APPLICATION NOTE

No. 851: Tuning and Exciting Dielectric Resonator Modes

Introduction

The many advantages found in the substitution of conventional resonators by dielectric resonators[1] (D.R.s) have been leading part of the microwave community into a continuous race to explore further potentials of this promising new area. New applications range from simple, low cost, oscillators for small earth stations[2] to spacecraft filters and multiplexers[3,4]. Different devices require different structures to excite and tune the resonator, especially when employing higher order resonant modes. The purpose of this Tech-Brief is to introduce the microwave engineer to some of the definitions, properties, coupling structures, and tuning schemes pertaining to the cylindrical dielectric modes used in most applications.

Definitions and Properties

The natural modes of a cylindrical sample of high dielectric constant material can be classified into four categories: TE_{opg}, TM_{opg}, HE_{ngg}, and EH_{npg}, where n and p are integers which describe the standing wave pattern in the azimuthal and radial directions respectively while g is in general a real number; reflecting the fact that the two circular boundary surfaces do not contain an integer number of half wavelengths as in metallic cavities. For the fundamental TE mode, g is usually substituted by the greek ($TE_{01\delta}$) and assumes values in the range 0.5 to 1.0.

TE and TM modes do not contain electric and magnetic fields in the axial directions (z) respectively. The HE and EH modes are called hybrid, because all six field components are present in both. Snitzer[5] suggested a simple scheme to classify the hybrid modes based on the value of the amplitude coefficient ratio of axial components of electric and magnetic fields:

$$P = \frac{\varpi\mu_o}{\beta}\,\frac{Hz}{E_zHz} \qquad (1)$$

where β is the axial wave number, w is the angular frequency and μ_0 the free space permeability. The modes for which P is positive are designated as EH and those for which it is negative as HE. The great majority of practical applications employ either the $TE_{01\delta}$ mode or the HE_{11g} mode, which are the first two to resonate when the D.R. is placed between conducting walls and air gaps left in between. Figure 1 shows a sketch of the fields for these two modes in the cross section of the resonator.

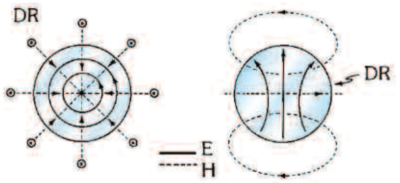
The ratio between the D.R. diameter and its length (D/H) together with the exterior boundary conditions such as tuning elements, holders, shields, and substrates determines which of the two modes has the lowest resonant frequency. For most configurations[6] the $TE_{01\delta}$ mode is dominant when D/H > 1.42.

Exciting the Resonator

The choice of an appropriate structure to couple energy in and out of a D.R. will depend on the following considerations:

- which mode is to be excited
- which transmission medium is to be utilized (waveguide, coaxial line, microstrip line, etc. . . .
- how much coupling is desired

Modes with strong exterior magnetic fields such as the TE_{018} are more effectively excited through coupling loops, which can assume, for example, the form of a bent coaxial probe, a circular sector microstrip line, or an offset straight line as illustrated in Figs. 2a, b, and c respectively.

