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A WIDEBAND MICROSTRIP-LINE-FED ISOSCELES TRAPEZOIDAL DIELECTRIC RESONATOR ANTENNA WITH MODIFIED GROUND PLANE

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Abstract—A microstrip-line-fed Isosceles Trapezoidal Dielectric Resonator Antenna (ITDRA) with a parasitic strip and modified ground plane is introduced. It is proved by simulation and experiment that the antenna's resonant frequency can be lowered and the bandwidth can be increased considerably by introducing a slot and optimizing its position and dimensions in the ground plane. The proposed antenna is a wide band antenna with a 2 : 1 VSWR bandwidth of 21.5% centered at 2.51 GHz and exhibits good radiation characteristics and moderate gain in the entire operating band. The antenna covers important application bands viz. ISM: Bluetooth/WLAN 2.4/Wibree (802.11 b/g/n)/ZigBee, WiBro and DMB. The wideband response in the relatively lower frequency range which includes the above mentioned application bands are not much seen anywhere in literature. Details of the design along with experimental and simulation results are presented and discussed.

1. INTRODUCTION

Recently interest has increased in the study of dielectric resonator antennas for their inherent merits of small size, low cost, low profile, ease of excitation and no conductor as an efficient radiator. They have gained much attention in the field of wireless communications due to their attractive features such as simple coupling schemes, zero inherent conduction loss, wide bandwidth which make them far superior to

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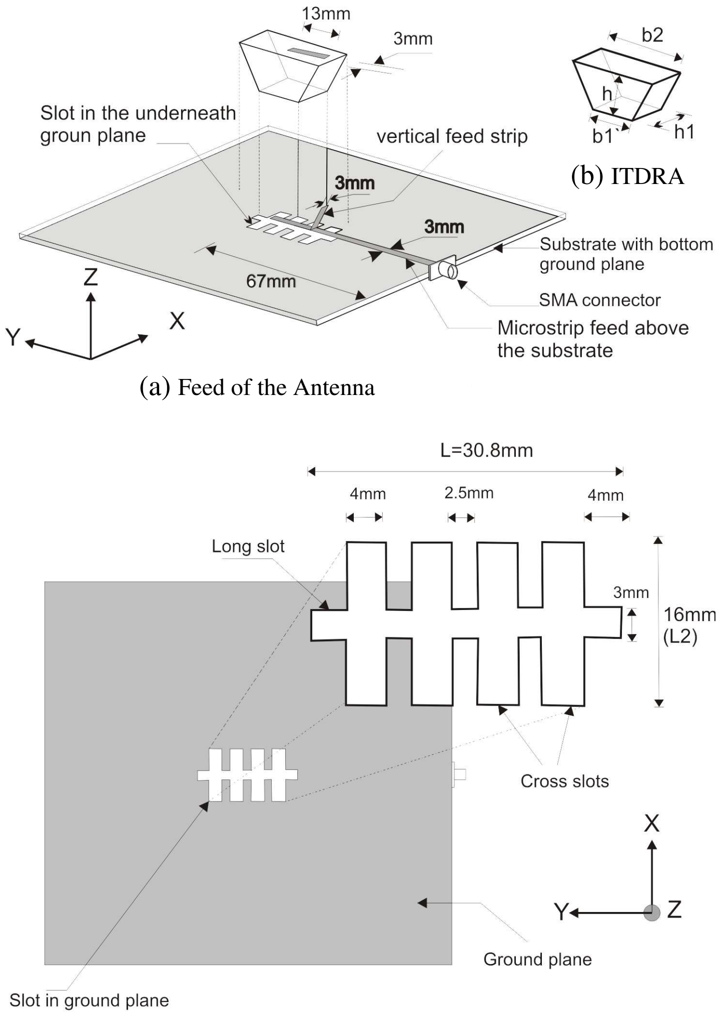
microstrip-patch antennas. Various shapes of DRA's are available: viz. rectangular, cylindrical, half cylindrical, spherical, triangular [1, 2], hexagonal [3] etc.

