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RECONFIGURABLE BROADBAND MICROSTRIP ANTENNA FED BY A COPLANAR WAVEGUIDE

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Abstract—In this paper, a novel reconfigurable two-layer microstrip antenna fed using a coplanar waveguide through a slot/loop combination is investigated. The slot/loop combination allows for easy reconfigurability of the frequency band of operation by incorporating switches in the feed network. Furthermore, broad impedance bandwidths were obtained by using two substrate layers consisting of a high-ε_r substrate that contains the feed network and a low-ε_r substrate that contains two patches, one patch on either side of the substrate. The two substrates are not separated by a ground plane. Impedance bandwidths of about 23% were obtained for two selectable frequency bands using two switches. The two frequency bands obtained for the parameters chosen in this paper are 8.73–10.95 GHz and 7.68–9.73 GHz.

1. INTRODUCTION

Microstrip antennas have been extensively investigated in the literature [1, 2] because of inherent advantages that include low cost, light weight, low profile, conformal, and compatibility with integrated circuits. Traditional feeding techniques include the use of directly [3, 4], electromagnetically [5, 6], or aperture coupled microstrip lines [7–9], coaxial probes [10–14], and coplanar waveguides [15–17]. Using coplanar waveguides offers the advantage of ease of integration with active devices due to their uniplanar design, eliminating the need for vias. In the literature, some feeding methods for single-layer microstrip antennas using coplanar waveguides, mainly inductive or capacitive coupling via a rectangular slot, have been explored [18]. Furthermore, since the CPW conductors are also used as the ground plane for the microstrip patch, the feed substrate used in conventional microstrip aperture coupling is no longer needed. Reconfigurability, tunability, as well as bandwidth improvements without detracting from the major advantages of microstrip antennas are important subjects of research. The most common technique for increasing the impedance bandwidth has been the use of parasitic patches in single layer and multilayer configurations [1, 2], using air or Styrofoam substrates [20, 21], as well as inclusion of slots in the patch, such as the U-patch antenna [19]. However, using parasitic patches increases the overall size of the microstrip antenna and, in case of coplanar patches, results in distorted radiation patterns [22]. In addition, increasing substrate thickness and/or using multilayers results in stronger surface waves, which in turn lowers efficiency, distorts radiation patterns due to edge scattering, and can cause scan blindness in microstrip arrays. While the U-slot antenna and similar configurations provide broadband operation, they do not allow for reconfigurability.

In this paper, we present a two-layer microstrip antenna with a novel feeding technique that uses a coplanar waveguide and a slot-loop combination. The proposed antenna offers broad impedance bandwidth as well as reconfigurability for multiband operation by incorporating switches in the feed. It uses only two substrates: a high dielectric constant feed substrate and a low dielectric constant patch substrate. Unlike the proposed antenna, published designs using two substrates with aperture coupling have much lower bandwidth [15–18] and do not easily allow for reconfigurability. The proposed configuration differs from conventional two-layer, microstrip-aperture coupled microstrip antennas in that the two substrates in the proposed configuration are not separated by a ground plane, and that a combination of high ε_r and low ε_r substrates is used resulting in enhanced bandwidth in addition to keeping feed dimensions small. In addition to the bandwidth advantage, the proposed configuration offers easy reconfigurability with the ability to include switches in the slot/loop combination part of the feed. It also has an advantage in realizing active antennas. The slot/loop combination allows biasing of active devices without disturbing the RF circuitry, as it can be used for both antenna excitation as well as isolation of DC bias. Theoretical simulations based on method of moments as well as experimental results concerning the proposed antennas performance are presented in this paper.

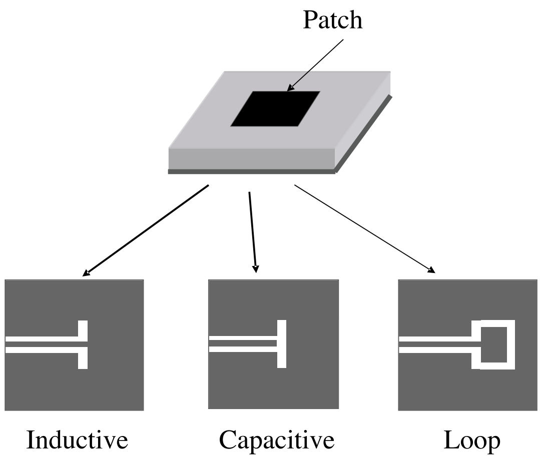


Figure 1. CPW Feed with inductive, capacitive, and loop slot coupling.

