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Design and Analysis of Selectable Multiband Isolation of SPDT Switch using Single Switchable Resonator

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ABSTRACT:

This paper proposes a selectable multiband isolation of Single Pole Double Throw Switch (SPDT) switch using single switchable resonator. The proposed SPDT switch was designed with functionality of selectable multiband isolation either in 2.3 or 3.5 GHz band. The key advantage of the proposed design is a multiband high isolation with compact circuit size. The design involves design and simulation using Advanced Design Software (ADS) and fabricated using FR4 board. Measurement was done for verification with simulation results. As a result, the simulated and measured results showed the return loss was more than 10 dB, insertion loss was less than 3 dB and isolation was higher than 25 dB in both 2.3 and 3.5 GHz bands. The proposed design is proposed for RF switch application such as multiband wireless communication system.

Keywords - Multiband, SPDT switch, switchable resonator, RF switch.

I. INTRODUCTION

Single Pole Double Throw switch (SPDT) is one type of the radio frequency (RF) switch as shown in Fig 1. It is used to switch signal between transmitting and receiving process to perform time division duplex (TDD) in RF front-end system such as WiFi, WiMAX and LTE [1]. For multiband wireless communications, the development of multiband sub-components (e.g. amplifiers, filters, switches and antennas) [2]–[6] are highly desired, and they were developed to support several RF front-end systems [7],[8].

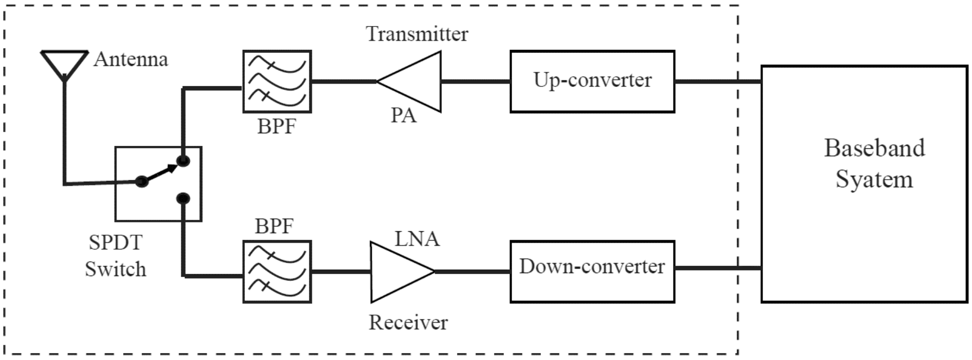

Fig 1: Application of SPDT switch in RF Front End System

RF switch functionality can be designed using micro-electro-mechanicals (MEMs) or solid-state elements such as PIN diode and Field Effect Transistor (FET). However, MEMs switches are not suitable for high- power applications due to their limited power capabilities [9]. Meanwhile, for PIN diodes or FETs, it has a unique variable resistance characteristic by utilizing small amount of voltage and current to control RF signal. Thus, PIN diode switch is more reliable compared to MEMs switches and widely used due to its fast switching speed, long lifespan and suitable for high- power applications [10], [11].

In modern wireless communication, there is a requirement for handling high power signals with low insertion loss, fast switching speed and high isolation performance in WiMAX systems (for example) where PIN diodes provide the required performance for WiMAX base-station applications [12]. On the other hand, multiband isolation is needed to support the multiband RF front-end system for different standards such as WiFi, WiMAX and LTE; or different spectrum allocations at various locations.

There are several popular techniques to improve isolation, such as multiples connection of shunt PIN diodes and combination of series-shunt-shunt PIN diodes. Shunt connected diode offers a better isolation performance for wider range of frequency and capable to handle more power since is it easier to heat sink the diode [13]. However, these will increase current consumption and overall circuit size [14]. Besides, switchable resonators also can be found in switch design by using shunt stub resonators. The bandstop response of the resonator provides additional isolation of SPDT switch [15]. Another technique is by using materials with fabrication process design. In this technique, the fabrication of PIN diode must have low capacitance because of the reactance of the diode during the OFF state must be large compared to the line impedance in order to get high isolation [16].

High isolation value between the transmitter and receiver in the RF front end system is an important parameter in the design SPDT switch, especially for high power applications. For a good isolation performance, it can prevent stray signals from leaking into the desired signal path. Hence, circuit design, resonant circuit and materials used for fabrication should take into consideration to improve the isolation performances. On the other hand, for discrete PIN diode, it is quite hard to get high isolation (>30 dB) when using only single PIN diode and usually multiple cascaded PIN diodes are required for high isolation performance [15].

