LOW VOLTAGE, HIGH POWER T/R SWITCH MMIC USING LC RESONATORS

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ABSTRACT

A novel T/R switch for high-power/ low-distortion operation at low control voltage is proposed. LC-resonant switches composed of inductors, capacitors, and switching FET's are incorporated in the TX and RX arms to provide a reverse control scheme which removes the RF voltage limitation in the transmit mode. An LC-resonant T/R switch with total periphery of 2.88 mm exhibits 3-rd IMR less than -40 dB for input power up to 28 dBm when controlled at 0V/-2V.

INTRODUCTION

The maximum input power of conventional series/shunt FET T/R switches are limited by the "off" state shunt FET in the TX arm and series FET in the RX arm due to RF voltage limitation, as well as by the "on" state series FET in the TX arm due to RF current limiting. The linearity when the TX arm is "on" (Transmit mode) depends strongly on the RF voltage swing across drain/source and gate of the "off" state FET. Therefore, higher breakdown voltage FET's, higher control voltage, and RF voltage distribution by stacking FET's are necessary for conventional T/R switches to offer high power/ low distortion operations[1-5].

This paper proposes a novel T/R switch that uses an FET-switchable LC resonator composed of spiral inductors, MIM capacitors, and switching FET's, that is incorporated in the TX and RX arms. The most significant advantage of the switchable LC resonator is to provide a reverse control scheme: the LC-resonator is "off" when the switching FET's are "on" and vice versa, effectively removing the RF voltage swing in the "off" state FET's in conventional T/R switches. A 1.9 GHz LC-resonant T/R switch MMIC with total GaAs FET periphery of 2.88 mm exhibits third IMR less than -40 dB for transmit power up to 28 dBm at 0V control voltage. Another control voltage of -2V is used for the receive mode.

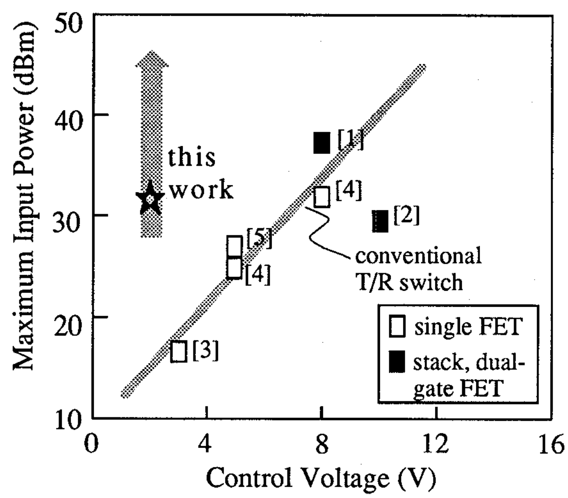

Fig. 1 Maximum input power comparison between the proposed LC-resonant T/R switch and conventional series/shunt FET T/R switches. Total FET peripheries of the proposed and referred switches are: 2.88 mm; 5.2 mm [1]; 3.5 mm [2]; 0.65 mm [3]; 4.7 mm [4]; 2.4 mm [5].

MAXIMUM INPUT POWER COMPARISON

Figure 1 shows the maximum input power comparison at 1 dB gain compression between the proposed and conventional FET T/R switches. The maximum input power is a factor relating to the linearity of T/R switches. An LC-resonant T/R switch permits an RF input power greater

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than 30 dBm in the transmit mode when controlled at 0V/-2V. The achieved maximum input power is 5 dB higher than conventional T/R switches with the same FET periphery, and 15 dB higher than conventional switches operating at similar control voltages (-3V/0V). A wider FET periphery in the proposed T/R switch offers higher RF input power: whereas, conventional T/R switches do not increase the capability because of RF voltage limiting even when using wider FET peripheries.

T/R SWITCH DESIGN

Figure 2 shows a typical T/R switch scheme composed of switches SW-a, SW-b, SW-c, and SW-d. Since switching FET's in SW-a and SW-c are "off" in the transmit mode for conventional series/shunt FET T/R switches, the RF voltage swing between drain/source and gate has to be less than $|V_b - V_p| / 2$ for linear operation of the T/R switch. Therefore, a higher breakdown voltage FET and higher control voltage are required as transmit power increases.

