A SiGe MMIC 6-Bit PIN Diode Phase Shifter

Mary Teshiba, Robert Van Leeuwen, Glenn Sakamoto, and Terry Cisco

***Abstract*—A 6-bit PIN diode phase shifter has been successfully demonstrated at microwave frequencies in a Silicon Germanium (SiGe) Bipolar technology. A post-silicon polymer dielectric interconnect technology is implemented to achieve low loss microstrip structures on the silicon substrate. The monolithic microwave integrated circuit exhibits flat phase shift, low VSWR, and low insertion loss variation, over the 7- to 11-GHz band. This phase shifter demonstrates the feasibility of integrating SiGe technology into microwave systems.**

***Index Terms*—monolithic microwave integrated circuit (MMIC), phase shifter, PIN diode, Silicon Germanium (SiGe).**

I. INTRODUCTION

SILICON GERMANIUM (SiGe) is a promising technology that offers microwave performance competitive with gallium arsenide (GaAs) with the process maturity, integration level, yield, and cost of conventional silicon fabrication. This paper describes a monolithic microwave integrated circuit (MMIC) phase shifter developed using IBM's SiGe Bipolar technology [1], [2]. IBM's process offers an 8-in wafer, three-level metal process with a menu that includes high performance SiGe HBTs, SiGe PIN diodes, and passive components (MIM capacitors and Polysilicon resistors). A post-silicon dielectric interconnect technology (Topside) is used to achieve low-loss microstrip structures on the low-resistivity silicon substrate [3]. This post process supports flip-chip package applications. Fig. 1 shows a cross sectional view of IBM's SiGe Bipolar process with Topside.

The Topside process adds a 15-μm-thick polyimide or benzocyclobutene (BCB) dielectric followed by an aluminum metal layer (top metal) to the IBM wafer. Microstrip structures are built in top metal and use the last metal of the three-level metal SiGe process (last metal) as the ground plane. The ground plane provides an effective shield from the lossy silicon substrate. Spiral inductors, transmission lines, and input/output (I/O) connections of the phase shifter are located on top of the dielectric. PIN diodes and MIM capacitors are located below the ground plane. Connections between Topside structures and the SiGe wafer devices below are through vias in the dielectric and openings in the ground plane. The 6-bit phase shifter is shown in Fig. 2.

II. DESIGN

The phase shifter design consists of six digital bits (180°, 90°, 45°, 22.5°, 11.25°, and 5.625°) cascaded in a linear arrangement. This provides 64 phase states between 0 and 360° in increments of 5.625°. The 180°, 90°, 45°, and 22.5° phase bits switch between PI and/or T-type highpass/lowpass phase shift networks using two single pole double throw PIN diode switches [4]. The 11.25° and 5.625° phase bits use a simplified topology of capacitive and inductive elements to achieve their phase shifts. These phase-bit topologies were selected due to their broad bandwidth performance and relative insensitivity to process variations. The schematics for the phase bit circuits are shown in Figs. 3 and 4.

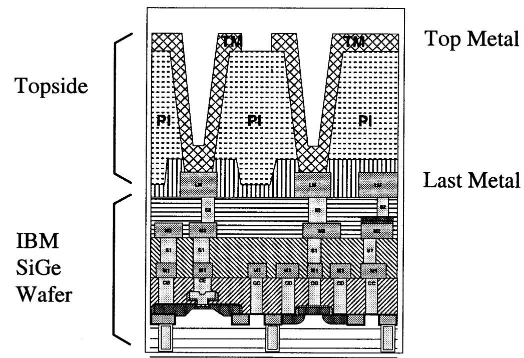

Fig. 1. Cross-sectional view of IBM's SiGe bipolar process with topside.

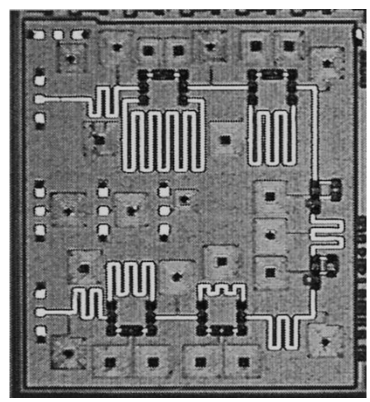

Fig. 2. PIN diode 6-bit phase shifter in SiGe. Chip dimension is 3800 μm × 3800 μm.

PIN diodes (7 × 7μm) designed for low "on" resistance and low "off" capacitance [5] were used for switching in the design. Diode biasing is provided through spiral inductors in combination with MIM bypass capacitors. The 180°, 90°, 45°, and 22.5° phase bits require two complementary bias inputs of ±1 V The 11.25° and 5.625° phase bits use the same voltages but requires a single bias input. A negative voltage (−3 V is required on the silicon substrate to prevent biasing of parasitic substrate diodes associated with the PIN diodes.

