Small-Sized High-Power PIN Diode Switch with Defected Ground Structure for Wireless Broadband Internet

Dong-Wook Kim

ABSTRACT—This letter presents a small-sized, high-power single-pole double-throw (SPDT) switch with defected ground structure (DGS) for wireless broadband Internet application. To reduce the circuit size by using a slow-wave characteristic, the DGS is used for the quarter-wave (λ/4) transmission line of the switch. To secure a high degree of isolation, the switch with DGS is composed of shunt-connected PIN diodes. It shows an insertion loss of 0.8 dB, an isolation of 50 dB or more, and power capability of at least 50 W at 2.3 GHz. The switch shows very similar performance to the conventional shunt-type switch, but the circuit size is reduced by about 50% simply with the use of DGS patterns.

Keywords—SPDT switch, PIN diode, defected ground structure.

I. Introduction

There has been a growing need for wireless Internet with the rapid increase of mobile Internet users. The wireless broadband Internet system using time division duplex (TDD) at 2.3 GHz is one of the systems that meet users' demands. In such a system, a switching component on a receiver path is a very significant element in protecting receiver circuits from the transmitter power reflected from an antenna. This requires the switch to have a high power handling capability of at least 50 W and high isolation of more than 40 dB.

In this letter, two types of high-power single-pole double-throw (SPDT) switches with shunt-connected PIN diodes are designed, fabricated, and measured. One has a conventional circuit topology with quarter-wave (λ/4) diode spacing, and the other has the same topology excluding the defected ground structure (DGS) in place of a λ/4 transmission line. Because the DGS is realized by etching only a few defects on the ground plane, it is easy to fabricate and has been widely used to reject a specific frequency band with its own resonance characteristic. The applications include a filter [1], [2], amplifier [3], oscillator [4], frequency multiplier [5], and so on. Another characteristic of the DGS, the slow-wave effect, is utilized to reduce the circuit size of the high-power switch in this work.

II. DGS Unit Pattern Design

Figure 1 shows a schematic view of a dumbbell-shaped DGS circuit. The microstrip line is on the top and the DGS is etched in the bottom of the metallic ground plane. The DGS pattern is indicated by the shaded region. A microstrip line width of 1.9 mm is used for the characteristic impedance of 50 Ω. The Rogers substrate (RO4003) for a three-dimensional electromagnetic (EM) field simulation has a thickness of 32 mils, a dielectric constant ε_r of 3.38, and a loss tangent tanδ of 0.0027 at 10 GHz. By adjusting the etched gap, etched square defect, and microstrip line width in the DGS pattern, a slow-wave factor of 3.08 is achieved when the phase velocity of the DGS structure is normalized to the phase velocity of the 50 Ω microstrip line. An etched gap of 0.5 mm, etched defect square of 2 mm × 5 mm, and line width of 7.4 mm are finally chosen and are depicted in Fig. 1. According to the extensive EM simulations, the microstrip structure of 9.5 mm with 5 mm

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Dong-Wook Kim (phone: +82 42 821 6887, email: dwkim21c@cnu.ac.kr) is with the Department of Radio Science and Engineering, Chungnam National University, Daejeon, Korea.

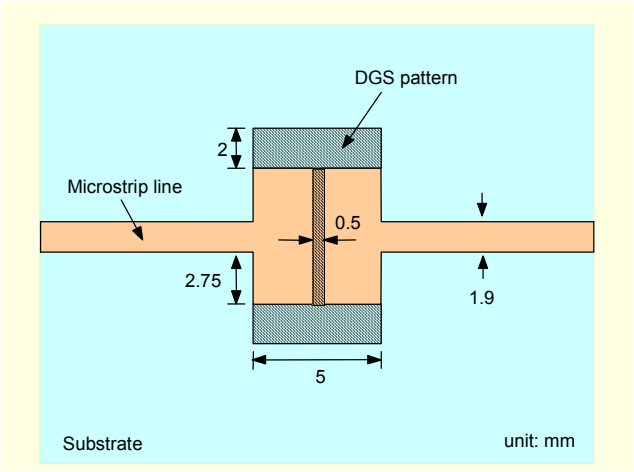

Fig. 1. A schematic of a dumbbell-shaped DGS pattern.

DGS pattern length shows about a 90 degree phase shift at 2.3 GHz and can replace a 20 mm conventional microstrip line.

