Analysis of DRA with Performance Evaluation for High Speed System Applications Using Partial Differential Equation based Framework

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Abstract— **A novel efficient design analysis has been proposed for a reduced-size dielectric resonator antenna (DRA) using perturbed system of partial differential equations. This has been done by using half-volume resonator with short-circuited plane of symmetry. The design serves as a new configuration of planar antenna, thus making integration of active devices easier. The antenna shows remarkable performance, having low cross-polarization levels and reasonably well radiation patterns. The antenna design has been simulated using a new analytical framework created in MATLAB giving accurate measurement details.**

Index Terms— **Dielectric Resonator Antenna, Half-volume, High Speed Systems, Perturbation analysis.**

I. INTRODUCTION

The ever increasing demand for high speed and reliable communication systems have pushed the development of microwave and mm-wave systems which requires new and improved antennas with outstanding performance characteristics. Moreover, many base stations and new communication systems require compact and cost-effective components. Since about 1970's, dielectric resonators have helped achieve the miniaturization of active and passive microwave components, such as oscillators and filters [1, 2] and have proved to be one of the driving forces behind advancement of communication systems such as Spatial Division Multiple Access.

A lot of extensive work has been done on microstrip-fed DRAs [1]-[8] and probe-fed DRAs [9]-[12], but only limited attempts have been made at designing DRAs using a common analytical approach. New feed mechanisms like CPW has been shown to be used to excite cylindrical resonator antenna [13]. There have been some recent developments also which shows that the CPW is quite effective as a mechanism for excitation for the rectangular type DRA [14]-[15]. There are also research on half-volume DRA which is fed by microstrip line. [16]-[17].

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It is the intent of this paper to propose a reduced size dielectric resonator antenna which is excited by coplanar waveguide through an aperture in the ground plane. The antenna design is optimized, using a new analytical framework created by authors of this paper in [18], to improve the coupling and performance parameters of the antenna. The design proposed in this paper has the clear advantage of fabrication ease owing to its single process of metallization and dielectric layers.

Detailed theoretical analysis is carried out for performance evaluation using the new analytical framework created in MATLAB. The gain, return loss, and radiation pattern of the proposed antenna are shown and analyzed. The choice of MATLAB as the design of analytical framework is primarily governed by the fact that it is highly capable in solving partial differential equations derived from the original Maxwell equations using which we have created this simulation framework.

II. MATHEMATICAL EQUATIONS OF ANALYSIS

As emphasized earlier, a new simulation framework has been developed to assess the performance of the DRA derived from the Maxwell's equations. Based on the different modes expected to be present in the CPW feed and antenna characteristics, equations for different resonant frequencies as a function of height has been derived using perturbed system of partial differential equations. This gives an important insight regarding the geometric parameters of the antenna that can be suitably chosen according to the equation for optimal performance.

The resonant frequency as a function of height for different permittivities for TE01 mode is :-

$$f_0 = 2.921 \cdot \frac{c\varepsilon_r^{-0.465}}{2\pi a}\left[0.691 + 0.319\frac{a}{2h} - 0.035\cdot\left(\frac{a}{2h}\right)^2\right] \quad \text{... (1)}$$

Corresponding to this equation, the results have been plotted and shown in figure below :-

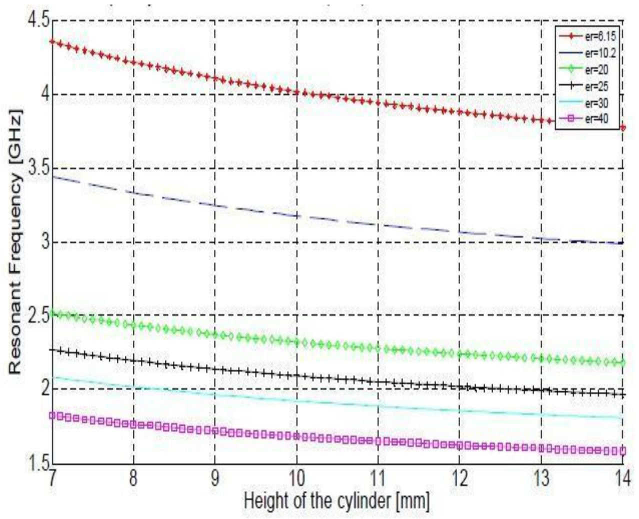

Figure 1: Graph of resonant frequencies for TE01 mode

Similarly, the equation for resonant frequency as a function of height for different permittivities for TM01 mode is :-

