A BROADBAND, LOW-SIDELOBE, DYNAMIC WEIGHTING, THREE-CHANNEL RECEIVE, X-BAND ACTIVE ARRAY

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ABSTRACT

Hughes has recently developed a broadband low-sidelobe active array that uses T/R modules of a common-leg architecture and parts from multiple suppliers for each MMIC chip. Design of an 1140 element (8 watts per element), 4 GHz, rms sidelobes (<43 dB), X-band active array is described. High-precision phase and amplitude control (PAC) modules on each row of elements enables independent aperture illumination for receive (sum, delta-azimuth, delta-elevation) and transmit-sum channels.

INTRODUCTION

This paper describes the development and testing of a one-meter by half-meter, broadband, low-sidelobe active array. The array is populated with 8-watt T/R modules, which operate over a 4 GHz bandwidth at X-band and utilize GaAs MMIC chips from various foundries. Machined-metal flared-notch radiators and air-stripline feeds were used to realize low-loss broadband performance. The array architecture enables independent aperture illumination control for receive-sum, azimuth-plane difference, elevation-plane difference and transmit sum. Unique phase and amplitude control (PAC) high precision modules are used in each column of T/R modules to provide additional amplitude and phase tuning.

ARRAY DESIGN

The array aperture is rectangular and is populated by 1140 flared-notch radiators arranged in a triangular lattice as shown in Figure 1. The lattice was designed to minimize the number of radiators (and thus T/R modules) required to populate the aperture while still providing the specified scan volume at the highest frequency of operation. The array is comprised of 15 easily removable "stick" assemblies that slide from the front into a frame that provides structural support. Each subarray stick consists of 80 radiators, a cold plate assembly, 76 T/R modules, T/R energy storage and filtering circuits, four level-1 RF power distribution assemblies and two high-precision phase and amplitude control (PAC) modules. A schematic diagram of one side of a stick assembly (opposite side is a mirror image) is illustrated in Figure 2 and a picture of this assembly is shown in Figure 3.

The radiators are machined-metal flared-notches with suspended-substrate stripline (air-stripline) feeds. These 80 element subassemblies were manufactured as two halves split along their length. The air-stripline circuit are inserted between the two halves which then are riveted together. The radiator subassembly connects with the array stick through blind-mate push-on RF connectors.

Four 19-way power dividers/combiners are used on each stick to distribute RF excitation power on transmit and collimate the RF power on receive. These Level-1 feed assemblies are implemented in air-stripline with Wilkinson power dividers to provide a well-matched high-

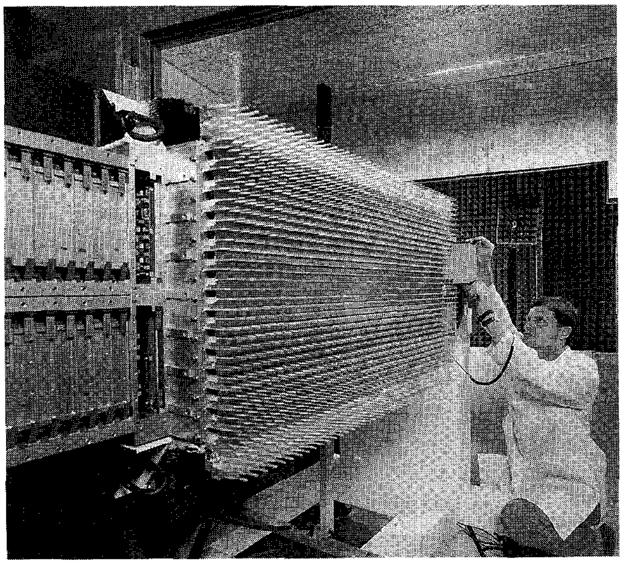

Figure 1. Photograph of 1140-element, broadband, low-sidelobe active array being prepared for testing in the high-power near-field range.

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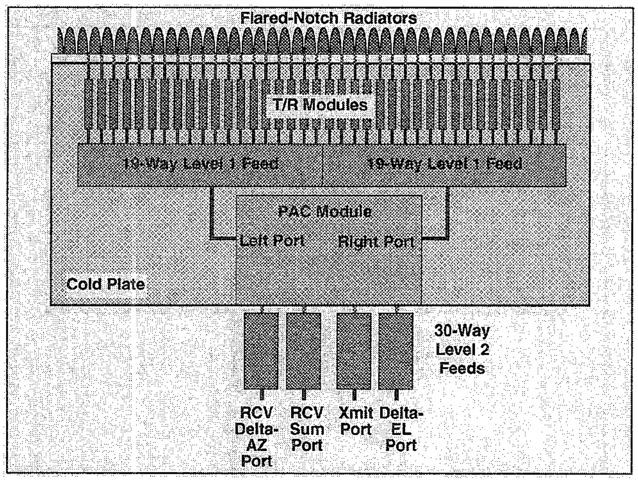