Therefore, this paper proposes a selectable multiband isolation of SPDT switch using single switchable resonator in 2.3 or 3.5 GHz band. Discrete PIN diodes were used in the proposed design due to its advantage of higher power levels application. Thus, by using this technique (single switchable resonator) and together with discrete PIN diodes, the key advantage of the design is a multiband high isolation with compact circuit size as compared to previous research works [15].

II. CIRCUIT DESIGN

Fig 2 depicts the circuit operation of the selectable multiband isolation SPDT switch using switchable resonator. In this design, it could select the operation frequencies in two different conditions which are either 2.3 GHz (Condition 1) or 3.5 GHz (Condition 2). The SPDT switch was designed to route the RF signal between transmitter and receiver arms. There are 6 PIN diodes (BAP64-02 from NXP) in the SPDT switch circuit. PIN diodes for D1 until D4 are in shunt configurations while the D5 and D6 are in series configuration. The D1 until D4 were used to control the selection of resonator of S1, S2, S3 and S4 for bandstop response at 2.3 or 3.5 GHz.

In Condition 1 (2.3 GHz band) for the transmit mode, RF signals propagate from the transmitter (Tx) at Port 1 to the antenna at Port 2. Thus, Vbias 1 and Vbias 2 were supplied with voltage control of -5V and +5V respectively to turn OFF the D1 and D2; and the series connected PIN diode of D5 was in ON state (short circuited). In this condition, no operation for the resonator of S1 and S2. Hence, RF signals propagated from transmit port (Port 1) to antenna port (Port 2) with low insertion loss. In contrast, the receiver arm, Vbias 3 and Vbias 4 were supplied with voltage control of -5V and +5V respectively to turn ON the PIN diode of D3 and D4; and the series connected PIN diode of D6 was in OFF state (open circuited). In this condition, the combination of S3 and S4 created a bandstop response at 2.3 GHz and eventually providing additional isolation in the receive arm (between Port 1 and Port 3). For the receive mode, the voltage control of Vbias 1 until 4 are in opposite values compared to transmit mode operation. These two modes are summarized in Table 1.

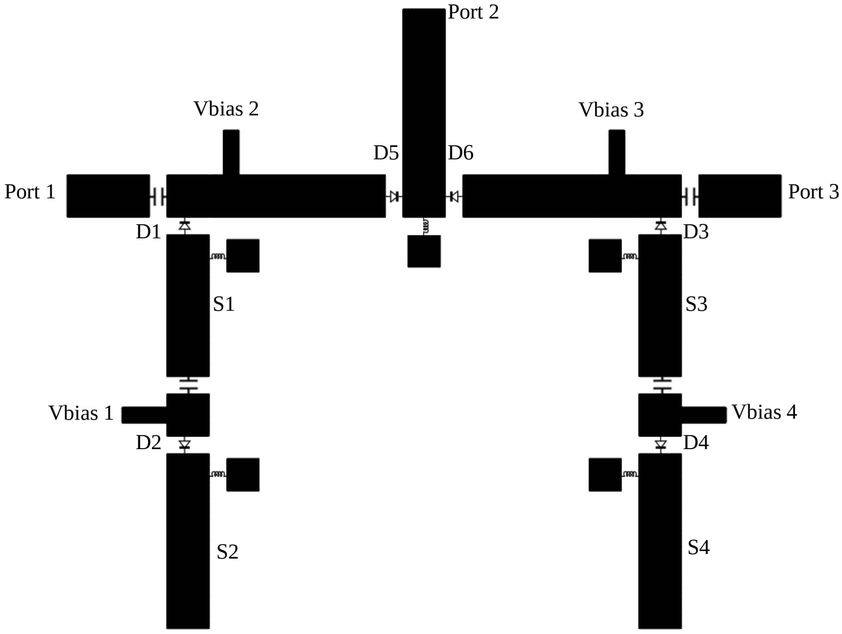

Fig 2: Circuit diagram of selectable multiband isolation SPDT switch using switchable resonator

In Condition 2 (3.5 GHz band) for the transmit mode, Vbias 1 and Vbias 2 were supplied with voltage control of -5V and +5V respectively to turn OFF the D1 and D2; and the series connected PIN diode of D5 was in ON state (short circuited). In this condition, no operation for the resonator of S1 and S2. Hence, RF signals propagated from transmit port (Port 1) to antenna port (Port 2) with low insertion loss. In contrast, the receiver arm, Vbias 3 and Vbias 4 were supplied with voltage control of -5V to turn ON the PIN diode of D3 only; and the D4 and the series connected PIN diode of D6 was in OFF state (open circuited). In this condition, the resonator of S4 was not functioning and only S3 created a bandstop response at 3.5 GHz. Hence, providing additional isolation (at 3.5 GHz) in the receive arm (between Port 1 and Port 3). For the receive mode, the voltage control of Vbias 1 until 4 are in opposite values compared to transmit mode operation. These two modes are summarized in Table 1.

