ELECTRONICALLY STEERED, RECEIVE MONOPULSE, ACTIVE PHASED ARRAY AT 94 GHz

J. Sowers, N. Byer, Lockheed Sanders, Nashua, NH
B. Edward, Lockheed Martin Ocean, Radar and Sensor Systems, Syracuse, NY
D. McPherson, Syracuse Research Corporation, Syracuse, NY
S. Weinreb, University of Massachusetts
Frank Rucky, Naval Surface Warfare Center

ABSTRACT

The first 94 GHz receive active phased array providing electronically scannable monopulse patterns in two orthogonal planes has been fabricated and tested. State of the art performance has been achieved. Beamwidths of 2.3 degrees and peak to null ratios of 20 dB have been recorded.

INTRODUCTION

State of the art performance has been achieved from a 64 element, receive, active phased array operating at 94 GHz. Electronically scannable monopulse patterns having 2.3 degree beamwidths and 20 dB peak to null ratios have been demonstrated in two orthogonal planes. To the best of the authors knowledge, this is the first active phased array capable of generating electronically scannable monopulse beams at 94 GHz. This paper will describe the electrical and mechanical design of the array, array fabrication, array test, and array performance.

ARRAY DESIGN

Several key design considerations for this array were narrow beamwidth, monopulse capability, and compact size. Narrow beamwidth is achieved with two 32-element crossed-line arrays. Monopulse capability was a function of the active phase shifters[1] and beamforming network. Compact size was achieved using MMICs for the front end electronics in conjunction with advanced mechanical design.

The major building block for the array was an eight channel module (octopak). An octopak is comprised of 8 radiating elements each with a MMIC low noise amplifier and phase shifter, followed by a 8:1 microstrip signal combining network. Previous work[2] has demonstrated arrays configured from an octopak with +/-30 degree scan capability and 3 dB beamwidths of 9.8 degrees. To reduce the beamwidth further, eight of these modules were combined into two, independent 32-element line arrays. These independent line arrays were constructed at right angles to each other to form a cross (i.e. crossed-line array). Data taken on each line array shows beamwidths of 2.3 degrees substantiating the expected reduction. Figure 1 shows the face of the crossed-line array.

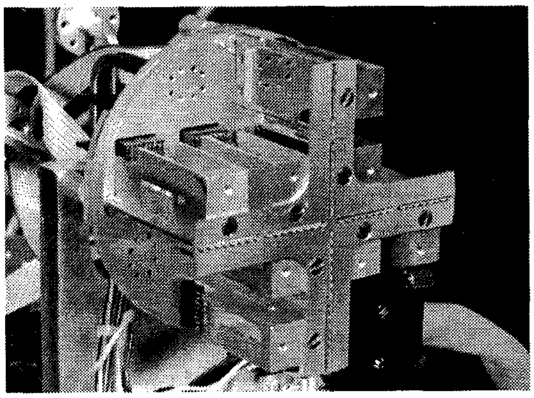

Figure 1. Front Face of the Crossed Line Array. Two independent 32-element line arrays are used to provide narrow beamwidths at varying azimuth and elevation angles.

0-7803-3246-6/96/$5.00 © IEEE

Monopulse capability requires the creation of sum and difference patterns at the output of the beamforming network. Accurate phase adjustment at the front end of the array and beamforming at the back end of the array are critical. GaAs varactor-controlled analog MMIC phase shifters are used for the elemental phase adjustment. An 8 bit D/A converter supplied the control for these phase shifters translating digital words to the required analog voltage. Worst case quantization errors of 7.6 degrees were achieved with this phase adjustment scheme.

The back end beamforming for the array was achieved in two steps using waveguide combining techniques. The first step combined the output of two octopaks in a sum port. The second step utilized a magic tee type configuration to add and subtract the signals providing both sum and difference ports. Peak to null ratios of 20 dB were achieved with this configuration. Figure 2 shows a block diagram of the array.

Compact size is a key design parameter. The RF front end electronics utilized GaAs PHEMT MMIC Low Noise Amplifiers[3] and GaAs MMIC Phase Shifters. These MMICs were mounted on a multilayer substrate for DC signal distribution minimizing octopak size. Inventive layout of the network distributing DC signals to each octopak was critical. Each octopak contained 13 DC inputs. These inputs consisted of the bias voltages for the active devices and the control signals required to achieve the proper array amplitude and phase tapers. A multilayer motherboard at the back of the array was used to distribute the DC signals through sub-miniature connectors. This arrangement allowed the diameter of the array to remain under 75 mm.

