A Novel Leaky-Mode Cylindrical Dielectric Resonator Used as Feeds of Omnidirectional Antenna For Wireless Communications

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Abstract

This paper presents a novel leaky-mode cylindrical dielectric resonator including mounting holder and radial-step, which can be used as feeds of a class of omnidirectional antennas suitable for wireless communication systems. An enhanced spectral domain (SDA) approach is extended to determining resonant properties of the proposed resonator. Numerical results are focused on low-order leaky TM-mode properties. The effects of different structural parameters on resonant frequencies and quality factors are studied in detail. Theoretical results are verified by experiments.

I. Introduction

For the past few years, much attention has been given to wireless communication technologies at microwave and millimeter-wave frequencies. Various wireless local area networks (LAN) have been proposed for special applications, such as intra-office communications and indoor wireless telephone services. In these communication systems, low-cost, low-profile, and high-performance omnidirectional antenna is strongly desired. As is well-known, a dielectric rod resonator placed between two parallel conducting plates has two resonant states, trapped and leaky states. In the leaky state, a portion of the energy leaks away from the resonator in the radial direction. As pointed out in [1], TM_{nm0} modes in this resonator structure are always in the leaky state, in particular, when n=0, fields of the modes are uniform in azimuthal, or ϕ–direction. Based on this property, a novel omnidirectional antenna has been proposed to meet the requirements of wireless communication applications [2].

A useful three-dimension (3-D) resonant structure is shown in Fig.1a, which consists of a cylindrical dielectric rod with relative dielectric constant ε_r and two metal disks with mounting holders. Accurate determination of its electromagnetic parameters, such as resonant frequencies and quality factors, is essential for its successful practical applications. Resonant modes in this structure are different from those of its counterpart without mounting holders, and the modes whose fields undergo integer one-half wavelength variation along z-direction do not exist in this structure. The available analytical techniques such as used in [1] are not applicable.

In this paper, the enhanced SDA is introduced and modified to calculate the resonant frequencies and quality factors of a composite cylindrical dielectric resonator. The method essentially is a combination of the spectral analysis technique used for solving partial differential equations with the power conservation theorem. Compared to other approaches, this method is more efficient in terms of analytical formulation and numerical accuracy. Numerical results are presented for low-order leaky TM-mode properties of the presented resonator. Effects of different structural parameters on resonant frequencies and quality factors are

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discussed in details. Measurement results agree well with the numerical calculations, which also validate the proposed analytical technique.

II. Theoretical Analysis

A modified configuration of the leaky-mode cylindrical dielectric resonator (Fig.1a) is shown in Fig.1b. The radial-step is considered from the view point of antenna applications. In the cylindrical coordinate system, the structure can resonate in three kinds of different modes: TM-mode, TE-mode, and hybrid-mode with respect to z-axis. Here, only leaky TM-modes with invariant fields in ϕ-direction are taken into account. In the leaky state, a free oscillation in the resonator can be described by a complex resonant frequency. The fields should have such time independence as $e^{j\varpi t}$, where $\varpi = \omega + j\alpha$ is a complex angular frequency; ω and α are resonant frequency and damping factor, respectively. In Fig.1b, the whole structure may be divided into four homogenous subregions. In accordance with the enhanced SDA, the analysis consists of two parts. The first one is that the relationship between electric and magnetic fields at boundary apertures of each subregion is formulated in spectral domain. The other is that characteristic equation is obtained on the basis of the power conservation along the radial direction in the space domain. Due to limited length of text, the detail of this method will be explained somewhere else.

III. Numerical Results and Experiment Verification

An algorithm for calculations of the resonant frequencies and Q-factors in the leaky-mode cylindrical dielectric resonators with mounting holders was implemented. As the first verification of our technique, the resonators proposed in [1], which are the special cases of our structure, are analyzed. The results obtained are the same as in [1]. Our measurement results, which will be shown later, further confirm the correctness of the proposed technique.

