector Scan—refers to azimuth scanning when conducted over a limited sector. Used for surveillance of a pre-selected area.

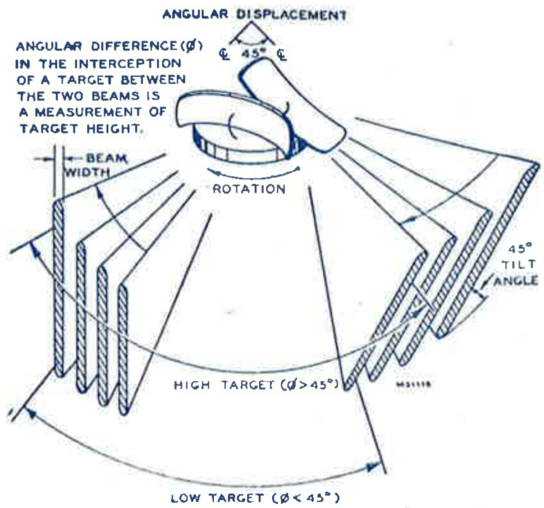


HELICAL SCANNING

3. Helical Scan—refers to a combination of azimuth and elevation scanning. Used to obtain greater air surveillance than that available with azimuth scan.

4. Beavertails—refers to a rapid elevation scan which is used to compute vertical height of targets. The name comes from the fact that the beam looks like a beaver's tail, being extremely narrow in the vertical plane. When this beam is nutated rapidly in elevation the resulting modulation of the target return is used to compute Relative Height Information, RHI.

5. "V" Beam—refers to another method used to obtain RHI but without the use of a nutator. This employs the use of two antennas, both of which beams are thin in the azimuth direction and sufficiently broad in elevation to give the desired vertical coverage. The first antenna

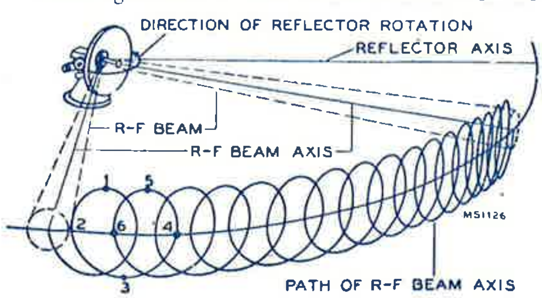


"V" BEAM

provides a vertical sheet and is so arranged that it is followed in azimuth, as the antennas are rotated, by the second antenna. The second antenna is displaced by a tilt angle of 45 degrees from the first. In each revolution a target is intercepted, first by the vertical beam, and then by the slant beam. The angle through which the mount turns between the two interceptions is a measure of the elevation angle of the target. From this the RHI can be computed.

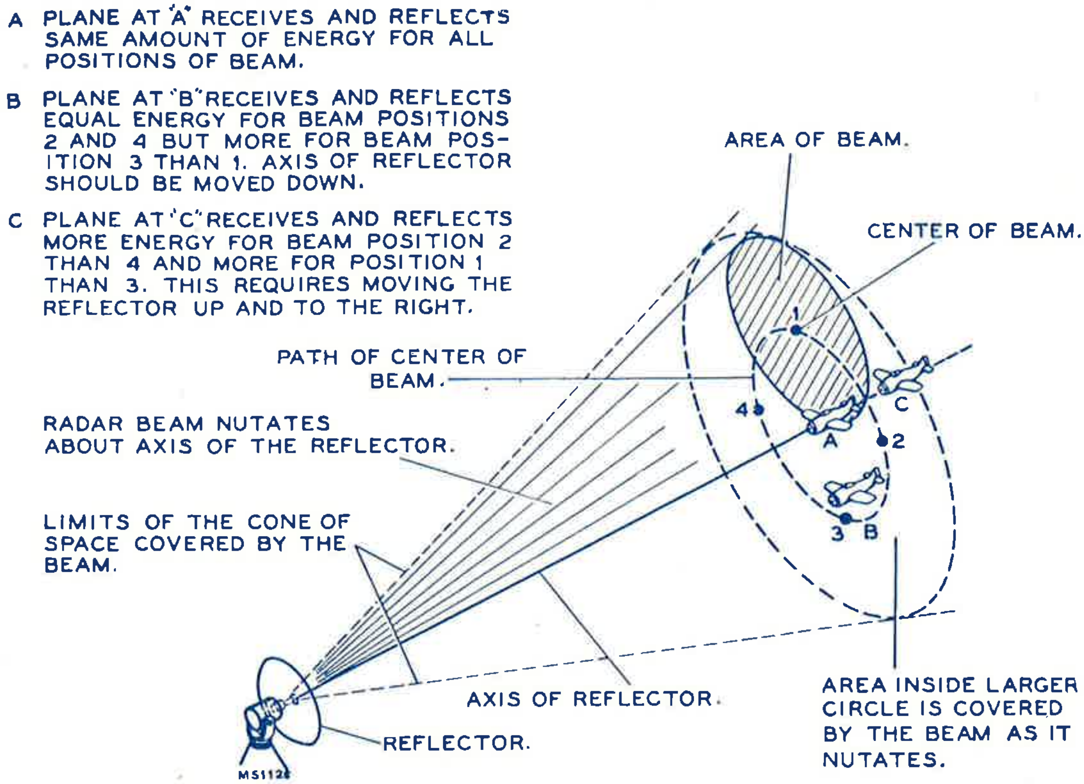
6. Conical Scan—refers to the circular nutation of the beam around a target and usually utilizing the off center modulation of the target signal strength to center the antenna on the target. Can be used to provide either an "on-center" display or to provide information for automatic tracking. Conical Scan is distinguished from other types of circular scanning by the fact that there is no "dead spot" in the center of the nutation.

