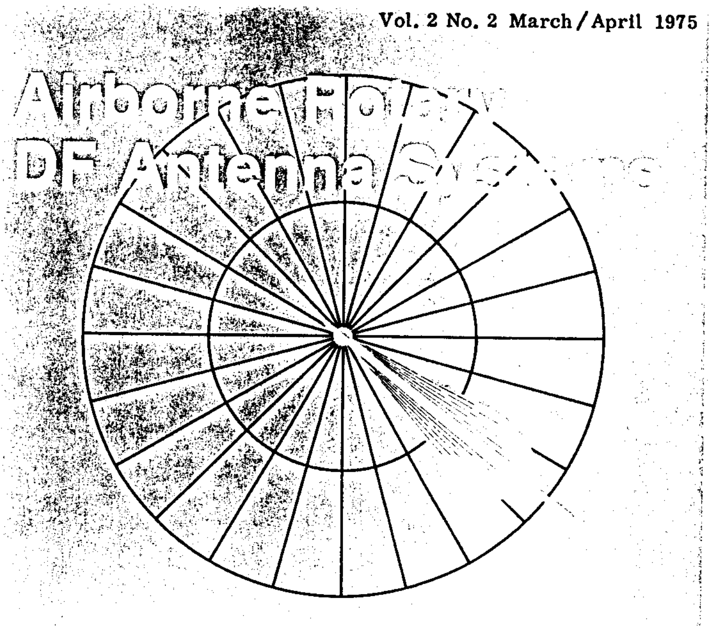
Tech-notes

Vol. 2 No. 2 March/April 1975

Airborne Rotary DF Antenna Systems



EW Reconnaissance Systems require that radiating emitters be sorted out from amidst other emitters of the same or different class; that such emitters be located to a reasonably high accuracy, if not precisely; and that the capability be provided to point a high gain receiving antenna at such emitters for the purpose of detailed signal analysis. An intercept antenna which only covers the field of view of interest is simply not sufficient to meet any of the above requirements. First of all, the intercept antenna is in itself no aid in sorting out one signal from another one within the pass band of the receiver. Thus, one must rely solely on signal sorting techniques which utilize the pulse width (PW) and pulse repetition interval (PRI) characteristics of the emitter. Secondly, the intercept antenna yields no clue as to the location of the emitter within the geographical sector of interest. Thirdly, the intercept antenna is low in gain since its beamwidth must be broad enough to cover the field of view in question, making detailed signal analysis more difficult because of the lower signal-to-noise ratio. However, when a rotary direction-finding (DF) antenna system is provided in addition to, or in lieu of, the intercept antenna; all of the above requirements can be satisfied to a high degree.

First, the rotary DF antenna is a narrow beam device which views only a small fraction of the field of view at any instant in time. Thus, when the DF antenna is used with a receiving system in which the receiver sweep rate is synchronized with the antenna scan rate, the density of signals detected within the receiver's pass band is reduced significantly, thus aiding in the sorting problem. Secondly, the rotary DF antenna system provides a means of determining the direction from which the signal is emanating within the sector. Location of the signal to within a reasonably small area can then be accomplished, if necessary, by DF "cuts" taken at successive time intervals corresponding to different aircraft locations. Thirdly, the rotary DF antenna system is a high-gain antenna due to its restricted azimuth beamwidth, and can be pointed at a target continuously (in spite of changes in aircraft heading) for detailed signal analysis at a high signal-to-noise ratio.

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Terry earned his B.S.E.E. degree at the University of Washington in 1960, followed by his M.S.E.E. and M.E.E. degrees in 1963 and 1964. Mr. Harper joined W-J Systems Division, Applications Engineering staff in 1972 and is currently responsible for the representation of W-J's capability in the area of Antennas and ECM equipment to customers within the Continental U.S.

In the antenna area, Mr. Harper is responsible for DF systems which include W-J's extensive line of rotary antennas with associated pedestals and control/display units. In the ECM area, Mr. Harper is responsible for the advanced technology associated with channelized receivers.

Mr. Harper has had extensive experience in the design and development of antennas and has technically supervised several new antenna developments which extended the state-of-the-art. These included a basic antenna patent which extended the applicability of linear antennas to broadband applications, antenna matching techniques related to a chirp radar experiment for the manned space flight program, automatic direction-finding techniques using digitally controlled pedestals, and static array direction-finding techniques using high speed, single channel amplitude comparison techniques. Terry is a member of the IEEE, AFCEA and the Association of Old Crows.