$$f_0 = 2.933 \cdot \frac{c\varepsilon_r^{-0.468}}{2\pi a}\left[1-\left(0.075-0.05\cdot\frac{a}{2h}\right)\left(\frac{\varepsilon_r-10}{28}\right)\right]\left[1.048+0.377\left(\frac{a}{2h}\right)-0.071\left(\frac{a}{2h}\right)^2\right]$$

... (2)

Corresponding to this equation, the results have been plotted and has been shown in figure below :-

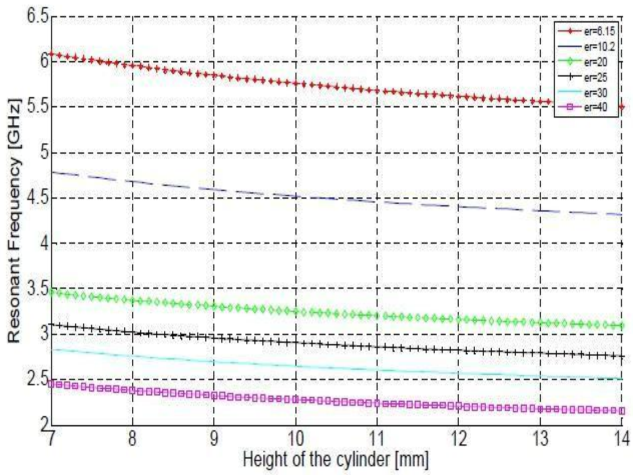

FIGURE 2: GRAPH OF RESONANT FREQUENCIES FOR TM01 MODE

The equation for resonant frequency as a function of height for different permittivities for HE11 mode is :-

$$f_0 = 2.735 \cdot \frac{c\varepsilon_r^{-0.436}}{2\pi a}\left[0.543+0.589\frac{a}{2h}-0.050\cdot\left(\frac{a}{h}\right)^2\right]$$

....(3)

The graph of this equation happens to be the one shown below :-

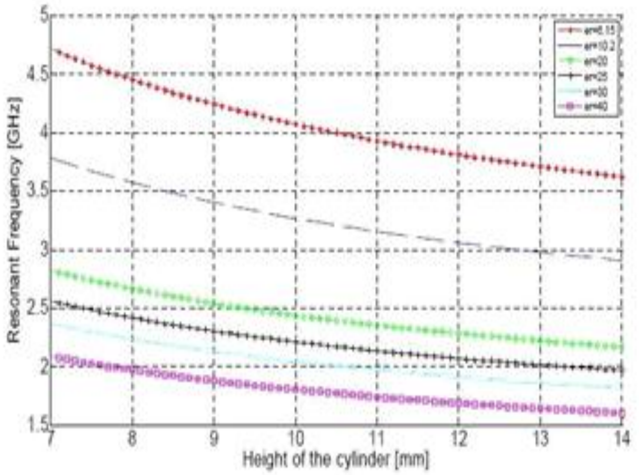

FIGURE 3: GRAPH OF RESONANT FREQUENCIES FOR HE11 MODE

sing the above equations and selection of optimal resonant frequency leads to direct selection of dielectric material with certain permittivity for creating the DRA with required characteristics.

The 3-D plot of the solution of perturbed system of equations along with associated contour has been plotted below :-

