W-BAND QUASIOPTICAL INTEGRATED PIN DIODE SWITCH*

Karl D. Stephan, Dept. of Elec. and Comp. Engineering, Univ.of Massachusetts, Amherst/ Millitech, Inc., S. Deerfield, MA

Paul F. Goldsmith, Dept. of Physics and Astronomy, Univ. of Massachusetts, Amherst/ Millitech, Inc., S. Deerfield, MA

***Abstract* - A quasioptical reflection/transmission switch using 464 PIN diodes in a 2.3-cm diameter grid array has been designed and tested. In the reflection state (diodes off), reflection loss was less than 0.5 dB at 94 GHz, and transmission loss exceeded 20 dB over a 12-GHz bandwidth. In the transmission state (diodes on), the array's transmission loss fell to as little as 3.7 dB, with a corresponding return loss of 9 dB, at 94 GHz. Potential applications of this new component include radar T/R switches, communications signal path routing, and electronic replacements for mechanical Dicke-switching choppers in millimeter-wave radiometers. Advantages include the ability to switch multiple beams simultaneously, and potentially high power-handling capability.**

Introduction

The diode grid is an outgrowth of developments in passive frequency-selective surfaces. Lam et al. [1] showed how a periodic grid of diodes embedded in a metal pattern may be analyzed by the same plane-wave equivalent transmission line approach used by Arnaud and Pelow [2]. Most work in this area has concentrated on either phase shifting or frequency multiplication, but the simpler function of on-off switching has been neglected up to now in quasioptical component development.

The motivating application for the switch is a quasioptical radiometric imaging system. In this kind of multielement radiometer the planar array of receivers must alternately "see" either the scene to be imaged or a uniform-temperature thermal load for real-time calibration purposes. This Dicke-switching function has heretofore been accomplished by mechanical rotating choppers, but for large-aperture systems mechanical quasioptical switches become impractical. Hence the need for an electronic quasioptical switch that will either: (a) reflect an incident beam with very low loss, or (b) transmit an incident beam with moderate transmission loss and return loss. In this application the critical specification is the reflection loss in the reflection mode, since loss in this mode adds directly to the system's noise temperature. Loss in the transmission mode is not as important since a lossy absorber is being viewed anyway. With these considerations in mind, we designed a PIN-diode periodic array that would show very low loss in the reflection mode, and reasonably good loss and match in the transmission mode, all in a band centered at 94 GHz.

Theory

As long as the grid period is less than a free-space wavelength at the design frequency, a plane-wave equivalent circuit analysis can be used in which an infinite periodic array is treated as a lumped-element network. The equivalent circuit of a PIN diode in its off state is a capacitor, so if a PIN diode is embedded in a metallic grid pattern that is primarily inductive, a series-resonant circuit results. By adjusting the shape and period of the array for a given diode capacitance, the series resonance can be made to occur at the frequency of operation, and a low-loss, highly reflective surface results when the diodes are off (nonconducting). Further details concerning grid equivalent circuits can be found in Whitbourn and Compton [3].

When a PIN diode is forward-biased it becomes a resistance of a few ohms, making the grid's equivalent circuit a series R-L across the transmission line of free space. By placing a passive grid a suitable electrical distance behind the active grid, the reflections from the two grids can be made to counteract each other, giving a reasonably good return loss and moderate transmission loss when the diodes are on. Transmission-line equivalent circuits for the reflection and transmission states are shown in Fig. 1.

*Patent applied for.

