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RESONACES OF A MULTILAYER HEMISPHERICAL DIELECTRIC RESONATOR

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Abstract

The bandwidth and resonant frequency of a multilayer hemispherical dielectric resonator is presented. The transcendental characteristic equations are setup by enforcing the boundary conditions at the dielectric interfaces. The results of available data are compared with the dominant broadside TE_{111} mode of a two layer dielectric resonator with an air gap. The bandwidth of a two layer dielectric resonator with different permittivity is considered.

1. Introduction

For a microstrip antenna, the ohmic power loss is considerable in higher frequency applications. As the trends of interest in higher frequency applications, a dielectric resonator shows to have great potential in this application of microwave engineering. In general, dielectric resonator (DR) is always used in high frequency microwave circuits (e.g., filter and oscillator) and also used as an effective radiator with different shapes [1]. It has the advantages of low power loss both in conductor loss and dielectric loss and small in size when operating at higher frequency. A hemispherical dielectric resonator with air gap resting on a ground plane has been shown its 3-dB impedance bandwidth can be enhanced considerably for TE_{111} mode [2]. A multilayer dielectric resonator is considered in the formulation. The results of the resonant frequency and bandwidth of a two-layer resonator are presented. In order to prove the numerical results are consistent, results of a dielectric resonator with an air gap are compared with results obtained in [2].

In this paper, the formulation of a multilayer dielectric resonator antenna will be presented in section 2. In section 3, the results of a two layer dielectric resonator is considered in the studies. Finally, the variation of bandwidth with different permittivity of dielectric will be discussed.

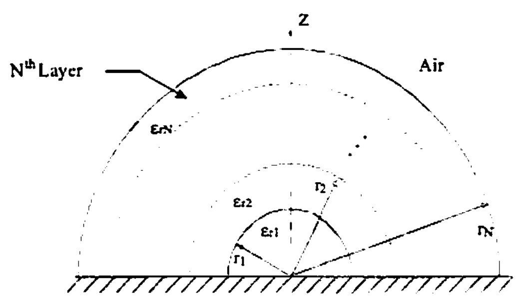

Figure 1. Configuration of multilayer hemispherical dielectric resonator.

2. Formulation

A multilayer hemispherical dielectric resonator antenna is shown in Fig.1. Since the hemispherical dielectric resonator is mounted on the ground plane, it can be treated as a spherical dielectric resonator in free space by the method of image.

The electric potential functions for different layers of the hemispherical dielectric resonator are expressed in term of spherical harmonics :

$$F_r(r)=\begin{cases} A_1\hat{J}_n(k_1 r)P_n^m(\cos\theta)e^{jm\phi} & ;r<r_1 \\ (A_2\hat{J}_n(k_2 r)+B_2\hat{Y}_n(k_2 r))P_n^m(\cos\theta)e^{jm\phi} & ;r_1<r<r_2 \\ (A_3\hat{J}_n(k_3 r)+B_3\hat{Y}_n(k_3 r))P_n^m(\cos\theta)e^{jm\phi} & ;r_2<r<r_3 \\ \vdots & \vdots \\ A_{N+1}\hat{H}_n^{(2)}(k_o r)P_n^m(\cos\theta)e^{jm\phi} & ;r>r_N \end{cases} \quad \text{.........................} (1)$$

The transverse components in different regions can be found using the electric potential function with explicit formulas [3]. The requirement of tangential field continuity at the surfaces $r=r_1, r_2, \ldots, r_N$ yield the transcendental equations. The equations can be rearranged in matrix form of $[\zeta][x]=0$, where $[x]$ is the field coefficients of different dielectric layers and $[\zeta]$ is a matrix with unknown k_1, k_2, k_3, ... k_N and k_o. For the existence of non-trivial solutions, the determinant of $[\zeta]$ should be zero.

