A Wideband Multiresonant Single-Element Slot Antenna

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1. Introduction

Current advancements in printed antenna technology have resulted in a variety of different techniques for designing low profile, cost effective, and highly efficient wideband antennas. Most of these techniques, deal with marginal bandwidth improvement of more traditional antennas such as patch or printed wire antennas. Another class of antennas that are suitable for miniaturization and have great reconfigurablility potentials, without compromising efficiency, is slot antennas. However, not much attention has been given to improving the bandwidth of this class of printed antennas. In this paper, we present a new technique for increasing the number of resonances, and hence the bandwidth, of a slot antenna by creating multiple fictitious short circuits along the slot.

Microstrip-fed, wide slot antennas have been theoretically studied in [1]. Also, experimental investigations on very wide slot antennas are reported by various authors [2]. The drawback of these antennas are twofold: 1) they require a large area for the slot and a much larger area for the conductor ground plane around the slot; 2) they usually generate high cross polarization levels that change with frequency [2]. This is mainly because these antennas can support two orthogonal modes with close resonant frequencies. The undesirable excitation of the orthogonal mode can easily occur and result in generation of strong cross-polarized radiation. Therefore, it is important to limit the maximum width of the slot antenna under investigation. A relatively wide slot antenna, fed with a narrow microstrip line can be designed to show dual resonant behavior with similar electric field (magnetic current) distributions at both resonant frequencies [3]. This similarity is critical since it results in similar radiation patterns and preservation of the desired polarization at different frequencies over the entire bandwidth of the antenna. The frequencies of the two resonances can be controlled in the design process such that the antenna acts as either a dual band antenna with frequency ratios from 1.1 to 1.6 or as a broadband one with bandwidths up to 37% [3]. In this paper, we will use the same concept and modify the microstrip feed to create two fictitious short circuits along the slot with relatively close resonant frequencies to obtain a much wider bandwidth. By using this technique, a single-element slot antenna with a bandwidth as high as 1.86:1 is designed and fabricated. This antenna shows similar radiation patterns with very low levels of cross polarized radiation over the entire bandwidth. In what follows, first the design procedure is studied and then the measured results are presented and discussed.

2. Design Procedure

When a relatively wide slot antenna is fed with a narrow microstrip line, the electric field generated by that part of the microstrip line over the slot (which does not have a ground plane), cancels the slot electric field, generated by the return current of the microstrip-line in the ground plane, at a certain location near the feed. This creates a fictitious short circuit along the slot near the microstrip feed and hence, generates a fictitious resonance with a frequency which is slightly higher than that of the main resonance. The next challenging step is to examine whether it is possible to create more than one fictitious short using a similar approach or not. If this is possible, the bandwidth of the antenna can drastically be increased by choosing these resonant frequencies such that the VSWR remains below 2 across the entire bandwidth. In order to test the validity of this idea, we begin by attempting to place two fictitious short circuits along the slot, using a two-prong microstrip feed. It is expected that this structure could present three distinct resonances at frequencies proportional to the resonant lengths *Lr1*, *Lr2*, and *Lr3* as shown in Figure 1. If the locations of the two feed lines are chosen properly, the three resonant frequencies will be close and the overall bandwidth of the antenna can be increased significantly.

The locations of the microstrip feeds, *Ls*1 and *Ls*2 in Figure 1, determines *Lr*2 and *Lr*3 and hence, the resonant frequencies of the two fictitious resonances. The feed topology chosen for this antenna (Figure 1) can be viewed as a three-port microstrip network that achieves power division using a microstrip-Tee. In order to obtain a broadband response, matching is performed by choosing the feed network parameters, *L*2, *W*2, *L*3, *W*3, *L*4, *W*4, *Ls*1, *Ls*2, *Lm*1, and, *Lm*2 (shown in Figure 1) appropriately. These parameters must be chosen such that the overall impedance bandwidth of the antenna is maximized. To do so, a combined full-wave and network simulation technique is used. First the antenna structure and its narrow microstrip feed lines (shown in Figure 2) are simulated as a four port network using a full-wave EM simulation tool. Then the S parameters of this four-port network are used in a network simulation and optimization software from which the optimized values of the feed network parameters are obtained. This technique allows for rapid optimization of the network parameters, but it ignores the coupling effects that exist between different components of the feed network. Therefore, a final full-wave simulation of the structure is performed and the different feed parameters are fine tuned to obtain the optimum response. Table I shows the optimized values of the antenna and its feed network dimensions.

