S-BAND PHASED ARRAY ANTENNA FOR THE E-9A[†]

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ABSTRACT

This paper describes the requirement, design and test results for the Airborne Phased Telemetry Array for the E-9A Airborne Platform.

INTRODUCTION

The E-9A is an airborne platform/telemetry relay system (AP/TM) developed for the Gulf Range to support test and evaluation programs of air-to-air missiles. A description of the complete system was given at the ITC/USA/'86 [1]. One of the subsystems of the E-9A is the telemetry (TM) relay subsystem. The mission requirements, which were the driving factor in the design of the antenna, are listed in Table I. This paper describes the design and gives the test results of this unique S-band phased array antenna. The antenna is an electronically steerable phased array capable of simultaneously receiving five independent telemetry signals within its field of view. It is a new polarization insensitive phased array (in conjunction with the receivers) that operates at 2.2 to 2.4 GHz and uses modular parts to improve reliability and reduce maintenance times. The antenna is mounted on the starboard side of a DeHavilland Dash 8 aircraft.

PHASED ARRAY ANTENNA SYSTEM DESCRIPTION

The antenna design is a one-dimensional scan, multiple-channel phased array 30 feet in length with a height of 30 inches (see Figure 1). The 144 column planar array is subdivided into eight interchangeable subarrays, with each subarray consisting of 18 identical columns which consist of wideband microstrip patch disk elements. The array features 1728 elements in a rectangular lattice. Each element is designed to provide dual orthogonal

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polarization oriented at ±45° with respect to the vertical axis (slant left and slant right polarization) and provides 200 MHz instantaneous bandwidth. Polarization insensitivity is achieved by the combination of the dual orthogonal polarization array and the high speed IF combiners in the telemetry receivers. In addition, polarization diversity considerably improves the quality of TM reception in the presence of multipath distortion.

Table I

Telemetry Mission Requirements and Source Characteristics	
Parameter	Requirement
Operating Frequency	2200 MHz to 2400 MHz (S-band)
Signal Sources	Up to 5 simultaneous dual emitters spatially separated
Source effective radiated power	23 dBm
Signal Bandwidth	3 MHz
Antenna Coverage in Azimuth	-60° to + 60°
Antenna Coverage in Elevation	Sea Surface to 25,000 feet
Fade Margin	10dB
S/N Ratio	13 dB
Acquisition Range	75 nautical miles
Tracking Range	50 nautical miles

Based on the specific system requirements shown in Table I, the minimum required G/T for the antenna system is 5.1 dB. To meet the required G/T in an airborne environment, emphasis was placed on minimizing losses and maximizing antenna gain. In addition, low elevation plane sidelobes were necessary to minimize the level of illumination of the aircraft wing and engine cowling as well as to reduce sensitivity to sea surface multipath. As a result, the azimuth aperture is uniformly illuminated, and a modified Taylor distribution is used in elevation to reduce the elevation plane sidelobes.

The technique selected to cover the scan volume was a fan beam (10° BW_{3dB}) in the elevation plane and a scan beam in the azimuth plane (0.72° BW_{3dB}) obtained by phasing the array. This was considered to be the simplest of all approaches. This technique results in an array with the largest length to height ratio and the simplest tracking algorithm. To avoid grating lobes in the field of view (± 60°), the elements were spaced 2.5 inches apart.

In addition, the spacing provided a convenient implementation of the corporate feed for the 144 columns in the horizontal plane.

Target acquisition is accomplished by a full scan of the scan volume while monitoring the receiver AGC. Once the target is detected, the system has an adaptive scan technique to focus on the target. Target tracking is accomplished with a beam dithering technique. Beam crossover occurs at 0.25 beamwidth to produce 6.7% amplitude modulation.

A diagram of the TM phased array antenna system is shown in Figure 2. All key antenna parts are shown in this diagram. The radomes are a specially designed A-sandwich construction that meets rigid mechanical and electrical requirements. The radome is 2.2 inches thick and is composed of two 0.02 inch fiberglass skins attached to a honeycomb core. Boresight losses at 2.3 GHz are only 0.03 dB mismatch loss and 0.07 dB ohmic loss. Like the radomes, the elements are specially designed devices that operate over the 200 MHz bandwidth. Element design efforts focused on maximizing bandwidth and minimizing return loss, particularly at ±60°. The elements are circular hollow disks built from epoxy fiberglass and mount directly on the elevation combiner. The 12-way elevation combiner forms the beam in the elevation plane. It is a quantized approximation of a 25 dB sidelobe ($\bar{n} = 6$) Taylor distribution. The quantized combiner network makes appropriate use of 2-way power dividers to provide about -22 dB sidelobes. This device is a multi-layer stripline assembly built by Triangle Microwave, Inc. with 48 inputs (four for each of the 12 antenna elements).

