Dual-Band Resonant Cavity Antenna With a Single Dielectric Superstrate

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***Abstract*—We present a novel technique to design a dual-band resonant cavity antenna that has only one dielectric superstrate. The technique is based on using a superstrate slab of high permittivity and a thickness of an integer number of half wavelengths. In representative examples, we use a ray-tracing theoretical model to study the dual-band behavior and explain it by observing how the reflection coefficient of the superstrate varies with frequency. The results are validated by simulation using commercial numerical electromagnetics software.**

I. Introduction

The concept of directivity enhancement by placing a superstrate of a partially reflective surface (PRS) parallel to an electric conductor ground plane with a simple primary radiator was first introduced by Trentini [1]. In his paper, ray-tracing was used to calculate the far-field radiation and to determine the resonance condition for maximum radiation at broadside direction (normal to the plane of the PRS and ground) as

$$\angle\Gamma_{\text{sup}} - 720^0 \cdot l/\lambda = 180^0, \quad (1)$$

where $\angle\Gamma_{\text{sup}}$ is the phase (in degrees) of reflection from the superstrate due to a plane wave impinging normally into it, l is the distance between the superstrate and the ground, and λ is the wavelength in free space. At resonance, the formed structure, named a resonant cavity antenna (RCA), has a high broadside directivity that is directly related to the magnitude of reflection from the superstrate. Due to the resonant nature of the RCA, its bandwidth is narrow and insufficient for use in many practical applications. To overcome this limitation, many dual-band RCAs have been produced by several research groups in the past decade [2]-[6].

In this paper, we present a new method to design a dual-band RCA using a single dielectric slab as superstrate. The thickness of the slab is an integer multiple of half wavelengths that generates two nearby bands of close directivity levels. We show results and explanations of two dual-band RCAs that are different in their frequency bands and directivities. The results are validated by full-wave simulations using IE3D.

II. Antenna Structure and Analysis

The general geometry of a dual-band RCA is shown in Fig. 1. The superstrate is an infinite dielectric slab of relative permittivity ε_r=10.2 that is placed at a distance $l=\lambda_0/2$ from an infinite perfect electric conductor (PEC) ground plane, where λ_0 is the wavelength in free space at the design frequency f_0. The thickness of the superstrate is an integer number n (n=1, 2, 3…) of half wavelengths. The primary radiator is a Hertzian dipole along the y-axis placed $\lambda_0/100$ above the ground plane. For $l=\lambda_0/2$, the resonance condition for maximum radiation at broadside direction (+z axis) in (1) can be rewritten as

$$\text{Total Phase} = 180^0 , \quad (2)$$

where

$$\text{Total Phase} = \angle\Gamma_{\text{sup}} - 360^0 f/f_0 .$$

We consider n=1 and n=2 in this study. The reflection and transmission coefficients of the superstrate (Γ_{sup} and T_{sup}) at any incident angle can be calculated based on the formulas of wave propagation through a three-layer medium in [7]. At broadside, the magnitude and phase of Γ_{sup} versus frequency are shown in Figs. 2a and 2b, respectively. For either n, we notice a 180^0 transition of phase in less than 1% frequency range. Such a transition contributes to the Total Phase (shown in Fig. 2c) and produces two distinct resonant frequencies of maximum radiation at broadside according to (2). Hence, a dual-band directivity enhancement is achieved.

Fig. 3 shows the broadside directivity of the dual-band RCA as it is calculated using the method described in [8]. Results by full-wave computational electromagnetic simulation are also shown and validate the dual-band behavior of the antenna. The two frequency bands of the RCA with n=2 are closer to each other than those of the RCA with n=1 because

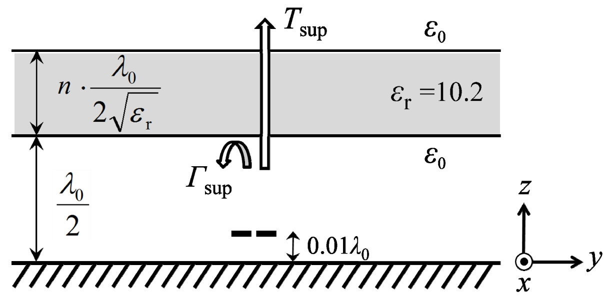

Figure 1. Dual-band RCA with a single dielectric superstrate. n is a positive integer.

