High-Speed Monolithic Millimeter-Wave Switch Array

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***Abstract*—A quasi-optical planar grid switch array comprised of hundreds of Schottky varactor diodes embedded within an overmoded waveguide is capable of generating switching times of 100–500 ps in the millimeter-wave region with Watt-level power-handling capabilities. A proof-of-principle high-speed V band switch array has been constructed with excellent agreement between theory and experiment. Less than 1.6-dB insertion loss and >16-dB on/off contrast ratio are measured at 61.5 GHz. The switch rise/fall time is <127 ps. An instantaneous bandwidth >7 GHz (contrast ratio >15 dB) has also been measured.**

I. Introduction

A MONOLITHIC millimeter-wave beam control grid array typically consists of hundreds or thousands of varactor diodes and antenna leads embedded in a periodic grid configuration where the variation in varactor capacitance results in an associated change in the reactance of the grid. A high-performance quasioptical V band beam switch grid array has previously been reported [1]. However, in the initial proof-of-principle experiment, the test configuration was not designed for high-speed switching applications. In addition, quarter-wavelength quartz plates were employed to facilitate impedance matching in the previous work [2]. The airgap between the GaAs wafer and the quartz plate leads to two major drawbacks: serious diffraction loss and narrow (<2 GHz in V band) [3] instantaneous frequency bandwidth.

In this paper, a novel high-speed V band quasioptical grid array design is presented, wherein an overmoded K band waveguide fixture has been employed as the mount for the GaAs wafer, matching plates, and the bias control board. The bias board consists of two cascaded 1 : 4 Wilkinson power dividers. Using this switch array (consisting of 200 diodes), <1.6-dB minimum insertion loss and 7-GHz instantaneous bandwidth with >15-dB on/off contrast ratio has been demonstrated, which agrees well with theoretical predictions. The measured switch rise/fall time is less than 127 ps (currently limited by the available pulsed bias source).

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II. Theory and Simulations

A new millimeter-wave beam control array configuration has been developed, where the input and output matching plates and the GaAs substrate are mounted together, which provides two major advantages over the previous approach [4]. First, by bonding the matching plates and wafer together, the number of different material interfaces has been reduced to a minimum. Hence, the instantaneous bandwidth of the system is increased. Secondly, the length of the entire system is reduced and the associated diffraction loss is reduced to a minimum.

Since the GaAs wafer has a high dielectric constant ($\epsilon \sim 13.1$) and low characteristic impedance ($Z_0 = 104\ \Omega$), appropriate matching plates are required to match the impedance of the GaAs wafer to that of air. A simplified configuration has been employed in the current test system, where quartz plates ($Z_0 = 193\ \Omega$, and $\epsilon \sim 3.9$) on each side of the GaAs wafer have been employed as matching plates. A schematic of a high-speed beam control switch array configuration is shown in Fig. 1. The microwave beam impinges from the left, passes through the GaAs wafer, and continues to the right. By optimizing the thickness of each quartz plate, a broad-band quasi-optical switch array has been designed and simulated.

The HP MDS simulation results are shown in Fig. 2, where the actual measured parameters of the Schottky diodes and calculated inductance values from the HP HFSS EM code were employed. With this grid array and dual matching plate configuration, greater than 8-GHz bandwidth (58 GHz to 66 GHz), with <1.5-dB reflection loss and >15-dB on/off contrast ratio is predicted.

III. Experimental Approach

A V band high-speed monolithic beam switch grid array has been constructed, wherein a K band waveguide fixture has been employed to hold the GaAs wafer and the quartz plate stack in order to provide confinement for the millimeter-wave signal and to reduce diffraction losses. A 1 × 0.4 cm^2 portion of the GaAs wafer (fabricated at the former Martin Marietta Laboratories) contains approximately 200 diodes and is predicted to handle 100-mW maximum power (limited by considerations of linear behavior). The diode cutoff frequency is estimated to be 1.5 THz.

The wafer is bonded to a printed circuit board (PCB), which consists of the back-to-back 1:4 Wilkinson microstrip power dividers. The current PC board (since 5.5 × 7.2 cm^2)

