Q-14

DIODE PHASE SHIFTER AND MODEL IN WAVEGUIDE

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ABSTRACT

Two models for a diode phase shifter in waveguide are presented. The first is a circuit model of the diode that can be used to predict response for design of different phase shift values. The second is an RLC model that can be realized as a strip and a strip with a gap for simulation of the diode.

INTRODUCTION

The characterization of diode mounting posts and structures, and probes is well documented [1,2,3] as are many waveguide iris discontinuities, including inductive strips [4]. The analysis of a gap in a strip hanging in waveguide has not been widely investigated [5], despite its possible applications in phased array diode scan lenses.

This paper presents three different but related findings. We have developed a series RLC model for a strip and gap hanging in waveguide, a circuit model for a PIN diode mounted on a strip in waveguide, and a simulator circuit for the diode. For the simulator, an inductive strip represents the diode's on state, while a strip with a gap represents the diode's off state. Figure 1 shows how the diode is replaced by the gap and strip. This configuration can be used in place of an array of diodes to simulate a diode scan lens, thereby reducing much of the expense during the development of large scanning lenses.

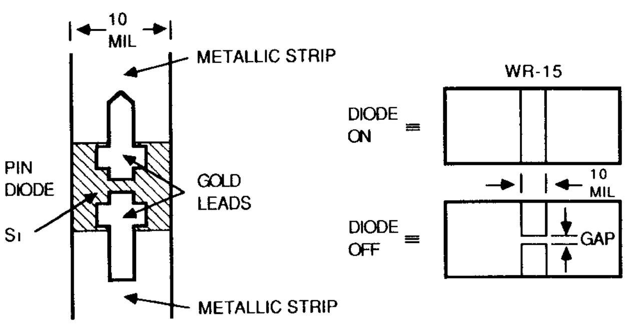

Fig. 1 PIN diode in waveguide simulated by strip and gap.

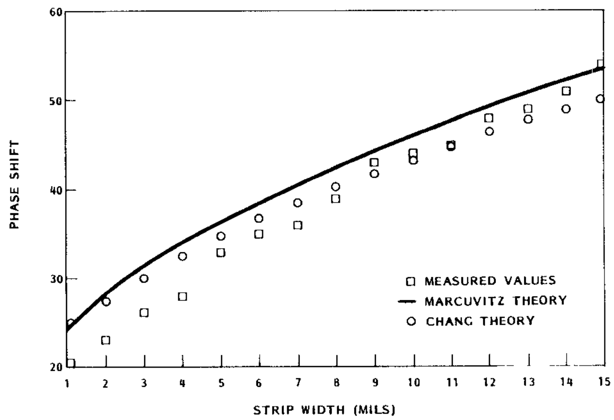

Fig. 2 Phase shift of strip in waveguide.

CHARACTERIZATION OF GAP AND STRIP

Marcuvitz [4] provided the model for the single centered strip in waveguide as a simple inductor. To confirm the impedance and phase shift of this model, strips of widths varying from 1 to 15 mils on 10 mil duroid were tested in a v-band waveguide fixture. The measured values of phase shift are plotted in figure 2 along with values calculated from Marcuvitz[4] and by Chang's variational methods[5]. The 10 mil thickness of duroid was experimentally normalized out by making the measurements referenced to a blank piece of duroid. The experimental results are consistent with theory.

To model the gap geometry, insertion loss and phase shift data was taken for gaps varying from 1 to 10 mils in 5 mil and 10 mil wide lines. The insertion loss and phase shift for a 4 mil gap in a 10 mil wide strip are plotted in figures 3 and 4. The measured resonances showed that the gap was indeed capacitive. Using these resonances, capacitance values were calculated; yielding a series RLC model to represent the gap and strip.

