A Novel Broadband Microstrip-Fed Wide Slot Antenna With Double Rejection Zeros

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***Abstract*—In this letter, a novel broadband microstrip-fed slot antenna with double rejection zeros is proposed and developed by constructing simultaneously a wide-slot radiator and a quarter-wavelength microstrip line resonator. A comprehensive explanation on its operating principle is at first given by using an equivalent two-pole filtering network, in which the radiation resistance is perceived as the output impedance. Extensive numerical results are then obtained using commercial electromagnetic simulator to demonstrate its attractive broadband feature. Finally, a few antenna samples are designed, fabricated, and measured to verify the predicted performance. Experimental results exhibit that the bandwidth of this proposed antenna configuration is significantly increased up to 32.0% as compared to 9.0% of its traditional counterpart.**

***Index Terms*—Broad bandwidth, double rejection zeros, microstrip-fed slot antenna, step-impedance inverter, two-pole filtering network.**

I. INTRODUCTION

MICROSTRIP (MS)-fed slot antenna was extensively investigated [1]–[5] in the past three decades due to its attractive features, such as low profile, lightweight, low cost, and ease of integration with other circuits. Yoshimura [1] originally proposed an MS-fed slot antenna by extending a strip conductor cross a narrow slot radiator and short-circuiting its terminal to the far side of this slot through the dielectric substrate. The great efforts in [2]–[4] were made to realize an electromagnetic (EM)-coupling MS-fed narrow slot antenna. Instead of a vertical via wire at the strip terminal, the feeding strip line is extended beyond the slot location by one quarter-wavelength ($\lambda/4$) to realize an equivalent short end. Recently, the complete circuit model of such a MS-fed slot radiator with different slot widths was investigated in [5] to imply that the wide slot width allows oneself to enhance its impedance bandwidth. Alternatively, a broadband wide slot antenna [6] was successfully constructed by terminating a uniform strip inside the region of a wide slot. However, only some final results were given without providing any design guideline.

In this work, a novel broadband MS-fed wide slot antenna is proposed and developed by incorporating an additional quarter-wavelength line resonator in the feeding network. Using the circuit model of a wide slot radiator in [5], its operating principle is at first qualitatively described on a basis of the equivalent topology of a two-pole bandpass filter [7]. Optimization design is then executed via agilent momentum to demonstrate its broadband impedance bandwidth in theory. Finally, a few antenna samples are designed, fabricated, and measured to evidently verify our predicted results and further exhibit its real broad bandwidth in comparison to its traditional narrow slot counterpart.