The dual polarized outputs from each element combiner are fed into a phased array module (PAM) which contains a bandpass filter, isolator, low noise amplifier, 5-way power divider and five 4-bit phase shifters. The PAM, built by Electromagnetic Sciences, Inc., contains twice this number of components allowing simultaneous processing of both slant right and slant left polarizations. This unit features a LNA with 0.95 dB noise figure (room temperature) and 46 dB gain. The PAM contains all the active electronic components in a single replaceable unit. Each PAM can be accessed and replaced using aircraft access panels at the bottom of the array enclosure.

The output from each PAM in the subarray is connected to an 18-way azimuth combiner. These devices perform a final signal summation at a subarray level. There are five 18-way azimuth combiners in the subarray with the each combiner containing the circuitry for each polarization. It is a stripline assembly built by Triangle Microwave, Inc. , with 36 inputs and 2 outputs. The corporate combiner sums all signals from the 8 subarrays. It is a combination of phased-matched semirigid cabling and ten 8-way azimuth combiners. A Built-in Test Equipment (BITE) network provides the capability to inject a signal into each elevation combiner throughout the entire array, including both polarizations. This network facilitates system checkout and fault isolation.

The outputs from the phased array are fed to the telemetry receivers (Astrolink MTR602) designed to meet the requirements of the airborne platform telemetry system. The dual channel receivers are capable of receiving and pre-detection combining of two (orthogonally polarized) signals. In addition, they have an AM module for each channel to detect the amplitude modulation induced on the RF signal due to the 10 KHz beam dither. The two receiver channels utilize common local oscillator signals which are phased locked to an internal 5 MHz reference oscillator to ensure the best combiner operation. Each receiver has its own FM data signal demodulator. A third FM discriminator is provided for the combined signal. The optimal ratio predetection diversity combiner uses AM/AGC weighted signals that permit the selection of the best signal under dynamic fade rates up to and exceeding 20 KHz.

The preprocessor interfaces between the TM receivers and the Antenna Control Computer (ACC). The AM signal from the receiver is synchronously detected and filtered to produce a track error voltage that is fed to the computer. The receiver AGC is filtered and also routed to the computer.

The ACC serves as the central processor and controller for the TM phased array antenna system. Its main functions are: checkout, diagnostics, in-flight status monitoring, and mission support. Its mission support function includes signal processing necessary for target acquisition and tracking. The ACC contains a specially designed Beamsteer Processor (BSP) which performs the processing of the individual phase shift commands for the PAMs. Eight Subarray Interface Units (SIU) demultiplex the serial data sent from the ACC and route it to the appropriate PAM for beam control. The SIUs are mounted inside the aircraft. As part of the BITE function, each PAM can be individually turned either on or off by the ACC.

SUMMARY OF ANTENNA PERFORMANCE

Two TM phased array antennas systems were built and tested by the Georgia Tech Research Institute (see Table II). The antennas met all design criteria.

Table II

Telemetry Antenna Assembly Specification	
Parameter	Specification
Frequency Range	2.2 - 2.4 GHz
Independent Beams	5
Polarization	Dual Linear: Slant Left and Slant Right
Azimuth Beam Steering Limits	±60° from boresight
Elevation 3 dB Beamwidth (BW_{3dB})	10°
Azimuth 3 dB Beamwidth (BW_{3dB})	0.72° at boresight
Nominal Gain (@ 2.3 GHz)	Boresight: 35 dB ±60°: 30 dB
Gain/Temperature Ratio	11.3 dB nominal at boresight
Nominal Sidelobe Levels: Azimuth Elevation	13 dB 22 dB
Squint Loss @ 12 MHz Offset	1.5 dB
Cross Polarization Isolation	20 dB nominal at boresight
Array Face Dimensions	30 feet long, 30 inches high
AngularTracking Rate	2.1 degrees/second (minimum)
Tracking Technique	Switched Beam (dithering)
Dithering Rate	10 KHz
Dither Crossover Loss	0.7 dB
Beam Pointing Update Rate	200 updates/second (all beams)
Acquisition Time	1.5 seconds
Acquisition Technique	1 coarse search (± 60°) and 3 fine searches after initial detection
Acquisition Threshold	10 dB minimum Receiver IF SNR (software selectable to <0 dB)

Beam Coast	Signal fades up to 1.0 second at all angular rates
Status Reporting	Status Display reports beam status (OFF, SEARCH, TRACK) and tracking angle for all five beams, receiver status, and system status
Diagnostics	Built-in (Status Display) and externally accessible (Ground Support Vehicle)
Power Requirements	400 Hz, 110 V AC (Computer); 28 V DC (Preprocessor, 4 power supplies and 5 receivers): 95 A max.