Many efforts have been devoted to develop wideband dielectric resonator antennas (DRAs) such as by inducing parasitic effects with attached metal strips [4, 5], making the feeding aperture radiate like a slot antenna to incur another band [6], leaving air gaps between a DRA and the ground plane to incur more effective radiation [7], modifying the DRA shape to create discontinuities [8] and so on. Excitation of a mode depends on the DRA geometry, feed structure and the feed location. Among various feed structures the simplest one is an open-ended micro-strip transmission line [9, 10] to excite the DRA.

This paper presents a more compact DRA of novel geometry, isosceles trapezoidal shape with wide band response for applications that cover frequency ranges for WLAN 2.4, WiBro and DMB. The antenna gives moderately high gain as high as 4.17 dBi. The antenna is fed by a microstrip line and the ground is modified as shown in Figure 1. The modification in the ground plane is made by making a slot in the desired shape for getting an optimum bandwidth and radiation pattern. The shape of the slot is optimized as in the form of a fish bone as shown in Figure 1 and it is symmetrically made in the ground plane with respect to the DRA for getting a symmetrical radiation pattern. Increased bandwidth is the result of merging multiple resonances originating in a close neighborhood by the combined effect of the slot provided in the ground plane and the presence of parasitic strip. Maximum bandwidth for the antenna is obtained in the useful range with cross slot length of 16 mm ($\sim \lambda_0$). It can be seen from Figure 5 that the ground plane slots have a positive effect on increasing the bandwidth of the antenna and reducing the resonance frequency. Cross slot length has a larger effect than the long slot length in lowering resonance frequency that in turn results in a compact antenna with wide band response. The proposed geometry has the advantage in that it covers lower bands including the above mentioned application bands, when compared to other proposed wideband DRA structures with parasitic strip [5, 11–13].

2. GEOMETRY OF THE ANTENNA

Antenna structure is shown in Figure 1. An isosceles trapezoidal DRA of permittivity $\varepsilon_{r1} = 20.8$, bases $b_1 = 15.4$ mm, $b_2 = 30.8$ mm, height $h = 13.3$ mm and thickness $h_1 = 13$ mm is fed by a 50 Ω transmission line of 66.5 mm (length) × 3 mm (width) fabricated on a microwave substrate of permittivity $\varepsilon_{r2} = 4$ with size 115 mm (length) × 115 mm



(a) Feed of the Antenna

(b) ITDRA

(c) Bottom view

Figure 1. Configuration of ITDRA fed by microstrip-line with slanted and parasitic strip.

(breadth) × 1.6 mm (thickness). The condition that $\varepsilon_{r1} \gg \varepsilon_{r2}$ for efficient coupling between the strip-line and the DRA is satisfied here. Length of the feed is optimized for getting the desired response as the maximum energy is coupled capacitively [10] if the DR is located at the point of maximum electric field on the feed.

A metallic strip with a height and width optimized as 9.5 mm and 3 mm respectively is adhered to the slanting surface at the feed side of the TDRA and is connected electrically to the feed line at a length $L = 16.7$ mm from its open end as shown in Figure 1(a). Without the slanted strip the intensity of radiation pattern is seen to be dominated towards the feed side. A parasitic strip on the top surface of the antenna with an offset of 5.9 mm from the center of the surface with a length and width optimized as 13 mm and 3 mm respectively is adhered for obtaining maximum band width. The angle of inclination of this strip with reference to the micro-strip feed line is also optimized as 10°. Loading effect of the top parasitic strip helps to reduce the Q of the antenna and thereby increasing its impedance band width to a certain extend.

The ground plane is modified as shown in Figure 1 by making a slot in the form of a fish bone with a long and cross rectangular slots. The long slot is kept under and along the micro strip-line with a dimension of $L_1 = 30.8$ mm (length) $\times$ 3 mm (breadth) and with an offset of 41.7 mm from the feed position. The cross slots have the dimensions of $L_2 = 16$ mm (length) $\times$ $B_2 = 4$ mm (breadth) and are separated among them by a distance of 2.5 mm. The entire slot is kept symmetrical with respect to the position of the DRA for getting symmetrical radiation pattern.

Antenna measurements are performed with HP 8510C vector network analyzer. The reflection (S_{11}), impedance (Z), radiation (S_{12}) characteristics and gain of the DRA are measured and discussed in the following section.

