# Design of a Stealthy Antenna Using COMSOL Multiphysics®

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**Abstract:**
This paper will describe some applications of COMSOL Multiphysics® to the analysis of Frequency Selective surface structures.
In particular attention will be focused to the possibility of designing a stealthy antenna using the FSS structure. In fact, since it possesses a dual filter concept of frequency and polarization for electromagnetic wave, the Radar Cross Section (RCS) of the antenna is reduced.

**Keywords: stealth antennas, Frequency selective surface, radar cross section reduction**

## 1. Introduction

The radar cross section (RCS) of a conventional antenna can be very large making it an easy target to pick up on basic radar systems.
If the antenna is placed on a stealthy aircraft or navy ship, for instance, it will destroy their invisibility to radar. The radar system scanning the area of the aircraft would pick up reflections from each part of the antenna (or other components). The sum of the reflections arriving in phase results in the identification of a large RCS on the radar display.
Stealthy antennas are designed to reduce the large RCS of conventional antennas. By replacing the large RCS of the conventional antenna with a much smaller RCS of a stealthy antenna, the object is much more difficult to detect, and therefore, the cloak of invisibility will be maintained.
Several methods have been investigated to reduce RCS of antennas. Different shape of the structures, use of active or passive elements, use of absorbing materials.
This paper aimed to present a reduction of RCS using FSS structures.
The major characteristics of FSS is to be band-pass structures, so are transparent at the operating frequency but rejects signals outside a band centered at the operating frequency [1].
They can be employed as or with radome for antenna systems without affecting the required characteristics of the antenna in the operative frequency band [2].
Before presenting some results, a brief overview on the main antenna parameters that constitute the of RCS is presented. Then a description of FSS analysis is reported. Finally, the design and the simulation of FSS is described highlighting how the use of COMSOL could help in this step [3].

## 2. Antenna Radar Cross section

The RCS, σ, of an object is its equivalent area which if scattered isotropically would
result in the same scattered power density [8]. It can be determined as the quotient
between the scattered wave $E_s$ and the incident wave, $E_i$ i.e.,

$$\sigma = \lim_{r\to\infty} 4\pi r^2 \frac{\left|E_s^2(r)\right|}{\left|E_i^2(r)\right|}$$

The RCS depends on the polarization and frequency of the incident wave. For two-dimensional objects the RCS is the equivalent length of the object.
Scattered electromagnetic fields occur when an incident wave is scattered from a target.
In fact, when an electromagnetic wave is incident on a target, electrical currents are induced in the target and a secondary radiation of these produce a scattered wave.
In the direction of the incident wave, the scattered field is reflected straight back to the source of the wave. This peak reflected wave is related to the standard antenna gain, G, and the radar cross section, as shown

$$\sigma = A \cdot G$$

where
A - peak effective area of the antenna, m2
G - peak gain of the antenna, dB
Considering the relation between A and G, RCS could be rewritten as,

$$\sigma = 4\pi \frac{A^2}{\lambda^2} = \lambda^2 \frac{G^2}{4\pi}$$

It is clear that high gain antenna should have a high radar cross section. To lower the RCS, the gain should be reduced. This is opposite to what antenna designers are supposed to do – increase the gain as much as possible.

## 3. FSS analysis and design

Frequency selective surfaces are usually constructed from periodically arranged metallic patches of arbitrary geometries or their complimentary geometry having aperture elements similar to patches within a metallic screen. These surfaces exhibit total reflection or transmission, for the patches and apertures respectively, in the neighborhood of the element resonances. The most important step in the design process of a desired FSS is the proper choice of constituting elements for the array. The element type and geometry, the substrate parameters, the presence or absence of superstrates, and inter-element spacing generally determine the overall frequency response of the structure, such as its bandwidth, transfer function, and its dependence on the incidence angle and polarization.
The characteristics of the FSS are that it is transparent at the operating frequency but rejects signals outside a band centered at the operating frequency.
This feature allows the antenna to be low RCS for all frequencies outside this band of frequencies.
The FSS elements shape can be chosen according the design requirements (single/multi band antenna, occupancy and bandwidth requirements, etc…).
The FSS structure could be integrated in the radome, if any, or could constitute the ground plane of the antenna, or could be placed on the antenna itself.

## 3. Use of COMSOL Multiphysics

Once the characteristics of the FSS are chosen, the design and optimization is based on the refinement of the elements shape.
The design process is speeded up using computational electromagnetic codes based on method of moments (MoM), finite element method (FEM), and finite-difference time-domain (FDTD) with periodic boundary conditions.
In the case of a FSS constitutes by a periodic array of elements, the availability of Periodic Boundary Condition (PBC) allow the simulation of a single cell unit and therefore a less time consuming process.
The design of the proposed structures was done considering a 3D model that include the unit cell of the FSS, the surrounding material and the terminal PML (at the bottom and top of the model).
The boundary system available also in the 4.3version of COMSOL Multiphysics® allow, as already said, the design of the unit cell of the FSS. Then, opportunely defining the boundary condition the entire structure is simulated.
In the example that will be shown in the next section, the conductive element is drawn at the center of a Cartesian coordinate system surrounded by air and defined as PEC together with two of the four walls. The other two are chosen as perfect magnetic conductors.
Then, using PBC an infinite surface is created forcing the right values for the electric and magnetic field components.
Concerning the mesh constraints, several test has been performed to choose the most suitable one based on both the accuracy desired and the computational effort required.