$$\det\begin{bmatrix} \hat{J}_n(k_1r_1) & -\hat{J}_n(k_2r_1) & -\hat{Y}_n(k_2r_1) & & & & & & & \\ \hat{J}_n'(k_1r_1) & -\hat{J}_n'(k_2r_1) & -\hat{Y}_n'(k_2r_1) & & & & & 0 & & \\ & \hat{J}_n(k_2r_2) & \hat{Y}_n(k_2r_2) & -\hat{J}_n(k_3r_2) & -\hat{Y}_n(k_3r_2) & & & & & \\ & \hat{J}_n'(k_2r_2) & \hat{Y}_n'(k_2r_2) & -\hat{J}_n'(k_3r_2) & -\hat{Y}_n'(k_3r_2) & & & & & \\ & & & \hat{J}_n(k_3r_3) & \hat{Y}_n(k_3r_3) & -\hat{J}_n(k_4r_3) & -\hat{Y}_n(k_4r_3) & & & \\ & & & \hat{J}_n'(k_3r_3) & \hat{Y}_n'(k_3r_3) & -\hat{J}_n'(k_4r_3) & -\hat{Y}_n'(k_4r_3) & & & \\ & 0 & & & \ddots & \ddots & \ddots & \ddots & & \\ & & & & & & \hat{J}_n(k_Nr_N) & \hat{Y}_n(k_Nr_N) & -\hat{H}_n^{(2)}(k_or_N) & \\ & & & & & & \hat{J}_n'(k_Nr_N) & \hat{Y}_n'(k_Nr_N) & -\hat{H}_n^{(2)\prime}(k_or_N) & \end{bmatrix}=0$$

......(2)

where k_2, k_3, ... , k_N, and k_o can be related to k_1 by the ratio of dielectric permittivity. Thus, the equation (2) can be rearranged to be a function of k_1. The k_1 is a complex wave number which can be resolved into k_r+jk_i. Both the resonant frequency f_r and the 3-dB bandwidth BW can be calculated

$$BW=\frac{2\cdot k_i}{k_r} \text{ ,and } f_r=\frac{k_r\cdot c}{2\pi\sqrt{\varepsilon_{r1}}} \quad \text{...} (3)$$

where c is the velocity of light, ε_{r1} is the permittivity of the innermost layer dielectric.

3. Results and Discussions

The multilayer dielectric resonator analysis approach can be also applied to single layer dielectric resonator. Results of a single layer spherical dielectric resonator are compared with the results obtained in [4,5]. It has shown that the results are consistent. Based on the physical parameters (r_2 =2.54cm, ε_{r1} =1, and ε_{r2} =8.9), the results are shown in Fig.2 and Fig.3.

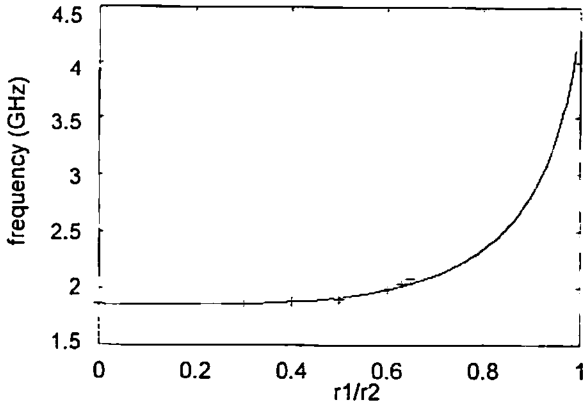

Figure 2. Resonant frequency of a two layer dielectric resonator ('+' results from [2])

In Fig.2, the resonant frequency of the hemispherical dielectric resonator with different r_1/r_2 is illustrated and compared with data extracted from [2]. The resonant frequency agrees with results obtained. It can be noticed the resonant frequency is inversely proportional to (r_2-r_1) which is the outermost layer dielectric material of the hemispherical dielectric resonator. In Fig.3, the percentage of bandwidth of a hemispherical dielectric resonator with an air gap is illustrated and compared with the results obtained from [2]. When r_1/r_2 is smaller than 0.4, the results are shown consistent. But when r_1/r_2 is greater than 0.4, the bandwidth is slightly lower than the results from [2]. That may be caused by the higher order mode excitation of the fed employed in [2]. It can be shown that when r_1/r_2 is about 0.9 then 45% bandwidth can be obtained. The raise of bandwidth is caused by reducing the stored energy inside the outermost layer of hemispherical dielectric resonator. In practice, the effect of coupler must be included in analysis and it is highly advised to use a suitable coupler. Since the coupler is very important, we would continue our work by including different types of coupler to excite the multilayer dielectric resonator.

