Monostatic, Bistatic, and Multistatic Radar Scenarios

Part 1: Monostatic and Bistatic Scenarios - Basics

Monostatic, bistatic, and multistatic radar scenarios are frequently addressed in radar related literature. Although a radar is an important part of many military and civil systems, some details related to the three scenarios are sometimes not clearly understood. This application note has been motivated by an intention to clarify some details and therefore help a wide circle of readers to understand a basic concept of monostatic and bistatic radar. The examples used throughout the text come from analyzing real life problems and can be found useful when investigating similar scenarios. The scenarios have been analyzed using **WIPL-D Pro CAD, a full wave 3D electromagnetic (EM) Method-of-Moments (MoM) based software and DDS, a WIPL-D Company product intended for solving very large EM structures**.

Although many relevant details are included in the representative examples presented here, some radar-related particularities insignificant from the perspective of scattering will not be considered here (e. g. the influence of atmospheric conditions, signal attenuation due to propagation, signal coding and digital signal processing or time domain analysis). The document will also explain setting up the analysis of monostatic and bistatic operation modes in WIPL-D.

In all of the examples transmitted EM wave will be marked with blue arrow, while EM wave scattered from the aircraft will be marked with red arrow.

To grasp basics of monostatic and bistatic scattering only Part 1, including Figure 1 and Figure 2, should suffice. Part 2 presents examples which can be found in the real-life and which are backed up with simulation results. The principles outlined in this application note apply directly to radars and EM propagation in air space, but **can be also useful for understanding acoustic underwater sonar operations.**

All systems and frequencies presented used here are for demonstration purposes, only. The dimensions of radar targets and other structures are approximate but comparable to real life devices.

Monostatic Radar Scenario

A monostatic radar represents the radar where the transmitter and the receiver are located at the same location. Usually, the same antenna or array is used for both, transmitting and receiving. The simplest and most illustrative example of a model of a *monostatic* scenario taken from WIPL-D environment is shown in Figure 1. It represents a ground-based radar emitting the signal (EM wave) which is scattered from an aircraft within the radar range. The signal scattered from the aircraft is then received with the same ground-based radar.

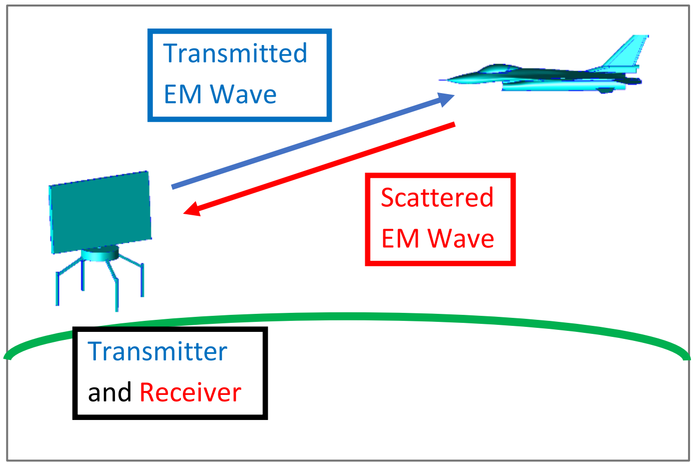

Figure 1. Monostatic scattering scenario. Not to scale.

Bistatic Radar Scenario

Bistatic radar represents a radar in which the transmitter and the receiver are placed at "reasonably" separated locations. Scenario shown in Figure 2 demonstrates the radar transmitting the EM wave, which is being scattered form the aircraft and subsequently received at a remote location. The particular scenario from Figure 2 can alternatively be named as *bistatic forward scattering*, or simply *bistatic scattering*.

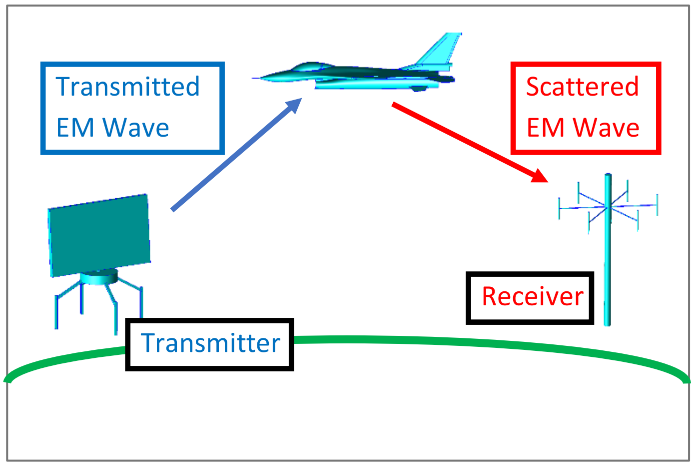

Figure 2. Bistatic scattering scenario. Not to scale.

