

# Finite Ground Coplanar Waveguide Shunt MEMS Switches for Switched Line Phase Shifters

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## Abstract

Switches with low insertion loss and high isolation are required for switched line phase shifters and the transmit/receive switch at the front end of communication systems. A Finite Ground Coplanar (FGC) waveguide capacitive, shunt MEMS switch has been implemented on high resistivity Si. The switch has demonstrated an insertion loss of less than 0.3 dB and a return loss greater than 15 dB from 10 to 20 GHz. The switch design, fabrication, and characteristics are presented.

## Introduction

NASA, military, and commercial satellites use phased array antennas to optimize satellite performance by steering and shaping the radiation pattern. Phased array antennas are also used for scanning radar systems in terrestrial systems. The enabling component in phased array antennas is the phase shifter. However, the insertion loss of GaAs MESFET, switched line phase shifters is too high for many applications and forces system designers to use more amplifiers and greatly complicates thermal management.

To solve these problems, RF MEMS switches have recently been developed. These include rotary MEMS switches [1], single supported cantilever MEMS switches [2], and capacitive membrane MEMS switches [3,4]. Capacitive membrane MEMS switches rely on electrostatic force to pull a double supported cantilever beam down and provide an RF short between the signal line and the ground plane.

In this paper, we present the design, fabrication, and characterization of a capacitive, Finite Ground Coplanar (FGC) waveguide, MEMS switch. The switch fabrication relies on standard air bridge processing and is thus fully compatible with SiGe/Si monolithic integrated circuit processing. Moreover, because the processing is not dependent on the substrate, the switches may also be fabricated on GaAs, glass, or other microwave substrates.

## Switch Design

Figure 1 shows an SEM image of the capacitive MEMS switch. The switch is implemented in FGC waveguide with center conductor, slot, and ground plane widths of 50, 35, and 150  $\mu\text{m}$  respectively, which yields a characteristic impedance of 50  $\Omega$ . The cantilever is isolated from the ground planes by a 10  $\mu\text{m}$  gap, thus the bias voltage

applied to the cantilever is isolated from the FGC. Cantilevers are built with and without 10  $\mu\text{m}$  square holes and widths between 90 and 250  $\mu\text{m}$ . These switches may be used in FGC waveguide T-junctions to develop single pole double throw switches as shown in Figure 2.

### **Fabrication and Measurement**

The RF switches are fabricated on a high resistivity Si wafer,  $\rho > 2500 \Omega\text{-cm}$  with 450 nm of thermally grown  $\text{SiO}_2$ , which electrically isolates the bias lines from the FGC waveguide. First, the underlay metal comprised of 20 nm of Cr and 1000 nm of Au is defined through standard lift-off processing. Second, 300 nm of PECVD  $\text{Si}_3\text{N}_4$  is grown on the wafer and patterned by Reactive Ion Etch (RIE) to isolate the cantilever from the FGC waveguide when the switch is in the down state. Third stage lithography is then used to define the sacrificial photo resist layer under the cantilevers. 100 nm of Cr and 200 nm of Au is electron-beam evaporated onto the wafer, followed by 100 nm of RF sputtered Au. This forms the seed layer for the Au electroplating. Fourth stage lithography is performed to define transmission lines and cantilevers, which are electroplated to a final thickness of 1.8  $\mu\text{m}$ . Finally, the photoresist and seed layers are removed.

The switches are characterized on an HP8510 vector network analyzer using GGB Industries RF probes. Between the Si wafer and the probe station wafer chuck, a quartz plate is used to isolate the circuits and prevent parasitic modes. The bias is applied to the top plate of the capacitive switch through a separate bias pad seen in Figure 1. To prevent high voltages from reaching the vector network analyzer if the switch fails, a high voltage bias tee is used. Unfortunately, the bias tee limits the RF characterization to the frequency range of 10 to 20 GHz. A Thru-Reflect-Line (TRL) calibration is implemented through the NIST MULTICAL software routine [5], with the calibration standards fabricated on the same wafer as the switches. Thus, the reference plane is at the edges of the switches. Probe placement repeatability limits insertion loss measurement accuracy to 0.1 dB.