2. PROPOSED ANTENNA CONFIGURATION

Aperture coupling using CPW feeds with capacitive or inductive slots and a single substrate, as shown in Fig. 1, was investigated in [15–18]. It was shown that the resonance frequency for capacitive coupling differs somewhat from inductive coupling. The bandwidth obtained was about 4–5%. In our design, shown in Fig. 2, we modified the coupling aperture to include a loop and a rectangular slot to allow for the placement of switches to allow for frequency band reconfigurability. We first investigated the effect of different slot shapes on the resonant frequency and bandwidth for our two layer configuration. Furthermore, we added a low dielectric constant substrate with a patch to enhance bandwidth. All simulations were performed using a 2.5D commercial software package (Ansoft Ensemble) based on the method of moments.

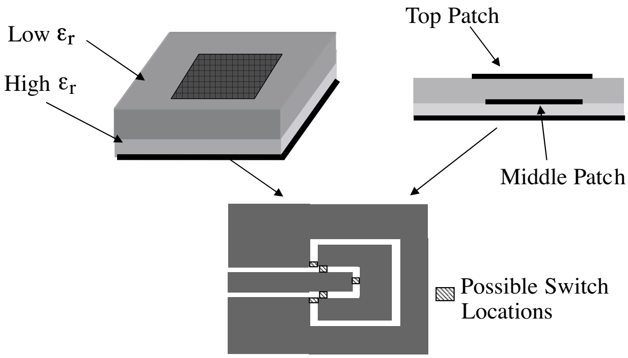


Figure 2. Proposed antenna configuration using loop/slot coupling.

In all numerical simulations and experimental work, the following substrates and dimensions are used: the lower substrate is RT/Duroid 6010 with $\varepsilon_r = 10.8$, thickness = 0.635 mm, top substrate is RT/Duroid 5870 $\varepsilon_r = 2.33$, thickness = 2.38 mm, CPW feed line has strip width = 2 mm and gap width = 0.5 mm resulting in 50 ohm characteristic impedance, and the patch dimensions are 5 mm × 5 mm for the middle patch and 8.5 mm × 8.5 mm for the top patch.

The return loss using capacitive slot-coupling for the two layer configuration is shown in Fig. 3. The slot width was 1 mm. The 10-

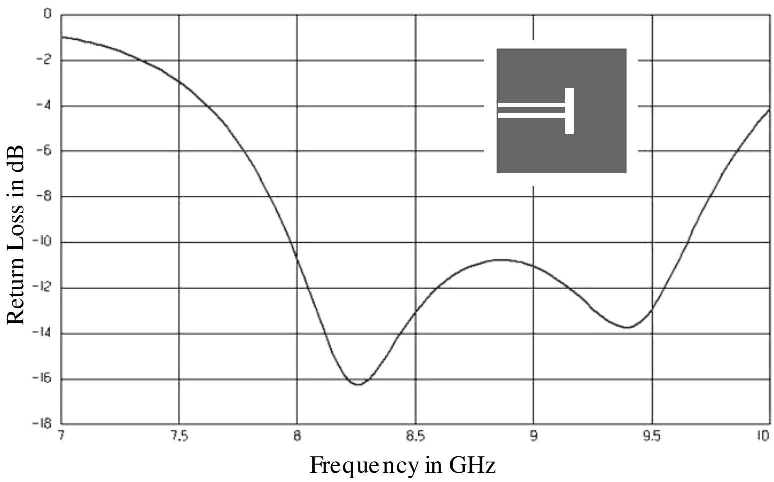


Figure 3. Return loss for capacitive slot coupling.

