A RING FILTER SWITCH FOR A LOW LOSS WIDEBAND AND VERY SHARP BANDSTOP FILTER

Hee-Ran Ahn and Bumman Kim
Department of Electronics and Electrical Engineering, Pohang University of Science and Technology, Korea; Corresponding author: hrahn@postech.ac.kr

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ABSTRACT: *A ring-filter switch is suggested for a low loss wideband filter with on-state and very sharp bandstop filter with off-state. It consists of a ring filter and a switching diode. The ring filter is a wideband filter but a band-stop filter with a certain condition. The fact can be used as a switch. To verify it, a microstrip ring-filter switch is fabricated and measured at a center frequency of 3 GHz.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 2828–2830, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22828

Key words: *ring-filter switch; ring filter; wideband and sharp band-stop filter*

1. INTRODUCTION

A switch is a device for changing the flow of a circuit and can be connected from one course and disconnected to another. There are different types of switches: SPST (single pole single throw), SPDP (single pole double throw), DPST (double pole single throw), DPDT (double pole double throw), and so on, and only the SPST will be discussed in this letter.

When an ideal switch is in on-state, its resistance should be near zero and very little power is dropped in the contacts, and in the off-state, its resistance is extremely high and much power is dropped in the contacts. However, the switch is flicked and the resistance must pass through a state. Some power is therefore dropped in the switch and the dropped power can not be ignored.

In this letter, a ring-filter switch is suggested using a ring filter to reduce the power loss caused by the on-state resistance and to have a special property: a wideband filter with the on-state and very sharp band-stop filter with the off-state.

The ring filter was first suggested as a wideband 180° transmission line [1]. It consists of a ring and two short stubs which are connected at 90° and 270° points of the ring to reject DC and even-multiples of a design center frequency. Feeding lines are directly coupled to a ring to alleviate high insertion loss caused by gaps in conventional ring-based circuits [2]. In the ring filter, the power excited at input is divided just like ring hybrids or three-port power dividers [3–7], and the divided powers are combined at the output like a three-port power combiner. The two combined powers are in same frequency responses, which is the main reason of the wideband responses. Therefore, it may be seen in other sense that two filters, “up- ” and “down-” filters are connected in parallel. If the two combined powers at the output are the same in magnitude and 180° out of phase, the excited power can not be delivered to the output. This may be done by making the two short stubs differ in length and can be used for an off-state of the switch. No power transmission occurs since the voltages where two short stubs are connected are the same in magnitude and 180° out of phase. Therefore, if the voltages are made same, or, the two positions are connected with each other, a power transmission may be accomplished. This state can be used for the on-state of the switch.

To verify the ring-filter switch, a microstrip ring-filter switch was designed at a center frequency of 3 GHz and fabricated on a substrate (ε_r= 4.8, H = 0.57 mm). The measured results are in good agreements with predictions.

2. ANALYSES

A ring-filter switch consists of a ring filter and a switching diode. It’s configuration is depicted in Figure 1(a) and its up-filter of the ring filter in Figure 1(b). The ring-filter switch is terminated in Z_1 and Z_2, and the ring filter consists of a ring and two short stubs. A power division ratio is shown as d_1 to d_2 in Figure 1(a). The two short-stubs are located at 90° and 270° points of the ring and the point, where each short stub is connected, may be considered as a hypothetical port whose termination impedance is Z_h. The Z_h is needed to design the ring filter and may be arbitrarily chosen when $Z_1 = Z_2$, and $Z_h = (Z_1 + Z_2)/2$ or $\sqrt{Z_1 Z_2}$ in the case of $Z_1 \neq Z_2$. Four transmission line sections form a ring and each length is equally ℓ. Their characteristic impedances are Z_{ca}, Z_{cb}, Z_{cc}, and Z_{cd}, and the lengths of the short stubs in the up- and down-filters are ℓ_{us} and ℓ_{ds}, respectively.

