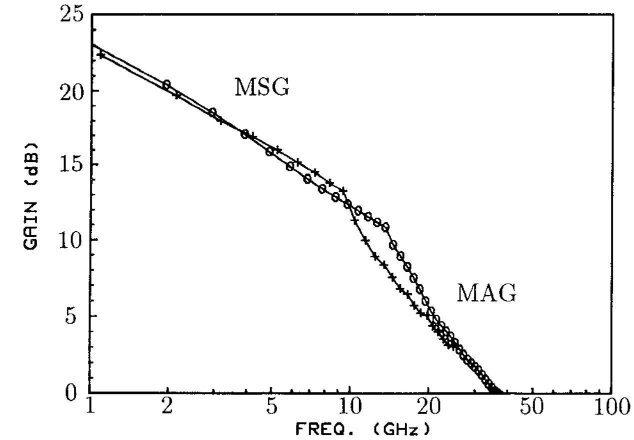

Fig 5 Maximum available gain (MAG)/maximum stable gain (MSG) versus frequency of the AlGaAs/GaAs HBT calculated from the measured S parameters by the optoelectronic system (∘) and from network analyzer measurement (+)

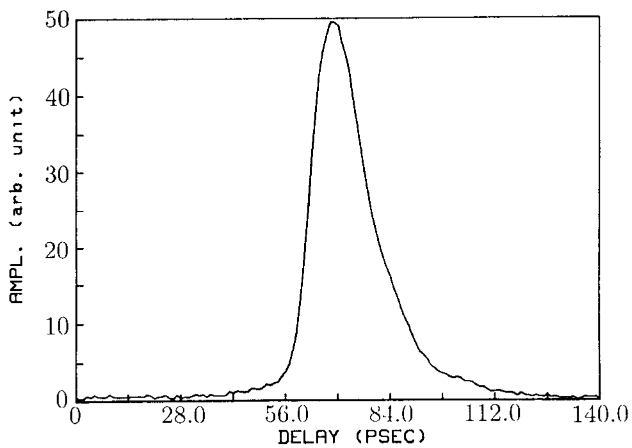

Fig 6 Optical response of the HBT used as a phototransistor for $V_{ce} = 3$ V.

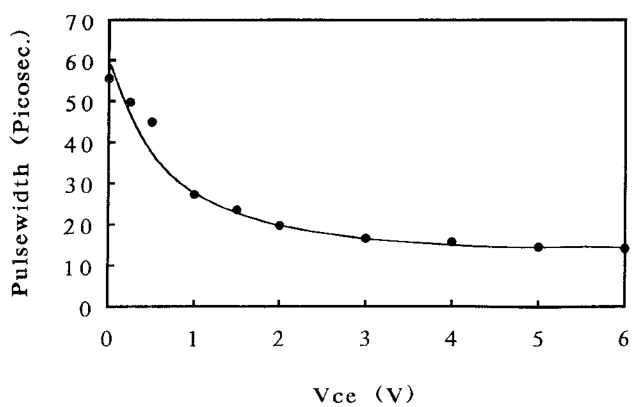

Fig 7 Variation of the optical response pulse width as a function of the collector-to-emitter voltage

on-wafer RF probes and a conventional vector network analyzer over the bandwidth of the network analyzer (26 GHz). The optoelectronically measured S parameters of the device were limited by the cutoff frequency of the device. The system itself has a bandwidth greater than 150 GHz. New HBT's with higher cutoff frequencies are currently being characterized. The optical response of the HBT was also measured using this system. HBT's appear to be very promising as high-speed optical detectors. Although in this study the optical switches were fabricated on a different substrate than the device, it is possible to integrate optical switches with devices on the same wafer and remove the effect of the bond wires on the measurements. This will allow on-wafer measurement of S parameters over a wide bandwidth.

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Control of a GaAs Monolithic *Ka*-Band Phase Shifter Using a High-Speed Optical Interconnect

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Abstract —**The use of a high-speed optical interconnect in the control of a *Ka*-band GaAs monolithic phase shifter is described. A 16 b serial control signal was used to modulate the output of a laser transmitter, and the transmitted optical signal was detected and demultiplexed into 16 parallel electrical outputs using a high-speed hybrid GaAs optoelectronic**

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integrated circuit (OEIC). Four of the parallel output lines were interfaced to the 4 b phase shifter, and high-speed, optically controlled switching of the phase shifter was observed at clock frequencies to 30 MHz using an interferometric technique.

I. Introduction

GaAs monolithic microwave integrated circuits (MMIC's), which could be used as array output modules, represent a major step toward improved, lightweight directly radiating phased array antennas for space communications applications [1]. The interconnection of these MMIC modules into a beam forming network (BFN), however, still represents a rather formidable topological problem that requires innovative solutions. In an effort to overcome these problems a variety of optics-based BFN's have been proposed [2]–[4].

