MONOLITHIC GaAs MULTI-THROW SWITCHES WITH INTEGRATED LOW-POWER DECODER/DRIVER LOGIC

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ABSTRACT

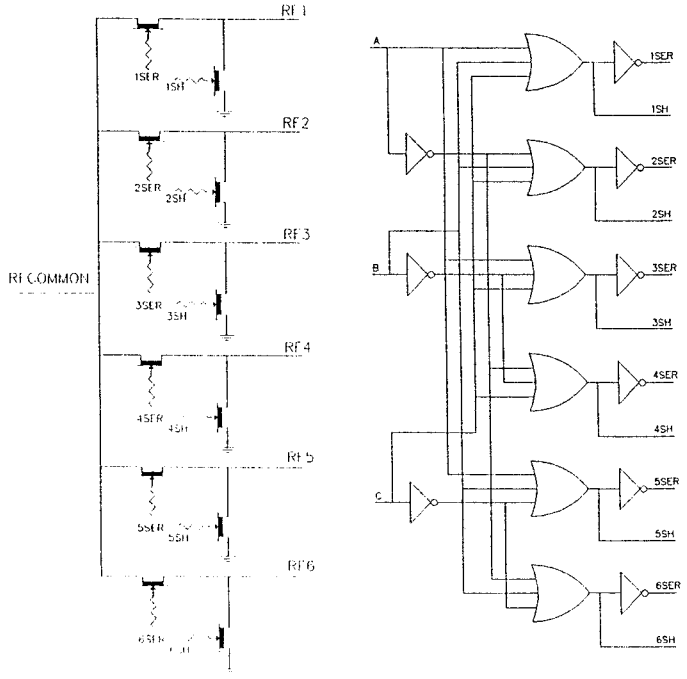
SP4T, SP6T and SP8T GaAs MMIC switches with integrated low-power decoder/driver logic are described. The integrated decoder/driver significantly reduces the number of on chip control lines, lowering cost, improving RF performance and easing PCB integration. Reflective and terminated versions are realized. Insertion losses range from 0.5-1.7dB, isolations range from 20-45dB, 1dB input power compressions range from 20-24dBm and single tone third order intercepts range from 40 to 42dBm at 2GHz. The logic operates over temperatures from -196°C to 125°C and supply voltages from 3-7V while consuming under 25mW of DC power. Control current requirements are under 200uA, allowing standard CMOS and TTL logic families to interface. Switching times are under 100nsec.

INTRODUCTION

Multi-throw switches are widely applied in the microwave industry for channel multiplexing, filter bank switching, step attenuator control and active antenna beam steering. As the industry matures, more complex subsystems are requiring higher order single-pole-N-throw (SPNT) switches to simplify their architecture. Conventional SPNT MMIC FET switch designs require N complementary pairs of driver control lines to bias the series/shunt switch FETs [1]. This leads to control line interface problems for higher order switches [2]. For example, a conventional SP8T MMIC switch requires 16 control line I/O pads, increasing die area and mating PCB complexity. Although SPDT switches with on-board driver logic have been reported [3], this is the first paper to describe the integration of SP4T, SP6T and SP8T microwave switches with on-board decoder/driver logic. By adding 2:4, 3:6 and 3:8 decoder/drivers on SP4T, SP6T and SP8T switches, the number of I/O control lines is reduced by 6, 9 and 13, respectively, significantly reducing die area. This improves RF performance by reducing trace length, ground inductance and parasitic coupling to the high speed control lines. The lower number of control lines also eases PCB integration. Both low loss reflective and higher isolation terminated SPNT MMIC switches are described.

CIRCUIT DESCRIPTION

Low loss reflective and high isolation terminated versions of the SP4T, SP6T and SP8T MMIC switches are realized. These SPNT switches use the same circuit architecture where a common input manifold leads directly to the N output series/shunt selection switches. Schematic diagrams of the SP6T reflective switch RF and logic connections are shown in Figure 1. The reflective topology provides the lowest insertion loss, however, "OFF" state output impedances are effectively short circuits. Three control lines (A, B and C) are used to select one of the six outputs or an "all OFF" state. The truth table for selecting each of the SP6T switch outputs is shown in Table 1. The terminated topology lowers the "OFF" state output VSWRs by switching in matched loads. These terminated versions also have improved isolations and slightly higher insertion losses.



a) RF Schematic b) Decoder/Driver Logic

Figure 1. Reflective SP6T Schematic.

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Depletion mode FETs are used for the RF switches while enhancement and depletion mode FETs are used for the low power decoder/driver logic to minimize power consumption. RF lines are directly coupled to achieve broadband performance. A negative bias, Vee, is required to bias the logic. Control input logic levels are 0 to -1V (Low) and Vee to Vee + 1V (High). A microphotograph of the unterminated SP6T switch is shown in Figure 2. The 1 x 1.5 mm^2 MMIC is fabricated using a standard 1μm gate-length, enhancement/depletion GaAs MESFET foundry process.