ARRAY FABRICATION

Ease of assembly and early verification of the array electronics were driving parameters for array

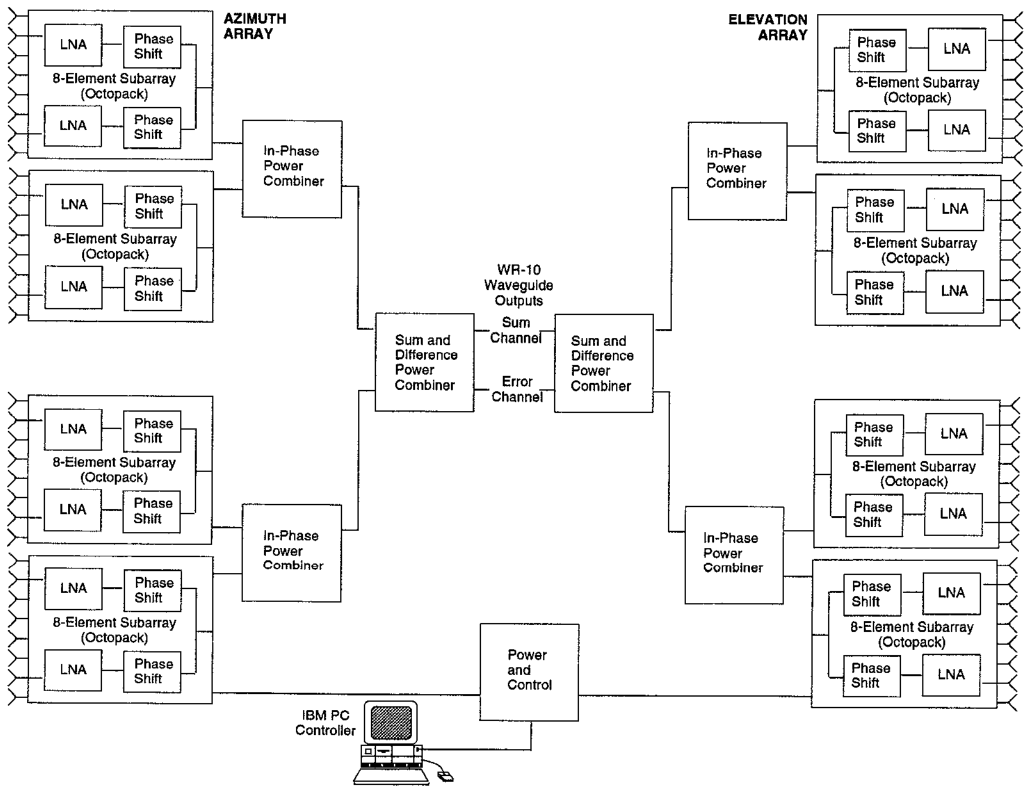

Figure 2. Array Block Diagram. Two levels of waveguide beamforming provide the sum and difference signals for this array.

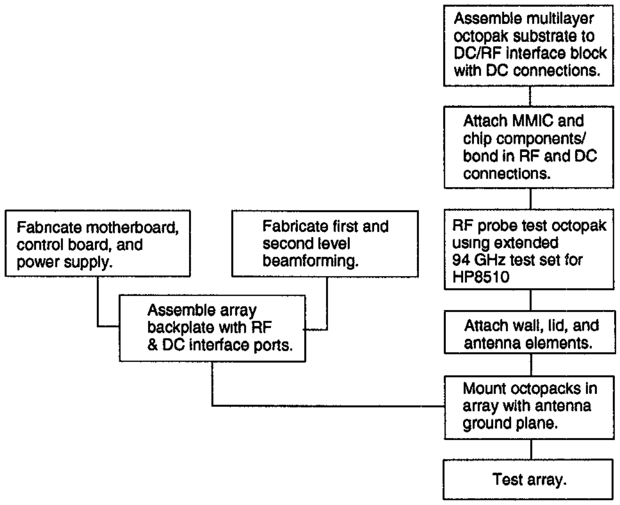

Figure 3. Assembly and Test Flow for the 94 GHz Active Phased Array. Octopaks and array electronics are separately assembled, tested, and mounted into the array backplate providing early verification of all functions prior to full up array assembly and test.

fabrication. An RF/DC interface block was designed for the octopaks providing ease of assembly. Octopaks were RF probe tested prior to array assembly supplying a method for early verification of the front end electronics. Additionally, the power and control electronics were fabricated separately and tested before array integration.

The interface block contained an MIC to waveguide transition for mating the octopaks to the beamforming circuitry. The block also contained a sub-miniature connector wired to the octopak's multilayer substrate providing a DC interface. Octopaks were assembled and tested with this block prior to array integration. Individual octopaks could easily be assembled onto the array backplate using this block. Figure 3 shows an assembly flow diagram for the array.

ARRAY TEST AND PERFORMANCE

Test consisted of array calibration and beam pattern measurements over a +/-30 degree scan angle. Both sum and difference patterns were recorded. A uniform array taper was used for all beam patterns. Additionally, element noise figure is estimated.

The calibration data required for beam pattern measurements consists of gain vs. gain state and phase vs. phase state for each channel of the array (measured at broadside). In addition, incidental phase shift vs. gain state and gain change with phase state were recorded. To simplify the data taking and beam steering algorithms, the gain vs. gain state was recorded at a fixed reference phase state for all channels and the phase vs. phase state was recorded at a fixed reference gain state for all channels. This calibration data was used to choose the gain and phase states for steering the array.