Table III presents a comparison of the design criteria and measured results. Figure 3 shows both an azimuth plane pattern for selected scan angles and an elevation plane pattern at 2.3 GHz.

Table III

Comparison of Design Criteria and Measured Results (@ 2.3 GHz)		
Parameter	Design	Measurement*
Elevation Plane (boresight) BW_{3dB} Sidelobe Level	 10° 22 dB	 10° 21 dB
Azimuth Plane (boresight) BW_{3dB} Sidelobe Level	 0.72° 13 dB	 0.72° 12.6 dB
Gain Boresight + 60° − 60°	 35dB 30 dB 30 dB	 35.3 dB 30.7 dB 30.2 dB
G/T Boresight +60° − 60°	 11.1 dB 6.1 dB 6.1 dB	 11.3 dB 6.6 dB 6.3 dB
Squint Loss	1.5 dB	1.5 dB

*Average of all five beams from measurements of second antenna.

CONCLUSIONS AND RECOMMENDATIONS

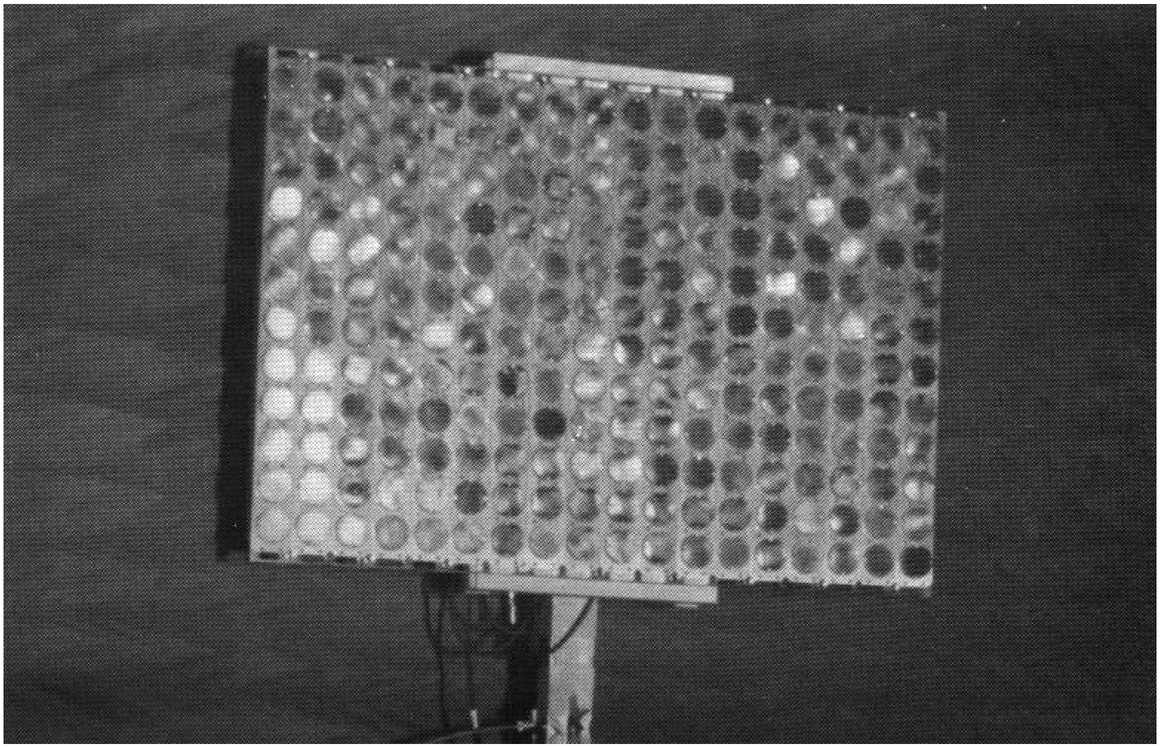
Two E-9A aircraft with the S-band phased array antennas are currently operating successfully at Tyndall AFB, Florida. Preliminary tests (at the time of this writing) have demonstrated that the phased array antenna meets system requirements.

REFERENCES

1 . Zoledziowski, Severyn, "An Airborne Telemetry Relay System for the Gulf Range", International Telemetering Conference, Las Vegas, Nevada, 13 - 16 October 1986.

