REALIZATION OF A MATCHING REGION BETWEEN A RADOME AND A GROUND PLANE

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Abstract—In order to reduce the monostatic signature of the junction between a radome and the metallic structure to which it is attached, a tapered resistive sheet can be used. In this paper, we describe an easy method to realize this tapering using geometric variations on a subwavelength scale, with a significant reduction of the number of processing steps as a result.

1. INTRODUCTION

Aircrafts need antennas to communicate or to scan the surroundings using radar. These antennas need to be shielded from wear and tear by a radome. To minimize the radar cross section of the aircraft, the radome can be made to be frequency selective by employing periodic structures within the radome wall. Ideally, this makes the radome completely transparent for frequencies in the pass band, and behave like a metal surface for other frequencies. The design of such surfaces is well documented in many journal papers and text books, and we refer to Refs. [9, 10, 15] and references therein for more detailed information. The interaction between the antenna and the radome is a large and challenging problem to model, see [6, 14] for some recent approaches.

Even if the radome itself is well designed in the respect that it has high transparency in the pass band and high reflectance elsewhere, there is usually quite a lot of scattering generated by the interface between the radome and the hull of the aircraft, due to the different surface properties. This is particularly troublesome in the pass band. Since frequency selective radomes are usually based on a resonant periodic structure, the reflection coefficient from the radome surface

can be located just about anywhere in the Smith chart. The hull of
the aircraft on the other hand, is usually made of metal and has a well
defined reflection coefficient of -1 for a very large range of frequencies.

In order to match these different reflection coefficients to each
other, it is necessary to introduce a matching region between the
radome and the hull. One solution to this is to introduce a tapered
resistive sheet, as is described in [2, 3, 7, 8, 11, 12]. The tapered sheet
starts off as a metal surface close to the hull, and transforms gradually
to free space properties as the matching region extends over the
radome. The typical design requires the tapering to occur over one
or several wavelengths. In general, the resulting bandwidth increases
if the tapering is made longer and smoother. Further reduction of
the radar cross section of the aircraft can be achieved by the use of
absorbers at the antenna [1], see [8] for a general overview of radar
cross section reduction.

2. IMPLEMENTATION BY CONDUCTIVITY AND THICKNESS

As observed in [4], to control the scattering pattern requires control
of the current distribution. In a physical optics approximation, this
corresponds to specifying the taper for the reflection coefficient Γ, i.e.,
a linear taper in current corresponds to a linear taper in Γ. Many
different tapering profiles are possible, for instance linear, quadratic,
or cosine (Hanning) tapers. In this paper, we focus on the linear taper
for simplicity, and refer to [2, 8] for examples of different tapers. To be
able to distinguish different shapes of the taper, it needs to be realized
with at least 5–10 regions of different reflection coefficients.

A straightforward realization of the tapered resistive sheet is given
by the following strategy. The equivalent resistance for a thin sheet
with conductivity d and thickness σ is $R = 1/(\sigma d)$. When backed by
free space, such a sheet has the reflection coefficient [13]

$$\Gamma = \frac{-\eta}{2R + \eta} = \frac{-\eta}{2/(\sigma d) + \eta} = \frac{-\eta\sigma d/2}{1 + \eta\sigma d/2} \tag{1}$$

where $\eta = 377\,\Omega$ is the wave impedance of free space. From this
formula, it is seen that the reflection coefficient Γ can be controlled by
two parameters, the conductivity σ and the thickness of the layer d.
By varying these parameters, a resistive sheet backed by free space can
be made to have a local reflection coefficient anywhere between 0 and
-1. The variations must typically occur over at least half a wavelength
at the longest wavelength, preferably a full wavelength [8, p. 353].

The problem is that this method of realizing the tapering may
call for many different orders of magnitude of either thickness d or

conductivity σ, requiring many processing steps in the manufacture. As an example, the tapering realized in Figure 5 ranges from $R = 0.19\,\Omega$ to $R = 11\,\text{k}\Omega$, a difference in 5 orders of magnitude. This increases the complexity of the manufacturing, and increases the cost.