Manuscript received March 5, 2002; revised May 30, 2002. The review of this letter was arranged by Associate Editor Dr. Arvind Sharma.

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Digital Object Identifier 10.1109/LMWC.2002.805534

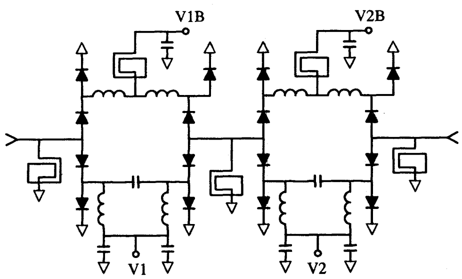

Fig. 3. The 180 and 90 and 45 and 22.5 phase 2-bit schematic.

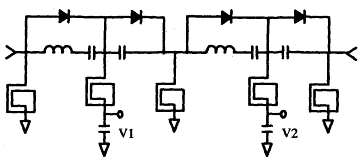

Fig. 4. The 11.25 and 5.625 phase bit schematic.

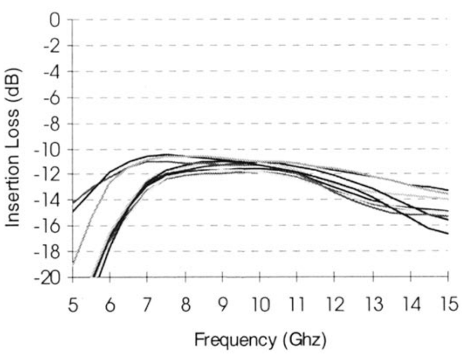

Fig. 5. Measured phase shifter insertion loss.

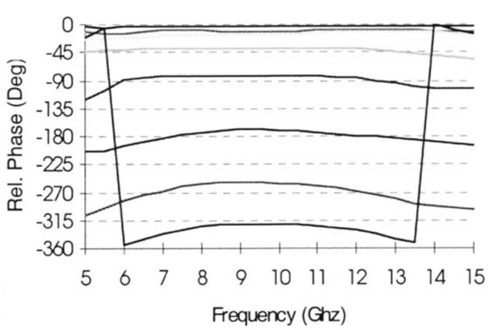

Fig. 6. Measured phase shifter phase performance (5.625°, 11.25°, 22.5°, 45°, 90°, 180°, 270°, 355°).

III. Measurements

The 6-bit phase shifter was tested on a Cascade Microtech Summit probe station. The supporting test station was capable of controlling the network analyzer (Hewlett Packard 8510) and recording the S-parameters for all phase states. DC probes were used to provide the necessary PIN diode biasing and the substrate voltages. Programmable current sources were used to bias each on-state diode at 2.5 mA. Total current for the phase shifter was 45 mA. Figs. 5–8 summarize the measured performance of the primary phase states over 5 to 15 GHz, where 7 to 11 GHz is the design band. In the reference state, all phase bits were switched to their highpass state. At 9 GHz, the measured output 1-dB gain compression is 3 dBm with a TOI of 17 dBm. Post measurement simulations indicate performance can be improved with additional device and Topside to silicon interconnect modeling.

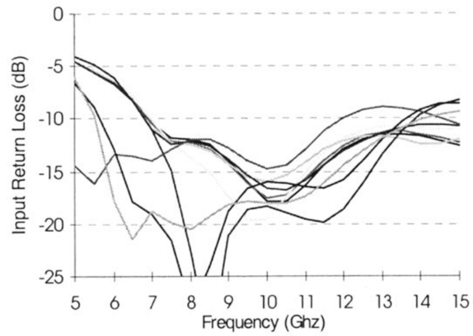

Fig. 7. Measured phase shifter input return loss.

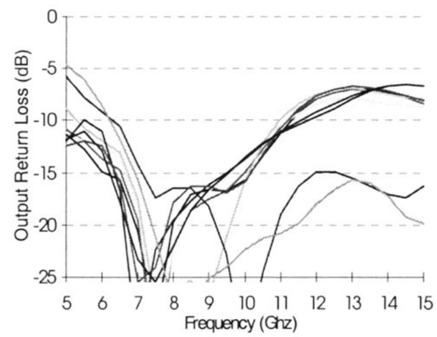

Fig. 8. Measured phase shifter output return loss.

IV. Conclusion

The phase shifter described is a first iteration design in IBM's SiGe Bipolar technology. The design successfully demonstrates the feasibility of using SiGe technology for microwave control circuit designs. Microwave switching, attenuation, and phase shifting can be accomplished using an available PIN diode device. With a menu that includes a high performance HBT device, IBM's SiGe Bipolar technology provides an environment for the development of highly integrated multifunction MMIC designs. Future designs will take advantage of IBM's development of a SiGe BiCMOS technology [6]. This process with Topside offers the potential of integrating RF/microwave signal processing with low power digital control logic and analog diode drivers onto a single chip.

References

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