### **Results**

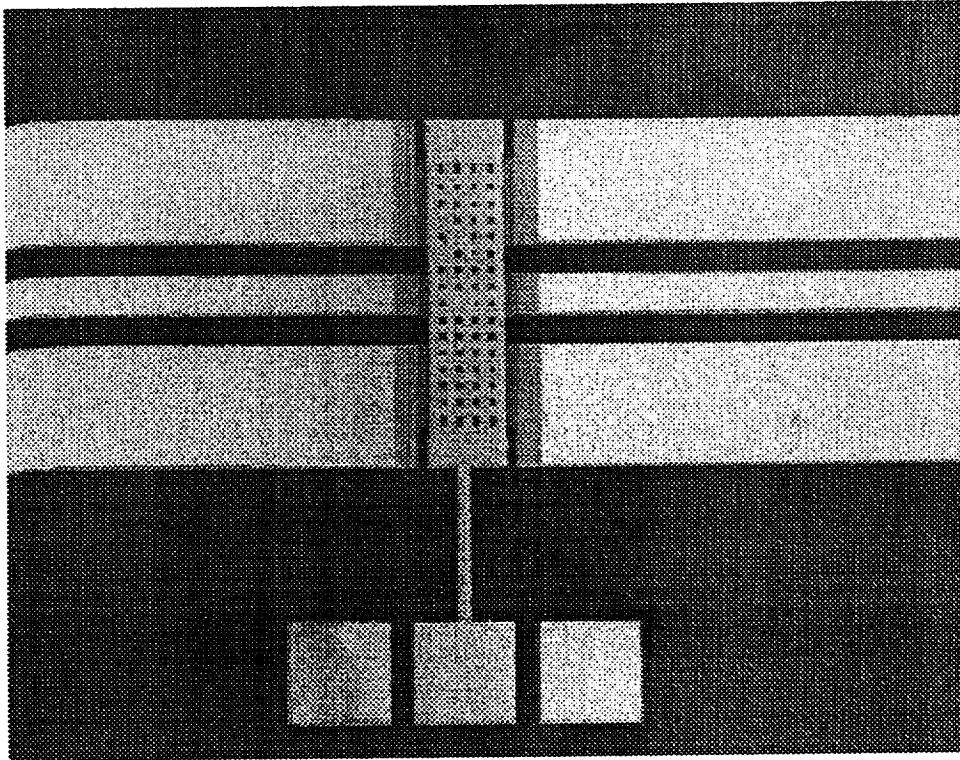
The switches exhibit signs of excessive stress as evidenced by a slight curling of the cantilever. This stress also resulted in a high voltage of 100-120V to fully pull the cantilever down; however the switch partially pulled down at 40V. The RF characteristics of the switch in the up or on state are shown in Figure 3. Through 20 GHz, the insertion loss is less than 0.3 dB and the return loss is greater than 15dB. The isolation of the switch in the off state increases with frequency as expected, but because the bias tee limited measurements to 20 GHz, high isolation could not be obtained. We are correcting this problem and will have the RF characteristics through 40 GHz for the full paper.

### **Conclusions**

Capacitive RF MEMS switches have been fabricated on high resistivity Si using standard air bridge processing. The switch has low insertion loss and good return loss through 20 GHz. These switches offer the potential to dramatically improve phase shifter performance, which will enable lower cost, simpler phased array antennas.

### References

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**Figure 1: SEM image of capacitive MEMS switch implemented in Finite Ground Coplanar Waveguide.**