7. Horizontal Scan—similar to conical scan except utilizing a vertical beam which is narrow in azimuth. Can be used to either provide an "on-azimuth" display or to provide information for automatic azimuth tracking.



PALMER SCANNING

8. Palmer Scan—refers to the circular nutation of the beam over a wide area for search purposes.



CONICAL SCANNING FOR TRACKING

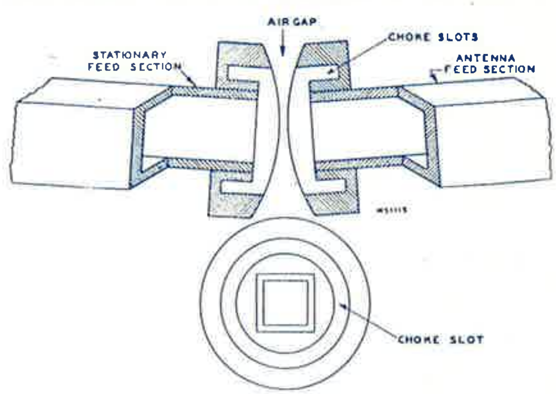
When combined with azimuth scanning the beam makes overlapping ovals in the sky. The name is derived from the use of overlapping ovals in the palmer method of writing.

9. Spiral Scan—refers to a type of scan which provides the broad area coverage of palmer scanning and at the same time removes the "dead spot" at the center of the scan. The beam starts out at the center of the scan and moves outwardly in a spiral motion. When the limit is reached (approximately equal to a palmer scan) the spiral motion starts decreasing which moves the beam inward and interlaces with the outward path.

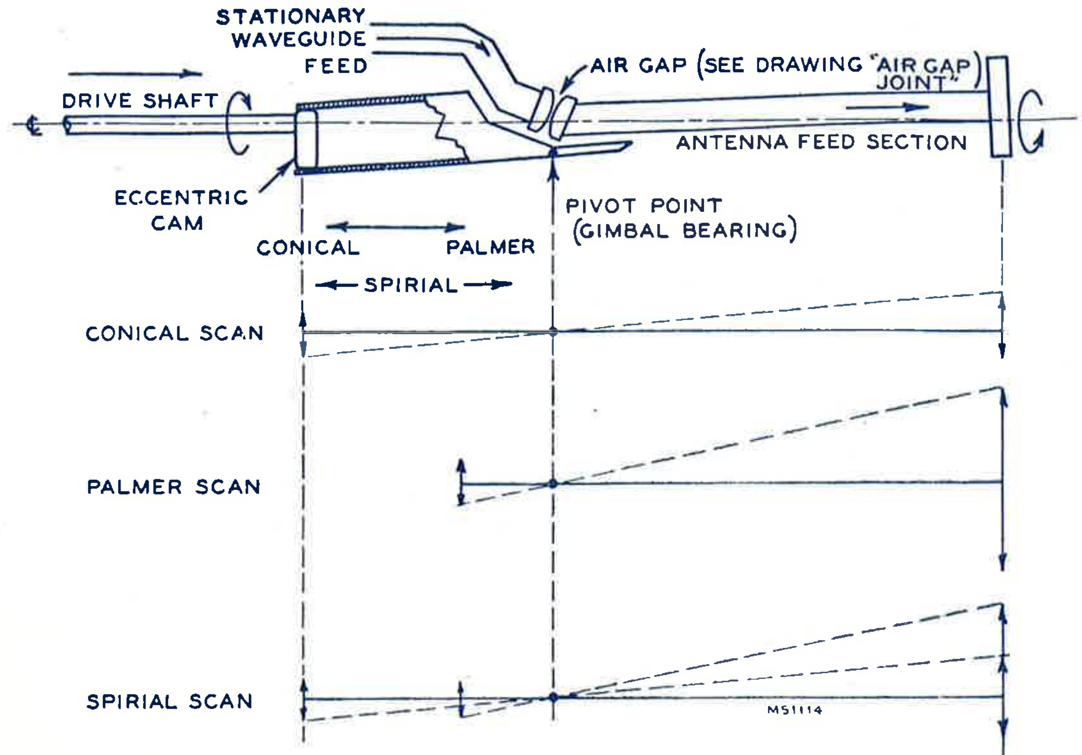
Usually any given equipment has several different types of the above scanning methods to increase the utility of operation.

