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A Design Concept for an MMIC Microstrip Phased Array

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1. ABSTRACT

A conceptual design for a microstrip phased array with monolithic microwave integrated circuit (MMIC) amplitude and phase controls is described. The MMIC devices used are 20 GHz variable power amplifiers and variable phase shifters recently developed by NASA contractors for applications in future Ka band advanced satellite communication antenna systems. The proposed design concept is for a general NxN element array of rectangular lattice geometry. Subarray excitation is incorporated in the MMIC phased array design to reduce the complexity of the beam forming network and the number of MMIC components required. The proposed design concept takes into consideration the RF characteristics and actual physical dimensions of the MMIC devices. Also, solutions to spatial constraints and interconnections associated with currently available packaging designs are discussed. Finally, the design of the microstrip radiating elements and their radiation characteristics are examined.

2. INTRODUCTION

NASA Lewis Research Center has an on-going program to develop monolithic microwave integrated circuit (MMIC) devices for satellite communication applications in the 20 and 30 GHz frequency bands. In parallel with this activity, research efforts have been focused on the development of active phased array technology making use of these MMIC devices. The advantages of active phased arrays with amplitude and phase control at each radiating element or subarray are well known. In addition to electronic beam steering at nanosecond switching speed, an MMIC phased array can provide adaptive nulling of interfering signals and dynamic compensation of a distorted wavefront.[1] To investigate and demonstrate the feasibility of MMIC phased array concepts, NASA Lewis is currently developing an MMIC phased array feed system using horn radiators and waveguide beam-forming networks with the MMIC devices placed inside waveguide housings.[2] An active phased array with MMIC devices in waveguide housings, however, does not offer any significant improvement in weight, size, and cost advantages. Recent research efforts on MMIC phased array have led to multi-layer planar structure design concepts where the radiating elements, MMIC devices, RF power distribution and logic control networks are deposited on different substrate layers.[3] To our knowledge, a total system integration based on such design concepts has not yet been realized to date. This paper discusses some considerations and constraints relating the MMIC microstrip phased array designs. Based on these considerations, a conceptual design for a MMIC phased array composed of modular microstrip subarray is proposed.

3. ARRAY DESIGN CONSIDERATIONS

Some considerations in active phased array designs are spatial constraints, interconnections, heat dissipation, and cost. At high frequency, the physical size of the microstrip antenna is generally too small to allow direct amplitude and phase control at each element. With the currently available packaging designs for the 20 GHz transmitting module as depicted in figure 1, the overall dimensions of the MMIC devices are larger than a single microstrip patch element. If MMIC devices were placed at each element, the element spacing would be large, and grating lobes would be generated. The spatial constraint may require the use of modular subarray as radiating elements. When an active phased array requires thousands of radiating elements, cost is an overriding factor[4] due to low production yields and high costs for the RF characterization of MMIC devices. The design concept developed by NASA Lewis uses modular subarray instead of individual radiating elements. The subarray modular approach reduces the cost and the complexity of the beam-forming network by reducing the number of MMIC devices required.

Another critical issue is that of heat removal. The projected efficiency for a power amplifier is typically less than 20 percent. The MMIC devices on substrate boards often generate excess heat causing warping and device malfunctions. To prevent excessive heating, MMIC devices are placed on separate substrate boards and proper thermal heat sinks for the MMIC devices are provided.

The multi-layer design approach requires very precise board alignment in electrically connecting several layers containing radiating elements, logic control circuit and beam-forming network. The interconnection of large quantities of MMIC devices and microstrip patch elements pose formidable topology and mutual coupling problems in active phased array designs. The complexity of high-level integration requires innovative feeding technique and proper choices of array architecture and beam-forming network design. Electromagnetic coupling techniques and optical beam-forming network concepts are currently being considered by NASA Lewis as viable approaches to these problems.[5]

4. ARRAY DESIGN CONCEPT

Figure 2 shows a design concept of an MMIC microstrip phased array. The MMIC amplitude and phase control modules are mounted on a small rectangular substrate panels with RF power and logic control lines extending to the edges. The panels are inserted vertically into a properly designed bracket connecting the radiating element layer to the RF power distribution layers at both ends. With MMIC devices mounted on individual substrate panels, the proposed array configuration allows device characterization as well as easy replacement of faulty devices. Furthermore, the existence of large spacing between adjacent MMIC panels alleviates heat dissipation difficulties. A thermal sink is generally required for multiple beam operations where several sets of amplitude and phase controls are placed on the same substrate panel. Figure 3 illustrates a scheme for heat removal using graphite aluminum (GR/AL) heat pipe. GR/AL is a composite material with the property of lightweight, low coefficient of thermal expansion and high thermal conductivity. NASA Lewis is currently supporting development of such material for space applications.

