INSTANTANEOUS BEARING DISCRIMINATORS WITH OMNIDIRECTIONAL COVERAGE AND HIGH ACCURACY

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Abstract

Monopulse Bearing Discriminators,[1] with full omni-azimuthal coverage, designed specifically for high probability of detection in dense signal environments are presented. S-band (2-4 GHz) developmental models give angle of arrival information on a single pulse basis with bearing errors less than 1.7 degrees RMS within ± 40 degrees of elevation angle. The theoretical bearing error (perfect components) is less than ± 1 degree peak.

Introduction

In threat sorting receiver systems it is necessary to measure frequency and angle of arrival, with high accuracy, on a single pulse basis. The current favorite for instantaneous frequency measurement is the digital IFM, originally developed by Mullard Electronic Labs[2]. The digital IFM provides frequency indication at rates exceeding 3 million per second with a resolution of 0.02 percent (12 bits).

The following paragraphs describe the operation and performance characteristics of a new type of monopulse Bearing Discriminator which has a 360 degree field of view. Existing angle-of-arrival techniques which perform the same function consist of either a circular array or multiple linear arrays of discrete antennas and use amplitude comparison receivers. The bearing accuracy of existing amplitude comparison receivers is typically 7 degrees RMS within ± 35 degrees of elevation angle.

The presented Bearing Discriminator is based on phase comparison, is wide open in both frequency and bearing, and it has the potential for overcoming the difficulties with presently used systems. S-band developmental models have bearing errors less than 1.7 degrees RMS within ± 40 degrees of elevation angle. The error is increased to 2 degrees RMS when elevation angles up to ± 60 degrees are used. High dynamic range and sensitivity is achieved by using limiting amplifiers in front of the phase comparators.

Theory of Operation

The heart of the new Bearing Discriminator[1] is a circular antenna array and a feed matrix. N antenna elements are equispaced around a cylinder and each element is connected to an input port of the feed network as is shown in Figure 1.

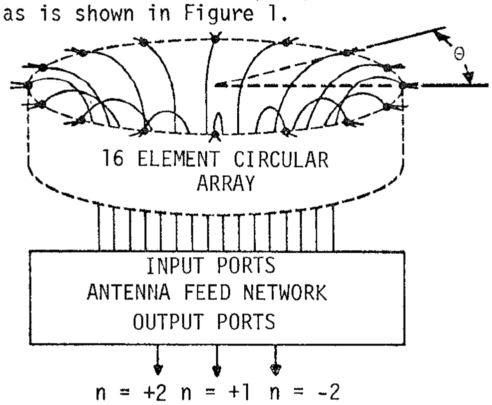

Figure 1 Antenna Array and Feed Network

The operation of the antenna and feed network is best described from a transmit point of view. Power applied to the output ports of the feed network generates modes with an $e^{jn\theta}$ phase progression, where θ is the bearing angle and n is the mode number related to each output port. In the far field of the array the pattern is omnidirectional in azimuth for all modes. The phase variation versus bearing angle is shown in Figure 2 for the modes n = +1, +2, and -2.

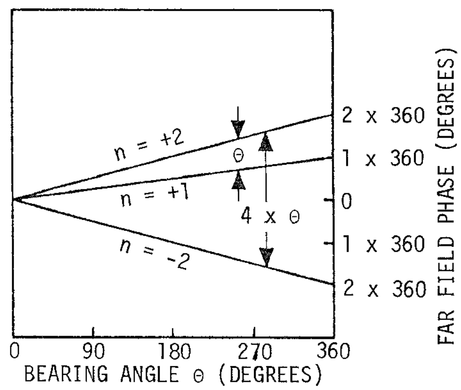

Figure 2 Phase in the Far Field Vs. Bearing Angle When Port n is Used as Input Port

If a signal source is located at an azimuthal angle θ, then from reciprocity, the received phase at the n = +1, +2, and -2 output ports of the feed network will have the same relationship as the far field phase in the transmit mode. If the n = +2 and n = -2 output ports of the feed network are phase compared, a 4θ measurement results. That is to say, if a signal source is at an angle θ, the phase comparison between the two ports is 4θ. This gives a high degree of accuracy in measurement of the bearing angle θ but the measurement is ambiguous over the full 360 degrees of angular coverage.