Methods of Nutation This discussion will cover principles of waveguides and their application to nutation.

Wobble Joint A wobble joint is the method most commonly used to displace the waveguide antenna feed in respect to the antenna assembly to produce scanning motion of the beam. The mechanical drive linkage determines the type of scanning and usually is arranged so that several types of scanning are available for selection. One of several methods of producing this type of nutation is the use of a cam drive. The waveguide antenna feed is balanced and is free to nutate depending on the type of motion coupled into the drive end. By the use of an eccentric cam attached to a drive motor conical, spiral and palmer scanning can be selected by controlling the depth of insertion of the cam shaft into the drive assembly. Coupling between the stationary waveguide and the antenna feed section is accomplished by the use of two choke flanges, separated by an air gap, and whose surfaces are made in the form of hemispheres so that they do not touch when the movable flange is nutated. This utilizes the same principle as the conven-



AIR GAP JOINT



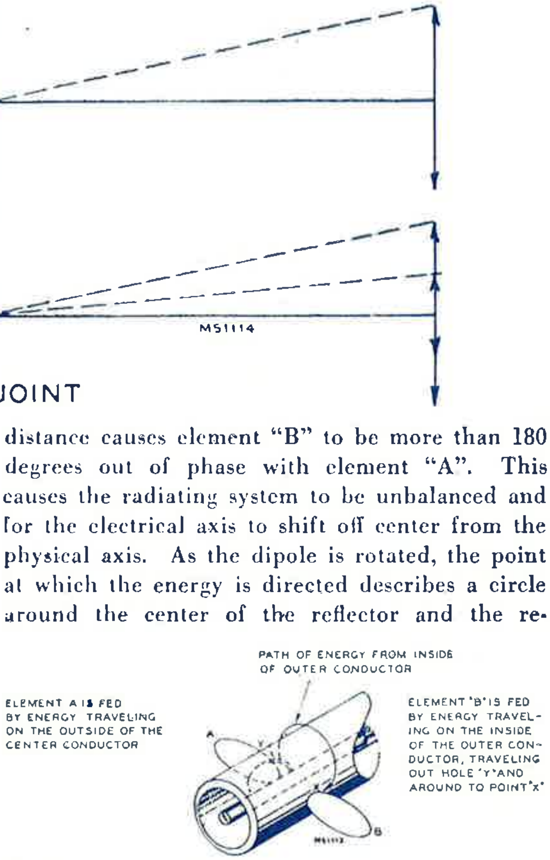
WOBBLE JOINT

tional choke joint which has been previously discussed. The electrical continuity of the r-f line is thus maintained even without actual contact, and the joint is electrically equivalent to a solid waveguide section.

Wobble Assembly When relative slow speed nutation is desired the entire antenna assembly may be nutated. This is done in some types of beavertail scans where the antenna assembly used to obtain height information is placed on a rocker base and then mechanically mounted on the main antenna assembly pedestal. The waveguide may either be coupled by a flexible section of waveguide or the use of a movable choke flange as described above.

