

# The RCS of a resistive rectangular patch antenna in a substrate-superstrate geometry

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**Abstract:** The scattering radar cross section (RCS) and the resonant frequency problem of a superstrate loaded resistive rectangular microstrip patch which is printed on isotropic or uniaxial anisotropic substrate are investigated, where an accurate design based on the moment method technique is developed. The choice of two types of basis functions (entire domain and roof top functions) is illustrated to develop the unknown currents on the patch. The accuracy of the computed technique is presented and compared with other computed results.

**Keywords:** Superstrate, Anisotropy, Resistive, Radiation, Patch, Antenna

## 1. Introduction

Microstrip antennas are now extensively used in various communication systems due to their compactness, economical efficiency, light weight, low profile and conformability to any structure. However, microstrip patch antenna is limited by its inherent narrow bandwidth. Therefore, this problem has been addressed by researchers and many configurations have been proposed for bandwidth enhancement [1-6]. The study of the superstrate layer is of interest, it can affect the performance of printed circuits and antennas and may prove beneficial or detrimental to the radiation characteristics, depending on the thicknesses of the substrate and superstrate layer, as well as relative dielectric constants [1]. In this paper we extend our study [2, 3] to the case of a superstrate-loaded resistive rectangular microstrip structure, where the superstrate layer loaded on the microstrip structure is often used to protect printed circuit antennas from environmental hazards, or may be naturally formed during flight or severe weather conditions [1, 4]. The full-wave moment method has been applied extensively and is now a standard approach for analysis of microstrip geometry [1-4], [7].

In this paper the integral equation includes a superstrate resistive boundary condition on the surface of the patch and the effects of anisotropic substrate are developed. It is worth noting that the effects of non-zero surface resistance and the uniaxial anisotropy on the scattering properties of a superstrate loaded rectangular microstrip structure has not

yet been treated. A novel proposed structure pertaining to this case will be presented in this paper.

## 2. Theory

The geometry for the superstrate-loaded resistive rectangular patch antenna is shown in Figure 1. The resistive patch with length  $a$  and width  $b$  printed on the grounded substrate, which has a uniform thickness of  $h$  and having a relative permittivity  $\epsilon_{r1}$  (region 1). The superstrate of thickness  $d$  with relative permittivity  $\epsilon_{r2}$  is obtained by depositing a dielectric layer on the top of the substrate (region 2).

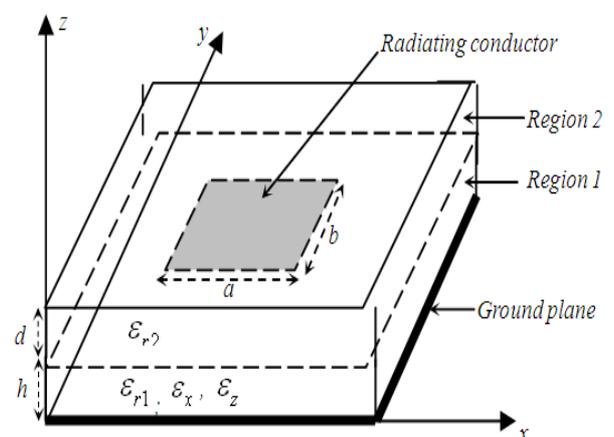


Figure 1. Resistive rectangular patch in a substrate-superstrate geometry

In the case of a uniaxially anisotropic substrate  $\epsilon_{r1}$  can be represented by a tensor or dyadic of this form [2]:

$$\bar{\epsilon}_{r1} = \epsilon_0 \text{diag}[\epsilon_x, \epsilon_x, \epsilon_z] \quad (1)$$

$\epsilon_0$  is the free-space permittivity; all the dielectric materials are assumed to be nonmagnetic with permeability  $\mu_0$ .

$\epsilon_z$  is the relative permittivity in the direction of the optical axis.

$\epsilon_x$  is the relative permittivity in the direction perpendicular to the optical axis.

The study is performed by using a full wave analysis and Galerkin's moment method to examine the scattering properties of a superstrate loaded rectangular patch antenna with a surface resistance, in which we extend our study [2, 3] to the case of this proposed geometry.