The GaAs MMIC's in a phased array antenna are relatively complex. They include a variable phase shifter and a variable power amplifier which permit the creation of the aperture phase and amplitude distribution that is appropriate to the desired radiated beam configuration. Some proposed architectures also include a local oscillator and a mixer at each antenna element [5], [6]. In fiber-optic-interconnected systems, optical fibers would be used to carry the control signals to the variable phase shifters and amplifiers as well as the signal to be transmitted and the local oscillator phase locking signal. Our research is addressed toward the meeting of needs for distribution of digital control signals within a phased array antenna. Because of the inherent wide bandwidth and low loss of optical fibers, all control signals for the variable phase shifter and amplifier on a MMIC module, or for several modules, could be multiplexed onto one optical channel, as shown schematically in Fig. 1, if appropriate optical receiver/demultiplexers were available. Even though the required data input rate to an individual phase shifter or amplifier control line may be modest, the overall multiplexed data rate from the controller will be high, and a wide bandwidth channel will be required. Some proof-of-concept demonstrations of the use of optical interconnects in the context of a phased array, using discrete components, have been reported [7]. In this paper we present the results of the application of a high-speed GaAs MESFET integrated circuit optical receiver/demultiplexer to the optics-based control of a monolithic *Ka*-band phase shifter.

II. The Optoelectronic Integrated Circuit

The optoelectronic integrated circuit (OEIC) that was used in the control of a MMIC phase shifter has been described in a previous publication [8]. It consists of two integrated submodules that were packaged together in a 34 lead flat pack, with a fiber pigtail for optical input, as shown in Fig. 2. The input chip is the receiver section, consisting of an interdigitated p-i-n photodetector and a three-stage amplifier, and the output chip includes a demultiplexer and output drivers [14]. The inputs to the OEIC are a 16 b serial optical data stream and an electrical bit clock and synchronization signal. The outputs are 16 parallel TTL level data streams and the input clock divided by 16. As reported in our previous paper, the demultiplexer-limited maximum clock frequency of the controller is 305 MHz. The minimum frequency is determined by the capacitive coupling between the amplifier stages, so the minimum data rate is dependent upon the pattern of the data being sent.

III. Optical Control of a *Ka*-Band Phase Shifter

To demonstrate the potential use of the OEIC in a phased array context, the demultiplexed outputs of the optical controller

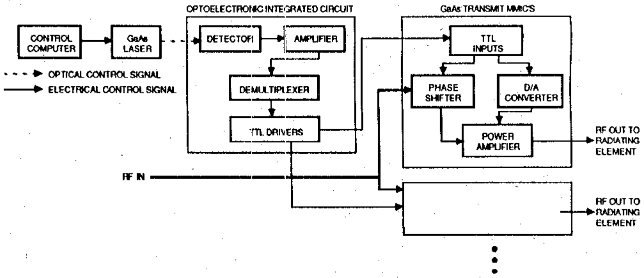

Fig. 1. Schematic diagram of an optically interconnected phased array.

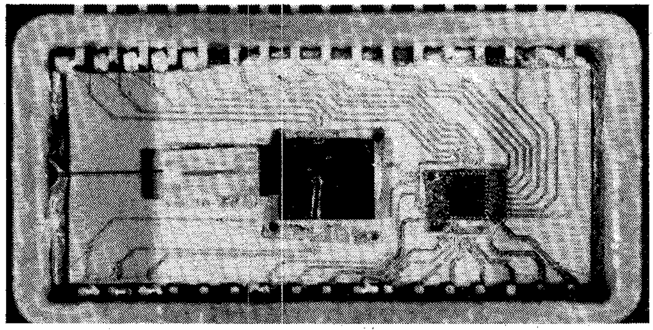

Fig. 2. The packaged optoelectronic integrated circuit.

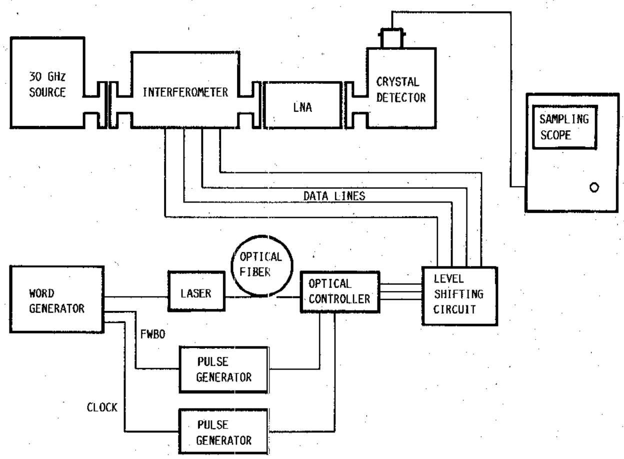

Fig. 3. Block diagram of the microwave interferometer.

were interfaced to the inputs of a 30 GHz 4 b monolithic phase shifter that was produced by Honeywell under a separate contract with NASA, and that has been described in previous publications [9]. The 4 b required by the phase shifter control three switched lines, each of which requires a bit and its complement, and one loaded line. Since the phase shifter and the optical controller were developed under separate programs and therefore were not designed with the interfacing of the two in mind, a voltage level shifting interface circuit was required. The interface circuit consisted of inverting gates to generate the complements and CMOS analog multiplexers to shift the optical controller's TTL outputs to the phase shifter's required 0 V and -6 V inputs, and was the speed-limiting element for this demonstration.