CONTROL INPUT			SIGNAL PATH STATE
A	B	C	RFCOM to:
High	High	High	RF1
Low	High	High	RF2
High	Low	High	RF3
Low	Low	High	RF4
High	High	Low	RF5
Low	High	Low	RF6
High	Low	Low	all off
Low	Low	Low	all off

Table 1. SP6T Truth Table

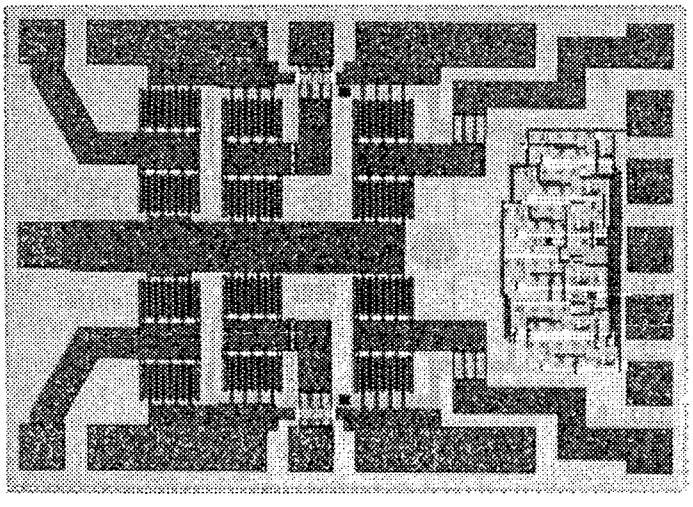

Figure 2. Microphotograph of Reflective SP6T Switch.

CIRCUIT PERFORMANCE

All six MMIC switches were evaluated in die form while four of the switches were evaluated in plastic packages. Fully de-embedded S-parameter measurements were obtained using LRM calibration standards.

Figure 3 shows the 'port 3' RF characteristics of the low loss reflective SP6T switch in die form at room temperature. Insertion loss is less than 0.6dB, input return loss is 15dB, output return loss is 19dB in the ON state and isolation is greater than 33dB at 2GHz. Output return loss degrades in the OFF state due to the short circuit termination. Turn off switching performance is shown in Figure 4. The 10/90% RF rise time (not shown) and fall time are under 25nsec. The 50% control to 10/90% RF rise/fall times are under 50nsec. Figure 5 shows the 'port 3' RF characteristics of the terminated SP6T switch in die form at room temperature. Insertion loss is 1.1dB, input return loss is over 13dB, output return loss is over 42dB in the ON state and 16dB in the OFF state and isolation is greater than 37dB at 2GHz. SP6T decoder/driver current is 4mA at -5V Vee for both designs. Control current on each of the A, B and C control lines is under 185µA. Switching is maintained from -196°C to 125°C.

A summary of the room temperature RF performance of the six SPNT switches, in die form, is shown in Table 2. The terminated versions have slightly higher insertion loss, significantly lower off arm output VSWRs and higher isolation. 1dB input power compressions range from 20-24dBm and third order intercepts exceed 40dBm at 2GHz.

A summary of the room temperature RF performance of four SPNT switches, assembled in SOIC and QSOP plastic packages, is shown in Table 3. The plastic encapsulation increases insertion loss and decreases return loss and isolation. 1dB input power compressions and third order intercepts are unchanged.

A summary of the room temperature switching characteristics and bias requirements of the SPNT switches is shown in Table 4. DC power requirements for the logic are extremely low, the SP8T logic consumes only 25mW at -5V. At -3V, power consumption is halved. Control currents are under 200uA, allowing standard CMOS and TTL logic interfaces. The 50% control to 10/90% RF switching speeds are under 100nsec at room temperature. Switching speed is halved at -196°C and doubles at 125°C.