The principal modifications are done especially at the Green's functions and at the resistance surface. We have included the effect of the superstrate in the Green's function formulation as [4] which are efficiently determined by the (TM, TE) representation [3].

$$\begin{aligned} \bar{\mathbf{G}}(\mathbf{k}_s) &= \begin{bmatrix} G^{TM} & 0 \\ 0 & G^{TE} \end{bmatrix} \\ &= -\frac{i}{\omega \epsilon_0} \begin{bmatrix} \frac{k_1 D_m}{T_m} & 0 \\ 0 & \frac{k_0^2 D_e}{T_e} \end{bmatrix} \cdot \sin k_1 h \end{aligned} \quad (2)$$

Where

$$\begin{aligned} T_m &= \cos k_2 d [\epsilon_1 k_3 \cos k_1 h - ik_1 \sin k_1 h] \\ &+ i \sin k_2 d \left[ \frac{\epsilon_1}{\epsilon_2} k_2 \cos k_1 h + i \frac{\epsilon_2 k_1 k_3}{k_2} \sin k_1 h \right] \end{aligned} \quad (3)$$

$$\begin{aligned} T_e &= \cos k_2 d [k_1 \cos k_1 h - ik_3 \sin k_1 h] \\ &+ i \sin k_2 d \left[ \frac{k_1 k_3}{k_2} \cos k_1 h + ik_2 \sin k_1 h \right] \end{aligned} \quad (4)$$

$$D_m = k_3 \cos k_2 d + i \frac{k_2}{\epsilon_2} \sin k_2 d \quad (5)$$

$$D_e = \cos k_2 d + i \frac{k_3}{k_2} \sin k_2 d \quad (6)$$

$$k_i^2 = \epsilon_i k_0^2 - k_s^2, \quad i=1,2,3, \epsilon_3 = 1.0 \quad (7-a)$$

$$k_s^2 = k_x^2 + k_y^2, \quad k_0^2 = \omega^2 \mu_0 \epsilon_0 \quad (7-b)$$

$\omega$  The angular frequency;

$\mathbf{k}_s$  The transverse wave vector;  $\mathbf{k}_s = \bar{x} k_x + \bar{y} k_y$  and

$$k_s = |\mathbf{k}_s|;$$

$\bar{x}, \bar{y}$  Unit vectors in x and y direction, respectively;

$$j = \sqrt{-1}$$

An integral equation can be formulated by using this Green's function on a thick dielectric substrate to determine the electric field at any point. The details of the solution of the transformed integral equation are presented in [1-3].

Entire domain sinusoid basis functions and roof top sub-domain basis functions are introduced to expand the unknown current on the metal patches of this proposed antenna [2, 3].

Since that we have included the effect of uniaxial anisotropic substrate and the effect of superstrate in the Green's functions, also the effect of the non-zero surface resistance at the resistance matrix and consequently at the impedance matrix the different antenna characteristics can be easily obtained similar to [1-4], [7, 8].

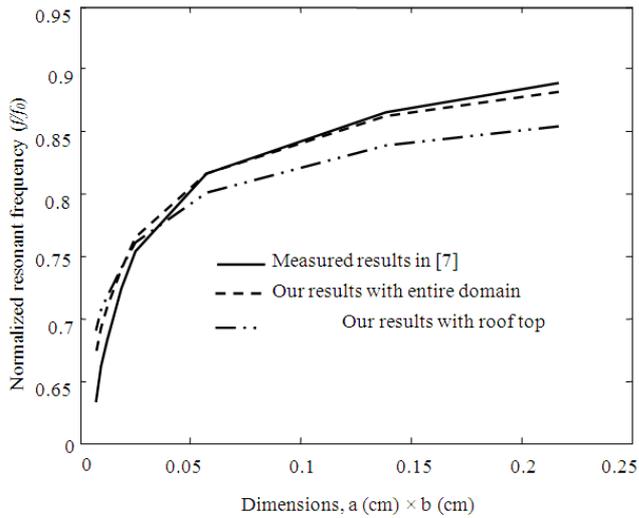
### 3. Numerical Results

The moment method technique with entire domain and roof top basis functions has developed to examine the resonant frequency and the scattering properties of a rectangular patch antenna.

For all our computations the mode that we will be studying is the TM01 mode with the dominant component of the current in the y direction. To simplify the analysis, the antenna feed will not be considered.

