A MONOLITHIC REDUCED-SIZE Ku-BAND SPDT FET SWITCH

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ABSTRACT

A GaAs Ku-band monolithic single-pole double-throw (SPDT) FET switch has been designed and demonstrated. Small-signal insertion loss is less than 1.4 dB over a 14 GHz to 18 GHz bandwidth with a VSWR less than 1.5:1. The common terminal to off-channel isolation exceeds 18 dB. The switching is achieved with a -4.5 volt signal on the gate of the on-channel FET with the other gate at 0 volts. The switching current requirement is only the reverse bias gate leakage current (typically 3 uA). Large-signal performance is similar with a -10 volt control signal. The small chip size, 1.3 mm X 1.3 mm X 0.15 mm, permits more than 2300 monolithic switches to be fabricated on a single 3-inch GaAs wafer.

INTRODUCTION

The switching theory of the shunt quarter-wave SPDT switch has been well known for years. A typical circuit schematic is shown in Figure 1. The off-channel FET is nearly a short circuit which reflects back through the quarter-wave transmission line to present an open circuit at the TEE junction. The on-channel FET can be regarded as a capacitance which resonates with the shunt inductive resonator to form an open circuit to allow the signal to go through. The quarter-wave 50 ohm transmission line is physically large and restricts the bandwidth. The high-impedance shunt inductive resonator in parallel with each FET also consumes GaAs real estate. These factors contribute to creating a large MMIC. A novel patented approach to reduce the size of the SPDT switch is partially used in this switch design. 1

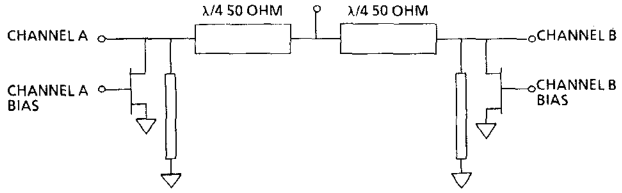

Figure 1. Shunt Quarter-Wave Switch Schematic

FET MODELING

For switching applications a single-gate power FET is used with no drain bias. With no bias voltage on the gate the drain-to-source channel is a very low impedance (5 ohm). With a negative bias voltage applied to the gate to pinch off the device the drain-to-source channel becomes a very high real impedance (5000 ohm) in parallel with the drain-to-source capacitance. To create FET models to aid in the switch design 900 uM gatewidth power FETs were RF characterized as 2-port devices with the unbiased drain being one port and the gate as the other port. The FET S- parameters with the gate voltage (Vg) at 0 volts and at -5 volts were used to create the on-state and off-state equivalent circuit models. The model used is shown in Figure 2.

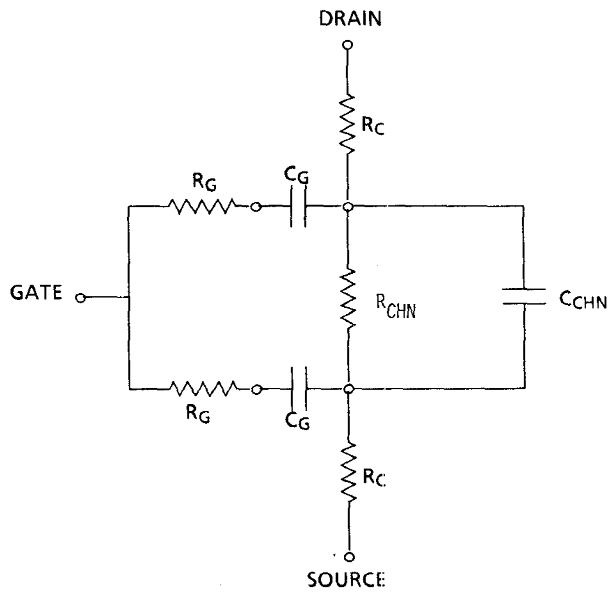

Figure 2. Switching FET Model

RC represents the contact resistance of the drain and source metalizations and is independent of gate bias. Rchn and Cchn are the resistive and capacitive portions of the channel impedance. Rg and Cg are model elements which characterize the finite isolation of the gate with respect to the channel.

MONOLITHIC CIRCUIT DESIGN

The objective of this design is to develop an Ku-band SPDT switch with a bandwidth greater than 10%, a power handling capability of 1.5 watts, VSWR less than 1.5:1, an off-channel isolation of at least 15 dB, and an on-channel insertion loss of less than 2 dB.

In this low-pass, reduced size switch design the capacitance of the pinched-off FET is used as part of a low-pass pi-filter circuit, as shown in Figure 3. The inductors are realized with tenth-wavelength high impedance transmission lines. Inductive high impedance transmission lines in parallel with the FETs are not required as in a conventional switch design approach. The center capacitor can be an open-circuit microstrip stub or a metal-insulator-metal (MIM) capacitor over a via to ground. The FETs can use the same via for grounding. The tenth-wavelength high impedance transmission line is much smaller and easier to realize on a monolithic chip than a quarter-wavelength 50 ohm transmission line. These features and the absence of the shunt resonator transmission lines yield a circuit that is much smaller than a conventional quarter-wavelength switch.

