COUPLER CROSSBAR MICROWAVE SWITCH MATRIX*

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Abstract

A microwave switch matrix is needed to provide dynamic transponder interconnectivity for the next generation of digital communication satellites. This paper describes the development of a unique 4 x 4 coupler crossbar microwave switch matrix which meets the future satellite-switched, time-division, multiple access (SS-TDMA) requirements.

Introduction

Future high-capacity satellite communication systems will require onboard signal processing[1], which will include switching of RF signals between multiple antennas to provide interconnection between the uplink and downlink beams. A dynamic, high-speed microwave switch matrix (MSM) will be needed to route communications traffic by cyclically connecting different RF input ports (receivers) to different RF output ports (transmitters). Figure 1 shows a satellite-switched TDMA system, which includes antennas, receivers, microwave switch matrix, distribution control unit, and transmitters.

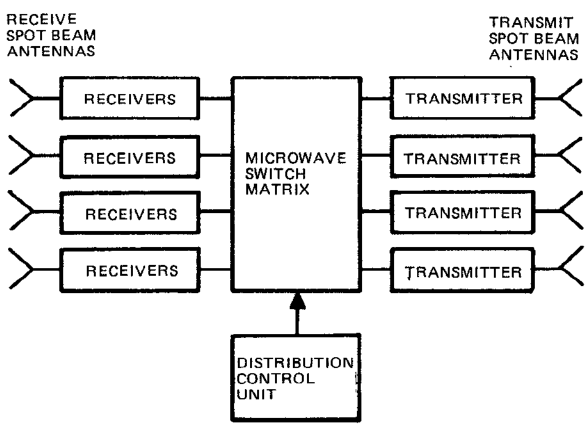

Figure 1. Satellite-Switched TDMA Transponder

This paper describes the development of a 4 X 4 microwave switch matrix (MSM) having coupler crossbar architecture and using dualgate GaAs FETs as switching elements. This 4 X 4 MSM verifies the design concept of the coupler crossbar architecture and demonstrates that the SS-TDMA system requirements can be met using this superior approach.

Switch Matrix Architecture

Several different types of MSMs have been developed[2-4] and reported using different architectures and switching devices. Some provide one-to-one connectivity only; others provide both one-to-one and one-to-many connectivity. The switch matrix architecture affects the modes of SS-TDMA system operation and determines RF performance, reliability, size, weight, and manufacturability. Table 1 summarizes the functional capabilities of each architecture.

Table 1. Comparison of MSM Architectures

Architecture / Function	SPMT	Divider/ Combiner	Rearrangeable Switch	Coupler Cross Bar
Broadcast Mode	No	Yes	No	Yes
Variable Switching Time	Yes	Yes	No	Yes
Mechanical Structure	Cubic	Cubic	Planar	Planar
Distribution Control Alogorithm	Simple	Simple	Complex	Simple

The broadcast mode (one input signal connected to multiple ouputs simultaneously) is advantageous for SS-TDMA system synchro. The variable switching time capability (turn on and turn off any crosspoints randomly in time) provides higher communication efficiency. The distribution control alogrithm determines the complexity of the digital control circuitry. Planar mechanical structure improves the switch matrix mechanical strength and reliability. After considering the functional requirements of future SS-TDMA systems, the coupler crossbar architecture was chosen as the preferred approach because it provides a broadcast mode along with a variable switching time capability. The planar mechanical structure of the coupler crossbar makes it easy to manufacture, with minimum size and weight.

Figure 2 shows the circuit of the 4 x 4 coupler crossbar MSM. Each crosspoint consists of two directional couplers and one switch, with the switch placed between the two couplers. The input couplers couple RF energy from the input to each of the switches on the same input row. By using couplers with predetermined coupling coefficients, the input power is equally divided among the switches on the same input row. The switches either pass or block the signal flow to the output couplers. When the switches are on, the signals pass through the output couplers to the selected output lines; when the switches are off, the signals are reflected back and absorbed by the built-in coupler loads. The output signals are then recombined by the serially connected output couplers and applied to the outputs.