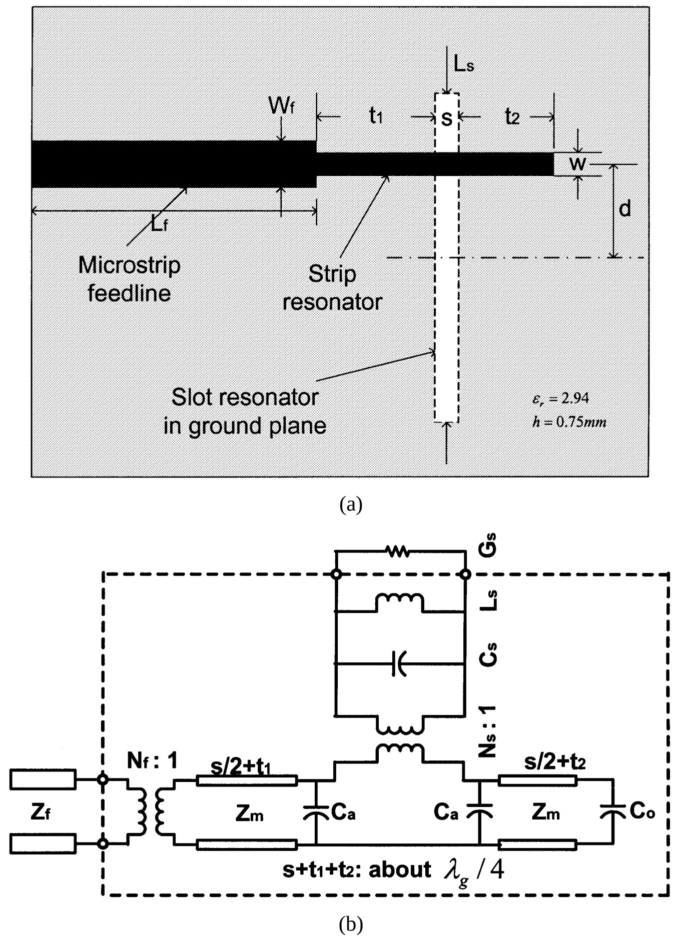

Fig. 1. Physical geometry and equivalent circuit topology of a novel broadband microstrip offset-fed slot antenna with double rejection zeros. (a) Physical geometry. (b) Equivalent topology.

II. GEOMETRICAL LAYOUT AND EQUIVALENT TOPOLOGY

Fig. 1(a) depicts the geometrical layout of the proposed MS-fed slot antenna, in which a slot radiator is formed on the lower ground plane, while the feeding strip conductor is extended perpendicularly cross the slot on the upper interface of the dielectric substrate. Different from the traditional slot antennas with a uniform microstrip line as discussed in [2]–[5],

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a thinner strip conductor section is used around the slot region. The length of the strip line is set to about one quarter-wavelength at the frequency of operation, i.e., $(t_1 + s + t_2) \cong \lambda_g/4$. This $\lambda/4$ line resonator with the opened-circuit end is then connected with the microstrip feeding line via step-impedance inverter [8] at the other end and is coupled to the half-wavelength ($\lambda/2$) slot radiator via electromagnetic coupling near the center. The feeding or coupling point for the slot radiator is moved away by the offset distance (d), from the center of the strip resonator in order to adjust the required coupling degree between these two resonators in optimization design.

The physical layout of this antenna can be equivalently characterized as a two-stage bandpass filter topology as described in Fig. 1(b). Following our early work in [5], the microstrip-fed slot radiator can be effectively perceived as an equivalent π-network with a series radiation-related lossy resonator and two identical shunt capacitors (C_a) on its two sides. In this view, the offset slot-to-strip coupling section is modeled as an equivalent transformer with the turns ratio of N_s to convert the radiator admittance ($Y_s = G_s + j\omega C_s + 1/j\omega L_s$) into its resultant series counterpart in the schematic. For instance, the step impedance inverter can be expressed as a transformer with the turns ratio of N_f as discussed in [8] and its value is determined by the ratio of two strip widths, i.e., ratio of two characteristic impedances, on the two sides of this step discontinuity. Furthermore, the radiation conductance (G_s) is particularly considered as the load admittance at the output terminal of such a fictional two-port network so as to build up the complete two-stage bandpass filter (BPF) topology with double rejection zeros (or transmission poles). As such, the pass bandwidth of this BPF dominantly determines the impedance bandwidth of the proposed MS-fed slot antenna.

III. Results and Discussion

Our optimization design of this antenna is carried out with Agilent momentum EM simulator and the substrate used here is the Duroid 6002 ($\varepsilon_r = 2.94$ and $h = 0.75$ mm). Based on the operating principle described above, the slot-resonator length (L_s) is selected as the half-wavelength of 24.0 mm with the width of $s = 5.0$ mm at the operating frequency of $f = 5.0$ GHz, and the strip-resonator length ($t_1 + s + t_2$) is designed as the quarter-wavelength of 9.8 mm with the width of $w = 0.5$ mm. The two offset feeding distances (t_2 and d) are carefully adjusted in order to achieve the desired coupling, i.e., turns ratio N_s, as illustrated in Fig. 1(b). To simplify the analysis, the dimensions of both the slot and strip resonators are fixed in our simulation to keep the turns ratio (N_f) and the radiation conductance (G_s) unchanged.