The beam steering algorithm used for this array adjusted the phase shifter for the desired phase shift, then adjusted the gain setting to offset gain variations with phase shift and channel-to-channel gain errors. Implicit in this method is the requrement that phase does not vary significantly as a function of gain state. While this is true for the range of operation of this array, further improvement in sidelobe levels could be expected with better beamsteering algorithms.

Figure 4 shows beam patterns for the array taken every three degrees from +30 degrees to -30 degrees. Beamwidths for these patterns range from 2.3 to 2.7 degrees while side lobe levels for these patterns are better than 10 dB.

Figure 5 shows a sum and difference pattern taken on the array at boresight. The peak to null ratio for this pattern is 20 dB.

Elemental noise figure is estimated with MMIC LNA on-wafer data and estimated radiating element loss. On-wafer noise figure data for the LNA's is typically 5 to 5.5 dB for the operating characteristics of the array. Estimated loss of the transmission line and radiating element is 1.0 to

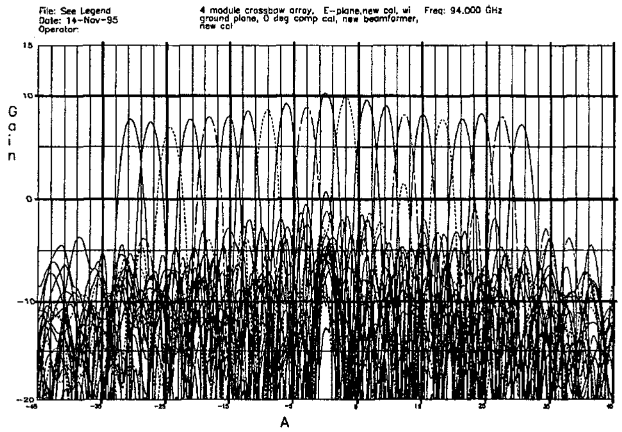

Figure 4. Sum Patterns for the 94 GHz Array. Patterns taken at every 3 degrees from +30 degrees to -30 degrees with beamwidths from 2 to 3 degrees.

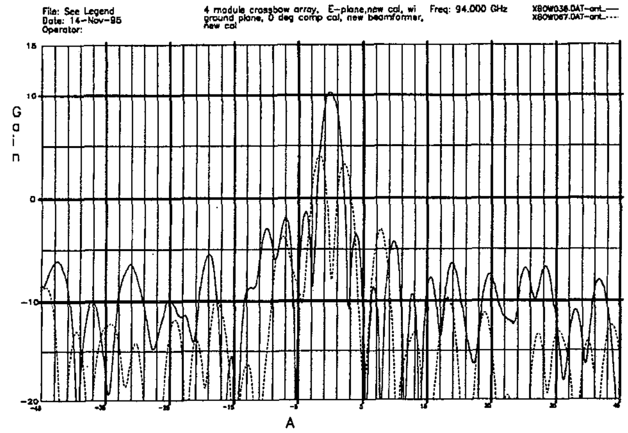

Figure 5 . Sum and Difference Patterns for the 94 GHz Array. Sum and difference pattern at boresight showing monopulse capability and a peak to null ratio of 20 dB.

Parameter	Specification	Performance
Frequency	93.5 - 95 GHz	93.5 - 95 GHz
Total Number of Elements	64	32 each in 2 crossed-line arrays
RF Outputs	Four WR-10 Waveguides	Sum and difference for each line
Element Noise Figure	<7.0 dB	<7.0 dB (estimated)
Active Gain	>35 dB	>36 dB (estimated)
Array Beam Width, On Axis	3.2° ±0.5	2.5°
DC Power (Excluding Controller)	20W	<5.0W
Size	<75 mm dia.	<75 mm dia.

Table 1. Array Specifications vs. Performance. The array performed within specification on the key parameters.

1.5 dB. Thus the elemental noise figure is estimated at less than 7 dB.

Table 1 summarizes key specifications and performance for this array.

SUMMARY

The first 94 GHz active phased array with sum and difference signals, providing monopulse capability, has been fabricated and tested. State of the art performance has been achieved. Beamwidths of 2.3 degrees and peak to null ratios of 20 dB have been recorded.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of Bob Webb. For their contributions in assembly and test of the octopaks, the authors would like to acknowledge Gene Fisher, Mike Zimmerman, Mike Trippe, Howie Steiner, Bette Gates, Jaime Everson, and Dave Pritchard. Assembly and test of the array and its control components could not have been accomplished without the work of Luke Smith.

REFERENCES

[1] Weinreb, S., et al, "Monolithic Varactor 360 Phase Shifters for 75-110 GHz," International Semi-Device Conference, *ISDRS Digest of Papers*, Charlottesville, VA, Dec. 1-3 1993.

[2] Edward, B.J., et al, "W-Band Active Transmit and Receive Phased Array Antennas," 1995 IEEE MTT-S International Microwave Symposium.

[3] Tu, D-W, et al, "High-Gain Monolithic PHEMT W-Band Four Stage Low Noise Amplifier," IEEE 1994 Microwave and Millimeter-Wave Circuits Symposium.