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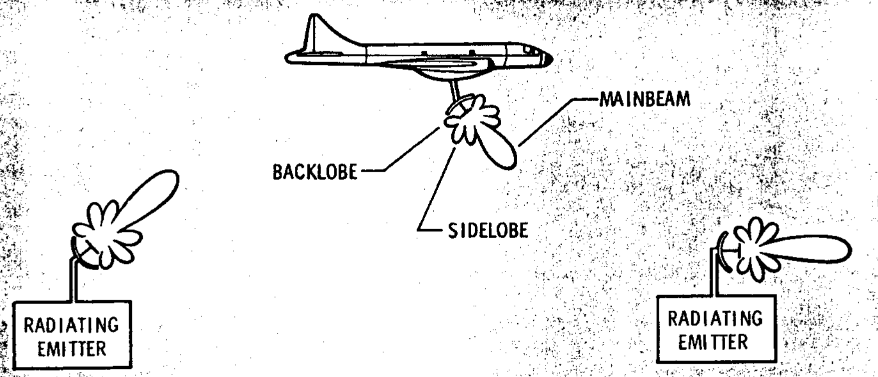

Fig. 1. A Rotary DF Antenna System application to EW Reconnaissance for sorting, mapping and analysis of emitter signals.

EW Reconnaissance Application

In a typical reconnaissance application, Fig. 1, the airborne operator wants to determine the presence or absence of emitters within a geographical area of interest. He may be interested in mapping the entire area or he may have certain apriori knowledge which dictates that he look for specific emitter types. In either case, the application requires the identification of emitting equipment. This means the determination of various signal-related parameters, such as, frequency, time of arrival, pulse width, pulse repetition interval, antenna scan rates, and signal modulation characteristics. This is complicated by the fact that the radio frequency environment is usually densely populated within a given sector or geographical area of interest. This requires a means at his disposal to sort out signals from one another. Frequency, as an example, is one discriminant but not all emitters operate at different frequencies. Identification of signal PRI also enables signals to be sorted from one another—but similar emitter equipments within the sector of interest may have identical pulse repetition rates. In addition, the operator needs to know where the signal is coming from in order to map the location of emitters within the geographical area of interest. Finally, the determination of signal modulation parameters requires a high signal-to-noise ratio from the receiving system.

The inclusion of a rotary direction-finding antenna system as part of the surveillance receiving system is an invaluable aid in the sorting, mapping and analysis of emitter signals. The determination of the direction of arrival (DOA) of an incoming signal will help distinguish emitters with similar frequencies by assigning different locations for the two signals. The determination of DOA also aids the operator in the mapping of an area even though the range from emitter-to-DF antenna is not pinpointed. The ability to point the DF antenna at the target in order to increase system gain for the purpose of detailed signal analysis is also available. The rotary DF antenna introduces different system modes of operation. For example, the synchronization of his receiver sweep rate with the antenna rotation rate provides a means to search for signals using the high gain of the DF antenna. This extends his effective range and enables him to detect signals sooner from scanning emitters and those which may be pointed away from his DF antenna.

Of course, other means of determining DOA are available to the operator than the rotating DF antenna system approach described herein. But no other technique offers the simplicity, low life-cycle cost and inherent high-gain of the rotary approach. Advances in the state-of-the-art technology for rotary DF antenna systems have resulted in the capability of extremely broadband frequency coverage with consistent rf performance

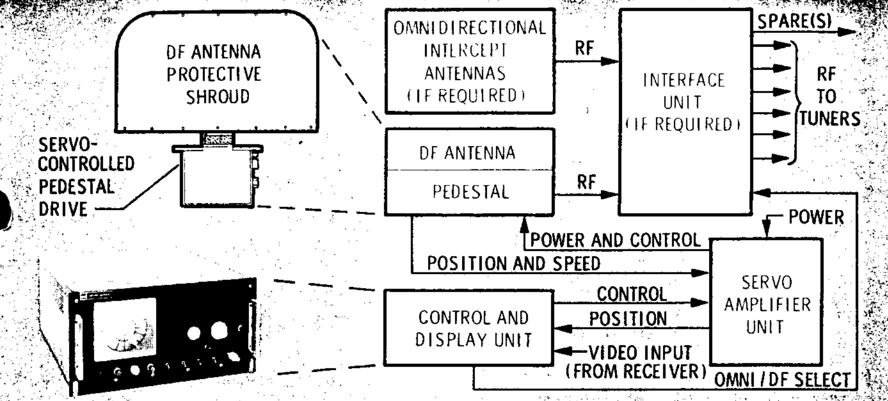

Fig. 2. A block diagram of a rotary DF antenna system incorporating an airborne operator's rotary DF equipment.

including tight boresight tolerance control, simple and reliable pedestal drive systems, closed-loop servo positioning, polar DF displays which provide integration and response to extremely narrow emitter pulse widths and automatic digital readouts for the operator. Furthermore, the rotary DF approach is particularly well-suited for interface with computer-controlled receiving systems with the availability of precise digital shaft encoders and software algorithms for automatic processing of receiving signal strength to determine DOA.

