A HIGH POWER K/Ka-BAND MONOLITHIC T/R SWITCH

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ABSTRACT

A high power K/Ka-band MESFET switch MMIC has been developed for use in Transmit/Receive (T/R) modules. The switch demonstrates 0.2 dB insertion loss compression with 30 dBm input power, 12 dB higher than previously reported for K/Ka-band MESFET switches. Also no isolation degradation was apparent with up to 28 dBm input power, a 13 dB improvement over the same previously demonstrated switches. A combination of techniques was used to yield higher power handling while preserving low loss and high isolation. These circuit techniques include the use of stacked MESFETs with large peripheries to improve power handling and transmission line transformers to minimize loss and maintain high isolation.

INTRODUCTION

To attain satisfactory performance, modern millimeter-wave RADARs require solid state millimeter-wave T/R modules with high power transmitters and low noise temperature receivers. T/R switches unify the transmitter and receiver within these modules and are therefore critical in attaining desired module and RADAR performance. Two important switch characteristics are insertion loss, which should be minimized, and isolation, which should be maximized.

Switch insertion loss degrades receiver noise temperature and transmitter efficiency. Switch insertion loss compression, arising from switching device nonlinearities, establishes a distortion ceiling for both the transmitter and receiver. Also sufficient isolation at high power levels between transmitter and receiver arms is necessary to prevent receiver damage.

Current Ka-band T/R modules require low loss, high isolation switches that remain uncompressed with one watt incident power. Monolithic millimeter-wave switches have been previously presented using PIN diodes and MESFETs. Ka-band PIN diode switches have demonstrated uncompressed insertion loss with greater than 35 dBm input power. Although this is a greater performance than exhibited by MESFET switches, PIN diode switches are not monolithically compatible with other MESFET circuitry, consume more DC power, and require complex off-chip bias circuitry and drivers. The latter degrade switching speeds to 2 ns rise and fall times.[1] The previous state-of-the-art maximum input power resulting in 0.2 dB insertion loss compression of K/Ka-band MESFET switches is 18 dBm.[2] This is unsatisfactory for module insertion and therefore a higher power, K/Ka-band MESFET switch has been developed.

Typical broadband millimeter-wave switches utilize a distributed topology. The power handling of these switches is limited by the MESFET breakdown voltage in the device's off state (on state switch arm) and the MESFET saturation current in the device's on state (off state switch arm).[3] Two techniques have been demonstrated to improve distributed MESFET switch power handling at microwave frequencies. First, dual gate MESFETs, rather than single gate devices, have been incorporated in distributed switches, to increase the threshold of voltage limiting. The dual gate device has improved voltage limiting because the voltage across each of the device's gate-drain junctions is approximately one half of that across a single gate MESFET junction. This approach does not double the RF voltage capability of the switch though, due to uneven RF voltage distribution resulting from gate-to-gate cross coupling. Alternatively, stacked MESFETs were chosen for this design.[4] This technique also increases the threshold of voltage limiting by placing two MESFETs in series directly. Again the voltage across each of the two MESFETs' gate-drain junctions is about one half of that across a single gate MESFET junction. Although stacked MESFETs have increased series inductance through the MESFETs and shunt capacitance from the MESFETs to ground due to the extra device periphery, they do have better power handling capability than dual gate MESFETs.

Circuit Design

Conventional low loss, K/Ka-band single pole double throw switches use shunt MESFETs and transmission line transformers, and provide 0.2 dB insertion loss compression with a maximum input power of 18 dBm. Insertion loss is

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typically 2 dB and isolation is at least 20 dB. In the design of this K/Ka-band high power switch, the same circuit approach used in lower power switches was taken, but with the addition of stacked MESFETs to increase power handling.

The schematic of the high power K/Ka-band switch is shown in Figure 1. This single pole double throw circuit is composed of two equivalent and independently biased arms. Figure 2 shows normal operation with the switch biased to pass signals between RF1 and RF3. The MESFETs are represented by their simplified equivalent circuits. The RF1 arm MESFETs are biased off, and act primarily as shunt capacitors. The capacitance of the pinched off MESFETs and the highly inductive series transmission line form a lumped element transmission line with an impedance of about fifty ohms. The RF2 arm MESFETs are biased on and act as shunt resistances. The MESFETs in the RF2 arm present a low impedance which is transformed to a higher impedance by a transmission line. This transmission line transformer is used, rather than a series MESFET, to isolate the off state arm from the on state arm to reduce the switch's insertion loss. The switch insertion loss mechanisms include the resistances of the on and off state MESFETs and the dissipative losses of the narrow transmission lines.

