Design and Analysis of Different Element DR Filters for Satellite Communication Application

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Abstract— This research paper presents a design of three-element DR filter and six-element DR filter for the use in satellite communication systems. Strict requirements on size, weight and power necessitate the use of low power, high quality factor and low loss components in space communications. Comparison of different element DR filters is done and their properties have been studied. The designed 6-element DR filter operating at a center frequency of 3.806 GHz with a bandwidth of 60 MHz and achieving a quality factor of around 39000 is well suited for the design of output multiplexers used in C-band satellite applications.

Key words: Bandwidth, dielectric, quality factor, resonator

I. INTRODUCTION

The action of typical filtering is to select energy at few frequencies to pass through a network as well as to reject others. Microwave region comprises of frequencies from 300MHz to 300GHz. Filters in this region usually take the form of resonators of distinct types. Resonators are the essential building blocks of any bandpass filter. LC resonator is an easiest example. More types are planar or microstrip resonators and the three-dimensional cavity type resonators, for instance, dielectric resonator. 3-D resonators are enormously selected for constructing narrow bandwidth filters for low loss wireless and space communication applications. The dielectric resonator technology has notably emerged as the superior technology for miniature high-Q filters contributing Q-values in the range of 3000 to 30,000 at 1GHz. The term "dielectric resonator" was first affirmed in 1939 by R.D. Richtmyer of Stanford University, who announced that dielectric objects can act as microwave resonators. The applications of different resonator configurations are described in fig.1

II. DIELECTRIC RESONATORS

A. Geometry:

From the theory of operation and fabrication considerations, various shapes of dielectric resonator are found to be more practical. Acceptably, the best and the most advantageous shape is cylindrical, analyzed in the simple work of Cohn. Generally, a dielectric resonator consists of

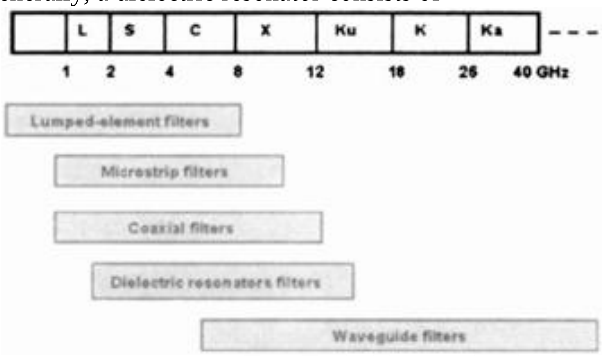

Fig. 1: Application of Various Resonator Configurations

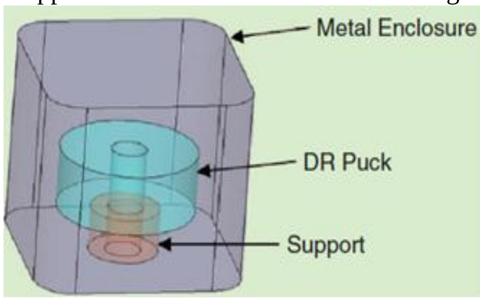

Fig. 2: A Model of Dielectric Resonator

a high-dielectric-constant ($10<\epsilon_r<100$) material in a cylindrical form called as a "dielectric puck", mounted inside a metal enclosure applying a low-dielectric constant ($\epsilon_r'<10$) support as shown model in figure 2. Usually, the enclosure has a square or rectangular shape with a side width that is 1.5-1.7 times the diameter of the DR. For the DR, 0.5<R/H<2, where 'R' is the radius of cylindrical resonator and 'H' is its height, both in mm obtained by following formulae:

$$\frac{1.2892\times10^8}{f_r\sqrt{\varepsilon_s}} > R > \frac{1.2892\times10^8}{f_r\sqrt{\varepsilon_r}} \tag{2.1}$$

Where, f_r is the resonant frequency in hertz, ε_s and ε_r are the dielectric constants of support and resonator, respectively. A close approximation of resonant frequency in GHz for DR is expressed as under where, V is the resonator volume in mm^3.

$$f_r = \frac{233}{\sqrt{\varepsilon_r}\times\sqrt[3]{V}} \tag{2.2}$$

B. Resonant Modes and Couplings in Dielectric Resonator:

A dielectric resonator, identical to other 3-D structures, has several modes of resonance. There are infinite numbers of modes that resonate inside the dielectric and satisfy all boundary conditions. These modes can be dissolved to Transverse Electric (TE), Transverse Magnetic (TM) and Hybrid (HE) modes. In a cylindrical DR, when height 'H' is less than diameter 'D' (H<D), the $TE_{01\delta}$ mode is the fundamental mode. The higher order modes or the spurious modes are TM and HE modes. They are frequently called as unwanted or the degenerate modes. The DR contained inside the rectangular evanescent cavity has the electric and magnetic field distribution as displayed in figure 3. The electric field is circular and strongest in the middle of the DR and the magnetic field is strongest along the axis of the cylindrical DR. Dielectric resonator filters are commonly operated as single mode resonators, dual mode resonators and less commonly as triple mode and quadruple mode resonators.