This model was simulated on Touchstone and compared to the measured data. The modeled values for the 4 mil gap on a 10 mil wide strip are L= 0.64 nH, R= 8 ohms, and C= 0.0119 pF. The modeled results of the insertion loss and phase shift for a 4 mil gap in a 10 mil wide strip are plotted in figures 3 and 4 with the measured values. It was

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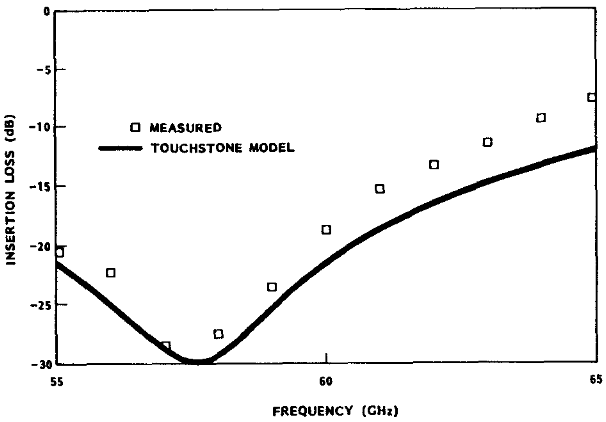

Fig. 3 Insertion loss for 4 mil gap in 10 mil wide strip.

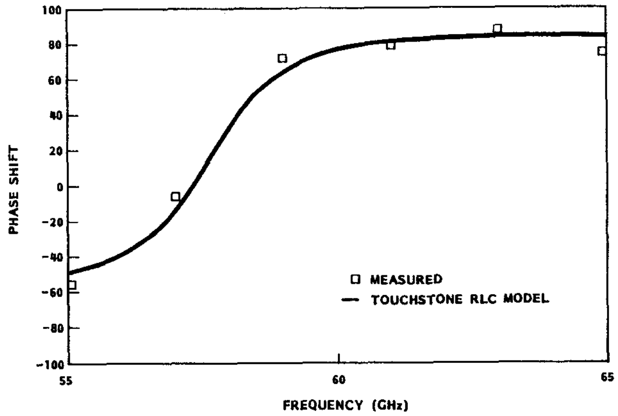

Fig. 4 Phase shift for 4 mil gap in 10 mil wide strip.

necessary to add the series resistance to the gap model to account for circuit losses. The series resistance of the inductive strip was found to be negligable. The capacitance values based on the resonance measurements were compared to capacitances derived from coupled lines [6] and compared favorably for small gap sizes. The coupled line model capacitance for the 4 mil gap was 0.0114 pF.

DIODE PHASE SHIFTER

The phase shift of the Hewlett Packard HPND 4005 PIN diode is due to the change in impedance between the on and off states of the diode. The diode is mounted on a 10 mil long gap in a 10 mil wide strip on 10 mil thick duroid. The effective modeled gap of the diode is not, however, the physical mounting gap. The test fixture for the phase shifter is pictured in figure 5. The fixture can be mounted in any V-band test set-up, like a network analyzer or phase bridge. The center of the fixture is v-band waveguide with a 10 mil deep cutout to hold the duroid board. The diode is DC

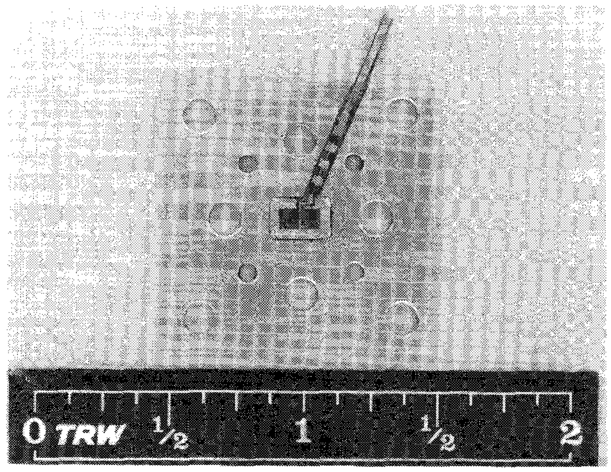

Fig. 5 V-band test fixture with diode mounting circuit.

biased by means of the filter extending to the upper right. A choke consisting of quarter wave sections of low and high impedance prevents RF leakage. A measured phase shift of about 18 degrees is acheived, as seen in figure 8.

