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A BAND-REJECTION TYPE RF SWITCH BASED ON A DUAL-MODE MICROSTRIP RING RESONATOR

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ABSTRACT: *A band-rejection type RF switch, which has very high off-state isolation, low on-state insertion loss, and adjustable bandwidth, is proposed using a dual-mode ring resonator and two PIN diodes. To enable sharp band stop and dual-mode transmission, the ring resonator is directly fed using nonorthogonal feeding. Two PIN diodes are mounted in shunt after a quarter-wavelength transmission line from each feeding point, to turn the switch on and off and to reduce the size of the ring resonator. To estimate the practicable transmission characteristics of the proposed switch in relation to the angle of feeding and the wire-bonded PIN diodes, a lossy transmission-line equivalent circuit model is proposed, and even–odd mode analysis is carried out. The calculated frequency response shows good agreement with the measurement. The fabricated switch exhibits off-state isolation of 43.08 dB, and on-state insertion loss of 0.74 dB, within the range of 2.298–2.401 GHz.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 947–950, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25080

Key words: *RF switch; ring resonator; PIN diode; dual-mode; band-rejection*

1. INTRODUCTION

Recently, a mobile broadband system using TDD (time division duplex) has come under the spotlight because of a dramatic increase in mobile internet usage. In TDD systems, such as WiBro (wireless broadband) and the long term evolution system, the same carrier frequency is used for uplink and downlink transmissions, and therefore, receiver circuits must be protected from the reflected transmitted power from the antenna. To facilitate this, a high performance switching circuit that has high off-state isolation, low on-state insertion loss, and high-power handling capability is an essential component for the safety of a receiver circuit.

The conventional RF switch, which is based on multiple PIN diodes and quarter-wavelength transmission lines, has some defects. To obtain high off-state isolation with this topology, many PIN diodes would be required with quarter-wavelength transmission lines. In this case, the overlapped parasitic elements, such as the junction capacitance of the PIN diode, the inductance of the bond-wire, and the inductance of an RF chock, would increase the signal loss. Moreover, the size of the switch is substantially increased in accordance with the number of added PIN diodes. A number of design methods using various microstrip resonators have been reported in the literature [1–4] that claim to enhance the performance of a switch. However, their bandwidths are too narrow and the off-state isolations and on-state insertion losses are not particularly good. Currently, MEMS technology is being used to actively develop RF switches that have high isolation and broad bandwidth [5–6]. However, their limited power capabilities restrict their use to low power applications. Therefore, PIN diode switches based on microstrip resonators are still very important for high power communication systems, and additional research in this area is required to further develop their switching performances.

In this article, a band-rejection type RF switch that has high off-state isolation, low on-state insertion loss, and adjustable bandwidth is proposed using a dual-mode microstrip ring resonator and two wire-bonded PIN diodes. To accurately estimate the transmission characteristics of the proposed switch, a transmission line equivalent circuit model, including the losses of substrate, is proposed using even–odd mode analysis, and the effect of wire-bonded PIN diodes on the resonance of the ring resonator is studied. As a result, a band-rejection type RF switch is designed in the 2.3–2.4 GHz range for WiBro applications.

2. CONCEPTION OF THE PROPOSED RF SWITCH

Figure 1 shows the structure of the proposed band-rejection type RF switch, which uses a dual-mode ring resonator and two PIN diodes. The dual-mode ring resonator is designed with nonorthogonal direct-feeding to enable sharp band-stop transmission and adjustment of bandwidth [7]. These resonant characteristics are much more suitable for RF/microwave switches than other microstrip resonators. Dual-mode resonance of a ring resonator can be achieved using various perturbation methods [8, 9]. In this article, we use the nonorthogonal feeding method because of its simplicity and perspicuity.

Two wire-bonded PIN diodes are mounted in shunt after the quarter-wavelength transmission lines from each feeding point.

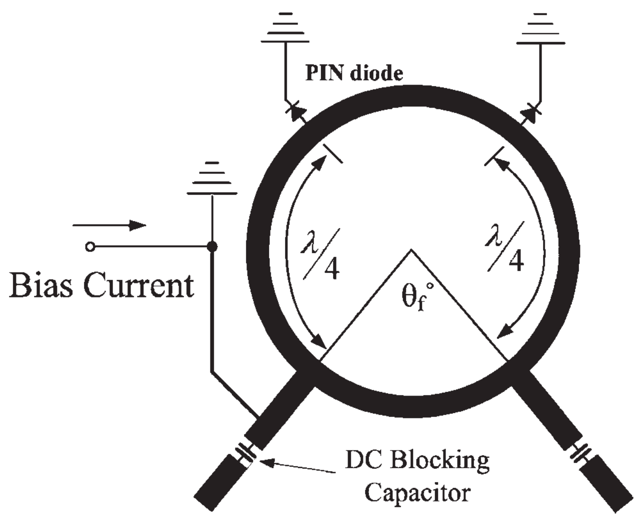

Figure 1 Structure of the band-rejection type RF switch using a dual-mode ring resonator

