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Design Comparison of RF SPDT Switch with Switchable Resonators for WiMAX and LTE in 3.5 GHz Band

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Abstract

In this paper, a design comparison of RF SPDT switch with switchable resonators for WiMAX and LTE in 3.5 GHz was reported and discussed. Four SPDT switch designs were compared to each other in terms of isolation, return loss, insertion loss, number of utilised PIN diodes, and absorptive feature. The first SPDT switch design, Design 1, used a two-cascaded switchable transmission line stub resonators. The second, Design 2, utilised a two-cascaded switchable radial stub resonators. The third, Design 3, was based on three-cascaded switchable parallel coupled lines and a single radial stub resonator. Design 4 was based on three-cascaded switchable rings and a single radial stub resonator. As a result, Design 4 showed a very good simulated and measured isolation, return loss and insertion loss at the operation frequency of 3.5 GHz. Besides, Design 4 resulted with the highest isolation with an absorptive feature.

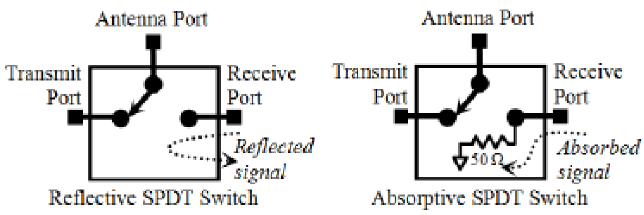
Keywords: SPDT, RF switch, absorptive SPDT switch, switchable resonator, ring resonator, parallel-coupled resonator

INTRODUCTION

Radio Frequency (RF) switch such as Single Pole Double Throw (SPDT), is one of the key components in the RF front-end system. It is commonly used in wireless data communication for Time Division Duplex (TDD) switching. One of the key parameters in SPDT switch design is the requirement of a high isolation between the transmitter and the receiver in order to minimise any high RF power leakage [1]. There are two types of SPDT switch; reflective and absorptive. As illustrated, Figure 1 shows the switching operation during the transmission mode for both reflective and absorptive RF SPDT switch.

Nowadays, the utilisation of switchable resonators in RF switch designs has gained interest. Several types of switchable resonators such as coupled line resonator [2], stepped impedance resonator (SIR) [3], [4], hairpin resonator [5], quarter wavelength transmission line resonator [6], [7], ring resonator [8], and transmission line stub resonator [9 -10] are used in RF switch designs.

In 2012, Phudpong [11] introduced an absorptive SPDT switch for WiMAX technology. However, the technique used in this switch required extra switching elements, such as PIN diodes and 50 Ω resistors.



(a) (b)

Figure 1: Switching operation during transmit mode for (a) Reflective SPDT switch and (b) Absorptive SPDT switch.

In our previous research works in [7],[12],[13]and[14], we proposed RF SPDT switch by using switchable stub resonators (transmission line stub and radial stub) and with switchable matched lossy resonators (parallel coupled line and ring). The use of a switchable parallel coupled resonator [13] and a switchable matched ring resonator [14] could provide an absorptive feature without the need of extra elements if compared to [11]. On the other hand, the use of a switchable transmission line stub resonator [7] and a switchable radial stub resonator [12] could provide high isolation for SPDT switch but cannot produce an absorptive feature. In this paper, a performance comparison was carried out of our reported SPDT switch designs by using these four different types of resonators.