Figure 2. Diagram of the array architecture, displaying RF interconnections of all subassemblies

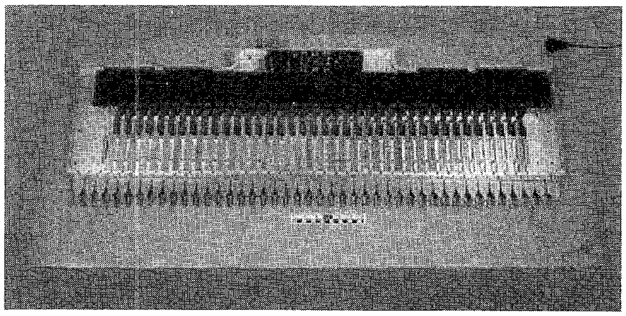

Figure 3. Photograph depicts the functional layout of all major stick subassemblies

bandwidth as shown in Figure 4. The feeds are designed for a uniform RF power distribution.

A PAC module shown in Figure 5 is connected to the input ports of the two level-1 feed assemblies. The module consist of a Hughes-patented air-stripline double-ring hybrid, a circulator, a Wilkinson power divider, and a vector modulator assembly (two sets of toroidal phase shifters). The ports of the hybrid feed the two 19-way feeds and provide sum and elevation difference outputs. The sum port of the hybrid feeds into a circulator that separates transmit and receive channels thereby providing capability to have independent illumination functions. The receive path is further subdivided into two RF signal channels, with each followed by a vector modulator assembly that provides high-precision phase and amplitude control. One signal path is used as the receive sum channel; the other provides the azimuth difference channel, or it can be used as a second sum channel with a different excitation taper for added flexibility. Control circuitry that provides 12 bits of accuracy is mounted conformal with the PAC module itself. The assembly is fastened directly on the array stick to provide thermal stability for the toroids.

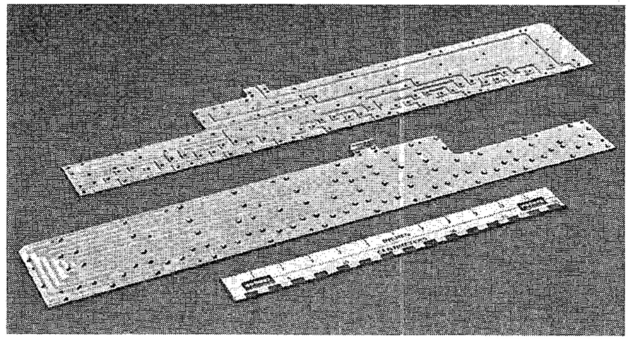

Figure 4. Photograph of the 19-way vertical feed assembly displaying internal air-stripline feed circuits

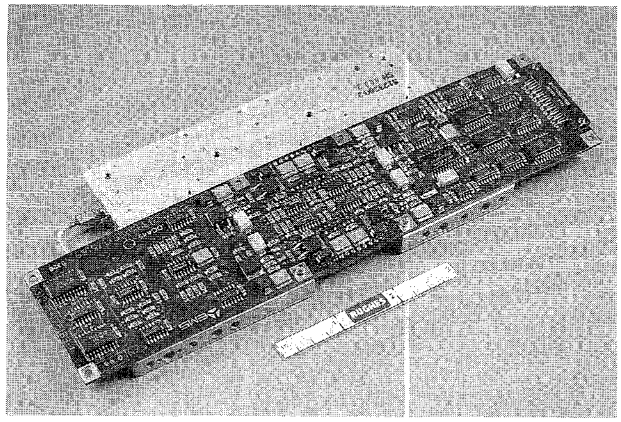

Figure 5. Photograph of phase and amplitude control (PAC) module

The four outputs from the PAC module, transmit-sum receive-sum, delta-elevation, and delta-azimuth are connected to four 30-way, level-2 feed subassemblies through blind-mate push-on RF connectors. The RF design of these feeds is identical to the 19-way level-1 feeds and implemented in airline, with Wilkinson power dividers to provide a uniform power distribution. Various aperture illuminations and tapers are achieved with a combinations of settings of the variable gain amplifiers in each T/R module and the PAC modules on each stick.

T/R MODULE DESIGN

A photograph of the T/R module is shown in Figure 6, and a module block diagram is given in Figure 7. The module uses a "common leg" architecture wherein the same MMIC phaser and variable gain amplifier (VGA) are used to provide independent amplitude and phase control on both transmit and receive. Two MMIC high-power amplifiers (HPA), each with about 16-dB of gain, are used to provide 8 watts of output power. The HPAs are driven by a two-stage 20-dB driver amplifier.

