Detecting Aircraft Shape via SAR

Synthetic Aperture Radar (SAR) is a technique which uses signal processing to improve the resolution beyond the limitation of physical antenna aperture. In SAR, a physical movement of the actual antenna is used to synthesize electrically large antenna aperture.

A large number of measurements is performed along a certain aperture to obtain SAR image. The size of the aperture sets the size of the synthetic antenna. The larger synthetic antenna is, the higher angular resolution is obtained. On the other hand, high range resolution is achieved by working with wideband signals. Therefore, when performing EM SAR simulation, calculations must be performed on multiple frequencies using huge number of excitations.

Due to the electrical size of radar targets, its scattering analysis is usually performed by using asymptotic methods. Applicability of these techniques in SAR systems is restricted by their limited accuracy, and the fact that simulation time linearly increases by increasing the number of transceiver positions.

Full-wave methods are generally highly accurate, but they are time consuming and require significant computational resources. In order to reduce these requirements, WIPL-D uses special techniques, such as quadrilateral mesh, instead of triangular one, empowered with higher order basis functions (HOBFs). For efficient solution of a large number of excitations, direct LU decomposition is used. Simulation time is further reduced by using parallel execution of the code on both, central processing units (CPUs) and graphical processing units (GPUs).

Examples

A sketch of the measurement scenario considered in this example is shown in Fig.1.

An electromagnetic plane wave propagates from the antenna to each of the points located in the scattering area under the investigation. The scatterer distributes the impinging electromagnetic wave to all directions; a small portion of the signal is reflected back and received by the antenna. Instead of a real antenna model, uniform plane wave can be used as an excitation.

It can be shown that the required resolution (the pixel size of this algorithm) is related to measurement setup:

$$dx = {}^{c}/_{(2 \cdot BW \cdot cos\theta)}$$
$$dy = {}^{\lambda}/_{(2 \cdot \Delta\Phi \cdot cos\theta)} \qquad (1)$$

where c is the speed of light, BW is the signal bandwidth, λ is the operating wavelength, ΔΦ is the size of the synthetic aperture and θ is the elevation angle. The length and width of the investigated area are set by the number of frequencies\aspect angles times the related pixel size.

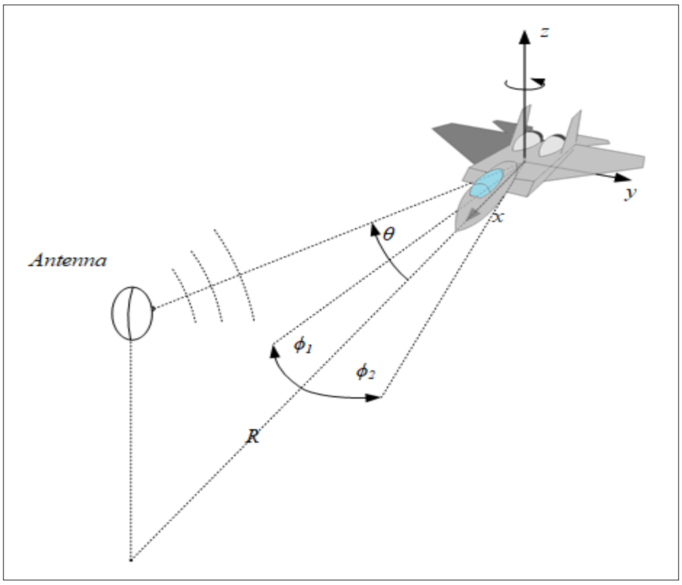

Figure 1. SAR measurement scenario.

For the SAR image calculation of a 12 m long and 8.05 m wing span fighter's aircraft, shown in Fig. 2, monostatic RCS simulation is performed in 76 equidistant frequency points, from 2 to 3 GHz, and 225 directions for each frequency. The central frequency of 2.5 GHz, with a signal bandwidth of 1 GHz and the angular aperture set to φ=16° yields to resolution lower than 0.2 m. Elevation angle is set to 20°.

