

Miniature Direction-Finding Antenna Array

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This article describes the design concepts that were combined to create a single direction-finding antenna system covering the wide bandwidth of 1 MHz to 18 GHz

Most tactical platforms using Direction-Finding (DF) antenna systems require the use of small aperture antenna arrays, especially on submarines and small aircraft where space is limited.

Recently, Astron was asked to provide the smallest possible DF antenna array for a submarine mast. However, to achieve this small array the multiple antennas for each band of frequencies must be brought closer together on the diameter and overlapped with the other frequency bands to decrease the height (see Fig. 1) for a typical, multi-band, DF array covering 1 to 18,000 MHz. Unfortunately, these desirable features, such as decreasing its volume, cause cross-coupling and degradation of each antenna's RF pattern causing serious errors in the angle to the target.

Astron was fortunate to have previously completed three phase 1 and 2 SBIR programs to resolve the basic problems of:

- Closer spacing of antennas to assure a miniaturized DF antenna array without effecting accuracy of target location.
- Miniaturizing of antenna elements to decrease DF antenna array height.
- Increasing frequency bandwidth coverage of the antenna elements, thus minimizing the number of frequency bands of antenna coverage required. This further reduces the height and weight of the final DF antenna systems.
- Miniaturized beam forming networks with automatic self testing to provide more efficient and rapid DF capability.

This includes the miniaturized Butler Matrix, low noise amplifiers, adaptive calibration networks, and automatic, real time, RF switching subsystems. This assured a smaller and lighter overall DF systems antenna array technology.

These techniques developed over the last seven years have been trade marketed as the HESA™ (High Efficiency, Sensitivity, and Accuracy). With each major antenna, beam forming system, and DF antenna array program completed, the HESA technology is further expanded. Without the HESA technology, Astron would not have been able to meet the stringent diameter, height and sensitivity requirements for the Submarine Mast Program.

Direction Finding System

To assist in understanding the full antenna array requirements and their operation, a typical, tactical, dual-channel, quadrature interferometer, DF system will be briefly covered (Fig. 2). The system computes a line-of-bearing (LOB) to a signal of interest. The antenna array assembly performs signal reception, amplification, real time RF switching and signal injection for system calibration. The DF system utilizes dual-phase, locked receivers to simultaneously compare two RF channels, to make sensitive differential phase and amplitude measurements of the signals received by the DF antenna array. Signals are extracted by the system and utilized to achieve the desired high accuracy LOB to the signals of interest.

The DF antenna assembly may consist of four antennas per frequency band (Fig. 1), each operating over a specific portion of the frequency band of system coverage. For

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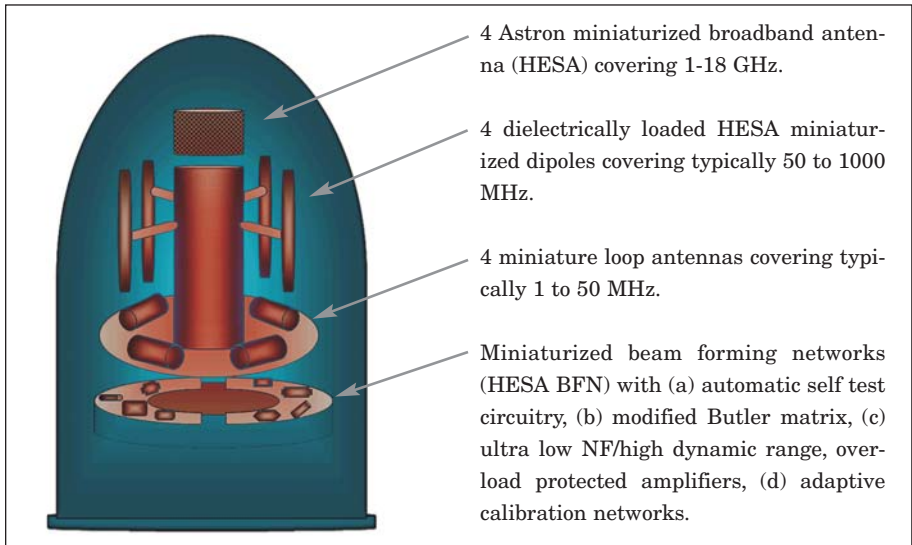


Figure 1 · A typical 4-element antenna per band sine/cosine/omni amplitude/phase output DF array. The accuracy of a 4-element antenna per band is typically 5 degrees (rms). An 8-element antenna per band is typically better than 3 degrees (rms) accurate.

greater accuracy each band would use more antennas, say six or eight. The increase in accuracy is discussed in Figure 1.