SPDT SWITCH USING SWITCHABLE RESONATORS

A few years ago, several research works on SPDT switch designs by using different techniques were published. The research works were SPDT switch with two-cascaded switchable transmission line stub resonators (Design 1) [7], SPDT switch with a two-cascaded switchable radial stub resonators (Design 2) [12], SPDT switch with a three-cascaded switchable parallel coupled lines and single radial stub

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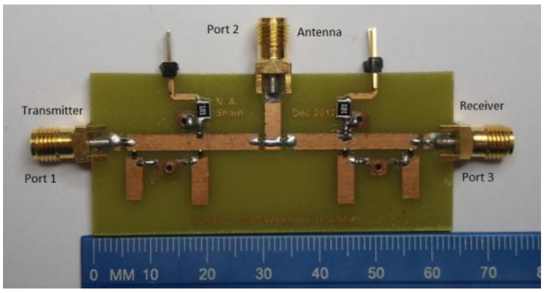
resonator (Design 3) [13] and SPDT switch with three cascaded switchable rings and single radial stub resonator (Design 4) [14]. The four switches were designed for WiMAX and LTE in 3.5 GHz band. Figure 2 illustrates the prototypes of SPDT switches with different switchable resonators.



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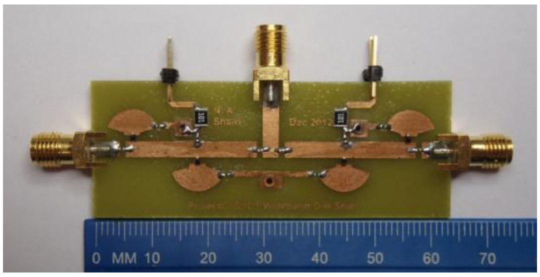

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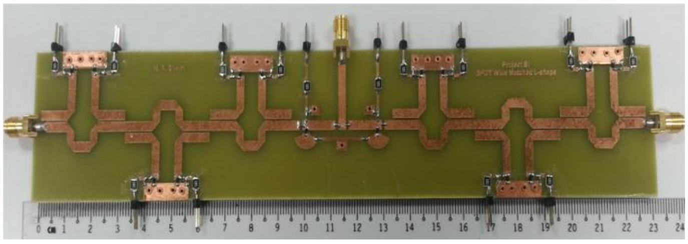

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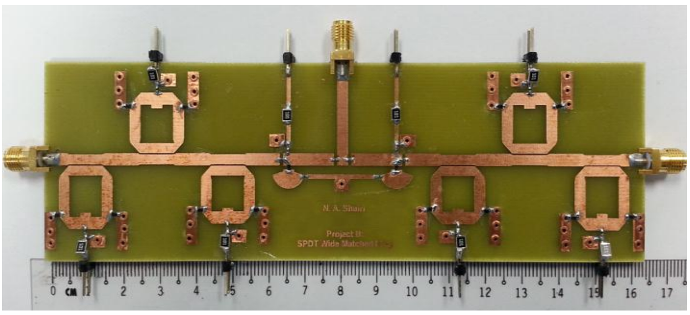


(d)

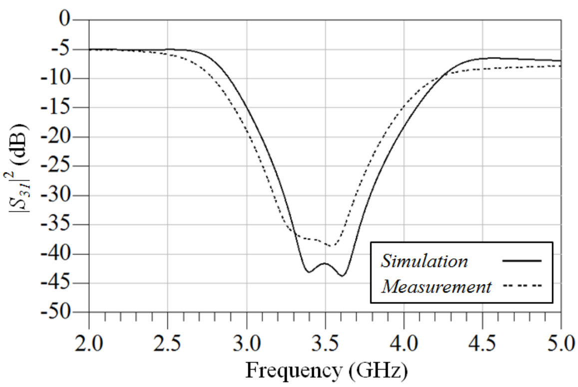
Figure 2: The prototype of SPDT switch with cascaded switchable (a) transmission line stub resonators [7], (b) radial stub resonators [12], (c) parallel coupled lines and single radial stub resonator [13], (d) rings and single radial stub resonator [14].

PERFORMANCE COMPARISON OF SPDT SWITCH DESIGNS

A. Isolation Performance

As illustrated in Figure 3 and Table 1, it was found that by using either switchable transmission line stub resonators, radial stub resonators, parallel coupled lines along with radial stub resonator or rings, and single radial stub resonator, all resonators were able to produce high and wide isolation bandwidth, in which more than -30 dB was obtained from 3.4 to 3.6 GHz. In the simulation result, Design 4 produced the highest isolation (-80 dB), while Design 2 showed a higher isolation than the other designs in measurement result.