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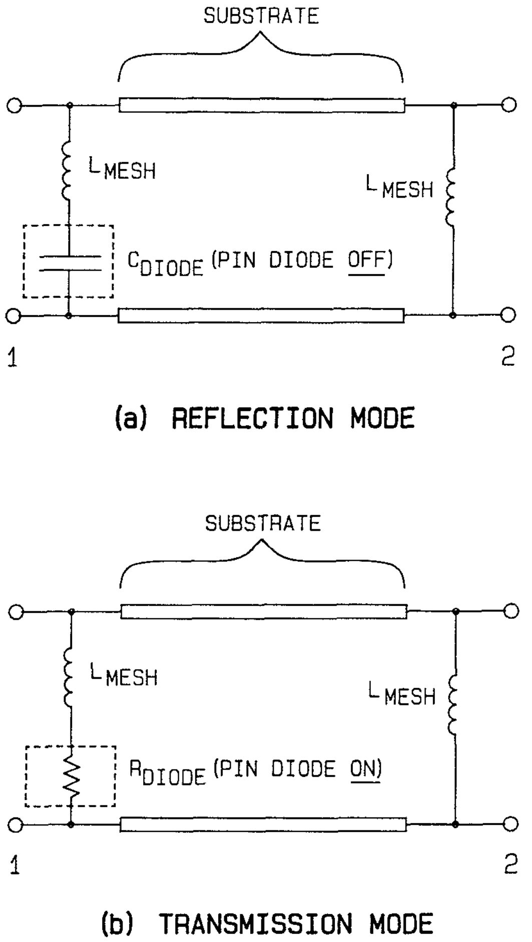

Fig. 1. Plane-wave equivalent transmission-line circuit of switch in (a) reflection mode and (b) transmission mode.

Experiment

The basic design of the grid was dictated by the off-state capacitance of the silicon beam-lead PIN diodes chosen (Hewlett-Packard type HPND-4005). A grid pattern with the inductance required for resonance was designed by a combination of analytical and empirical techniques. The square grid's period (diode-to-diode spacing) was chosen to be 0.89 mm. This period required 464 diodes to cover the 2.3-cm diameter circular opening in the chrome-gold coating on the alumina substrate.

The transmission-mode design required that the electrical path length through the dielectric substrate to a second similar shunt admittance be approximately one-quarter wavelength in order to reduce reflections. This was achieved by etching a pattern similar to the active grid on a second substrate. The diodes were replaced in the second substrate's pattern by short segments of conductor to simulate turned-on diodes. To obtain the proper electrical length, the two 0.25-mm alumina substrates were separated by a 0.15-mm fused-quartz slab called the spacer in Fig. 2. A drawing of the complete active array with DC bias connections is shown in Fig. 3.

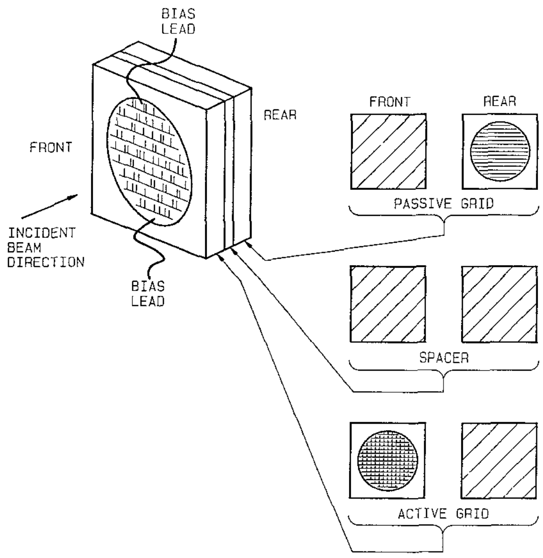

Fig. 2. Diode grid and matching layers to improve transmission performance.

Transmission and reflection tests were made in a quasioptical test setup using two scalar horn feeds and two 7.5-cm diameter dielectric lenses. The 80-120 GHz beam was focused to a beam waist between the lenses having about a 0.75-cm waist radius.

Reflection tests were done at an incidence angle of 17 degrees to normal. To eliminate a rapid response ripple due to multiple reflections between the test lenses, the data were smoothed by taking a running average over 5% of the full-scale frequency span, but no other data correction was performed other than normalization for the reference case. The reference for zero reflection loss was obtained by substituting an aluminum plate for the quasioptical switch, giving an absolute accuracy of only +/- 0.2 dB or so, probably due to positioning variations.