If the n = +2, and n = +1 output ports are phase compared, a θ measurement results. This output is used to resolve the ambiguities in the 4θ measurement.

In this manner, a very accurate method of measuring bearing angle using a moderate number of elements is produced. An antenna array using 16 elements with a θ and a 4θ channel as described has a theoretical bearing error of less than ± 1 degree peak.

Expressed in Bessel functions, $J_n(x)$, the array factor of a circular array with N elements using port n of the feed network is [3,4]:

$$E^n(\theta,\phi)=N\cdot(j)^n e^{jn\theta}\left(J_n(x)+j^N J_{n+N}(x)e^{jN\theta}+ j^{2N}J_{n+2N}(x)e^{j2N\theta}+\ldots\ldots+j^{-N}J_{n-N}(x)e^{-jN\theta}+ j^{-2N}J_{n-2N}(x)e^{-j2N\theta}+\ldots\ldots\right)$$

where Θ is the bearing angle
$x = (2\pi/\lambda) r \cos \emptyset$
$\emptyset$ = is the elevation angle
r is the radius of the array

This equation shows that the bearing accuracy is relatively insensitive to elevation angle and that modes with $|n|$ approaching N/2 will have increased errors due to the error terms $J_{n+N}(x)$ and $J_{n-N}(x)$. The radius r has to be small enough so that the equivalent of grating lobes for linear arrays are not generated.

The described configuration with a Θ and a $4 \cdot \Theta$ channel is just one of several. A Θ, $4 \cdot \Theta$, and $16 \cdot \Theta$ channel receiver would have improved accuracy by a factor of 3-4 but would be more complex.

Experimental Data

A picture of a developmental model of the antenna and feed matrix is shown in Figure 3. The unit is designed for S-band (2-4 GHz) and consists of a 16 element circular array of tapered slot radiators connected to a 16 port feed matrix. The antenna arrays are manufactured using printed circuit techniques and are very small. A 16 element array in S-band has a radius of 5 inches and the 7.5 - 18 GHz unit has a radius of 1.5 inches for 16 elements.

Figure 3 shows a device where the three modes - n = +1, n = +2, and n = -2 are coupled from the antenna to the three feed network output ports.

The indicated bearing error of the 4Θ channel of this unit is shown in Figure 4. The bearing error is less than $\pm$ 3 degrees peak. The corresponding error of the Θ channel is less than $\pm$ 17 degrees peak.