3. IMPLEMENTATION BY GEOMETRY

Instead of changing the obvious parameters d and σ to change the effective resistance of the sheet, we propose to use heterogeneities in the sheet in order to realize a sufficiently variable reflection coefficient of the sheet. This drastically reduces the number of processing steps needed.

We consider a resistive tapering that only requires a single resistive sheet of given thickness and conductivity. The resistance per square of the resistive sheet is reduced by adding isolated metal patches in it, and is increased by making holes in it. The patches and holes can be of arbitrary shape, e.g., squares and rectangles. A symmetric patch/hole gives an isotropic resistivity whereas an asymmetric patch/hole can be used to realize an anisotropic resistivity.

The reflection coefficient of a periodic structure utilizing square patches and holes in a resistive sheet with intrinsic resistance per square $R = 1/(\sigma d) = \eta/2$ is shown in Figure 1. It is seen that this geometry offers every reflection coefficient between 0 and -1, and hence it is simple to design any desired tapering.

In Figure 2, we show a typical realization of a linear tapering of the reflection coefficient by the following steps. 1) One fixed unit cell size was chosen, allowing for 9 transition steps between air and PEC.
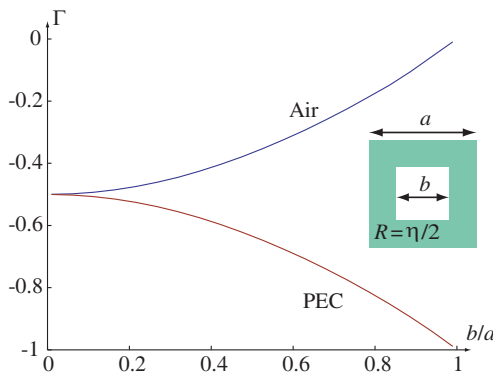
Figure 1. Reflection coefficient of the periodic air and PEC patches in a resistive sheet, respectively.
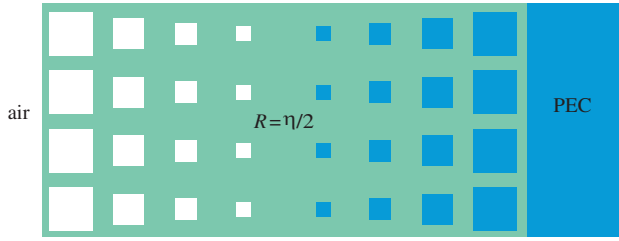
**Figure 2.** Illustration of a resistive tapering from air to PEC.
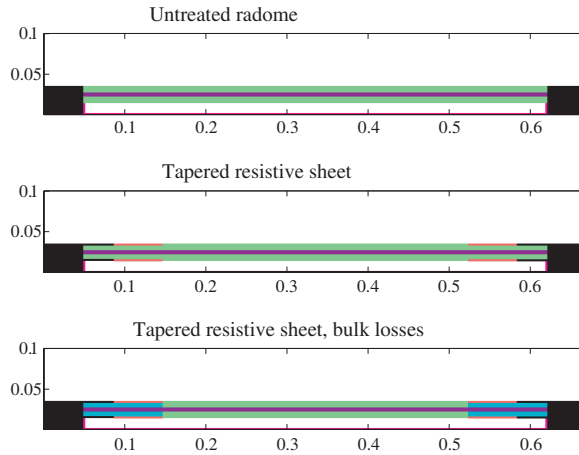
Figure 3. Geometry of the simulation cases (units in meter). The frequency selective radome is mounted in a metal surrounding (black regions), and three different cases are simulated. The top case corresponds to no edge treatment, the middle to using only a tapered resistive sheet, and the bottom uses both a tapered resistive sheet and additional loading in the dielectric underneath the sheet.

