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# Comparison of Various Full-wave Softwares in Calculating the RCS of Simple Objects

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## *Abstract*

This paper introduces several full-wave simulation Softwares for calculating radar cross section (RCS) of targets. The RCS of sphere and square flat plate at frequency 10 GHz (X band) are computed and compared in three commercial Softwares: HFSS, CST and FEKO. These simple objects are chosen for this comparison because the analytical relations and measured results for their RCS are existed in literature. The computed results are compared and discussed in terms of memory requirements, calculation time and accuracy.

***Keywords:*** *RCS, Full-wave Softwares, Sphere, Square flat plate*

## 1. Introduction

Nowadays, radar systems play a significant role for detection and location of reflecting objects such as ship, aircraft, vehicle and spacecraft [1, 2]. Radar has many applications in various area [1, 3]. In air-defense systems, it acts the functions of weapon control [3]. All radars are used in remote sensing such as weather observation, mapping of sea ice to remote shipping and short-range blow ground probing. The other popular applications of radars are aircraft safety and navigation [3]. The RCS is the property of a scattering object which shows the magnitude of the echo signal to the radar. The RCS of a target depends on various factors such as frequency and polarization of a radar signal, the size, the geometry and composition of the target and the viewing direction [4]. The main challenge is computation and measurement the RCS of different objects. Some numerical methods are applied in RCS studies such as the method of moments (MOM) [5], the fast multi pole method (FMM) [6, 7], the finite difference time domain (FDTD) [8-10] and transmission line matrix (TLM) [11, 12]. Recently researchers utilize popular Softwares such as FEKO, CST, HFSS, MAXWELL and COMSOL to simulate the RCS of the various objects. These softwares are easy to work but the main matter is that which software is suitable for the object and gives the exact solution for the RCS. Some articles have compared the numerical methods or softwares with each other. In [13], various computational electromagnetic methods are compared to determine the accuracy of various methods. Another study has be done in [14] to compare the various Full-wave methods such as finite integral time domain (FITD), finite element method (FEM) and MOM in the commercial software CST. Considering the RCS of an airplane is more attractive area for researchers [15-17]. For instance, a comparison between MOM, the multi-level fast multi-pole method (MLFMM) and higher-order basis functions (HOBF) in a FEKO simulator has be done in [15]. In this paper, several full-wave simulation Softwares are introduced for calculating radar cross section (RCS) of targets. The RCS of sphere and square flat plate at frequency 10 GHz (X band) are computed and compared in three commercial Softwares: HFSS, CST



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and FEKO. This article is organized as follows. In section II, a brief study on the properties and methods of three softwares FEKO, CST and HFSS will be presented and discussed. Then, Section III studies RCS of the simple configurations such as sphere and square flat plate. These simple configurations are chosen because their mathematical relations and measured results for RCS are existed. Finally, section IV concludes the paper.

## 2. Summary of used softwares

In this section, a brief study on the properties and methods of three softwares FEKO, CST and HFSS will be presented:

### 2.1 FEKO

In this solver, four simulation methods are used. First one is MOM which is utilized for calculating induced currents on object faces. This method applies a small mesh size of less than 1/10 wavelength ($\lambda$). Therefore, very large computation memory is required for this method. MLFMM is second numerical technique which simplifies calculation process between points that are far apart and reduces computation memory size. The mesh size of this method is like MOM. Another method is HOBF that applies a large mesh size as 1 wavelength ($\lambda$). In this technique, computation memory and time reduces extremely in comparison to MOM. The last computational technique is geometrical optic (GO) that employs a ray-tracing method and its mesh size is like HOBF. GO is reliable only for simple surface structures and also very large objects. The FEKO allows user to manually select one of the above method. Also, a triangle mesh with three level (fine, standard, coarse) is used by default. This software divides the object to small meshes (unlike HFSS that divides all problems to small meshes even for free space).

### 2.2 CST

This simulator employs several methods. The FITD is a method which is derived from the integral of Maxwell's equations. This method keeps all advantages of the FDTD like fast mesh generation and the fast calculation speed. The common method in CST is FEM which is more computing time and memory intensive. This method uses tetrahedral meshes. Another popular method is MOM which is applicable to scattering and radiating problems. The MOM has desired accuracy but it needs to large memory. The MLFMM is the other technique in this software. This method is used to overcome the MOM problem. CST uses method associated with selected solver. The default mesh in CST is tetrahedral mesh. This software is suitable for calculating RCS of large and metallic objects like fast crafts.

### 2.3 HFSS

This software utilizes FEM which it divides all problem solving environment (even free space around the object) to small meshes. Therefore, the powerful computer system is required for this simulator for calculating RCS. Due to many meshes, this simulator is not suitable for medium and large objects like fast crafts and then it should be used for calculating the RCS of small objects.