## 4. Results

FSS has found many applications in antenna systems. They could be used as reflector antennas or as frequency windows in/with radomes.
Here, the attention is focused to create a structure that does not substitute the antenna itself but that can be used to “stealthy” it.
Different simple structures have been designed to obtain an FSS that could be used also together with the existing systems. In particular, the requirement was to find a “frequency windows”

that has a good transmission in the operative bandwidth so to be applied also with an existing radome.
To this aim the proposed results show the behavior of the selected geometry in the operative bandwidth without considering the actual antenna system in which the FSS will be applied.

As an example, a simple FSS array was designed and then the unit cell element has been simulated in order to optimize the design.
In particular, since the FSS has to be used as "cloak of invisibility" for the antenna, its behavior inside and outside of the operative bandwidth has been studied in order to minimize the RCS of the source.
The examples below are designed mainly to test and to stress the PBC of COMSOL Multyphisics to understand the response of the structure.
In Fig. 1 is show the geometry of the unit cell of the first FSS designed.
It is a metallic strip surrounded by an air box. It is designed to optimize the PBC of COMSOL in order to study efficiently the entire array.

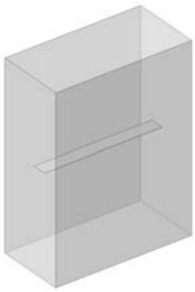

**Figure 1 -** Geometry of the unit cell

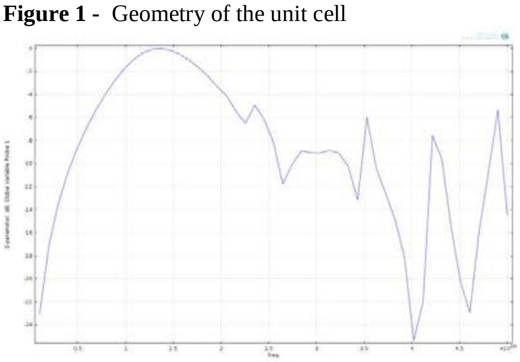

**Figure 2 –** S-parameter of the structure in Fig.1

In 2 it is shown the frequency response of the designed FSS.

The good performances of the FSS in the selected bandwidth, as well known, imply good performances of the whole system.

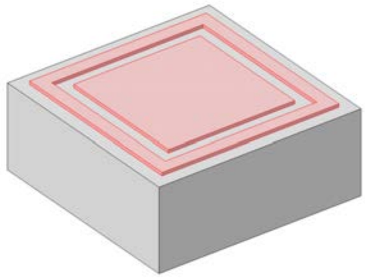

**Figure 3 –** Geometry of the single element of the FSS constituted by patch slotted.

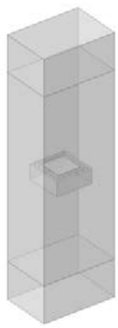

**Figure 4 –** Simulation geometry of the unit cell

In Fig.3 is shown a different geometry for the FSS. It is consider a dielectric substrate (Rogers RT5880 on which is designed a patch with a rectangular slot. Also for these structure the frequency response is analyzed and optimized to obtain the best performances in terms of transmission/reflection coefficient in order to minimize the RCS.

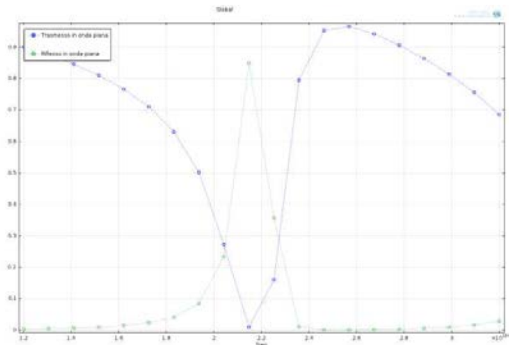

**Figure 4 –** Frequency response of the structure in Fig.3

In the previous examples, the mesh size is chosen as the best compromise between solution accuracy and computational effort required.

## 5. Conclusions

In this paper the design of an FSS surface using COMSOL Multiphysics has been described.
The performances of the proposed structures have been optimized to obtain the best frequency response in order to use these kind of surfaces as a “cloak of invisibility” for an antenna system.
The general purpose design allow the use of the FSS both with or without an existing radome.

## 6. References


1. Benedict A. Munk, *Frequency Selective Surfaces: Theory and Design*. New York: Wiley-Interscience, 2000.
2. J. D. Kraus and R. J. Marhefka. *Antennas*, McGraw-Hill, New York, third edition, 2002.
3. *COMSOL Multiphysics 4.3 User’s Guide*, COMSOL, 2012.
4. L.-S. Ren*, Y.-C. Jiao, J.-J. Zhao, and F. Li, *RCS Reduction for a FSS-Backed Reflectarray using a Ring Element*, Progress In Electromagnetics Research Letters, Vol. 26, 115-123, 2011.
5. B. Lu, X. Gong, J. ling, and H. W. Yuan, *Radar Cross-Section Reduction of Antennas Using a Stop-Band Frequency Selective Surface*, Microwave Journal, pp. 6-18, August 2009.
6. Tomáš Höhn, Modeling Frequency Selective Surfaces in COMSOL Multiphisics.