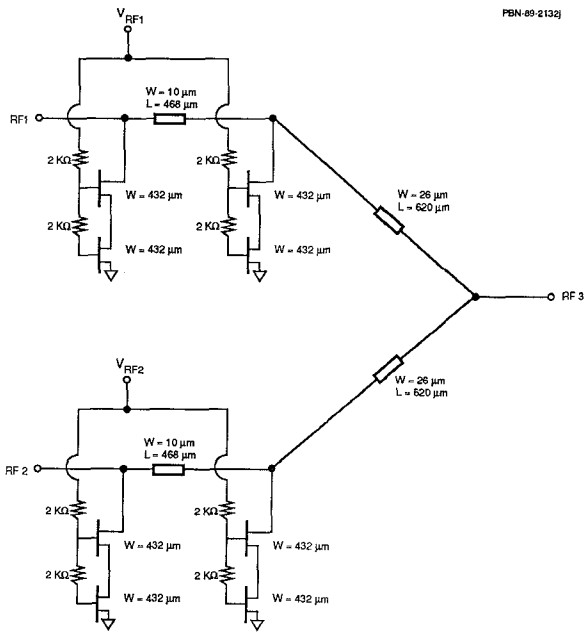

Figure 1. K/Ka-band High Power T/R Switch Schematic.

Circuit Fabrication

The circuit was fabricated with a standard GaAs MMIC process with E-beam defined 0.5 micron gate lengths on $2*10^{17}$ cm^{-3} ion implanted material. A single recess process is used, producing reliable and consistently high breakdown

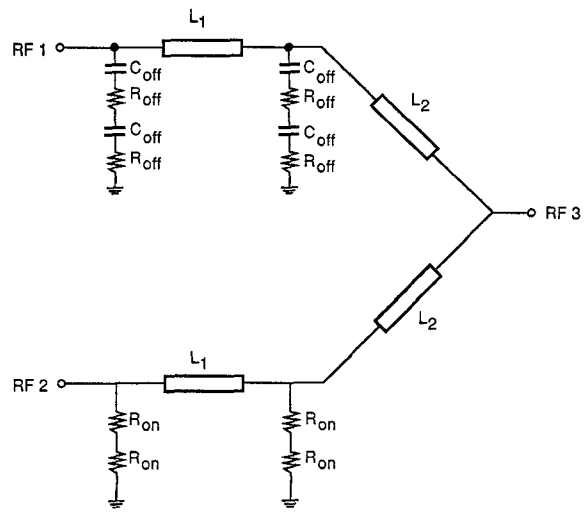

Figure 2. Equivalent Circuit of K/Ka-band High Power T/R Switch with RF1 Arm Switched On.

voltage devices. The MESFETs typically exhibit a reverse breakdown voltage of 12.5 V at 1 mA/mm and with a pinchoff voltage of 4 V. The MESFET gates are biased through 2000 ohm open gate MESFET resistors. The switch requires no external bias components and is 87 x 80 x 4 $mils^3$ in size. A photograph of the switch is shown in Figure 3.

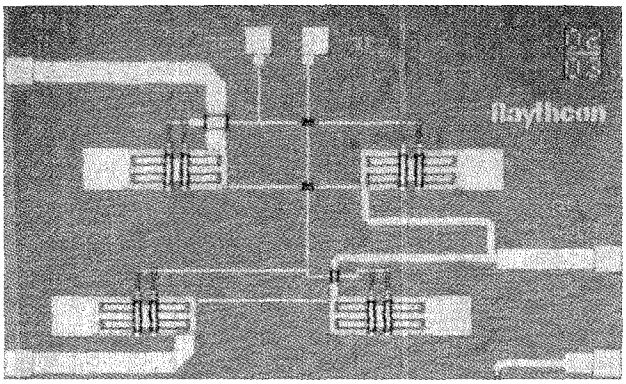

Figure 3. Photograph of High Power K/Ka-band T/R Switch.

Circuit Performance

The K/Ka-band switch exhibits less than 2 dB insertion loss and and greater than 20 dB isolation (Figure 4). The insertion loss is symmetrical in both arms (Figure 5). The input and output return losses are better that 10 dB in K- and Ka-bands (Figure 6). The switch exhibits 0.2 dB compression with 30 dBm input power (Figure 7). No isolation compression occurs with up to 28 dBm input power (Figure 8). To obtain this performance the on and off state MESFETs were biased with a gate voltages of 0 and -10 V. Figure 9 shows the switching speed for this circuit with an 18 GHz RF signal. The rise and fall times are both less than 500 ps.

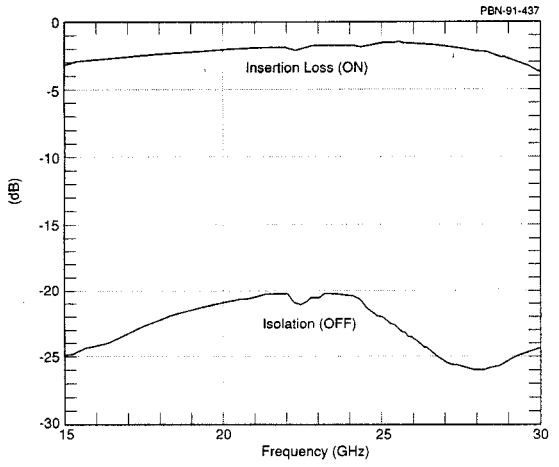

Figure 4. Insertion Loss and Isolation of High Power K/Ka-band T/R Switch.

