Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

7th International Conference
on Electrical Engineering
ICEENG 2010

RCS REDUCTION USING ARRAYS OF PATCHES

By

W. M. Mahfouz* A. M. Ghuniem **

Abstract:

The radar echo characteristics of inanimate objects are given by the radar cross section (RCS) of the object. The RCS is proportional to the ratio of the scattered power density at the receiver to the incident power density at the target. Echo reduction and its effects are often the important concern of modern radar designers. There are different types employed to reduce the RCS, Shaping, radar absorbing material (RAM), passive cancellation, active cancellation, and plasma field[1]. Cancellation methods require loading the object with discrete antenna like elements (slots, dipoles or patches) whose impedance must be chosen so as to cancel the returns from other parts of the body. In this paper a cancellation technique is used to reduce RCS of a metallic object by using array of microstrip patches designed at required frequency and distributed on the surface of plate with different structures. The best structure of array of patches, which gives minimum RCS independent of the polarization, is selected. The effects of height of substrate, dielectric constant of substrate, the spaces between patches, and structure size on RCS reduction are discussed. Computer simulations with ZELAND package and measurements were performed to confirm the obtained results.

Keywords:

Radar and microwave

---

* Egyptian Armed Forces
** Suez Canal University

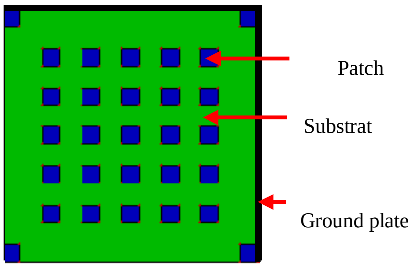
1. Introduction:

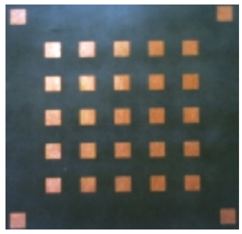
Reduction of RCS shortens the detection range, where RCS is proportional to the power four of the range. There are different types employed to reduce the RCS, Shaping, radar absorbing material (RAM), passive cancellation, active cancellation, and plasma field.
Complex targets like ships and aircraft can be represented as collections of basic geometric elements, such as flat plates, cone frusta, spheroids, edges, vertices, or blended surfaces. As such, we typically isolate the dominant sources of target echo and fix our attention on a limited number of individual elements instead of the composite target.
We emphasize that radar cross section reduction is a study of compromises in which advantages are balanced against disadvantages, and this fact should become apparent. When target surfaces are reshaped or reoriented to achieve the reduction, RCSR at one viewing angle is usually accompanied by an enhancement at another. If radar absorbing materials (RAM) are used, the reduction is obtained by the dissipation of energy within the material, thus leaving the RCS levels relatively unchanged in other directions. On the other hand, the use of RAM is paid for with added weight, volume, and surface maintenance problems. Thus, each approach involves its own form of trade-off. This is another reason why we cannot deal with specific systems: the trade-off cannot be made without information that is not currently available.
The object of shaping is to orient the target surfaces and edges to deflect the scattered energy in a direction away from the radar, applied for the targets much greater in size than the wave length, expensive. The success of shaping depends on the existence of angular sectors over which low RCS is less important than over others.
Radar absorbing materials reduce the energy reflected back to the radar by means of absorption. Radar energy is absorbed through one or more of several loss mechanisms, which may involve the dielectric or magnetic properties of the material. The loss is actually the conversion of radio frequency energy into heat [2]. Its advantages are applied for areas whose shape could not be optimized and wide bandwidth. The most important consideration for RCS reduction is removal of specula return. However, one is often faced with a situation where it is not possible to shape the given structures because of the objective of the mission. In such cases, one usually chooses a RAM coating which has a performance limitation, cost ineffectiveness, and manufacturing difficulties. Further, it is difficult to procure RAM performance in the sense of required bandwidth and angle range. Several works for RAM design have been done [3–5].
Passive cancellation, introduce an echo source whose amplitude and phase can be adjusted to cancel another echo. It is represented by a designed size and shape of an interior cavity on the object which when loaded presents optimum impedance at the aperture. Applied for simple target, inexpensive, limited in application, impedance frequency dependence, and more echoes It has for the most part been discarded as a

useful RCS reduction technique [6].
Active cancellation, the target emits radiation in time coincidence with the incoming pulse whose amplitude and phase cancel the reflected energy [2]. The target must be smart i.e., must sense, angle of arrival, intensity, frequency and waveform. Applied at low frequency, expensive, increase pay load, interference with the target systems.
Plasma field, it is a new method which generates plasma fields from ionized air particles around the aircraft. This field absorbs and scatters the electro magnetic wave which results in reduction of the RCS of the aircraft, it gives a reduction 20 dB. The following topics describe the needs for plasma field generation, needs electro static charge generator of weight 100 Kg, needs antenna mounted on the front and rear of the aircraft, needs a power of 5000 kW supplied from the engine. However, it is weight and pay load. The plasma field decreases the mission effectiveness of the aircraft radar for detection and tracking. The requirements of RCSR conflict with the conventional or traditional requirements for the structures such as, costs, reduced pay load (by added weight), reduced range, and increase maintenance duty. A compromise should be hold to increase the mission effectiveness.
In this paper, a radar cross- section reduction technique is described, which is achieved by using an array of patches, designed at a certain frequency. The array of patches is arranged in different structures on the flat plate. The RCS of the different structures of the array of patches are evaluated and compared with the RCS of flat plate. A discussion of the RCS changes with the height of the substrate, the dielectric constant of substrate, polarization, the size of the patches, and the spaces between patches is explained.