Fig. 2(a) depicts the simulated return loss (S_{11}) of a proposed slot antenna versus strip-offset distance (t_2) with the fixed slot-offset distance of $d = 9.9$ mm. It can be observed here that two minimum values (or rejection zeros) clearly appear at the lower and higher frequencies, i.e., $f_1 = 4.4$ GHz and $f_2 = 5.3$ GHz, achieving an almost constant wide matching bandwidth (BW $\cong 32\%$) regardless of varied t_2. As explained by Fig. 1(b), these two zeros are basically attributed by two cascaded resonators, i.e., $\lambda/4$ strip resonator and $\lambda/2$ slot radiator.

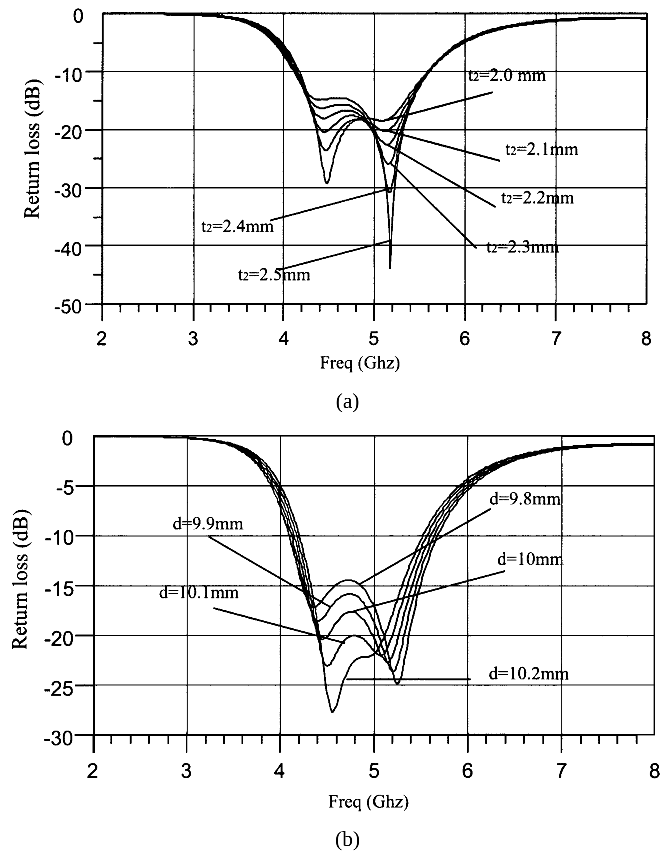
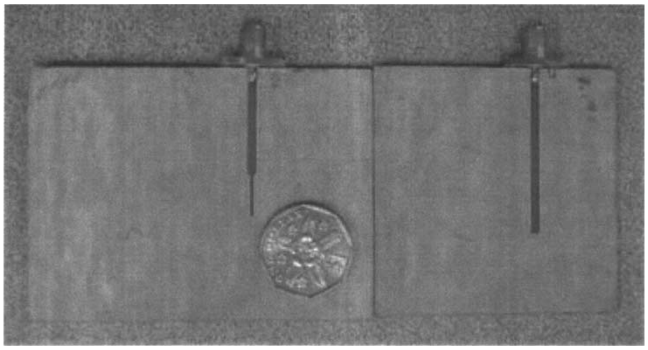


Fig. 2. Simulated returned loss of the proposed slot antenna versus different offset distances. (a) Offset distance (t_2). (b) Offset distance (d).