Coupling is an important topic of discussion. Mainly, coupling is provided by coaxial probes or microstrip section. In this work, the external coupling at both input port (port 1) and output port (port 2) is realized utilizing a connector probe. The interresonator sequential coupling can be realized either via magnetic fields or electric fields. Here, the internal coupling is achieved by placing an aperture in between a pair of synchronous resonators. It can be determined by the following formula, where f_2 and f_1 are two Eigen frequencies attained from Eigen mode solution solver in a 3-D EM simulator.

$$k=\frac{(f_2-f_1)}{BW} \qquad (2.3)$$

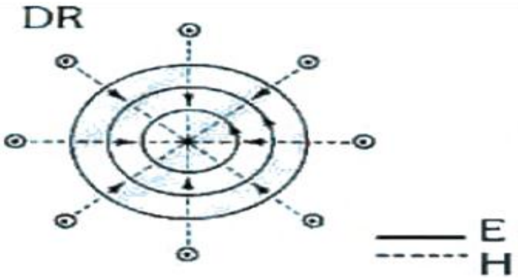

Fig. 3: Illustrating Electric and Magnetic Field in $Te_{01\delta}$ Mode *(*Top View*)*

III. DIELECTRIC RESONATOR AND FILTER DESIGN EXAMPLE

The size of the DR becomes smaller, with the higher dielectric constant due to the reason that more electric and magnetic field is confined in the DR. Practically, the dielectric material should have high Q and dielectric constant (ϵ_r) within 30-40 for all DRs to be used in DR filters. For this example design, ceramic dielectric material with composition Ba Zn Ta Oxide and dielectric constant 30.7 is chosen. This DR puck is isolated from the cavity wall by locating an alumina support with low dielectric constant (9.2) as well as low loss tangent (0.008). The coaxial ports measure $\lambda/4$ from the center of the DR puck. Hence, this DR is used to design 3-element DR filter (figure 4) and 6-element DR filter (figure 6) by employing suitable electric and magnetic field coupling between all resonators possessing very low loss. The losses in the DR filter chiefly come from the losses in the dielectric resonator itself and the losses at the cavity walls where the dielectric is placed in. Several other losses can be due to the losses in support and coupling. In HFSS, both parametric sweep and optimization techniques are occupied to achieve the accurate simulation results.

A. *Driven Modal Solution:*

In the Driven modal solution solver, mode-based S-matrix solutions are expressed in terms of the incident and reflected

