Ultra Compact, Low Loss, Varactor Tuned Phase Shifter MMIC at C-Band

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***Abstract*—This paper presents a high yield, ultra compact, low loss phase shifter MMIC, realized with a commercial 0.6 μm GaAs MESFET process. Phase shift is enabled by varying the varactor capacitances of the lumped element equivalent of a transmission line. Continuously adjustable phase control over 90° is achieved from 4 GHz up to 6 GHz, with a loss of less than 2.2 dB. At 5.2 GHz, a loss of 1.2 dB and a loss variation of ± 0.5 dB is measured. Phase and loss variations for several circuits from different wafers are within $\pm 1°$ and ± 0.1 dB, respectively, indicating low dependences on process variations. The phase shifter requires a circuit size of only 0.2 mm^2, which to our knowledge is the smallest size for a continuously adjustable passive phase shifter with comparable performance, reported to date.**

***Index Terms*—MESFET, microwave monolithic integrated circuit, phase shifter, varactor.**

I. Introduction

PHASE shifters are important components for many applications, such as radar, smart antennas and measurement systems. A variety of different passive and active phase shift topologies have been reported in literature. However, most of the reported phase shifters require large circuit areas [1], have relative high losses [2], consume high dc-power [3] or have large amplitude and phase variations within process tolerances, thus requiring a calibration or a costly selection [4].

In this work, phase shift is enabled by varying the transmission phase of a varactor tuned transmission line. Low losses can be achieved with this topology, while consuming negligible dc-power. In comparison to former works [5], [6] using coplanar waveguide lines we apply lumped elements for the transmission line, thereby significantly decreasing the required circuit size. Because of its simple design and its broadband frequency characteristics, a high yield is reached, making the circuit very well suited for commercial low-cost fabrication.

II. Circuit Design

A lowpass filter in π-configuration can be used to replace a transmission line with quarter wavelengths (90°) at frequency f and characteristic impedance Z_o by using inductors and capacitances with values as follows:

$$L = \frac{Z_o}{2\pi f} \tag{1}$$

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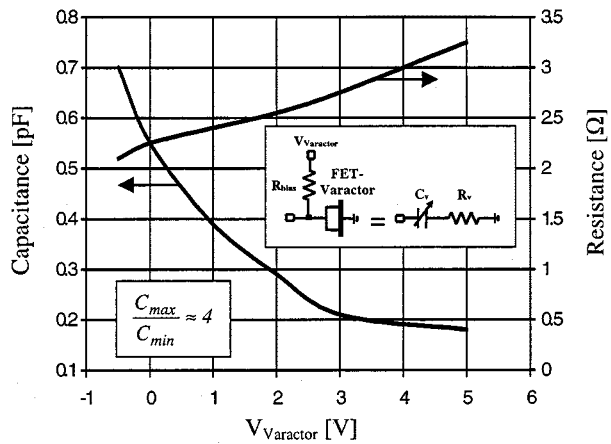

Fig. 1. Measured capacitance C_v and parasitic series resistance R_v of a MESFET varactor versus control voltage at $f = 5.2$ GHz. Gate widths $= 300$ μm, gate lengths = gate-drain lengths = gate-source lengths $= 0.6$ μm. Drain and source are connected together.

and

$$C = \frac{1}{2\pi f Z_o}. \tag{2}$$

In this work, $Z_o = 50\ \Omega$. The transmission phase of this filter can be controlled by varying the capacitance C [(2)], using varactor diodes with a capacitance C_v in the range from $C_{\min}$ up to $C_{\max}$.

The Triquint TQTRx GaAs foundry process was used for the fabrication of the phase shifter MMIC. This process features MESFET's with gate lengths of 0.6 μm and inductances with quality factors of approximately 20 at 5 GHz. Depletion MESFET's with drain and source connected together are used as varactors and are biased by a resistor. Fig. 1 shows the capacitance variation versus varactor control voltage for these varactor diodes. Diode widths of 300 μm have been chosen to obtain an average varactor capacitance of

$$C_{v,\,av} = \frac{C_{\max} + C_{\min}}{2} \approx C. \tag{3}$$

At 5.2 GHz, a phase control range of approximately 32° has been simulated for a circuit with one lowpass filter stage. Simulations were performed in HP CDS, using measured S-parameters of the varactors and the inductors.

The phase control range can be increased by cascading several of these lowpass structures. A design goal for this work was to obtain a phase control range of 90°, requiring three cascaded stages. In Fig. 2, the circuit schematics of this structure is shown.

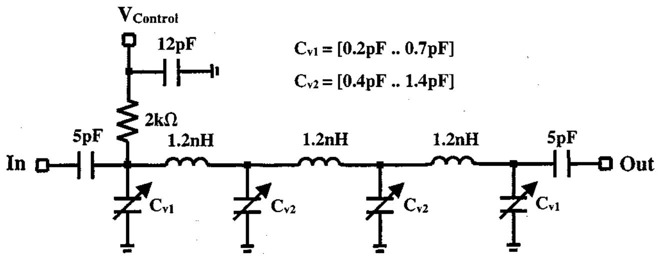

Fig. 2. Circuit schematics of the distributed phase shifter. The phase can be controlled by adjusting the capacitance values of the varactors.