The resonant modes in the leaky-mode cylindrical dielectric resonator are more complicated to specify with mounting holders than without mounting holder. In the following discussion, the modes will be designated as TM^r_{0m}, where the superscript indicates resonant mode, the first subscript(0) indicates the mode with invariant fields in the ϕ-direction, and the second subscript indicates the order of the resonant frequency. Fig.2 shows resonant frequencies and quality factors of the first two TM-modes versus the dielectric rod height. It is observed that as the size of mounting holder remains constant, the resonant frequencies increase while the quality factors decrease with increasing height of the dielectric rod. The quality factor of TM^r_{02} is more sensitive to the change of height, especially, in the case of a smaller height. As pointed out in [1], a leaky state can be converted into a trapped state with the increasing order of z-direction variation of fields. To validate numerical results, measurements for the resonant frequency of TM^r_{02}-mode were carried out with three heights of dielectric rod and the results are shown in Fig.2. The numerical and measured data are in good agreement. The slight deviation may be due to the influence of finite radius of the metal disks used in the measurement of open resonator structure, and also there is a difference between the measurement setup using forced oscillation and the damped free-oscillation model used in the numerical analysis. For a resonant-type radiating problem, the model on the basis of free oscillation assumption is not realistic. As pointed out in [6], this model results in a spatially growing wave. However, earlier work has shown that this theoretical model is a good approximation of practical problem [1]. Fig.3 illustrates the significant influences of radiating slot width on the resonant frequency and quality factor. The resonant frequency increases with the radiating slot. On the other hand, the effect of radiating slot width on the quality factors of the first two leaky-modes is different. The quality factor of TM^r_{01} is almost unchanged while that of TM^r_{02} decreases with the increase of radiating slot width. This is important for determining the operating-mode for practical applications. The effects of radiating slot thickness (r_2-r_1) on the resonant frequencies and quality factors of the first two leaky modes are shown in Fig.4. The resonant frequencies decrease while the quality factor of TM^r_{02} increases with the thickness. This implies the decreasing radiation of TM^r_{02} with the thickness of interest. Fig. 5 demonstrates the influence of radial-step height (h_4) on resonant frequencies and quality factors. It is seen that the quality factor of TM^r_{02} increases with the higher radial-step height. This may be explained by the reflection due to the step.

IV. Conclusion

A novel leaky-mode cylindrical dielectric resonator used as the feed of a class of omnidirectional antennas is proposed for wireless communication application. The resonant frequencies and quality factors of the first two leaky-modes in the resonator are analyzed by an enhanced spectral-domain method. Effects of different structural parameters on the resonant frequency and quality factor are discussed in detail. Measurement results agree well with numerical calculation.

V. References

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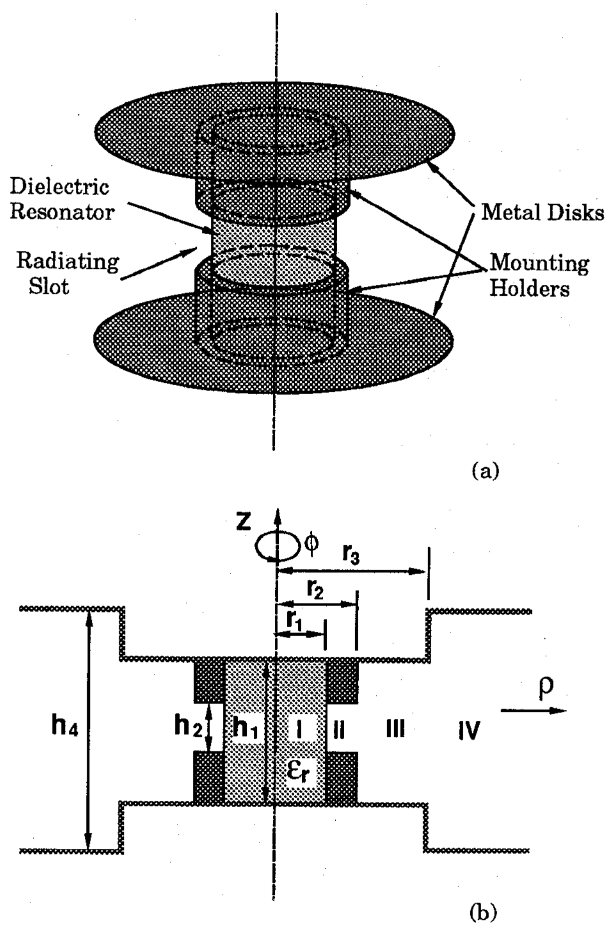