It should be noted that for calculating the RCS of various targets, one method for each full-wave softwares is popular between the researchers. For instance, the researchers calculate RCS by FEM method in HFSS simulator because this software is mostly well-known with this method.

## 3. Simulation results and discussion

The RCS ($\sigma$) is the property of a scattering object which shows the magnitude of the echo signal to the radar. On electromagnetic scattering, RCS is defined as following relation [2]:

$$\sigma = \frac{power\ reflected\ toward\ source / unit\ solid\ angle}{incident\ power\ density / 4\pi} = 4\pi R^2 \left| \frac{E_r}{E_i} \right|^2 \qquad (1)$$

where $R$ is the range to the target, $E_r$ and $E_i$ is the electric field strength of echo signal back at the radar and incident on target, respectively. In this section, we concentrated on RCS of the simple configurations such as sphere and square flat plate. These simple configurations are chosen because their mathematical relations and measured results for RCS are existed in literature. It should be emphasized that for calculating the RCS of these simple targets, only one method for each full-wave softwares is selected in this paper. For instance, the mentioned objects have been simulated in HFSS by FEM method because this software is mostly well-known with this method. For FEKO and CST softwares, MOM and ray-tracing will be used, respectively.

### 3.1 Sphere

Sphere is one of the simple objects which we have chosen to simulate in various softwares and compare their results. RCS of sphere is obtained from following equation [2]:

$$\sigma_{sphere} = \pi a^2 \qquad (2)$$

where $a$ is radius of sphere. This relation is valid for optic region ($\frac{2\pi a}{\lambda} \gg 1$). It should be emphasized that the RCS of sphere is independent of wave polarization. The sphere with radius 5cm ( $a = 15cm$ ) is simulated in HFSS, CST and FEKO commercial softwares at frequency 10 GHz (X - Band) with normal incident wave, as illustrated in Figure 1. This frequency have been chosen because aircrafts works at X – Band frequencies. The sphere is supposed to be perfect electric conductor (PEC) in simulations for decreasing the meshes. As seen in Figure 1, it is not required to define a radiation boundary condition for simulated sphere in FEKO unlike HFSS and CST softwares.

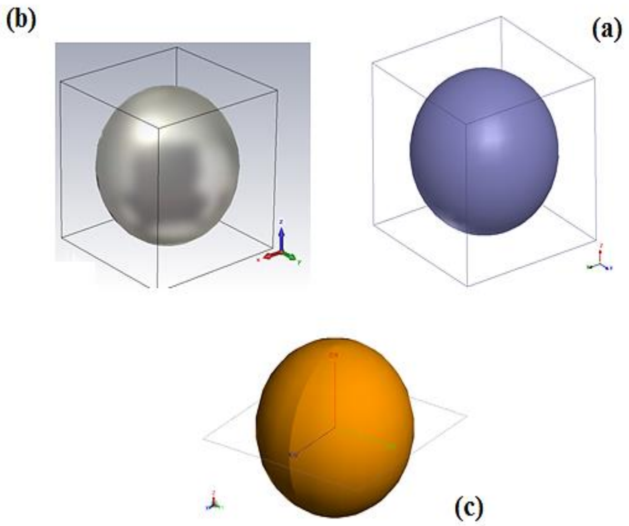


**Figure1:** Simulated spheres in various softwares: (a) HFSS, (b) CST, (c) FEKO

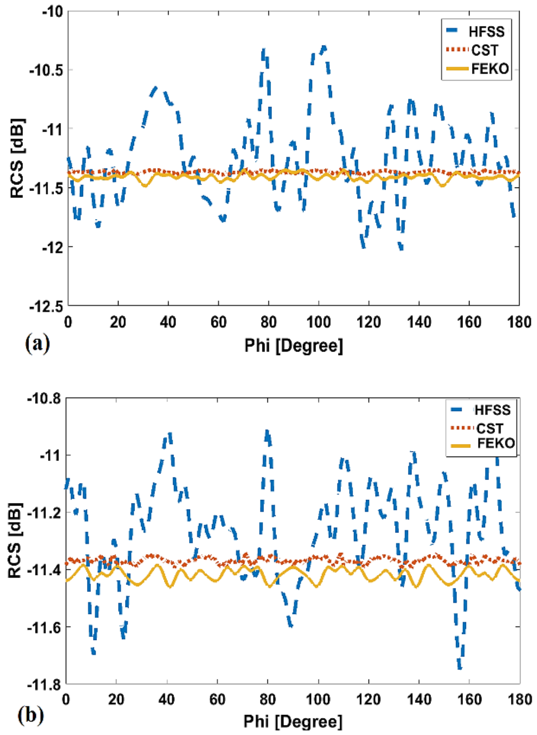


**Figure 2:** RCS simulation results of three commercial softwares for the sphere with radius of 15 cm for an incident wave at frequency 10 GHz (X - Band) with: (a) Horizontal polarization, (b) Vertical polarization

