An Analog MMIC Phase Modulator for X-Band Satellite Transponder Applications

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Abstract—**The design and measured performance of a novel GaAs MMIC analog linear phase modulator for the next generation space-borne communications systems are presented. The analog phase shifter is based on the reflection-type hybrid coupled approach and uses a novel lumped quadrature hybrid and MESFET varactors as a building block. Three cascaded sections (with tapered varactor sizes) of this building block along with two high-isolation amplifiers have been realized in a single chip (96 mils × 36 mils). This MMIC provides an X-band (8415 ± 50 MHz) phase modulation with ± 2.6 radians (300°) of peak phase deviation, ± 2% of phase deviation linearity, 1.5-dB insertion loss and better than 12 dB input and output return loss performance.**

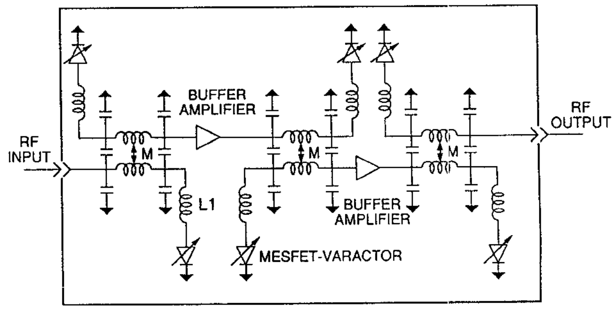

Fig. 1. Block diagram of the three section linear phase modulator with two high-isolation amplifiers.

I. Introduction

THE NEXT generation of space-borne communication systems require reliable and small size phase modulators capable of continuous, linear phase modulation with low-loss and well-controlled phase performance[1]. Published results on hybrid coupled reflection-type [2] X-band and 6–18 GHz GaAs MMIC analog phase shifter designs [3], [4] have used traditional Lange couplers. The X-band MMIC achieved 105° phase shift from a single chip measuring 100 mils × 77 mils. And the single section 6–18 GHz phase shifter (148 mils × 68 mils) achieved 120° phase shift.

In this letter, we describe a very compact, single-chip (96 mils × 36 mils), three-section, X-band linear phase modulator MMIC (design goals: ± 2.5 radians = 286.5° phase shift, less than 5-dB insertion loss at 8415 ± 50 MHz frequency) consisting of lumped-element couplers, tapered MESFET varactors and series inductors along with two high-isolation amplifiers in between sections.

II. GaAs MMIC Linear Phase Modulator

Fig. 1 shows the block diagram of the three-stage linear phase modulator with two high-isolation amplifiers. The basic building block of a single-section continuously variable reflection phase shifter consists of a pair of MESFET varactors coupled to a lumped element quadrature coupler[5] with a series inductor. The X-band lumped coupler is made up of a multi-turn bifilar spiral inductor and MIM capacitors and is a modification of the two-stage 2–6-GHz lumped coupler [5], [6]. The model of the 0.5 × 600-μm MESFET varactors (shorted drain and source to form the cathode) used in the CAD simulations is based on the measured C-V characteristics over 0.1 to 10 GHz. The measured C-V behavior exhibited greater than 2:1 capacitance change over the bias range of −2 V to −6 V. Buffer amplifiers are used to provide greater than 38 dB of isolation (to minimize VSWR errors and maximize phase shift) and ~2.7 dB of gain between sections. The buffer amplifiers use a single-stage 0.5 × 200-μm MESFET's in a cascode configuration and draw a total of 20 mA from a 6 V supply. For each section, the MESFET varactor, series inductor L1 and lumped quadrature hybrid were optimized by tapering the values to achieve the overall desired phase shift (± 2.5 radians) and insertion loss variation.

Fig. 2 shows the MMIC layout of the X-band analog phase modulator measuring only 96 mils × 36 mils. Bondwires were used to ground this 7-mil thick chip. This compact layout using lumped elements is about one-quarter the size of the conventional distributed element design approach.

III. Measured Results

The measured phase shift performance for the X-band linear phase modulator is shown in Fig. 3. The $S21$ phase measured at 2-V reverse bias was used as the reference. By changing the reverse bias from 2 V to 6 V, a continuous, linear phase shift of ± 2.6 radians (300 degrees) was obtained between 8.2 to 8.7 GHz. The phase shift as a function of the varactor bias voltage is shown in Fig. 4 for 8.4 and 8.5 GHz frequencies. The phase shift linearity is better than ± 2% over the frequency band of interest for deep space transponder (DST) applications. For the reverse bias condition, the measured insertion loss of the phase modulator on a carrier (with fixture loss) over the full