III. Switch Design

To handle the average RF power of 50 W or more, the diode should have a high breakdown voltage and large junction area. The large area leads to high off capacitance, causing worse isolation than a low power device. The chosen Metelics PIN diode has an on series resistance of 0.5 Ω, off capacitance of 0.4 pF, and parallel resistance of more than 200 kΩ. Based on the diode parameters, the isolation of a series diode is less than 6 dB at 2.3 GHz, although parasitic elements are ignored [6]. Therefore, it is not cost-effective to use series-connected diodes for 40 dB isolation. To obtain high power handling capability and high isolation, the shunt-connected diode structure is used and is shown in Fig. 2. The shaded microstrip lines of the shunt configuration are constructed with the 50 Ω conventional microstrip lines (type A) and DGS microstrip lines (type B). In the case of type B, L_2 is 9.5 mm, which is much less than an L_1 of approximately 20 mm. The 50 Ω microstrip lines besides the DGS in type B are used for the convenience of surface mounting work.

In designing the PIN diode switch, an especially high power switch, setting the reverse bias is very important because one cannot have enough bias voltage due to a power supply limitation. The minimum reverse bias of the PIN diode is expressed as in [7] as

$$|V_{DC}| = \frac{|V_{RF}|}{\left[1+\left[\pi f W^2/0.95\mu V_{RF}\sqrt{D}\left[1+\sqrt{1+\left[0.95\mu V_{RF}\sqrt{D}/W v_{sat}\right]^2}\right]\right]^2\right]^{0.5}},$$

where f is the carrier frequency, W is the intrinsic region thickness, μ is the carrier mobility, D is the RF pulse duty cycle, and v_{sat} is the saturation velocity. When $D = 1$ and $W = 30$ μm, a minimum reverse bias of about 25 V is required for 50 W RF power operation. In this design, a reverse bias voltage of 30 V is used in consideration of the bias margin.

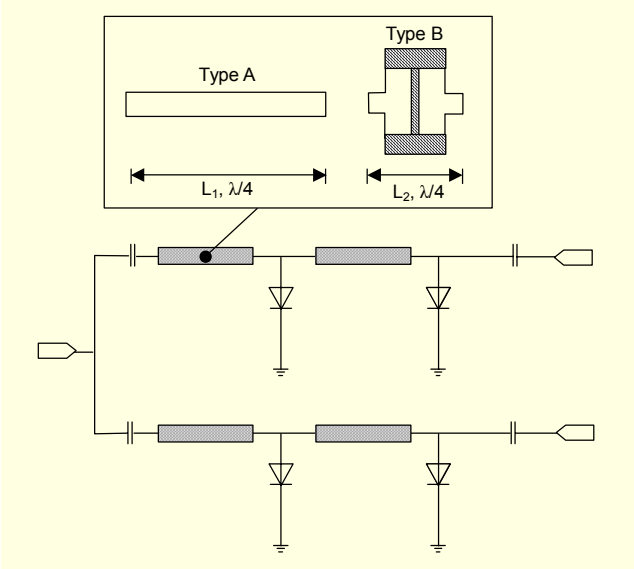

Fig. 2. A schematic of an SPDT switch with shunt-connected diodes. Type A: a conventional microstrip line, type B: the DGS microstrip line.

IV. Measurement

Fabricated SPDT PIN diode switches are shown in Fig. 3. To show the size reduction effect of the DGS patterns for λ/4

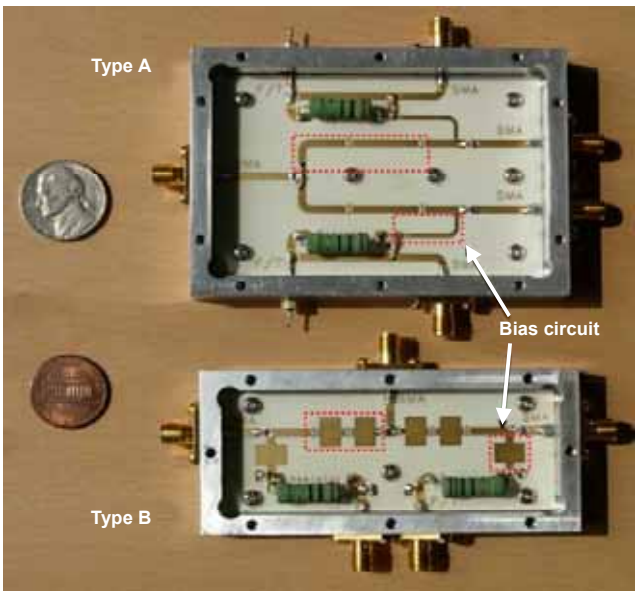

Fig. 3. The fabricated high-power SPDT PIN diode switches.