However, all the SPDT switch designs produced a very good isolation performance (> -30 dB) and could meet the specification [15], [16], [17]. Therefore, Design 1, Design 2, Design 3 and Design 4 were successfully demonstrated for WiMAX and LTE high power applications in 3.5 GHz band. However, the slight difference in simulation and measurement results was because of substrate tolerances, active/passive components, parasitic capacitance and PIN diodes inductance [18], [19].



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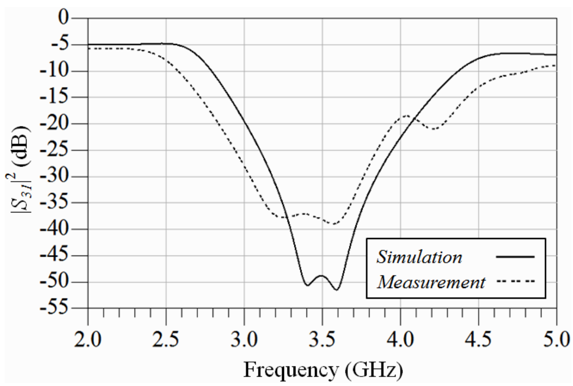

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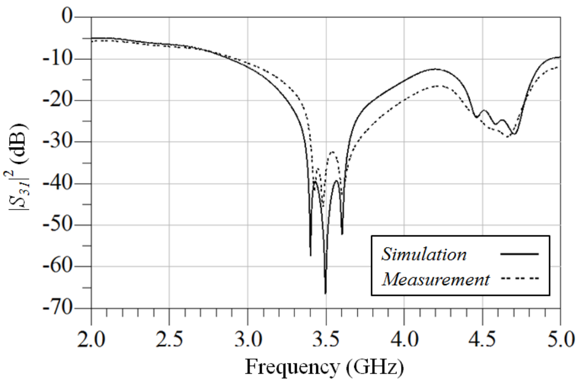

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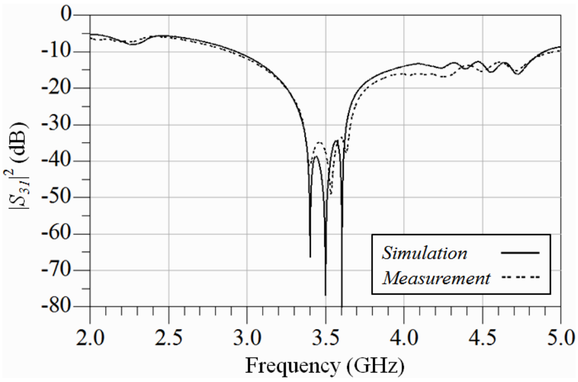

(d)

Figure 3: The isolation S_{31} performance of SPDT switch (a) Design 1 [7] (b) Design 2 [12] (c) Design 3 [13] (d) Design 4 [14].

Table 1: Summary of Simulation and Measurement Result of SPDT switch Designs

Designs		Insertion Loss (dB)	Return Loss at Port 1 (dB)	Isolation (dB)
Design 1 [7]	Simulation	-0.74 to -0.82	-29.88 to -23.22	-43.08 to -43.69
	Measurement	-1.46 to -1.86	-19.90 to -14.49	-37.45 to -36.89
Design 2 [12]	Simulation	-0.66 to -0.73	-31.30 to -25.54	-50.55 to -51.32
	Measurement	-1.44 to -1.71	-24.27 to -19.81	-37.05 to -38.67
Design 3 [13]	Simulation	-1.72 to -1.87	-37.77 to -26.47	-57.51 to -52.35
	Measurement	-2.66 to -2.68	-27.90 to -26.62	-30.27 to -41.83
Design 4 [14]	Simulation	-1.41 to -1.51	-20.39 to -16.93	-66.53 to -80.97
	Measurement	-1.94 to -2.16	-19.49 to -16.80	-41.50 to -33.51

B. Absorptive Feature

Table 2 presents the return loss (S33) performance at absorptive port (Port 3) that was produced by different types of switchable resonators in SPDT discrete switch designs. It was observed that the use of a switchable transmission line stub resonator (in Design 1) and switchable radial stub resonator (in Design 2) produced a very low return loss at the unused port (Port 3) during transmit mode. These SPDT switches (Design 1 & 2) were kept as reflective switches, which meant that the unwanted signals were reflected by the switch.

