A NOVEL PHASE SHIFTER USING A GaAs MESFET IN PASSIVE CONFIGURATION

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ABSTRACT

A new kind of voltage controllable phase shifter has been developed. The technique used to develop this phase shifter employs GaAs MESFETs as passive elements, similar to those used for monolithic microwave integrated circuit (MMIC) switches and attenuators. The result is a phase shifter that is smaller and that requires fewer components. A demonstration, single MESFET phase shifter was produced for the 3.7 to 4.2 -GHz satellite band. This phase shifter provided near flat, voltage linear phase shifts up to 45 degrees across the design band with a maximum insertion loss of 6 dB.

INTRODUCTION

The increasing use of phased arrays for radar and communications applications has created a need for electronically controllable microwave phase shifters that are inexpensive and simple to produce. This paper discusses new methods for producing phase shifters utilizing GaAs MESFETs connected as a passive element. The technique is a by-product of work on linearizers in which passive FET elements are used as controllable nonlinearity generators (Katz 1989). Similar elements are used in MMIC switches and attenuators. Thus, the approach appears well suited for implementation in MMICs.

Using this technique, miniature phase shifters can be produced that require fewer components, yet provide wide bandwidth and display linear phase characteristics that are directly proportional to the control voltage. A single FET can typically provide 40 to 60 degrees of linear phase shift over a 1- to 2-GHz band. Several stages can be cascaded for additional phase shift.

Although the technique appears applicable at frequencies from VHF to above Ku-band, this paper first discusses general circuit considerations, and then focuses on the design of a single-stage, phase shifter for the 3.7- to 4.2-GHz satellite band. Both the results of the computer simulation and the measured performance of this phase shifter are presented.

PASSIVE FET PHASE SHIFTER CIRCUIT

When FETs are operated as passive control elements, they are normally connected in a common gate configuration, as shown in Figure 1. Bias is applied at the gate only, and the drain and the source are operated at DC ground potential. The Rf signal input and output connections are through the source and the drain. The direction of the signal flow is not important because of the circuit's passive nature.

$$S21 = S12 \quad (1)$$

GaAs FETs, when used as passive control devices, have been considered virtual voltage con-

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trolled resistors, whose value are determined by the DC bias voltage applied to the gate of the device (Jain and Gutmann 1990). The operating point of the FET is determined by the gate parameters. As the negative voltage applied to the gate is increased, the source-to-drain channel is pinched-off. The gate voltage is used to control the drain-to-source impedance, and thus the bias voltage controls the operation of the device.

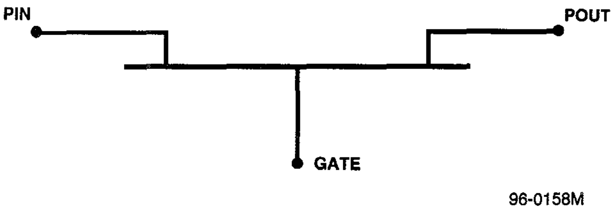

Fig. 1. Passive FET Control Elements (Normally Connected in a Common Gate Configuration).

Analysis of the S-parameters of passive FET elements reveals that these devices are more complex and contain components that are both voltage-dependent resistive and reactive. A simplified passive FET model based on the work of Chen and Kumar is shown in Figure 2 (Chen and Kumar 1989). When the AC gate terminal impedance is high (typically greater than 5 KOhms), the voltage dependent reactive elements have little effect on source/drain device impedance. This is the condition used for attenuator/switch applications. However, if a low AC impedance (Zg) is placed between the gate terminal and ground, the voltage-dependent reactive elements can dominate the device's transfer characteristics. Such a connection is shown in Figure 3. In this case both insertion loss (IL) and phase shift vary with gate voltage. By careful selection of gate impedance and gate bias range, a set of parameters can be found that minimize IL change and maximize phase shift.

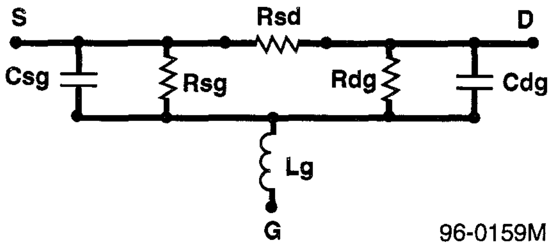

Fig. 2. Simplified Model of a Passive MESFET Element.