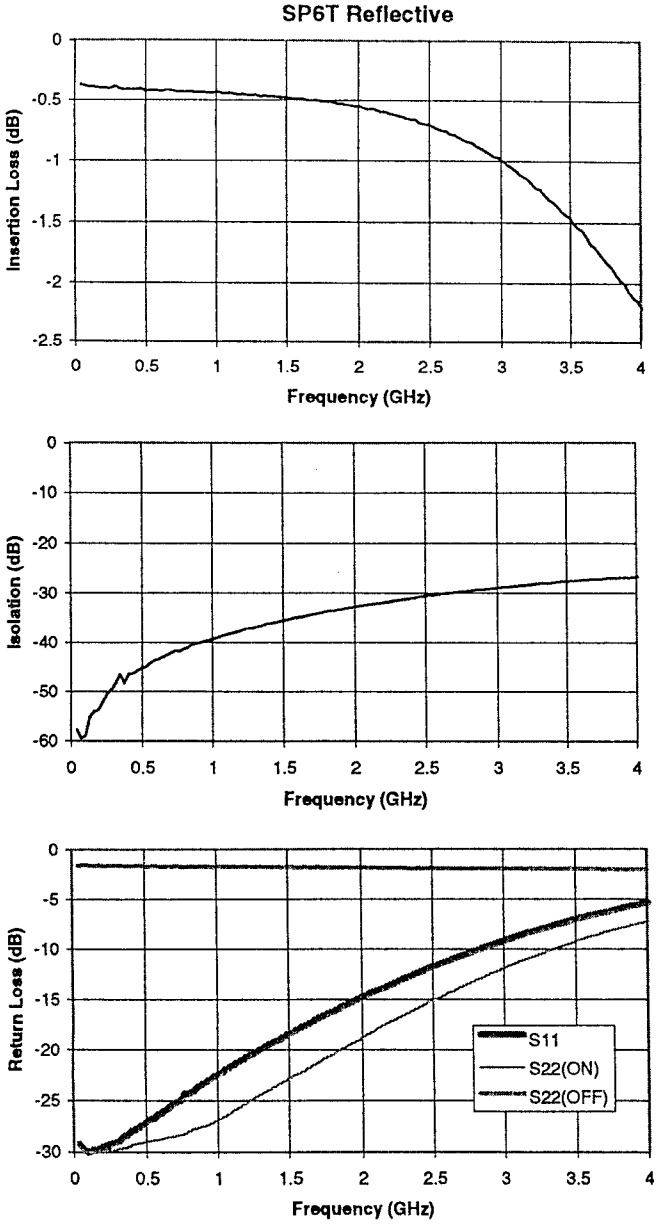

Figure 3. S-Parameter Response of SP6T Reflective Switch

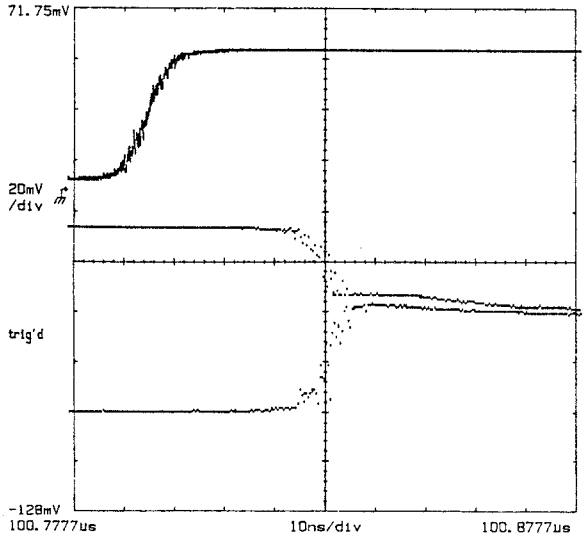

Figure 4. Switching Performance of SP6T Reflective Switch

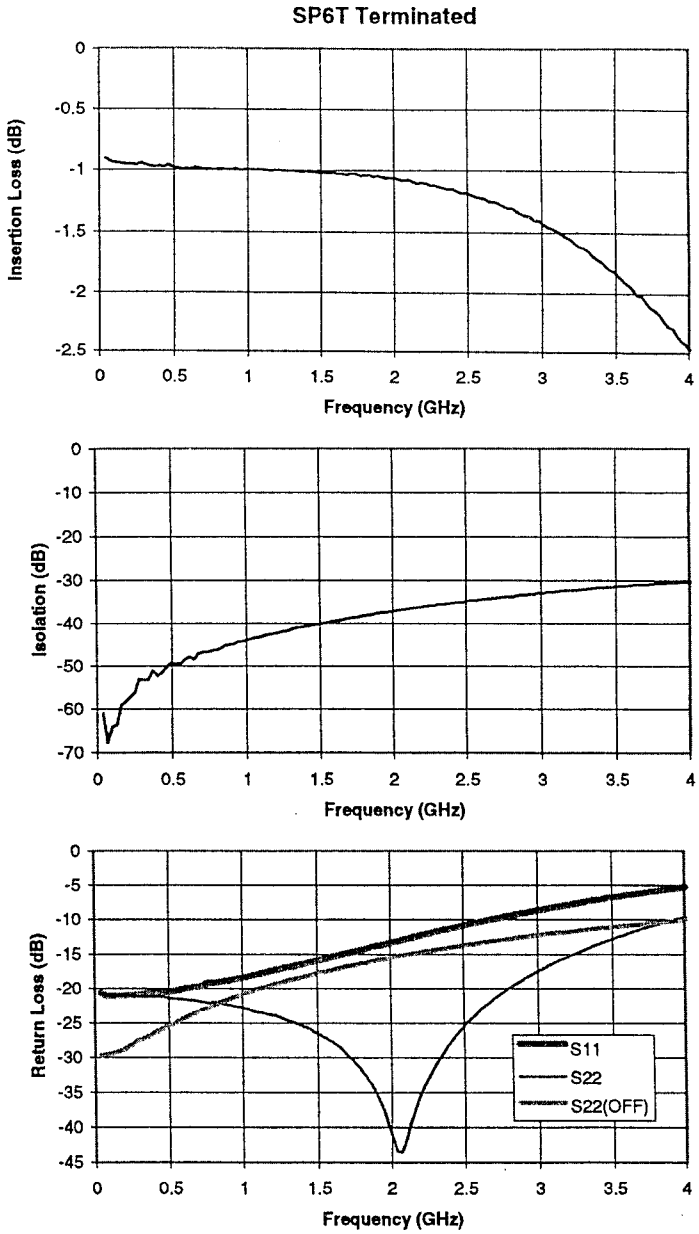

Figure 5. S-Parameter Response of SP6T Terminated Switch

DISCUSSION AND CONCLUSION

This paper describes the integration of SP4T, SP6T and SP8T microwave switches with on-board decoder/driver logic for the first time. By adding low power 2:4, 3:6 and 3:8 decoder/drivers on SP4T, SP6T and SP8T switches, 75% fewer control lines are required. This lowers die cost, improves RF performance and eases PCB integration. Both low loss reflective and high isolation terminated SPNT switches are discussed. Insertion losses range from 0.5-1.7dB, isolations range from 20-45dB, 1dB input power compressions range from 20-24dBm and single tone IP3s range from 40 to 42dBm at 2GHz.. The logic operates from -196°C to 125°C with supply voltages from 3-7V while consuming under 25mW of DC power. Low control current requirements allow for standard CMOS and TTL logic interfaces. Switching rates of several MHZ are possible. These switches demonstrate a higher level of integration than previously reported and find applications in cellular and PCS subsystems.

REFERENCES

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3. J.A. Eisenberg, et al, High Isolation 1-20GHz MMIC Switches With On-Chip Drivers", 1989 IEEE Monolithic Circuits Symposium Digest, pp. 41-45.