Table 1: Summarization of the process during receiver and transmitter modes

		Transmit Mode	Receive Mode
Condition 1: Selecting 2.3 GHz	Vbias1	-5V	5V
	Vbias2	5V	-5V
	Vbias3	-5V	5V
	Vbias4	5V	-5V
	PIN Diode D1	OFF state	ON state
	PIN Diode D2	OFF state	ON state
	PIN Diode D3	ON state	OFF state
	PIN Diode D4	ON state	OFF state
	PIN Diode D5	ON state	OFF state
	PIN Diode D6	OFF state	ON state
	Resonator S1	No Response	(S1 + S2) Bandstop Response at 2.3 GHz
	Resonator S2	No Response	
	Resonator S3	(S1 + S2) Bandstop Response at 2.3 GHz	No Response
	Resonator S4		No Response
Condition 2: Selecting 3.5 GHz	Vbias1	-5V	-5V
	Vbias2	5V	-5V
	Vbias3	-5V	5V
	Vbias4	-5V	-5V
	PIN Diode D1	OFF state	ON state
	PIN Diode D2	OFF state	OFF state
	PIN Diode D3	ON state	OFF state
	PIN Diode D4	OFF state	OFF state
	PIN Diode D5	ON state	OFF state
	PIN Diode D6	OFF state	ON state
	Resonator S1	No Response	Bandstop Response at 3.5 GHz
	Resonator S2	No Response	No Response
	Resonator S3	Bandstop Response at 3.5 GHz	No Response
	Resonator S4	No Response	No Response

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III. RESULTS, ANALYSIS AND DISCUSSION

The circuit design of selectable multiband isolation SPDT switch was fabricated and the performance in terms of isolation, return loss and insertion loss were validated experimentally using the Network Analyzer. Fig 3 shows the prototype of the proposed SPDT switch. Simulation was conducted in ADS and the optimized dimensions of the resonators (*S1*, *S2*, *S3* and *S4*) were finalized before the fabrication of the design. Hence, the total dimension of the prototype (shown in Fig 3) is 45 mm x 48 mm. The circuit design was fabricated using FR4 substrate with the thickness of 1.6 mm and relative dielectric constant ε_r = 4 .7.

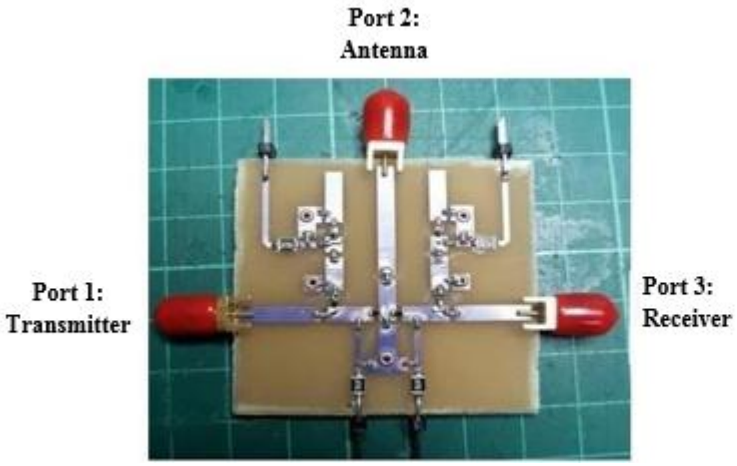

Fig 3: Prototype of the proposed SPDT switch

A. *Condition 1: Select 2.3 GHz*

Fig 4 shows the comparison between measured and simulated results of *S*-parameter in term of return loss, insertion loss and isolation. For Condition 1, which is selecting the 2.3 GHz band, the result for both simulation and measurement showed a good response of *S*-parameter. As depicted in Fig 4, generally, the return loss was higher than 10 dB, insertion loss was less than 3 dB and isolation was more than 25 dB.