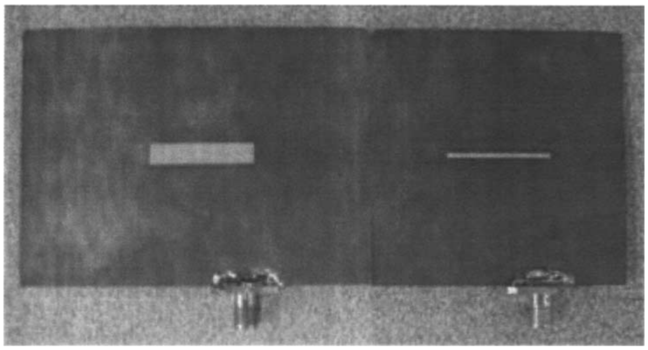
At $t_2 = 2.0$ mm, S_{11} at f_1 (lower zero) almost achieves -30 dB, but that at f_2 (higher zero) is about -17 dB, indicating an asymmetric frequency response. As t_2 increases from 2.0 mm to 2.5 mm, S_{11} at f_1 is found to gradually move up to -14 dB, while that at f_2 drop off below -40 dB. As the result, for a fixed d, t_2 should be set up around 2.1–2.2 mm in order to realize a wide bandwidth with symmetrical response.

Now, let us investigate the return loss (S_{11}) versus slot-offset d under the fixed $t_2 = 2.2$ mm. Fig. 2(b) describes the relevant simulation results, in which S_{11} achieves lower than -10 dB within the bandwidth for all the five cases. Further, S_{11} can be observed to fall down -20 dB over the bandwidth as the offset d increases from 9.8 to 10.2 mm, showing an excellent impedance matching characteristic. Until now, our numerical results have demonstrated that the proposed slot antenna provides a broadband impedance bandwidth with double rejection zeros by adjusting the offset feeding point between the strip and slot resonators.

To provide a tangible verification of the above-described attractive performance, two MS-fed slot antenna samples are designed and fabricated. Fig. 3(a) and (b) illustrate the top- and bottom-view photographs of the proposed and conventional MS-fed slot antennas. Both slot radiators have the same length of $L_s = 24$ mm, while their slot widths are chosen as 5.0 and 0.5 mm, respectively. Fig. 4 plots the measured results of these two slot antennas for comparative study. At first, the measured bandwidth of the proposed antenna can be seen to be about 32.0% with two visible zeros, as shown in Fig. 2(a) and (b).



(a)



(b)

Fig. 3. Photographs of two fabricated microstrip-fed slot antennas for experimental verification. (a) Top view. (b) Bottom view.

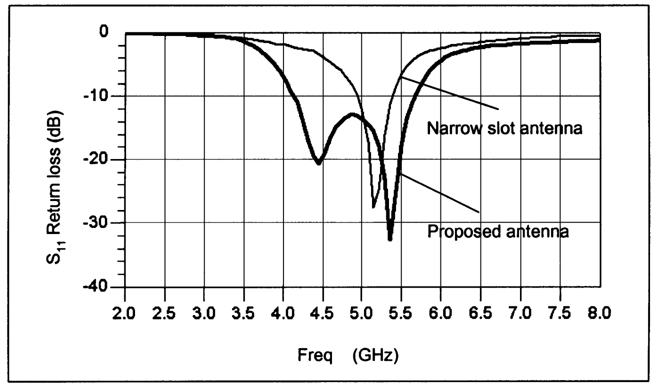


Fig. 4. Comparison between the measured returned loss (S_{11}) of the proposed and the conventional microstrip-fed slot antennas.

On the other hand, its conventional counterpart has the bandwidth of about 9.0% with a single zero that is contributed by the slot radiator itself. Again, our experimental results exhibit that an additional $\lambda/4$ strip resonator, formed at the microstrip feeding section, can really bring in an additional rejection zero and, thus, effectively enhance the impedance bandwidth of the MS-fed slot antenna.

IV. Conclusion

A novel broadband MS-fed wide slot antenna is proposed by forming an additional $\lambda/4$ microstrip line resonator along the feeding section. After its operating principle is explained in depth by an equivalent two-stage bandpass filtering topology, extensive numerical simulation is carried out with a full-wave EM simulator to investigate its two-pole return loss behaviors in theory. To provide a comparison, two antenna samples are designed, fabricated and measured. A superior broadband performance is demonstrated. It is our belief that such a feeding network principle based on the filter theory can be widely used in design of other types of planar printed antennas with enhanced bandwidth.

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