The spatial and interconnect problems delineates the choice of subarray-type configuration. Figure 4 shows four modular subarray configurations currently under investigation. Subarray (a) is a corporate fed 2 by 2 rectangular subarray. Subarray configurations b, c, and d all have a driven center element and surrounding parasitic elements. The parasitic subarray configurations have the potential advantages of lower feed losses, reduced feed line radiation, lower sidelobes, and increased bandwidth.[6] Experimental investigations are being carried out to study the circuit and radiation characteristics of these subarray configurations. Figure 5 shows the typical radiation patterns of a 2 by 2 rectangular subarray and a 3 by 3 parasitic subarray along with that of a single microstrip patch.

The use of electromagnetic coupling between the feed line and the radiating element through an aperture will greatly simplify the interconnect problem. An aperture-coupled microstrip antenna with a perpendicular feed has been investigated and proven feasible.[7] This technique is particularly attractive for use in the excitation of the parasitic subarrays. However, further study and investigation is required to improve the coupling efficiency.

5. CONCLUSION

A conceptual design for a microstrip phased array with currently available MMIC amplitude and phase control devices has been described. The proposed design addresses the problems of spatial constraints, interconnections and heat removal. Although the hardware and fabrication techniques for the MMIC phased array system may already exist, much work still needs to be done to reduce the complexity of MMIC control and interconnectivity while achieving good performance.

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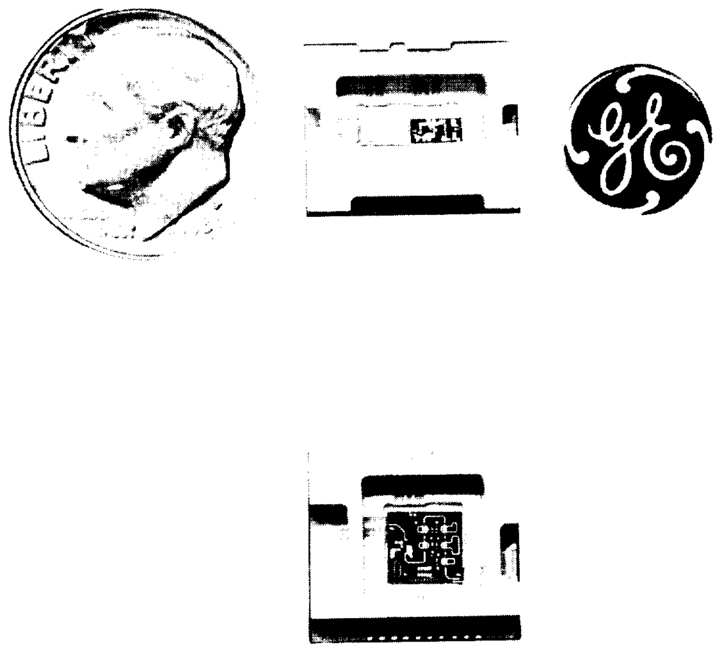


FIGURE 1. - PACKAGING DESIGNS FOR 20 GHz MMIC DEVICES.

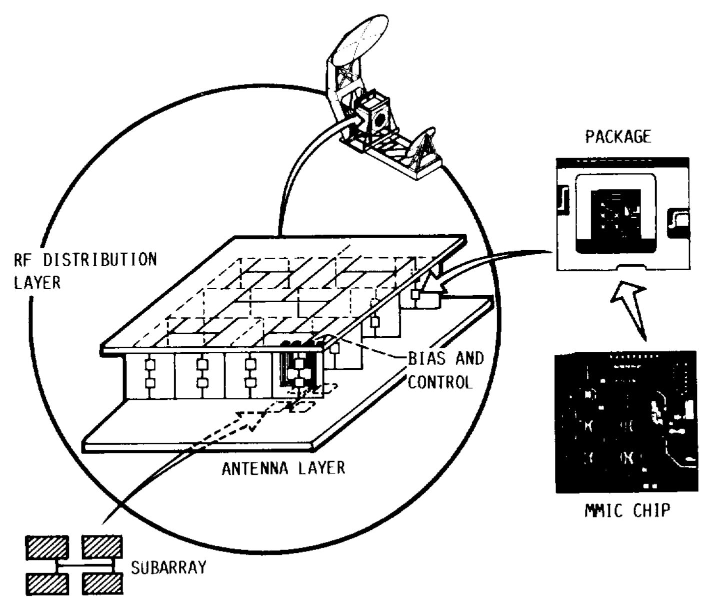


FIGURE 2. - MMIC MICROSTRIP PHASED ARRAY CONFIGURATION.