The ABCD parameters of the up-filter in Figure 1(b) are

$$A_u = \cosh^2\gamma\ell + \frac{Z_{ca}}{2Z_s}\sinh 2\gamma\ell \coth\gamma\ell_{us} + \frac{Z_{ca}}{Z_{cb}}\sinh^2\gamma\ell \quad (1)$$

$$B_u = \frac{Z_{ca} + Z_{cb}}{2}\sinh 2\gamma\ell + \frac{Z_{ca}Z_{cb}}{Z_s}\sinh^2\gamma\ell \coth\gamma\ell_{us}$$

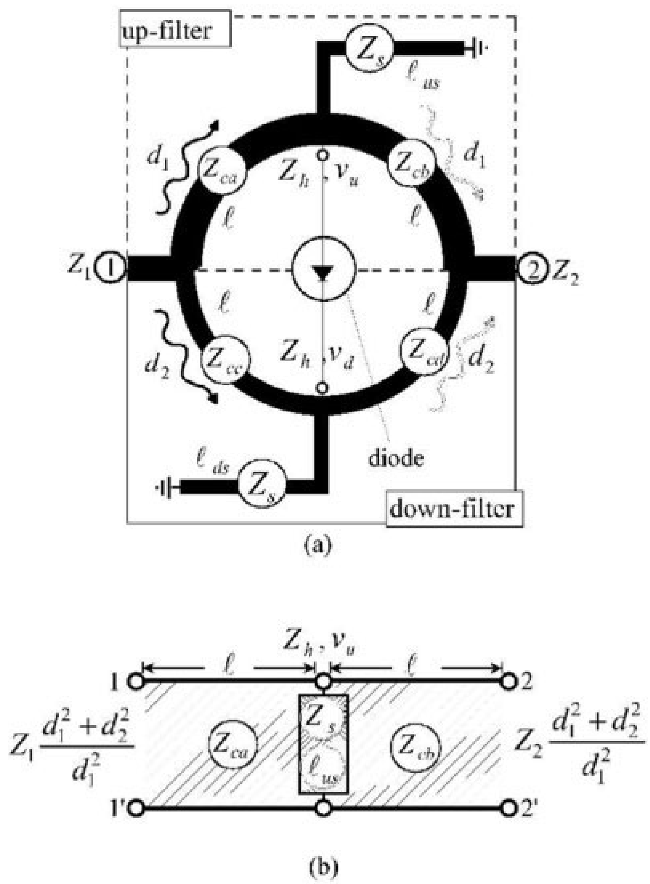

Figure 1 A ring filter switch consisting of a ring filter and a diode. (a) A ring-filter switch and (b) its up-filter

$$C_u = \frac{\sinh 2\gamma\ell}{2Z_{ca}} + \frac{1}{Z_s}\cosh^2\gamma\ell \coth\gamma\ell_{us} + \frac{\sinh 2\gamma\ell}{2Z_{cb}}$$

$$D_u = \frac{Z_{cb}\sinh^2\gamma\ell}{Z_{ca}} + \frac{Z_{cb}}{2Z_s}\coth\gamma\ell_{us}\sinh 2\gamma\ell + \cosh^2\gamma\ell$$

where $\gamma = \alpha + j\beta$ (α and β: attenuation and phase constants), $Z_{ca} = \sqrt{Z_1 Z_h \frac{d_1^2 + d_2^2}{d_1^2}}$, $Z_{cb} = \sqrt{Z_2 Z_h \frac{d_1^2 + d_2^2}{d_1^2}}$.