Past Rotary Direction-Finding Antenna Systems

Rotary direction-finding systems began with nothing more than a manually rotatable directional antenna, a receiver and a pair of headphones. Because the emitter source and the direction-finding system were not stationary, a variety of so-called automatic DF systems came into use. Normally an electrically driven DF antenna was interfaced to a synchro motor that was used to rotate a pair of deflecting coils of a cathode-ray oscilloscope in synchronism with the antenna. As the directional antenna swept through the direction of the emitter source the spot on the CRT face traced out a curve similar to the directional pattern of the receiving antenna. The bearing or DOA was usually indicated by maximum deflection relative to some reference direction. The magnetic type of indicator was soon replaced by an electrostatic deflection type CRT. In the later type the amplified receiver output was applied to the rotor of a so-called scanning capacitor. The rotor of the capacitor turned in synchronism with the antenna. As the rotor turned, two voltages in quadrature were induced in 2 sets of stator plates. These voltages were then applied to the horizontal and vertical deflecting plates of an electrostatic CRT. Thus, the beginnings of rotary direction-finding antenna systems. The antennas used with these early direction-finding systems were inherently narrow-band in nature covering only specific frequency ranges of interest.

Role of Modern Rotary DF Antenna Systems

In contrast to the rotary direction-finding antenna systems of the past, modern state-of-the-art rotary DF systems employ broadband antennas, servo-controlled pedestal drive systems, synchro position resolvers, storage display CRT's and digital position readouts. A block diagram of such a rotary Direction-Finding System is shown in Figure 2. The DF antenna is a small, lightweight structure enclosed in a protective shroud which yields high-gain directive radiation patterns over the entire frequency range of interest—in this case 1–18 GHz. The pedestal drive is a compact mechanical unit capable of turning the antenna at high speed in a SCAN mode of operation or rapid automatic positioning of the antenna in a POINT mode of operation. The Control/Display unit is a rack-mount device which serves to control the operation of the remote antenna/drive and display a polar video pattern on a storage CRT for determination of angle of arrival (AOA). A servo amplifier unit provides the necessary power to the pedestal and all other synchro instruments. Omnidirectional antennas may be used for receiver intercept purposes and an interface unit may be required for rf preamplification and/or rf signal distribution.

The DF system is responsive to all types of emitter signals—both pulsed and CW. Instantaneous 1–18 GHz frequency coverage by the DF antenna allows it to be interfaced to a form of wide-open receiver as well as the yig-tuned superheterodyne type. This makes the antenna suitable for a combined frequency/azimuth search role in which the receiver "dwell time" is based upon the time required for the antenna to rotate through a sector corresponding to the half-power beamwidth of the antenna. A complete frequency-azimuth search can be accomplished in one revolution of the DF receiving antenna or approximately 300 milliseconds with a rotational speed of 200 rpm.

On the other hand an omnidirectional antenna may be used for signal interception providing an instantaneous 360° field of view. Upon signal interception and identification, the operator may then choose to select the DF antenna in order to determine the direction of arrival of the incoming rf signal. But, in this mode of system operation the operator may lack the sensitivity required for signal interception. This disadvantage may be overcome with the use of a high-sensitivity superheterodyne receiver. In fact, the probability is high that the emitter may be detected even if pointed away from the receiving antenna. If not—there is a high probability that the DF antenna will be able to detect the emitter even in the backlobe/sidelobe region. If the rotary DF antenna system only detects the "main bang" or main beam of the emitter as it rotates through the DF receiving antenna pattern, then a longer time period will elapse before a stored image is displayed on the CRT to determine AOA. If the rotary DF antenna system is sensitive enough to detect the emitter's backlobe, then the stored image will be created much sooner since the DF receiving antenna normally rotates at a speed much faster than the emitter's scan rate. If, in the latter situation, the emitter main beam happens to rotate into the region where it points at the DF receiving antenna, strobes are likely to be created on the display when the DF antenna is not pointed at the emitter. These strobes are caused by the DF antenna's own sidelobe/backlobe structure. However, these "hits" are scattered over the polar display because of the high speed of the DF antenna, and are easily sorted out and ignored by the operator.

