Optically Controlled Phased Array Antenna Concepts Using GaAs Monolithic Microwave Integrated Circuits

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OPTICALLY CONTROLLED PHASED ARRAY ANTENNA CONCEPTS USING GaAs MONOLITHIC MICROWAVE INTEGRATED CIRCUITS

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ABSTRACT

The desire for rapid beam reconfigurability and steering has led to the exploration of new techniques. Optical techniques have been suggested as potential candidates for implementing these needs. Candidates generally fall into one of two areas: those using fiber optic Beam Forming Networks (BFNs) and those using optically processed BFNs. Both techniques utilize GaAs Monolithic Microwave Integrated Circuits (MMICs) in the BFN, but the role of the MMIC for providing phase and amplitude variations is largely eliminated by some new optical processing techniques. This paper discusses these two types of optical BFN designs and provides conceptual designs of both systems.

INTRODUCTION

The advantages of using large direct radiating phased arrays for rapid beam scanning are well known. However, conventional techniques for implementing large phased arrays have resulted in heavy, high loss distribution systems. MMICs have offered the ability to have a low loss distribution system that has graceful degradation. Still, the interconnection of many MMIC modules poses formidable topology, EMI, and crosstalk problems.

In an effort to utilize the advantages of MMICs, new BFN techniques have been proposed. These techniques employ optical components not only to distribute signals, but also to form the phase and amplitude distribution. Two general categories of optically controlled GaAs MMIC-based array antennas have been identified. Those systems using fiber optic BFNs and those using optically processed BFNs are discussed in this paper. Conceptual diagrams of both fiber optic and optically processed BFNs are shown in Figs. 1 and 2, respectively.

FIBER OPTIC BFNs

Several concepts for using fiber optics in antenna applications can be found in the literature (Refs. 1 and 2). This paper will consider only those applications that use the fiber as an optical transmission line. In this type of system, the GaAs MMIC is complex; it is equipped with variable phase shifters (VPSs) and variable power amplifiers (VPAs) to create an array aperture with the appropriate phase and amplitude distribution. The optical fiber is used for interconnection and offers mechanical flexibility, low
loss, lightweight, minimum crosstalk, and greatly diminished EMI to
the BFN.

The use of fiber interconnection is critical when large,
lightweight arrays are being considered. The inherently large
bandwidth of fiber allows it to carry multiple signals of both RF
and data. A more complete description is given by Bhasin, et al.
(Ref. 3). It is important that the MMIC module to which the fiber
is connected be small and lightweight for large packing densities,
an even more important consideration is the design of the
module/fiber connection. When large arrays are considered, the
module must be accessible from the back, because fiber connection to
the edge limits the array size. A conceptual drawing of an MMIC
module is given in Fig. 3. A block circuit diagram of an optical
integrated circuit being developed under a NASA contract is shown in
Fig. 4. Table I gives a list of characteristics for fiber optic
BFNs.

OPTICALLY PROCESSED BFNs

The use of optical processing components to obtain the desired
amplitude and phase distribution is the basis for this type of
system. This technique is realizable because the antenna far-field
pattern (FF) is the Fourier Transform (FT) of the antenna’s
near-field (NF) distribution, and two optical signals can be mixed
to produce a microwave difference frequency. By using optical
processing components, a two-dimensional FT can be performed in
realtime by the FF diffraction of coherent light (Ref. 4). As
suggested by Koepf, the antenna NF phase and amplitude distribution
is created by forming an optical version (image mask) of the desired
antenna FF pattern with coherent light. After passing this signal
through a FT lens and mixing it with a second coherent optical
(reference) signal whose frequency is different by the frequency of
the desired microwave carrier, an optical phase and amplitude
distribution at the desired microwave carrier frequency is
produced. This distribution is then sampled by a fiber optic array
and the resulting optical signals are carried to remote MMIC
amplifiers in a microwave antenna array. A more detailed
description and some preliminary experimental results can be found
in Ref. 5.

The complexity of the MMIC device in this type of system is
greatly reduced. The MMIC requires no VPS or VPA; the only function
necessary is constant gain amplification. This eliminates the need
for MMIC control lines. Instead, the conversion efficiency of the
optical demodulator and noise level of the amplifier are the primary
concerns. In addition, this system exhibits some unique properties
for magnification and spatial sampling. Table I gives a list of
characteristics for optically processed BFNs. NASA is funding a
Hughes Aircraft Company study to investigate this concept.

CONCLUSIONS

Two general approaches for using optical techniques for
creating BFNs have been presented. These techniques exploit
different attributes of optical components. In general, these techniques fall into one of two categories: those that use fiber optic cables for signal distribution only and those that use various optical components (FT lenses, fiber optic arrays, and image masks) to create the antenna NF phase and amplitude distribution. Both techniques require the use of MMICs, however, the latter does not require a complex MMIC having VPSs and VPAs. As the development of optical components continues, and as array element numbers and frequencies get higher, either or both of these types of systems could provide for developing large, lightweight, rapidly reconfigurable, and steered phased array antennas.

REFERENCES


TABLE I. - CHARACTERISTICS OF OPTICALLY CONTROLLED BFNs

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<thead>
<tr>
<th>Fiber optic BFNs</th>
<th>Optically processed BFNs</th>
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<tr>
<td>Lightweight, high density distribution system</td>
<td>Uses simplified MMIC</td>
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<tr>
<td>High speed data transmission</td>
<td>Creates NF distribution using optical image mask</td>
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<td>Reduced crosstalk and EMI</td>
<td>Continuously adjustable beam steering</td>
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<td>High reliability due to monolithic integration</td>
<td>Unique magnification and sampling capabilities</td>
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<tr>
<td>Allows interface to optical processing</td>
<td>Requires critical optical processing component development</td>
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<td>Higher level of power consumption</td>
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Figure 1. - Optically controlled and FED monolithic IC's for phased array antenna.
Figure 2. - Optically processed beam forming network.
Figure 3. - Block circuit diagram of optical/MMIC interface.
Figure 4. - MMIC module with fiber optic interconnection.
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