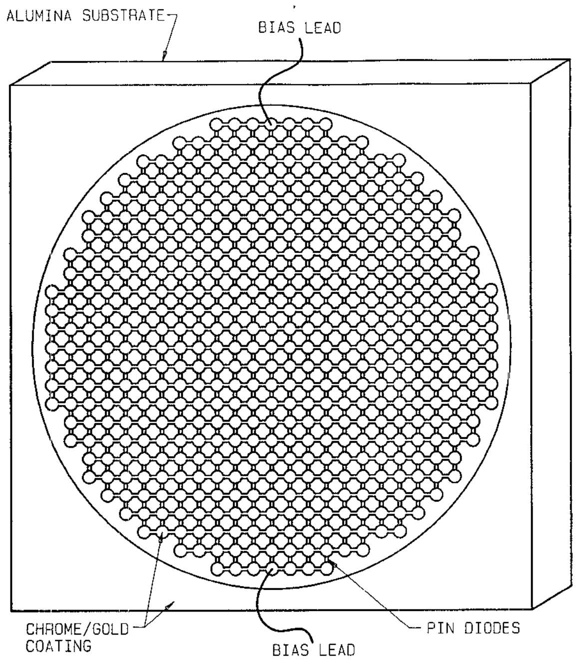

Fig. 3. View of 464-diode array with bias connections.

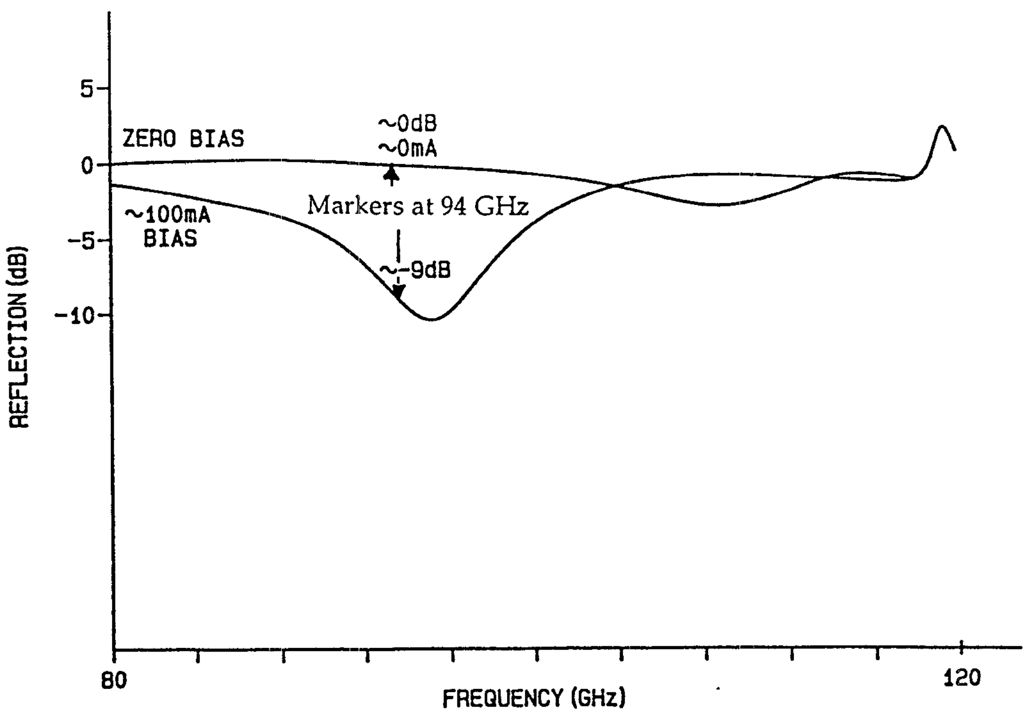

Fig. 4. Quasioptical reflection loss versus frequency for diode switch, zero bias and 100 mA forward bias.