A question may arise as to what speed the DF antenna is to be set while in the SCAN mode of operation. If only main beam intercepts are being received by the rotary DF antenna system, theory[1] shows that any rotational speed between 60 and 200 r.p.m. is sufficient as to the probability of intercept. A lower or higher antenna speed will decrease the probability of intercept because as the speed increases fewer main bang pulses are received. However, if the rotary DF antenna is sensitive enough to detect the scanning emitter at all times, then the probability of intercept increases as the speed of the DF antenna increases. A stored image on the CRT display is thus built up sooner due to the higher speed.

There is a practical limit to the speed at which rotary antennas can be reliably balanced and maintain long life operation. Antenna balancing for speeds up to 200–300 rpm is typical. Antenna balancing for rotational speed higher than 300 rpm is more difficult and reduces the life of the system's rotary joints. The tendency of modern rotary DF antenna systems is to provide a lower maximum speed in order to extend life and reduce primary power requirements.

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[1] Reference No. 1.

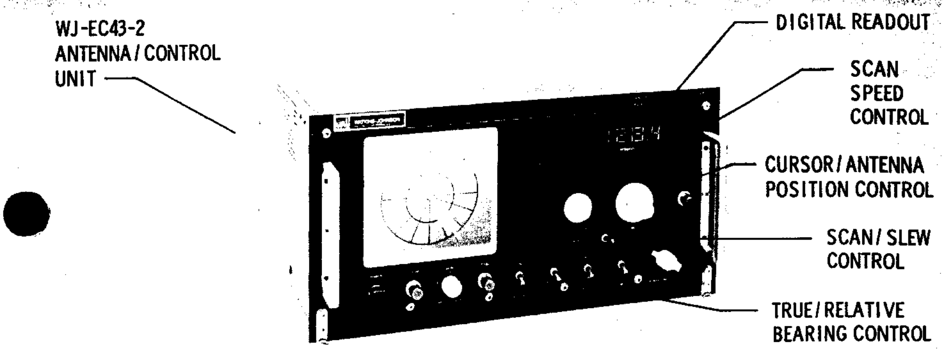

Fig. 3. Antenna Control/Display Unit used to determine the DOA of an emitter signal during SCAN mode of operation and to position the DF antenna during POINT mode of operation.

The rotary DF antenna system provides unique capability in terms of SCAN, or POINT mode of operation. By selecting the POINT mode, the antenna is automatically stopped and slewed to a preset cursor position in a matter of a few seconds. This mode can be used to set the DF antenna onto the target emitter pointing angle for signal analysis purposes. By means of compass stabilization, the DF antenna will remain pointed at the target emitter irrespective of changes in aircraft heading. Thus, the modern rotary direction-finding antenna system provides high probability of intercept and flexibility of control in modern receiving systems.

The DF Display—Antenna to Operator Interface

The DF display is the interface between the DF antenna system and the operator and, as such, is a critical component in determining the effectiveness of the integrated DF system. The rotary DF display unit presents, in effect, the radiation pattern of the DF Antenna on the face of a CRT. Thus, the orientation of the main beam on the screen represents the emitter bearing. The bearing reference may either be the nose of the aircraft, or it may represent north; i.e., true bearing. In the latter instance, the bearing information is of most use since it is independent of actual aircraft heading.

In order to aid the operator determine the center of the pattern, an electronic cursor is provided which may be positioned to the antenna pattern center or centroid, Fig. 3. The cursor angle may be read in reference to a scale or, more conveniently, by means of a direct digital readout by a four digit LED display. The cursor position control may also be coupled to the antenna position control. In a POINT mode of operation, rotating the cursor/antenna position control rotates the antenna to the desired position. In the SCAN mode of operation, the cursor position control is decoupled from the antenna position control. Thus, the cursor is simply used to determine the direction of arrival of the incoming signal. The position of the cursor may be used to rotate the antenna to the direction of arrival of the incoming signal by commanding the antenna to go from the SCAN mode of operation to the POINT mode of operation. This is accomplished automatically by a closed-loop servo positioning electronics.