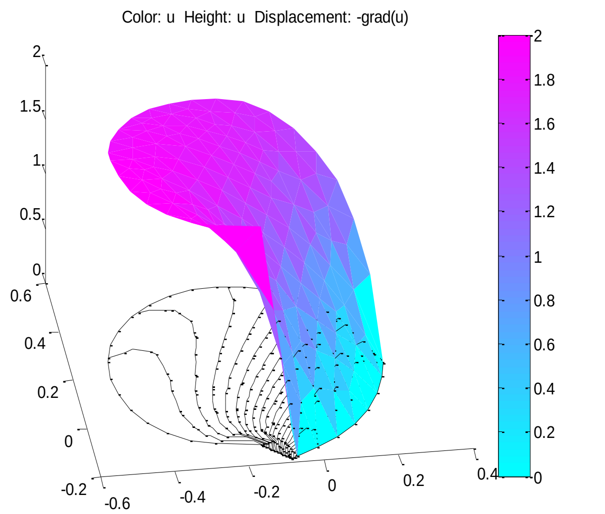

Figure 4: 3-D plot of solutions of perturbed Partial Differential Equations

The solutions indicate high density of activity on the top while it reduces considerably towards the bottom. This is because the equations predict that the non-linear optimization of the perturbed system gives better result with convergence after sufficiently large number of iterations as expected from the dynamics of DRA.

III. DESIGN AND GEOMETRY OF THE ANTENNA

The design and the geometry of the antenna has been decided in a manner that leads to maximum performance characteristics specifically for real-time high speed communication systems.

The top view and the corresponding side view of the dielectric resonator antenna is shown in the figure below for greater understanding :-

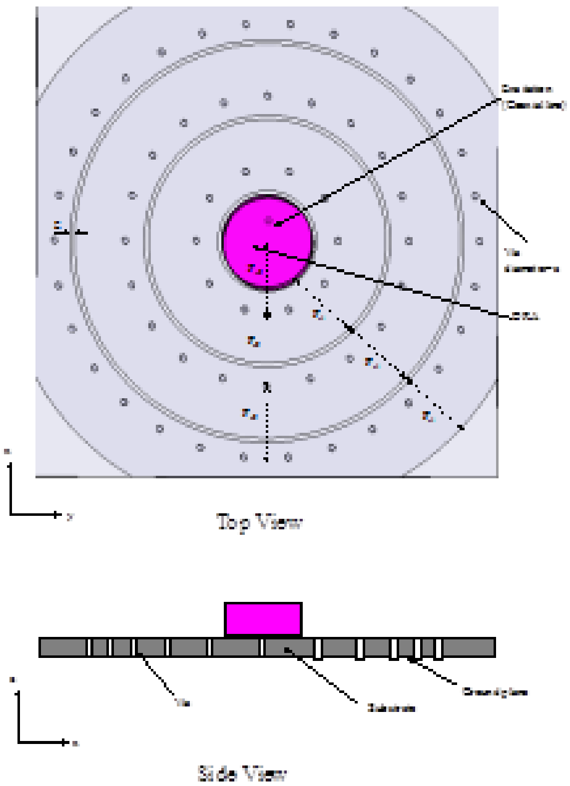

Figure 5: Top view and side view of the DRA

The DRA has a radius of R = 15 mm, height h = 10.5 mm and a permittivity of ε_{dra} = 31.5. The coaxial line connecting the CPW feed is at a distance of 9 mm from the center. The DRA is printed on a substrate of permittivity 2.2 and thickness 3.2 mm. The metallic via have a radius a=2mm, and they are disposed with the same transversal period and the same radial period P_{r2}=23.6mm. In this structure, no back conductor for the substrate was used in order to reduce the adverse effects of the leaky waves that might otherwise degrade the performance of the antenna. However, the dimensions are chosen such that the radiation under the substrate is insignificant.

The entire design of the antenna was created in HFSS software and accordingly a sample simulation was performed to verify the design. During simulation the practical performance characteristics of the antenna is inferred which is later used to simulate within the analytical framework created in MATLAB. The result obtained is then correlated with the HFSS software for accurate validation of the analytical method.

IV. Simulation Results

The simulation was performed using MATLAB. A combination of PDE toolbox and scratch coding was used to come up with graphs of various performance metrics.

In figure 6 below, the return loss of the proposed antenna is shown.

