A SiGe MMIC Variable Gain Cascode Amplifier

Qasim Chaudhry, Raul Alidio, Glenn Sakamoto, and Terry Cisco

***Abstract*—A silicon germanium variable gain cascode amplifier has been developed to combine the functionality of an amplifier and an attenuator into one monolithic microwave integrated circuit (MMIC). The cascode amplifier, which was designed for a 7–11-GHz frequency range, achieved a gain of 12.5 dB, an input return loss of 7.5 dB, and an output return loss of 12.5 dB. The cascode amplifier exhibited 16 dB of gain control.**

***Index Terms*—Amplifier, cascode, HBT, MMIC, SiGe, Variable Gain.**

I. Introduction

INTEGRATION of key components is essential to reducing the size and cost of airborne radar systems. In conventional radar systems, signal amplification and attenuation are accomplished by two separate circuits. Using IBM's 5HP silicon germanium (SiGe) technology [1], [2], a variable gain HBT cascode amplifier was designed to accomplish both functions on one single monolithic microwave integrated circuit (MMIC). The 5HP process offers an f_T of 47 GHz and $f_{\max}$ of 70 GHz.

The fabricated X-band SiGe cascode amplifier has shown promising measured results. The measured amplifier performance showed a forward gain of 12.5 dB, an input return loss of 7.5 dB, and an output return loss of 12.5 dB, and a variable gain response of 16 dB in 1-dB steps. The amplifier's gain flatness and input/ouput return loss response were maintained with attenuation. In addition, the cascode amplifier exhibited an output TOI of 21 dBm and an output $P_{1\,\mathrm{dB}}$ of 13 dBm at 8 GHz.

II. Device Characterization and Modeling

The cascode amplifier is composed of two $0.5 \times 20 \times 10\ \mu\mathrm{m}^2$ graded epitaxial base SiGe HBT n-p-n transistors. The common-emitter, common-base configuration was modeled with two n-p-n transistors. The common-emitter, common-base configuration was characterized as a single three-terminal device at $Vc = 4v$ and $Ic = 100$ mA. The $G_{\max}$ of the device is 29–25 dB in the 7–11 GHz frequency range. Gain control is achieved by adjusting the base bias of the common-base section. For the amplifier to exhibit good VSWR, it is important for the match of the composite device to remain invariant to the changes in base bias required to set the attenuation. The plot in Fig. 1 shows the desired minimal change in S11* and S22* of the common-emitter, common-base three-terminal configuration over the required bias conditions.

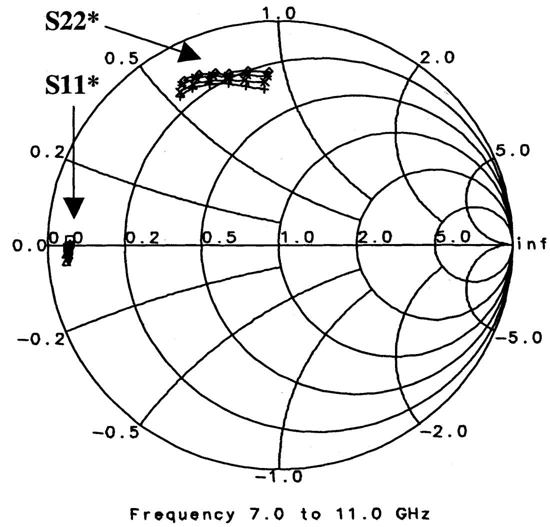

Fig. 1. S11* and S22* of common-emitter, common-base configuration at $Vc = 4.0v$, $Vb1 = 0.93v$, $Vb2 = 2.0{\sim}3.0v$.

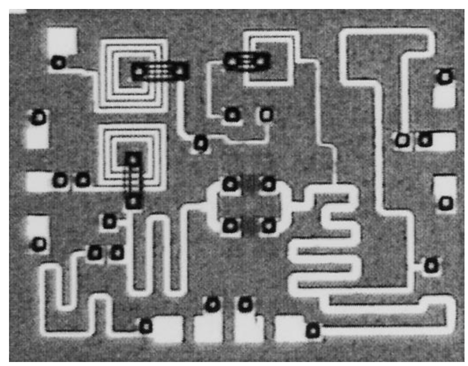

Fig. 2. Photograph of cascode amplifier.

III. Amplifier Design and Fabrication

A photograph of the X-band variable gain amplifier is shown in Fig. 2. The chip dimension is $1200 \times 1600\ \mu$m. The amplifier was fabricated using IBM's SiGe technology with Topside processing [3]. The Topside processing which consisted of 15 μm of polyimide and a top metal layer of AlCu was necessary to provide a microstrip interface for realizing amplifier matching networks. The schematic of Fig. 3 shows the common-emitter, common-base cascode configuration of the variable gain amplifier. The benefits of using a cascode device include the inherent reduction of the Miller capacitance multiplication effect [4], [5], which enhances the high frequency response of the amplifier, and provides a compact two-stage structure.