The problem is solved by incorporating an LC resonant switch which provides SW-a and SW-c with on-state switching FET's in the transmit mode. A proposed FET-switchable LC-resonant circuit is shown in Fig. 3, where a pair of FET switches (FET SW1, SW2) are combined with an inductor and capacitors. The LC-resonant circuit is open ("off") between ports ① and ② when the FET switches are in the "on" state because of the parallel resonance of inductor L and capacitor C_1. On the other hand, the circuit allows the signal to pass ("on") between ports ① and ② when the FET switches are in the "off" state because of the series resonance of inductor L and capacitors C_2 and C_s. When the FET switches are ideal and include no parasitics, the values of C_1 and C_2 are designed equal in order to provide the same resonant frequency in both FET states of the switching operation. However, since the stray capacitance, C_s, between FET drain and source is not negligible, capacitors C_1 and C_2 are designed to satisfy the following equation:

$$C_2 + C_s + C_1 C_s / (C_1 + C_s) = C_1.$$

There are three other LC-resonant circuit schemes considered. The circuit in Fig. 3 is used because of the smallest insertion loss.

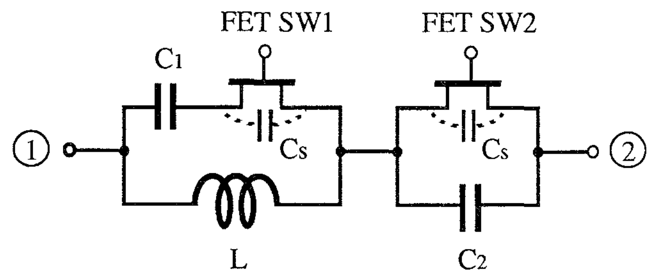
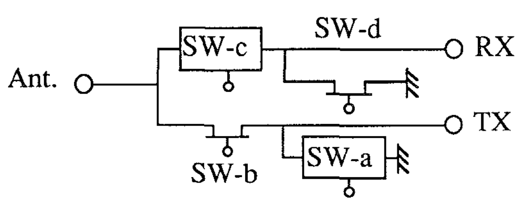


Fig. 3 FET-switchable LC-resonant circuit scheme



SW-a &c	State of FET's in SW-				Required FET perf.
	a	b	c	d	
Proposed LC resonator	ON	ON	ON	ON	Current proof
Conventional FET switch	OFF	ON	OFF	ON	Current & Voltage proof

Fig. 2 A typical T/R switch scheme and state of the switching FET's in SW-'s for proposed and conventional T/R switches in Transmit mode

Figure 4 shows a T/R switch incorporating the FET-switchable LC resonator. The LC resonators are used as a shunt switch in the TX arm and as a series switch in the RX arm. The series switch in the TX arm and the shunt switch in the RX arm are single FET switches. The LC resonators are positioned in places where a large RF voltage swing is applied in the transmit mode. In as much as all FET's in the transmit mode are in the "on" state (Vcont=0V), the RF voltage swing across the FET drain and source is negligibly small, that is, the T/R switch operates free from the RF voltage swing. A control voltage as small as twice the FET pinch-off voltage (Vp) is enough to switch from the transmit mode to the receive mode. Therefore, the maximum transmit power can be increased only by increasing the switching FET periphery and without any device improvement in breakdown voltage.

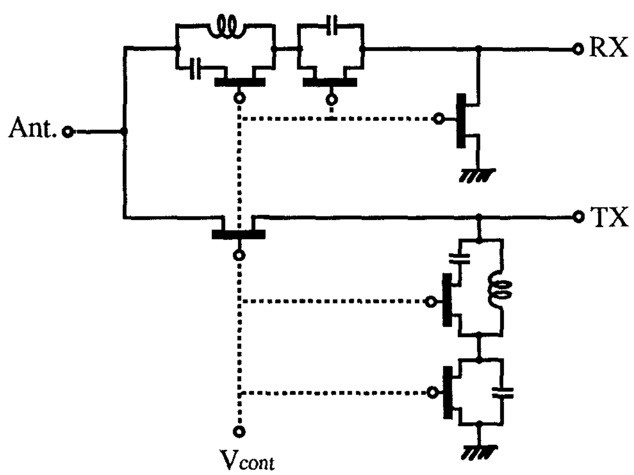


Fig. 4 Circuit scheme of a T/R switch incorporating FET-switchable LC-resonant circuits