Monostatic, Bistatic, and Multistatic Radar Scenarios

Part 2: Examples

Monostatic Radar Scenarios

Scenario shown in Figure 3 combines situation outlined in Figure 1 with some numerical results obtained using WIPL-D Software simulations. Beside the radar and the aircraft, Figure 3 presents a radiation pattern of the ground-based radar. The pattern has been included in a simulation scenario by manually creating a theoretically expected pattern. Calculated monostatic scattering result of simulated aircraft at 1.3 GHz is also included at the figure. This particular frequency band around 1.3 GHz is typically used for long-range air traffic control. In WIPL-D environment monostatic scattering results can be obtained with *Operation Mode* set to *monostatic RCS*. EM wave excitation should be defined, and the directions in which RCS results will be calculated specified. In WIPL-D environment field generators can be used as excitation in RCS simulation, which is very suitable for mimicking measurement setups.

In WIPL-D, scattering and radiation pattern are by default calculated with respect to the coordinate origin. Angle θ=0 relates to the horizon. It should be noticed that for airborne aircrafts, local theta angles around -1 degrees are significant for this sort of scenarios due to radar location and usual aircraft altitudes. In that sense, aircraft shown in Figure 3 was simulated in 1801 points for theta angle span between 180 degrees and 270 degrees (see Figure 3).

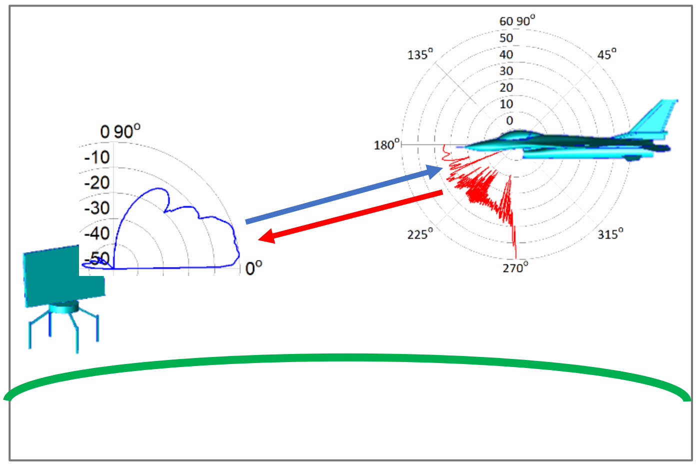

Figure 3. Monostatic scenario with ground-based radar, antenna radiation pattern, aircraft, and aircraft monostatic scattering. Not to scale.

An additional monostatic scenario is presented in Figure 4. It encompasses a bird's view of a combat scenario in which the monostatic radar is used. In this particular scenario a rocket launched toward the aircraft is equipped with a monostatic radar operating at 10 GHz, being a part of a rocket tracking system. This kind of a monostatic system and its operation are usually referred as *Active radar homing*. The transmitter and the receiver operate at the same location - the monostatic radar is located inside the rocket nose.

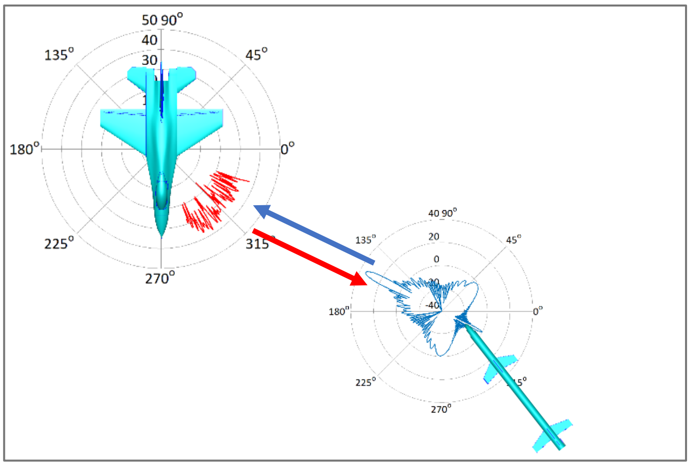

Figure 4. An example of monostatic scattering scenario. Target illuminator radar in the missile operates in *Active radar homing* regime. This regime is usually active during terminal phase of rocket flight. An aircraft with monostatic scattering at 10 GHz and the rocket with antenna radiation pattern are displayed. Not to scale.