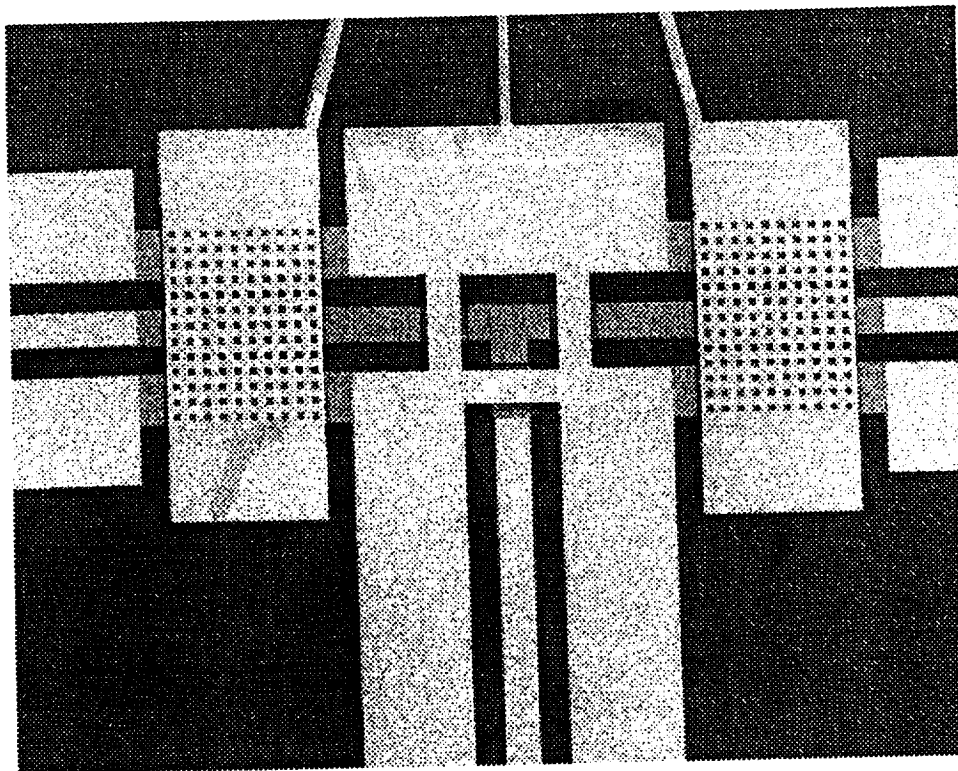


Figure 2: SEM image of single pole double throw switch formed by Finite Ground Coplanar waveguide T junction with two capacitive switches.

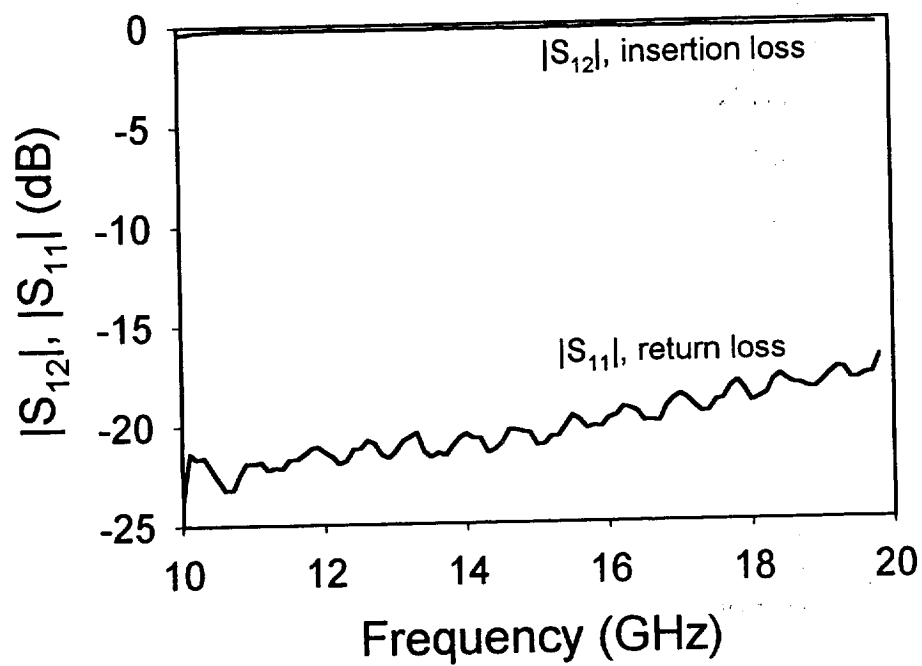


Figure 3: RF characteristics of capacitive MEMS switch in the on state, membrane width is 250  $\mu\text{m}$ .