2. Sulecki, J. M., "A Comparison of Circular Polarization with Dual Polarization Diversity in the Presence of Multipath", Ibid.

a) Phased Array Antenna on the E-9A Aircraft.



b) Subarray under Test.

Figure 1. Photographs of the Aircraft (a) and Subarray (b).

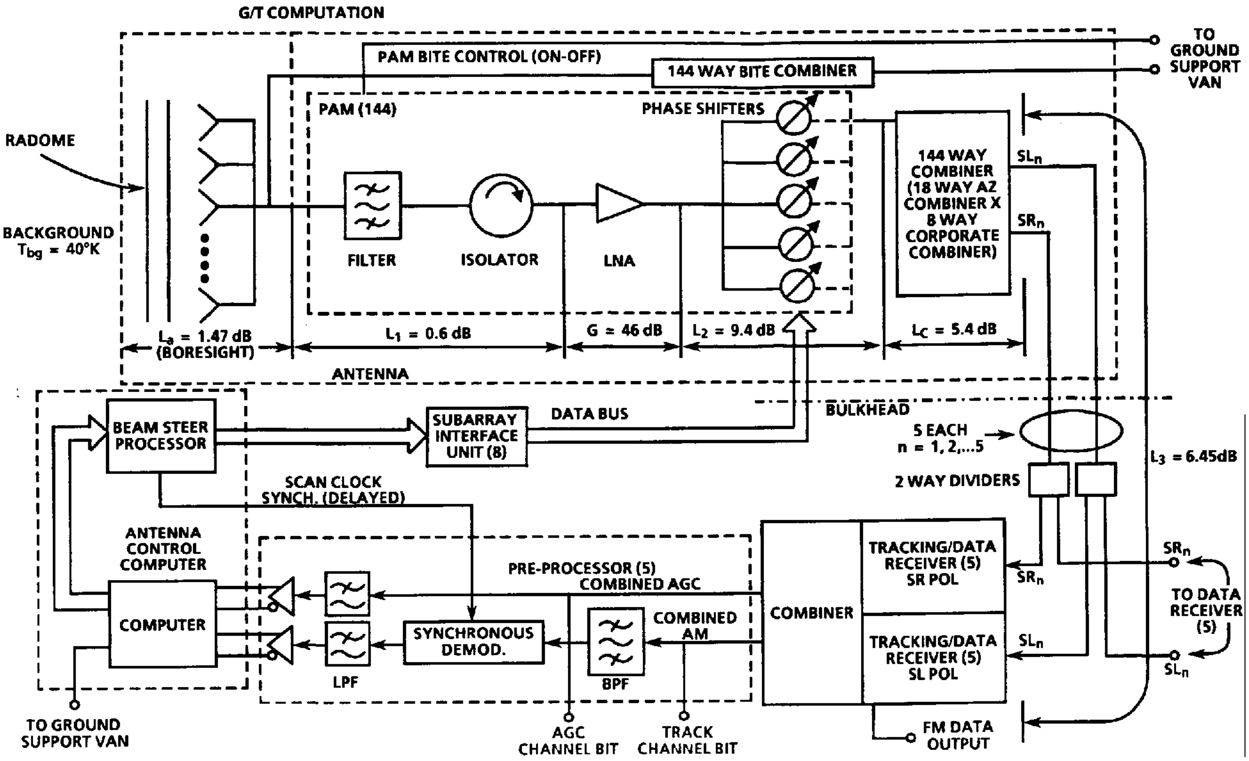
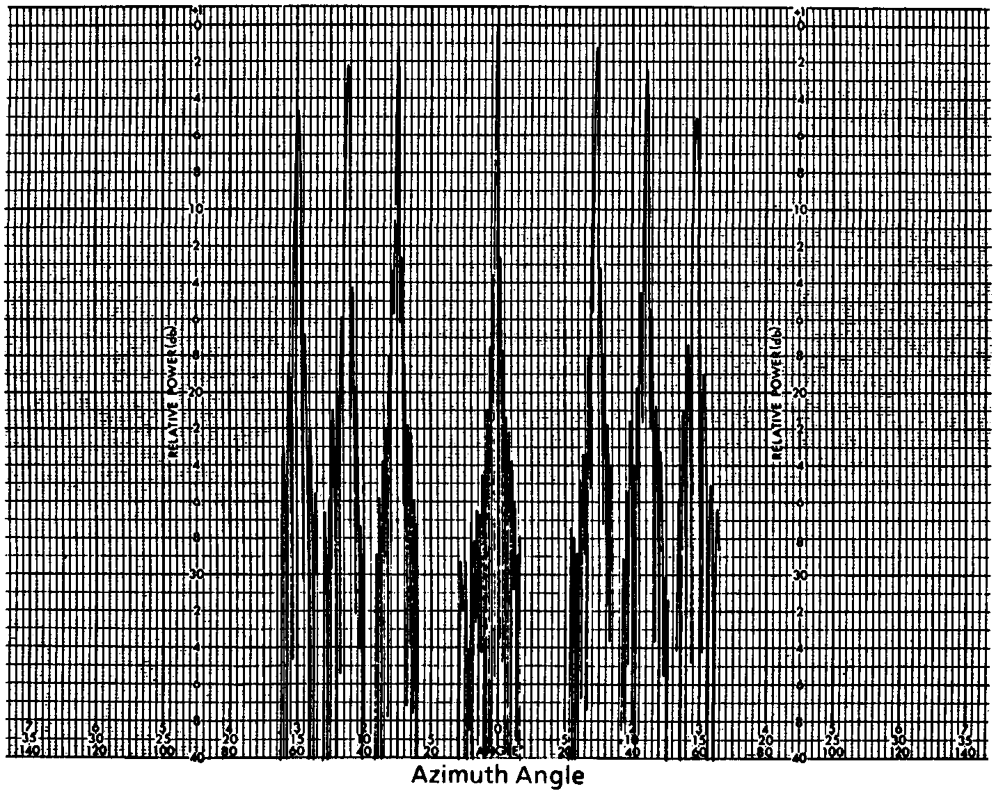
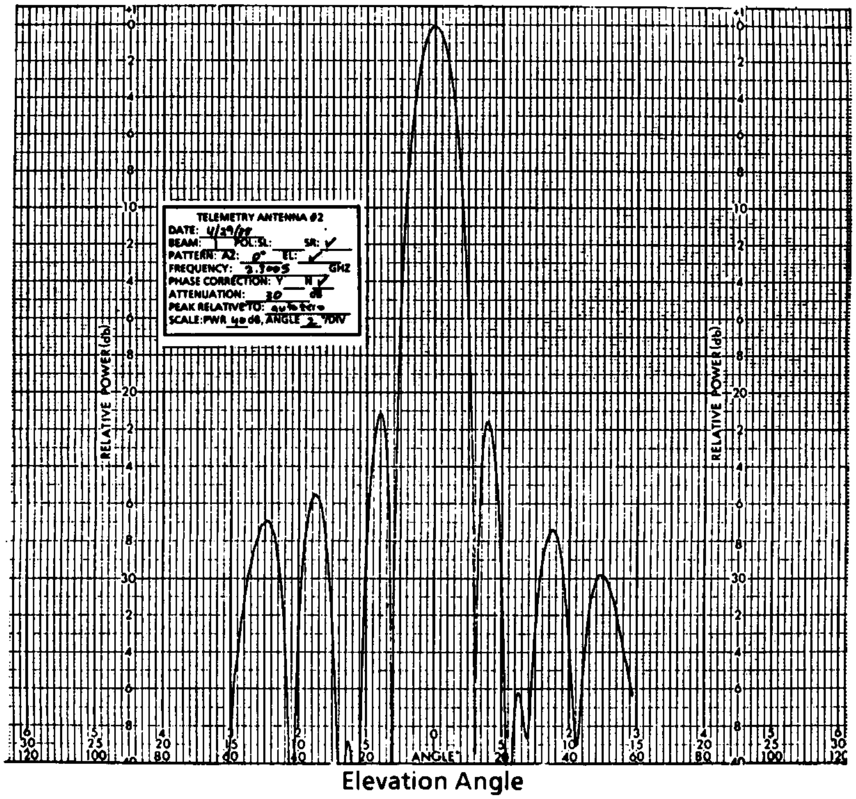


Figure 2. Phased Array Telemetry Antenna System Diagram



a). Azimuth Plane Pattern for Selected Scan Angles.



TELEMETRY ANTENNA #2
DATE: 4/29/[illegible]
BEAM: 1 POL: SL: SR: ✓
PATTERN: AZ: 0° EL: ✓
FREQUENCY: 2.3005 GHZ
PHASE CORRECTION: Y N ✓
ATTENUATION: 30 dB
PEAK RELATIVE TO: autozero
SCALE: PWR 40 dB, ANGLE 2 °/DIV

b). Elevation Plane Pattern (Boresight).

Figure 3. Selected Antenna Patterns at 2.3 GHz.