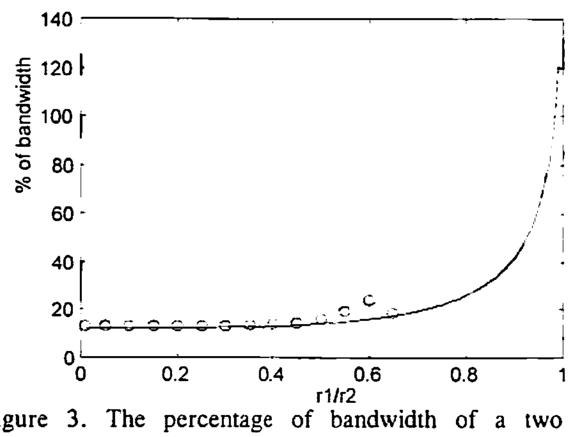

Figure 3. The percentage of bandwidth of a two layer hemispherical dielectric resonator with air gap ('o' results from [2])

The effect on bandwidth with different dielectric permittivity is shown in Fig.4. Considering a single layer hemispherical dielectric resonator with ε_r=8.9 and ε_r=2.5, 13% and 46% bandwidth can be obtained, respectively. The curve of ε_{r1} =8.9 and ε_{r2} = 2.5 ($\varepsilon_{r2}/\varepsilon_{r1}$=0.28) has the bandwidth is about 46% when r_1/r_2 is smaller and then drop rapidly to reach about 13% after r_1/r_2 is greater than 0.9. The transition of bandwidth from 46% to 13% means the outer layer (ε_{r2} = 2.5) dominate the effect on bandwidth with small r_1/r_2, and reduce the effect when r_1/r_2 is increased.

The innermost layer (ε_{r1} =8.9) increases the effect after r_1/r_2 is greater than 0.3 and totally takes over the domination of bandwidth after r_1/r_2 reaching 0.9. On the contrary, If ε_{r1} =8.9 and ε_{r2} = 15 is chosen ($\varepsilon_{r2}/\varepsilon_{r1}$ = 1.69), the bandwidth is raised from 7% to 13% by varying the r_1/r_2 from 0.4 to 0.9.

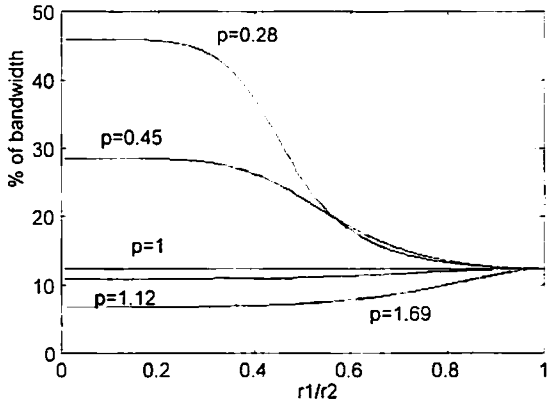

Figure 4. The effect on bandwidth of different ratio of permittivity of dielectric with ε_{r1} = 8.9, ($p = \varepsilon_{r2} / \varepsilon_{r1}$)

For $\varepsilon_{r2}/\varepsilon_{r1}$ is small than 1, the bandwidth will be dropped from higher percentage of bandwidth to lower level during increase the r_1/r_2. For $\varepsilon_{r2}/\varepsilon_{r1}$ is greater than 1, the bandwidth will be raised from low level percentage to higher during increase of r_1/r_2 .

4. Conclusion

The complex transcendental equations of a multilayer hemispherical dielectric resonator are formulated. Results are verified by comparing with a dielectric resonator with an airgap. The TE_{111} mode of a two layer dielectric resonator is considered in the studies with the effect of different r_1/r_2 and the different ratio of dielectric permittivity materials. For a multilayer dielectric resonator, the thickness and the permittivity of the dielectric can be varied to suit specific applications.

References

[1] Long S.A. and McAllister M.W., 'The Dielectric Resonator Antenna', *International Conference on Infrared and Millimeter Waves 1985*, pp.354-355

[2] Wong K.L., Chen N.C. and Chen H.T., 'Analysis of a Hemispherical Dielectric Resonator Antenna with an Airgap', *IEEE Microwave and Guided Wave Letters*, Vol 3, No. 9, Oct 1993, pp.355-357

[3] Harrington R.F., 'Time-Harmonic Electromagnetic Fields' *McGraw-Hill*, New York, 1961, pp.269-272.

[4] Qastine M., Coutrtois L. and Dormann J.L., 'Electromagnetic Resonances of Free Dielectric Spheres', *IEEE Trans. on Microwave Theory and Tech.* Vol. MTT-15, No. 12, Dec 1967, pp.694-700

[5] Long S.A. and McAllister M.W., 'Resonant hemispherical Dielectric Antenna', *Electronics Letters* 2nd August 1984, Vol 20, No. 16, pp.657-659