With an emitter transmitting a signal of constant amplitude, the pattern displayed on the face of the CRT will be a very accurate indication of the bearing. However, the emitters of interest are seldom this cooperative, and as a result, only a portion of the pattern is displayed during any scan or scans of the DF antenna past the emitter. Therefore, a means of preserving and adding to the pattern; i.e., achieving pattern integration is desirable. This is accomplished by the use of a storage CRT that permits in-

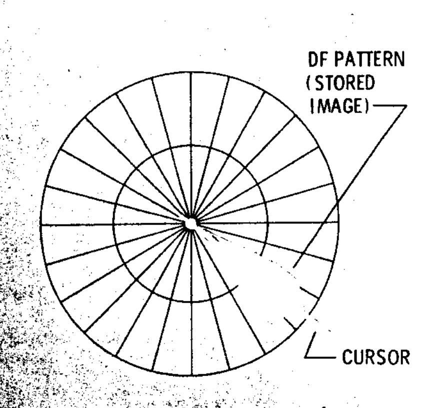

Fig. 4. DF radiation pattern and cursor line alignment.

tegration of the pattern over many revolutions of the DF antenna.

An example of a possible operational procedure may clarify the use of the display as follows: Assume a signal is being received and a DF pattern created and stored on the CRT is in the general shape of a "feather", Fig. 4. Rotating the cursor/antenna position control brings the cursor line to the feather center which is the direction of arrival of the incoming signal. The cursor angle is then read out on the digital readout. If constant reception of the signal is desired, turning the scan/slew control to SLEW (POINT), will cause the antenna pedestal to position itself to the cursor bearing. Thus, while the POINT mode is activated, the cursor and digital bearing readout represent the pointing angle of the antenna in either true or relative bearing. If the switch is in true position, the antenna will continue to point in the commanded true direction even though the aircraft heading changes.

Within the control display unit the following components are required to produce the desired display: video amplifier, compass and pedestal repeaters, resolver, oscilloscope and pulse generator. The video amplifier amplifies the video signal from the receiver and also stretches the pulse width in order to enhance the CRT display. The output of the amplifier is simultaneously applied to X, Y, and Z inputs of the CRT with the X and Y inputs via the resolver. The Z, or intensity input, serves to intensify the most significant portion of the trace; i.e., the trace representing the center of the DF antenna radiation pattern. A DF Select Switch is provided to select either DF Tuner Band or Omni. A polarization switch also may be included to select either vertical, horizontal or circular polarization for the DF antenna.

A pulse generator produces a pulse with the proper characteristics to form the cursor line on the CRT. Obviously, the cursor line should not be stored on the CRT while the received signal pulses are being stored. Careful pulse shaping by the generator creates a pulse having a rise-time and duration just below storage threshold, yet which develops adequate contrast for viewing. The non-storing cursor line can be seen while superimposed upon a stored image, an important operational characteristic.

The video amplifier/pulse stretcher is a very significant part of the storage tube display concept, due to the characteristics of the storage tube itself. The basic requirement is that the image be reliably stored, even though a single narrow pulse is received. To achieve consistent and reliable storage, a sufficient amount of energy must be contained within the pulse, and the rise and decay times must have certain characteristics. Generally the pulse, as delivered to the display by the receiver, does not have the proper characteristics. The pulse stretcher accepts these pulses and creates the optimum pulse for application to the CRT; rf signals with pulse widths as narrow as 100 nanoseconds may be reliably processed.

Critical DF Component-Pedestal

The success of modern rotary DF systems is critically dependent upon the antenna drive. The antenna pedestal has a simple, but unique role; rotate or point the DF antenna responsively upon command of an operator or by means of direct digital control via an on-board computer.

To best accomplish both rotating and pointing of the DF antenna in the two modes of operation, the rotary DF system incorporates a closed-loop servo system type of response. A close-loop servo system design assures constant and repeatable speed control in the SCAN mode of operation, regardless of wide temperature variations. In addition, in the POINT mode of operation, where the antenna is slewed to a desired direction upon command, a closed-loop servo system enables rapid and accurate pointing. Also, the closed-loop servo system allows rapid transition from the high-speed slew mode to the pointing mode of operation i.e., a command to stop the rotary DF antenna at a specific azimuthal position may be accomplished within a few seconds and with negligible overshoot.

The servo system may use a conventional tachometer and synchro feedback devices, thus forming an analog system design. As an alternative, the servo system may employ digital encoders which simplify the interface of the DF antenna system with digitally organized receivers or on-board control computers.

The pedestal rotation speed for modern rotary DF systems is typically specified as variable between 0 and 200 rpm, although pedestals have been built to rotate antennas as fast as 2000 rpm. At faster DF antenna rotation speeds, the life of the system is reduced and requires very critical antenna balancing.

