AN AFFORDABLE LOW-PROFILE MULTIFUNCTION STRUCTURE (ALMS) FOR AN OPTOELECTRONIC (OE) ACTIVE ARRAY

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ABSTRACT

Three "Leap-Ahead" technologies that can be combined into a design to make affordable shared aperture active array radars are discussed in this paper. They are Microwave Multi-Chip Module packaging, digital radar, and photonic signal manifolding and true time delay beamsteering.

1.0 INTRODUCTION

Packaging of active array radar transmit/receive (T/R) modules is the key technology that will lead to compact antennas. Reducing the amount of packaging that is used to house electronic components and subassemblies will provide a lighter weight integrated antenna structure. Improved packaging can be aided by utilizing three "leap ahead" technologies of Microwave Multi-Chip Module (MCM) packaging, digital radar design and photonic manifolding. The use of these three technologies is a radical change from the way we now build active array antennas.

Use of microwave Multi-Chip Module packaging, digital and photonic (also termed fiber optics, optoelectronics and lightwaves) technologies will provide the affordability, small size, wide bandwidth, flexibility, EMI resistance and producibility needed for the next generation shared, conformal aperture active array radars. The MCM concept for building the active array T/R modules will provide the small size and producible integrated structure that is assembled in a three-dimensional (3-D) antenna module unit. The unit will be made up of several vertically stacked wafers with several T/R channels that make up a subarray module and associated module beamsteering, signal processing and control.

A digital type manifold will be smaller and more flexible than the conventional RF signal manifold to the array. A digital radar design confines all RF signals to the T/R Module area and uses digital type signals for both transmit signal input reference and received signal output to the subarray module. This type of manifold moves digital technology up on the array and adapts extremely well to the use of photonics.

Application of fiber optic manifolds for the signals to and from the subarray module will reduce array size and weight, and be utilized with optoelectronic (OE) true-time-delay (TTD) beamsteering to provide a wideband, flexible and producible total radar active electronically scanned antenna system. This system will have distributed subarray functions for RF signal generation for both transmit and receive local oscillator signals; analog-to-digital converters (A/D) for digitized received signals; control and built-in-test functions; and digital preprocessing capability.

2.0 ACTIVE ARRAY RADAR

Currently used radars have a mechanically scanned antenna, a large high-power transmitter, and other units all collocated. The packaging of the units in the radar is a major portion of the radar because units are housed in large packages at all levels as shown in Figure 1. The actual components or chips that perform the radar functions are small but the support structure to house them is large. This large structure adds cost, weight and complexity that prevents the radar from being configured for best unit location in its support platform.

An active array uses electronic phase shifters to provide fast electronic beamsteering and thus

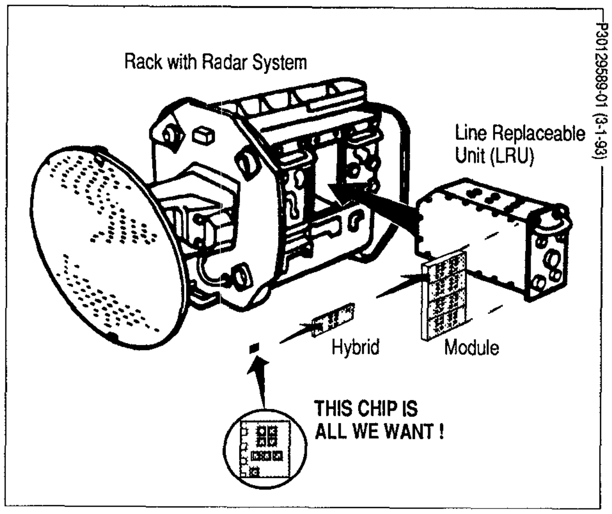

Figure 1. Present Avionic Packaging Concept Could be Improved to Reduce Size and Weight

eliminated the need for the mechanical gimbal used in a mechanically scanned antenna. The active array antenna contains T/R modules with solid-state RF power amplifiers for RF transmission, low-noise amplifiers for RF reception and the electronic phase shifters for beamsteering. The use of T/R modules further reduced radar size by eliminating the large high-power transmitter. The active array radar system also offered advantages in improved radar system performance and reliability.

3.0 ACTIVE ARRAY PACKAGING

Present active array programs have focused on reducing the cost drivers associated with manufacturing packaged T/R modules that are assembled one-by-one onto thermal cold plates resembling "sticks." The sticks, of various lengths, are then assembled into the back plate and electrically connected to the RF, logic, and dc manifold. The ends of the sticks are connected to a cooling manifold. Figure 2 shows a typical assembly of modules that comprise an active array. The cost of interconnecting this assembly of 2,000 T/R modules (channels) is not only expensive but it also typically weighs several hundred pounds and is approximately 12 inches or more in depth. This assembly is not low profile. It cannot be integrated easily or conformed to the skin of an aircraft; placed high on the mast of a ship; put in mobile ground-based systems or the very limited space of a missile; or conformed to the weight and space sensitive design of spacecraft.