The DF antenna array collects vertically polarized signals and applies them to the antenna base switch/amplification modules, which allows the RF signal to be routed to

the RF distribution unit, and to the appropriate receivers. The signals are then down converted to a baseband IF (typical 50 or 100 kHz), and sent to the RAPID to be digitized. FFTs and other advanced digital signal processing techniques are applied utilizing an array processor to calculate the LOB of the signal of interest.

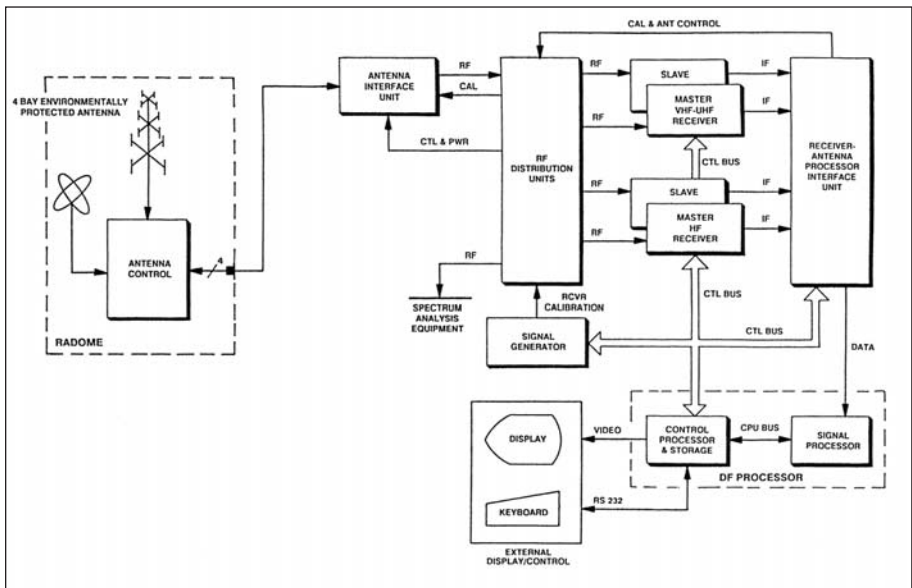


Figure 2 · A typical dual channel space quadrature interferometer system utilizing Astron's broadband miniature sine/cosine/omni amplitude/phase DF array.

Calculating an LOB with a minimum error requires measurement of the incident wave with a minimum amount of disturbance. Calibration of the DF system is performed to minimize errors caused by variations in the receiving system. There are two basic system calibrations in this system—signal injection and antenna calibration. The communication receivers, RF and IF amplifiers, signal processors, and other components used in each channel of this dual channel system are not completely phase, or amplitude matched. Differences in the phase and amplitude response of each channel will cause LOB errors. To minimize these channel dependent errors a signal generator is used to inject a balanced signal into each channel in the antenna, and the differential response is measured and stored to correct errors caused by variations in the system RF path. The signal injection is a dynamic process performed on each DF cut. Anomalies in the response of the DF antenna from theoretical will also cause LOB errors. The response of the DF antenna as a function of frequency and azimuth is determined by transmitting a known signal and measuring the response. This data is then used to generate azimuthal antenna calibration tables to correct DF antenna anomalies. Utilization of these calibration tables increases the accuracy of the DF system.

Antenna Element Design

Obviously, the use of a monopole antenna element would greatly reduce its height and increase its gain, since a $\lambda/4$ monopole element would have a 5.2 dBi gain, compared to a dipole antenna element whose gain would be only 2.1 dBi, plus, having a doubled, $\lambda/2$ height. Since the ground plane available in the array is small and negligible, a dipole will be essential. Note the very high take-off angle that a monopole has with a small ground plane (Fig. 3).