3. RESULTS AND DISCUSSIONS

Measured and simulated plot of return loss ($|S_{11}|$), of the DRA are compared in Figure 2 and shown that they are in good agreement. Effect of ground plane modification on the return loss characteristics of the antenna is shown in Figure 6. It is seen that the modification of ground plane changes the radiation characteristics of the antenna. It is apparent from the figure that long slot has the tendency to shift the resonances towards upper side of frequency whereas the cross slots shift them towards the lower side. When both long and cross slots are introduced together, two resonances occurred, one is at slightly lower side and the second is on far upper side of the original resonance that created when no modification on ground plane is made. So in the proposed antenna these two resonances are developed in the close neighborhood so as to merge together to form a wide band response of

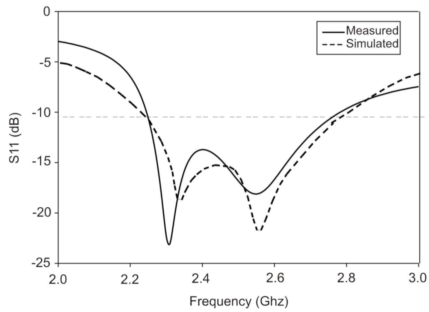
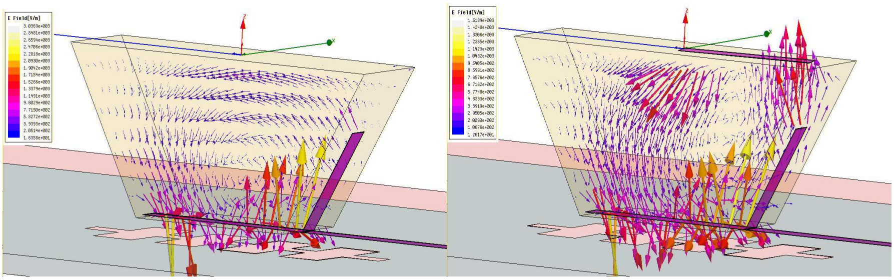


Figure 2. Measured and simulated return loss of the antenna for the optimum configuration.



(a) without parasitic strip (b) with parasitic strip

Figure 3. Simulated E field vector inside the DRA at 2.55 GHz.

540 MHz centered at 2.51 GHz giving 21.5% impedance bandwidth.

The input field is effectively coupled to the DRA from the microstrip line at the bottom surface as well as from the tip of slanted strip. Without the parasitic strip, the simulated electric field distribution within the DRA indicates the fundamental TE^z_{111} mode (Figure 3(a)). But the presence of parasitic strip disturbs the field distribution as the boundary condition doesn't allow the tangential components of the electric field near to it. This causes the E field loop in the YZ plane to be broken at the top surface of DRA near to the parasitic strip. So the normal component of the field is concentrated at both sides of the parasitic strip as shown in Figure 3(b). This makes the excited mode not a pure TE^z mode but instead a pseudo-TE^z mode. The plot of S_{11} for the antenna with and without parasitic strip is shown in Figure 4.

Effect of tilt of parasitic strip with respect to the microstrip line on the return loss characteristics is also shown in Figure 5. It indicates that a tilt of 10° gives an optimum response for a strip-length and

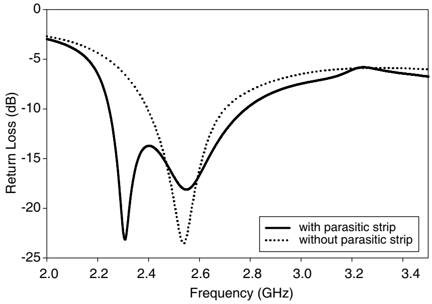


Figure 4. Effect of parasitic strip on the return loss characteristics of the DRA.

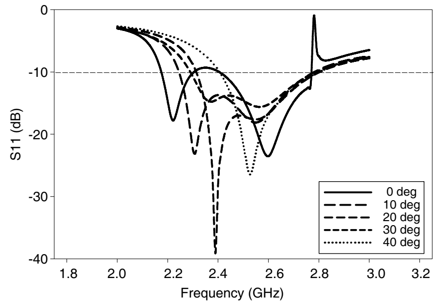


Figure 5. Effect of angle of inclination of parasitic strip on the Return loss characteristics.