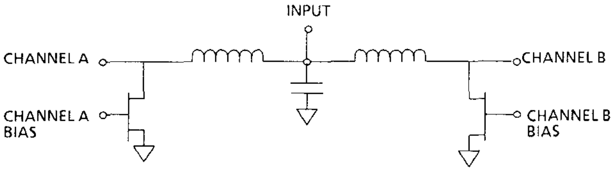

Figure 3. Low-Pass Reduced-Size Switch Schematic

The switch was initially designed using the reduced-size topology. Shunt inductive resonators were added to the output side of the FETs, as shown in Figure 4, to increase the predicted bandwidth of the switch and also contributed to better input and output VSWR. Due to the short wavelength at Ku-band the circuit is still small with the shunt inductive resonators included. The monolithic switch, illustrated in Figure 5, is only 1.3 X 1.3 X 0.15 mm in size. More than 2300 chips are fabricated on a single 3-inch GaAs wafer.

RF PERFORMANCE

The switch exhibits a small-signal insertion loss of less than 1.2 dB from 14 GHz to 18.3 GHz with the input and output return loss exceeding 15 dB. Small-signal performance at 30 C and 85 C is presented in Figure 6. Insertion loss degrades only 0.1 dB for a 55 degree C increase in temperature. Large-signal performance over temperature is shown in Figure 7. Input to off- channel isolation exceeds 18 dB at 13 GHz and improves with increasing frequency (see Figure 8).

A switch biased at -4.5 volts has survived an RF input power level greater than 5 watts (37 dBm) with no apparent degradation. A plot of the limiting characteristics of a switch at 14 GHz biased for small-signal operation is shown in Figure 9. The through-path insertion loss begins increasing with input levels above 26 dBm. The off-channel isolation begins degrading at input levels above 30 dBm. Larger control voltages (-10 volts) allow the switch to work with low loss and good isolation for input power levels exceeding 31 dBm.