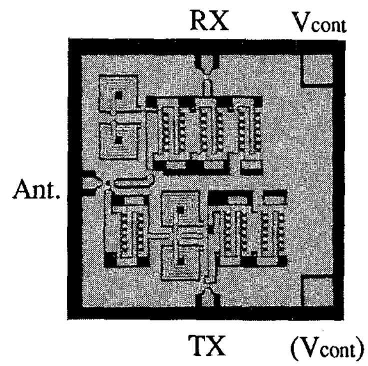


Fig. 5 Photograph of a fabricated LC-resonant T/R switch MMIC. Six switching FET's each of which has an FET periphery of 0.48 mm, a pair of 7 nH spiral inductors and MIM capacitors are integrated on a 2 mm x 2 mm x 0.6 mm GaAs chip.

The T/R switch MMIC is fabricated using uniplanar MMIC technology as shown in Fig. 5. The Q factor of the spiral inductor at 1.9 GHz is about 17. The RF current through the switching FET's of the LC resonator does not exceed the RF current through the switching FET's in a conventional T/R switch when the inductor value is less than 8.5 nH, because the loaded Q of the resonator is less than 1 at the inductor values.

MEASURED RESULTS

The linearity of the LC-resonant T/R switch in a two-tone measurement is shown in Fig. 6 compared with that of a conventional FET T/R switch, in which a pair of stacked FET's are used instead of the LC resonators in Fig. 4. These T/R switches are controlled at 0V or -2V/0V and the total FET periphery of the T/R switches is 2.88 mm. The LC-resonant T/R switch (solid lines) is linear enough to exhibit 3rd-IMR less than -40 dB for an input power up to 28 dBm. Whereas, with the conventional switch (dashed lines) the linearity degrades above 16 dBm input power. Even when controlled at -5V/0V, the linearity is degraded by the RF voltage swing above 24 dBm.

Figure 7 shows the measured frequency response of the proposed T/R switch in the transmit mode. An insertion loss of less than 1.5 dB, an isolation greater than 35 dB, and a return loss of better than 15 dB were measured between 1.8 GHz and 2.0 GHz. The frequency range is tuned to 1.9 GHz applications. Figure 8 shows the frequency response in the receive mode measured at control voltages of -2V (black lines) and -5V (gray lines). Very little difference between the two control voltages is observed.

The power handling capability of the proposed T/R switch in the transmit mode is shown in Fig. 9. The output power curve is linear for an input power up to 32 dBm, and the isolation does not show any degradation at the highest input power level.

CONCLUSION

The ability of the LC-resonant T/R switch to control high levels of power with low distortion even at low levels of DC voltage makes it ideally suited for transmit/receive switch applications in hand-held, battery powered communications equipment. Furthermore, this ability is believed to offer high power switchings at millimeter-wave frequencies where breakdown voltage of active devices is low.

ACKNOWLEDGMENTS

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[3] M. J. Schindler and A. M. Moris, "DC-40 GHz and 20-40 GHz MMIC SPDT switches," IEEE Microwave and Millimeter-Wave Circuit Symposium Dig. 1987, pp. 85-88.

[4] DC-6 GHz GaAs SPDT switch (SW-200): product of Adams Russel.

[5] DC to 6-GHz SPDT FET switch (TGS8704): product of Texas Instruments.