2) Labeling the unit cell closest to air by 1 and the one closest to PEC by 9, the reflection coefficient in cell n should be $\Gamma_n = -1 + n/10$. 3) For reflection coefficient Γ_n, read off the ratio b/a required for the hole or PEC patch from Figure 1.

It is not necessary to use a fixed unit cell, but it simplifies the design procedure. A fixed unit cell will limit the design in terms of grating lobes, although the onset frequency of these can be pushed up by choosing the unit cell as small as the manufacturing technique allows. Also, with a smaller unit cell a smoother transition region is obtained. Typically, at least 5–10 cells are necessary.
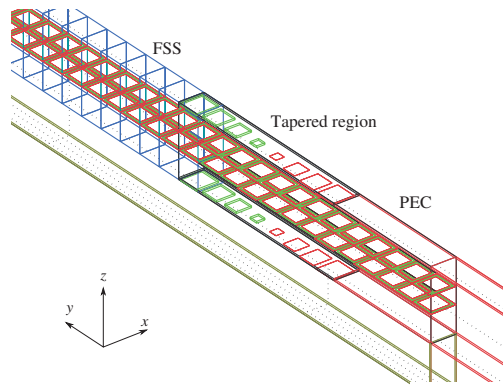
Figure 4. Blow-up of the edge region when the tapered resistive sheet is realized as described in Section 3. The structure is periodic in the x-direction with a unit cell of 7.5 mm, implying grating lobes at 20 GHz.
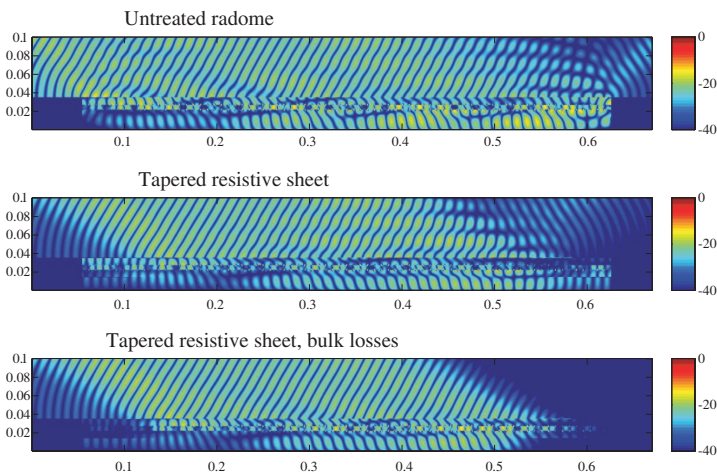

Figure 5. Results of the full wave simulation. A TM polarized plane wave is obliquely incident from the right at $60°$ relative the surface normal and frequency 15.4 GHz, and the scattered field is plotted in dB scale. A continuous tapered resistive sheet has been used, realized by varying the conductivity as described in Section 2. The frequency is chosen so that the periodic structure in the radome supports a surface wave for TM polarization, contributing to strong scattering if the edges are not properly treated. This scattering is visible in the right part of the mid graph where only a resistive sheet is used, and absent in the lower graph where additional bulk losses at the edges are introduced. This corresponds to the narrow peaks around 16 GHz in Figure 9.

4. RESULTS

To evaluate the proposed realization of a tapered resistive sheet, the following test was performed. A frequency selective pass band radome with three dielectric layers and two metal surfaces with a periodic square slot structure was implemented numerically using Finite Differences in the Time Domain (FDTD), using the PB-FDTD program described in [5].

The geometry is depicted in Figure 3, with a blow-up of the edge region in Figure 4. The radome structure is periodic (infinite) in the x-direction, and finite in the y-direction, z being the normal direction to the radome. At each end of the radome in the y-direction, an infinite metallic ground plane was attached. The tapered resistive sheet, extending 1 dm from the metal surrounding onto the radome structure (about three wavelengths on the center frequency 10 GHz), was realized both as a continuous tapered sheet (down to the precision of the FDTD discretization) by varying the conductivity as described in Section 2, and as a geometric tapering with fixed conductivity as described in Section 3. The unit cell of the geometric tapering was chosen to coincide with the unit cell of the frequency selective structure for ease of implementation, see Figure 4.