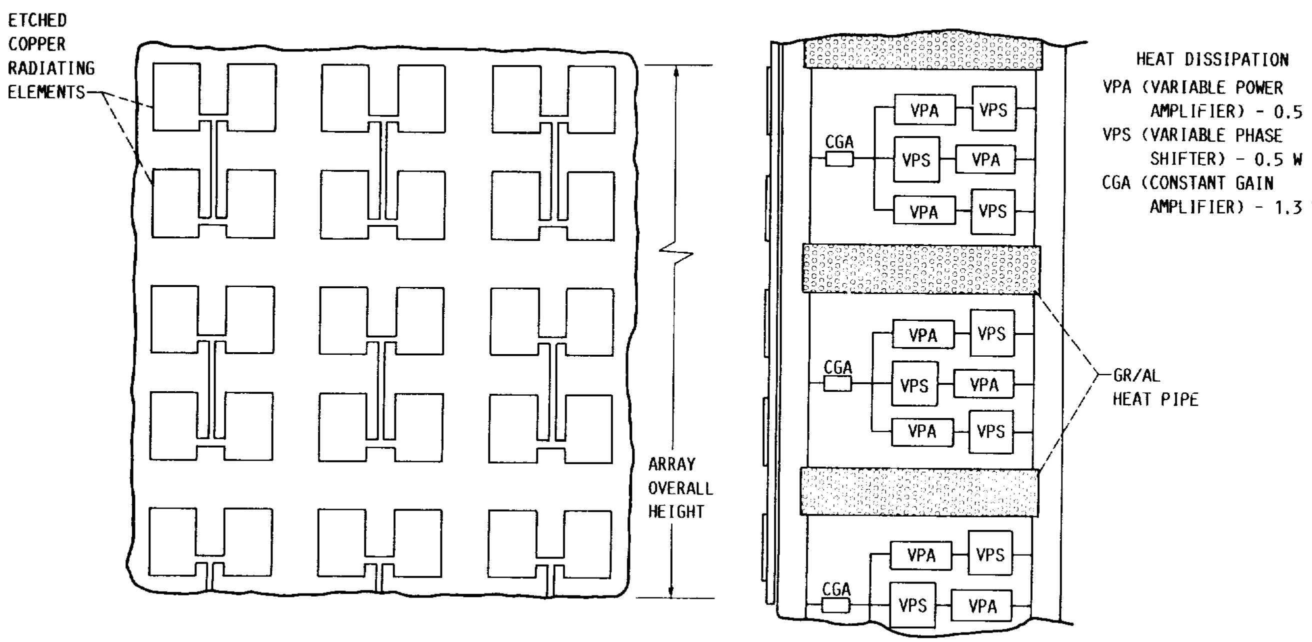


FIGURE 3. - CONCEPT FOR HEAT REMOVAL USING GR/AL HEAT PIPE.

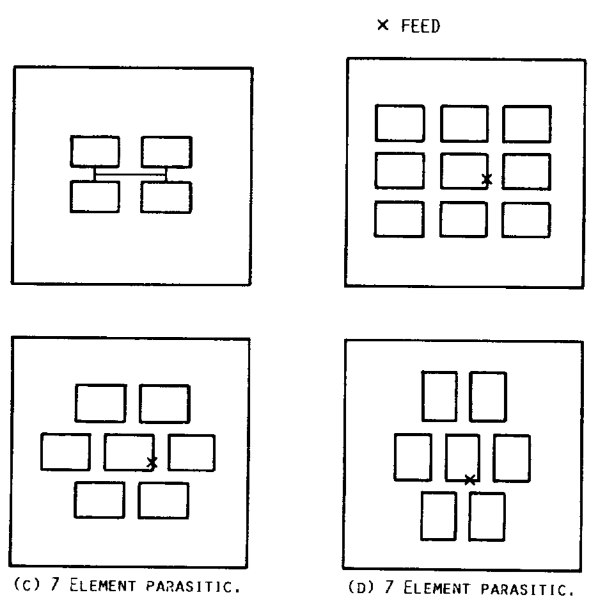
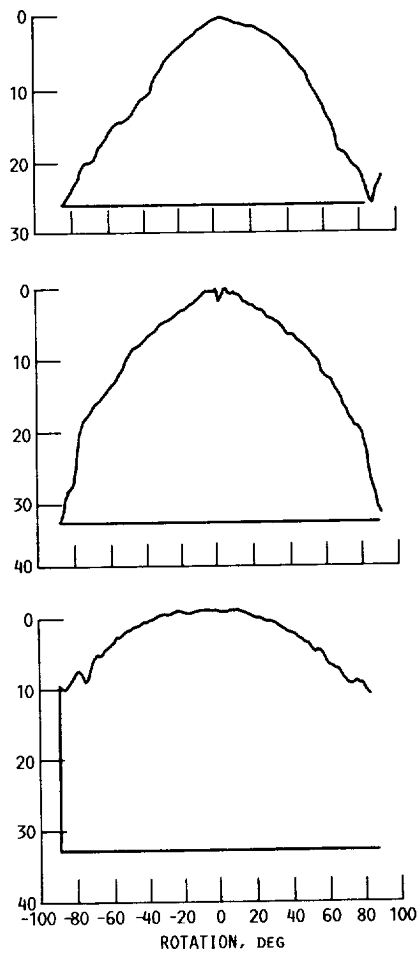


FIGURE 4. - SUBARRAY CONFIGURATIONS.



(c) Single microstrip antenna.

Figure 5. - E plane radiation patterns.

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