We present here a completely new technology for the packaging and assembly of an active array that will provide substantial cost savings while furnishing a lightweight, low-profile (<2 inches in depth) that will have applications to aircraft, ground-based, missile, ship, or spacecraft radars. For comparison, the weight of a 2,000 element array using this new technology is estimated to be less than 75 pounds.

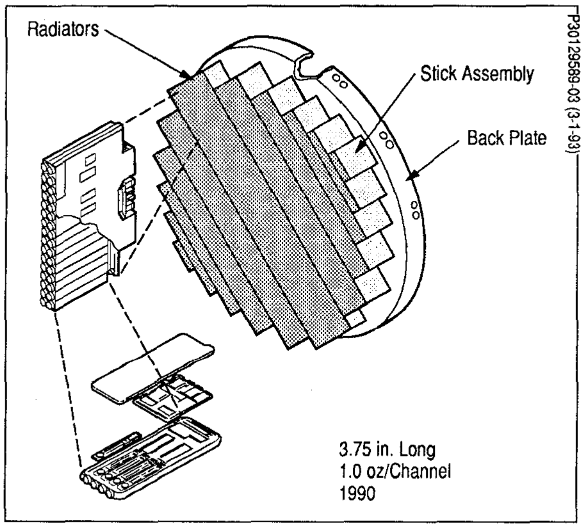

Figure 2. The "Stick" Assembly of T/R Modules is not Conformal and Requires a Myriad of Electrical and Mechanical Connections that Help Make Active Arrays Unaffordable

We will use the proven and cost-effective batch processing technology that is used to process silicon wafers in order to fabricate the array assembly of subarray modules of aluminum nitride (AℓN) electrical substrates for the T/R channels, radiators, subarray circuits, and distribution manifolds for RF, dc, and logic signals.

The assembly uses the Aluminum Nitride (AℓN) substrate that is processed using a multilayer hot press process for providing the electrical interconnects for the T/R channels in a subarray module. Figure 3 shows two AℓN substrates that have been processed to provide the electrical connections between GaAs and silicon chips on the same wafer. GaAs chips on the MCM substrate are simultaneously electrically and mechanically connected to the wafer by reflowing the solder bumps on all the chips. Rework, if any, is expected to be minimal. This attachment using flip chip technology has proven to be highly reliable in the silicon industry and Hughes has extended its application to GaAs die. The MCM substrates are electrically attached to radiators and signal manifolds that are also printed on other layers of AℓN substrates. These wafers or circuitry, radiators, manifolds and cold plates are assembled into three-dimensional stacks resembling tiles.

Figure 4 shows how these wafer stacks (tiles) can be assembled as subarrays into any size array. The number of tiles that are assembled together can be adjusted to fit any radar configuration. Since the

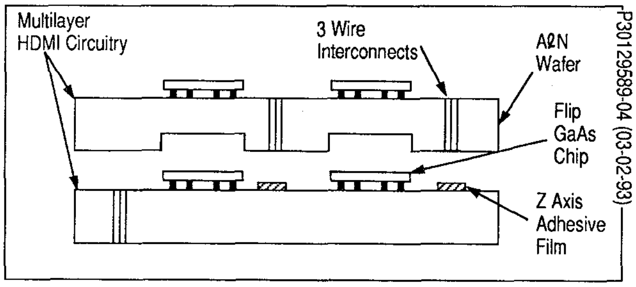

Figure 3. Molded Three Wire Interconnects Will Provide RF Feedthroughs for 3-D Conformal Packaging

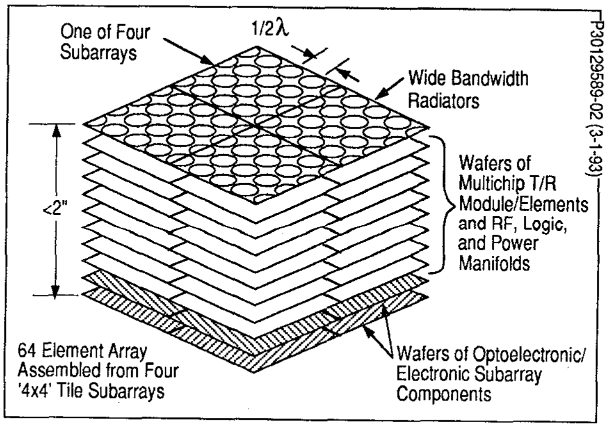

Figure 4. An Active Array can be Assembled Using a Three Dimensional Stack of MCM Wafers (Tiles or Subarrays)

array is lightweight and low profile, it can be structurally integrated into the skins of aircraft. Figure 4 also shows that the multichip T/R module components that provide the transmit and receive capability for each of the wide bandwidth T/R elements are distributed on wafer layers. The lower (cross hatched) wafers provide the optoelectronic and electronic components that provide the subarray mixing from RF to a lower frequency, the analog to digital converters and the photonic transmitters and receivers that manifold the transmit, receive and control signals to/from the rest of the radar via fiber optic link interconnects.