Wobble Reflector In some cases the r-f feed is maintained stationary and the reflective assembly nutated. This is only practical at lower scan rates due to the mechanical problem present. Also as compared to a system that nutates the entire antenna assembly, it has the disadvantage of broadening the beam as the antenna feed is moved out of the focal point of the reflective assembly.

Balanced Conical-scan Dipole This type of dipole closely resembles the standard type of dipole with the exception of the feed holes to feed element "B" at point X have been omitted. Element "A" is fed from the center conductor in the conventional manner. Element "B" is fed from the inside of the outer conductor through hole Y around the outside of the outer conductor to the element. This extra distance causes element "B" to be more than 180 degrees out of phase with element "A". This causes the radiating system to be unbalanced and for the electrical axis to shift off center from the physical axis. As the dipole is rotated, the point at which the energy is directed describes a circle around the center of the reflector and the re-

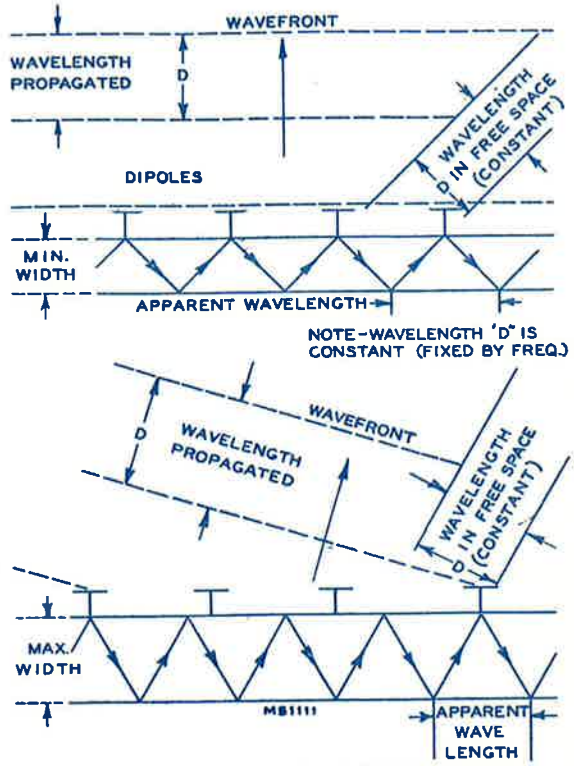


BALANCED CONICAL-SCAN DIPOLE

radiated energy describes a cone giving the desired conical scan. The advantage of this method of producing scan is the fact that the assembly is mechanically balanced and therefore easy to rotate. Only one predetermined type of scan can be used by this method which is a function of mechanical design and produces a fixed off axis displacement of the electrical center.

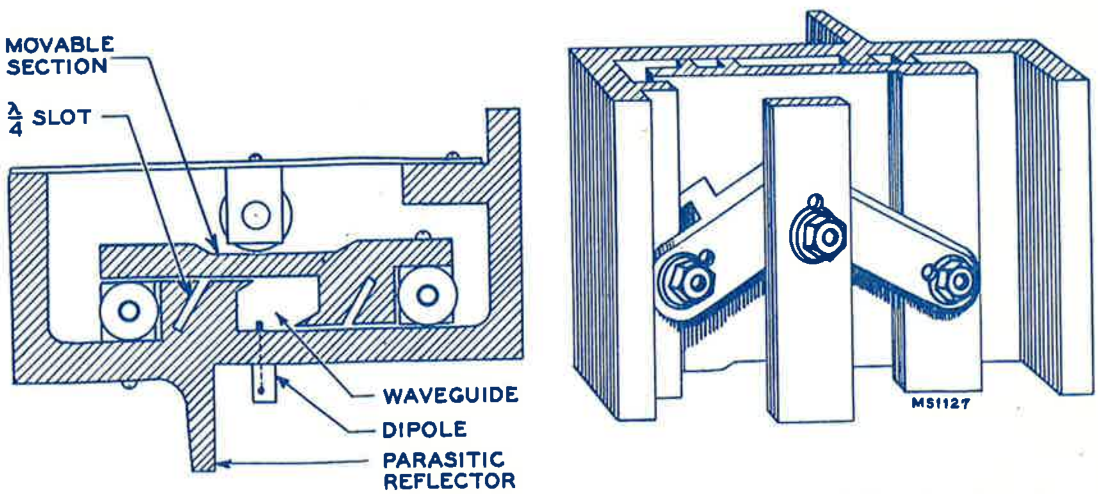
Horizontal and Beavertail Feeds Generally the method employed for nutation is the use of a reciprocating feed horn which is fed by a wobble joint to produce motion of the beam in a horizontal plane (or in the case of a beavertail feed in a vertical plane).