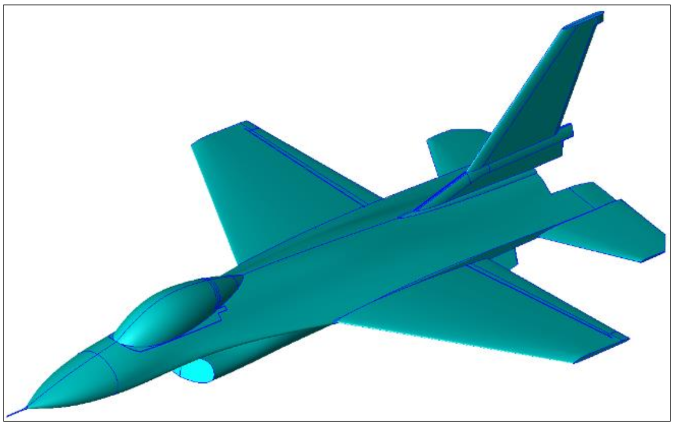

Figure 2. Model of the analyzed fighter aircraft shown in WIPL-D Pro CAD.

In order to reduce number of unknown coefficients and decrease the simulation time, two reduction techniques are applied:

- Because the model is geometrically symmetric and the excitation is not, (A)Symmetry is applied to the simulation. It yields to, approximately, four times faster simulation. The drawback is that each frequency point requires two runs (with PEC and PMC plane).

- The referent frequency is equal to the operating frequency for each frequency point. This way, the simulation time is significantly reduced, as number of unknowns vary between 77,196 at 2 GHz and 141,820 at frequency of 3 GHz.

The simulation is challenging because of the required large number of frequency points and large number of incoming monostatic RCS directions per frequency.

Comparison of the calculated SAR image and geometry of the aircraft is shown in the Figure 3. As it can be seen, there is a very good correlation between the aircraft geometry and its SAR image.

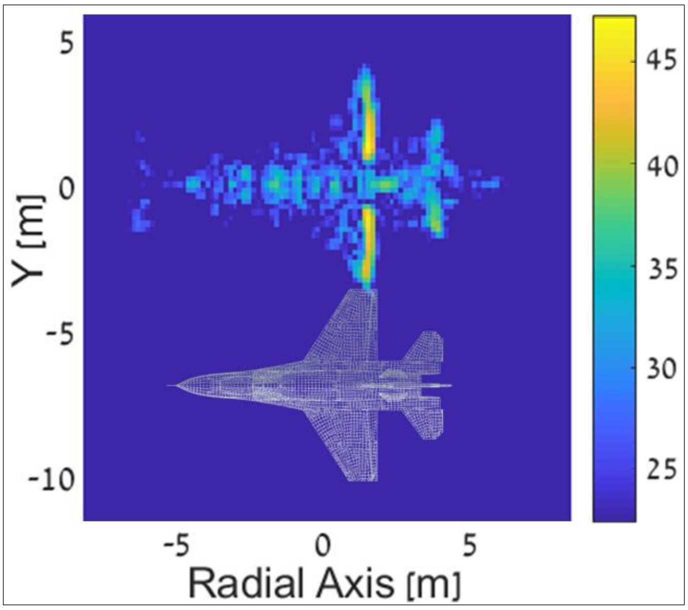

Figure 3. SAR image of the aircraft model.

Configuration of the computer used in this example is:

Intel Xeon CPU E5-2660 v2 @2.2 GHz (2 processors), 256 GB of RAM, 7 hard-disk drives with I/O speed around 100 MB/s, 4 GPUs GTX 1080 Ti, Windows 10 Professional 64-bit. The matrix fill in is done by CPU, while the matrix inversion phase is speeded up by using GPU.

The simulation details are listed in Table 1.

Table 1. Simulation details.

Number of Frequency Points	Number of monostatic RCS directions per Frequency	Simulation Time
76	225	47 h 41 min

Conclusion

The simulated SAR image is in good agreement with actual shape of the target. The fact that the required simulation time is relatively small, indicates that WIPL-D is very suitable for the very efficient analysis of SAR systems.

Monostatic RCS simulation of a 12 m long fighter aircraft needed for construction of SAR image with resolution below 0.2 m and central operating frequency 2.5 GHz is performed on a GPU based workstation in approximately 2 days.