In a similar way, those of the down-filter are

$$A_d = \cosh^2\gamma\ell + \frac{Z_{cc}}{2Z_s}\sinh 2\gamma\ell \coth\gamma\ell_{ds} + \frac{Z_{cc}}{Z_{cd}}\sinh^2\gamma\ell$$

$$B_d = \frac{Z_{cc} + Z_{cd}}{2}\sinh 2\gamma\ell + \frac{Z_{cc}Z_{cd}}{Z_s}\sinh^2\gamma\ell \coth\gamma\ell_{ds}$$

$$C_d = \frac{\sinh 2\gamma\ell}{2Z_{cc}} + \frac{1}{Z_s}\cosh^2\gamma\ell \coth\gamma\ell_{ds} + \frac{\sinh 2\gamma\ell}{2Z_{cd}}$$

$$D_d = \frac{Z_{cd}\sinh^2\gamma\ell}{Z_{cc}} + \frac{Z_{cd}}{2Z_s}\coth\gamma\ell_{ds}\sinh 2\gamma\ell + \cosh^2\gamma\ell \quad (2)$$

where $Z_{cc} = \sqrt{Z_1 Z_h \frac{d_1^2 + d_2^2}{d_2^2}}$, $Z_{cd} = \sqrt{Z_2 Z_h \frac{d_1^2 + d_2^2}{d_2^2}}$

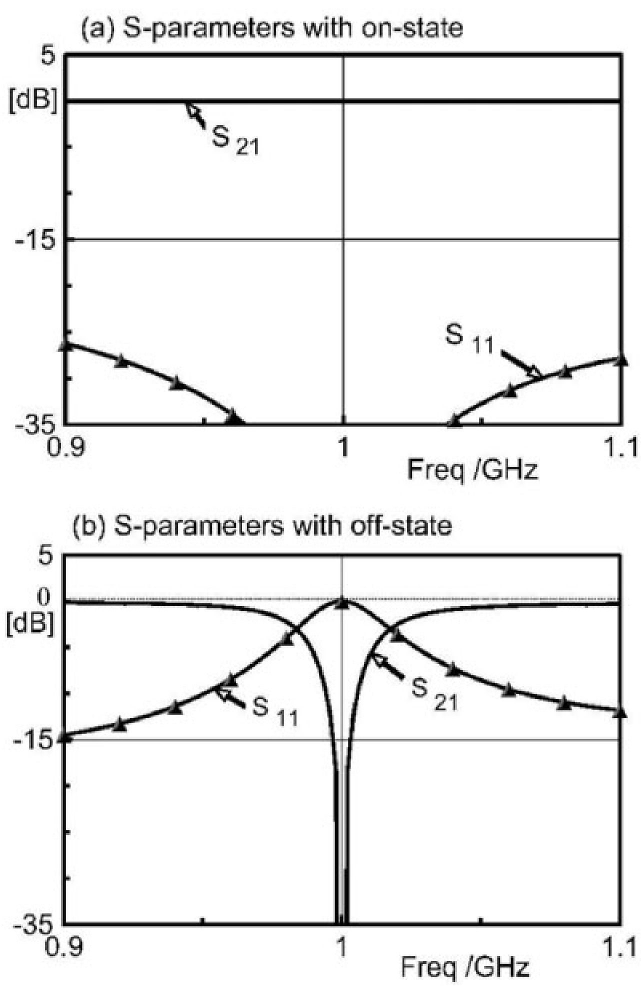

Figure 2 Simulated scattering parameters of the ring filter switch. (a) On-state and (b) off-state