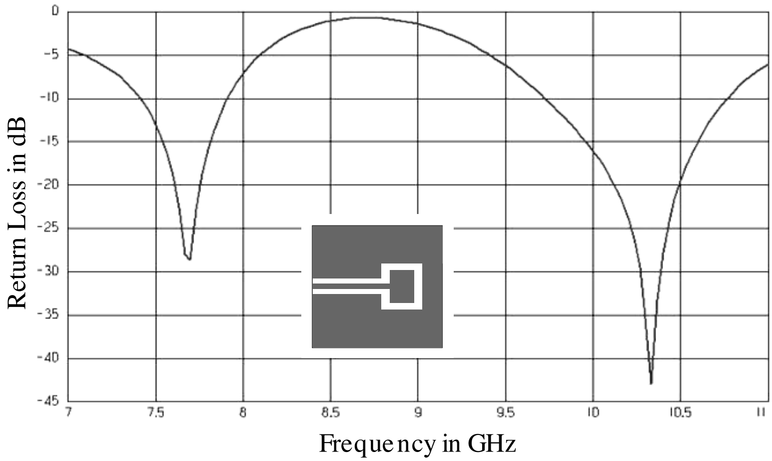


Figure 4. Return loss for loop coupling.

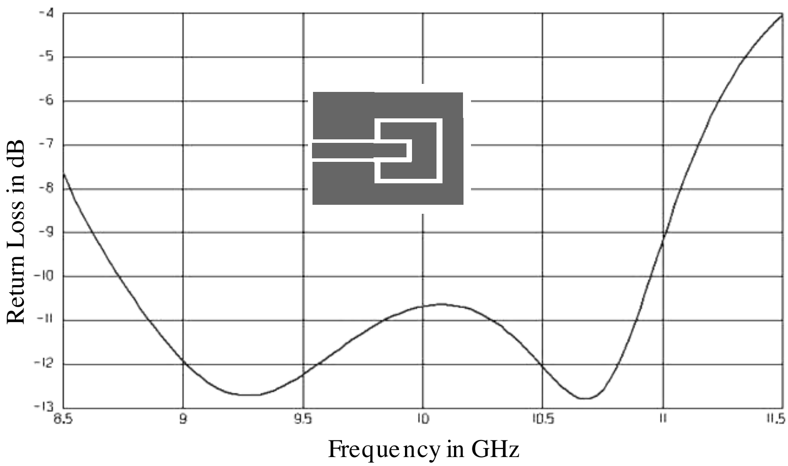


Figure 5. Return loss for slot/loop combination.

dB frequency band is 7.975–9.65 GHz resulting in a 19% bandwidth. The return loss using a loop only is shown in Fig. 4. The loop dimensions were: inner square = 5 mm × 5 mm and the outer square = 7 mm × 7 mm. The return loss is shown is Fig. 4 where a dual band is observed, a lower band: 7.4–7.9 GHz (6.5% bandwidth) and a higher band: 9.7–10.8 GHz (10.7% bandwidth). The return loss using a loop/slot combination is shown in Fig. 5. The 10-dB frequency

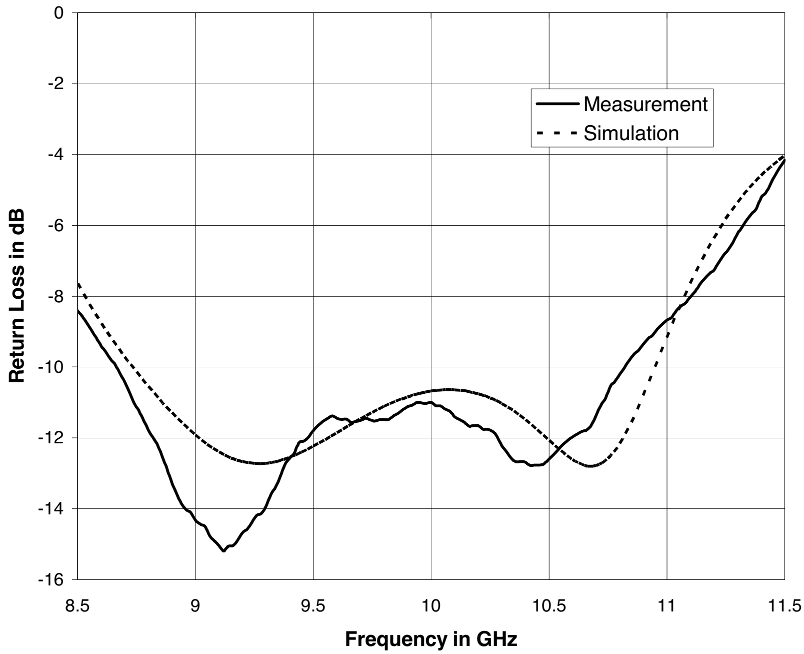


Figure 6. Measured and calculated return loss for slot/loop coupling.

band is 8.73–10.95 GHz resulting in 22.6% bandwidth. This last configuration, the loop/slot combination, is suitable for incorporation of switches to enhance capacitive coupling, loop coupling, or both resulting in frequency band reconfigurability. This is investigated in the next section. We verified the results for the slot/loop coupling configuration experimentally. An antenna having dimensions and substrate parameters similar to those assumed in the simulations was built and tested. The measured return loss is shown in Fig. 6 which indicates a bandwidth of 21.8% (8.68 GHz–10.8 GHz); clearly, the measured results are in good agreement with simulations.