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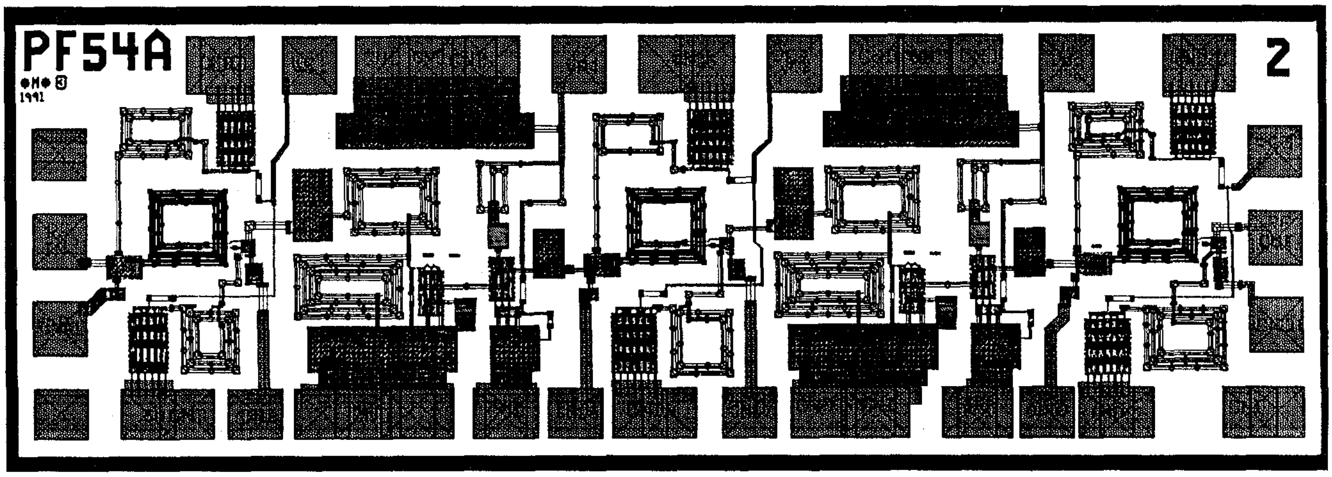

Fig. 2. Layout of the X-Band MMIC analog (300°) phase modulator (Chip size: 96 mils × 36 mils; bond pads: 4 mils × 4 mils).

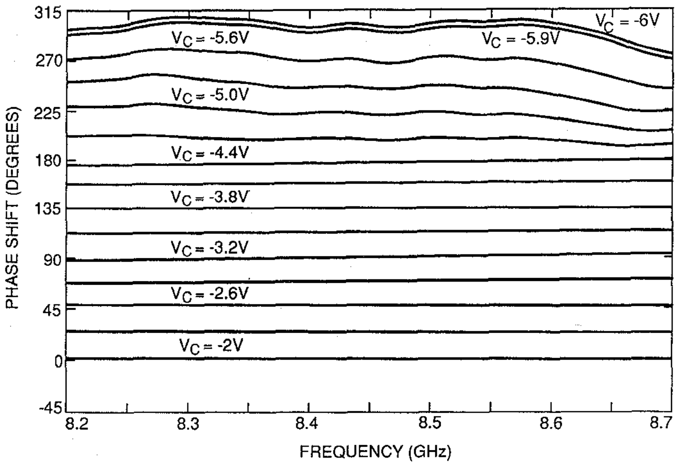

Fig. 3. Measured phase shift as a function of frequency at different bias levels of the varactors (V_C is the varactor bias control voltage).

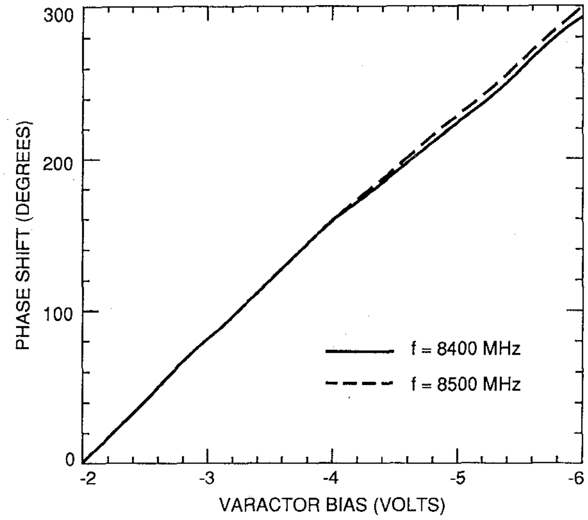

Fig. 4. Measured phase shift as a function of the varactor bias voltage at 8.4 GHz and 8.5 GHz.

range of phase shift and frequency was 1.5 ± 1.2 dB. The insertion loss variation with the control voltage needs to be reduced to ± 0.5 dB to satisfy the system requirements. It has been found from the reverse simulations of the measured data of the different building blocks of the linear phase modulator that the lumped coupler is tuned more close to 9.4 GHz (less than ± 0.25-dB amplitude deviation), when all the RF and ground bondwires are taken into account. A second fabrication iteration incorporating the necessary design modification is underway. This lumped element design technique can be used for a broader bandwidth application using a two-stage lumped coupler design [5], [6].

IV. Conclusion

The design and performance of a very compact (96 mils × 36 mils) single-chip X-band GaAs MMIC three section linear phase (300°) modulator for DST applications are presented. Commercial microwave circuits which require continuous phase control in trimming multiple channels (high data-rate communication systems, telecommunications and telemetry) will also benefit from this MMIC.

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