Directional Coupler Design

Four types of microstrip directional couplers having coupling coefficients ranging from 3 dB to 7 dB are needed for the 4 x 4 MSM. The coupling coefficients are selected to provide equal power distribution at all the output ports with equal input power. By using couplers having different coupling coefficients, identical switching elements can be used without the need for gain adjustment circuits. This is a significant advantage over the fixed cou-

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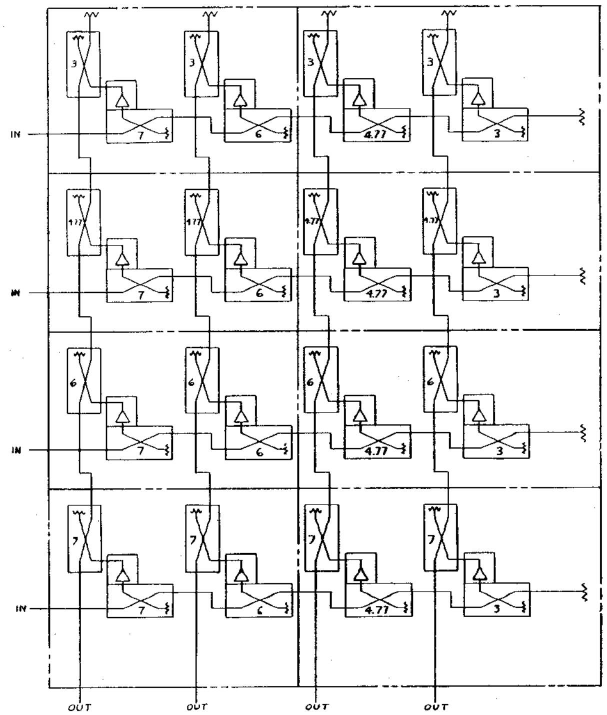

Figure 2. 4 x 4 Coupler Crossbar Microwave Switching Matrix

pling, variable gain switch amplifier design. Four-finger interdigitated couplers were chosen for the coupler design. Using ion-beam milling, couplers having coupling coefficient variations of less than 0.1 dB can be manufactured consistently.

<u>Microwave Switch Design</u>

The MSM requires a switching component that provides an on-tooff isolation of greater than 50 dB. A dual-gate FET was chosen as the switching device because of its switching speed (less than 0.1 ns) and high isolation (25 to 30 dB). To achieve the 50 dB isolation requirement, a two-stage cascade design was necessary for the crosspoint switch. Each switch module incorporates a 50 ohm RF feedthrough, a dc bias line, and a switching voltage feedthrough. Some of the feedthroughs in the modules are oriented perpendicular to the circuit substrate to reduce the MSM dimension. Each switch circuit is self-biased through thin film source resistors to help simplify device biasing and to reduce the number of dc feedthroughs required. Electrical design began with a thorough device characterization followed by a theoretical circuit design of interstage, input, and output matching circuits. Computer analysis and optimization were then performed. The final circuit diagram of the switch is shown in Figure 3. The circuit is fabricated on 0.01-in Alumina substrate using ion beam etching. The module performs closely to computer prediction and achieves greater than 20 dB gain during the on condition with less than 1 dB of passband ripple from 3.5 to 4.5 GHz. The on-to-off isolation is greater than 60 dB, with power output equal to 8 dBm at the 1 dB compression point. Phase shift is less than 0.2 deg and carrier-to-3rd order intermodulation distortion (C/IMD(3)) is greater than 42 dB at the desired operating point (P_{in} = -17 dBm).

<u>Switch Driver Design</u>

The switch driver is the interface circuit between the dual-gate GaAs FET switch and the distribution control unit. The switching action is programmed by the distribution control unit and triggered by the clock signal from the distribution control unit. Each switch driver delivers the necesary on and off switching voltages to the second gate of the dual-gate FET. A positive 0.5 volt at the second gate of dual-gate FET turns on the crosspoint microwave switch, and a negative 3.0 volts turns off the crosspoint microwave switch.