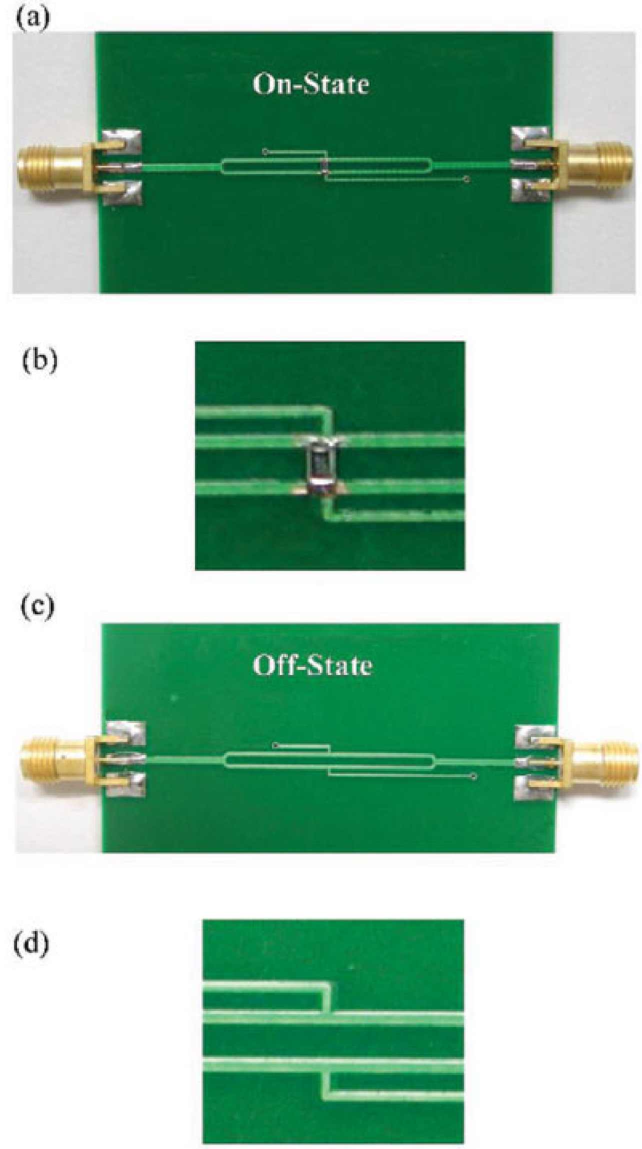

Figure 3 Ring-filter switch. (a). On-state, (b) magnified center of the on-state, (c) off-state, and (d) magnified center of the off-state. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Lossless ($\alpha = 0$) and no discontinuity effect are assumed, and if ℓ, ℓ_{us}, and ℓ_{ds} are set as written in (3),

$$\beta_o\ell = \pi/2,$$
$$\beta_o\ell_{us} = \pi/2 + \mu$$
$$\beta_o\ell_{ds} = \pi/2 + \nu, \quad (3)$$

the Y-parameters of the ring filter are derived as

$$Y = -jZ_s\frac{\sin(\mu+\nu)}{\sin\mu \sin\nu}\begin{bmatrix} \frac{1}{Z_{ca}^2} & \frac{1}{Z_{ca}Z_{cb}} \\ \frac{1}{Z_{ca}Z_{cb}} & \frac{1}{Z_{cb}^2} \end{bmatrix}, \quad (4)$$

where they are derived at a center frequency and an equal power division case, or, $d_1 = d_2$ is applied.