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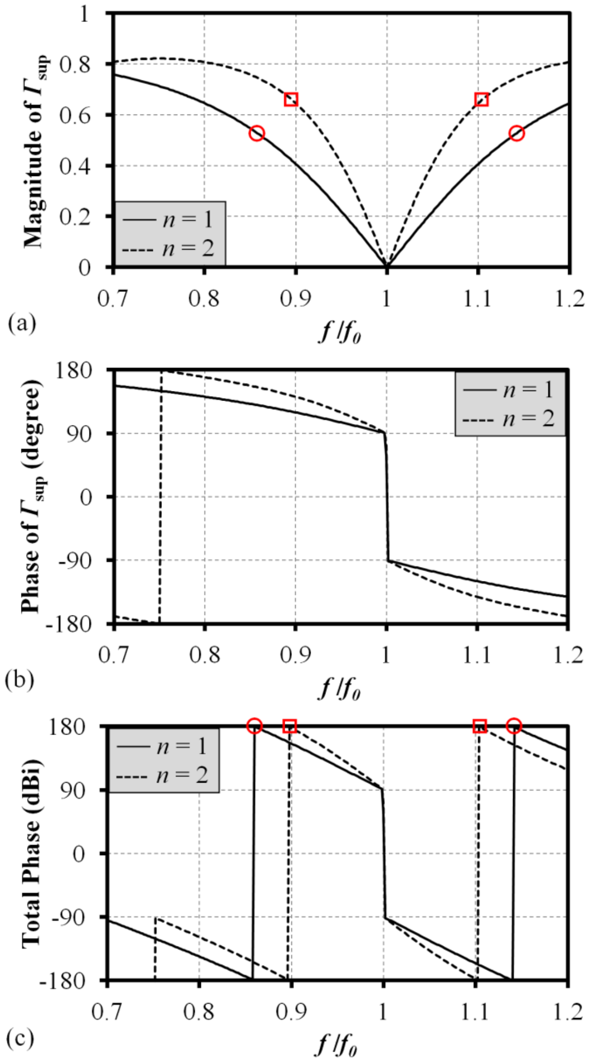

Figure 2. (a) Magnitude, (b) phase of reflection of the superstrate layer, and (c) Total Phase of the dual-band RCA in Fig. 1. A plane wave impinging normally (i.e. at broadside; +*z* axis) into the superstrate layer is assumed.

the resonance condition of (2) is met at closer frequency points for n=2 than for n=1. This can also be seen from the markers placed in Fig. 2c. Moreover, the directivity of the RCA with n=2 is higher than that of the RCA with n=1. That is referred to the magnitude of the reflection coefficient of superstrate, which is higher for n=2 than for n=1 at the corresponding aforementioned resonant frequencies, as shown by the markers in Fig. 2a. Here, it should be emphasized that the dual-band behavior is achieved by conjointly selecting the thickness of the superstrate to be an integer multiple of half wavelengths and placing the superstrate at a half-wavelength distance from the ground plane. Otherwise, the directivity levels at the bands expected by (2) will be unequal, and the dual-band function of the antenna would be significantly unbalanced.

Lastly, from Fig. 3, we notice that the lower frequency bands are slightly lower than those predicted by the Total Phase in Fig. 2c. We justify this small deviation (less than 4%) by the fact that the phase study is performed in the broadside direction only, whereas the directivity is a function of radiation at *all*

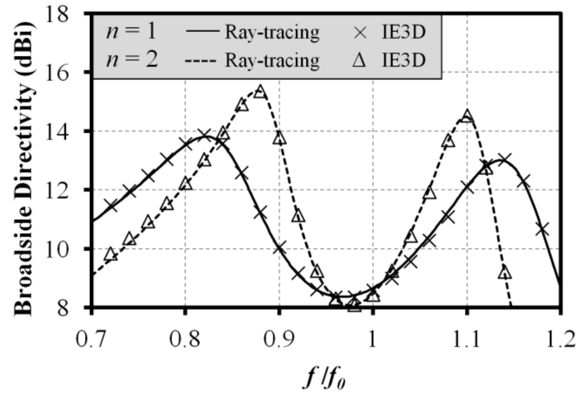

Figure 3. Broadside directivity of the dual-band RCA in Fig. 1.

angles. However, the phase study delivers a helpful insight into the dual-band behavior of the RCA.

III. Conclusion

We presented a novel technique to design dual-band RCAs by using a single dielectric superstrate slab of thickness equal to an integer number of half wavelengths. Two dual-band RCAs, one with a half-wavelength-thick superstrate and the other with a full-wavelength-thick superstrate, were studied and compared in terms of their bands and directivities.

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