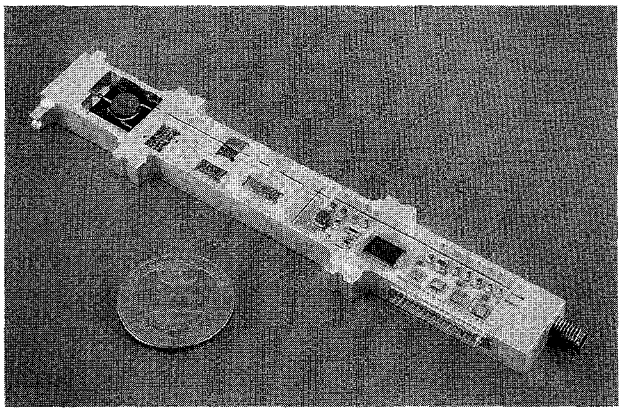

Figure 6. Photograph of the 8-watt broadband T/R module

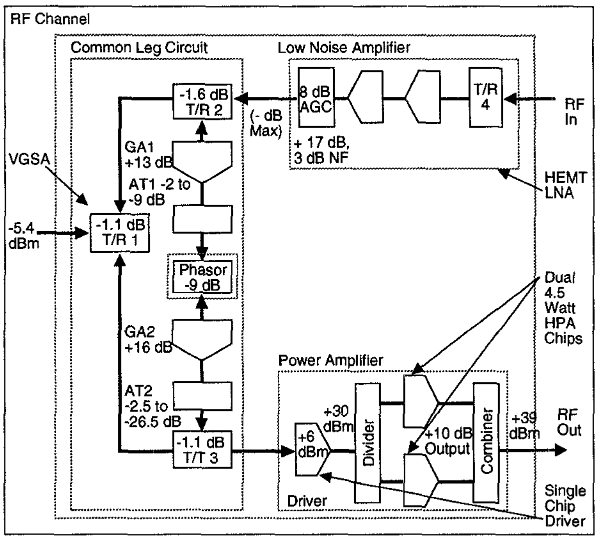

Figure 7. Block diagram of the 8-Watt T/R module showing the common-leg architecture

The module noise figure of 4 dB is set by an 18-dB low-noise amplifier preceded by a receiver protection switch. Critical MMIC chips were supplied by more than one foundry and various combinations of chips worked satisfactorily in the module. Table 1 lists the foundries for each MMIC chip.

TABLE 1. LIST OF FOUNDRIES FOR EACH MMIC CHIP

Chip Type	*Foundry*
HPA	Hughes Avantek
Driver Amplifier	Hughes AT&T
VGA	M/A-COM Samsung
LNA	TI M/A-COM
Phaser	M/A-COM
Switch	Hughes

The modules operate over a 4 GHz bandwidth with optimum performance over the 8 to 10 GHz band. The transmit gain is about 40 dB and the receive gain is 27 dB. The module rms amplitude error is less than 1 dB and the rms phase error is less than 4 degrees.

The physical configuration of the module consists of four substrates (one ferrite, two thick-film alumina, one LTCC) mounted in an aluminum housing with coaxial RF feed-throughs and a 16-pin connector for bias and signal control. Seven MMIC chips are mounted face-up on carriers before mounting on the substrates to provide a good TCE match. A hermetic package is achieved by laser welding a lid to the aluminum housing.

Figure 8 shows the output power averaged over the modules as a function of frequency.

POWER CONVERTERS

To achieve the low-voltage power with low ripple and low risk, off-the-shelf parallelable 75 kHz phase-modulated squarewave power converters were used. These were conduction cooled, but installed in liquid-cooled cardcages at each end of the antenna. By phase shifting the synchronization of the parallel power converter's switching waveforms and by careful design of the power distribution and off-module filtering, a ripple spectrum less than 100 microvolts at the input to the T/R modules was achieved.

ARRAY CALIBRATION AND TEST

First, each linear subarray, or "stick," is assembled. Module burn-in is performed at this level. At the comple-

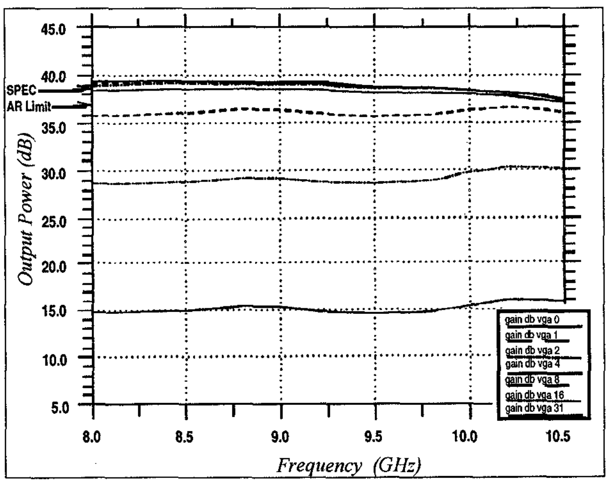

Figure 8. T/R module output power averaged over all the modules as a function of frequency

Module burn-in is performed at this level. At the completion of burn-in, the stick is tested functionally while radiating into free-space to a test probe.