A velocity feedback type of servo system controls the speed of the DF antenna to within 1% of the command speed over a wide temperature range and a wide fluctuation in supply voltage. In the POINT mode of operation, the DF antenna can typically be positioned to within 1° of the command position with a position readout accuracy of better than 0.1°. The pedestal, shown in Figure 5, contains the following major components:

- Servo motor/tachometer
- Synchro or Digital Encoder
- Slip rings

The servo motor drives the antenna in a SCAN mode of operation, and acts to position the antenna in the POINT mode of operation. The motor contains a tachometer generator used for precise

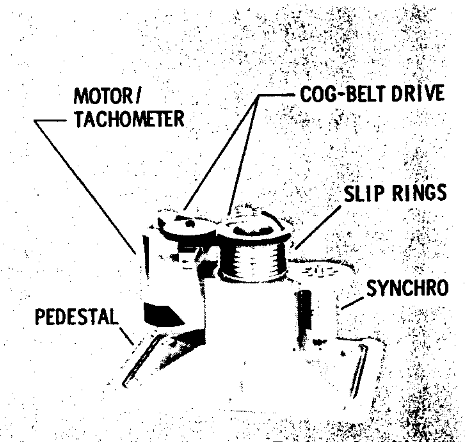

Fig. 5. The WJ-EP-22 Pedestal with pressurized cover removed.

speed control in the SCAN mode and for damping in the POINT mode. The synchro control transmitter provides three-wire antenna position information to the control/display unit.

The pedestal is designed with simplicity, ruggedness, reliability and ease of maintenance as paramount objectives. The basic structure is a casting with heavy-duty sealed bearings employed for rotational support, and a permanent magnet dc drive motor with integral tachometer employing a steel-cord, cog-belt drive system. The position sensing assembly consisting of a synchro feedback device or optional digital encoder is driven independently of the motor drive assembly. This means that periodic motor brush replacement can be accomplished without affecting the data package synchro alignment. The pedestal is designed with a protective cover which, when removed, allows access to all subassemblies for periodic maintenance without any inherent necessity to remove the pedestal itself. This protective cover also serves as a pressure housing which means that installation can be made inside of a pressurized bulkhead without aircraft modifications. The pedestal contains no gears requiring lubrication. Periodic maintenance or replacement of motor brushes or belts is facilitated by the fact that no dissassembly is required to remove the belts and direct access to motor brushes is possible without removing the motor.

DF Antenna Structure and Boresight

Modern DF antennas incorporate varied types of feed structures which vary widely depending upon the operating frequency range and polarization requirements. High-gain requirements in the 1 to 18 GHz range are generally met with some form of paraboloidal reflector and feed. In the 1 to 12 GHz range the crossed log-periodic dipole antenna performs well as a feed and allows polarization versatility (i.e. choice of vertical, horizontal or either sense of circular polarization). For requirements where circular polarization is sufficient the planar or conical log spiral (2-arm versions) provide broadband characteristics for feed and dish structures. These antenna systems may be implemented with a simple single or dual channel rotary joint permitting a straight-forward approach to beamshaping, i.e. satisfying a minimum elevation beamwidth range requirement while allowing a relatively narrow azimuth beamwidth for high-gain and good DF resolution.

An alternative approach includes a fixed-feed with rotating reflector which eliminates the rotary joint but makes the beamshaping requirement a more difficult objective to achieve. Another alternative is the use of a circularly polarized primary radiator for each octave band allowing the ultimate in beamshaping flexibility, but leads to complicated multiplexing requirements or multiple rf channels in the rotary joint. At Watkins-Johnson several alternative design approaches are offered.

The DF Antenna shown in Figure 6 consists of a curved parabolic reflector approximately 30 inches in diameter by 16 inches in height. A crossed log-periodic feed provides selectable (vertical, horizontal or either sense of circular) polarization from 1 to 12 GHz. The 12 to 18 GHz frequency range is covered by a smaller planar spiral feed and a parabolic reflector mounted back to back with the larger reflector. The entire antenna assembly is enclosed by a thin fiberglass shell which protects the antenna and minimizes the wind resistance for high speed rotation.