In fact, in some cases the reflected power would lead to performance degeneration of adjacent circuit device components. Besides, this problem must be solved as there may be some applications that require good voltage standing wave ratio (VSWR) for all operating ports.

Table 2: Simulation and Measurement Result of SPDT switch Designs' Return loss

Designs		Return Loss at Port 3 (dB)	Technique
Design 1 [7]	Simulation	-1.08 to -1.04	Switchable transmission line stub resonators
	Measurement	-1.83 to -1.80	
Design 2 [12]	Simulation	-0.73 to -0.75	switchable radial stub resonators
	Measurement	-2.02 to -1.96	
Design 3 [13]	Simulation	-19.60 to -22.31	switchable parallel coupled lines and single radial stub resonator
	Measurement	-17.05 to -18.03	
Design 4 [14]	Simulation	-14.89 to -28.33	switchable rings and single radial stub resonator
	Measurement	-11.70 to -23.00	

However, the utilised techniques in Design 3 and Design 4 could solve the problem due to reflective signals. As listed in Table 2, it is clearly seen that the simulated and measured results of Design 3 and Design 4 showed a return loss (at Port 3) higher than -10 dB and met the specification [15],[16],[17].

Therefore, it was found that the use of one of the two techniques; parallel coupled lines and single radial stub resonator (Design 3) and switchable rings and single radial stub resonator (Design 4) produced an absorptive feature in SPDT switch. Moreover, these are new techniques that produce absorptive feature in SPDT switch without an additional absorptive circuit. As for the best of return loss performance (for measurement of S33), Design 4 produced the maximum return loss (S33) of -23 dB at 3.5 GHz as compared to the other designs in Table 2.

C. Number of PIN diodes

From Table 3, it is observed that Design 1 and Design 2 had equal number of PIN diodes and circuit size. They were designed by using less PIN diodes than Design 3 and Design 4. On the other hand, Designs 3 and 4 required a higher number of PIN diodes as compared to Design 1 and 2. This is a trade-off between high or wide isolation performance and the number of PIN diodes used, thus contributed to the circuit size as well. However, further reduction of circuit size was obtained by using a ring resonator (Design 4). In terms of percentage, 23.2% of size reduction was achieved by using ring resonator as compared to the parallel coupled line resonator (Design 3).

Table 3: Comparison of number of PIN diodes of all the SPDT switch Designs for WiMAX/LTE

	Circuit Size (*length* x *width* in mm)	**Number of PIN diodes**
Design 1 [7]	63 x 20 = 1260 mm^2	4
Design 2 [12]	63 x 20 = 1260 mm^2	4
Design 3 [13]	230 × 44 = 10120 mm^2	14
Design 4 [14]	162 × 48 = 7776 mm^2	14

CONCLUSION

This paper reported and discussed a comparison of SPDT discrete switch with switchable stub resonators (transmission line stub and radial stub) and with switchable matched lossy resonators (parallel coupled line and ring). In general, the isolation of more than -30 dB was achieved in the SPDT discrete switches by using these four types of switchable resonators that required a minimum number of PIN diodes or produced an absorptive feature in the designs. Amongst these compared SPDT switch designs, Design 4 produced the highest isolation at a resonant frequency of 3.53 GHz with an absorptive feature. In addition, all designs were demonstrated with the application of WiMAX and LTE in 3.5 GHz band.

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