A HIGH PERFORMANCE V-BAND MONOLITHIC FET TRANSMIT-RECEIVE SWITCH*

G. L. Lan, D. L. Dunn, J. C. Chen, C. K. Pao and D. C. Wang

Hughes Aircraft Company
Microwave Products Division
P. O. Box 2940, Torrance, CA 90509-2940

ABSTRACT

A state-of-the-art performance has been achieved for a monolithic V-band GaAs FET switch. The insertion loss for the switch-on path is less than 1.5 dB across 2 GHz bandwidth (59 to 61 GHz) and is less than 3.2 dB across 8 GHz bandwidth (56 to 64 GHz). The isolation, switch-off, is greater than 25 dB across 2 GHz bandwidth (59 to 61 GHz) and is greater than 23 dB across 8 GHz bandwidth (56 to 64 GHz). The monolithic FET switch circuit has also demonstrated a switching speed of less than 1 nanosecond and RF power handling capability in excess of 450 mW.

INTRODUCTION

In recent years, much attention has been given to millimeter-wave phased array radar systems. Currently, all existing systems employ various hybrid circuits which are very labor intensive and not too practical for large volume production. In addition, all the parasitic reactances associated with the packaged and unpackaged devices cause severe circuit performance degradation in the millimeter-wave frequency range. To achieve minimum size and weight and maximum performance and reliability, it is envisioned that monolithic millimeter-wave integrated circuit (MMIC) technology will be used to the fullest extent. To that end, multifunctional chips compatible with processing technology will be integrated to form a single element.

GaAs field effect transistors (FETs) are currently used as two-state RF switch elements in phase shifter and transmit-receive (T-R) switch modules. They are particularly useful in monolithic circuitry because they interface simply with other FET circuits without the need for additional processing steps. Their power consumption is negligible, and, therefore, they may be favored in designs where low prime power consumption becomes an important factor. The use of FETs as switching elements at microwave frequencies is well documented (1). An area of interest will be the extension of microwave FET switches into the millimeter-wave range. The theory indicates that the FET switch should be able to provide good performance at millimeter-wave frequencies, but the problem is how to implement the device and circuit so that low loss, high isolation, and good power handling capability can be achieved at these frequencies. In this paper, the circuit design methodology and fabrication process leading to realization of a high performance fully monolithic millimeter-wave FET T-R switch are described.

FET SWITCH CIRCUIT DESIGN

The FET switch terminals are the source and drain; the gate is the control electrode and is held open circuit with respect to the RF being switched. In the low-impedance state ("on" state), the gate bias is 0 V, and in the high-impedance state ("off" state), the gate is biased beyond pinch-off. A FET biased beyond pinch-off is not really an open circuit because of the drain-to-source capacitance of the FET. If not compensated for, this small capacitance will create significant losses at millimeter-wave frequencies. The most direct way to compensate for the capacitance is to place a resonating inductor between the drain and the source. Figure 1 shows the circuit diagram for the FET T-R switch; the switch contains two identical arms joined to a common point and each arm contains a pair of FETs connected in shunt configuration. In normal operation, one arm passes the signal and the other arm isolates the signal. The FETs are spaced by one quarter wavelength between the devices and the common joint. These quarter-wavelength transformers are used to provide high isolation and to minimize the loading effect.

Figure 2 shows the complete monolithic V-band FET T-R switch. It contains all the RF and bias circuitry on chip. RF open at the gate is provided by a high-impedance quarter-wavelength section connected to a

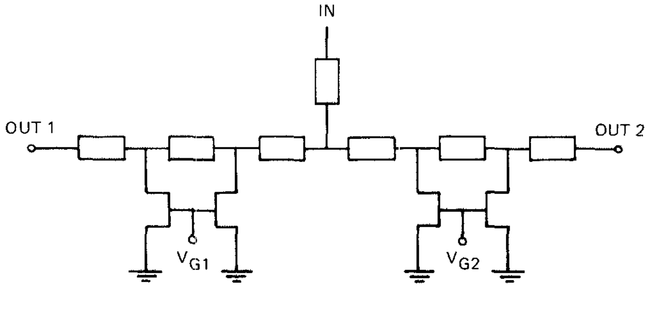

Figure 1. Circuit diagram of the FET T-R switch.