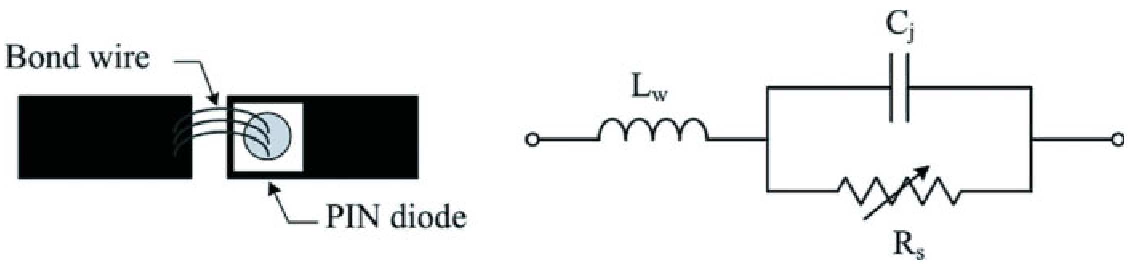

Figure 2 Wire-bonded PIN diode and its equivalent circuit. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

They turn the switch on and off by changing the resonant frequency of the ring resonator. Because the shunt reactance of the PIN diode increases or decreases the electrical length of the circumference of the ring resonator, the resonant frequency is shifted down or up according to the bias condition, but the resistance of the PIN diode is concerned only with the insertion loss. Figure 2 shows the equivalent circuit of the wire-bonded PIN diode. It consists of series inductance of the bond-wire and junction capacitance in parallel with series resistance of the PIN diode. In this article, we use the Metelics PIN diode MPN-7380, the value of each element is listed in Table 1.

3. EQUIVALENT CIRCUIT AND EVEN–ODD ANALYSIS

For the accurate determination of performance related to signal loss, we calculate the dominant loss factors of substrate such as dielectric loss and conductor loss and included it while determining the frequency response of the proposed switch. The attenuation constant of the dielectric and the conductor [10] are:

$$\alpha_d = 8.686 \frac{k_0 \varepsilon_r(\varepsilon_e - 1)\tan\delta}{2\sqrt{\varepsilon_e}(\varepsilon_r - 1)} (dB/m), \tag{1}$$

$$\alpha_e = 8.686 \frac{\sqrt{\omega\mu_0/2\sigma}}{Z_0 W} (dB/m), \tag{2}$$

where, k_0 is the wave number of air, ε_r and ε_e are the dielectric constants of the substrate and effective dielectric constant of the microstrip line, respectively, and σ is the conductivity of the copper of the microstrip line. Thus, the propagation constant of the microstrip line can be written as:

$$\gamma = (\alpha_d + \alpha_c) + j\beta_m \tag{3}$$

where, $\beta_m = k_0\sqrt{\varepsilon_e}$ is the phase constant of the microstrip line. Using (1), (2), and (3), the loss of the microstrip line is sufficiently taken into account in extracting the scattering parameters of the proposed RF switch.

Because of its symmetric structure, the scattering parameters of the proposed RF switch can be easily extracted by the superposition of even- and odd-mode excitations. Figure 3 shows the equivalent circuit models to extract even and odd admittances.

For the even-mode extraction, the same current of $+i/2$ is applied to each feeding point and there is no current flows flowing through the symmetry line. Thus we can bisect the network with open circuits at these points to obtain the networks of Figure 3(b). Then, looking into the input port, the even-mode admittance can be written as:

$$Y_{\text{even}} = Y_0 \tanh\gamma l_1 + Y_0 \frac{Z_0 + \tanh\gamma l_2/(Y_d + Y_0\tanh\gamma l_3)}{1/(Y_d + Y_0\tanh\gamma l_3) + Z_0\tanh\gamma l_2}, \tag{4}$$

where, Y_d is the admittance of the wire-bonded PIN diode, and l_1, l_2, and l_3 are the lengths of the divided microstrip lines in Figure 3.