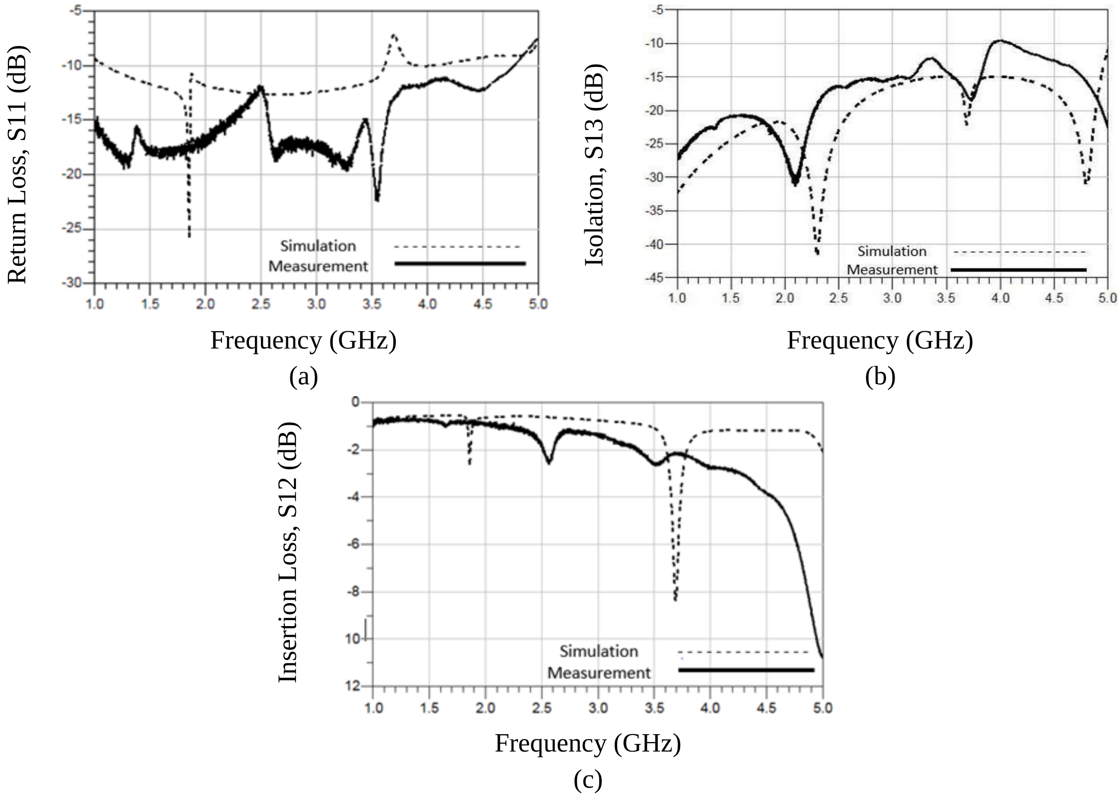

Fig 4: Comparison performance results between simulation and measurement of the proposed SPDT switch at 2.3 GHz band (a) return loss (S_{11}); (b) isolation (S_{13}); (c) insertion loss (S_{21})

However, there is a different between the measured and simulated result for isolation performance. At resonant of 2.3 GHz, the simulated isolation achieved 42 dB however the measured isolation is 20 dB. In simulated result, the resonant frequency of the resonator shifted to lower frequency at 2.1 GHz which successfully achieved high isolation of 32 dB. The resonant frequency shifted down is probably due to substrate tolerance, parasitic inductance and capacitance during fabrication and soldering process of the prototype. The summary of the results is listed in Table 2.

Table 2: Performance results in 2.3 GHz band

Selectable SPDT Switch		Isolation (dB)	Insertion Loss (dB)	Return Loss(dB)
2.3 GHz	Simulation	42	0.6	12.5
	Measurement	20	1.1	14.5

B. Condition 2: Select 3.5 GHz

Fig 5 shows the comparison between measured and simulated results of *S*-parameter in term of return loss, insertion loss and isolation. For Condition 2, which is selecting the 3.5 GHz band, the result for both simulation and measurement showed a good response of *S*-parameter. As depicted in Fig 5, generally, the return loss was higher than 10 dB, insertion loss was less than 3 dB and isolation was more than 20 dB.