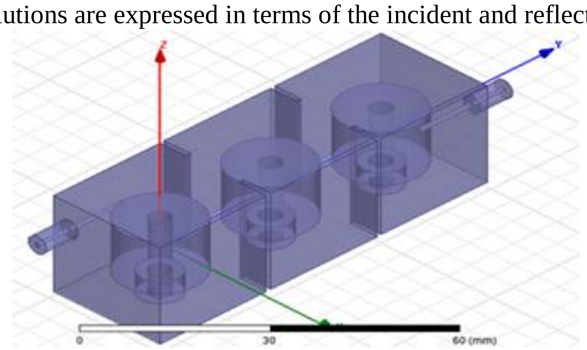

Fig. 4: A 3-Element Dielectric Resonator Filter Design in HFSS

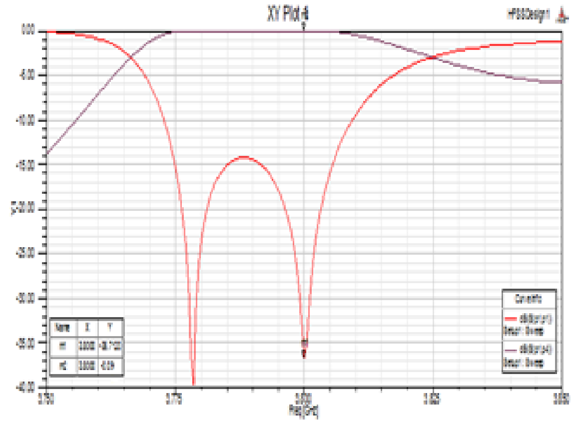

Fig. 5: Return Loss and Insertion Loss In 3-Element Dielectric Resonator Filter

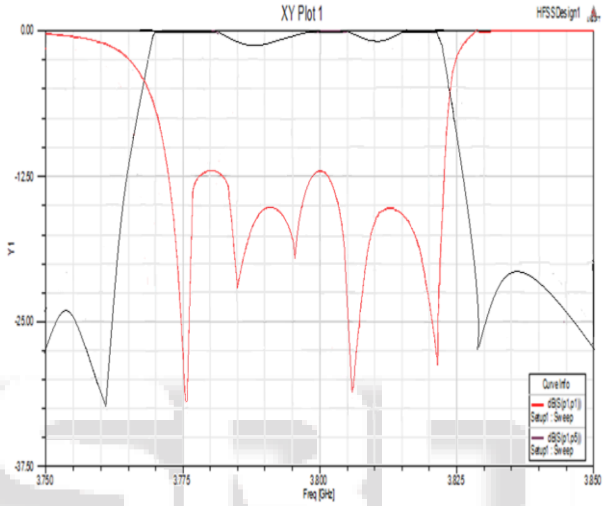

Fig. 6: A 6-Element Dielectric Resonator Filter Design in HFSS

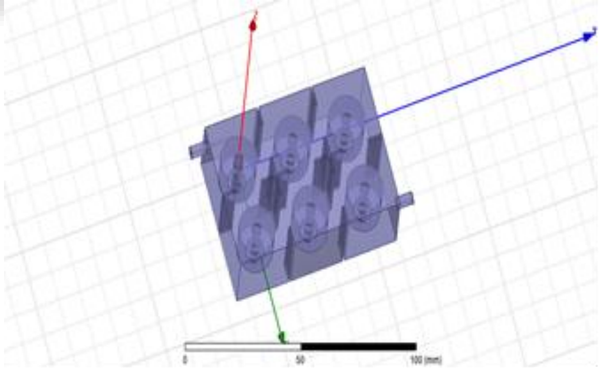

Fig. 7: Return Loss And Insertion Loss In 6-Element Dielectric Resonator Filter

powers of the passive and high frequency structures. It also defines the problem with port excitations. The DR is used to make a low loss 3-element DR filter operating at frequency 3.80 GHz with return loss (S_{11}) -36.71 dB and insertion loss (S_{12}) -0.09 dB as observed from figure 5 and quality factor of 17000 is shown in figure 8. The same DR is used to make a low loss 6-element DR filter operating at center frequency 3.806 GHz to be utilized in output multiplexer for satellite communication system with return loss (S_{11}) -31 dB and insertion loss (S_{12}) -0.5 dB as observed from figure 7 and quality of around 39000 as shown in figure 9.

