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Enhancement of Scattering Field Strength of Reflectarray Elements by Dielectric Superstrate

1st Keisuke Konno
Department of Communications Engineering, Graduate School of Engineering, Tohoku University
Sendai, Japan
keisuke.konno.b5@tohoku.ac.jp

2nd Qiang Chen
Department of Communications Engineering, Graduate School of Engineering, Tohoku University
Sendai, Japan
qiang.chen.a5@tohoku.ac.jp

***Abstract*—In this paper, it is demonstrated that scattering field strength of reflectarray elements can be enhanced by introducing a dielectric superstrate. Rigorous expressions of far field radiated from current source covered by the dielectric superstrate are derived and well-known resonance conditions are revisited for the reflectarray elements. Numerical simulation is performed and effect of dielectric superstrate on the scattering field strength of the reflectarray elements is demonstrated.**

***Index Terms*—Dielectric slab, Reflectarray, Resonance conditions**

I. Introduction

A reflectarray is well-known as one of the powerful devices for future wireless technologies [1]–[3]. The reflectarray is composed of a number of scatterers called as reflectarray elements. The reflectarray elements are tuned so that their scattering fields are in-phase at a specific direction. Resultant beam forming capability makes the reflectarray to be promising alternatives of array antennas, that are composed of expensive microwave components such as phase shifters, amplifiers [4]- [8].

In previous works, numerous reflectarrays have been developed. Wideband reflectarrays have been developed using multi-layer structures or additive manufacturing technologies [9]–[11]. Electronically and mechanically reconfigurable reflectarrays have been developed so far [12]–[14].

On the other hand, a dielectric superstrate has been used for enhancing radiation performance of antennas so far. Starting from the original works by Sugio et al., Jackson has presented so-called resonance conditions of the dielectric superstrate for enhancing radiation field strength of the antennas [15]-[22]. Recently, their works have been extended for scattering performance of the scatterers [23].

In this paper, [23] is reviewed and effect of the superstrate on scattering performance of the reflectarray elements is presented. Starting from two-dimensional radiation problems of a current source over a ground plane covered by a dielectric superstrate, rigorous expressions of far-field and so-called resonance conditions are demonstrated. Finally, numerical simulation is performed and it is demonstrated that the scattering field is maximum under the resonance conditions.

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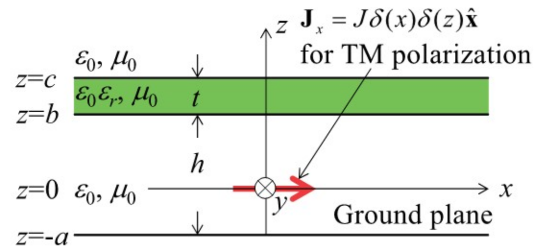

Fig. 1. Current source backed by ground plane covered by dielectric superstrate.

II. Theory

Fig. 1 is a current source over a ground plane covered by a dielectric superstrate. Once the current is assumed to be infinitely long along y-direction, expressions of electric field of the current are obtained as follows [12]–[14], [23].

$$E_\theta^{\mathrm{TM}}(\theta, h, t, \varepsilon_r, a) = \frac{-j\omega\mu_0 J}{\sqrt{2\pi k_0 \rho}} \frac{e^{-j(k_0\rho - \pi/4)} E_0^{\mathrm{TM}}(\theta, a)}{F^{\mathrm{TM}}(\theta, h, t, \varepsilon_r)}, \quad (1)$$

$$E_0^{\mathrm{TM}}(\theta, a) = \sin(k_0 a \cos\theta)\cos\theta. \quad (2)$$

$$F^{\mathrm{TM}}(\theta, h, t, \varepsilon_r) = \cos(k_0 t\xi) e^{jk_0 h\cos\theta} + \sin(k_0 t\xi) \times \{\frac{\xi}{j\varepsilon_r\cos\theta}\cos(k_0 h\cos\theta) + \frac{\varepsilon_r\cos\theta}{\xi}\sin(k_0 h\cos\theta)\}, \quad (3)$$

$$\xi = \sqrt{\varepsilon_r - \sin^2\theta}. \quad (4)$$

According to (2) and (4), so-called resonance conditions, i.e. thickness and height of the superstrate for maximizing the electric field strength at a specific direction, are obtained as follows.

$$h_{(m,\theta)} = \frac{m\lambda_0}{2\cos\theta} \quad \text{where} \quad m = 1, 2, ..., \quad (5)$$

$$t_{(n,\theta)} = \frac{(2n-1)\lambda_0}{4\sqrt{\varepsilon_r - \sin^2\theta}} \quad \text{where} \quad n = 1, 2, ..., \quad (6)$$

Normalized electric field strength under the resonance conditions is as follows.

$$\left|\frac{E_\theta^{\mathrm{TM}}(\theta, h_{(m,\theta)}, t_{(n,\theta)}, \varepsilon_r)}{E_0^{\mathrm{TM}}(\theta, a)}\right| = \left|\frac{\varepsilon_r\cos\theta}{\sqrt{\varepsilon_r - \sin^2\theta}}\right|. \quad (7)$$

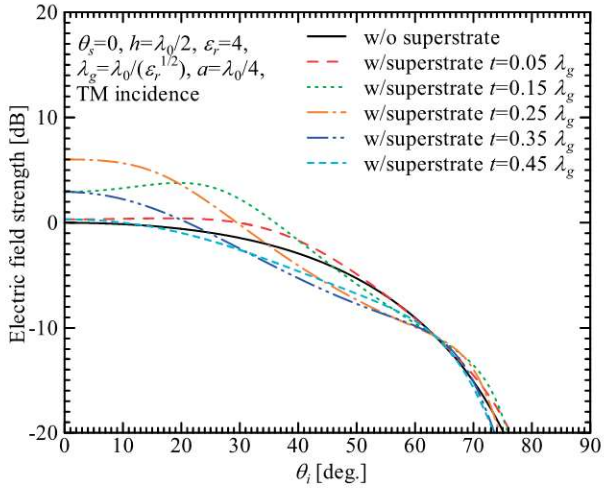

Fig. 2. Scattering field strength of the reflectarray element at normal direction (θ_i is angle of plane wave incidence.).

Eqs. (5)-(7) indicates that the electric field strength toward normal direction (i.e. $\theta = 0$) is $\sqrt{\varepsilon_r}$ times larger than that without the superstrate when the current is covered by the dielectric superstrate under the resonance conditions (i.e. $t = t_{(1,0)} = \frac{\lambda_0}{4\sqrt{\varepsilon_r}}$ and $h = h_{(1,0)} = \frac{\lambda_0}{2}$). For scattering problem, it should be notified that the effect of the superstrate is doubled because of reciprocity and the electric field strength toward the normal direction is ε_r times larger than that without the superstrate.

III. Numerical Results

Fig. 2 shows scattering field strength of the reflectarray element modeled as a current over the ground plane covered by the dielectric superstrate. As the thickness t approaches to $t = t_{(1,0)} = \frac{\lambda_0}{4\sqrt{\varepsilon_r}} = \frac{\lambda_g}{4}$, it is easily found that the electric field strength approaches the maximum. Here, $\varepsilon_r = 4$ and the maximum electric field strength is 6 dB as expected from (7) and reciprocity.

IV. Conclusions

In this paper, effect of the dielectric superstrate on the scattering performance of the reflectarray element was demonstrated. Quantitative relationship between geometries of the superstrate and scattering field strength have been described and validated numerically.

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