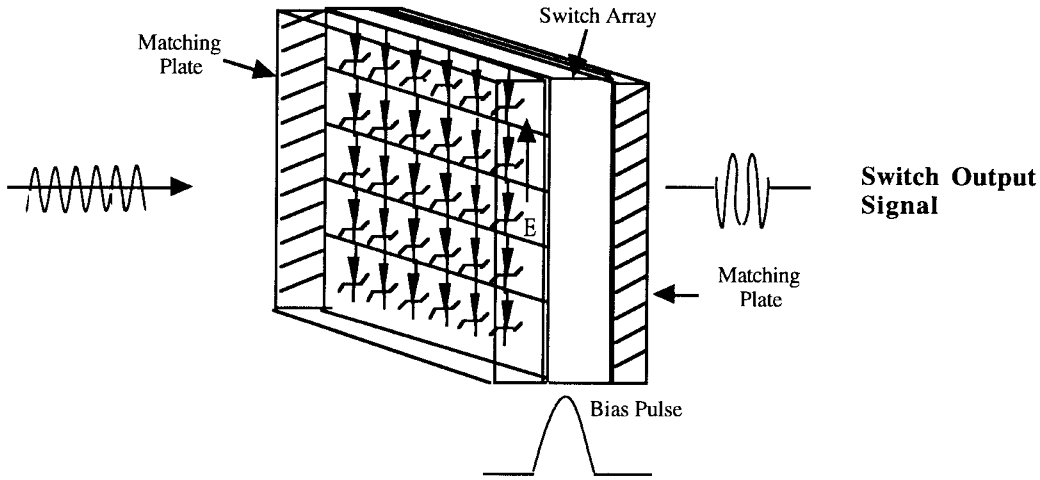

Fig. 1. High-speed quasi-optical beam control switch configuration.

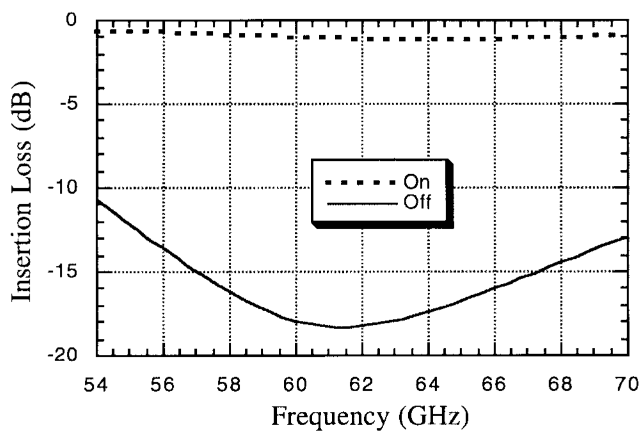

Fig. 2. Simulation of V-band high-speed switch.

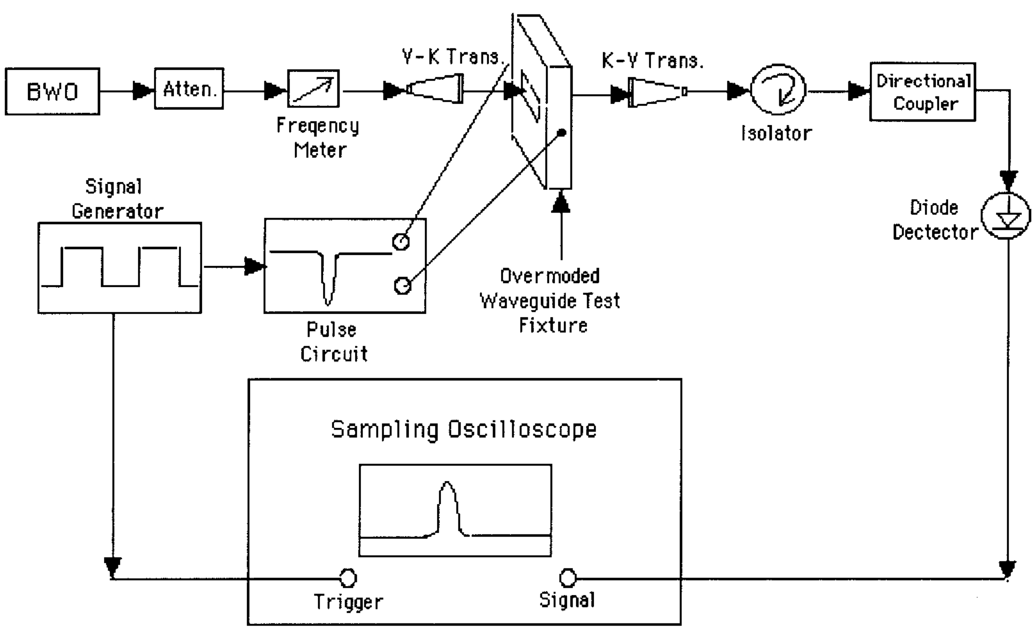

Fig. 3. High-speed beam control switch testing setup.

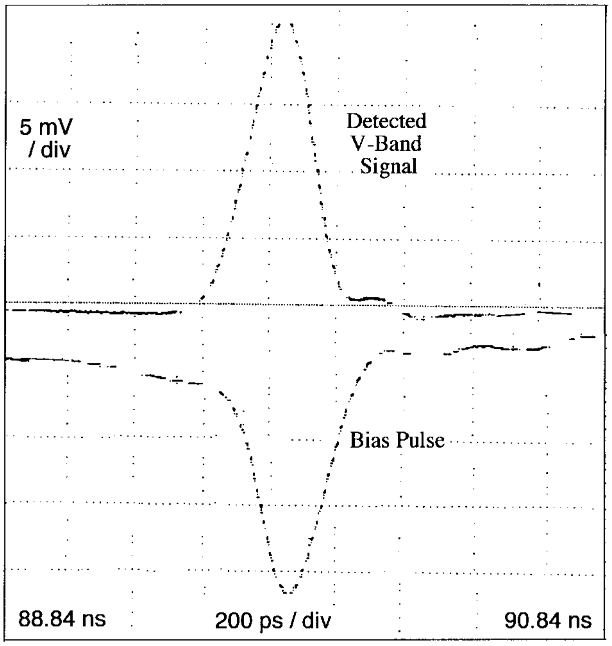

Fig. 4. Time history of transmitted millimeter-wave power and bias pulse.

