A Two Step Stair Shaped Dielectric Resonator Antenna with AMC for UWB Applications

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Abstract

This paper presents an ultra-wide band (UWB) antenna with two steps stair shaped dielectric resonator (SSDR) antenna. The two steps SSDR is placed precisely on the aperture to achieve an ultra-wide bandwidth of 136.2%. The first step of SSDR (DR_1 and DR_2) is fed directly by the microstrip line through aperture coupling technique whereas the second step (DR_3) is a parasitic DR placed adjacent to DR_1. The SSDR is radiating with $TE^{y}_{1\delta 1}$ – like mode at 5.32 GHz and $TE^{x}_{\delta 11}$ – like mode at 6.3 GHz. The parasitic DR is improving the impedance matching and increasing the bandwidth by 11.3% due to the dielectric loading effect. Further a dual band artificial magnetic conductor (AMC) is placed below the UWB antenna to improve the antenna radiation characteristics. The improvement in average gain and gain variation is 36.7 % and 13.5% respectively. The antenna radiation efficiency is 81.6% with AMC reflectors.

1. Introduction

Dielectric resonators are the most attractive choices for evolving wireless communication systems in the coming years. It has advantages when it comes to ohmic losses, bandwidth enhancement, and integration with different feeding networks and radiating elements. Since Long et al. [1] identified dielectric resonators as radiators in 1983, their application to various communication scenarios has been a research focus for decades. These resonators have been investigated as a single band, multiband, and wideband radiators for different applications. [2]. A unique type of antenna called as an ultra-wideband antenna is modernizing the communication system. [3]. Its ability to integrate into many type of indoor communication systems for smart devices makes it particularly effective in intelligent communication systems. These antennas are not only competent, but they are also safe, dependable, and cost-effective, with a high data rate. Unlike other wireless communication systems, identification of other UWB devices is not dependent on signal strength but based on the time it takes for a short radio pulse to travel between devices utilizing techniques such as Time of Flight (ToF), Time Difference of Arrival (TDoA), etc. [4-5]. As a result, it is considerably more precise and different than other wireless technologies. Most of the DR-based UWB

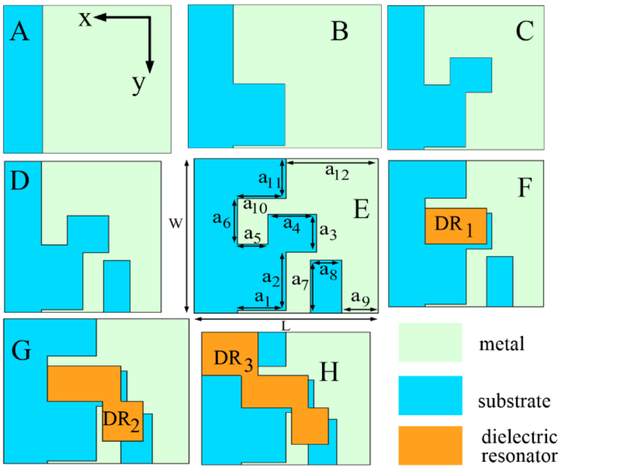


Figure 1. Evolution of proposed antenna design, a_1 = 8, a_2 = 11, a_3 = 7, a_4 = 8, a_5 = 5, a_6 = 8.5, a_7 = 10, a_8 = 5, a_9 = 6, a_{10} = 8, a_{11} = 7.5, a_{12} = 15, L= 30 and W = 29 (all dimensions are in mm).

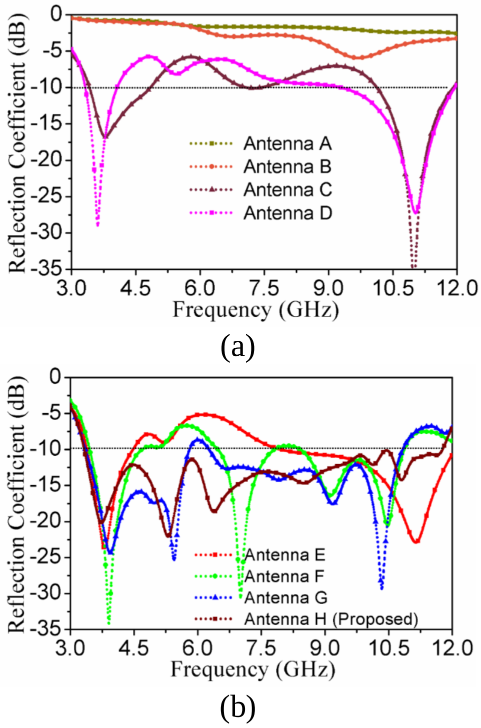


Figure 2. Reflection coefficient of antenna design evolution: (a) S11 of Antenna A to Antenna D and (b) S11 of Antenna E to Antenna H (proposed).

antennas reported [6-9], so far are hybrid antennas, i.e., the integration of dielectric resonators with the planar structures. The technique involves the modification in DR-shape, introduction of air-gaps, and stacking of DRs in order to reduce the overall quality factor of the antenna, hence improving the bandwidth.