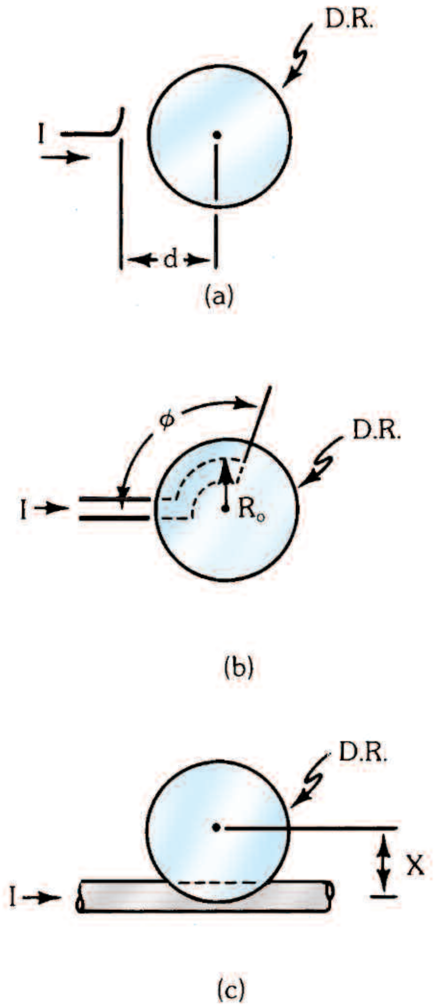


(a)$TE_{01\delta}$ (b)HE_{11g}

Figure 1

The amount of coupling obtained in any one structure can be quantitatively measured by the external Q, defined as:

$$Q = \frac{\text{(stored energy per cycle)}}{\text{(energy delivered to the load per cycle)}} \tag{2}$$



For side-coupled resonators (Figure 2a), Q_e will decrease as "d" decreases. In the microstrip couplings (Figs. 2b and 2c), Q_e will decrease as the D.R. approaches the substrate in the z direction, but in the plane of the pictures, Q_e achieves a minimum4 (maximum coupling) when the following relations hold:

$$R_o = 0.32D \quad X = 0.35D \tag{3}$$

In the case of the curved microstrip probe, Q will decrease with the angle →, but will achieve minimum when the length of the line (→R_o) approaches a quarter wavelength in its substrate.[4]

Hybrid modes are more effectively coupled via a straight probe[3] and Q_e will decrease proportionally to the probe length.

Tuning the Resonator

Tuning a D.R. means adjusting its resonant frequency to a prescribed value. Several techniques can be used to achieve that, namely:

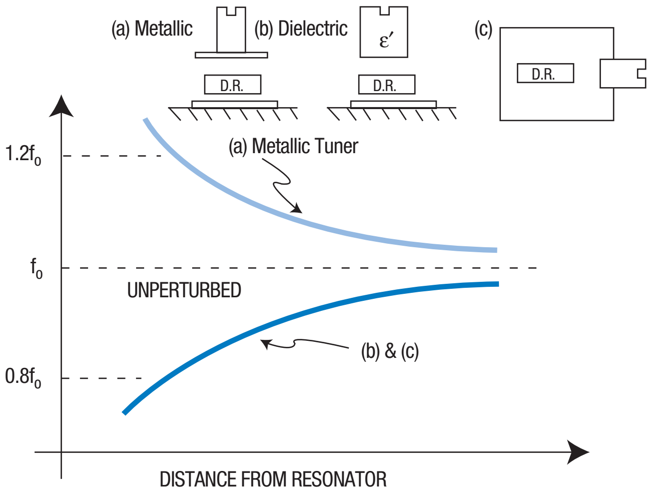
- changing either the diameter or length of the D.R.
- perturbing the fringing fields outside the D.R. via screws, plungers, dielectric, or ferromagnetic materials, etc.
- perturbing the D.R. shape through moving a piece of its own, or other material in and out of a hole made in the D.R.

The choice of a particular method will have to consider the following factors:

- the mode to be tuned
- the mechanical configuration of the final device, and
- the amount of tuning desired and its direction (to lower or higher frequencies)

A detailed discussion on the merits of each tuning technique is out of the scope of this Tech-brief, but some general principles will be helpful to acquaint the engineer with the capabilities of each method. For example, the tuning of TE modes is easily achieved via perturbations on the fringing fields performed by metallic or dielectric bodes placed parallel to the circular surface. The tuning of HE modes is best done by screws running perpendicular to the z axis of the D.R. Figure 3 exhibits a schematic of the general effect the above-mentioned methods will have on the unperturbed resonant frequency. Metallic plungers approaching the D.R. will pull the frequency up for both TE and HE modes and dielectric ones will push it down. Side screws will also push down the frequency of HE modes as they approach the D.R.

The amount of tuning that can be obtained by any of these methods can reach up to ±20% of the unperturbed value of f_o, however, it is good practice to restrict this amount to below 5% in order to prevent degradations[1] on both temperature coefficient and unloaded Qs.



References

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