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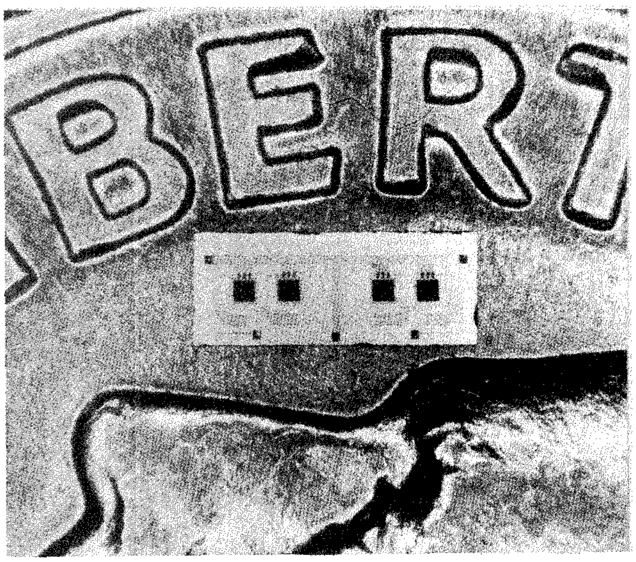


Figure 2 V-band monolithic FET T-R switch.

low-impedance quarter-wavelength open circuit stub. The dimensions of the T-R switch are 0.8 x 2.45 mm.

MONOLITHIC FET T-R SWITCH PROCESS

A low cost, high yield process has been developed for the fabrication of V-band monolithic millimeter-wave integrated switch circuits. The process includes formation of the FET channel layer, device isolation, fabrication of ohmic contacts, Schottky gates, overlay metallization for circuitry, airbridge interconnects, wafer thinning, via hole etching , and back metallization.

The key to fabricating the high yield and high performance monolithic FET T-R switch is the use of direct ion implantation into qualified LEC substrates. We used the selective implant of both N layer for the active channel and N^+ layer for the ohmic contact region. The doping profile of the active channel was optimized between the breakdown voltage (power density) and the transconductance (switching speed) of FET devices. The peak concentration and depth of doping profile are 1.6×10^{17} cm^{-3} and $0.25 \mu m$, respectively. A heavy N^+ doping of 10^{18} cm^{-3} was formed with 4-μm source-to-drain spacing to provide the low source resistance, thus reducing the insertion loss of the switch device.

A Ge/Ni/Au ohmic contact was deposited, followed by 380°C alloying. Proton bombardment was used to ensure the device isolation properties. An optical contact lithography was used to produce high-yield 0.6-μm gates with Ti/Pt/Au Schottky metal for gate formation. Finally, the GaAs wafers were thinned to 100 μm and the via holes were etched using a reactive ion etch (RIE) dry process. The FET parameters, such as I_{DSS} of 174 mA, V_{po} of 6 V, and g_m of 45 mS, were achieved on the test FET.

PERFORMANCE

The monolithic FET T-R switch was mounted on a V-band fixture for RF evaluation. The RF coupling between the microstrip circuit and waveguide was provided by a small length of coaxial cable. The average insertion loss of the test fixture was measured to be approximately 2 to 2.5 dB from 56 to 64 GHz.

The small signal performance of the monolithic FET switch was characterized by using the Hughes-developed millimeter-wave automatic vector network analyzer. The measured switch ON/OFF performance is shown in Figure 3. The switch-on insertion loss is shown to be less than 3.5 dB across the frequency band from 59 to 61 GHz. The 3.5 dB insertion loss also includes 2 to 2.5 dB test fixture loss, so the actual switch loss is less than 2.5 dB. Across the frequency band of 56 to 64 GHz, the switch insertion loss (excluding test fixture loss) is less than 3.2 dB. The switch-off isolation is greater than 25 dB across the frequency band of 59 to 61 GHz and is greater than 23 dB across the frequency band of 56 to 64 GHz. The switching speed of the monolithic FET T-R switch was also measured to be less then 1 nanosecond, as shown in Figure 4.

Insertion loss of the monolithic FET switch was measured at power levels up to 32 dBm (1.6 W). Figure 5 shows the insertion loss of the switch versus input power. The insertion loss remains approximately constant until 26.6 dBm (450 mW). The insertion loss, however, increases drastically when the input power increases above 450 mW. This extreme change of insertion loss is caused by the output power limited by voltage swings across the shunt FETs. The FETs, however, suffered no detectable degradation after removing the 1.6 W of RF power.