Variable Cross-Section Waveguide for Sector Scanning It has been shown that by the use of a squeeze section the apparent wavelength within the waveguide can be progressively increased by decreasing the dimensions along the wide side of the waveguide.



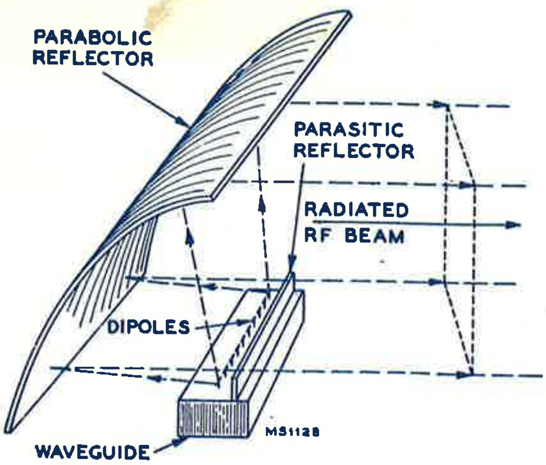
EFFECT OF CHANGING WAVEGUIDE WIDTH ON DIRECTION OF PROPAGATION

This principle can be further applied to change the phase of the energy available at different points along the waveguide. If dipole elements are placed along the waveguide at the apparent half wave-length points with the waveguide at its minimum width, the radiation pattern at right angles to the waveguide from the dipoles will be at zero degrees relative. Practically the dipoles are spaced at a little over the half wavelength points to decrease standing waves due to re-radiation in the wave-guide. This causes the beam to be tilted approximately one degree to the right. If the guide width is then progressively increased, the apparent half wavelength points decrease, causing the energy to be radiated from any particular dipole to leave at an earlier instant than before, relative to the preceding dipole. As the guide becomes progressively wider, the combined wave front of radiation is tilted at a progressively greater angle from normal. By oscillating the movable wall of the waveguide, the beam can be made to scan over a limited sector. This is the method of scan employed in GCA, Ground Control Approach, to provide scanning of both the azimuth and elevation beams. It will also be noted the use of quarter-wavelength slots to prevent energy from escaping along the junction points of the waveguide. It also can be seen how the center conductor of the dipole extends down into the waveguide to couple energy out to the radiating element. The depth of insertion is increased along the waveguide to produce an equal amount of energy to be coupled out by each dipole as the power diminishes progressively along the wave-guide.



(A) SCANNER CROSS-SECTION (B) SCANNER LINK ASSEMBLY

VARIABLE CROSS-SECTION WAVEGUIDE



FORMATION OF PRECISION BEAM

PRECISION ANTENNA SYSTEM.

The antenna array consists of a length of special waveguide, composed of two parallel sections, which feed a linear broadside array of slotted dipoles. The dipoles are spaced slightly more than half a minimum wavelength apart along the wide side of the waveguide channel, and are fed slightly out of phase, each succeeding dipole being the same amount later in the cycle. Thus the phase differential is the same between any pair of dipoles in the array. The antenna produces a beam narrow in azimuth (vertical sheet).

The slotted dipoles are mounted along the wide side of the supporting waveguide assembly with the center conductor extending into the guide as a pick-up probe. The insertion depth of the dipole probes is varied along the length of the array to produce a uniform distribution of power radiation, the probe depth being greater at the upper or load end of the waveguide than at the lower or input end. This type of energy distribution is utilized in order to reduce side lobes to a minimum. To produce a broadside pattern the polarity of alternate dipoles is reversed. The small percentage of power not picked up by the probes, and which reaches the outer end of the waveguide is dissipated by an attached sand load or absorber unit, thus preventing formation of high standing waves due to reflection. If the dipole spacing were exactly equal to a half-wavelength of the wavelength inside of the guide $\left(\frac{\lambda g}{2}\right)$ the beam would be perpendicular to the guide. However, large standing waves would appear in the guide because of reflections from individual probes returning energy in phase with the input into the guide. The guide dimensions and dipole spacing of the array are selected to prevent these conditions.

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