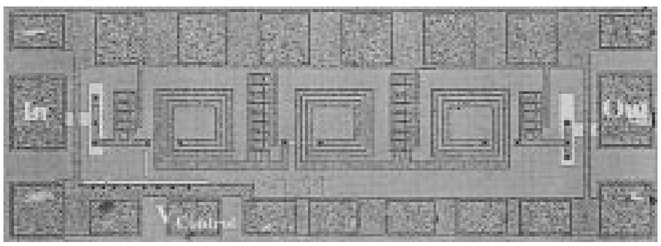

Fig. 3. Photograph of the phase shifter MMIC. Total chip size is 0.4 mm × 1.15 mm. Effective circuit size is approximately 0.2 mm^2.

TABLE I
SUMMARY OF THE MEASURED PERFORMANCES AT 4 GHz, 5.2 GHz, AND 6 GHz, RESPECTIVELY

	4GHz	5.2GHz	6GHz
Phase control range	90°	95°	105°
Transmission loss	1.1dB	1.2dB	1.5dB
Transmission loss variation	±0.4dB	±0.5dB	±0.7dB
Return loss	>13dB	>15dB	>15dB

A photograph of the MMIC chip is shown in Fig. 3. The total size of the chip is 0.45 mm $\times$ 1.15 mm and the effective circuit area is only 0.2 mm^2.

It is noted that the phase control range can be increased by increasing the number of stages. A phase control range of over 360° was simulated using a distributed structure with 12 stages.

III. MEASUREMENTS

The circuit has been measured on-wafer, using a HP 8510B network analyzer. The transmission phase, transmission loss and the return loss versus control voltage were measured for four circuits from two different wafers. As shown in Figs. 4 and 5, a phase control range of 95° was measured at 5.2 GHz, while having a transmission loss of 1.2 dB, a transmission loss variation of $\pm$0.5 dB and return losses of higher than 15 dB. The transmission loss and phase variations within the different circuits are smaller than $\pm$1° and $\pm$0.1 dB, respectively, indicating the low dependence of the circuit on process variations.

Within the whole phase control range, a 1 dB output compression point of higher than 8 dBm was measured at 5.2 GHz.

The circuit has excellent performances in the frequency range from 4 GHz up to 6 GHz. Table I summarizes the measured results at 4 GHz, 5.2 GHz, and 6 GHz, respectively.

IV. CONCLUSION

The design and the results of a varactor tuned transmission line phase shifter at C-band have been presented. By using lumped element equivalents for the transmission line, the

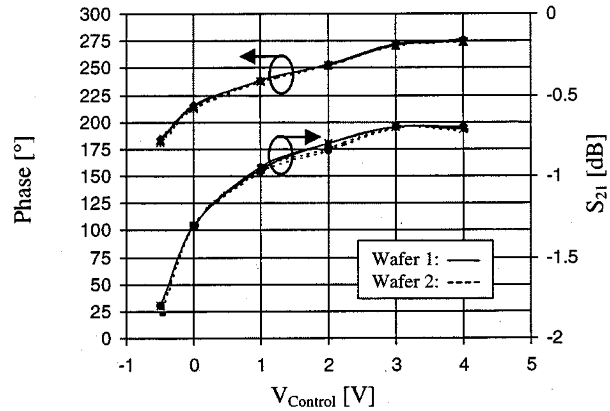

Fig. 4. Measured transmission loss and transmission phase versus control voltage of four circuits from two different wafers at 5.2 GHz.

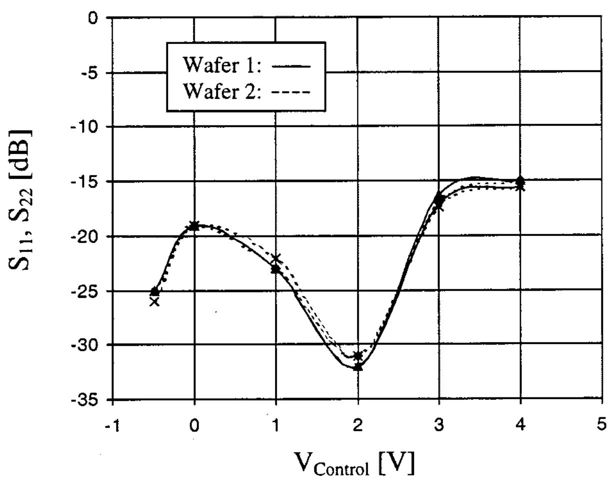

Fig. 5. Measured return losses ($S_{11} = S_{22}$, symmetry) versus control voltage of four circuits from two different wafers at 5.2 GHz.

circuit size has been significantly decreased in comparison to former approaches. The MMIC has a low transmission loss, excellent large signal performance and allows a continuously adjustable phase control of over 90°. Because of its passive nature and its simple design, the effects of process variations are small, enabling low-cost mass-fabrication.

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