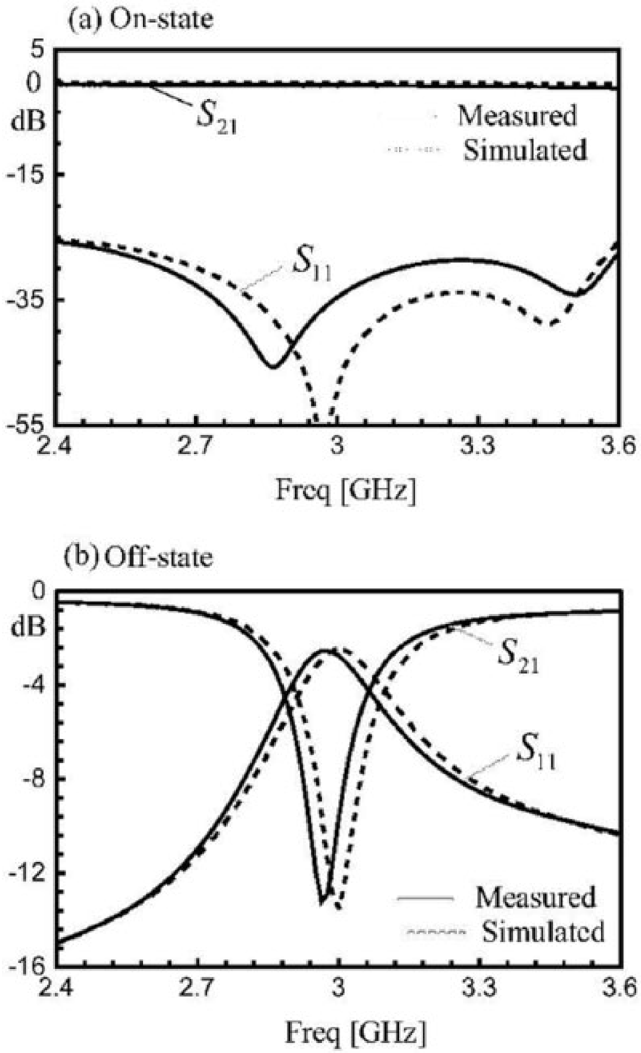

Figure 4 Measured results are compared with predictions. (a) On-state and (b) off-state

$\mu \neq 0$, $\nu \neq 0$ and $\mu + \nu = 0$ in (4) result in

$$Y = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \tag{5}$$

(5) implies that matching and power transfer can not occur with the condition $\mu + \nu = 0$. Therefore, the condition $\mu + \nu = 0$ is a necessary and sufficient condition for the zero *Y*-parameters. The prime reason of no matching and no power transmission at the center frequency is that the voltages of ν_u and ν_d in Figure 1 are same in magnitude but 180°out of phase. If the different voltages, ν_u and ν_d are made same, or, the two points with ν_u and ν_d are connected with each other, it will operate a normal ring filter. This may be used for the switch. With on-state of the diode, it could have a few ohms between the two hypothetical ports.

One case that Z_{ca}, Z_{cb}, Z_{cc}, and Z_{cd} in Figure 1(a) are equally 70. 71 Ω and $\mu = 30°$ in (3) was simulated and the simulation results are plotted in Figure 2 where its on- and off-states are plotted in Figures 2(a) and 2(b), respectively. For the simulations, it is assumed that 1 Ω or infinite Ω is produced between the hypothetical ports according to the switching diode state.

As shown in Figure 2(a), with the on-state, the insertion loss is 0 dB and the return loss −70 dB at a center frequency of 1 GHz, which are the filter responses, and with the off-state, −200-dB insertion loss and 0-dB return loss are shown in Figure 2(b), which are the band-stop characteristics.

3. MEASUREMENTS

Based on the analyses, a ring-filter switch was designed at a center frequency of 3 GHz and fabricated on a substrate ($\varepsilon_r = 4.8$, $H = 0.57$ mm). The two states of the ring-filter switches are shown in Figure 3 where the on-state is in Figure 3(a) and its center part is scaled up in Figure 3(b), while the off-state and its magnified center part are in Figure 3(c) and 3(d), respectively. In this case, $\beta_o\ell = 90°$, $\beta_o\ell_{us} = 50°$, $\beta_o\ell_{ds} = 130°$, Z_{ca}, Z_{cb}, Z_{cc}, and Z_{cd} are equally 70. 71 Ω, $Z_s = 85$ Ω and the 1 Ω resistor is connected between two hypothetical ports for the on-state. The measured results are compared with the predictions in Figure 4 where the solid lines are measured data and the dotted ones simulated ones. As expected, the measured results are in good agreement with the predictions.

4. CONCLUSIONS

The ring-filter switches were introduced and analyzed. Depending on the states of the switch, a wideband filter or a very sharp band-stop filter can be produced. Therefore, it can be used for a various applications such as high power system to reduce harmonics.

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