4.0 DIGITAL RADAR

Digital technology and components capability are progressing at a rapid pace because of a large commercial use. Digital circuits are being designed to replace many functions that have been performed with analog circuits.

A "digital" radar is one where digital type signals replace RF analog signals in the transmit and the receive signal distribution manifold up to and from the array. For the transmit function, digital type signals are sent up as a reference signal that is used to establish the RF transmitted signal phase in a signal generator for the RF transmit signal. For receiving, the RF receive signal is mixed to a lower frequency where it is digitized in an analog-to-digital (A/D) converter (ADC) and sent off the antenna as a digital received signal. The active array T/R channels in a subarray are unchanged. All the RF signal generation and digital on receive are accomplished at the subarray module level using the T/R channels subarray RF input/output manifold signals.

Both digital transmit and receive use a true time delay beamsteerer to establish the phase of the RF carrier independent of frequency and to delay the carrier modulation envelope to separately establish the time delay. The RF carrier signal on transmit and the local oscillator signal on receive will have the correct phase for steering the array. The correct time delay for aligning the transmitted signal envelope is set in a transmit modulator. The time delay in receive is set by delaying the A/D clocks for the received signals. Thus, both phase and time delay are established using a TTD beamsteerer.

5.0 PHOTONICS

Active arrays can benefit from the use of optoelectronics for "leap-ahead" technology applications in TTD beamsteering for wide instantaneous bandwidth and wide bandwidth; in RF and digital signal manifolding; and for testing, calibration, and built-in test. Both the design and the state of development of the active array make that array an excellent candidate for the insertion of optoelectronics.

A fiber optic link consists of a laser transmitter connected to a photodiode receiver by a length of fiber. The link acts as an electrical signal transport in that the laser is modulated by the electrical input signal producing amplitude modulated light delivered via the fiber to the photodiode where the signal is demodulated (detected) from the light carrier and provided for use at the output of the link. The attributes of photonics that allow optoelectronics components to be well suited for use in radar are wide bandwidth, small size, lightweight, low loss in the fiber cable, and no electromagnetic interference.

An active array radar can be configured using the remoting capability of fiber optics so that most of the radar units are conveniently located away from the antenna. All electrical inputs and outputs (except dc power) of RF and control signals are carried over a fiber optic manifold. All radar signals can be sent over a single fiber to each subarray by using optical wavelength division multiplexing (WDM). Use of WDM means that light wavelengths are multiplexed and de-multiplexed by optical filtering. A different wavelength light carrier is obtained by using laser transmitters and photodiode receivers which operate at different light wavelengths in the optical spectrum.

Several ways that an optoelectronic TTD beamsteerer can be implemented are with lasers, photodiode and optical switches. The use of each of those switches allow the selection of different links of fiber cable or other means of guiding lightwaves (as waveguides in materials) to obtain the desired delay time. Both the laser and the photodiode act as switches by controlling their bias current or voltage, and also perform their normal function of light generation and modulation or detection when they are biased on. All optical switches (light input and light output) can be made out of several electro-optical materials where the switch activation is controlled electronically.

6.0 SUMMARY

Technology and techniques have been described that can lead to the development of an affordable active array design that will provide the basis for an antenna to meet the military and commercial needs for radar, EW and communication, and that can be used for airborne, ground, ship, missile, and space based systems.

A photonic/MCM/digital radar system will provide a wide bandwidth, shared aperture radar that will be multifunctional and flexible, and one that can be reconfigured for use in a large number of applications. The 3-D design is compact and lightweight for use in conformal and/or embedded structures (smart skins) applications. The use of an all digital type corporate transmit and receive feed system with a photonic manifold provides a flexible, fault and calibration tolerant configuration. The MCM design will provide subarray wafers that can be manufactured in a cost effective manner and have high yield, very small size, minimum depth, lightweight and flexibility in mounting and assembling into large arrays, with high reliability and minimum maintainability support requirements.

The basic research is in place and based on progress to date there appears to be no major technical risk areas that cannot be solved during development. Since the payoff is so great in this "leap ahead" design concept, any technical risk involved is well worth taking.

7.0 ACKNOWLEDGMENT

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