TABLE 1 Value of the Elements of a Metelics PIN Diode MPN 7380

	L_w (nH)	C_j (pF)	R_s (Ω)
Value	0.5	0.6	3000 (zero biased) 0.5 (forward biased)

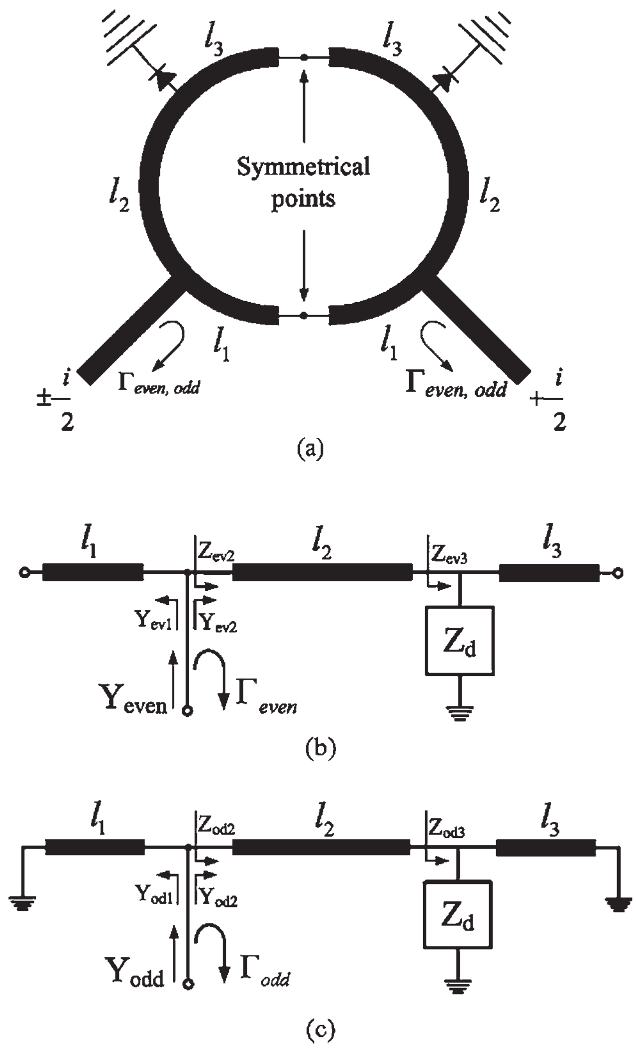

Figure 3 Decomposition of the equivalent circuit model into even- and odd-mode excitation. (a) Symmetry of the proposed RF switch, (b) even-mode excitation, (c) odd-mode excitation

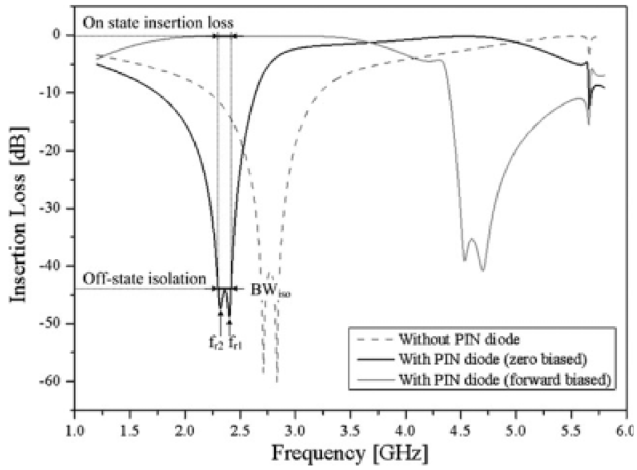

Figure 4 Frequency response of the proposed switch

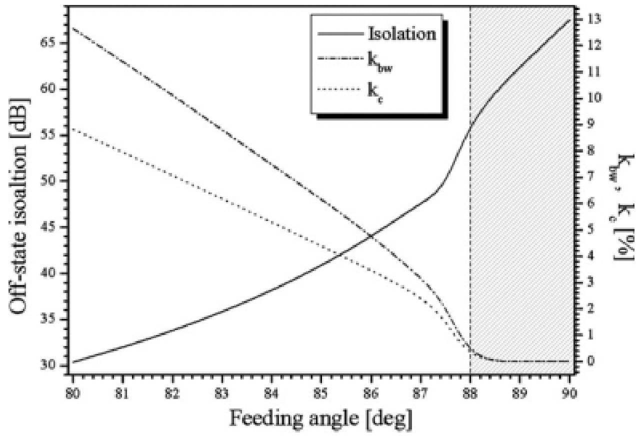

Figure 5 Off-state isolation, k_c and k_{bw} according to the angle of feeding

Similarly, for the odd-mode excitation, there are voltage-zero points along the middle of the circuit in Figure 3(a) by applying a current of $\pm i/2$ to each feeding point, respectively. And then, from the odd-mode equivalent circuit model in Figure 3(c), the odd-mode admittance is calculated as follows:

$$Y_{\mathrm{odd}} = Y_0 \coth \gamma l_1 + Y_0 \frac{Z_0 + \tanh \gamma l_2/(Y_\mathrm{d} + Y_0 \coth \gamma l_3)}{1/(Y_\mathrm{d} + Y_0 \coth \gamma l_3) + Z_0 \tanh \gamma l_2}. \quad (5)$$