CONCLUSIONS

A state-of-the-art V-band monolithic FET switch has been demonstrated. This monolithic switch achieved less than 1.5 dB of insertion loss and greater than 25 dB of isolation over 2 GHz bandwidth and less than 3.2 dB of insertion loss and greater than 23 dB of isolation over an 8 GHz bandwidth. A switching speed of less than 1 nanosecond and power handling capability of 450 mW have

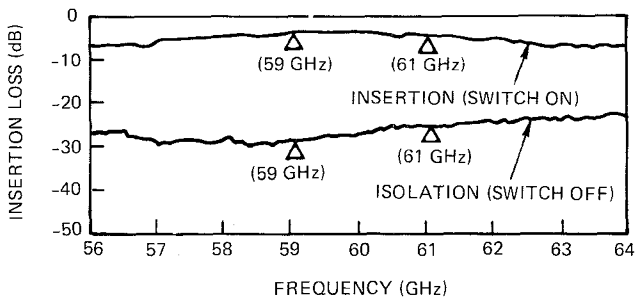
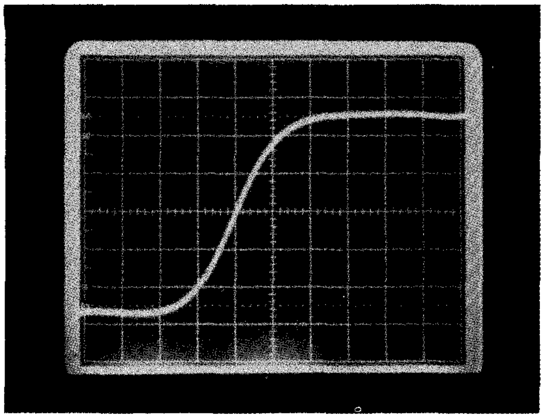
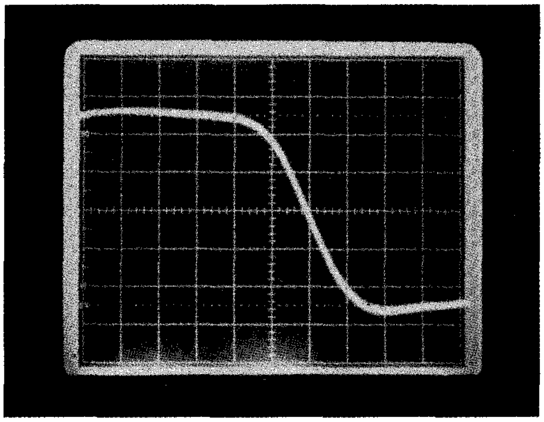


Figure 3. Insertion loss and isolation of the V-band monolithic FET T-R switch (including test fixture loss).



$\tau_{ON} \approx 1$ nsec
HORIZONTAL SCALE = 0.5 nsec/DIV



$\tau_{OFF} \approx 1$ nsec
HORIZONTAL SCALE = 0.5 nsec/DIV

Figure 4. Switch speed performance of the V-band monolithic FET T-R switch.

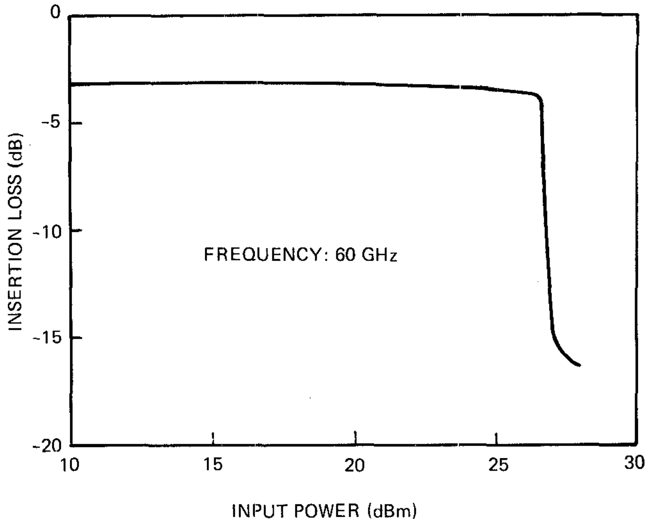


Figure 5. Insertion loss of the V-band monolithic FET T-R switch versus input power (including test fixture loss).

been demonstrated. Additional work is currently underway to improve the power handling capability.

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