Significantly Enhanced Isolation of SPDT Switch Using Punched Hole Structure

Sang-Hyun Park and Young-Wan Choi

***Abstract*—Experimental results of a series-connected single pole double throw (SPDT) switch in a novel punched-hole-structure (PHS) are presented. In the PHS, the dielectric and ground layers are punched out in a specific size from the micro strip line, and diodes are placed over the punched holes to connect the microstrip lines. Radio performance of the novel SPDT switch can be improved due to additional L-C parameters introduced by the punched holes. When the radius of punched hole is the same to the width of microstrip line, 0.03 λ_c (λ_c: wavelength of 2.7 GHz), the implemented SPDT switch shows an increase of about 20-dB isolation between two output ports, compared to a conventional SPDT switch without holes. Furthermore, by tuning capacitors around the punched holes, the operating frequency band can be widened by approximately 250% in our SPDT.**

***Index Terms*—Conducting wire, insertion loss, isolation, operating frequency band, PIN diode, punched hole structure, SPDT switch.**

I. Introduction

In general, conventional single pole double throw (SPDT) switch has had problems such as high insertion loss, low isolation between ports, narrow operating frequency band, and high current consumption. When many diodes are applied to improve isolation of SPDT switch, insertion loss is increased and power efficiency according to the bias condition are decreased because the performance of conventional SPDT switch depends on the characteristics of active devices, i.e. diodes. Recently, RF components using the defected ground structure (DGS) have been reported [1]–[3]. However, most of researches on DGS are to show the validity of modeling of DGS circuit rather than its applications in microwave or millimeter-wave components.

In this letter, a novel SPDT switch employing a periodic punched-hole-structure (PHS) is presented. The PHS is realized by making periodic holes of a certain size in the microstrip line, dielectric layer, and ground layer, and by connecting wires with a certain size of diameter over the punched holes. Here, the diameter of the hole is greater than the width of the microstrip line. Due to its additional L-C parameters determined by the diameter of hole, characteristics of PHS are similar to that of microstrip photonic band gap (PBG) [4]–[6]. Generally, PBG materials are periodic structure capable of prohibiting the propagation of all electromagnetic waves within a certain band frequency. In our novel SPDT switch, the wires in the PHS are replaced by PIN diodes. In order to show the effect of the hole size on the radio performance, SPDT switches with different hole sizes are fabricated. Their experimental results are sufficient to show the validity of PHS and its applications.

Manuscript received May 7, 2002; revised July 4, 2002. This work was supported by the Chung-Ang University ITRI Research Fund. The review of this letter was arranged by Associate Editor Dr. Shigeo Kawasaki.

S.-H. Park and Y.-W. Choi are with the Laboratory of Microwave-Photonics, Department of Electrical and Electronics Engineering, Chung-Ang University, Seoul, Korea (e-mail: hanque2@hotmail.com; shpark@aceteq.co.kr).

Digital Object Identifier 10.1109/LMWC.2002.807700

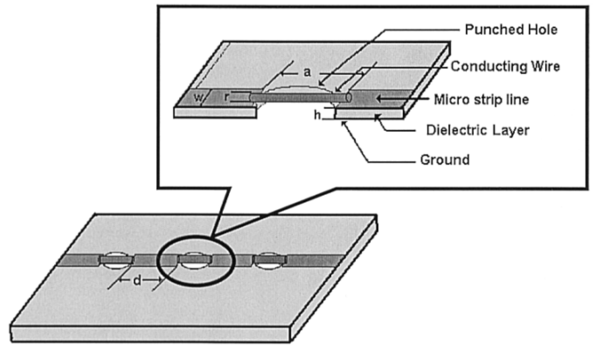

Fig. 1. Proposed unit PHS structure.

II. Structure and Characteristics of Microstrip Line With PHS

Fig. 1 shows the novel microstrip line with PHS, in which wave cannot propagate when it comes up to the punched hole with a specific size. Instead of wave, induced current goes only through conducting wire over punched hole. If the conducting wire over ground is designed to keep the 50-Ω characteristic impedance of microstrip line, propagation constant of wave is similar to that of general microstrip line. However, the size of punched hole and conducting wire disturb the field distribution and wave propagation in the microstrip line with PHS. This structure can change characteristics of transmission line such as line capacitance and inductance [2], [3]. When the microstrip line has periodic punched holes, this structure has PBG property due to its effective additional L-C parameters. To demonstrate the effectiveness of PHS, the radius of the punched hole is determined with the same size of the microstrip width. The period of punched hole is determined by center frequency and propagation constant [7]. The period of punched hole used in this work is three times of the punched hole diameter.