Consequently, the scattering parameters of the proposed switch can be obtained from the superposition of even- and odd-mode reflection coefficients [9] as follows:

$$S_{21} = \frac{\Gamma_{\mathrm{even}} - \Gamma_{\mathrm{odd}}}{2}, \; S_{11} = \frac{\Gamma_{\mathrm{even}} + \Gamma_{\mathrm{odd}}}{2}, \quad (6)$$

where, Γ_{even} and Γ_{odd} are even- and odd-mode reflection coefficients, respectively.

The frequency response of the proposed switch is illustrated in Figure 4. For a more detailed examination regarding the angle of feeding, we notate the fundamental-mode resonant frequency, which is determined by the circumference of the ring resonator as f_{r1}, and the second-mode resonant frequency, which is related to nonorthogonal feeding as f_{r2}. In addition, some design parameters are defined as follows:

$$f_\mathrm{c} = (f_{\mathrm{r1}} + f_{\mathrm{r2}})/2 \quad (7)$$

$$k_\mathrm{c} = (f_{\mathrm{r1}} - f_{\mathrm{r2}})/f_\mathrm{c} \quad (8)$$

$$k_{\mathrm{bw}} = \mathrm{BW}_{\mathrm{iso}}/f_\mathrm{c} \quad (9)$$

where, f_c is the center frequency, k_c and k_{bw} are the coefficients for dual-mode resonance and bandwidth (relating to the feeding angle), respectively.

When dual-mode resonance occurs, three frequencies exist where the differential quotients of S_{21} equal zero. Of these frequencies, fundamental frequency f_{r1} and second mode resonant frequency f_{r2} are determined. In addition, using (6), (7), (8), and (9), the value of off-state isolation, the bandwidth $\mathrm{BW}_{\mathrm{iso}}$, and the design parameters defined above are calculated for different feeding angles as shown in Figure 5. In the shaded region of Figure 5, dual-mode resonance exists, but it seems to be single-mode because the resistance of the PIN diodes reduces the quality-factor of the ring resonator.

Figure 6 shows the ratio of the shifted resonant frequency because of the effective capacitance of zero-biased PIN diodes and the resonant frequency of the ring resonator without a PIN diode. Because a frequency shift in the switch off state is a matter of primary concern, we omit the frequency shift by the inductive reactance of the forward-biased PIN diode. Using these calculated results, we can estimate the practicable performance of the proposed switch accurately and easily design within certain specifications.

4. SWITCH DESIGN AND MEASUREMENT

A band-rejection type RF switch based on a dual-mode ring resonator was designed and fabricated on a RO4003 substrate (ε_r = 3.38 and h = 20 mil) using a Metelics PIN diode MPN 7380. Regarding switch specifications, a center frequency of 2.35 GHz, a bandwidth of 100 MHz, and isolation of 43 dB were selected for use in WiBro applications. Under these conditions, k_{bw} was calculated as 4.255% using (9); and the off-state isolation, k_c, and the angle of feeding were extracted as 54.0 dB, 3.18%, and 86.2°, respectively from Figure 5. Using the extracted k_c and (8), the fundamental resonance frequency f_{r1} was calculated as 2.387 GHz. At this frequency, the effective capacitance of the zero biased PIN diode was calculated as 0.663 pF, and the circumference of the ring resonator was determined as 65.44 mm from Figure 6. The size of the ring

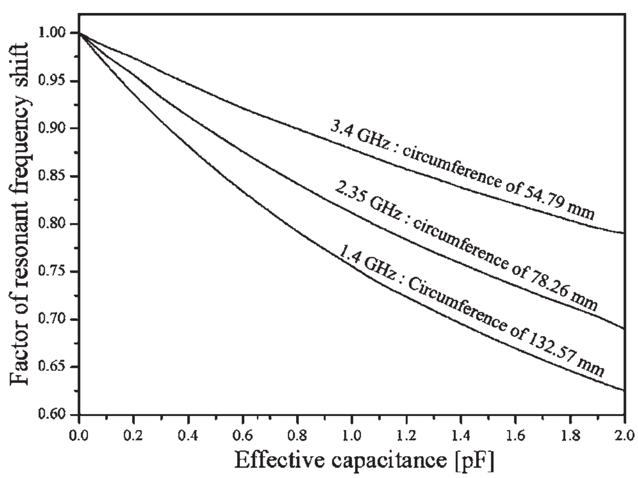

Figure 6 Resonant frequency shift according to effective capacitance of the PIN diode