The next scenario (Figure 5) represents two ground-based radars, in monostatic regime operating separately. This scenario can represent a ground-based radar network operating with broken communication links between radars. The monostatic RCS from aircraft is calculated for θ angle of -2 degrees.

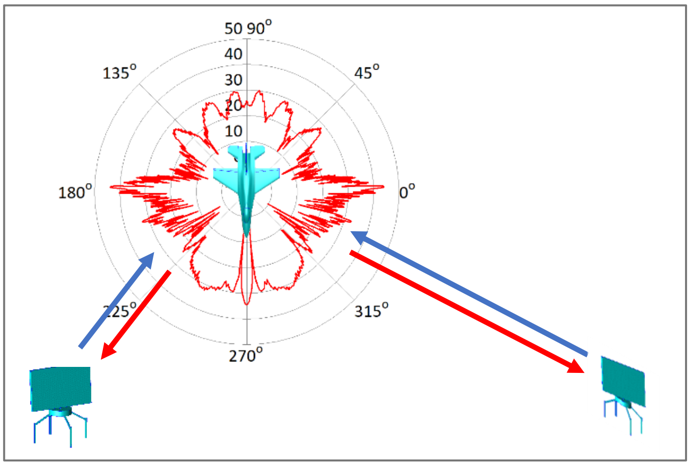

Figure 5. An example of monostatic scattering scenario. Two ground-based radars working separately in monostatic regime and an aircraft, with monostatic RCS. Not to scale.

Bistatic Radar Scenarios

An example of bistatic radar scenario which expands the basic idea presented earlier in Figure 2 is shown in Figure 6. In this case, the receiver and the transmitter are separated and the aircraft is simulated using WIPL-D environment by choosing the option *Operation Mode\bistatic RCS*. It should be noticed that, in general, a bistatic scattering is calculated faster than monostatic scattering. It should be also noticed that the case of a *pseudo-monostatic scenario* where the transmitting and receiving antennas are separated, but remain at a close distance should also be approached as a bistatic case.

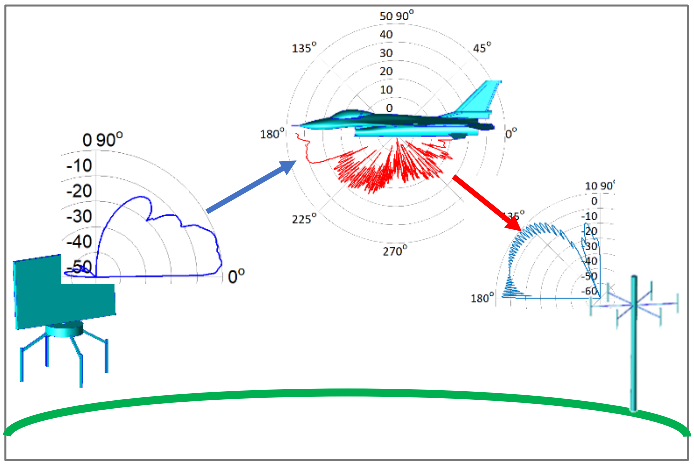

Figure 6. Bistatic radar scenario with transmitter antenna, an aircraft, and with a receiving antenna. Not to scale.

The scenario shown in Figure 6 clearly outlines following general specifications of a bistatic radar system. First of all, it enables covert operation of the receiver which is very suitable for military operations especially if the receiver is highly mobile (e.g., attached to a vehicle). Furthermore, there are also possible enhanced RCS values of the target to be exploited comparing to the monostatic case due to geometrical effects on the target (the scatterer).

There are many air-to-air and surface-to-air missile systems which use a form of bistatic radar named *Semi-active radar homing* illustrated in Figure 7. It consists of two aircrafts and a rocket launched from one of the aircrafts towards another. It can be seen that one aircraft (aircraft #1) illuminates the second aircraft (aircraft #2) while the rocket receives scattered EM wave using it for homing on target.

The detailed analysis of scenario shown in Figure 7 supports optimal distribution of weight and power consumption between an aircraft and a rocket. A receiver, being a light and low power electronic device, is favorably located inside a rocket, while weighty and power intensive transmitter remains on a more robust aircraft platform.