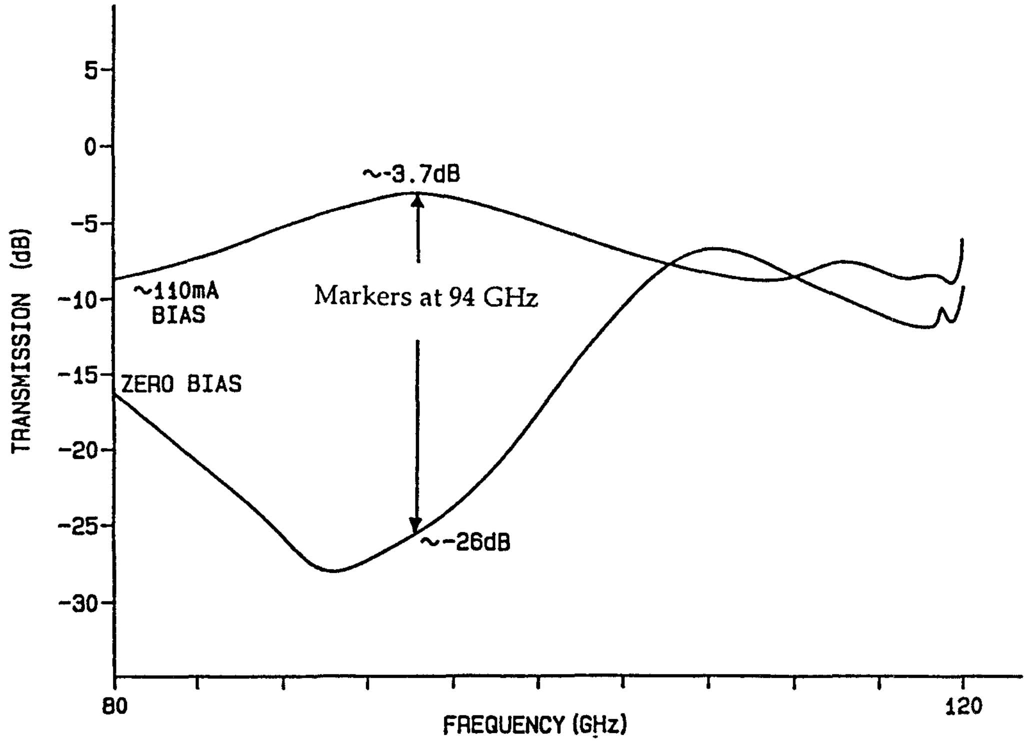

Fig. 5. Quasioptical transmission loss versus frequency for diode switch, zero bias and 110 mA forward bias.

Fig. 4 shows the quasioptical reflection coefficient magnitude of the grid over the 80-120 GHz band. Reflection loss at the design frequency of 94 GHz in the reflection state (diodes off) was too small to measure accurately, but was probably in the range of 0.2-0.4 dB. This loss increased to 9-10 dB in the transmission state under the application of 100 mA bias at approximately 20 volts to the array.

Transmission performance in the two switch states is shown in Fig. 5. In the reflection state (diodes off), the reflection loss of 0.2-0.4 dB is accompanied by a good transmission isolation loss that exceeds 20 dB over a 12-GHz bandwidth. This excellent isolation is due to the low series resistance of the off-state PIN diodes, which makes the series resonance an almost perfect short across the equivalent transmission line of free space. When the diodes are turned on, their on-state series resistance of 5 to 10 ohms causes a transmission loss of about 3.7 dB at the design frequency.

Conclusions

A quasioptical integrated PIN-diode switch has been demonstrated at 94 GHz. It shows very low reflection loss and high isolation when off, and moderate transmission loss when on. The basic concept is amenable to monolithic integration, and should find applications in such areas as high-power radar T/R switching and single- and multi-pixel radiometric Dicke switching.

References

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