Room temperature Filters and Oscillators with Bragg effect dielectric resonators

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Introduction:

Low noise oscillators require high-Q resonators for low phase noise and high stability. The Q-factor of a standard dielectric resonator is usually limited by the dielectric loss-tangent of the material. One way of beating the loss-tangent limit is by building a layered structure that confines the mode mainly in the central air region through Bragg reflection.

To design such structures using $TE_{0,n,p}$ modes, many methods of solving the electromagnetic boundary value problem have been developed [1-2]. We focused our investigation into the approximate non-Maxwellian models that divide the resonator into sections then apply the separation of variables technique in each of the sections individually while matching the boundary conditions between them [3]. These models only approximately satisfy Maxwell's equations, as the derivative of the field is non continuous between boundaries. However, they give solutions of frequency typically within 1% of the actual solution. For better accuracy, numerical techniques are required. We'll use in this case the method of lines software [4].

In the past this has solely been achieved with $TE_{m,n,p}$ modes of azimuthal mode number m=0 in cylindrical resonators[1] (n is the radial mode number and p the axial). This is because the mode has only an E_ϕ electric field that remains tangential to both the radial and axial surfaces, which is a requirement of Bragg reflection. In this work we show the discovery of new modes of $m > 0$, which also maintain Bragg confinement in hollow cylindrical structures. The modes are hybrid (all field components), however, the dominant fields for these modes are E_r , E_ϕ and H_z and Bragg reflection is allowed as the radial component of the Electric field exists near the central region of the resonator and supplies a tangential boundary condition to the axial Bragg reflectors. In contrast the azimuthal electric field exists mainly at all boundaries of the Bragg reflectors and Bragg confinement of the mode is also achieved in the radial direction.

First model:

In this paper we present the main equations that allow the approximate calculation of the dimensions of a TE_{0qp} mode resonant cylindrical cavity with an arbitrary number of alternating dielectric and free-space layers given the desired resonance frequency and cavity aspect ratio. We show that this solution turns out to be a more compact and higher Q-factor solution than previously calculated [1-2].

This is because the effect of the aspect ratio on the propagation vectors is properly taken into account. We show that previous analysis is the same as assuming a one-dimensional approximation in which the aspect ratio of the Bragg reflectors is ignored. In this analysis the radial and axial layers are made of the same dielectric material and positioned inside a cylindrical metallic enclosure.

We start the analysis by describing the simplest cylindrical DBR with two circular reflectors inserted as shown in Fig. 1.
The origin is selected at the centre, where the resonator exhibits symmetry in both the *r* and *z* directions. The structure can be divided into distinct regions: the main resonance region of thickness *t*0 (region 0), and the Bragg reflector region. The Bragg reflector has two layers and can be divided into two regions of different permittivity and thickness *t*1 and *t*2 as shown in Figure 1 (region 1 and 2, respectively).

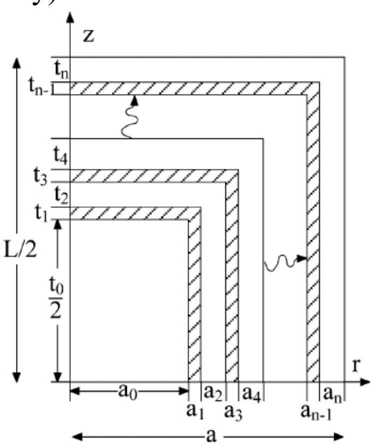

Figure 1: Schematic of DBR resonator with n-layer reflectors in both directions along the z- and r-axis of the resonator.

We assume the transverse electric (TE) field distribution (E_φ) for the $TE_{0,1,3}$ mode has a sinusoidal dependence in the *z*-direction and Bessel function dependence in the *r* direction. The Bragg reflector region and the main resonance regions are considered separately, with the boundary condition matched at the interface.

The simplest Bragg reflection or antiresonance condition requires a node at the boundary between layer 0 and 1 [5]. Thus, it is required that the E_φ goes to zero at $z = t_{o/2} + t_1 + t_2$ and $z = t_{o/2}$. We also have the extra condition, which requires a maximum at $z = t_{o/2} + t_1$. As a result we obtain three equations for axial direction.

Note that, even though both region 0 and 2 could be free space, for this solution we cannot assume $k_{z0} = k_{z2}$ as region 1 and 2 form an antiresonant structure, which must depend on the radius of the resonator, and thus the aspect ratio. Thus, we define a coefficient, γ, that relates the two wave vectors, and also for a greater number of Bragg layers, such that:

$$k_{z2} = \gamma . k_{z0}.$$

Also, due to the permittivity mismatch between layer 1 and 2, we assume the following:

$$k_{z1} = \sqrt{\varepsilon_r} . k_{z2},$$

Where ε_r is the relative permittivity of the dielectric material of layer 1.
Because the form of the E_φ field distribution in the radial direction is chosen to be a Bessel function, $J_1(kr.r)$, in the simple model, we can use the boundary condition that the field must go

to zero at the cavity walls. Then we got three equations for the radial equations. By equating the two systems of three equations by determining the aspect ratio of the structure (AR = height/Diameter), we can deduce the value of γ.

Second model:

We extended the first one, which allows us to find all dimensions for a Bragg resonator by arbitrary imposing the dielectric thickness and keeping the Bragg effect. The study is done on the same scheme but instead of imposing a quarter wavelength thickness for the Bragg reflector. We consider two extra parameters ρ, α, for each propagation directions, that are proportional to the dielectric thickness inside the radial or axial Bragg reflectors. That allows us to get a Bragg effect resonator whatever the dimensions of dielectric we can get into a manufacturer catalogue at the right frequency within 5% of accuracy.

New Hybrid Whispering Gallery Bragg mode:

This is a new type of Bragg confined mode in a dielectric loaded cavity. The Bragg structure is composed of a hollow alumina cylinder squashed between two discs of the same material. The dielectric is placed in a silver platted copper cavity. A resonance was observed at 13.4 GHz with an unloaded Q-factor of order 2×10^5, which is more than a factor of six above the dielectric loss limit. It appeared this mode possesses a number of azimuthal variations greater than zero. A Bragg structure usually requires a pure Transverse Electric mode with no azimuthal variations and only an electric field component, E_φ. The results obtained with this new type of resonator exceeded the best performances of commonly used dielectric resonators at room temperature, even with the first and second model. A third model is in progress to get directly the dimensions of such resonator.

Conclusion:

We have shown for the first time a simple model to get directly the dimensions of a Bragg resonator by only solving simultaneous equations and also the existence of a new type of Bragg mode with greater than zero azimuthal variations in a hollow ceramic alumina structure. We obtained 90% of confinement in the inner freespace region for $m = 1$, which is promising for filters and low phase noise oscillators.

References:

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