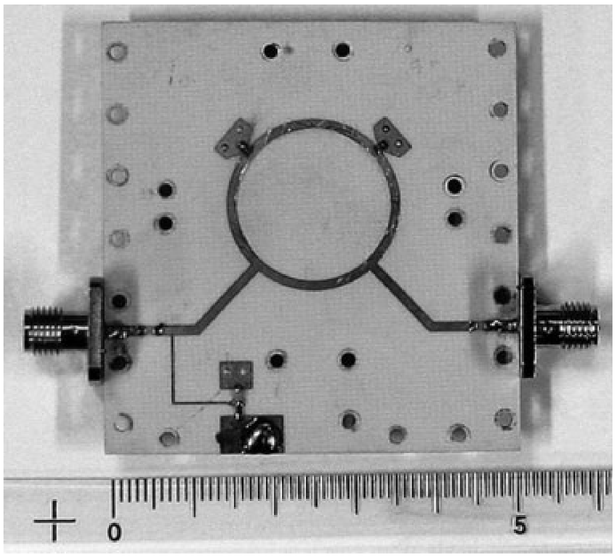

Figure 7 Fabricated band-rejection type RF switch using dual-mode ring resonator

resonator with PIN diodes is reduced by 69.8% compared with a ring resonator without PIN diodes.

The fabricated band-rejection type RF switch is shown in Figure 7, and the measured and calculated frequency responses are illustrated in Figure 8. The off-state isolation greater than 43.08 dB and the on-state insertion loss less than 0.74 dB are exhibited within the range of 2.298–2.401 GHz.

5. CONCLUSIONS

A high performance band-rejection type RF switch using a dual-mode ring resonator and PIN diode has been designed and fabricated. Off-state isolation of 43.08 dB and on-state insertion loss of 0.74 dB were exhibited with a center frequency of 2.35 GHz and a bandwidth of 100 MHz. For the accurate estimation of the practicable performance of the proposed switch, a lossy transmission-line equivalent circuit was proposed, and the effects of the wire-bonded PIN diode and the angle of feeding on the resonance of the ring resonator were studied with an even–odd mode analysis. The measured results show good agreement with the calculated results and the design specifications. Because the proposed switch has very high isolation, adjustable bandwidth, and low insertion loss combined with a simple structure, it should be well suited not only in WiBro applications but also in any other TDD systems.

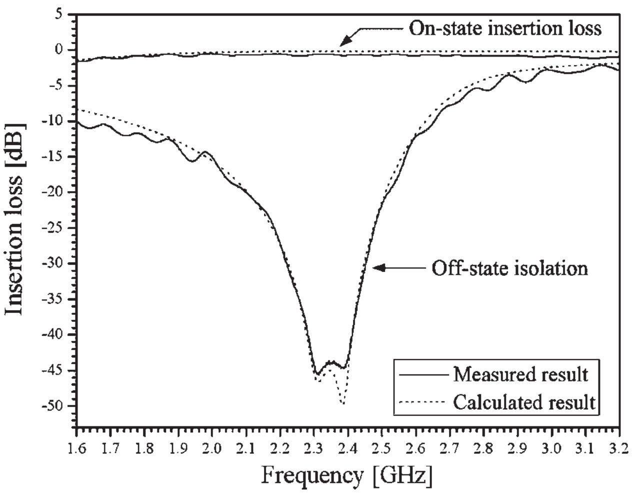

Figure 8 Measured frequency responses of the proposed RF switch compared with the calculated results

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A RECTANGULAR RING BACKED CPW UWB FILTER WITH NOTCHED BAND

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ABSTRACT: *A band notched CPW UWB filter backed by rectangular rings is proposed. Initially, cascading of aperture-backed second-order microstrip filters is done to achieve the UWB passband. Later, to take advantage of the CPW geometry, the filter is converted to CPW configuration with rings at the back to achieve sharp cutoff characteristics and a notch at 5.1 GHz.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 950–954, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25088

Key words: *UWB filter; CPW filter; notched band; rectangular ring backed filter*

1. INTRODUCTION

As is well known, the FCC has released the unlicensed use of ultra-wideband (UWB) allocating 7500 MHz of spectrum (3.1–