Parameter	L	W	L2	W2	L3	W3
Value	31	6	11	1.8	19.73	0.43
Parameter	L4	W4	Ls1	Ls2	Lm1	Lm2
Value	6.2	0.72	2	6	3.3	1

Table I. A SUMMARY OF THE PHYSICAL DIMENSIONS OF THE BROADBAND SINGLE-ELEMENT SLOT ANTENNA. ALL DIMENSIONS ARE IN *mm*

3. Measurement Results and Discussion

The proposed antenna is fabricated on a 500μm thick RO4350B substrate with a dielectric constant of εr=3.4, and loss tangent of 0.003 with a ground plane size of $11.5cm \times 10cm$. The return loss (S11) of the antenna is measured using a calibrated vector network analyzer and is shown in Figure 3. It is shown that the VSWR of the antenna remains below 2 over a bandwidth range of 2.96 GHz to 5.52 GHz corresponding to a 1.86:1 ratio. The radiation patterns of the antenna are measured at 5 different frequencies in the anechoic chamber of the University of Michigan and three of which are presented in Figures 5 and 6. It is observed that the radiation patterns at different frequencies are similar, which is expected from a wideband antenna. More importantly, the cross polarization levels are very small for all the measured patterns. Specifically, a Co-Pol/Cross-Pol ratio of better than 30 dB is observed at boresight in all of the measured radiation patterns. The cross polarization levels at other directions are also very small, indicating excellent polarization purity.

As can be observed from Figure 5, the patterns of the antenna are almost the dual of those of an electric dipole. The only difference is that the patterns in the E-Plane (unlike the H-Plane of an electric dipole) show two minima at ±90° which are caused by two different mechanisms. The first mechanism is the out of phase radiation from the edges of the ground plane, which is destructively added to the radiation from the main slot. This is not observed in the H-plane, since the radiation in H-plane shows two inherent nulls at ±90° as a result of the boundary condition that forces the tangential component of the electric field to go to zero. The second reason for having these minima is that the slot antenna is covered with a dielectric substrate at one side. This forces the normal component of the electric field at grazing angles to go to zero as described in [4]. Since this boundary condition only exists at one side of the aperture, this mechanism only creates a minima and not a null. The antenna gain is measured in the anechoic chamber using a standard double ridge horn and is presented in Figure 4. It is seen that the gain of the antenna remains relatively constant over its entire bandwidth. Based on the measured VSWR, radiation patterns, polarization purity, and gain of the antenna, the overall antenna bandwidth is determined to be the same as its impedance bandwidth (1.86:1).

4. Conclusions

A very simple way of designing wideband printed antennas with excellent radiation parameters over the entire bandwidth was presented. Many of the existing wideband, single-element, printed antennas achieve wideband operation from different radiation mechanisms and field distributions at different frequencies, which results in inconsistent radiation patterns over their bandwidth. Unlike such antennas, the antenna studied in this paper has consistent radiation parameters over a 1.86:1 bandwidth and has very low cross polarization levels at different directions and frequencies.

References

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[4] C. A. Balanis, "*Antenna Theory: Analysis and Design, Chap. 12*", Wiley, 2nd Edition, 1996.

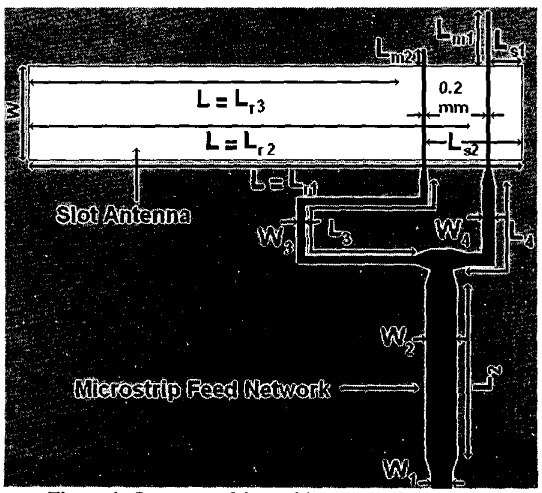

Figure 1. Geometry of the multi-resonant slot antenna.

