A 3 Bit K/Ka Band MMIC Phase Shifter

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A K/Ka band 3 bit GaAs MMIC phase shifter has been demonstrated. It uses passive MESFET switching elements and is bi-directional. The phase shifter uses high-pass/low-pass filter circuits in which MESFET off-state capacitances are incorporated as filter elements. This technique allows high performance, broadband phase shifter response to be achieved. The K/Ka band phase shifter uses MESFETs with the same characteristics as those used in amplifiers operating in the same band, for ease of future integration. The phase shifter operates from 18 to 40 GHz.

Introduction

A broadband phase shifter can be realized by switching between a low-pass filter and a high-pass filter [1]. For GaAs MMIC implementations, FETs are the most readily available switching elements. The source and drain are used as rf terminals, and the gate is used as the bias (switch control) terminal. The FET can be adequately modelled as a resistance in the "on" state (when the gate voltage is zero), and as a series connected capacitor and resistor in the "off" state (when gate voltage is between pinch-off and breakdown) [2].

A conventional high-pass/low-pass phase shifter is made by switching between separate high-pass and low-pass filters. The switching elements are located external to the filters. In MMIC implementations, passive FETs are typically used as switching elements. In such a design the off-state capacitance of the FETs tends to degrade the performance and limit the bandwidth of the phase shifter.

A high-pass/low-pass filter phase shifter can also be made with a single circuit containing a number of internal switching elements. Depending on the states of the various switching elements, the circuit behaves as either a high-pass or a low-pass filter. By selection of appropriate circuit topologies, it is possible to incorporate switching FET off-state capacitances as filter elements [3]. Since these capacitances are no longer undesired parasitics, high performance, broadband phase shifter response is more easily achieved.

The K/Ka band phase shifter described in this paper is comprised of three bits - 45°, 90°, and 180°. The topology used in the 45° and 90° bits is shown in Figure 1 [4]. This circuit uses five FETs. When FETs F1, F2, and F4 are "on" and F3 and F5 are "off", a 3 element "T" low-pass filter is realized. When the biases are reversed, a 3 element "T" high-pass filter is realized. Most of the "off" state FET capacitances are incorporated as filter elements. By properly selecting the

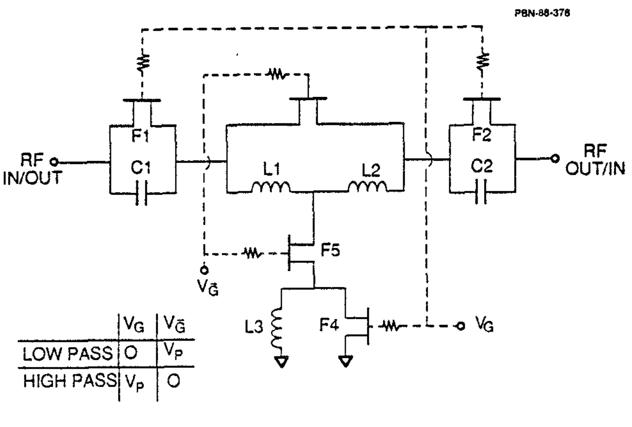

Figure 1. Schematic Diagram for the 45° and 90° Bits.

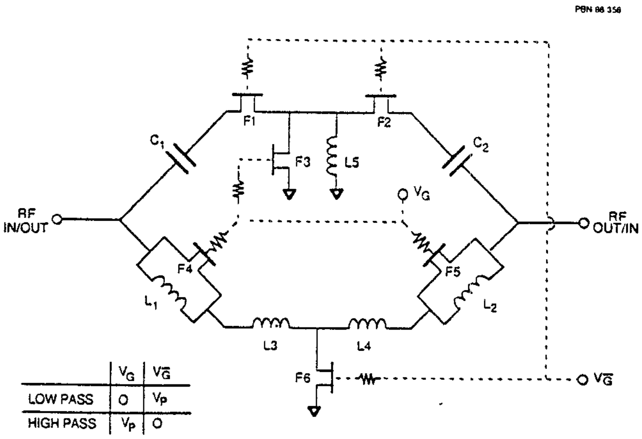

Figure 2. Schematic for the 180° Bit.

effective capacitance and inductance values in the filters, various phase shifts may be realized [1]. The circuit in Figure 1 does not provide optimal performance as a 180° phase shifter; element values are difficult to realize, and phase variation over the frequency band is excessive.