In this paper, a modified two step stair shaped DR (SSDR) is presented, which is radiating along with the aperture created on the ground plane to achieve ultra-wide bandwidth. The proposed UWB antenna is investigated in terms of reflection coefficient, gain, radiation pattern, and radiation efficiency. Further, an AMC structure is placed beneath the proposed antenna and antenna far field parameters are studied.

2. Antenna Design and Analysis

2.1 Antenna Design

The antenna design evolution is shown in Figure 1. The corresponding reflection coefficient at each step in design evolution is shown in Figure 2.

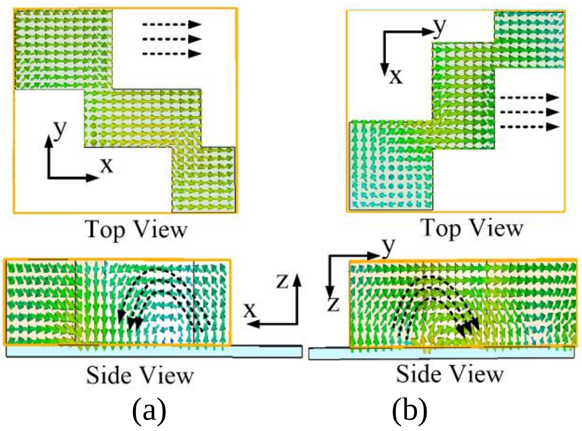


Figure 3. (a) TE $^{y}{}_{1\delta 1}$ – like mode at 5.32 GHz, (b) TE $^{x}{}_{\delta 11}$ – like mode at 6.3 GHz on the two step stair shape DR.

The antenna is designed on a FR – 4 epoxy substrate of thickness 0.8 mm, $\varepsilon_{r,\,subs}$ = 4.4 with loss tangent of tanδ = 0.025. Referring to Figure 1. and Figure 2., Antenna 'A' is simply a partial ground plane fed by a microstrip line on the back side of substrate. Antenna 'A' does not resonate but after creating a rectangular slot in the partial ground plane (Antenna 'B') a possibility of resonance is observed. Further, another slot is created in addition with the existing slots, thus modifying the overall slot (Antenna 'C') and two resonance bands are observed in the lower and higher frequency region. A second slot is created in the defected ground plane (Antenna 'D') which improves the impedance matching in the higher frequency region. A third slot which is a rectangular slot, is created as shown in Antenna 'E' which shows similar behavior to Antenna 'C' and 'D'. Two resonance bands i.e., 3.38 GHz to 4.46 GHz and 8 GHz to 12.3 GHz are obtained. From Antenna 'C' to Antenna 'E', impedance matching is improved hence bandwidth is improved, but the resonance frequency range are similar. On placing the first DR i.e., DR_1 as shown in

TABLE - I
ANTENNA EVOLUTION AND THEIR FREQUENCY BANDS

Antenna	Frequency Bands (GHz)	Antenna	Frequency Bands (GHz)
A	Nil	E	3.38 to 4.46 & 8.00 to 12.3
B	Nil	F	3.46 to 4.68, 6.47 to 7.8 & 8.42 to 10.87
C	3.43 to 4.83 & 10.1 to 11.9	G	3.35 to 5.82 & 6.25 to 10.83
D	3.32 to 4.06 & 9.20 to 11.96	H (Proposed)	3.32 to 11.8

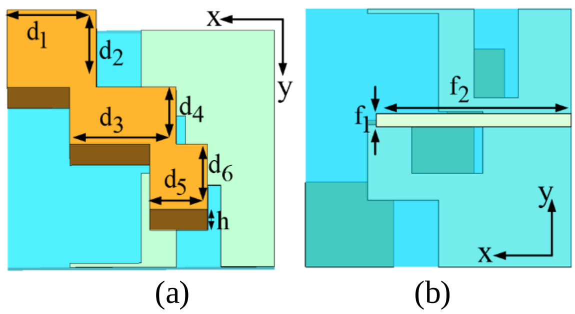


Figure 4. (a) Perspective view showing the dimensions of the DR ($\varepsilon_{r,}(Alumina)$ = 9.8), d_1 = 10, d_2 = 9.5, d_3 = 12, d_4 = 7, d_5 = 6.5 and d_6 = 8 (b) Back view of the antenna showing feed line dimensions, f_1 = 1.5 and f_2 = 22 (All dimensions are in mm)