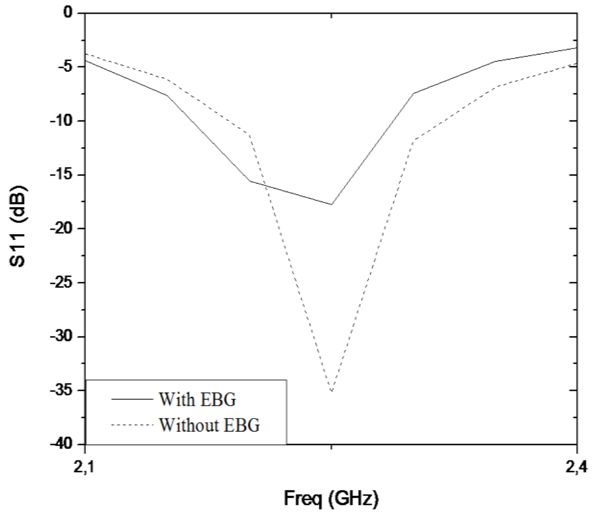

Figure 6: Simulated return loss of the proposed antenna

Note that the return loss is around –35 dB at resonance. This indicates that most of the input power at the feedline is absorbed by the resonator which is then radiated into the surrounding space. The graph shows two scenarios that is with etched background plane (EBG) and without EBG to provide greater insight into the working characteristics of the antenna.

The graph for the gain of the antenna is shown in the figure below :-

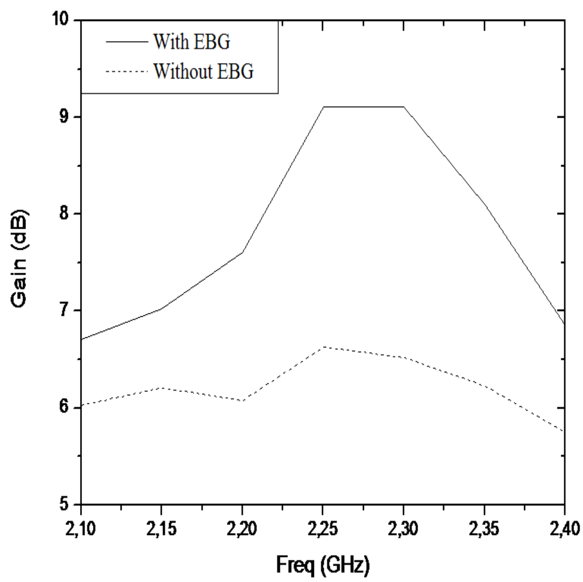

Figure 7: Simulated gain of the proposed antenna

As can be seen that the maximum gain of the antenna remains constant across a range of operational frequency which is highly desired characteristic in any antenna.

The simulated radiation pattern observed by plotting the graph is shown in the figure below :-

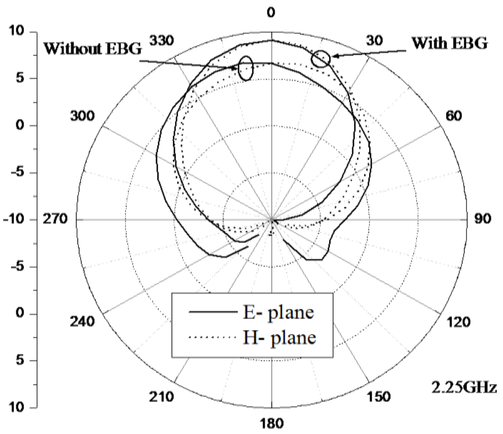

Figure 8: Simulated radiation pattern of the proposed antenna

The simulated radiation patterns in both the E- and H-planes are shown. It was also noted that the cross polarization levels were low. The radiation is mostly in the resonator direction and negligible radiation is directed below the substrate.

The interference between the antenna radiation pattern and the far-field pattern of the diffracted waves results in the measured co-polarized component ripples around the simulated component. The E-plane suffers from greater diffraction than the H-plane, due to the fact that the space wave in the vicinity of the truncated ground plane is stronger in the E-plane. In consequence, the diffracted fields are also stronger in the E-plane.

All of these simulation results show and validate the efficacy of the analytical framework developed to simulate and verify the performance characteristics of any DRA using relevant mathematical modeling.

V. Conclusions

In this paper, a new analytical framework using mathematical modeling has been proposed that led to accurate design of DRA fed via CPW. Detailed performance evaluation of the proposed antenna was carried out and it was conclusively shown how the new analytical framework leads to design criteria which allows one to select appropriate dielectric material for the DRA giving better results. The antenna shows good performance in terms of low cross-polarization levels, matching to the feeding structure, and low back radiation.

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