In this work, we use the TLX9-0200-C1/C1 board of Taconic Company. The relative dielectric constant (ε_r) is 2.5, the thickness of dielectric layer $(\boldsymbol{h})$ is 0.5 mm, and the diameter of the punched hole $(\boldsymbol{a})$ is 3.3 mm. The periodic distance of punched hole $(\boldsymbol{d})$ is 6.6 mm. The width of microstrip line $(\boldsymbol{w})$ is 1.65 mm. The diameter of conducting wire $(\boldsymbol{r})$ is 0.3 mm and its characteristic impedance is designed to have 50 Ω. These values are calculated using APPCAD tool. The characteristics of microstrip

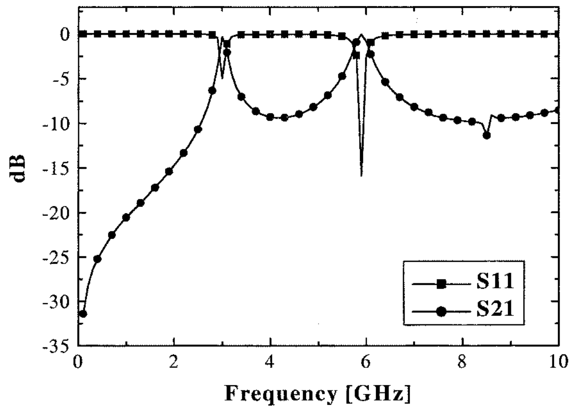

Fig. 2. Simulated characteristics of proposed PHS.

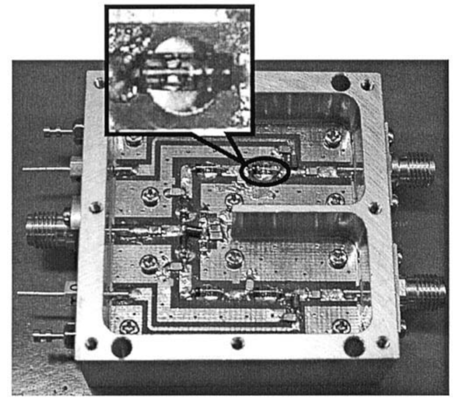

Fig. 3. Implemented SPDT switch with PHS. The captured figure shows that diode is placed over Punched hole.

TABLE I
DESIGN GOAL OF SPDT SWITCH WITH PHS

Frequency Range	1.8GHz ~ 2.4GHz
Insertion Loss	Below 1.0dB
Return Loss (Input / Output)	Below -15dB (below 1.5:1)
Isolation between ports	Above 50dB
Current Consumption	Less than 7Vx80mA

line with three-stage PHS are obtained by using HFSS v.6.0. According to the simulation result in Fig. 2, the PHS has similar characteristics to a bandpass filter with resonance frequency at 2.95 GHz and 5.9 GHz. Therefore, it is believed that microstrip line with PHS is useful for RF components to increase the isolation and to reduce the harmonics.

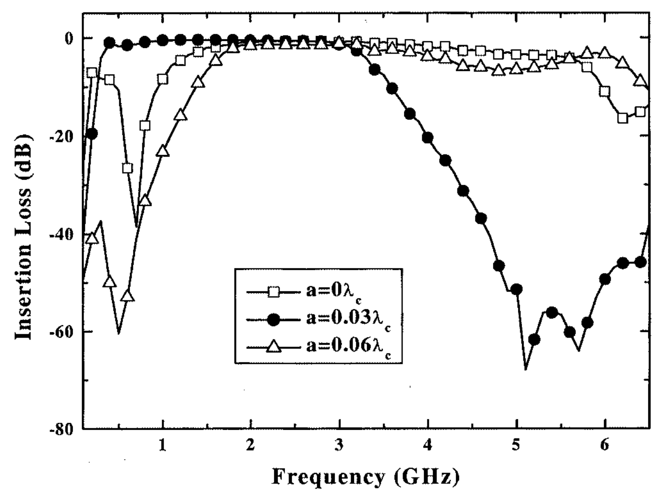

Fig. 4. Insertion Loss of SPDT switch according to diameter of punched hole.