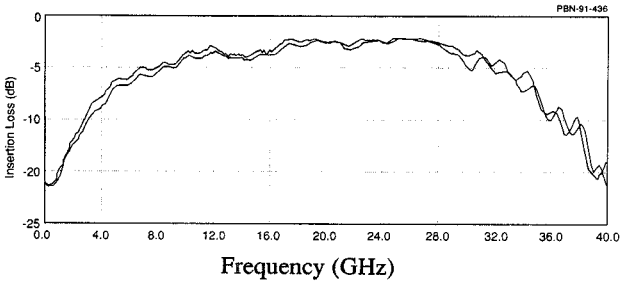

Figure 5. RF1 to RF3 and RF2 to RF3 Insertion Losses.

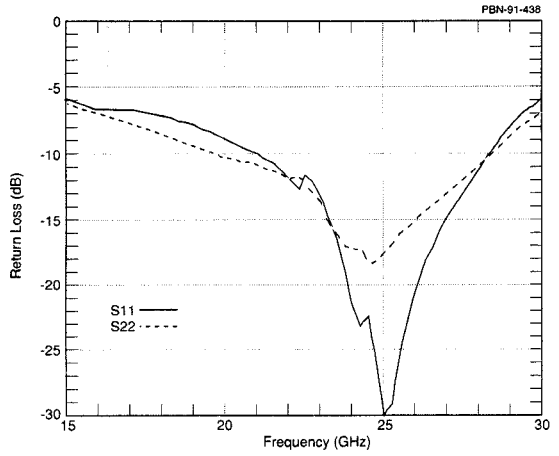

Figure 6. RF1 and RF3 Return Losses.

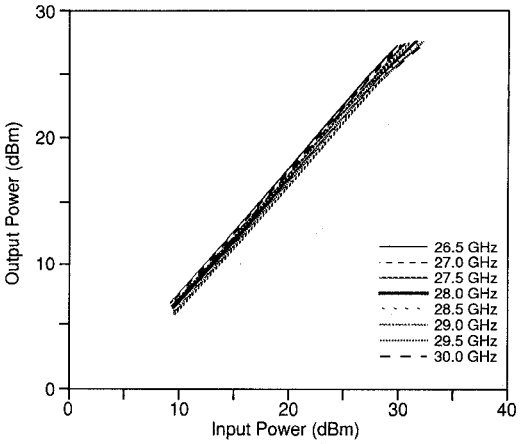

Figure 7. Power Compression of High Power K/Ka-band T/R Switch.

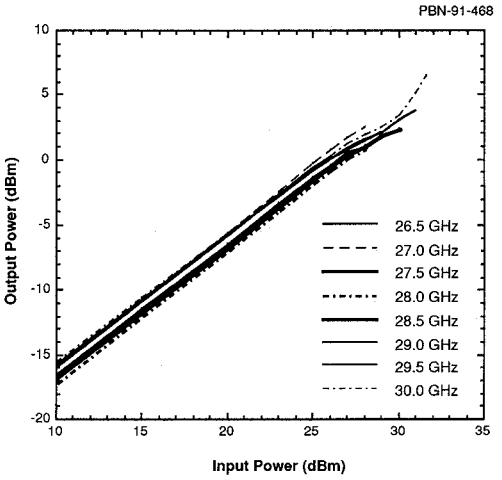

Figure 8. Isolation Compression of High Power K/Ka-band T/R Switch.

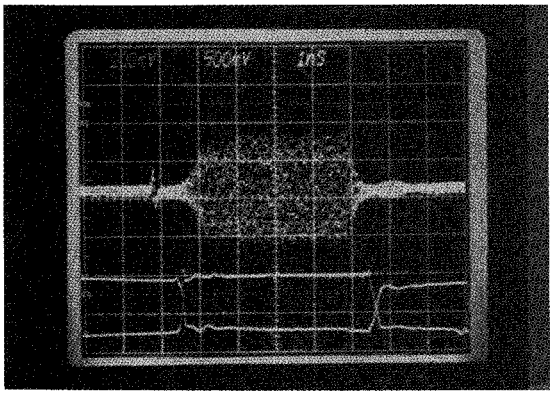

Figure 9. Switching Speed of High Power K/Ka-band T/R Switch.

CONCLUSION

A K/Ka-band high power switch suitable for insertion in T/R modules has been demonstrated. This fully monolithic circuit has the highest uncompressed power handling of any MESFET switch in K/Ka-band. Superior performance was accomplished by using stacked FETs. This technique can be applied to MESFET switches incorporating more throw positions and operating at higher frequencies. The high power switch has exhibited RF performance competitive with PIN diode switches. MESFET switching speed is four times faster than a PIN diode switch and can be integrated with other monolithic MESFET circuits.

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