To ensure that the computer programs are correct, comparisons are shown in Figure 2 for a perfectly conducting patches of different sizes without dielectric substrates (air) and with no superstrate, the substrate has a thickness  $h = 0.317$  cm. It is important to note that the normalization is with respect to  $f_0$  of the magnetic wall cavity. The calculated results for the two sets of basis functions shown in Figure 2 agree very well with experimental results obtained by other authors [7], we found an excellent agreement with a slight shift in the resonant frequency when we use entire domain basis functions compared to the measured results given by [7], on the other hand computations show that the roof top sub-domain basis functions provides a significant improvement in the computations time with less iterations in the evaluation of the resonant frequency of a microstrip patch compared to the entire domain sinusoid basis functions [3, 8]. It should be noted that the convergence of the solution was investigated by varying the number of subsections.

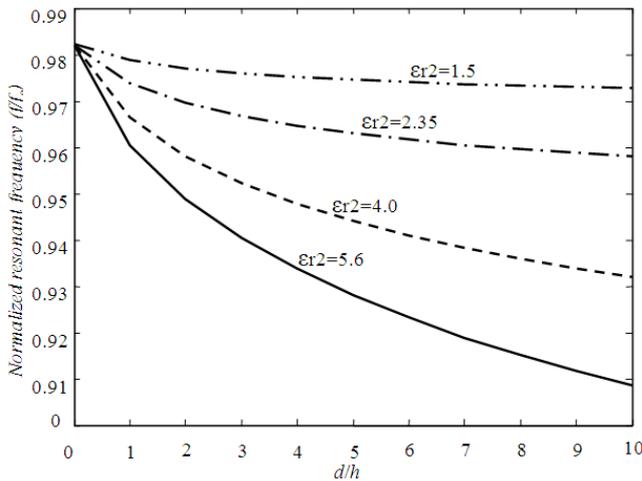
As mentioned previously, good convergent solutions are reached by using entire domain basis functions, for this reason, the use of these basis functions has developed to examine the resonant frequency and the scattering properties for the following results.



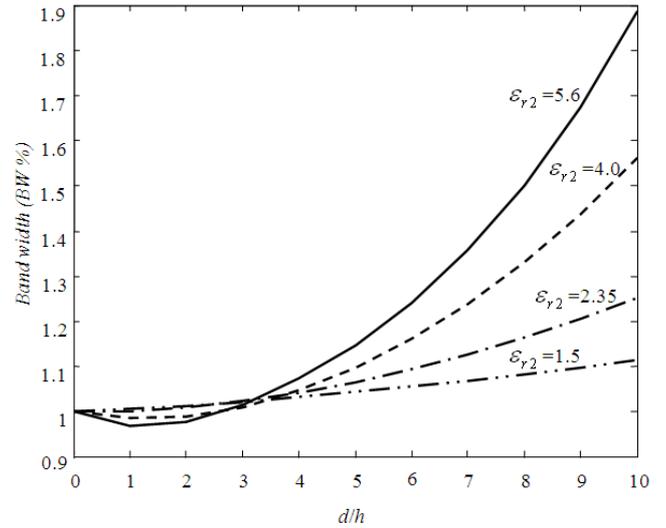
**Figure 2.** Measured and calculated resonant frequencies versus the dimensions of the patch for a rectangular microstrip antennas with no superstrate.

The substrate has a relative permittivity of  $\epsilon_{r1}=2.35$  with a uniform thickness of  $h=0.1\text{cm}$  and the patch dimensions is  $6.0\text{cm} \times 5.0\text{cm}$ .

In Figures 3 and 4, the resonant frequency (the real part of the complex resonant frequency) and the band width versus the superstrate thickness for different dielectric constants of the superstrate are shown. The obtained results show that when the superstrate thickness as well as the superstrate permittivity is increased, the resonant frequency decreases.