	RF PERFORMANCE @ 1GHz / 2GHz					
Description	Insertion Loss (dB)	Input Return Loss (dB)	Output Return Loss ON (OFF) (dB)	Isolation (dB)	Input Power for 1 dB Compression (dBm)	Input Third Order Intercept (dBm)
SP4T low loss	0.3/0.5	21/14	24/16 (1.2/1.4)	42/35	24	42
SP4T terminated	0.75/0.8	20/17	23/20 (26/23)	52/45	23	42
SP6T low loss	0.4/0.55	22/15	27/19 (1.7/1.8)	39/33	23	40
SP6T terminated	1.0/1.1	18/13	23/42 (21/16)	44/37	22	40
SP8T low loss	0.7/0.9	21/14	24/17 (2.5/2.6)	40/34	20	40
SP8T terminated	1.0/1.4	19/13	19/15 (22/20)	55/44	20	40

Table 2. SPNT Switch Die RF Performance Summary @ 25°C.

		RF PERFORMANCE @ 1 GHz / 2 GHz			
Description	Package	Insertion Loss (dB)	Input Return Loss (dB)	Output Return Loss ON (OFF) (dB)	Isolation (dB)
SP4T low loss	SOIC 14 pin	0.5/1.0	20/11	23/11	32/24
SP4T terminated	SOIC 14 pin	0.8/1.2	19/13	19/13 (17/16)	38/30
SP6T low loss	QSOP 24 pin	0.6/1.3	21/14	21/15	27/20
SP8T terminated	QSOP 24 pin	1.3/1.7	15/8	17/12	40/32

Table 3. Packaged SPNT Switch RF Performance Summary @ 25°C.

	SWITCHING CHARACTERISTICS		BIAS REQUIREMENTS @ -5V	
Description	TR/TF 10% - 90% (nsec)	50% Control On/Off to 10% - 90% (nsec)	Driver Current (mA)	Control Current (µA @ 0Vstate)
SP4T low loss	50/10	90/40	3	<155
SP4T terminated	35/15	65/45	3	<170
SP6T low loss	25/10	50/40	4	<180
SP6T terminated	25/10	50/40	4	<185
SP8T low loss	20/20	55/40	5	<170
SP8T terminated	20/20	55/40	5	<165

Table 4. SPNT Switch Performance Summary @ 25°C.