The 180° bit uses the bridge topology shown in Figure 2 [3]. When FETs F1, F2, and F6 are "on" and FETs are F3, F4, and F5 are "off", a 5 element "pi" high-pass filter is realized. When the biases are reversed, a 5 element "pi" low-pass filter is realized. In this circuit FET "off" capacitances are also incorporated as filter elements. The circuit in Figure 2 does not provide optimal performance for 45° and 90° phase shifters because many of the element values would be difficult to realize.

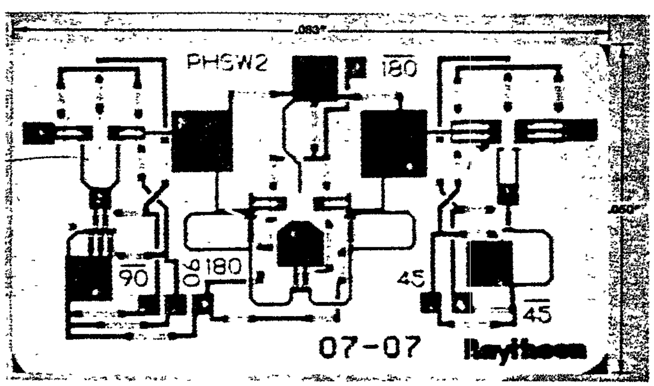

Figure 3. Photograph of the 3-Bit K/Ka Band Phase Shifter.

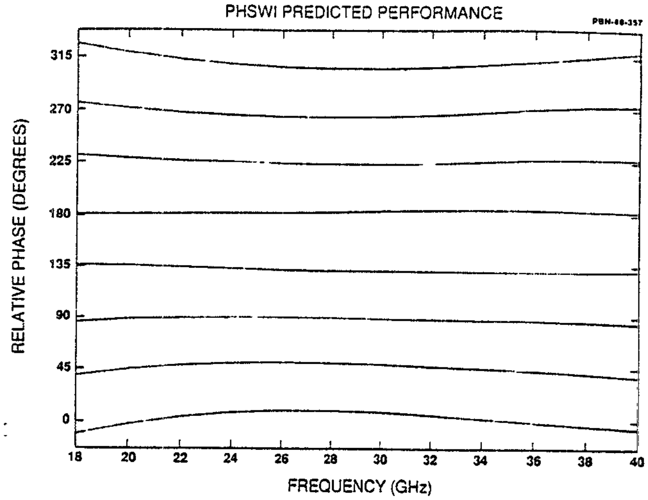

Figure 4. Predicted Phase Performance of the 3-Bit Phase Shifter.

Circuit Performance

The complete 3-bit K/Ka band phase shifter MMIC chip is shown in Figure 3. The 90° bit is on the left side, the 45° bit is on the right side, and the 180° bit is in the center. Appropriate matching networks are used between bits. All the biases are connected to FET gates through 1 and 2 kohm FET resistors. This prevents the bias lines from affecting the RF performance of the circuit by presenting an RF open to the gates. High impedance transmission lines are used as inductors. The chip measures 50 x 83 mils (1.3 x 2.1 mm).

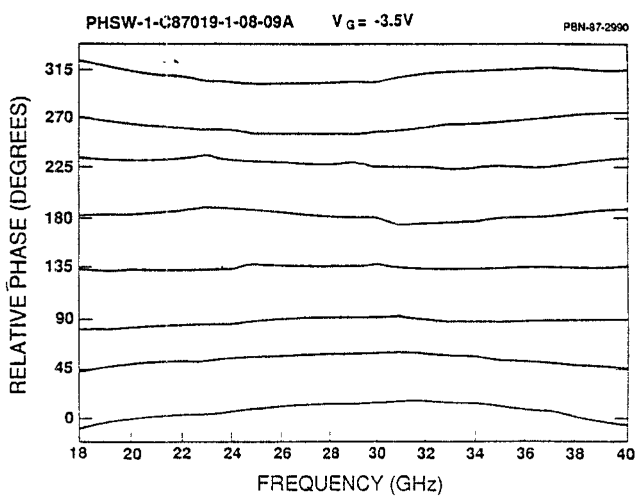

Figure 5. Measured Phase Performance of the 3-Bit Phase Shifter.