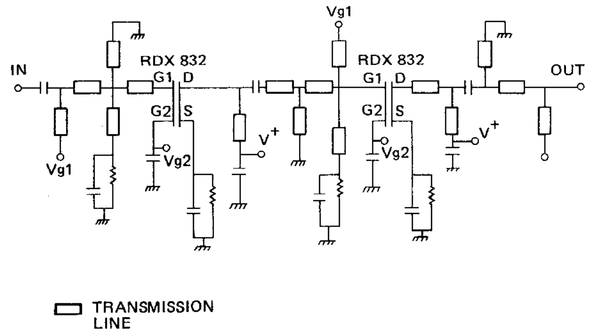

Figure 3. Microwave Switch Circuit Design

The major design goals for the switch driver include fast switching speed, low power consumption in the on state, and little or no power consumption in the off state. To meet these goals, a single high speed switching bipolar transistor driver circuit controlled by a high speed flip-flop integrated circuit was chosen. Characterization of the driver loading was also performed to minimize DC power consumption while still meeting the switching speed requirement. To reduce size, weight, and assembly time, two switch drivers were fabricated on a single substrate using thick film technology. The dual thick-film hybrid module controls two adjacent crosspoints located in the MSM. Each driver module (two crosspoints) dissipates 20 mw in the off state and 140 mw in the on state. Switching rise and fall times are both less than 10 ns when capacitively loaded by the input impedance of the second gate of the dual-gate FET.

<u>Measured Performance Of The 4 x 4 MSM</u>

Figure 4 is a top view of the 4 x 4 MSM showing the output couplers and switch amplifier module, and Figure 5 is a bottom view of the MSM showing where the thick film driver circuit is mounted on the multilayer driver circuit board. Table 2 summarizes the performance of the 4 x 4 MSM. The MSM demonstrate a 1 GHz bandwidth from 3.5 to 4.5 GHz. In the on state the MSM provides 4 db gain, and in the off state the MSM has over 60 db of insertion loss. The isolation (on-to-off ratio) of the switch is better than 64 db. (See Figure 6.)

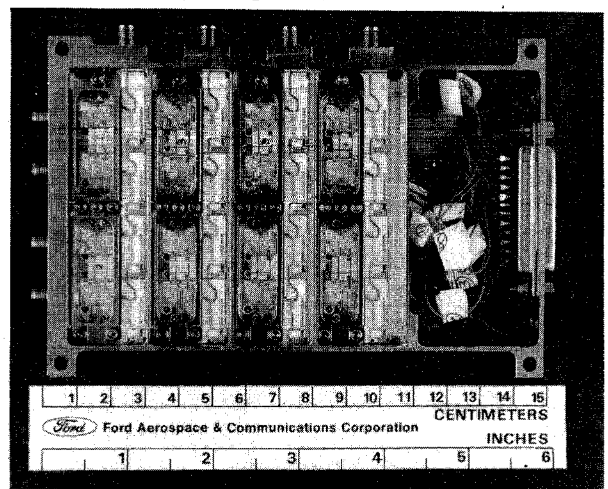

Figure 4. 4 x 4 Microwave Switch Matrix (Top View)

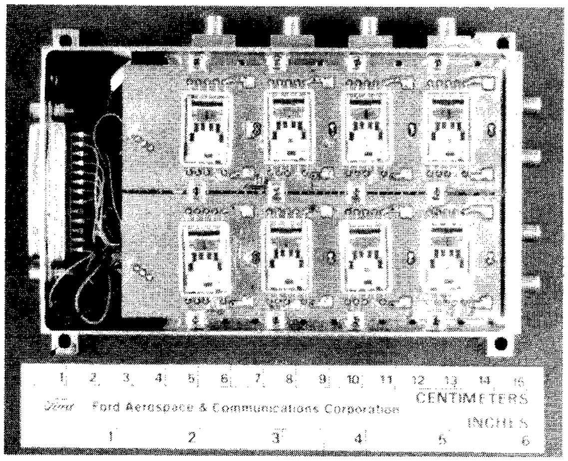

Figure 5. 4 x 4 Microwave Switch Matrix (Bottom View)

Table 2. Measured Performance of 4 x 4 Microwave Switch Matrix

Parameter	Measured Data
MSM size	4 x 4
Bandwidth (instantaneous)	3.5 – 4.5 GHz
Insertion gain of any on-path	4 dB
Insertion loss variation (any 500 MHz)	≤ 1 dB
Path-to-path insertion loss variation (500 MHz)	≤ 1.5 dB
On-to-off isolation	≥ 60 dB
Group-delay variation (any 500 MHz)	≤ 0.5 ns
Phase linearity (p_{out} < +6 dBm)	≤ 0.5°
Amplitude linearity (C/I) (p_{out} = p1 + p2 ≤ +6 dBm)	≥ 30 dB
Rise or fall time	≤ 10 ns
Differential delay	2.5 ns (max)
Connectivity	Any N to any M
MSM mass	0.4 kg
MSM volume	14 x 9 x 2.5 cm