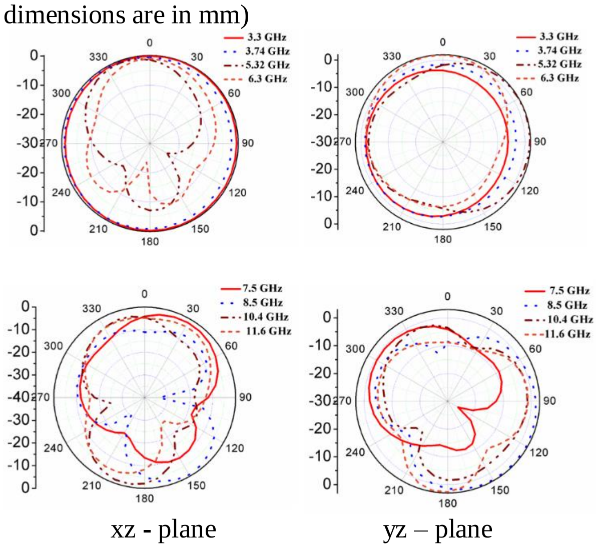


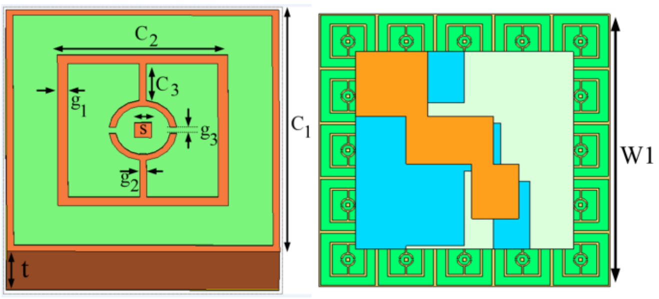
Figure 5. Radiation pattern of the proposed UWB antenna.

are similar. On placing the first DR i.e., DR_1 as shown in Antenna 'F', a multi-band response is obtained due to the DR_1 resonance and aperture resonance. Adding DR_2 adjacent to the DR_1 which together creates the first step in stair shape DR (Antenna 'G'). Due to the dielectric loading, overall increase in the size of the DR and change in shape from its regular geometry, the resonance of the first step

DR shifts to lower frequencies i.e., 5.32 GHz and 6.3 GHz. It can be observed that the aperture resonance at higher frequency is shifted to lower frequency due to the dielectric loading of the DRs on the aperture. Finally, a third DR i.e., DR_3 is loaded on the third slot (Antenna 'H') precisely which is not directly fed by the microstrip feed line rather, it is acting as a parasitic DR to the first step stair DR. This DR improves the impedance matching and bandwidth at higher frequencies, thus achieving the bandwidth from 3.32 GHz to 11.8 GHz. The DR modes at the resonance frequencies 5.32 GHz and 6.3 GHz are $TE^{y}_{1\delta 1}$– like and $TE^{x}_{\delta 11}$ – like mode as shown in Figure 3. It can be observed from the electric field distribution on the two step SSDR of Figure 3. that the parasitic dielectric resonator DR_3 is not actively participating in DR modes rather DR_1 and DR_2 are contributing towards modes of two step SSDR. Table – I show a tabular representation of the frequency bands corresponding to antenna evolution at each design step in Figure 1. Figure 4. shows the perspective view and of the proposed structure and the antenna feed line.

2.2 Antenna Design with AMC

The proposed antenna designed so far shows a degradation in the antenna radiation characteristics. So to improve the antenna radiation performance, an AMC structure has been designed. Figure 6 (a). shows the unit cell design of the AMC structure. A dual band AMC structure is chosen for covering the maximum band of operation throughout the ultra – wide bandwidth.



(a) (b)

Figure 6. (a) Proposed AMC unit cell design, C_1 = 8, C_2 = 5, C_3 = 1.2, g_1 = 0.3, g_2 = 0.2, g_3 = 0.2, t = 2.4 and s = 0.5 (All dimensions are in mm). **(b)** Proposed UWB Antenna with AMC structure, W1 = 40 mm.

