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Optical Control of an 8-Element Ka-Band Phased Array Using a High-Speed Optoelectronic Interconnect

M.A. Richard and P.C. Claspy
Case Western Reserve University
Cleveland, Ohio

K.B. Bhasin
Lewis Research Center
Cleveland, Ohio

and

M. Bendett
Honeywell, Inc.
Bloomington, Minnesota

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OPTICAL CONTROL OF AN 8-ELEMENT Ka-BAND PHASED ARRAY ANTENNA USING A HIGH-SPEED OPTOELECTRONIC INTERCONNECT

M. A. Richard and *P. C. Claspy, Department of Electrical Engineering,
Case Western Reserve University, Cleveland, OH,
K. B. Bhasin, National Aeronautics and Space Administration,
Lewis Research Center, Cleveland, OH,
and M. Bendett, Honeywell, Inc.,
Sensors and Signals Technology Center, Bloomington, MN

ABSTRACT

Optical distribution of control signals in electronically steered phased array antennas is being considered. This paper describes a demonstration experiment in which a high speed hybrid GaAs optoelectronic integrated circuit (OEIC) was used to control an eight element phased array antenna. The OEIC, which accepts a serial optical control signal as input and converts it to 16 demultiplexed parallel outputs, was used to control the monolithic GaAs phase shifters of a Ka-band patch panel array antenna. Antenna pattern switching speeds of 2.25 μs, limited by interface circuitry, were observed.

1. INTRODUCTION

Because of advantages such as low weight and high beam steering speeds offered by phased array antennas, future NASA missions such as Mars Rover and Mission Planet Earth call for the use of such antennas for purposes of communication and radiometry.[1] While the development of steerable microwave frequency phased arrays has been stymied in the past by the lack of small phase shifters and power amplifiers, recent advances in GaAs monolithic microwave integrated circuit (MMIC) technology have resulted in the development of high quality integrated power amplifiers and phase shifters.[2] With these advances, large arrays, on the order of 100 to 1000 elements, are becoming feasible.

The use of such a large number of elements at millimeter wave frequencies presents unique challenges in the distribution of RF and control signals to each element because of the small element spacings involved. As a way to surmount this problem, various fiber optic-based solutions have been proposed and investigated. Optical fibers hold much promise for use in large phased arrays because of their light weight, low attenuation, mechanical flexibility, large bandwidth, and immunity to cross talk and EMI. As the operational frequencies of arrays increase, the amount of available space for interconnection of elements decreases, so multiplexing of control signals onto a single fiber would clearly be advantageous. This would allow beam control data to be brought from a data source and be distributed locally to the phase shifters and amplifiers while simultaneously achieving a reduction in weight and space consumed.[3] When this is done, the input data rate becomes high even though the rate to an individual control line may be low. In this paper we describe the use of a single optical fiber to distribute control data to the phase shifters of an eight-element array.

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*NASA Resident Research Associate at Lewis Research Center.

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2. EXPERIMENTAL ARRANGEMENT

A system consisting of a phased array antenna, an optoelectronic integrated circuit (OEIC) controller, and optical source and fiber, and the necessary electronics, shown schematically in Fig. 1, was set up to demonstrate optical control of a phased array antenna. The OEIC, which has been described in a previous publication,[4] is a hybrid device that requires a serial optical bit stream input, as well as electrical clock and synchronization inputs, and produces 16 parallel, demultiplexed, electrical outputs and a data valid (clock divided by 16) output. It is capable of operation at speeds up to approximately 300 Mb/sec.

The antenna, shown in Fig. 2, was developed by Honeywell[5] for another program, and is a narrow band, eight element system that is tuned to 28.2 GHz. It has an eight-way corporate feed network that divides the input power equally among eight phase shifters that, in turn, feed the eight radiating elements, each of which consists of 10 patches spaced by 1.94 cm. Each phase shifter is a 4-bit device that has 16 possible delay settings in 22.5° increments from 0° to 337.5°.[6,7] The 64 control lines are brought out to two ribbon connectors on opposite sides of the antenna. A phase look-up table was available to permit compensation for path length differences within the feed network in establishing an antenna beam direction. As a result of process tolerances the pinchoff voltages of the FET's in the antenna phase shifters ranged from -5 V to -6 V, and a voltage control circuit to accommodate this was obtained from Honeywell.

Since the OEIC and the antenna phase shifters were not designed to be directly interfaced, voltage level shifting was required between the two systems. The OEIC was therefore used to control an electronic switch which, in turn controlled the voltages applied to the phase shifters. Rather than controlling all 32 bits of the array (8 shifters $\times$ 4 bits/shifter), eight bits were strategically selected so that by changing only these bits the antenna pattern could be switched between normal to the plane of the antenna and 20° from the normal to the plane. For the optical control experiment an oscillator/amplifier combination was used to feed a 28.2 GHz signal, at +21 dBm, to a 25 dB horn that served as a transmitter radiator. An HP 8018 data source was programmed to output a sequence of data so that the demultiplexed outputs of the OEIC, that controlled the previously selected eight antenna phase shifter bits, would alternate between high and low levels at 200 KHz. The array was centered on and perpendicular to the horn axis, with a separation of 3 m.