Since the radome structure supports a surface wave for the TM polarization at an angle of incidence of about 60°, some bulk losses
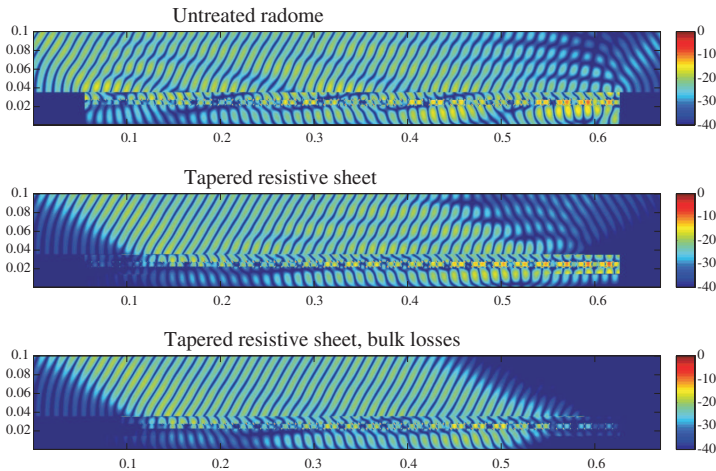
Figure 6. Same case as in Figure 5, with the tapering realized by the procedure described in Section 3 and Figure 2. The effect of the tapered sheet is the same.
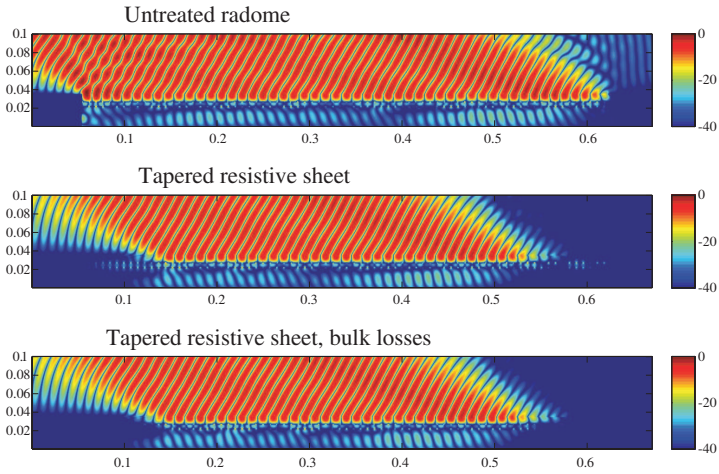
Figure 7. Same case as in Figure 5 (continuous tapered sheet), TE polarization. The extra scattering from the surface wave is absent in this polarization.
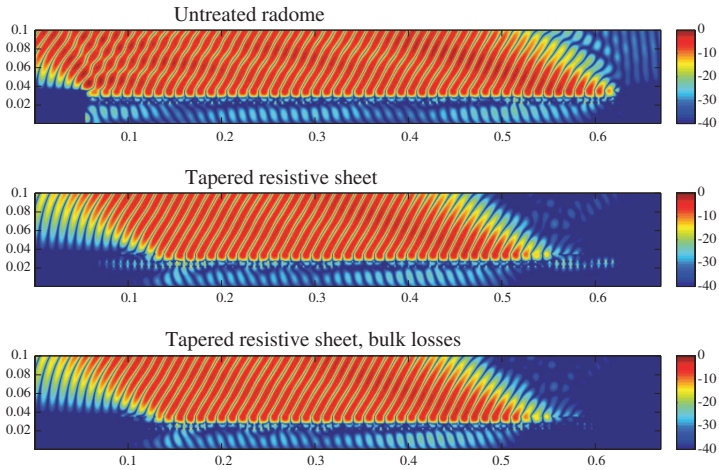

Figure 8. Same case as in Figure 7, with the tapering realized by the procedure described in Section 3 and Figure 2.