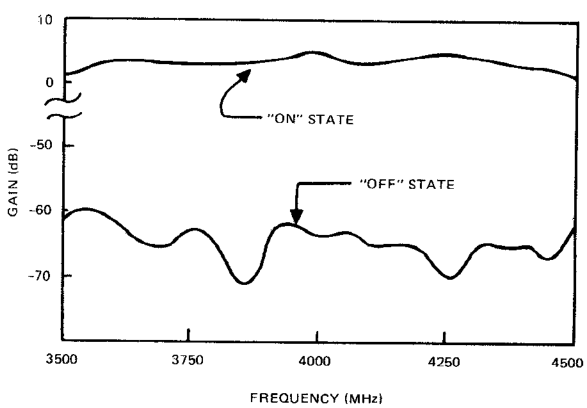

Figure 6. Typical 4 x 4 Crosspoint On and Off Performance

Figure 7 shows a typical dynamic switching pattern of the 4 x 4 MSM. The switching pattern information is stored in the memory of the distribution control unit and continues to repeat the 100 μs frame shown. One RF-in port has been modulated with a triangular waveform to easily identify which crosspoints have been activated along that input line. An RF detector at each output port records the switched on through signal.

It was also demonstrated that less than 10 nsec switching speed (10 to 90 percent) can be achieved.

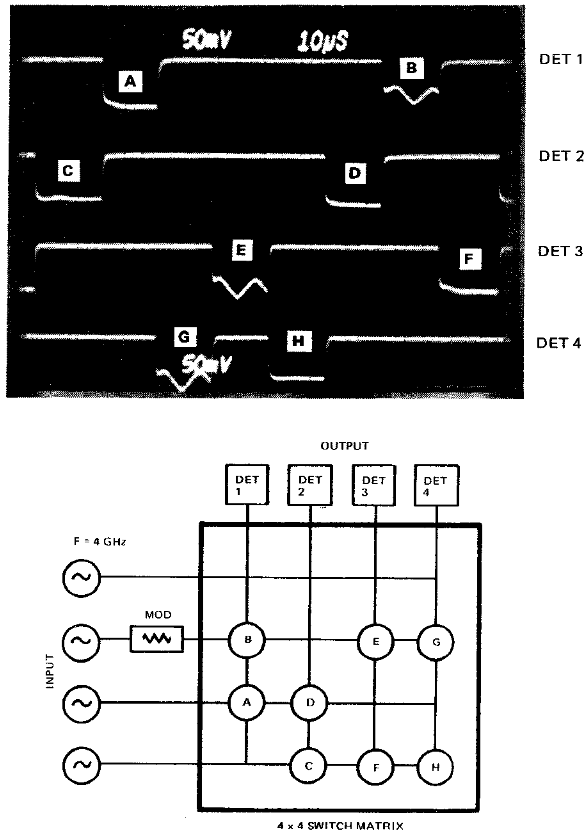

Figure 7. Dynamic Switching Test

Conclusion

The design and test results of an experimental 4 x 4 coupler crossbar MSM presented herein demonstrate the feasibility of the newly developed coupler crossbar architecture using dual-gate GaAs FETs as switching elements. This coupler crossbar MSM demonstrates the unique features of switching with gain, high switching speed, and compact packaging techniques. The MSM has been successfully operated under the control of the distribution control unit in the SS-TDMA mode of operation and has demonstrated that it meets the functional requirements for the next generation high data rate communication satellites.

References

1. P. T. Ho, J. H. Wishiewski, J. R. Pelose, and H. M. Perraso "Dynamic Switch Matrix for the TDMA Satellite Switching System," AIAA 9th Communications Satellite Systems Conference, San Diego, Calif. March 1982. pp. 135-141

2. F. Assal and M. Rozec, "Fast Fully Redundant, 4 GHz 8 x 8 Microwave Switch Matrix for Communications Satellites," 9th European Microwave Conference, Brighton, England, September 1979, pp. 216-222.

3. R. A. Gaspari, and M. H. Yee, "Microwave GaAs FET Switching," 1978 IEEE Symposium, IEEE MTT-S, 1978, pp. 58-60.

4. M. Yamaguchi, Y. Ito, M. Kyogoku, T. Kudo, and M. Akao, "4 GHz, 8 x 8 Switch Matrix for SDMA System," International Microwave Symposium, Palo Alto, California, 1975, pp. 170-172.