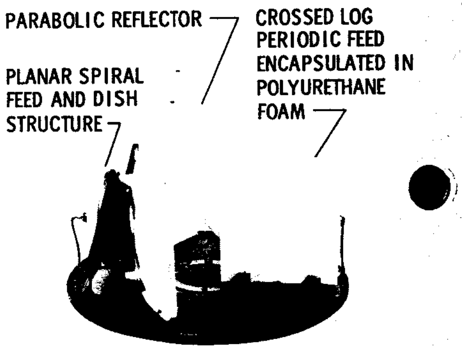

Fig. 6. The WJ-L6/A1 DF antenna structure with protective shroud removed.

The antenna gain varies from 10 dB at 1 GHz to above 20 dB at 12 GHz. Unidirectional radiation patterns are exhibited throughout the frequency range with azimuth beamwidths varying from approximately 30 degrees at 1 GHz to 3 degrees at 12 GHz. Sidelobe levels are held greater than 10 dB below the main beam. The key to achievement of a high system DF accuracy is the control of the radiation pattern boresight versus the referenced mechanical boresight of the antenna, shown in Figure 7. This chart illustrates the extent to which the peak of the radiation pattern "wanders" from the mechanical pointing angle of the antenna; the latter being the position transmitted by the synchro to the DF display unit.

DF Angle of Arrival Accuracy

As discussed previously, the accuracy with which the direction-finding system can determine the bearing or angle of arrival (AOA) of an emitter is dependent upon the antenna boresight radiation pattern shift. However, another very significant factor limits the achievable accuracy—and that is aircraft reflections. This is a factor which is unavoidable and usually represents the most significant limit of DF bearing determination.

The rotary DF Antenna is usually located below or above the aircraft fuselage and is susceptible to reflections fore and aft from the fuselage itself and from the

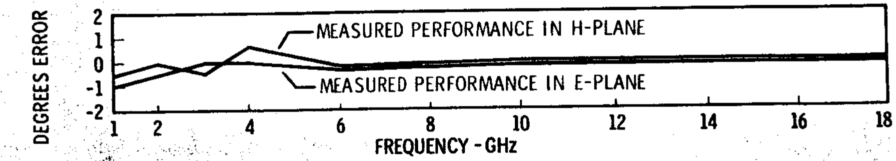

Fig. 7. Radiation pattern boresight versus referenced mechanical boresight of the WJ-L6/A1 antenna.

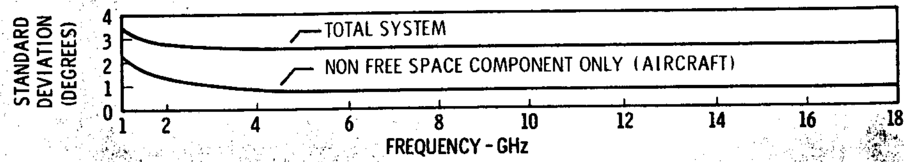

Fig. 8. The angle error standard deviation resulting from diffraction and reflection of the aircraft structure.

wings. External equipment on the fuselage also introduces unwanted reflections. However, the rotary DF system is advantageous in that at any given instant, it detects a restricted portion of the aircraft structure due to its limited azimuth field of view as defined by the relatively narrow antenna beamwidth. Therefore, the narrow beam nature of this directional technique minimizes the pattern distortion arising from diffraction and reflection of the aircraft structure. Figure 8 shows the total standard deviation of angular error* for the rotary DF system as installed on a particular aircraft. Note that the non-free-space component of error (i.e. installation on the aircraft) represents a significant portion of the overall total system DF error. Above approximately 4 GHz the standard deviation approaches a constant value determined by the reflecting geometry of the aircraft installation.

Alternative DF Techniques

Generally, alternative techniques fall into the "monopulse" technique category. The monopulse technique includes sum and difference (phase and/or amplitude) time of arrival, and interferometer. Table I shows the comparison between the characteristics of rotary and monopulse techniques.

Table 1. Comparison of Characteristics: Rotary DF and Monopulse Techniques.

PARAMETER	MONOPULSE	ROTARY
GAIN	LOW-MEDIUM	MEDIUM TO HIGH
BEAMWIDTH	BROAD	NARROW
ACCURACY, FREE SPACE	HIGH	GOOD TO HIGH
AIRCRAFT EFFECTS	SEVERE	MODERATE
COMPLEXITY	MATCHED CHANNELS (2 OR MORE)	SINGLE CHANNEL ONLY
REACTION TIME	NEAR INSTANTANEOUS	MORE THAN 1 PULSE REQUIRED FOR GOOD ACCURACY
SYSTEM SENSITIVITY	LOW	HIGH
INSTALLATION REQUIREMENTS	FIXED SECTOR ANTENNAS WITH POSSIBILITY FOR FLUSH-MOUNTING	MINIMUM OF 6 CUBIC FEET REQUIRED EXTERNAL TO AIRCRAFT SKIN WITH PROTECTIVE RADOME REQUIRED
RELIABILITY	MATCHED CHANNELS ARE SUSEPTIBLE TO DEGRADATION WITH AGE	CRITICALLY DEPENDENT UPON DRIVE SYSTEM AND ROTARY JOINT
COST	EXPENSIVE	INEXPENSIVE
AUTOMATIC OPERATION	COMPUTER-CONTROLLED	CAN BE COMPUTER-CONTROLLED