3. RECONFIGURABILITY USING LOOP/SLOT COUPLING

The return loss for the loop/slot coupling configuration can be used to realize different frequency band characteristics by using switches. Three different switch locations were investigated: (a) a switch in the slot at the end of the feed line, (b) two switches in the CPW gaps, or (c) two switches in the loop, as shown in Fig. 6. In the simulations,

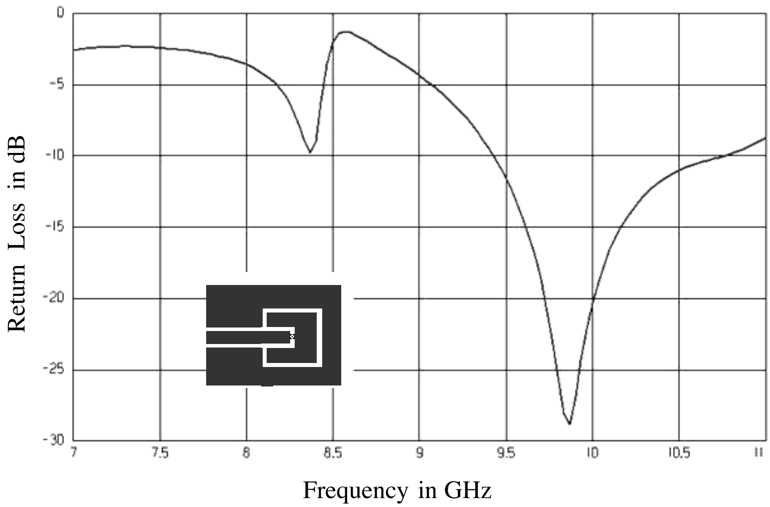


Figure 7. Return loss for a switch in the coupling slot.

presence or absence of thin conducting strips or pads were used to simulate ideal switches. For case (a), a switch in the slot, the return loss when the switch is on is shown in Fig. 7. The 10-dB frequency band for this case is 9.43–10.77 GHz (a bandwidth of 13.3%). Another resonance is seen around 4.8 GHz, however since the return loss is above the 10-dB level, it does not qualify as an acceptable frequency band. The return loss changes significantly for case (b), when two switches are placed in the CPW gaps. The resulting frequency band is 8.9–10.8 GHz (a bandwidth of 19.3%), as shown in Fig. 8. The frequency band changes again and a broader bandwidth is obtained when the two switches are moved to the loop side (case (c)), as shown in Fig. 9. The resulting frequency band is now 7.68–9.73 GHz for a bandwidth of 23.5%. The following table summarizes simulation results obtained for the various cases:

	No switches	**Switch in slot**	**Switches in the CPW**	**Switches in loop**
Frequency Band (GHz)	8.73-10.95	9.43-10.77	8.9-10.8	7.68-9.73
Percentage Bandwidth	22.6%	13.3%	19.3%	23.5%

Placing all five switches obviously creates complications for the biasing circuitry, and is not necessary. Clearly, having switches in the CPW gaps (case (b)) does not add anything to slot/loop coupling with no switches, except for a small reduction in bandwidth. If two broad

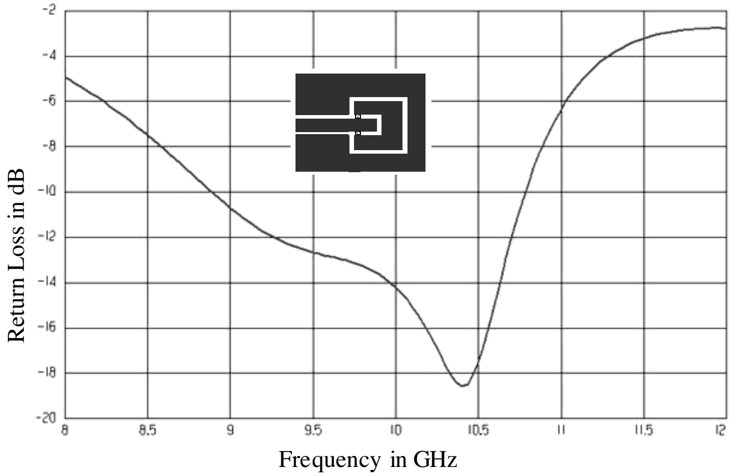


Figure 8. Return loss for two switches in CPW.