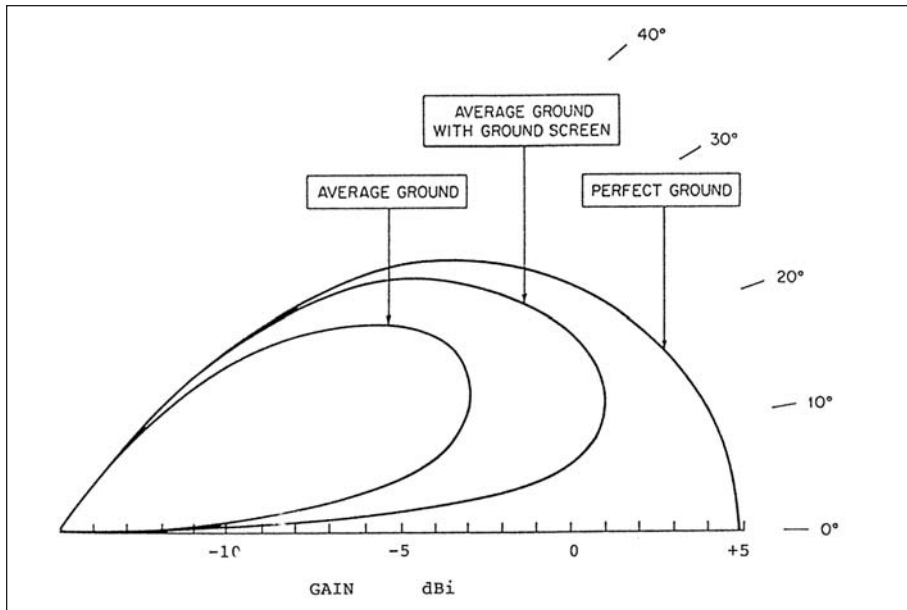


Figure 3 · Monopole radiation elevation pattern for perfect, good and poor ground.

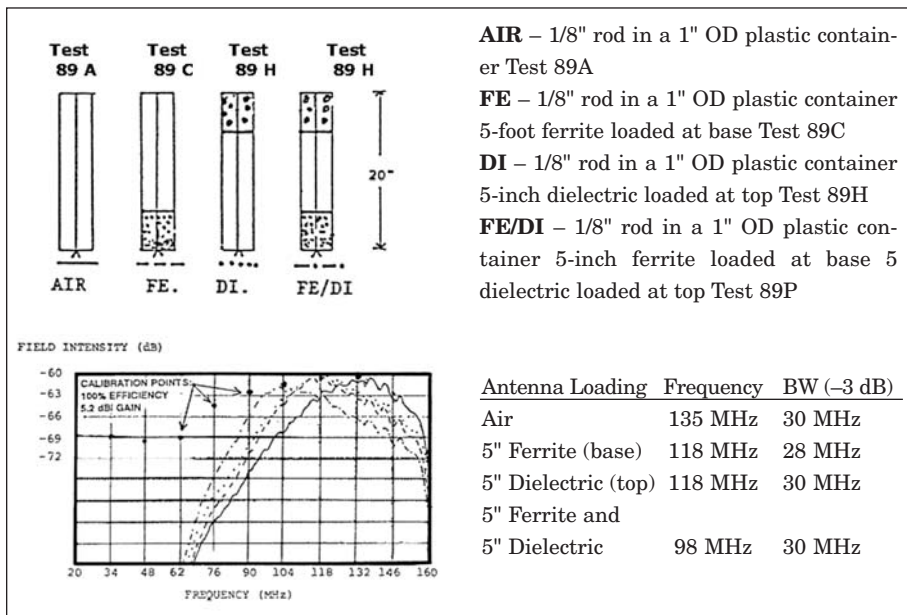


Figure 4 · Optimum dielectromagnetic loading of monopole antennas.

Antenna Element Miniaturization-Dielectric/Ferrite Loading

As part of the HESA technology, antenna elements can be dielectromagnetical loaded to achieve foreshortening (miniaturized while still operating efficiently). To illustrate the use of this powerful dielectric/ferrite antenna-loading tool, let us apply it to the external dielectric/ferrite loading

of a monopole, as shown in Figure 4. A test was run on the Astron VHF/UHF calibrated antenna range to verify the theory, regarding the ideal location of dielectrics and ferrites on a monopole antenna, to achieve maximum foreshortening. A special jig composed of a hollow 20-inch, low RF loss fiberglass cylinder (1-inch O.D.) was devised for holding a 20-inch, 0.125-inch, O.D.

copper rod at the tube's center in a vertical position. The first test, 89A, involves getting the RF response of the 0.125 inch copper rod (operating as a monopole), vs. frequency over a range of 20 to 160 MHz. The 20-inch rod monopole has a maximum response at its resonance frequency of 135 MHz, which is shown in Figure 4. Its efficiency at its resonance frequency should be 100% and indeed it is. Note the 100% efficiency mark at 132 MHz mark (obtained from the initial range calibration).

The next test, 89C, involved filling the lower five inches of the fiberglass cylinder jig (still holding the 20-inch rod at its center axis in a vertical position) with a powdered ferrite having a relative permeability of $\mu = 4$. The powder surrounded the rod at its base, externally loading the bottom five inches. The maximum foreshortening expected would be the square root of 4 or 2:1. The 0.125-inch copper rod is only partially loaded with ferrite material. The effect of the ferrite was to lower the resonance frequency to 112 MHz (down from 135 MHz). This effectively achieved only foreshortening of 1.24, the 20-inch rod's electrical length effectively being increased from 20 inches to 24.8 inches.