Subarrays are inserted quickly and easily into the array from the front. The assembled array then is integrated with the power supplies and the beam steering computer (BSC) in a high-power near-field range. Initial tests establish digital control of the antenna's T/R modules and verify voltages. Extensive calibration data over all amplitude and phase states is collected using the near-field probe. This data, collected at four frequency bands, is used to generate the state tables that match the ideal commands to the best response of the individual modules. After state table generation, the array is phased-up; this process aligns the phase and gains of the modules to each other to form a beam.

As a final step, the calibration terms are loaded into the BSC and the calibrated antenna pattern performance is verified in a high-power near-field range. The range is capable of simultaneously measuring both transmit and receive (or two receive channels) at up to six beam position in each pass of the near-field scanner. The far field patterns calculated from the near-field data include both azimuth and elevation patterns as well as far-field contours of the beam at each of the six beams. Representative transmit and received measured patterns are shown in Figure 9.

As calibrated and tested in a high-power near-field range, the array met all specifications.

ACKNOWLEDGMENT

The development of this complex assembly required the efforts of many individuals too numerous to mention all by name here. The authors acknowledge their significant contributions to the success of the array development. Special thanks is given to Terry Cisco for the MMIC developments and Brian McWirter for subsystem design.

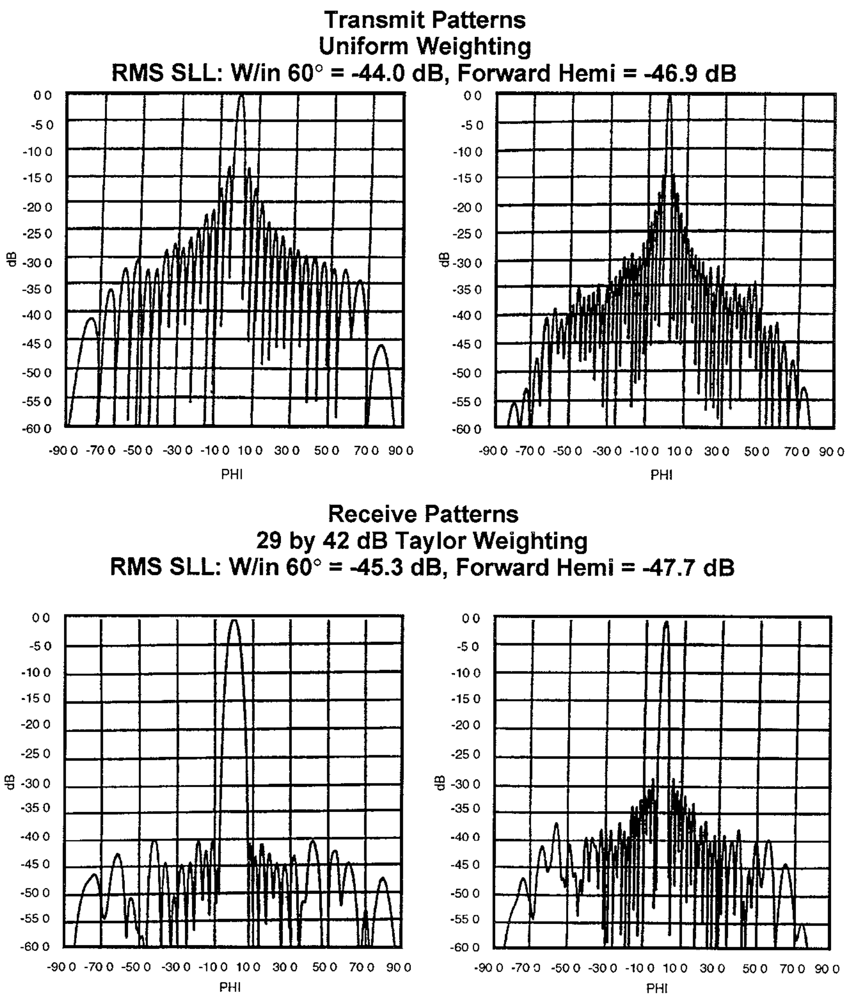

Figure 9. Typical elevation and azimuth radiation patterns of the active array