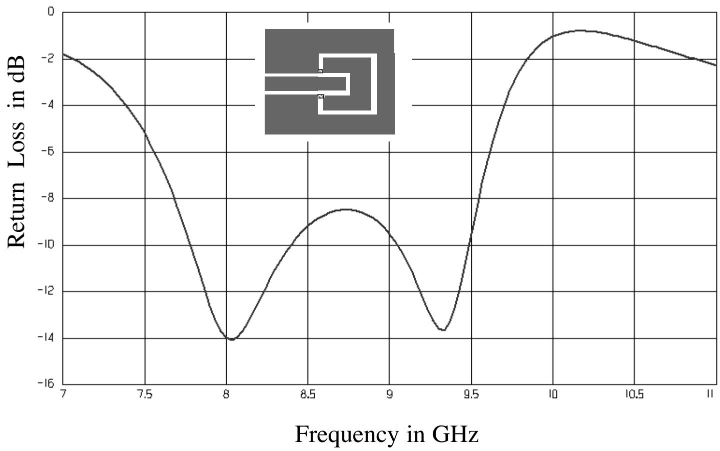
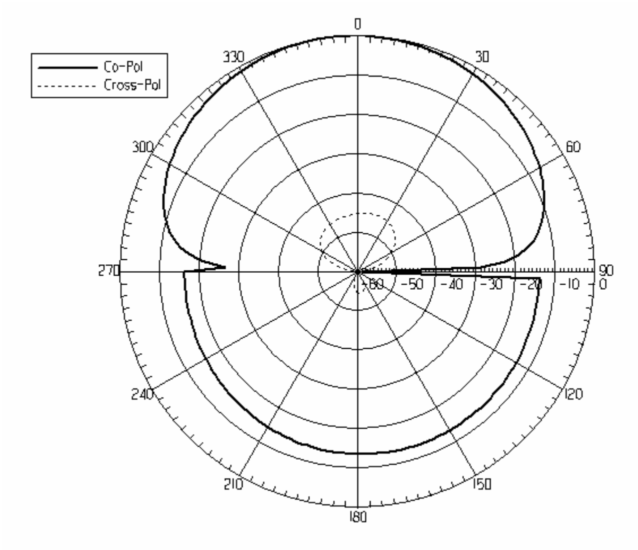


Figure 9. Return loss for two switches in the loop.

frequency bands are desired, only two switches in the loop are necessary (case (c)). Biasing the two is straightforward since they both have to be either on or off simultaneously. Only two wires are needed: one connected to the conductor inside the loop and another connected to the ground plane. The two resulting frequency bands are those in the second column and last columns in the table above, 8.73–10.95 GHz and 7.68–9.73 GHz (no switches and switches in the loop columns