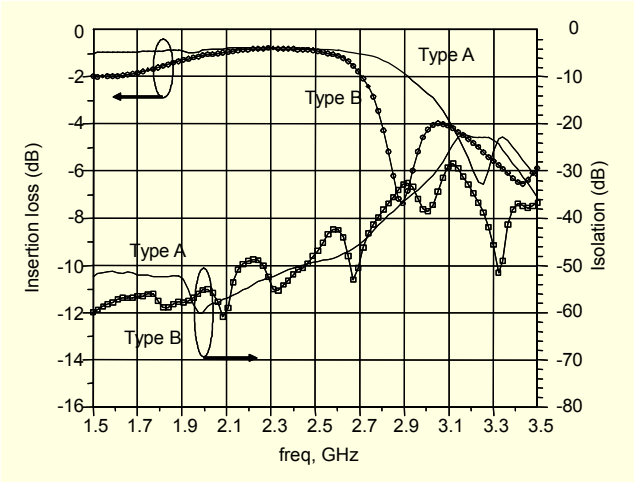

Fig. 4. The measured insertion loss and isolation of the type A and type B SPDT switches.

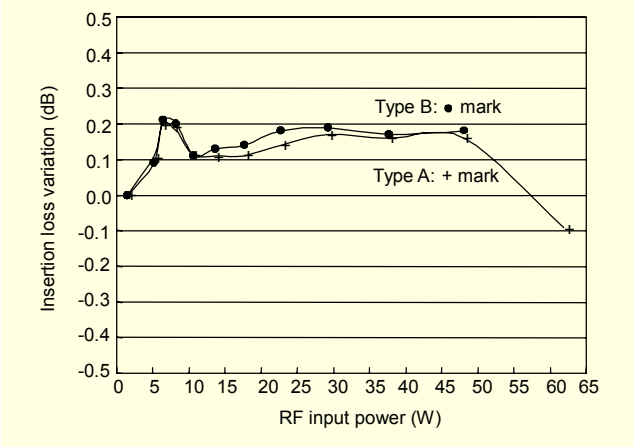

Fig. 5. Insertion loss variation of type A and type B switches with RF input power.

transmission lines, the dashed boxes are indicated in the figure. The lengths of the microstrip lines for the diode connection and bias supply are reduced by about 50%, so the whole size of the SPDT switch is decreased remarkably.

Figure 4 shows the insertion loss and isolation performance of both switches. In the frequencies of 2.3 to 2.4 GHz, the insertion losses of type A and type B are approximately 0.75 and 0.8 dB, respectively. Type B has a faster increase below 1.9 GHz and a more rapid decrease above 2.6 GHz in the insertion loss curve than does type A. This is because the DGS intrinsically has a narrow band characteristic and type B is best matched to a system in the frequency band of 2.3 to 2.4 GHz. The measured isolation is more than 50 dB with only two diodes on one arm. Overall, type B shows very comparable results to type A, in spite of being half the size.

The power and switching speed measurements show that both switches have an average RF power handling capability of more than 50 W and a rise and fall time of less than 320 ns. Figure 5 shows the insertion loss variation of type A and type B switches with RF input power. The slight variation is due to a high power amplifier used as a signal source in the measurement setup.

V. Conclusion

A small-sized, high-power SPDT switch with DGS is designed, fabricated, and measured for wireless broadband Internet application. It shows an insertion loss of 0.8 dB and isolation of more than 50 dB at 2.3 GHz. The switch configuration using λ/4 transmission lines and shunt PIN diodes is chosen for high isolation, and the DGS pattern is used for a dramatic size reduction of the switch while maintaining comparable performance to a conventional switch. The power and switching time measurements show it has a power capability of more than 50 W, and switching speed less than 320 ns. Therefore, the shunt-connected SPDT switch with DGS patterns can be used successfully in a high power wireless broadband Internet system if it is properly designed.

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