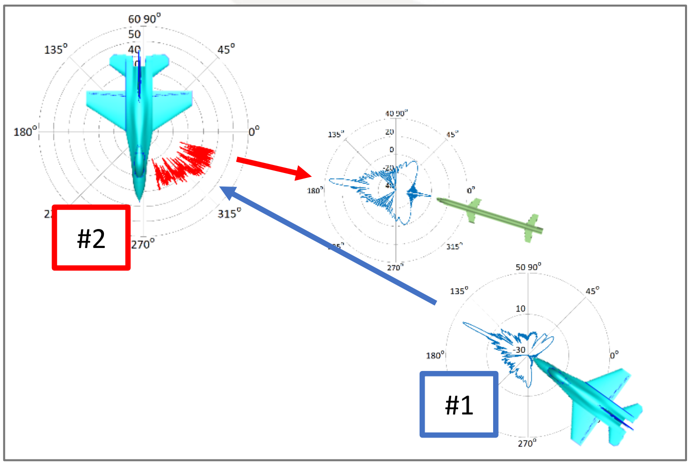

Figure 7. An example of bistatic scattering scenario. Seeker in a missile operates in passive radar homing regime when radar based on attacking aircraft illuminates the target. The rocket is equipped with receiver without transmitter. Not to scale.

Multistatic Radar Scenario

Basic bistatic and monostatic radar systems of the past do not exploit enough today's available technology. In general, there are some drawbacks related to simple monostatic and bistatic operation that should be overcome. For example, a fault in either transmitter or receiver in a monostatic or in a bistatic radar system will produce complete failure of the radar. Also, a single high-power transmitter is easier to locate, jam or destroy.

On the other hand, it is difficult to successfully locate, jam or destroy a network of multiple transmitters and multiple receivers. It is certainly more desirable to operate a system with higher redundancy where possible failures of one component will not significantly degrade the whole system. This requires spatially distributed radar devices. Such spatial diversity is achieved in *multistatic* radar systems and allows different aspects of a target to be viewed simultaneously. For example, a multistatic system can process two signals scattered from a target in two directions. Perhaps the most important fact is that such a system can deal with stealth objects much more effectively than single monostatic or bistatic systems. Such system also has increased robustness to electronic countermeasures.

Multistatic radar system, although much more effective in operation comparing to monostatic and bistatic systems, has some drawbacks. For example, it requires persistence of network between system components used for data interchanging and data fusion. Also, it requires almost perfect temporal synchronization. Finally, the system complexity is generally high and it is harder to be deployed.

An example of multistatic radar system with an example of network with data links is displayed in Figure 8. This multistatic radar contains of two spatially separated monostatic radars and four receivers used similar as in bistatic radar configuration. It should be highlighted that scattered signals presented in Figure 8 can originate from both radar transmitters.

An additional example of multistatic radar system will be only mentioned, here. This is a type of passive radar which exploits the transmitters of opportunity. For example, reflected signals coming from various civil applications can be received and processed to create a passive radar image of the environment.