The next test, 89H, removed the ferrite powder and added five inches of dielectric powder (having a relative permittivity of $\epsilon = 4$) at the top five inches of the rod. The result was similar to 112 MHz and an effective foreshortening of 1.24. The last test, 89P, left the five inches of dielectric at the top five inches, and returned the five inches of ferrite powder at the bottom of the 0.125-inch rod. The resonance dropped to 98 MHz, a foreshortening of about 33%, and increasing its effective electrical length to 28 inches. In all tests the efficiency was essentially 100%. These tests showed that the optimum position for the ferrite is at the base (where the current is the highest) while the optimum position for the dielectric is at the top (where the voltage is highest).

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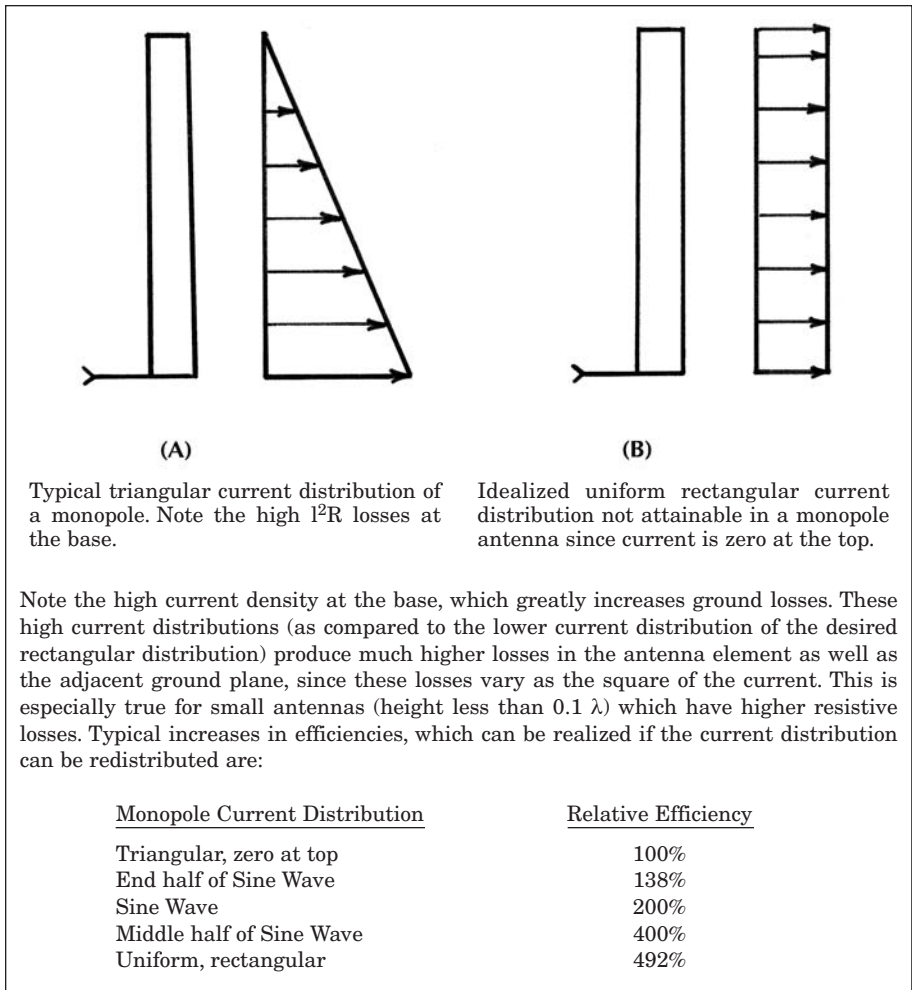


Figure 5 · Effect on efficiency of monopole antenna linear and non-linear current distribution.

Antenna Element Miniaturization: Current Redistribution

Figure 5 shows the effect on efficiency of an antenna as a function of its RF current distribution. By redistributing the current to make it more linear its efficiency can be greatly increased, allowing it to be foreshortened while maintaining its high efficiency. The redistribution is accomplished by appropriate use of dielectric and ferrite loading of the anten-

na elements. Both computer simulation and antenna range testing is used to optimize the current redistribution, achieving a simplified, traveling wave antenna.