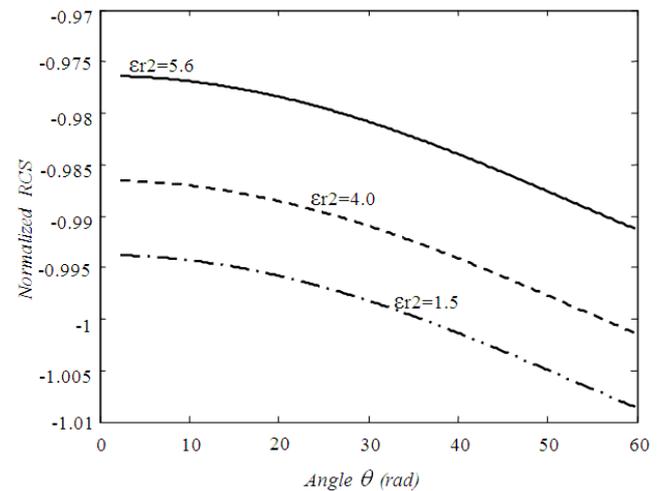


**Figure 3.** Normalized resonant frequency of a superstrate-loaded rectangular patch versus the superstrate thickness  $d$ .



**Figure 4.** Normalized band width of a superstrate-loaded rectangular patch versus the superstrate thickness  $d$ .

The variation of the band width is very small for  $d$  less than about  $4h$ . As the superstrate thickness increases ( $4h < d$ ) the variation becomes significant for high superstrate permittivities. The obtained results show that the resonant frequency and the band width vary more significantly when the superstrate permittivity is greater than that of the substrate. These behaviors agree very well with those obtained by [4] with slight shifts in frequency and band width between our results and those of [4] are noted. It is worth noting that for these two figures the normalization is with respect to that of the perfectly patch ( $R_s=0 \text{ Ohm}$ ) with no superstrate ( $d=0$ ).



**Figure 5.** Normalized radar cross section versus angle  $\theta$  for different dielectric constants of the superstrate loaded rectangular patch antenna,  $d=0.1\text{cm}$  at  $\phi = 0$ .

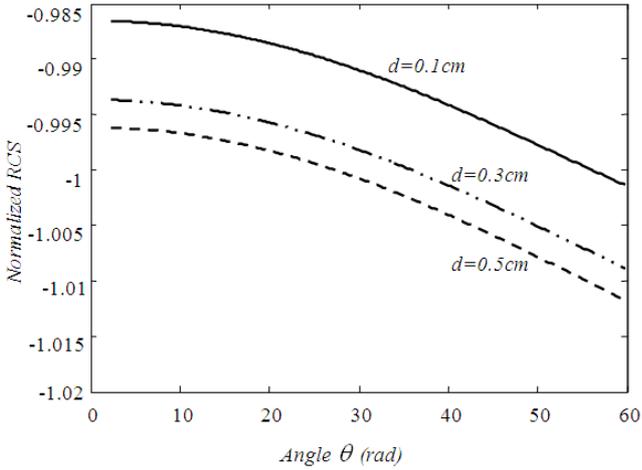


Figure 6. RCS versus angle  $\theta$  for various values of thicknesses of the superstrate loaded rectangular patch antenna,  $\epsilon_{r2}=4.0$ .

Figures 5 and 6 show the normalized scattering radar cross section RCS of a superstrate-loaded rectangular microstrip versus the angle  $\theta$  for different dielectric constants and different thicknesses of the superstrate loaded rectangular patch antenna. Results showing RCS reduction are presented for high superstrate thicknesses and low superstrate permittivities.

Figure 7 shows the normalized scattering radar cross section RCS of a superstrate-loaded rectangular microstrip versus the angle  $\theta$  for different surface resistance  $R_s$ . We observe that when the surface resistance is increased, the level of the radar cross section decreases. Consequently the addition of a resistance on the surface of a microstrip patch antenna has been shown to decrease the scattered energy from the antenna.

For Figures 5, 6 and 7 the normalization is with respect to that of the perfectly patch ( $R_s=0$  Ohm) with no superstrate ( $d=0$ ).