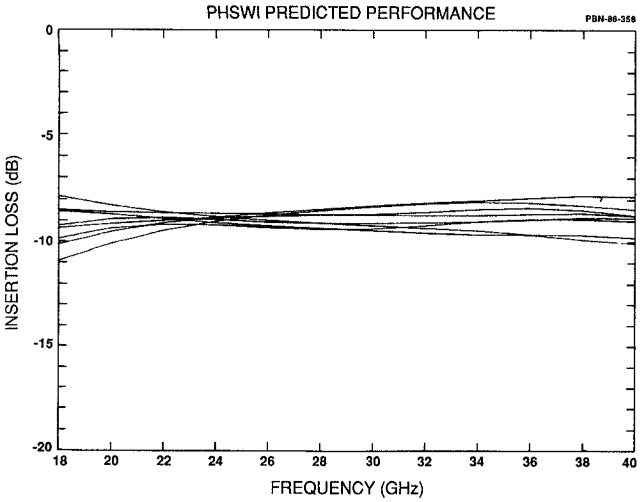

Figure 6. Predicted Insertion loss f the 3-Bit Phase Shifter.

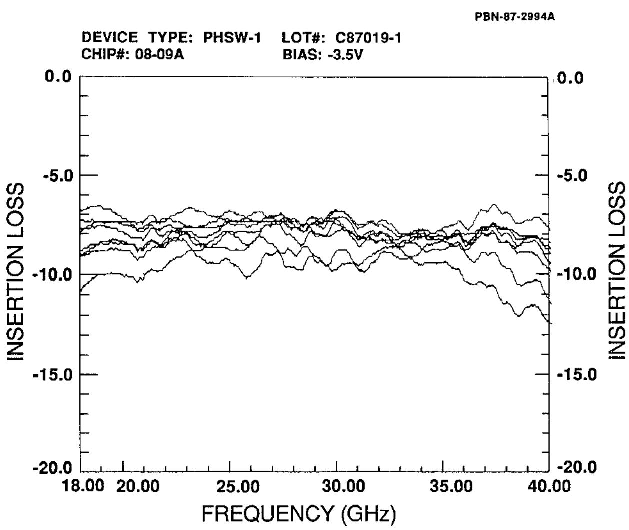

Figure 7. Measured Insertion Loss of the 3-Bit Phase Shifter.

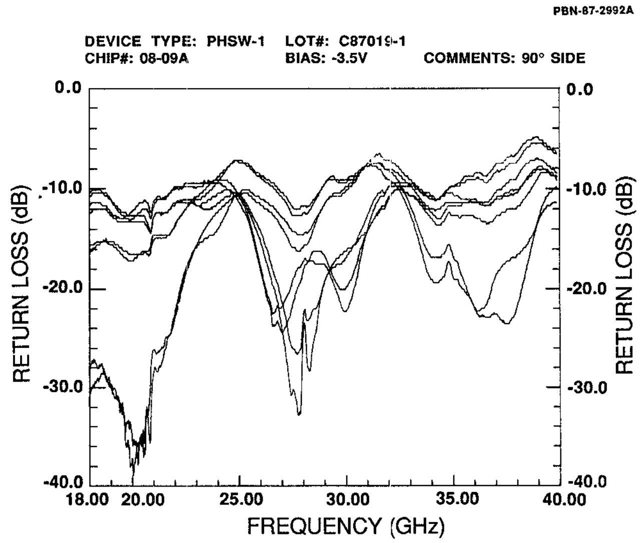

Figure 8a. Measured Return Loss of the 3-Bit Phase Shifter.