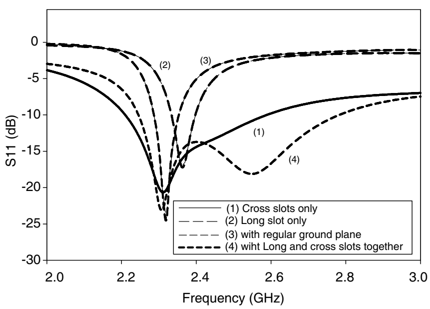


Figure 6. Effect of ground plane modification on the return loss characteristics.

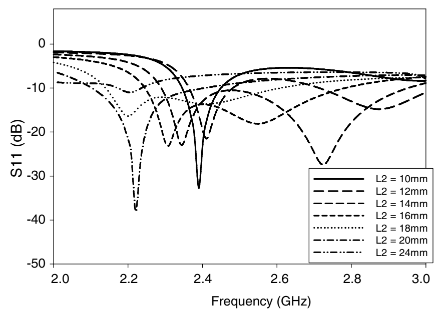


Figure 7. Return loss for different cross slot lengths when $B_2 = 4\,\mathrm{mm}$ and $L = 30.8\,\mathrm{mm}$.

width of 13 mm and 3 mm respectively.

Since there is a long slot in the ground plane underneath to the open end of microstrip feed, the feed itself acts as a monopole antenna and radiates at 4.8 GHz. The length of microstrip that extends to the slot in the ground plane decides the frequency of radiation of the monopole while the shape of the slot determines shape of the radiation pattern and hence the directions at which the maximum intensity of radiation occur. The cross slot has an effect of reducing the resonance frequency of the antenna. This is because the coupling between a microstrip line and a perpendicular slot in a ground plane is due to a magnetic field [14] and thus can be expressed as an ideal transformer [15].

The impedance of the cross slot line is strongly dispersive, so that turns ratio 'n' computed by expression (3) in [16] varies with frequency.

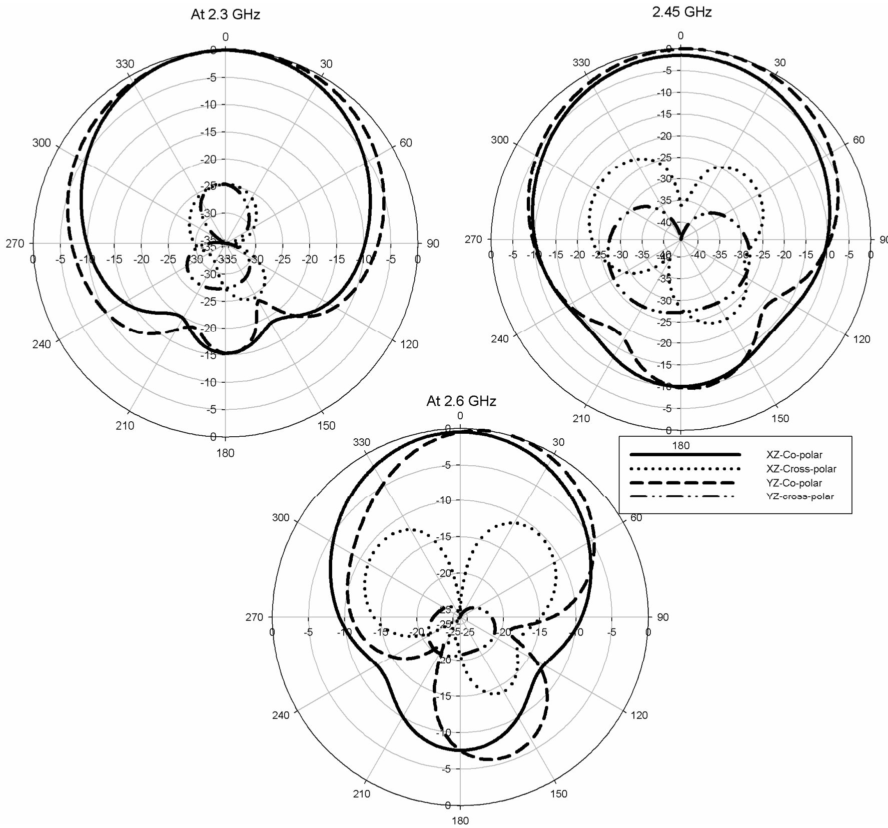


Figure 8. Radiation Patterns at 2.3 GHz, 2.45 GHz and 2.6 GHz.