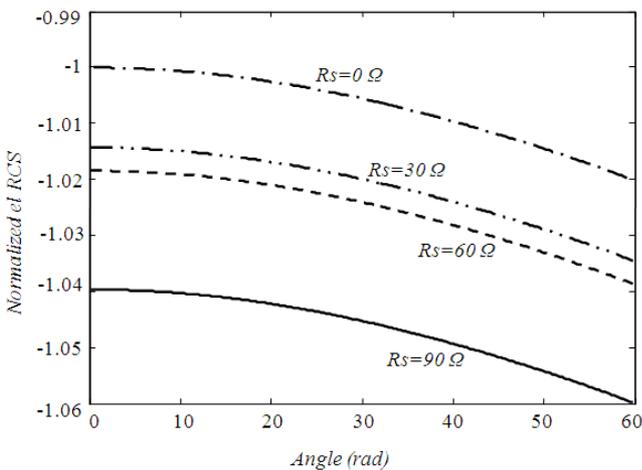


Figure 7. Radar cross section versus angle  $\theta$  for different surface resistance  $R_s$  of a superstrate loaded rectangular microstrip patch;  $h=0.2cm$ ,  $d=0.159cm$ ,  $\epsilon_{r1} = \epsilon_{r2}=2.35$  at  $\phi = 0$ .

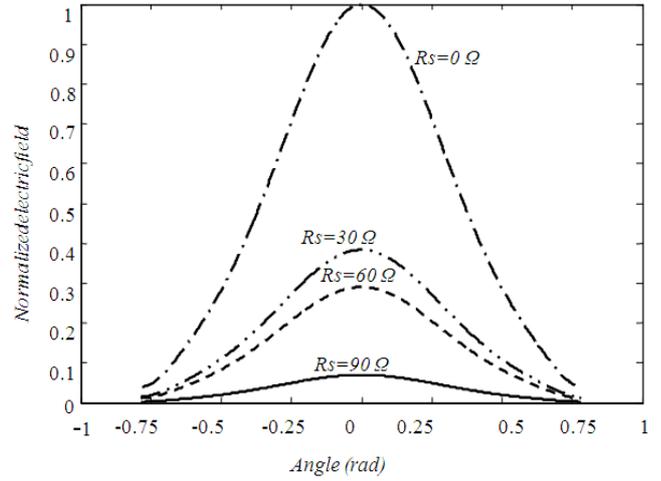


Figure 8. The effect of the surface resistance on the electric field  $E_\theta$ , at  $\phi = 0$ .

Figure 8 shows the scattering properties for the  $E_\theta$  component of the electric field at  $\phi = 0^\circ$  plane displayed as a function of the angle  $\theta$  and as a function of surface resistance. It is clear that when the surface resistance on the patch is increased, the level of the components  $E_\theta$  decreases consequently. However, it is important to note that our results for the  $E_\theta$  component do not change with the surface resistance at  $\phi = 0^\circ$ .

According to the simulation it is worth noting that the component  $E_\phi$  is dominant than the component  $E_\theta$  and the total field take the shape of the component  $E_\phi$ .

Table 1 shows the scattering radar cross section RCS for an imperfectly conducting patch with the surface resistance  $R_s=30 \Omega$  compared to a perfectly one and printed on a substrate of thickness  $h=0.2$  cm, where isotropic, positive and negative uniaxial anisotropic substrates are considered. The patch dimensions are:  $a=1.5cm$ ,  $b=1.0$  cm. It can be seen clearly that the permittivity  $\epsilon_z$  has a stronger effect on the scattering radar cross section than the permittivity  $\epsilon_x$  for both cases. Also it is noted that the study in this table is done with no superstrate.

Table 1. Effects of the surface resistance on the radar cross section for isotropic, negative and positive uniaxial substrates,  $\theta = 60^\circ$ ,  $\phi = 0^\circ$ ,  $a=1.5cm$ ,  $b=1.0cm$ ,  $h = 0.2cm$ .

$\epsilon_x$	$\epsilon_z$	AR	RCS(dBsm)	
			$R_s(\Omega)=30$	$R_s(\Omega)=0$
2.32	2.32	1	-29.27	-28.57
4.64	2.32	2	-29.39	-28.82
2.32	1.16	2	-29.12	-28.05
1.16	2.32	0.5	-29.25	-28.68
2.32	4.64	0.5	-29.64	-29.50

## 4. Conclusion

The moment method technique has been developed to examine the complex resonant frequency, the half band width, the radar cross section (RCS) and the radiation of a superstrate loaded resistive rectangular microstrip patch which is printed on isotropic or uniaxial anisotropic substrate with the optical axis normal to the patch. The formulation is carried out in the spectral domain. The choice of roof top subdomain basis functions and the entire domain were illustrated to develop the unknown currents on the patch. The accuracy of the computed technique was presented and compared with other computed results.

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