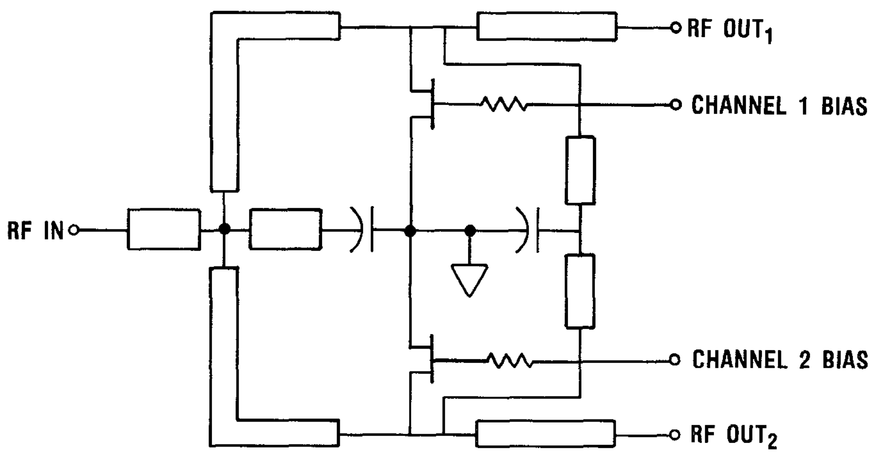

Figure 4. Ku-Band Switch Schematic

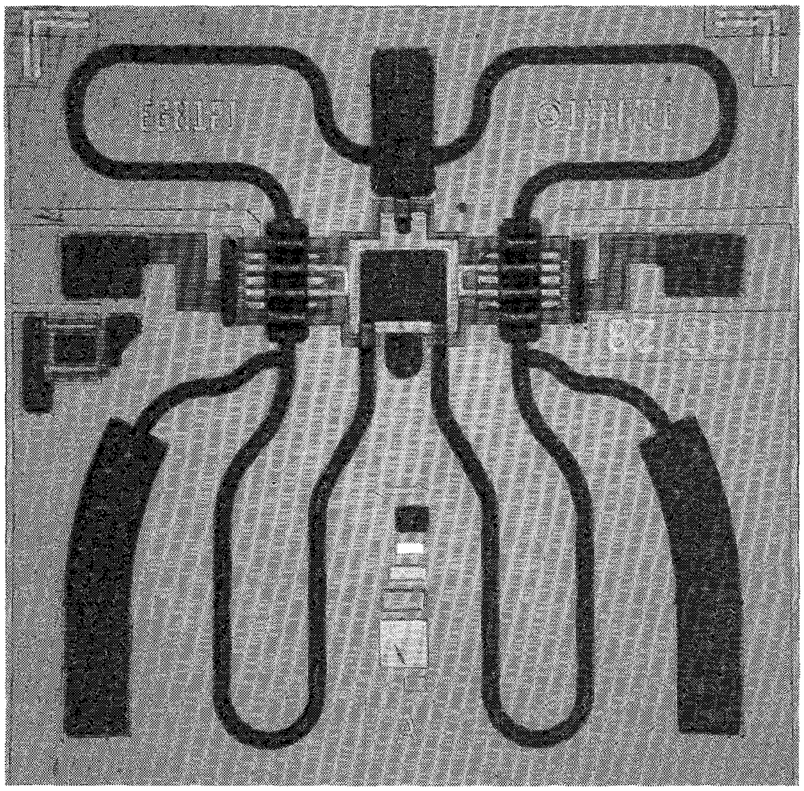

Figure 5. Ku-Band Monolithic SPDT Switch

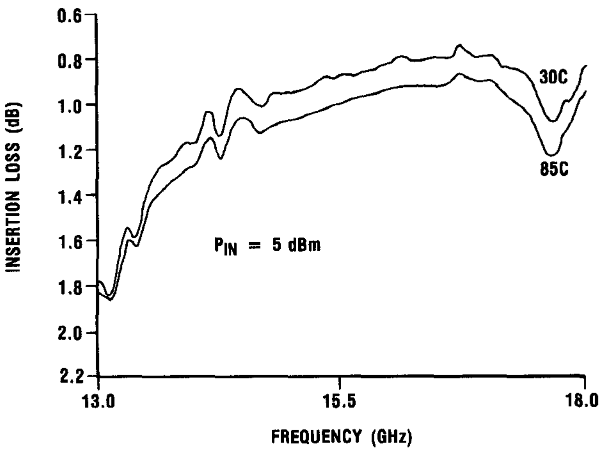

Figure 6. Small-Signal Insertion Loss

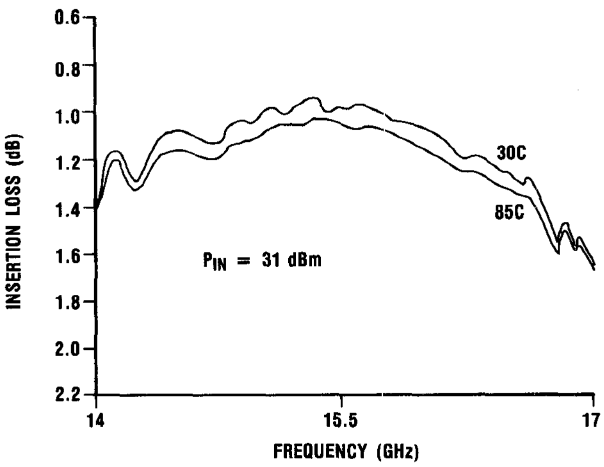

Figure 7. Large-Signal Insertion Loss

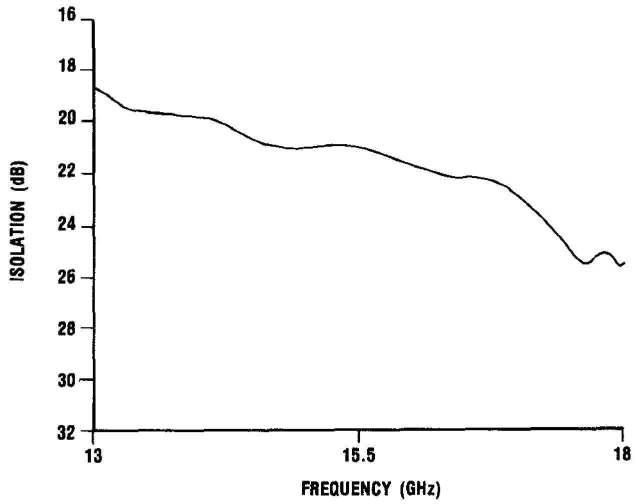

Figure 8. Input to Off-Channel Isolation

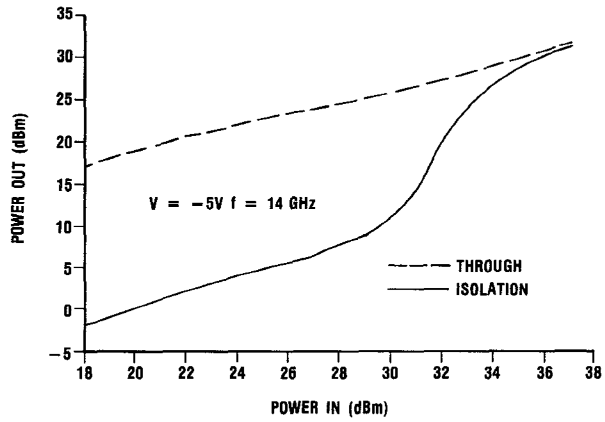

Figure 9. Switch Limiting Characteristics

CONCLUSION

A small monolithic FET switch has been designed and fabricated for frequencies from 14 GHz to 18 GHz. This circuit exhibits low loss, good isolation, good burnout characteristics, and very low DC power consumption.

ACKNOWLEDGEMENT

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REFERENCE

[1] U.S. Patent No. 4,556,808 entitled "NOVEL MICROWAVE MONOLITHIC SPDT FET SWITCH CONFIGURATION" issued on December 3, 1985.