DIODE CIRCUIT MODEL

The circuit model for the HPND4005 PIN diode shown in figure 6 was used for our circuit analysis. Ls is the added inductance of the strip on which the diode is mounted. The other values come from a Hewlett Packard application note. The lead inductance, Ll, is 0.15 nH, the series resistance, Rs, is 2 ohms, the junction resistance, Rj, is 4.8 ohms when the diode is on and 3k ohms when the diode is off, the junction capacitance, Cj is 0.011 pF, and the package capacitance, Cp, is 0.009 pF. This circuit model was analyzed on Touchstone and compared with measured values of phase shift, insertion loss, and return loss, resulting in the good agreement presented in figures 8, 9, and 10. This circuit

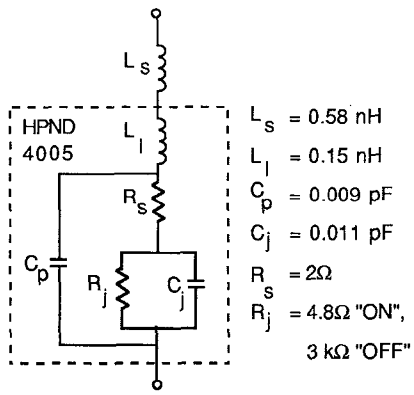

Fig. 6 PIN diode circuit model.

model can be used to predict the response of different physical geometries (through changing strip inductance) for different phase shift values.

THE DIODE MODELED AS A GAP

With the information gathered through the strip and gap testing and circuit modeling, the diode can be represented by an RLC circuit that corresponds to a gap in the 10 mil wide line. The values used to represent the on and off states are shown in figure 7. The 0.023 pF capacitance was chosen to fit the measured insertion loss and corresponds to a gap of about 0.1 mil. The resistance and inductance are the same as in the previous gap model. The graphs in figures 8, 9, and 10 show the phase shift, insertion loss, and return loss of the RLC model along with those of the circuit model and the measured values. The figures show that both the circuit model and the RLC model agree well with each other and with the measured data.

The return loss measurements show that a large part of the insertion loss is due to reflected power. From the circuit model at 60 GHz, only 0.22 dB is lost in the circuit in the off state and only 0.14 dB is lost in the on state. The reflected power could be greatly reduced by either quarter wave spacing of circuits (in the case of multiple sheets) or the use of inductive posts on either side of the diode. Circuit losses of this magnitude imply that a 15 layer phase shifter would only have a loss of 3 dB.

CONCLUSIONS

It has been shown that a PIN diode mounted on a strip and hanging in waveguide can be effectively modeled as circuit elements for analysis. It has also been shown that the PIN dioe can be simulated as a strip and a strip with gap. The close agreement between the measured data on the diode mounted in waveguide and the circuit model shows that much of the optimization of a diode grid phase shifter could be done on Touchstone. The good agreement between the RLC gap modeland the measured data shows that the strip and gap simulator could replace the use of diodes in an array for testing purposes. By using this passive model, large scale arrays can be simulated, tested, and optimized without the costly use of a large number of diodes.

ACKNOWLEDGEMENTS

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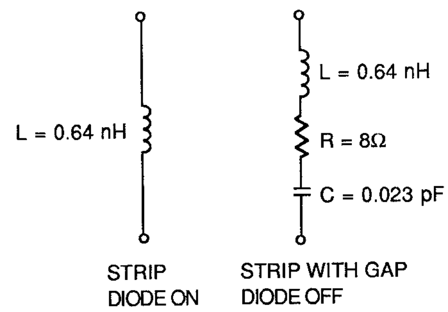

Fig. 7 Strip and gap models.

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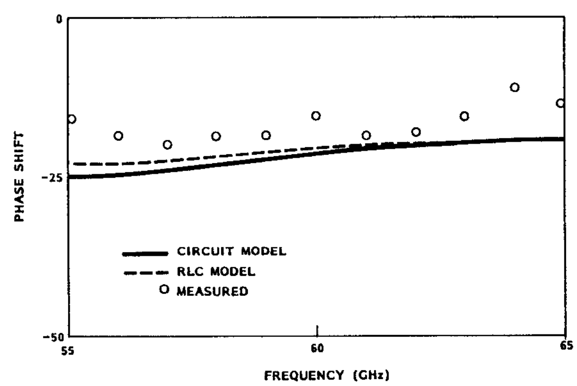

Fig. 8 Phase shift of PIN diode, circuit model, and simulator.