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*Mean and Standard Deviation Tabulations are found on page 11

The monopulse system's broad field of view results in lower sensitivity. In addition, monopulse antenna types will tend to detect more of the aircraft structural surfaces resulting in degradation of the high potential accuracy inherent in these techniques. This can result in the necessity for extensive system calibration and look-up data tables which accounts for the frequency-dependent variation of DF antenna radiation patterns. The monopulse DF techniques are capable of measurements on a single-pulse basis, although signal-to-noise ratio restrictions usually require a train of pulses for threshold qualification and higher DF accuracy. The rotary DF technique also requires a train of pulses from an emitter in order to realize its full potential accuracy.

Both techniques accommodate computer control and automatic data processing. Software computation of DOA for the rotary DF system is a straightforward procedure. It involves calculating the "centroid" of the received signal power distribution versus angle. The rotary DF technique normally requires a mounting configuration below the belly of the aircraft or above the fuselage, with a protective radome surrounding the antenna which is aerodynamically compatible with the airframe involved. A major consideration in choosing between the rotary DF technique and a monopulse technique is cost. With the necessity for multichannel amplitude and/or phase matching and consequently multiple receivers required for the various monopulse techniques, the rotary DF antenna system is much lower in cost with components available on an off-the-shelf basis. Information obtained from the DF antenna system can, of course, be made available for use in other on-board avionics systems. This includes reactive-type EW systems such as ECM.

Summary

The characteristics of high-gain and relatively high DF accuracy make the rotary DF System attractive from a technical standpoint. Modern display techniques using storage CRT's with electronic cursors and digital readouts improve operator interpretation and result in higher DF accuracy. Automatic computation of DOA results in accuracies which rival those of comparable monopulse systems. Installation requirements are simple given a minimum weight and space allowance for the particular aircraft. Reliability has improved substantially with the advent of a pedestal design which is simple, rugged and easy to maintain. Finally, the cost of the rotary DF antenna system is low with the availability of standard off-the-shelf designs.

This issue of Tech-notes has discussed considerations which lead to the following set of rules for specifying a DF antenna system:

- Maintenance of the widest beamwidth possible to reduce DF analysis time, consistent with required antenna gain and system DF accuracy requirements.
- Use of a storage display to permit effective scan-to-scan signal integration and minimize DF analysis time.
- Operation at the minimum DF antenna rotational rate to extend the life of the RF rotary joints and mechanical components as well as minimize weight and primary power requirements.

Mean and Standard Deviation Tabulation

The error data which led to the curve of Figure 8 includes those effects arising as a result of non-free-space conditions (installation on the aircraft). This data was analyzed by computing the sample mean ($\bar{x}$):

$$\bar{x} = \sum_{i}^{n} \frac{x_i}{n}$$

and the unbiased estimate of the population standard deviation (S):

$$S = \sqrt{\sum_{i}^{n} \frac{(x_i - \bar{x})^2}{n - 1}}$$

where x_i is a sample data point, n is the number of samples and i is an integer between 1 and n.

These statistics were computed for various groupings of conditions, namely:

- At each frequency, for each polarization and each elevation angle.
- At each frequency, for each elevation angle, with the polarization grouped together.
- At each frequency, for each polarization, with elevation angles grouped together.
- All data grouped together.

A small residual mean value (0.01°) was considered to be of no significance except in computing the standard deviation. It represents a boresight error which would be removed by system recalibration.

It is noteworthy that the standard deviation of frequency groups decreases as the frequency is increased, diffraction becomes less significant and the standard deviation of the error decreases. As the frequency is increased further, the limiting case of geometric optics is approached in which specular reflection is the dominant mechanism. As this limit is approached, the rate of change of the standard deviation diminishes, and approaches a constant value determined by the reflecting geometry. This behavior is clearly evident in the plot of standard deviation versus frequency shown in Figure 8.

References:

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