(loss tangent 0.14 at 10 GHz) were introduced in the core dielectric layer below the tapered resistive sheet as well. This additional loading absorbs the surface wave, which reduces the signature of the radome for TM polarization and improves on the design in [2].
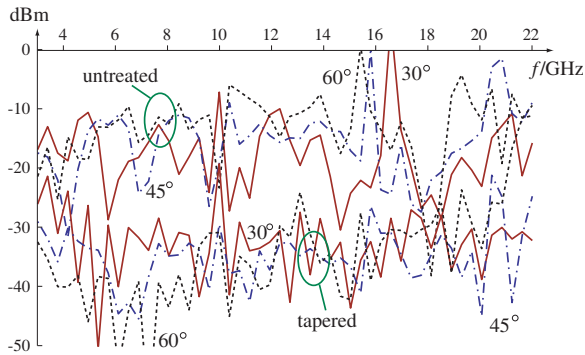
Figure 9. The monostatic RCS corresponding to TM polarization and geometric tapering. The results are given for three angles of incidence: 30° (solid), 45° (dot-dashed), and 60° (dashed). The curves around −15 dBm are for the untreated radome edge, whereas the ones around −35 dBm are for the tapered resistive sheet and bulk losses in the radome at the edges. It is seen that the edge treatment significantly reduces the monostatic RCS.
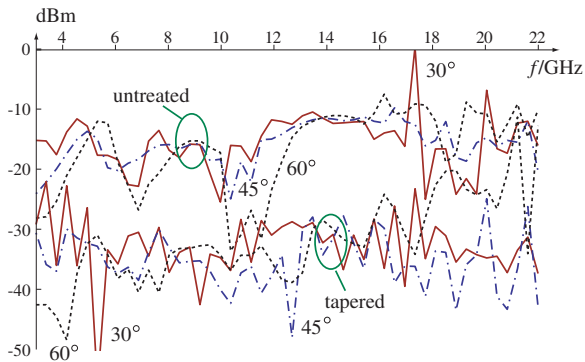
Figure 10. The monostatic RCS corresponding to TE polarization and geometric tapering. The curves correspond to the ones in Figure 9. The strong contribution from the surface wave scattering at 16 GHz in Figure 9 is almost absent for this polarization.

The results of the full wave simulations are shown in Figures 5–8. The discrete geometric tapering is compared with simulated results for a continuous tapering (varying the conductivity σ and keeping the thickness d constant), and it is seen that the results are very similar. In Figures 9 and 10, the backscattered field from the geometric tapering

case is plotted as a function of frequency, to demonstrate the broad band properties of the realization.

5. DISCUSSION AND CONCLUSIONS

The proposed method drastically reduces the number of processing steps needed to realize a tapered resistive sheet, compared to solutions where the thickness or conductivity of the sheet is changed. The sheet can be processed in only two steps: first etching out the metal patches from a standard substrate, and then screen printing the resistive sheet with corresponding holes. Since the precision of making patterns in metal or resistive sheets is very high, at least compared to wavelength in radar bands, the proposed method also significantly increases the precision of the design. In order to improve the design using tapered resistive sheets in [2] for TM polarization, we have also added small bulk losses in the dielectric below the tapered resistive sheet.

Ideally, the unit cell of the geometric variations of the tapered resistive sheet should be as small as the manufacturing technique allows. In our numerical example, we have used a relatively large unit cell, the same size as the unit cell of the frequency selective structure, and still obtained results very similar to the continuous tapering. This demonstrates that significant RCS reduction can be achieved even with a rather coarse geometry.

ACKNOWLEDGMENT

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