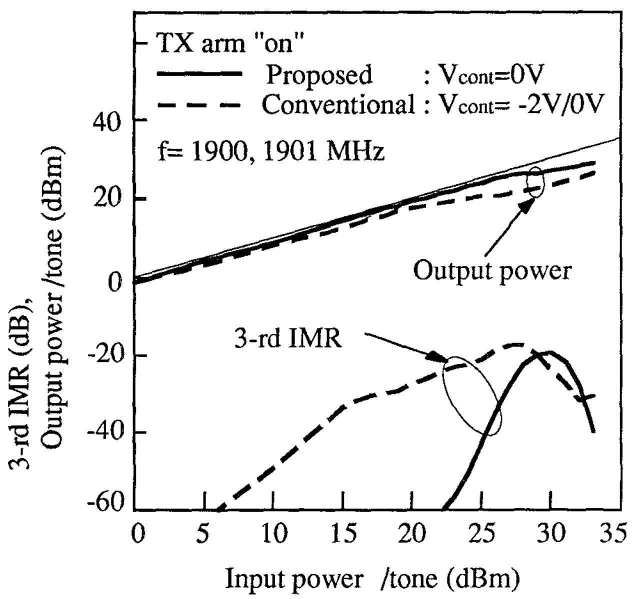

Fig. 6 Comparison of linearity between the proposed LC-resonant T/R switch and a conventional T/R switch with stacked FET's in Transmit mode. The FET periphery of both switches is 2.88 mm.

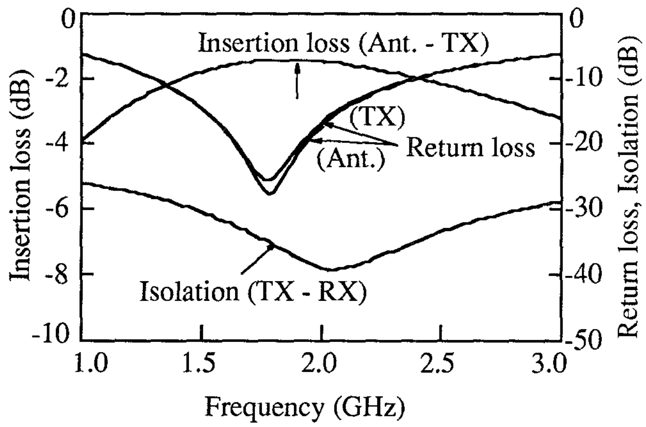

Fig. 7 Frequency response of the LC-resonant T/R switch in Transmit mode. Vcont is 0V.

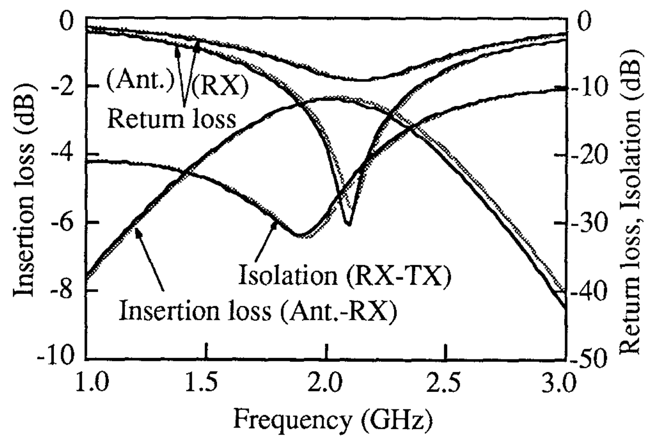

Fig. 8 Frequency response of the LC-resonant T/R switch in Receive mode. Vcont is -2V (black line) and -5V (gray line).

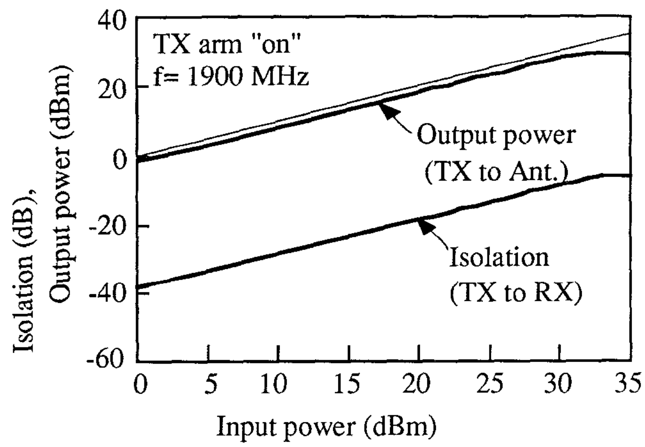

Fig. 9 Power handling capability of the proposed LC-resonant T/R switch in Transmit mode