Fig.1 Cylindrical Leaky-Mode Resonator :
(a) a 3-D structure, (b) an analysis modeling with step

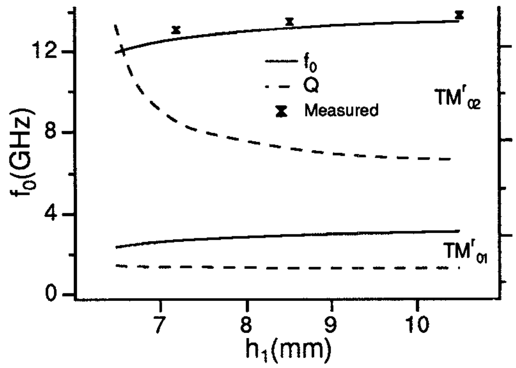

Fig.2 Resonant frequencies and quality factors versus dielectric rod height for the first two leaky modes with r_1=7.2 mm, r_2=7.7 mm, h_2=h_1-6 mm, h_4=h_1, and ε_r=2.56.

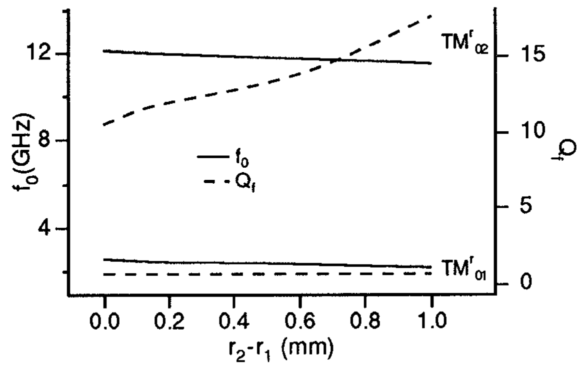

Fig.4 Effects of radiating slot thickness on resonant frequencies and quality factors of the first two leaky modes with r_1=7.2 mm, h_1=h_4=10 mm, h_2=1.0 mm, and ε_r=2.56.

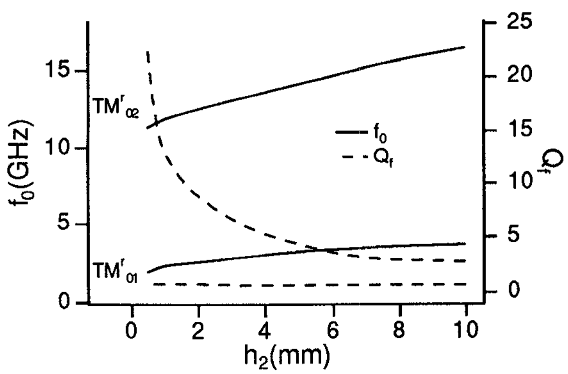

Fig.3 Effects of radiating slot width (h_2) on resonant frequencies and quality factors of the first two leaky modes with r_1=7.2 mm, r_2=7.7 mm, h_1=h_4=10 mm, and ε_r=2.56.

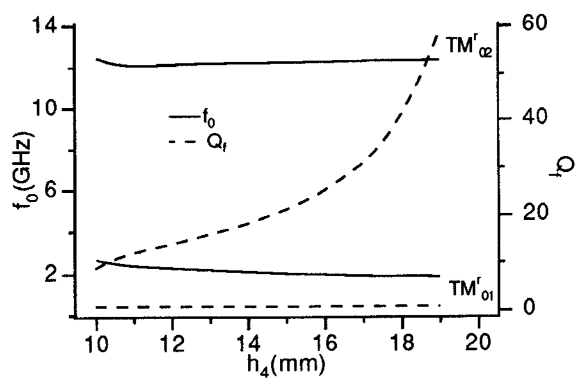

Fig.5 Effects of radial-step height (h_4) on resonant frequencies and quality factors of the first two leaky modes with r_1=7.2 mm, r_2=7.7 mm, r_3=10 mm, h_1=10 mm, h_2=2 mm, and ε_r=2.56.