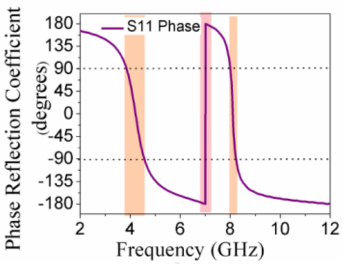


Figure 7. Phase reflection coefficient of proposed AMC structure.

Figure 7. shows the phase reflection coefficient of the AMC structure which shows a dual band behavior. The first AMC band is in between 3.84 GHz to 4.56 GHz. The second AMC band is in between 8 GHz to 8.2 GHz. The dual band AMC is observed due to the dual slots in the AMC unit cell. In between the two AMC bands a PEC band is observed around 7 GHz. Further, a 5 x 5 array of unit cell is placed beneath the UWB antenna and its radiation characteristics are studied. Figure 6 (b). shows the proposed antenna multilayer structure with AMC below the UWB antenna. The AMC structure is placed at an optimized distance of ≈ $\lambda_o/6$. The parametric study of reflection coefficient on the distance between antenna and AMC structure is shown in Figure 9. The performance of AMC over gain, radiation efficiency and radiation pattern of the antenna is shown in Figure 10. and Figure 11. respectively. Table - II shows the improvement in gain and radiation characteristics due to the AMC reflector. The AMC structure is providing overall improvement in antenna radiation characteristics throughout the operating range. This is because. a ground plane with a conducting surface underneath the AMC surface acts as a reflector surface for the whole operating band. Additionally, the gain enhancement is occurring over the required bandwidth as a result of the field patterns' constructive and destructive interference with reflections from the suggested AMC structure [10]. Overall, the percent improvement in average gain and gain stability is 36.7 % and 13.5 % respectively.

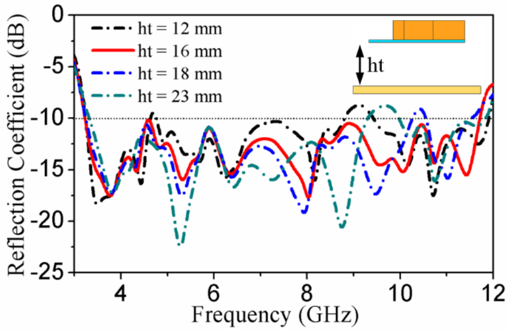


Figure 9. Parametric study of S-parameters on variable 'ht' of the proposed MIMO antenna with AMC.

The impact of AMC structure on the radiation efficiency curve is shown in Figure 10. It is observed that the radiation efficiency on average for UWB antenna is 84.45 % where as when AMC structure is included, it is 81.58 %. Also, the blue and red curve (showing efficiency) are well following each other. This shows, that the efficiency is not degrading significantly and the AMC structure is not showing any strong coupling effects with UWB antenna structure. Hence, a significant improvement in antenna radiation characteristics is achieved. Referring to Figure 5. and Figure 11., the effect on radiation pattern due to AMC structure can be compared. The UWB antenna has inconsistency in its radiation pattern. The pattern is omni - directional, directional and tilted in backwards due to antenna geometry. Whereas, with the implementation of AMC structure in the antenna geometry, the radiation pattern is improved significantly and the patterns are consistent throughout the operating range. A directional pattern is observed throughout the achieved ultra wide bandwidth which is suitable in most of the communication applications.

TABLE - II
AMC PERFORMANCE ANALYSIS

Performance Parameters	UWB Antenna	UWB Antenna with AMC	% Improvement
Average Gain (dBi)	3.31	5.23	36.7
Gain stability (dBi)	3.18 (2 -5.18)	<2.75 (3.92-6.7)	13.5
Radiation Pattern	back-lobes and backward radiation	Directional radiation pattern and reduced backlobes.	-

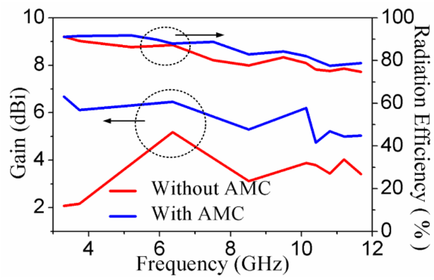


Figure 10. Gain and radiation efficiency comparison of the proposed UWB antenna with and without AMC structure.