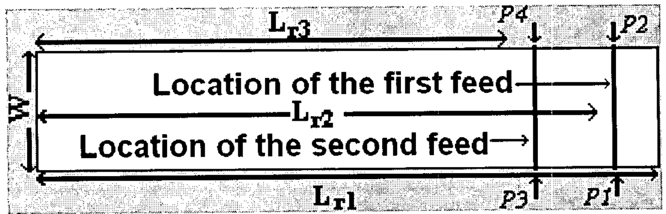

Figure 2. Geometry of the four-port structure used in the full-wave simulation tool. P1, P2, P3, and P4 show the location of the four ports.

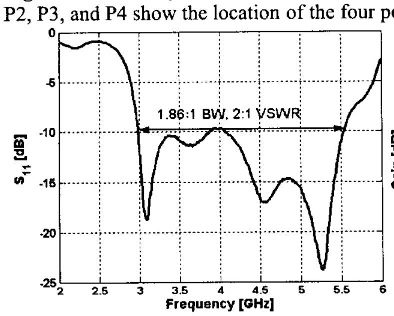

Figure 3. Measured return loss of the wideband slot antenna.

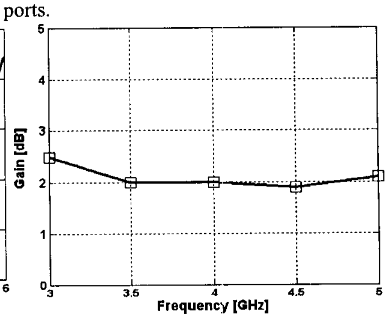

Figure 4. Measured gain of the wideband multi-resonant slot antenna.

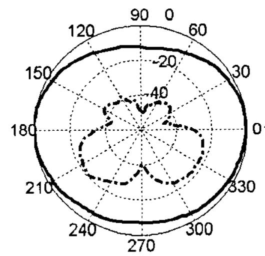

Figure 5a. *f=3.0 GHz*

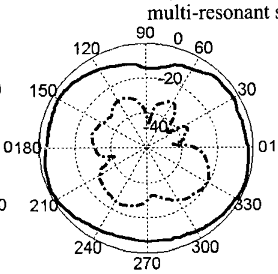

Figure 5b. *f=4.0 GHz*

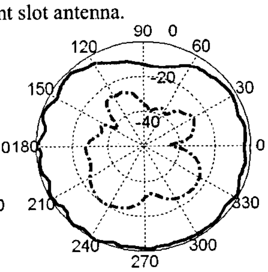

Figure 5c. *f=5.0 GHz*

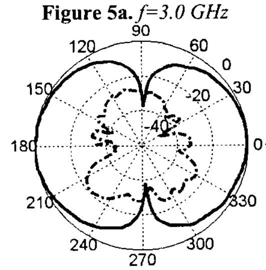

Figure 6a. *f=3.0 GHz*

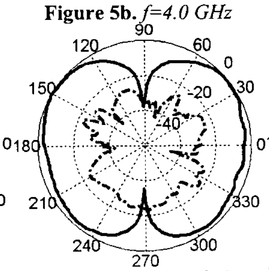

Figure 6b. *f=4.0 GHz*

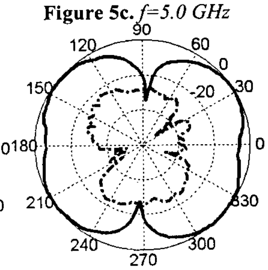

Figure 6c. *f=5.0 GHz*

Fig. 5 E-Plane **and Fig. 6** H-Plane radiation patterns of the wideband slot antenna. Solid line: Co-Pol, Dash Dot line: Cross-Pol