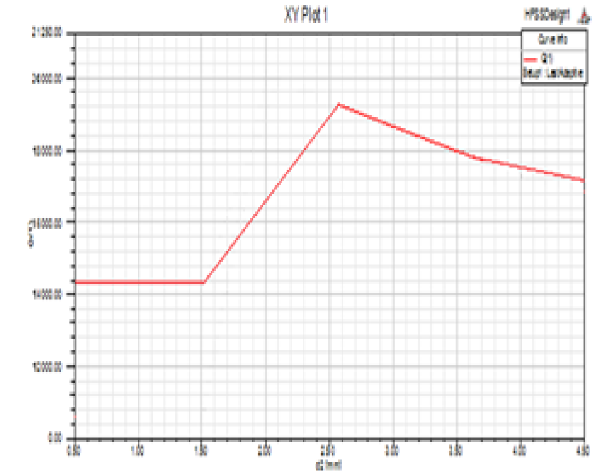

Fig. 8: Quality Factor in 3-Element Dielectric Resonator Filter

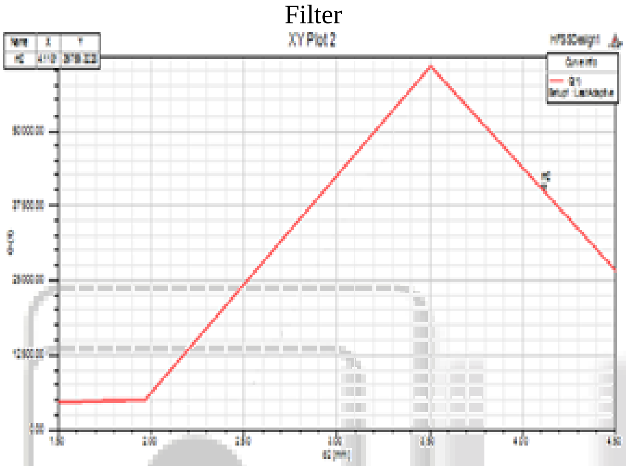

Fig. 9: Quality Factor in 6-Element Dielectric Resonator Filter

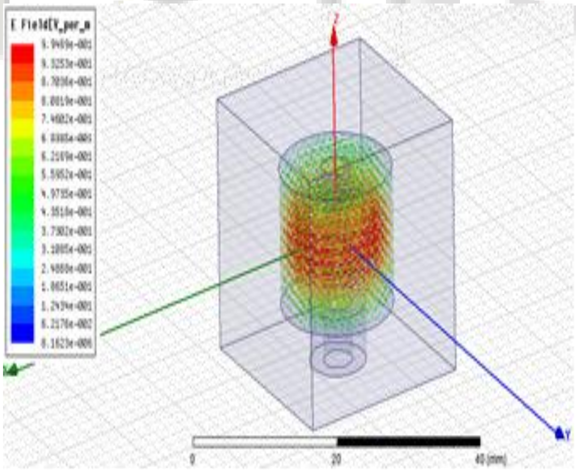

Fig. 10: Electric Field Distribution in DR *(Side View)*

B. *Eigen Mode Solution:*

The Eigen mode solution solver in HFSS finds the Eigen modes or resonances of lossy as well as lossless structures. It can calculate the unloaded quality factor along with the electric and magnetic field distributions at those resonant frequencies in the dielectric resonator and DR filter as shown in figures 10 and 11. The port, their excitation and radiation boundaries may not be defined. Also the frequency sweeps are not available. The interresonator coupling between two dielectric resonators through coupling apertures can be observed from figure 12.

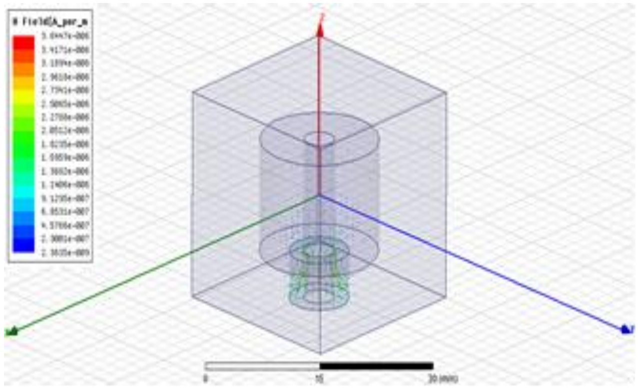

Fig. 11: Magnetic Field Distribution in DR

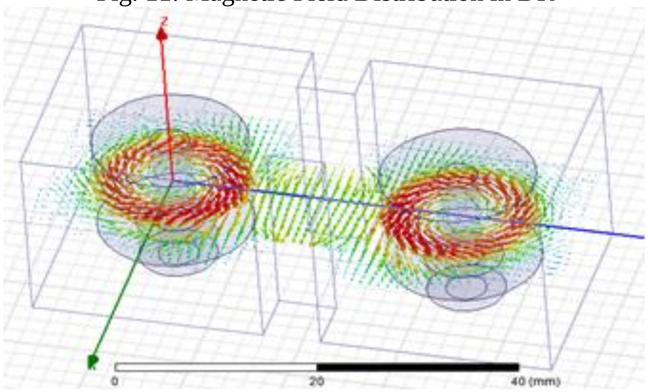

Fig. 12: Coupling Mechanism between two DRs

Parameter	Specification	3-element DR Filter	6-element DR Filter
Bandwidth	36 MHz	37 MHz	60 MHz
Return Loss	≥ 20 dB	-36.71 dB	-31 dB
Insertion Loss	≤ 0.5 dB	-0.09 dB	-0.5 dB
Quality Factor	3000 to 30,000 and above	17000	39799

Table 1: Dr and Dr Filter Specifications and Results

C. *Parametric Model Creation and Analysis:*

Parametric analysis enables to simulate several designs variations using a single model. A series of variable values is defined within a range, or a variable sweep definition. The results can then be compared to determine how each design variation affects the performance of the design. The design parameters that are assigned a quantity such as geometry dimensions, material properties, boundary and excitation properties, can be varied. The number of variations in parametric sweep setup is limited. All variables must be defined to the nominal design before starting the parametric analysis.

D. *Results and Discussion:*

General specifications and results obtained after simulation of 3-element DR filter and 6-element DR filter design are summarized in table 1. Hence, it can be observed that 6-element dielectric resonator filter with greater quality factor is more suitable to find application as output multiplexer in satellite communication systems.

IV. Conclusion

This research effort has become successful. It presents the study, design and analysis of a Cylindrical Dielectric

Resonator as the technology is useful in designing various Dielectric Resonator Filters. Furthermore, these filters are compared to find the best suited for satellite communication applications. Dielectric Resonator and filter obtain low loss and high quality factor due to their inherent low loss dielectric material. A complete as well as step by step design methodology has been described in the paper. An investigation of the parametric studies on the resonator and filter parameters has also been presented. It possesses many variables for tuning and further advancement.

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