3. EXPERIMENTAL RESULTS

Toggling the phase shifters between the two states caused the array pattern to alternately point directly toward the transmitter, then 20° from it, with the result that the output signal from the antenna alternated from a maximum to nearly zero, as shown in Fig. 3. In the figure the top trace is one OEIC output data line and the lower trace is the amplified detector output. (In the lower trace the response speed was limited by the time constant of the detector that was used to record the antenna output.) In this experiment the clock frequency was 50 MHz, the average optical power to the OEIC was 200 μW and the beam switching rate was 3.2 μs. By rearranging the data pattern the switching rate could be reduced to 2.25 μs, but in all cases the maximum switching speed was limited by the interface circuitry.

4. CONCLUSIONS

In this paper we have reported the results of an experiment involving the optical control of a 28.2 GHz phased array antenna. In this work an eight element antenna was controlled by the demultiplexed output of a single optically fed controller, demonstrating the feasibility of applying such devices to the antenna control problem. The speed of switching was limited by the interface circuitry to 2.25 μs.

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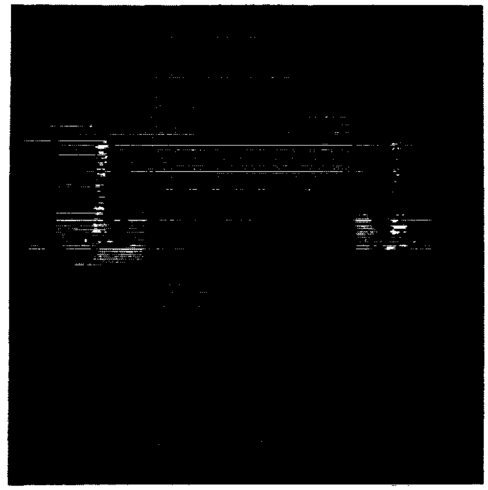

Fig. 1. The 8-element Ka-band phased array antenna.

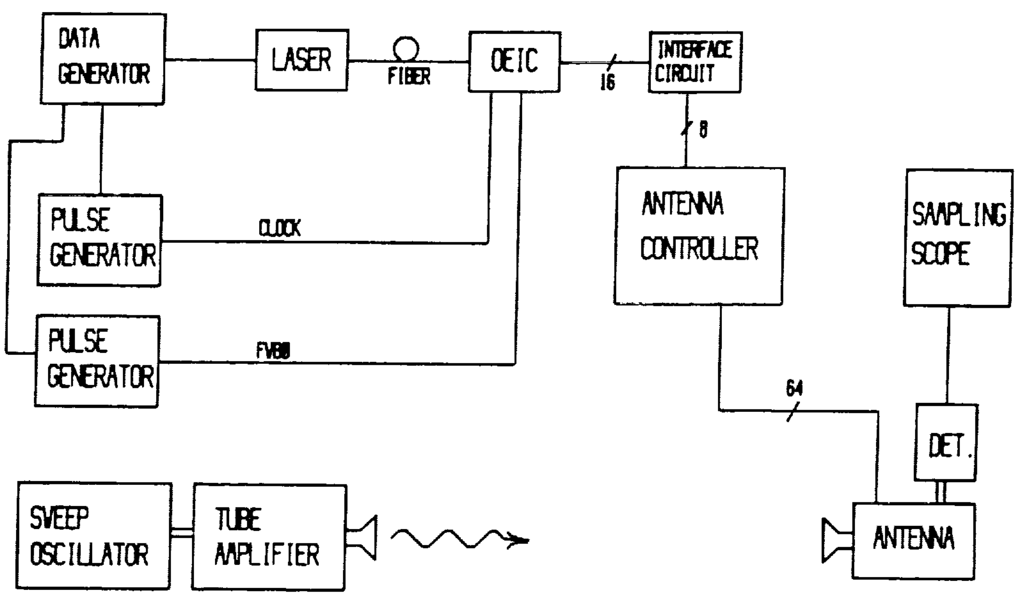

Fig. 2. Experimental arrangement.

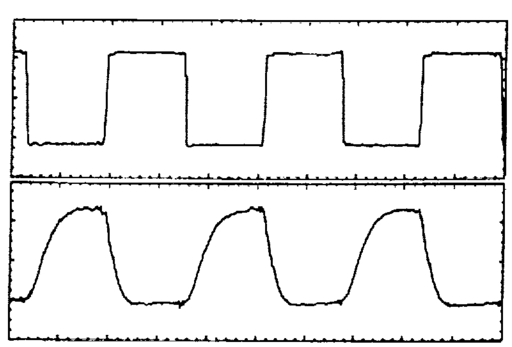

Fig. 3. Antenna switching results. Top trace: Single data line of antenna control signal. Vertical scale: 60μV/div.; Bottom trace: Detector output. Vertical scale: 4 mV/div. Horizontal scale for both traces: 2 μs/div.

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