(a) E-Plane



(b) H-Plane

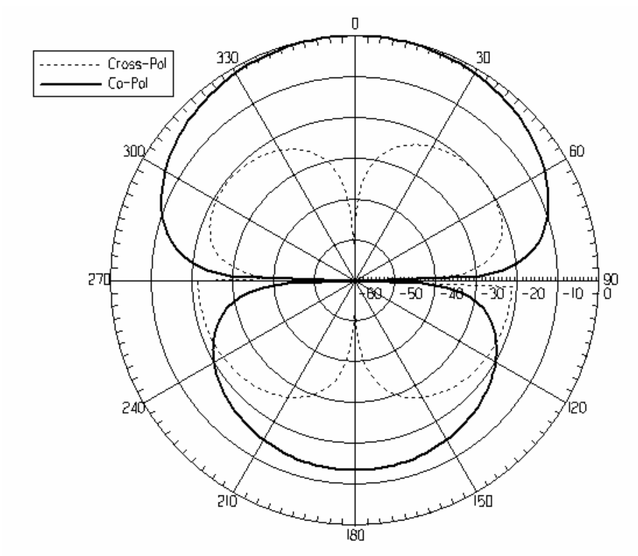
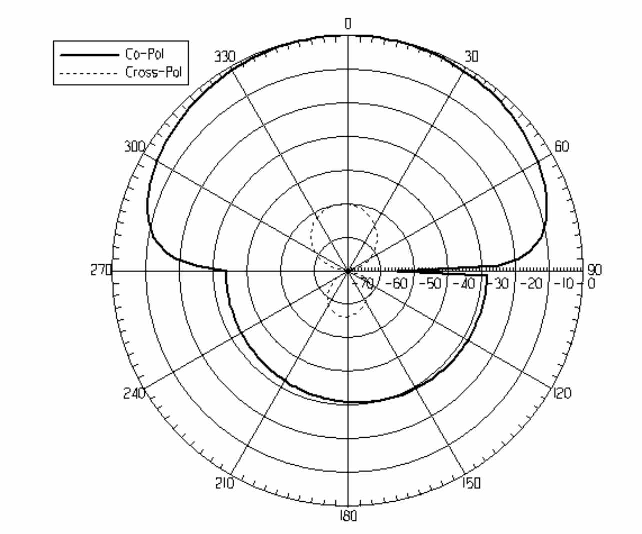


Figure 10. Radiation patterns for slot/loop coupling when switches are OFF.

(a) E-Plane



(a) H-Plane

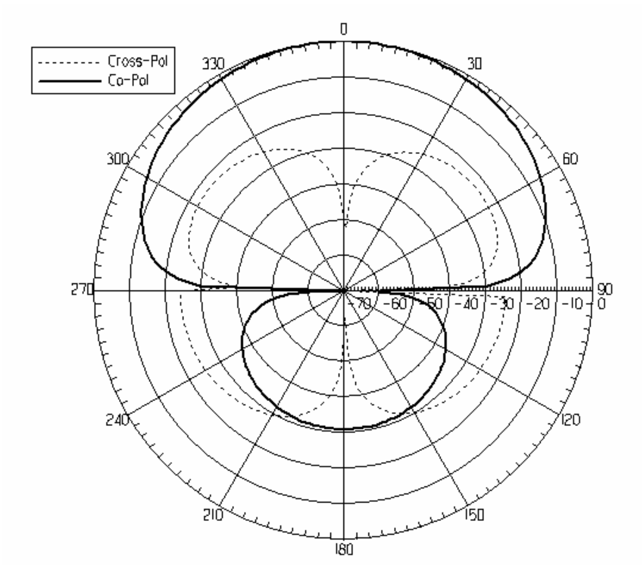


Figure 11. Radiation Patterns for slot/loop coupling when switches are ON.

which correspond to the switches being off or on) with a bandwidth of approximately 23% for each. The radiation patterns for the two frequency bands are shown in Figures 10 and 11. Clearly, in both cases, the antennas are linearly polarized with cross polarization levels less than about -20 dB and front to back ratios of 12 dB (switches off) and 30 dB (switches on). The F/B ratio is worse when the two switches are off (12 dB) because, in this case, the excitation of the patches is due primarily to the loop portion which is near resonance. When the two switches are on, the excitation will be due mainly to the small capacitive slot at the end of the CPW feed resulting in very small back radiation.

4. CONCLUSIONS

A two-layer microstrip antenna fed using a coplanar waveguide through a slot/loop combination was investigated in this paper. The two layers consist of a high-ε_r substrate containing the feed network and a low-ε_r substrate containing two patches, one on either side. The two substrates are not separated by a ground plane. This arrangement produced impedance bandwidth of about 23%. Furthermore, the use of the slot/loop combination allows for easy reconfigurability of the frequency band of operation by incorporating two switches, easily biased. For the parameters used in the paper, the two bands obtained were 8.73–10.95 GHz when the two switches are off and 7.68–9.73 GHz when the two switches are off. Back radiation is minimal, it is negligible (F/B ratio = 30 dB) when the switches are on and somewhat higher (F/B = 12 dB) when the switches are off. The difference in F/B ratio is due to the fact that when the two switches are off, the excitation of the patches is due mainly to the loop portion of the feed which is near resonance, whereas when the two switches are on, the excitation will be due to the small capacitive slot at the end of the CPW feed resulting in very small back radiation.

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