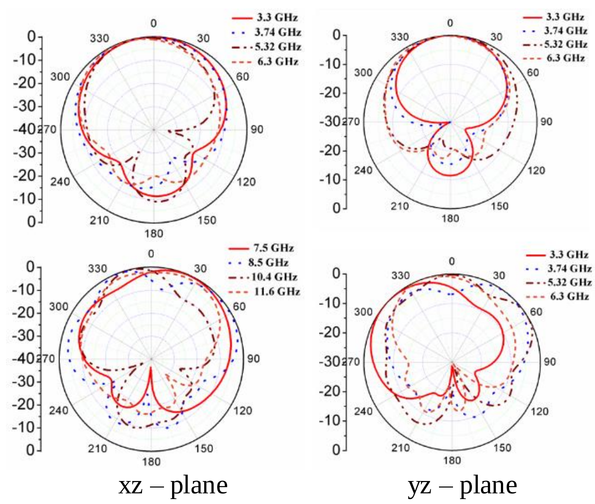


Figure 11. Radiation pattern of the proposed UWB antenna with AMC structure.

3. Conclusion

In this paper, a two step stair shaped dielectric resonator (SSDR) antenna is presented which gives ultra wideband characteristics. The DR_1 and DR_2 are contributing along with aperture towards ultra wide bandwidth and radiation characteristics. The DR_3 which is adding the second step in SSDR antenna is a parasitic DR that improves the impedance matching and the antenna bandwidth due to the dielectric loading effect. A dual band AMC structure is placed below the UWB antenna that improves the antenna radiation properties significantly. The impedance bandwidth achieved is 136.2 %. Antenna gain is improved by 36.7 % and stability in gain is improved by 13.5 % with less 2.75 dB difference. The proposed antenna has a good radiation efficiency of more than 81 %.

4. References

1. S. Long, M. McAllister and L. Shen, “The resonant cylindrical dielectric cavity antenna,” *IEEE Transactions on Antennas and Propagation*, **31**, 3, May 1983, pp. 406-412, doi: 10.1109/TAP.1983.1143080.

2. A. Petosa, “*Dielectric resonator antenna handbook”*, Artech House, Norwood, MA, 2007.

3. U.S. Federal Communications Commission, "*Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems*," U.S. FCC, Washington, D.C., Rep. FCC 02-48, Apr. 2002.

4. Y. Chen, E. Gunawan, K. S. Low, S. -C. Wang, C. B. Soh and L. L. Thi, “Time of Arrival Data Fusion Method for Two-Dimensional Ultrawideband Breast Cancer Detection,” *IEEE Transactions on Antennas and Propagation*, **55**, 10, Oct. 2007, pp. 2852-2865 doi: 10.1109/TAP.2007.905868.

5. G. P. Pochanin et al., “Measurement of Coordinates for a Cylindrical Target Using Times of Flight from a 1-Transmitter and 4-Receiver UWB Antenna System,” *IEEE Transactions on Geoscience and Remote Sensing*, **58**, 2, Feb. 2020, pp. 1363-1372, doi: 10.1109/TGRS.2019.2946064.

6. A. Sharma, G. Das and R. K. Gangwar, “Composite Antenna for Ultrawide Bandwidth Applications: Exploring Conceptual Design Strategies and Analysis,” *IEEE Antennas and Propagation Magazine*, **60**, 3, June 2018, pp. 57-65, doi: 10.1109/MAP.2018.2818013.

7. Z. Song et al., “Equilateral Triangular Dielectric Resonator and Metal Patch Hybrid Antenna for UWB Application”, in *IEEE Access*, **7**, 2019, pp. 119060-119068, doi: 10.1109/ACCESS.2019.2936013.

8. A. Sharma and A. Biswas, “Wideband stacked maltese cross-shaped DR antenna for WiMAX and WLAN applications,” *IET Microw. Antennas & Propagtion*, **11**, 2, 2017, pp.247-252, doi: 10.1049/iet-map.2016.0367

9. M.S.Iqbal and K.P.Esselle, “Pulse-preserving characteristics and effective isotropically radiated power spectra of a new ultrawideband dielectric resonator antenna,” *IET Microw. Antennas Propagation*, **12** Iss.7, 2018**,** pp.1231-1238, doi: 10.1049/iet-map.2017.0172.

10. A. P. Feresidis, G. Goussetis, S. Wang and J. C. Vardaxoglou, "Artificial magnetic conductor surfaces and their application to low-profile high-gain planar antennas," *IEEE Transactions on Antennas and Propagation*, **53**, 1, Jan. 2005, pp. 209-215, doi: 10.1109/TAP.2004.840528.