III. FABRICATION OF SPDT SWITCH WITH PHS AND MEASUREMENTS

In order to design a novel SPDT switch with the proposed PHS, PIN diode of Agilent 5082-3039 is employed instead of the conducting wire line in Fig. 1. When bias voltage is supplied to PIN diodes, leakage electric field around punched hole is less than the electric field induced from electric current through the PIN diode. It helps to improve the isolation. Also, the characteristics like the bandpass filter as shown in Fig. 2 suppress the harmonics of SPDT switch. Our design goal for SPDT switch is summarized in Table I. In order to investigate the effectiveness of punched hole, we fabricated three kinds of SPDT switches varying the size of punched hole. When λ_c is the wavelength for the center frequency of 2.7 GHz, the diameter of each punched hole is 0 λ_c, 0.03 λ_c, and 0.06 λ_c. The diameter of $\boldsymbol{a} = 0\ \lambda_c$ means that the implemented SPDT switch is a conventional one. When $\boldsymbol{a} = 0.03\ \lambda_c$, the diameter of hole is twice of the microstrip line width. For performance comparisons, we measured the isolation, insertion loss, and return loss. Because of parasitic L-C parameter around the punched hole, resonance frequency is shifted and pass band are widened by additional capacitor. The fabricated SPDT switch with $\boldsymbol{a} = 0.03\ \lambda_c$ hole is shown in Fig. 3.

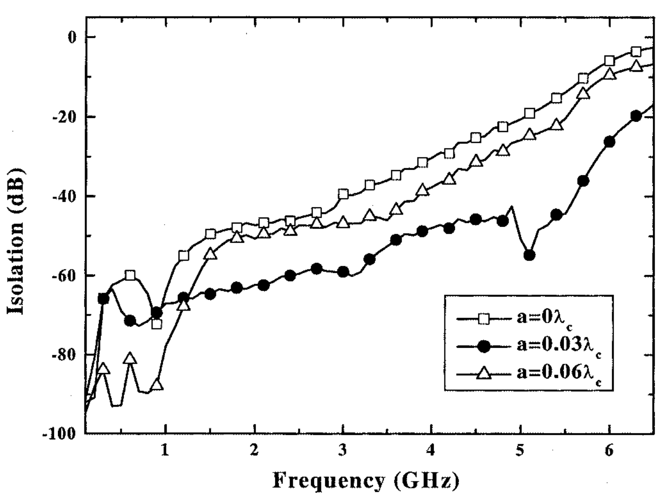

Fig. 5. Isolationof SPDT switch according to diameter of punched hole.

IV. RESULTS

-factor related to operating bandwidth is decreased. Results of measured isolation, insertion loss, and return loss of implemented SPDT switches are shown in Figs. 4–6. When $\boldsymbol{a} = 0.03\ \lambda_c$, at 2.3 GHz, insertion loss is 0.6 dB, and return loss

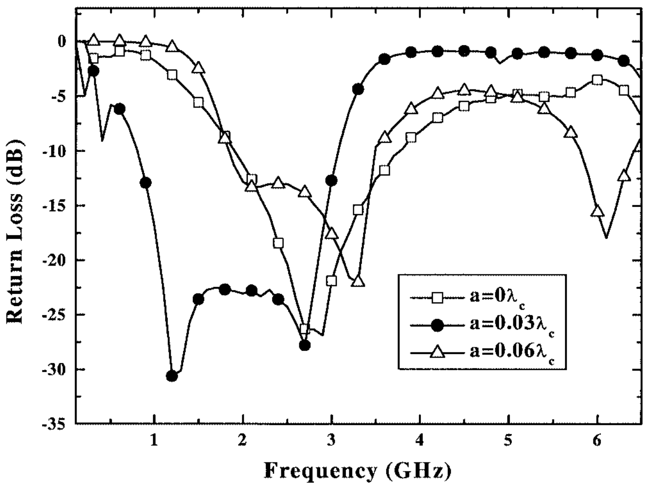

Fig. 6. ReturnLoss of SPDT switch according to diameter of punched hole.

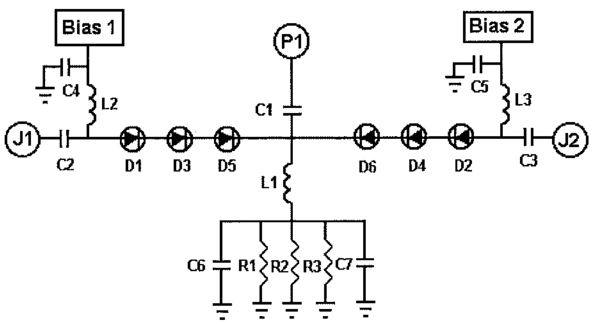

Fig. 7. Schematicdiagram of implemented SPDT switch.