is designed to have a switching speed of up to 2 GHz. S-parameter measurements with an HP 8510 network analyzer show that this PCB exhibits less than 1-dB insertion loss over the frequency range of 0.5 $\sim$ 1.5 GHz, in relatively good agreement with the predicted value obtained with the HP MDS simulator package.

The test setup is shown in Fig. 3 where a V band BWO has been employed as the radio frequency (RF) source, a high-speed pulse generator (Avtech, model: AVM-2-C-P) has been utilized to provide the bias pulse which exhibits 331-ps fall time and 153-ps rise time with pulse width 318 ps at an amplitude of $\sim$15 V, and a calibrated V band diode detector and directional coupler have been employed to measure the millimeter-wave power. Two V-to-K band waveguide transitions have been used to connect the input and output waveguides to the switch array fixture.

With this configuration (as shown in Fig. 1), the high-performance grid array switch has $<$1.6-dB insertion loss and $>$16-dB on/off contrast ratio at 61.5 GHz, where the HP MDS simulator predicted a 17-dB contrast ratio at the same frequency. Fig. 4 is a scanned picture from a Tektronix 11802 (50 GHz) digitizing sampling oscilloscope. The top curve is the measured V band signal transmitted through the switch and detected by the detector. The measured switch fall time is 127 ps, rise time 168 ps, with a pulse width (FWHM) of 317 ps, which is limited by the bias pulse. In this measurement, an extra length of coaxial cable has been added to shift the reference signal, which thereby enables the oscilloscope to display the two pulse signals on the same screen.

The insertion loss of the high-speed switch has also been measured. Less than 1.6-dB insertion loss over an operating range of 50–70 GHz has been demonstrated, as shown in Fig. 5. A third-order polynomial has been utilized to curve fit the measured data. The small discrepancy is believed to be due to the V-to-K band waveguide transitions and overmoded waveguide testing fixture, which are not considered in the simulation model.

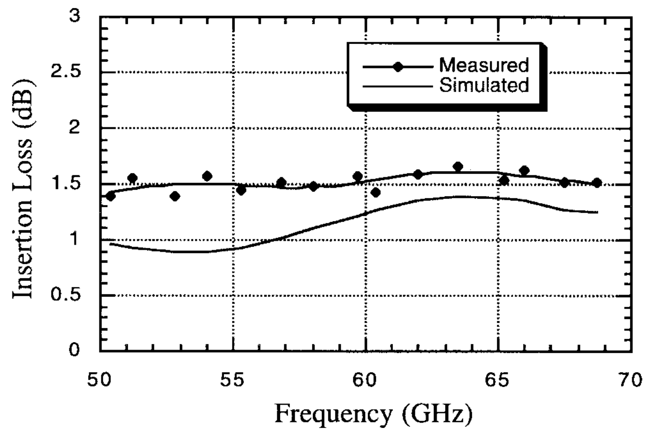

Fig. 5. Insertion loss as a function of frequency.

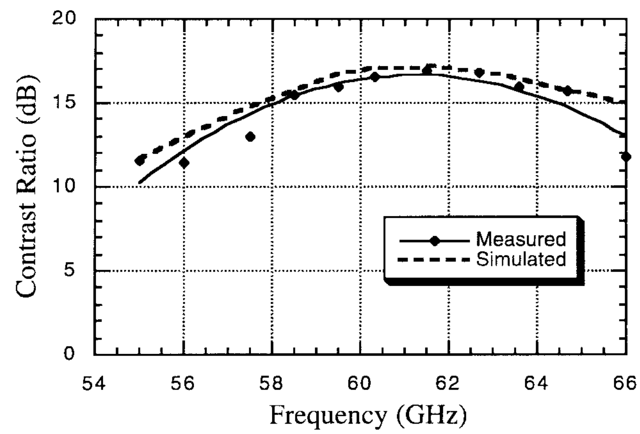

Fig. 6. Comparison between measured and simulated contrast ratio.

The measured results are very close to the simulation results; a comparison is shown in Fig. 6. The solid line shows the array on/off contrast ratio for the range from 55 to 66 GHz; better than 10-dB on/off ratio has been measured for this frequency band. The measured single-diode characteristics have been employed in the simulation. The diode series resistance is $\sim$6 Ω, and the zero bias capacitance is 68 pF.

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