This is the factor which helps in varying the resonant frequency of the antenna when the slot-length is varied (Figure 7), as this coupling transformer acts as the impedance matching device. These facts along with the shape and dimensions of the DRA determines the first and second resonances occurred in the DRA. With an optimum shape, position and dimensions of the slot, the two resonances come in close neighborhood and merge together to show a wideband response.

Figure 7 shows the effect of cross slot length L_2 of the ground plane modification on the return loss characteristic of the antenna. Length of the long slot is having less effect compared to the cross slots. The cross slot length (L_2) was gradually increased for verifying the corresponding S_{11}. It was seen that the centre frequency is reduced for increasing length of cross slots. As the slot dimension L_2 increases the first and second resonances shift towards the lower side up to $L_2 = 16$ mm and further the second resonance disappears while the first resonance still shifts towards lower side. It is noted that a strong matching resonance occurs for $L_2 = 20\,\mathrm{mm}$ with a weak resonance on either side of the dimension.

The polarization of the antenna is also verified. The low cross-polarization levels confirm that the antenna is linearly polarized over the entire impedance band. The normalized XZ and YZ plane radiation patterns of the antenna for three different frequencies viz. 2.3 GHz, 2.45 GHz and 2.6 GHz in the resonance band are shown in figure 8. Since the antenna structure is symmetrical with respect to the XZ and YZ plane separately, the radiation patterns in YZ and XZ plane are symmetrical.

Different orientations of the antenna with respect to the slot in

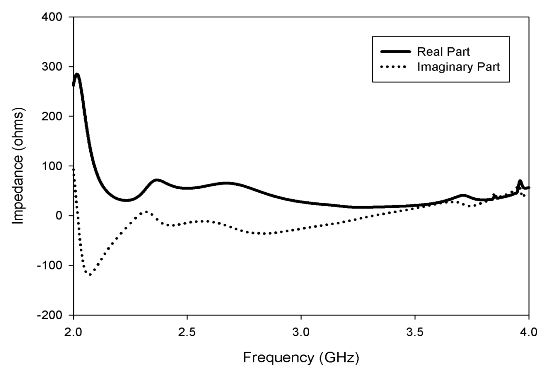


Figure 9. Input Impedance vs. Frequency.

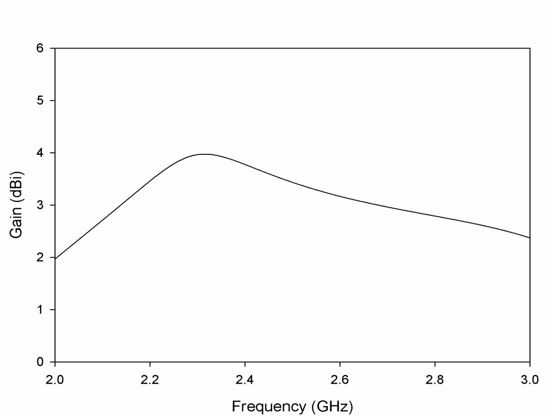


Figure 10. Gain of the proposed antenna.

ground plane and microstrip line feed is also tried out for studies and verified that the proposed one gives the best result. Plot of input impedance against frequency which is shown in Figure 9 confirm that the impedance matching between the feed and the antenna is occurred at frequencies corresponding to the resonant modes.

The measured gain of the antenna is shown in Figure 10. The antenna has a peak gain of 4.17 dBi at 2.19 GHz and a least of 2.2 dBi at 2 GHz with an average value of 3.19 dBi.

4. CONCLUSION

A wideband Dielectric Resonator Antenna with a novel geometry has been proposed and developed. The antenna offers an impedance band width of 21.5% centered at 2.51 GHz and linear polarization of radiation throughout the band. The wide impedance band width is the result of dual radiating modes which are excited in close vicinity as a result of the parasitic strip and the slot in ground plane. This wideband response is in relatively lower frequency range which includes important application bands viz. ISM: Bluetooth/WLAN 2.4/Wibree (802.11 b/g/n)/ZigBee, WiBro and DMB. Radiation patterns are found to be broad over the entire bandwidth with good cross-polarization levels.

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