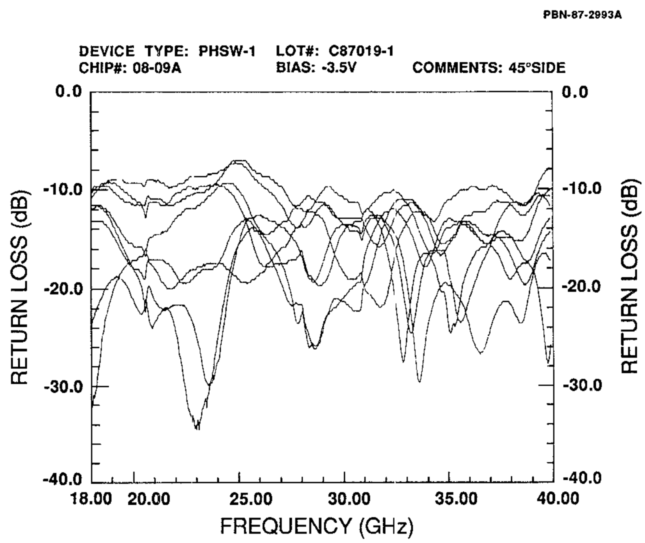

Figure 8b. Measured Return Loss of the 3-Bit Phase Shifter.

The FET active layer has a carrier concentration of 4.5 x 10^{17} cm^{-3}, with a contact layer concentration of 3.5 x 10^{18} cm^{-3}. Vapor phase epitaxy (VPE) was used. This doping was chosen to match mm-wave amplifiers. Integration of K/Ka band amplifiers and phase shifters is planned. The FETs have 0.5 micron gates for high yield.

The predicted and measured phase shifts of the circuit are shown in Figures 4 and 5 respectively. The accuracy of the phase shift over the 18-40 GHz band is very good, and phase error is well balanced over the band. The predicted and measured insertion losses are plotted in Figure 6 and 7 respectively. From 20 to 35 GHz the insertion loss is between 7 dB and 11 dB, with a maximum loss variation of 3 dB. Maximum loss from 15 to 40 GHz is 12 dB. Measured return losses are plotted in Figure 8. Return loss is generally better than 10 dB with occasional peaks at some frequencies in some states. The worst return loss is 5 dB at 39 GHz on the 90^{o} side.

RMS averaged phase and amplitude error have been calculated for the measured phase shifter performance and are plotted in Figure 9. Maximum RMS phase error is 9.8 degrees at 28 GHz. The RMS phase error averaged over the 18-40 GHz band is 7.2 degrees. The RMS amplitude error has a maxima of 1.1 dB at 18 GHz and 1.2 dB at 40 GHz. The RMS amplitude error averaged over the 18-40 GHz band is 0.97 dB. Error power over the band is 0.0296 and is comprised 47% of amplitude error and 53% of phase error.

Summary

A 3-bit MMIC K/Ka band broadband phase shifter was successfully demonstrated. Adequate and well balanced phase error and amplitude errors have been demonstrated over the 18-40 GHz band. Average insertion loss is 9 to 10 dB. The phase shifter uses FETs similar to those used in amplifiers operating in the same frequency band. This will allow the circuits to be easily integrated.

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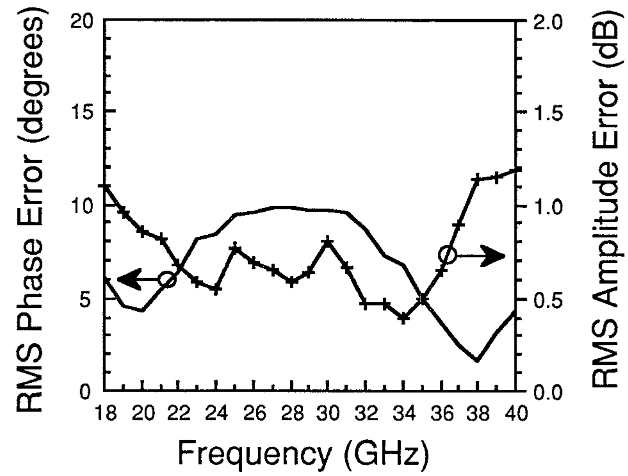

Figure 9. Measured RMS Average Phase and Amplitude Error for the 3-Bit Phase Shifter.

References

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