APPLICATION NOTE

Introduction to Dielectrics

Brief Historical Background

In 1939, R.D. Richtmyer [reference 1] showed that unmetallized dielectric objects can function similarly to metallic cavities, which he called Dielectric Resonators (DRs). Practical applications of DRs to microwave circuits, however, began to appear only in the late 1960s as resonating elements in waveguide filters [reference 2]. Recent developments in ceramic material technology have resulted in improvements including small controllable temperature coefficients of resonant frequency over the useful operation temperature range and very low dielectric losses at microwave frequencies. These developments have revived interest in DR applications for a wide variety of microwave circuit configurations and subsystems [references 3, 4].

Some of the advantages of the substitution of conventional resonators by DRs are:

- Smaller circuit sizes.
- Greater degree of circuit and subsystem integration, due to simpler coupling schemes from Microwave Integrated Circuits (MICs) to DRs.
- Better circuit performance, when compared to MIC line resonators, with regard to both temperature and losses.
- Reduction of overall circuit cost for comparable performances.

Basic Properties

The important material properties for DR applications are:

- The temperature coefficient of resonant frequency ($_f$), which combines three independent factors of temperature coefficient of the dielectric constant ($_\varepsilon$), thermal expansion of the material (α_L), and thermal expansion of the environment in which the resonator is mounted.

Resonant frequency shifts due to intrinsic material parameters are related by the temperature coefficients given in Equation 1.

$$ {}_f \approx \tfrac{1}{2}\, t_\varepsilon - {}_L \qquad \textbf{(1)}$$

Where:
t_ε = Temperature coefficient of the dielectric constant.
$_L$ = Thermal expansion coefficient of the ceramic.

- The Unloaded Q Factor (Qu), which depends strongly on both dielectric losses and environmental losses. The Qu is defined by the ratio between the stored energy to the dissipated energy per cycle.
- The dielectric constant of the material, which ultimately determines the resonator dimensions. At present, commercially available temperature stable DR materials exhibit dielectric constants of about 36 to 40.

Cylindrical Resonator Design

Among the theoretically explored geometrics, the cylindrical shape has been widely accepted as the most advantageous one.

Practical circuit applications often require mounting the resonator in the proximity of conducting walls and/or other dielectric materials, therefore, an accurate prediction of the resonant frequency is possible only when all these boundary perturbations are taken into account in the theoretical analysis [reference 5].

Figure 1 shows the general effect of conducting parallel plates on both the resonant frequency and Qu of the fundamental mode (TE$_{018}$) of cylindrical resonators. As L/H decreases, the resonant frequency of the DR can be varied in a controllable manner. The exact point at which the Q degrades to 75% of the nominal unperturbed value depends on both the operating frequency and the conductivity of the plates, but fluctuates around L/H = 2.

Important: Tuning the frequency by means of approaching conducting surfaces is achieved at the cost of reduction in both Qu and temperature stability. The decrease in temperature stability is due to the increasing slope of the tuning curve as the distance between the resonator and plates decrease [reference 5].

The effects of the presence of a dielectric coated conductor plane, such as a micro-strip substrate, were shown [reference 5] to be negligible (less than 1% shift in the frequency). This occurs when the thickness of the substrate is less than a quarter of the DR thickness, and the dielectric constant of the substrate is less than one-half that of the DR dielectric constant. Similarly, side walls were shown to exhibit little or no effect whenever placed at a distance greater than the DR diameter.

The DR aspect ratio (thickness/diameter) can also exercise some effect on tuning and Q, but Trans-Tech, Inc. (TTI) recommends a choice of H/D = 0.4 for both optimum Q and minimum interference of spurious modes [reference 3].

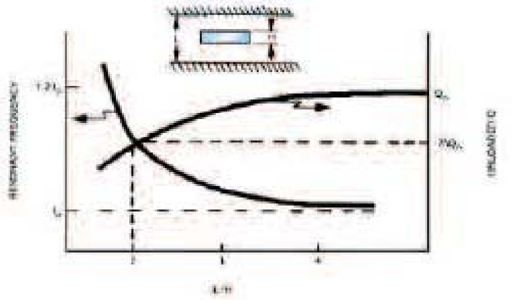

Figure 1. Resonant Frequency vs Qu Frequency

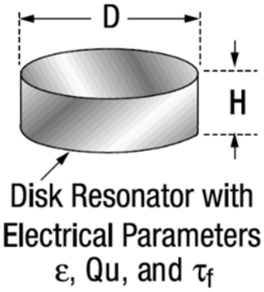

Figure 2. Disk Resonator with Electrical Parameters

References

[1] R.D. Richtmyer, *Dielectric Resonators*, Journal of Applied Physics, Volume 10, June 1939, pp. 391–398.

[2] S.B. Cohn, *Microwave Bandpass Filters Containing Hi-Q Dielectric Resonators*, IEEE Transactions on Microwave Theory and Techniques, April 1968, pp. 218–227.

[3] J.K. Plourde and C.L. Ren, *Application of Dielectric Resonators in Microwave Components*, IEEE Transactions on Microwave Theory and Techniques, August 1981, pp. 754–770.

[4] R.R. Bonetti and A.E. Atia, *Analysis of Microstrip Circuits Coupled to Dielectric Resonators*, IEEE Transactions on Microwave Theory and Techniques, December 1981, pp. 1333–1337.

[5] R.R. Bonetti and A.E. Atia, *Design of Cylindrical Dielectric Resonators in Inhomogeneous Media*, IEEE Transactions on Microwave Theory and Techniques, April 1981, pp. 323–327.

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