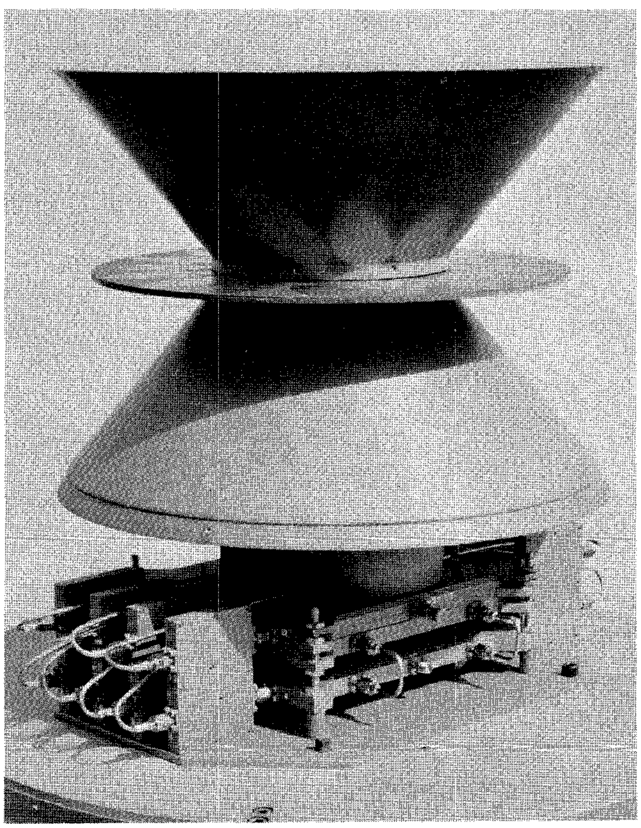

Figure 3 Antenna Array and Feed Network for S-band (2-4 GHz) Bearing Discriminator

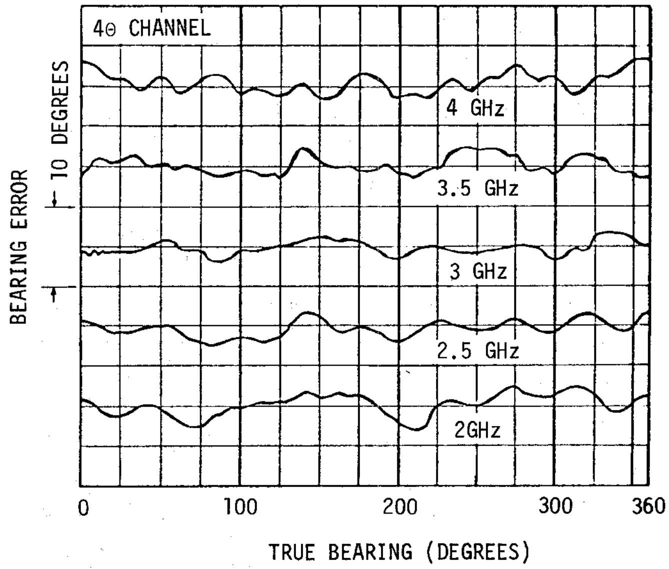

Figure 4 Bearing Error vs. True Bearing Angle, 4Θ Channel. 10 Degree Offset Between Curves

Receiver

Following the antenna and feed network, processing is identical with that utilized in Digital Frequency Discriminators.[5] The phase information contained in the Θ and 4Θ modes is measured using phase comparators. After video amplification, the measurements are quantized utilizing 4-bit and 6-bit binary encoders. The 4Θ channel is quantized to a 6-bit binary word which is ambiguous every quadrant. 4-bit quadrant information is obtained from the quantization of the Θ channel. An ambiguity resolving network receives this information and produces an 8-bit bearing word with a resolution of 1.41 degrees. This information is unambiguous over the full 360 degree instanteous field of view. The Bearing Discriminator is wide open in frequency (and bearing) and responds in real time to pulse signals with pulse widths as short as 100 ns in the 7.5 - 18 GHz band and 200 ns in the 2 - 8 GHz band.

Sensitivity and Dynamic Range

System sensitivity depends on antenna and amplifier gain, amplifier noise figure, and the allowable signal-to-noise ratio at the phase comparator inputs. To get the highest accuracy on production Digital Frequency Discriminators threshold is set to -68 dBm for a 2 - 4 GHz receiver and the same number has been used for DBD's. The corresponding sensitivity for both a 2 - 8 GHz receiver and a 7.5 - 18 GHz receiver is -60 dBm.

For $\pm$ 60 degree elevation coverage the antenna gain is approximately 0 dBi (including the feed network loss) at 0 degree elevation angle. Additional reduction of sensitivity is due to polarizer, radome, protection limiter, circulator and cable losses.

The dynamic range of the receiver extends from sensitivity to at least 0 dBm resulting in a dynamic range exceeding 60 dB.