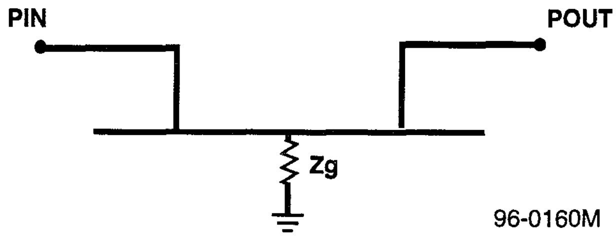

Fig. 3. A Low Gate Impedance (Zg).

C-BAND PHASE SHIFTER DESIGN

To demonstrate the value of passive FETs in phase shifter applications, a C-band phase shifter was designed. An NEC 710 GaAs MESFET was chosen for this purpose. (The actual choice of MESFET does not appear to be critical in this application.) The S-parameters of this device were measured at a variety of voltage levels, and this data was used to develop a model of the FET. Design goals were chosen to have maximum insertion loss (ILmax) -

$$\text{ILmax} < 6 \text{ dB} \qquad (2)$$

and maximum peak-to-peak change in insertion loss (ΔIL) dB across the desired range of phase shift -

$$\Delta\text{IL} < 1 \text{ dB} \qquad (3)$$

EEsof's Touchstone was then used to analyze the circuit and determine an optimum Zg to provide a maximum phase shift across the 3.7- to 4.2-GHz band for the above constraints. The required Zg was determined to be an inductor in series with a capacitor. The final circuit is shown in Figure 4. No significant advantage was found in altering the input or output match of the FET. The FET was thus connected directly to 50-ohm transmission lines. Blocking capacitors and chokes were used to provide DC isolation and ground returns on both the input and output sides of the FET.

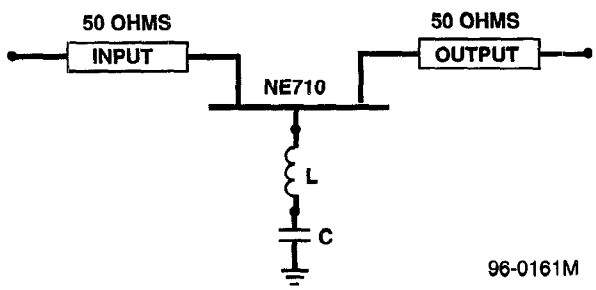

Fig. 4. C-Band Passive FET Phase Shifter Circuit.

The calculated phase and loss curves are shown in Figure 5. This figure shows that 45 degrees of phase shift should be achievable with the circuit. An initial unanticipated feature is the linear phase versus voltage transfer characteristic displayed by the phase shifter model.

TEST RESULTS

A test phase shifter was fabricated on an alumina substrate using bond wires for the gate inductor and the chokes. The IL and phase shift displayed by this circuit were measured with an HP 8510 network analyzer (see Figure 6). As predicted almost exactly by the model, a 43-degree phase shift was obtained with less than 1 dB of ΔIL at the center of the band. (The measured changes in phase and loss as a function of gate bias are shown in Figure 5 for comparison with the simulated values.) ΔIL was less than 1 dB over the entire 500-MHz frequency band of interest. The error in phase flatness was less than 5 degrees across this same band. The variation in phase with voltage was also approximately linear, as indicated by the computer model. The only discrepancy from the model was ILmax, which was projected to be under 5 dB and was measured as 5.8 dB at the band center and 6 dB at its highest point.