TABLE II
RADIO PERFORMANCE OF SPDT SWITCH ACCORDING TO DIAMETER OF PUNCHED HOLE

Diameter of punched hole	$0\ \lambda_c$	$0.03\ \lambda_c$ (3.5mm)	$0.06\ \lambda_c$ (7mm)
Insertion Loss (< 1.0dB)	1.9GHz~3.3GHz	0.8GHz~2.9GHz	-
Return Loss (<-15dB)	2.2GHz~3.3GHz	1.0GHz~2.9GHz	2.8GHz~3.4GHz
Isolation (>50dB)	~1.5GHz	~3.6GHz	~2.2GHz

is -23 dB, and the isolation between ports is -61 dB. Also, the implemented SPDT switch shows that insertion loss is less than 1 dB for the frequency range between 0.8 and 2.9 GHz, and isolation is less than 50 dB up to 3.6 GHz, and return loss is less than 20 dB between 1.1 and 2.8 GHz. Fig. 4 shows that insertion loss of the SPDT switches at 2.3 GHz are about the same for all structures. But SPDT switch with $\boldsymbol{a} = 0.03\ \lambda_c$ has wider frequency range for the insertion loss under 1 dB and has better attenuation characteristic to suppress high frequency harmonics. Fig. 5 shows that isolation of SPDT switch with $\boldsymbol{a} = 0.03\ \lambda_c$ is better than those of SPDT switches with $\boldsymbol{a} = 0\ \lambda_c$ and $\boldsymbol{a} = 0.06\ \lambda_c$ by 10 dB and 5 dB, respectively, at 2.3 GHz. Below 1.2 GHz, isolation of SPDT switch with $\boldsymbol{a} = 0.06\ \lambda_c$ is better than others. Because the performance of applied PIN diode is not guaranteed at higher frequency, isolation above 4 GHz is insignificant performance. However, larger size of punched hole does not necessarily increase the isolation in SPDT switch with proposed PHS. Fig. 6 shows the return loss of the SPDT switches. The range for the return loss less than -20 dB of SPDT switch with $\boldsymbol{a} = 0.03\ \lambda_c$ is from 1.0 to 2.9 GHz. That of SPDT switch with $\boldsymbol{a} = 0\ \lambda_c$ is from 2.2 to 3.3 GHz, while that of SPDT switch with $\boldsymbol{a} = 0.06\ \lambda_c$ is from 2.8 and to 3.4 GHz. Obviously, very wide frequency range with small return loss can be achieved with $\boldsymbol{a} = 0.03\ \lambda_c$. Furthermore, when capacitors of 1.2 pF are added for tuning near punched hole, C-coupling is increased and parasitic L-C parameters from periodic punched hole is affected. So, the Q-factor is decreased to lower value and the operating frequency band of SPDT switch with $\boldsymbol{a} = 0.03\ \lambda_c$ can be widened by approximately 254% in regard to return loss.

In Table II, the results for isolation, insertion loss, and return loss are summarized according to the size of the punched hole. As shown in Fig. 2, the periodic punched hole structure has the characteristics of bandpass filter. L-C parameter caused by the size of the punched hole affects C-coupling value and Q-factor. As punched holes are getting larger, C-coupling related to insertion loss is increased while Q

V. CONCLUSION

In this work, we proposed the novel SPDT switch with PHS, and demonstrate significant enhancements in isolation, insertion loss, and return loss. The SPDT switch with $\boldsymbol{a} = 0.03\ \lambda_c$ shows an increase of about 20-dB isolation and broadband by 254%, compared to the conventional SPDT switch with $\boldsymbol{a} = 0\ \lambda_c$. Consequently, a novel microstrip line with proposed PHS can enhance isolation of SPDT switch and broaden the operating frequency band. By using our proposed SPDT switch, the number of employed diodes can be minimized, and thereby the efficiency of current consumption can be increased.

REFERENCES

[1] B. G. Kang, J. S. Kim, H. Ahn, S. H. Kim, and D. Ahn, "Design of RF switch with defected ground structure," in *Microwave Conf., Asia-Pacific*, 2000, pp. 165–168.

[2] J. S. Lim, H. S. Kim, J. S. Park, D.Dal Ahn, and S. W. Nam, "A power amplifier with efficiency improved using defected ground structure," *IEEE Microwave Wireless Compon. Lett.*, vol. 11, pp. 170–172, Apr. 2001.

[3] D.Dal Ahn, J. S. Park, C. S. Kim, J. Kim, Y. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure," *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 86–92, Jan. 2001.

[4] J. I. Park, C. S. Kim, J. Kim, J. S. Park, Y. Qian, D. Ahn, and T. Itoh, "Modeling of photonic bandgap and its application for the low-pass filter design," in *Proc. APMC*, 1999, pp. 331–334.

[5] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, "Novel 2-D photonic bandgap structure for microstrip lines," *IEEE Microwave Guided Wave Lett.*, vol. 8, pp. 69–71, Feb. 1998.

[6] Y. Qian, V. Radisic, and T. Itoh, "Simulation and experiment of photonic bandgap structures for microstrip circuits," in *Proc. APMC*, 1997, pp. 585–588.

[7] V. Radisic, Y. Qian, and T. Itoh, "Novel architectures for high-efficiency amplifiers for wireless applications," *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 1901–1909, Nov. 1998.