In Figure 2, the simulation results for the sphere with radius 15 cm is demonstrated for both horizontal and vertical polarizations in three commercial softwares. These results confirm that the RCS of sphere is independent of polarization. Also, the FEKO and CST results have good agreement but there is oscillation in HFSS results. One of the advantages of simulation softwares is their ability to display the distribution of surface currents. However, in Ray-Tracing method which have been used in CST, the hotspot of RCS in two dimensions can be represented instead of surface current distribution. Figure 3 shows the distribution of surface current on sphere in HFSS and FEKO softwares and two dimensions hotspot for sphere in CST software. One can see that obtained current distributions on the surface of sphere in FEKO and HFSS are similar. It is obvious that the maximum amplitude of surface currents is concentrated in small circle region where is perpendicular to wave propagating direction, as depicted in Figure 2(c).

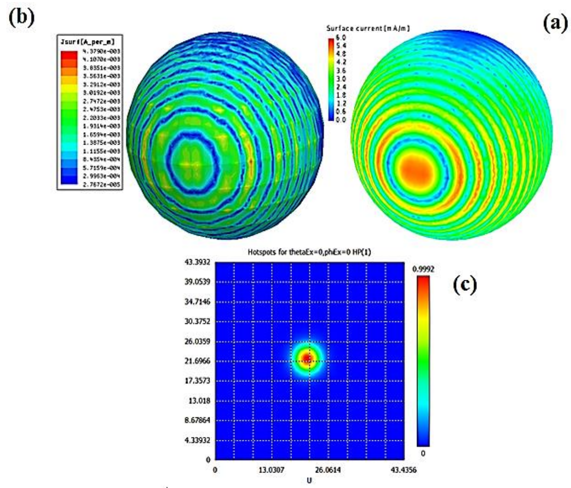


**Figure 3:** (a) and (b): Distribution of surface currents on the sphere with radius of 15 cm for an incident wave at frequency 10 GHz (X - Band) in FEKO and HFSS softwares, respectively,
(c) Calculated hotspot in two dimensions in CST commercial software.

Table. 1 summarizes the various parameters of simulated sphere target in three softwares. This table indicates that CST is faster than other softwares for calculating the RCS of this target. Also, CST is superior over two other softwares in memory consumption (2 GB) but it should be emphasized that Ray-tracing is accurate for only large PEC objects.

**Table 1**: Comparison of various parameters for simulated sphere with radius of 15 cm at 10 GHz frequency (X- Band) in three full-wave commercial softwares (CST, FEKO and HFSS)

| SOFTWARES | METHOD | RUN TIME | MEMORY [GB] | ACCURAY |
|---|---|---|---|---|
| CST | Ray-Tracing | 15 seconds | 2 | high |
| FEKO | MOM | 11 minutes and 50 seconds | 6 | high |
| HFSS | FEM | 15 minutes and 24 seconds | 10 | low |

### 3.2 Square flat plate

Flat plate is one of the simple targets which the RCS of square flat plate with the length of $a$ in optics region can be expressed as [2]:

$$\sigma_{square\ flat\ plate} = \frac{4\pi a^2}{\lambda^2} \tag{3}$$

In [2], RCS of a square flat plate with length $a = 30\,cm$ at frequency 10 GHz (X - Band) have been measured and calculated 113 $m^2$ when viewed normal to the surface. The square flat plate with length $a = 30\,cm$ at frequency 10 GHz (X - Band) have been stimulated in CST, HFSS and FEKO softwares and the results are demonstrated in Figure 4. The plate is supposed PEC for simplicity. Figure 4 indicates that the RCS result depends on polarization of incident wave especially at $\theta = 90^0$, as expected. Therefore, the RCS results of CST is not acceptable at $\theta = 90^0$. By comparing the Figure 2 and Figure 4, it is concluded that the RCS simulation results for the square flat plate have better agreement with each other than the similar results for sphere.

Figure 5 illustrates the distribution of surface current on the square flat plate in HFSS and FEKO softwares and two dimensions hotspot for the plate in CST software at $\theta = 0$. As mentioned before, in Ray-Tracing method which have been used in CST, the hotspot of RCS in two dimensions can be represented instead of surface current distribution. One can see that surface current distribution on sphere surface obtained in FEKO and HFSS are similar. It is obvious that the whole surface of the plate has main role in RCS. Therefore, the maximum strength of RCS occurs at normal incidence. It is concluded that the best software for simulating the simple targets especially large PEC objects is CST for optic region. HFSS and FEKO are suitable softwares for calculating the RCS of small and medium targets with various materials like dielectrics.