Digital Bearing Discriminator Performance

A breadboard S-band (2-4 GHz) Digital Bearing Discriminator (DBD) using the presented concept has been built and tested. As was shown in a preceding paragraph the antenna array and feed matrix covers the 2-4 GHz band, but the available receiver for this unit only covered 2.25 - 3.75 GHz. Figures 5 and 6 show the performance of a DBD with a Θ and a 4Θ channel. The peak to peak bearing error in Figure 5 is 10 degrees which corresponds to a 1.7 degree RMS error. The bearing error increases rapidly above 60 degrees of elevation angle.

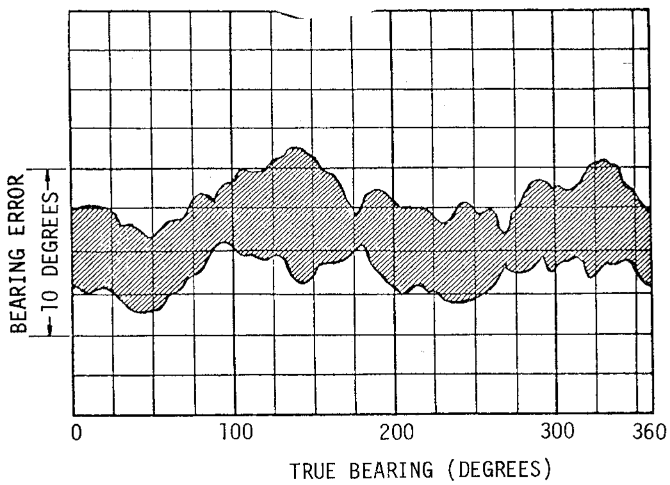

Figure 5 Bearing Error Vs. True Bearing Angle. DBD Performance 2.25 - 3.75 GHz.

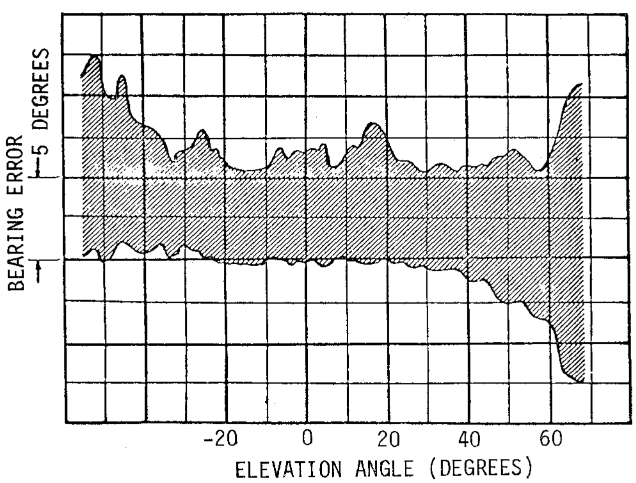

Figure 6 Bearing Error Vs. Elevation Angle. DBD Performance 2.25 - 3.75 GHz.

A less expensive but also less accurate DBD would use a Θ channel only and data for such a system shows that the bearing error is 6 degrees RMS i.e. the 4Θ channel reduces the bearing error by a factor of approximately 3.5.

Future Development

The purpose of building the described DBD was to verify the theory. Improved Bearing Discriminators for the 2 - 4 GHz band are under construction as well as units for the 2 - 8 GHz and 7.5 - 18 GHz bands. The purpose is to investigate, in the 2 - 4 GHz band, what the best possible performance could be. Feed networks with n = 0, ± 1, ± 2, ..., ± 7 output ports have been built so that all modes can be investigated to find how to get the best bearing accuracy.

Conclusions

Small, lightweight, monopulse Digital Bearing Discriminators (DBD's) with frequency coverage up to 18 GHz are under development. The DBD is wide open in frequency (within each band), wide open in bearing and it has high dynamic range and sensitivity.

A DBD has been built and tested in S-band (2-4 GHz). The performance of this breadboard DBD is very encouraging and it is now being tested in realistic environments, over water etc. State of the art bearing errors are presently 1.7 degrees RMS over more than ± 40 degrees of elevation angle.

References

1. Patent Pending

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