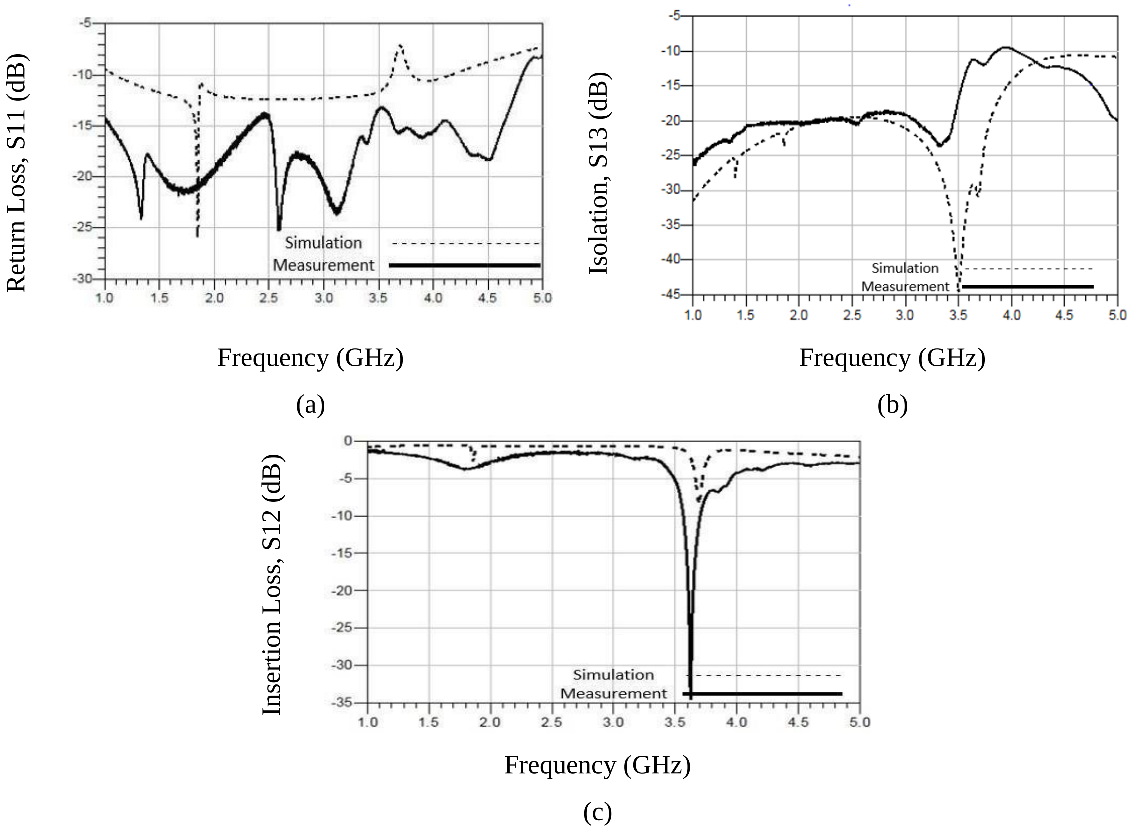

Fig 5: Comparison performance results between simulation and measurement of the proposed SPDT switch at 3.5 GHz band (a) return loss (S_{11}); (b) isolation (S_{13}); (c) insertion loss (S_{21})

The performance comparison of return loss, insertion loss and isolation in 3.5GHz between simulated and measured results are listed in Table 3.

Table 3: Performance results in 3.5 GHz band

Selectable SPDT Switch		Isolation (dB)	Insertion Loss (dB)	Return Loss (dB)
3.5 GHz	Simulation	46	0.9	11.7
	Measurement	17	5.2	13.5

Furthermore, for the isolation performance of the SPDT switch, there is a different between the measured and simulated results. At resonant of 3.5 GHz, the simulated isolation between transmitter and receiver arm was 46 dB, however the measured isolation at the same frequency was 17 dB. However, as shown in Fig 5(b) the measured resonant frequency for isolation shifted to lower frequency at 2.1 GHz and the isolation was 24 dB. The insertion loss also showed the shifted frequency where the measured insertion loss was 5.2 dB. The resonant frequency shifted down is probably due to substrate tolerance, parasitic inductance and capacitance during fabrication and soldering process of the prototype.

IV. CONCLUSION

A SPDT switch with single switchable resonators for selectable multiband isolation was successfully simulated and validated with measured result in 2.3 and 3.5 GHz bands. This proposed design allows selecting only one band and unselecting another band for two different application or frequency standard. The design was simulated in ADS software and fabricated on the FR4 board. As a result, the designs showed >20 dB isolation, <3 dB insertion loss and >10 dB return loss in 2.3 and 3.5 GHz bands. This design is proposed for multiband RF front-end system such as WiMAX, LTE of 5G technology.

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