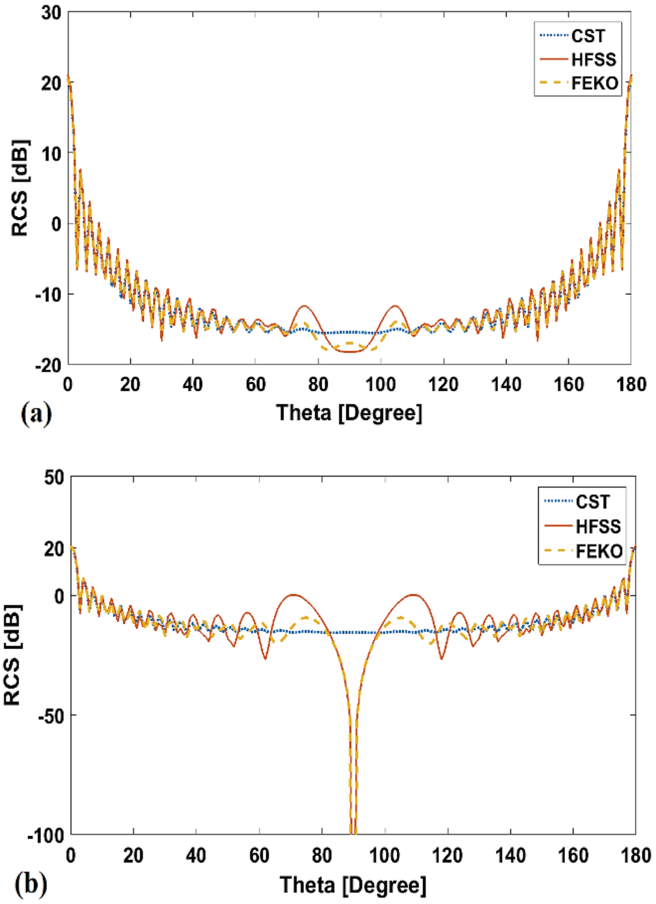


**Figure 4:** RCS simulation results of three commercial softwares for the square flat plate with length $a = 30\,cm$ for an incident wave at frequency 10 GHz (X - Band) with: (a) Horizontal polarization, (b) Vertical polarization

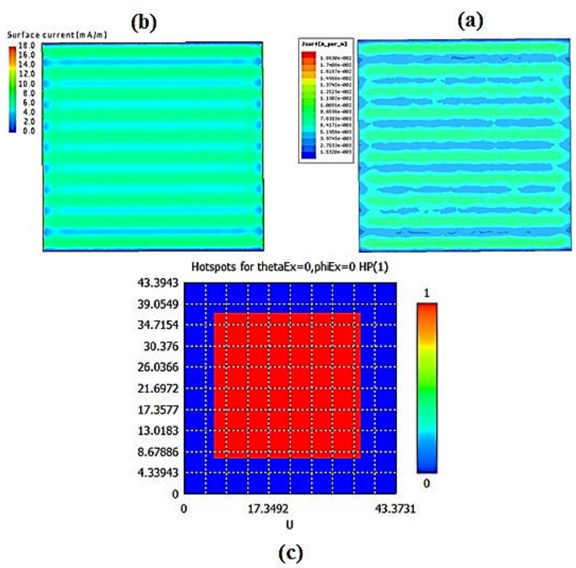


**Figure 5:** (a) and (b): Distribution of surface currents on the square flat plate with length $a = 30\,cm$ for an incident wave at frequency 10 GHz (X - Band) in FEKO and HFSS softwares, respectively,
(c) Calculated hotspot in two dimensions in CST commercial software.

## Conclusion

In this paper, we introduced several full-wave simulation Softwares for computing radar cross section (RCS) of various targets. The RCS of the sphere with radius of $a = 15\,cm$ and the square flat plate with length of $a = 30\,cm$ at frequency 10 GHz (X band) are computed and compared in three commercial Softwares: HFSS, CST and FEKO. These simple objects are chosen for this comparison because the analytical relations and measured results for RCS were existed in literature. The computed results are compared and discussed in terms of memory requirements, calculation time and accuracy. Finally it was concluded that the best software for simulating the simple targets especially large PEC objects is CST for optic region and HFSS and FEKO are suitable softwares for calculating the RCS of small and medium targets with various materials like dielectrics.

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