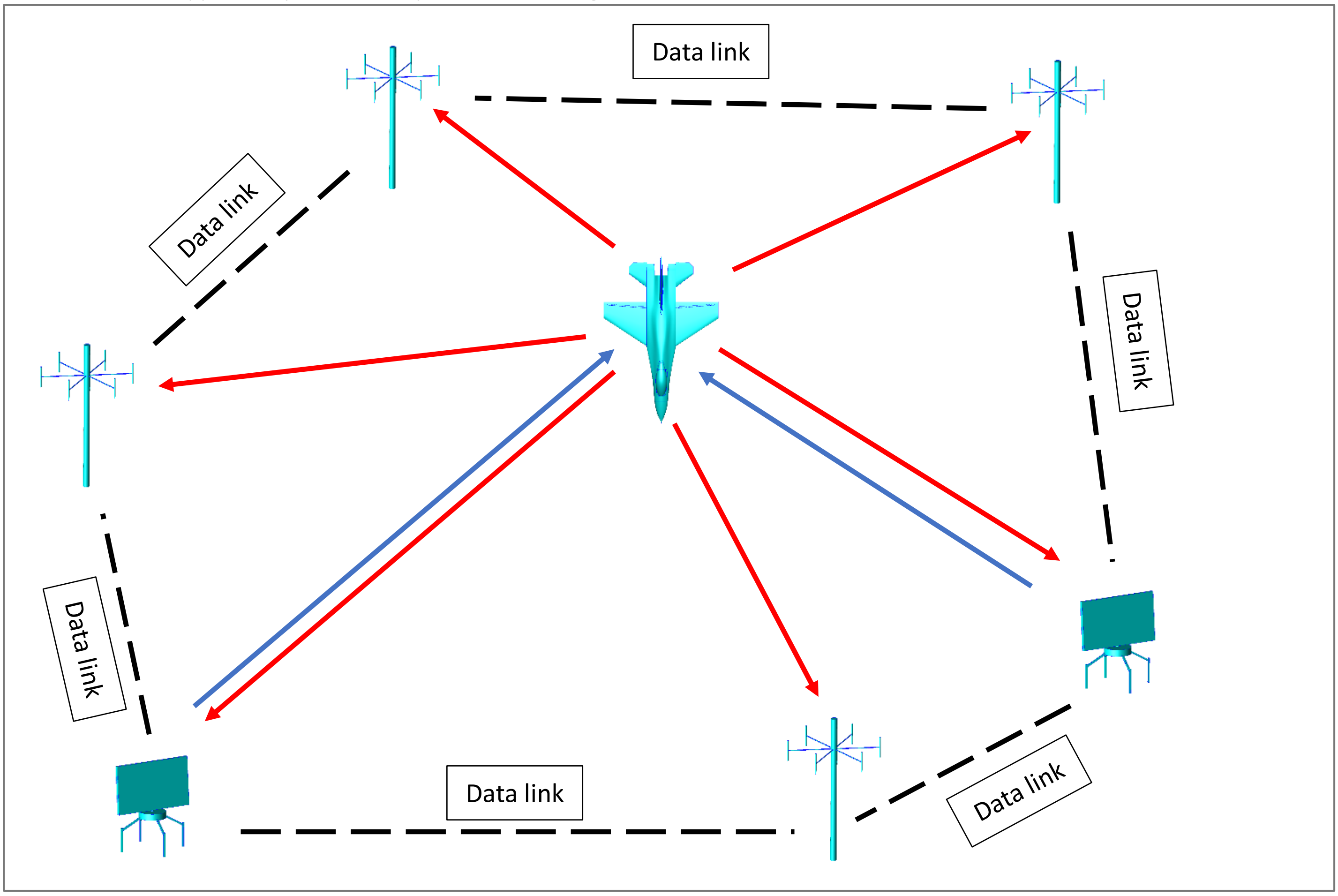

Figure 8. An example of multistatic radar system with an example of data link network. The scattered signals can originate from both radars (transmitters). Not to scale.

Simulations

All the simulations performed here are completed on the workstation presented in Table 1.

Table 1. Workstation used for the simulations

Hardware	Description
Processor	Intel® Xeon® Gold 6248R CPU @ 3.00GHz 3.00 GHz (2 processors)
RAM	768 GB
GPU	2 GPU cards: GeForce RTX 3080

The number of elements, number of unknowns, and total simulation time required for the simulations presented here are given in Table 2. Simulation data for aircraft scattering shown in Figure 3 is similar to simulation data for aircraft scattering shown in Figure 5. Simulations at 1.3 GHz are performed using WIPL-D Pro CAD, while the simulations at 10 GHz are performed using DDS. Maximum number of directions is defined for models simulated in monostatic operating mode at 1.3 GHz and it is equal to 3,601.

Table 2. Number of elements, number of unknowns, and total simulation time

Model	Number of elements	Number of unknowns	Simulation time
Monostatic RCS at 1.3 GHz (aircraft scattering in Figure 3)	5,929	159,832	21 [min]
Bistatic RCS at 1.3 GHz (aircraft scattering in Figure 6)	5,929	159,832	19 [min]
Monostatic RCS at 10 GHz (aircraft scattering in Figure 4)	91,980	2,614,870	~ 25 [hours]; DDS Simulation
Bistatic RCS at 10 GHz (aircraft #2 scattering in Figure 7)	91,980	2,614,870	~12.5 [hours]; DDS Simulation

Conclusion

The motivation behind this application note is to help various readers to understand basic concept of monostatic and bistatic radar scenarios. Examples explaining realistic monostatic, bistatic, and multistatic scattering scenarios are provided. The explanations were supported with WIPL-D Pro CAD, a full wave 3D electromagnetic (EM) Method-of-Moments (MoM) based software and DDS, a WIPL-D Company product for solving very large EM structures.

Very basic explanations of monostatic and bistatic scattering were presented in Part 1 of this document. Part 2 contains some advanced examples which can be recognized in some of real-life scenarios. Majority of presented scenarios are supported with results from the simulations, which is very useful for illustrating radar systems operations. The basic principles outlined here relate to radars and EM propagation. Similar principles can be applied with scenarios related to acoustic underwater sonar operation.