The power sensitivity of the phase shifter was also investigated. The input power was varied from less than -25 dBm to -10 dBm, with no change in the magnitude or phase response. At power levels greater than -5 dBm, the magnitude

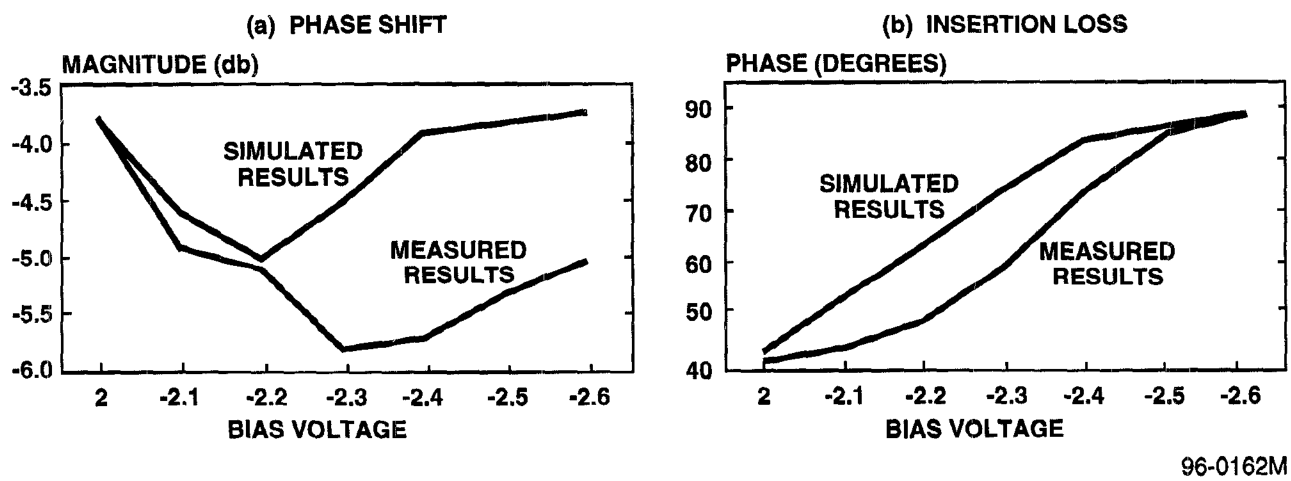

Fig. 5. Simulated and Measured Phase Shifter Response Versus Voltage.

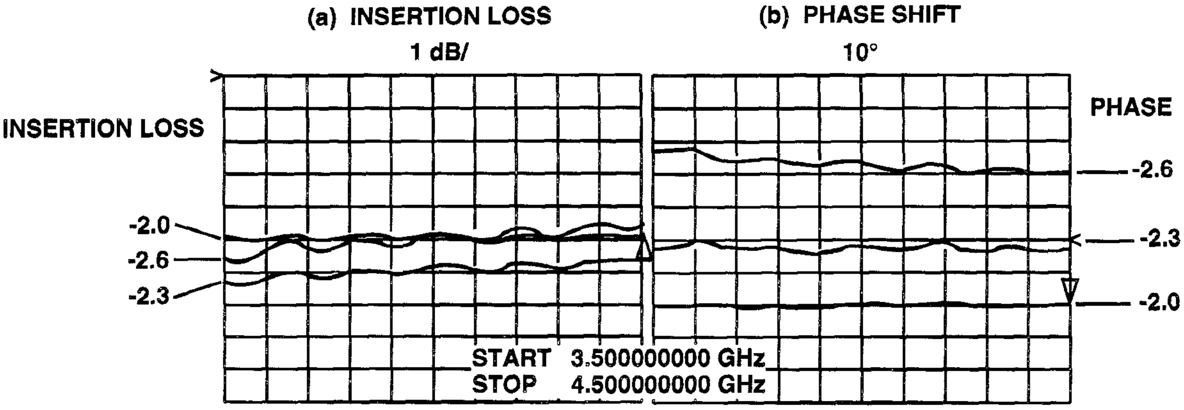

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Fig. 6. Measured Phase Shifter Response Over Frequency with Bias Voltage as a Parameter.

and phase response began to shift notably. This indicates that use of the phase shifter should be limited to applications at which power levels are below -5 dBm.

CONCLUSION

Passive FET elements can be used to produce electronically controllable phase shifters that are compact and easy to design, produce, and tune. Phase shift is controlled by the FET's gate bias voltage. These phase shifters are particularly attractive for applications that require less than 60 degrees of phase change and for which modest amount of loss variation (<1 dB) and low power levels are acceptable. Such circuits can be implemented with a single GaAs FET and a minimal number of additional components. More complex circuitry should achieve still greater phase shifts and reduced loss variation.

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