An interferometric technique was devised to allow real-time measurement of fast changes in the effect of the phase shifter on the phase of a *Ka*-band signal. As shown schematically in Fig. 3, the phase shifter was inserted in one leg of an interferometer. A 30 GHz microwave signal of -8 dBm was applied to the input of

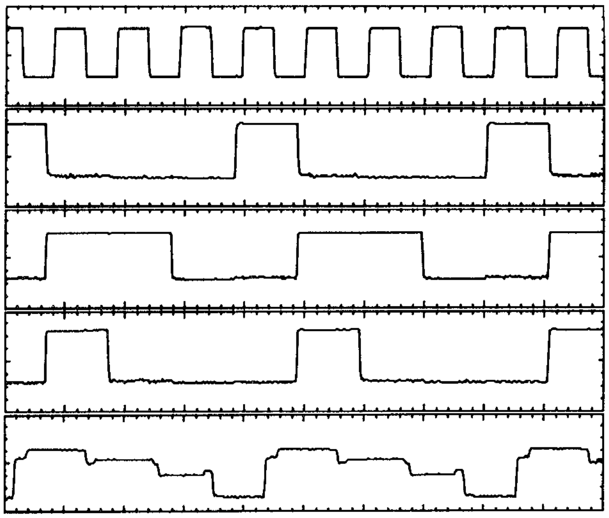

Fig. 4. Controller and interferometer outputs when three phase shifter bits are controlled at a high-speed clock frequency of 30 MHz. The top trace is the clock divided by 16, the center three traces are the OEIC output data, and the lower trace is the interferometer output. The ordinate scale is 200 mV/div for the top four traces and 1 mV/div for the lower trace. The abcissa scale for all traces is 500 ns/div.

a 10 dB power splitter. The higher power output from the splitter was fed through the phase shifter input into the output port of a 3 dB power splitter that was used as a power combiner, while the lower power output was input directly into the second port of the power combiner. To compensate for the 9 dB insertion loss of the phase shifter, a 30 GHz low-noise amplifier [10] was connected to the output of the test setup. A crystal detector attached to the output of the combiner indicated the level of output power. To set the initial condition of the system, the propagation time through the phase shifting leg of the interferometer was adjusted, by changing the bit settings on the phase shifter, until the detector indicated maximum power output, corresponding to constructive interference between the two recombined signals. Beginning with this configuration, switching the 180° bit of the phase shifter caused the power output to fall to zero, indicating complete destructive interference, while switching the 45° and 90° bits caused intermediate levels of destructive interference.

Three demultiplexed outputs from the OEIC were used, along with their complements, to control the 180°, 90°, and 45° switched lines of the phase shifter. Since the data input to the controller are through the laser, fiber, and detector, while the clock and synch (FWB0) are input directly to the demultiplexer as electrical signals, problems with timing can cause uncertainties in the output waveforms. To eliminate this problem, a delayable triggered pulse generator was used to adjust the delay of the two electrical signals and synchronize them with the optical input. For this experiment the average input optical power was 250 μW and the high-speed (input) clock was kept at 30 MHz in order to stay within the limitations of the level-shifting circuitry. Different input data patterns were used to control each phase shifter input bit so that combinations of delay lines could be inserted into the path and their effects observed. An example of the success in combining the OEIC with the phase shifter to control the phase of a 30 GHz signal is given in Fig. 4, where one set of input data patterns, along with the resulting interferometer outputs and the output clock, is shown. It should be noted that there are constant delays between the clock and data and between the data and the interferometer response. The former are the result of different propagation times for data and clock in the OEIC, while the latter are the result of delays in the CMOS level-shifting circuit, as are the irregularities in the interferometer signal.

IV. Conclusions

In this paper we have described the first experiment in which a *Ka*-band monolithic phase shifter is controlled through a high-speed fiber-optic interconnect. The interface between the serially encoded optical control signal and the electrically controlled phase shifter uses a new optoelectronic integrated circuit that converts the serial optical input into 16 parallel optical outputs. Switching of the 4 b phase shifter at instrumentation-limited input clock frequencies to 130 MHz was observed in real time using a novel interferometric technique. The optical control of a phase shifter in this manner represents a significant step toward the development of an optically controlled phased array antenna.

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