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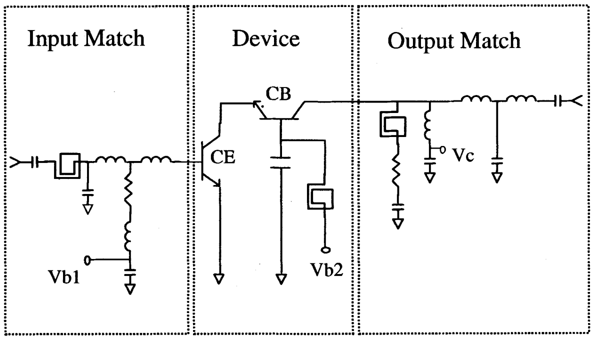

Fig. 3. Schematic of cascode amplifier.

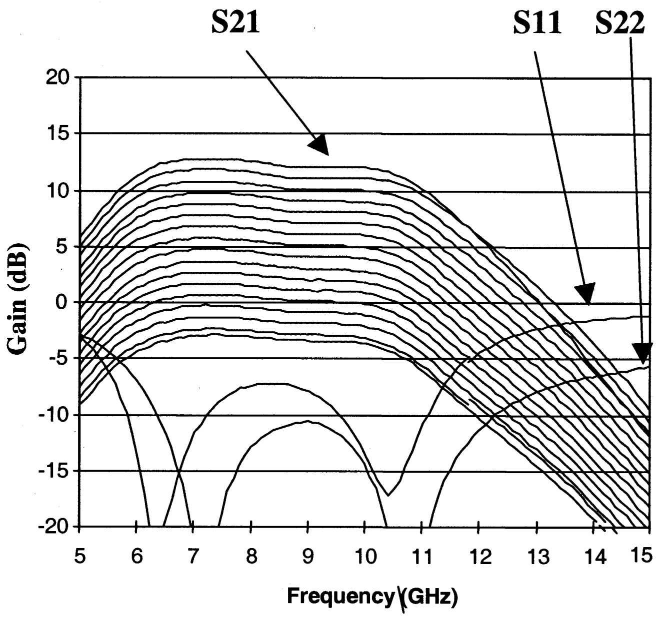

Fig. 4. Variable-gain, input and output return loss of cascode amplifier.

Lossy matching techniques were used in designing the cascode amplifier. This approach offers the benefits of low VSWR, flat gain, and compact size. The lossy match networks also help stabilize the cascode device. Polysilicon resistors and MIM capacitor available in the SiGe process are used in the matching networks. The shunt spiral inductors function both as matching and bias networks.

IV. Measurements

The RF performance of the variable gain amplifier was evaluated by using on-wafer probe testing. An HP8510 network analyzer and a spectrum analyzer were used to characterize the small signal and TOI performance of the amplifier. The variable gain control performance of the amplifier was achieved by current limiting the common-base heterojunction bipolar transistor (HBT) in the cascode device.

In the 7–11-GHz band, the amplifier exhibited a maximum forward gain of 12.5 dB and 16 dB of gain control in steps of

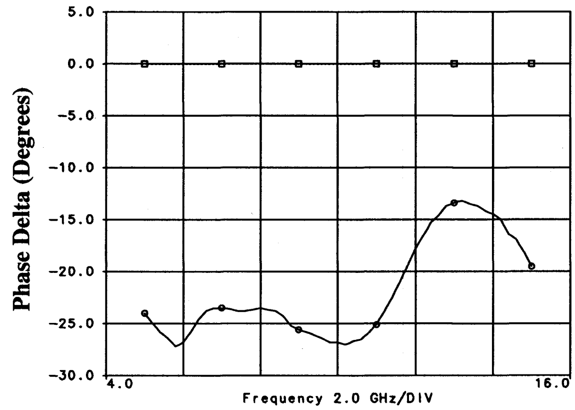

Fig. 5. Insertion phase delta between maximum and minimum gain states.

1 dB. The gain control was achieved manually in an open loop configuration. The measured input return loss of the amplifier was 7.5 dB and the measured output return loss was 12.5 dB. The amplifier also achieved an output TOI of 21 dBm and a output $P_{1\,\mathrm{dB}}$ of 13 dBm at 8 GHz. The measurements are in agreement with the simulated amplifier performance. The slight loss in gain and VSWR can be attributed to the modeling of the SiGe HBT n-p-n transistor's. As the HBT models get more mature, simulation versus measurement degree of confidence should increase. Variable gain performance and input/output return loss of the amplifier are plotted in Fig. 4.

The forward insertion phase difference between maximum gain state and minimum gain state was measured to be $-25°$. The phase delta between the maximum gain state and minimum gain state are plotted in Fig. 5.

V. Conclusion

An X-band variable gain cascode amplifier has been designed on IBM's SiGe technology with Topside processing. The amplifier has shown promising results as a variable gain amplifier. A maximum gain of 12.5 dB and a minimum gain of -3.5 dB has been achieved over 7–11 GHz. The input and output return loss of the amplifier is 7.5 and 12.5 dB, respectively, over all the variable gain states.

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