Gain/Bandwidth—Height/Width Ratio

The data in Figure 6 clearly shows the expanding gain/bandwidth for a constant height antenna (12.5 inches), while varying its width incrementally

Diagram	H	W	RESONANT FREQUENCY (MHz)	BW@ -3 dB (MHz)		TEST
				-3 dB	+3 dB	
	12.5"	12"	215	140	~ 500+	3B-14
	12.5"	5.8"	215	160	~ 500+	3A-12
	12.5"	1/8" ROD	225	190	290	JK-7

Figure 6a · Summary of bandwidth vs. antenna size measurements.

from 12.5 inches, 5.8 inches and 0.125 inches. It was the combining of the previously discussed HESA technologies that enabled Astron to achieve the desired 30 to 2,000 MHz coverage of the JTRS/SINCGARS airborne blade antenna. Other HESA technologies are available for direction finding arrays, SATCOM, and UHF/VHF/UHF communications antennas.

Cross-Coupling Between Antennas

Cross-coupling between all of the antennas within the small radome covered DF antenna array can cause distorted RF patterns, and LOB inaccuracies, if not seriously considered. Some of the techniques used to assure an accurate DF array are:

- (a) relative position and shape of the antenna elements
- (b) current distribution in all of the antenna elements relative to each other
- (c) co-location of all pertinent components in each sub-band
- (d) interconnections between ground planes optimized
- (e) use of ferrites to decrease RF coupling fields.

Astron Wireless utilizes state-of-the-art computer simulation software, laboratory, and field testing, while incorporating our HESA antenna, beam former network, and other component technology. This process results in cost effective, active, and passive DF antenna systems for diverse applications. It exhibits optimum and enhanced performance against its larger counterparts, yet occupies the smallest form factors available to date.

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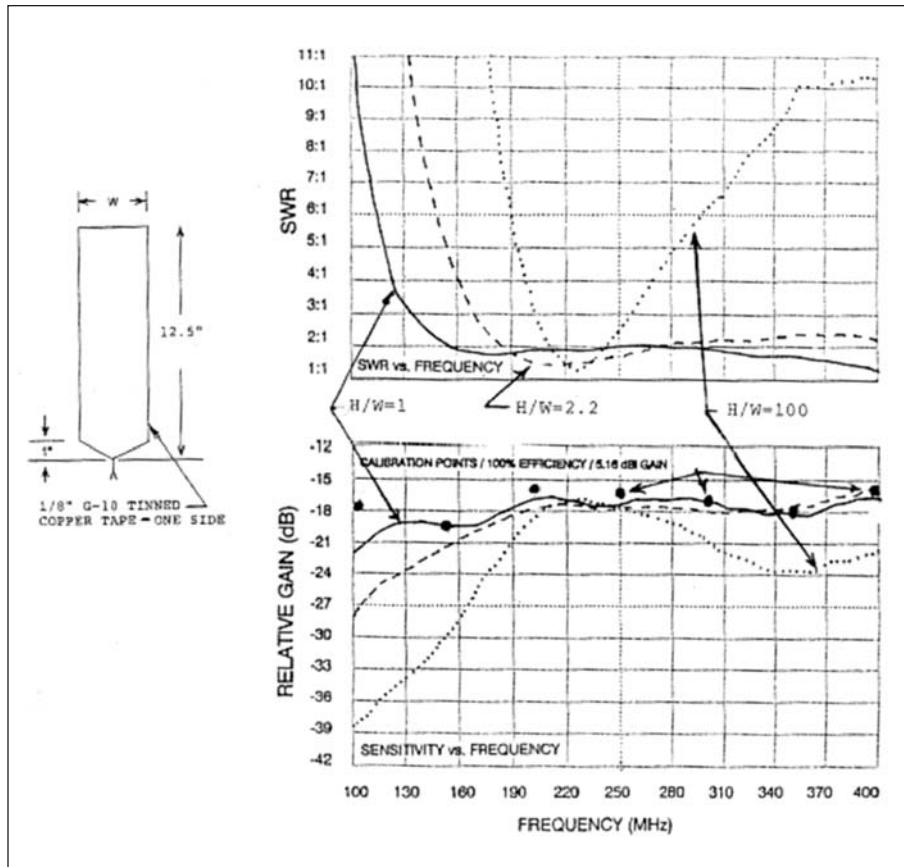


Figure 6b · Gain/bandwidth plots of DF antenna vs. height/width.

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About the Author

Joseph R. Jahoda, Astron's chief technology officer, founded Astron 27 years ago. He graduated from College of the City of New York in 1950 with a B.E.E. and from Polytechnic Institute of Brooklyn in 1954 with a M.E.E. He has been involved in R&D for ECM and communications systems ever since. He can be reached at 703-450-5517; or jjahoda@astronwireless.com.