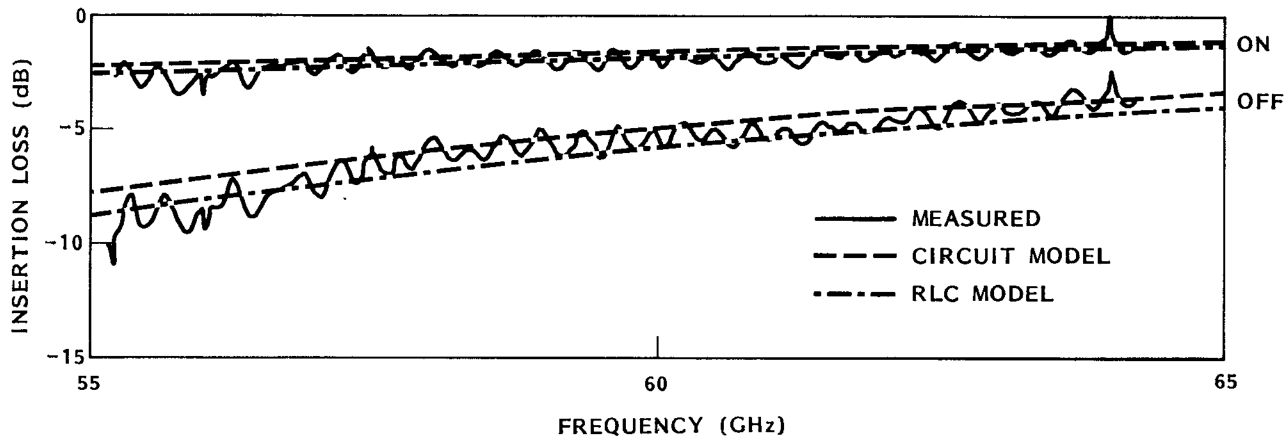

Fig. 9 Insertion loss of PIN diode, circuit model, and simulator.

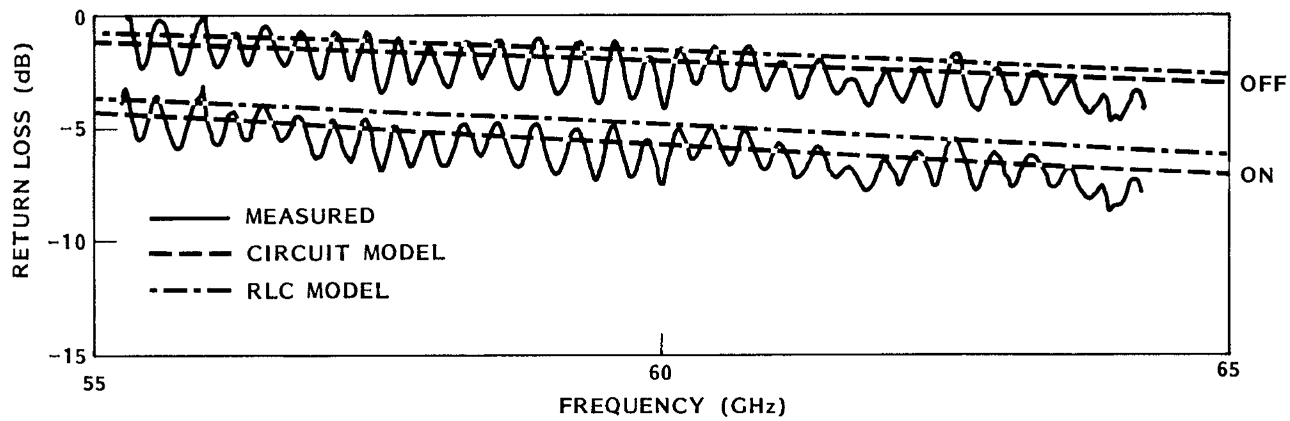

Fig. 10 Return loss of PIN diode, circuit model, and simulator.