2. Design & Fabrication of a Patch Antenna at f= 9.4 GHz:

Design & Fabrication of a Patch Antenna at f= 9.4 GHz
The width and the extension of the length ΔL of the patch can be determined [7], [8].
For $\varepsilon r = 2.2$, h =0 .787 mm, fr =9.4 GHz, hence,
W = 12.6154 mm
L= 10.30699 mm
Teflon and similar types of soft plastic substrates having dielectric constants ranging from 2 to 10, can provide a large substrate area at a low cost, as long as rigidity. Low dielectric constant is suitable for high frequencies. Therefore, we use a Teflon substrate with dielectric constant 2.2 and height 0.787 mm. Figure (1) shows the designed structure of the array of patches. Figure (2) shows the shape of the fabricated structure of the array of patches.





Figure(1): *The designed structure of the array of patches*

Figure (2):*The Shape of the fabricated Structure of the array of patches*

3. Simulation of Different Arrays of Patches:

This section is devoted to the determination of RCS for different configurations of array of patches using ZELAND package. The structures are shown in table (1).

Table (1): *Different structure of array of patches*

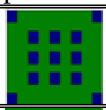
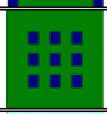
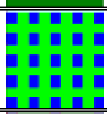
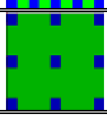
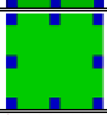
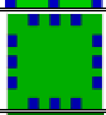
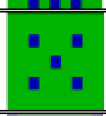
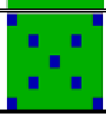
Shape of structure of patches	Name of the structure
	Array of 3×3 patches +corner
	Array of 3×3 patches
	Array of 5×5 patches
	Array of 3×3 patches with large separation
	Array of 3 patches at the edges
	Array of 3 patches around the surface
	Array of 5 patches
	Array of 5 patches + corner

Figure (3) shows the RCS for array of 3×3 patches + corner at different frequencies. It is clear that the minimum RCS holds at the designed frequency (f = 9.4 GHz).

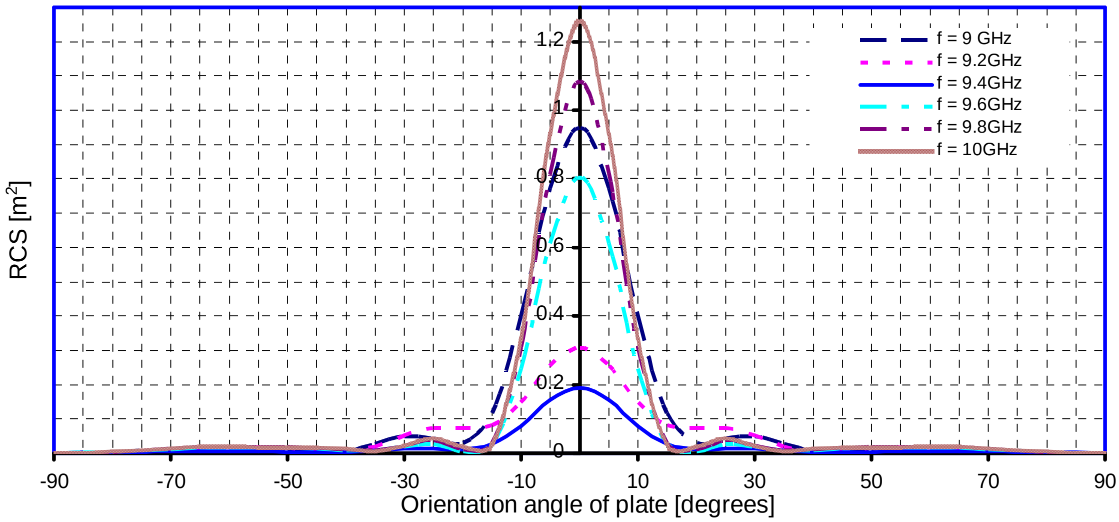


Figure (3): *RCS of array of 3×3 patches + corner at different frequencies*

Figure (4) shows the RCS reduction for array of patches 5×5 compared with the flat plate at (f = 9.4 GHz). The reduction at normal incidence is equal to -1.137 dB. The ratio of the patches area to flat plat area is large, then the reflection from the patches is greater than the reflection from the plate, hence the cancellation is reduced. Consequently, the RCS reduction is reduced.

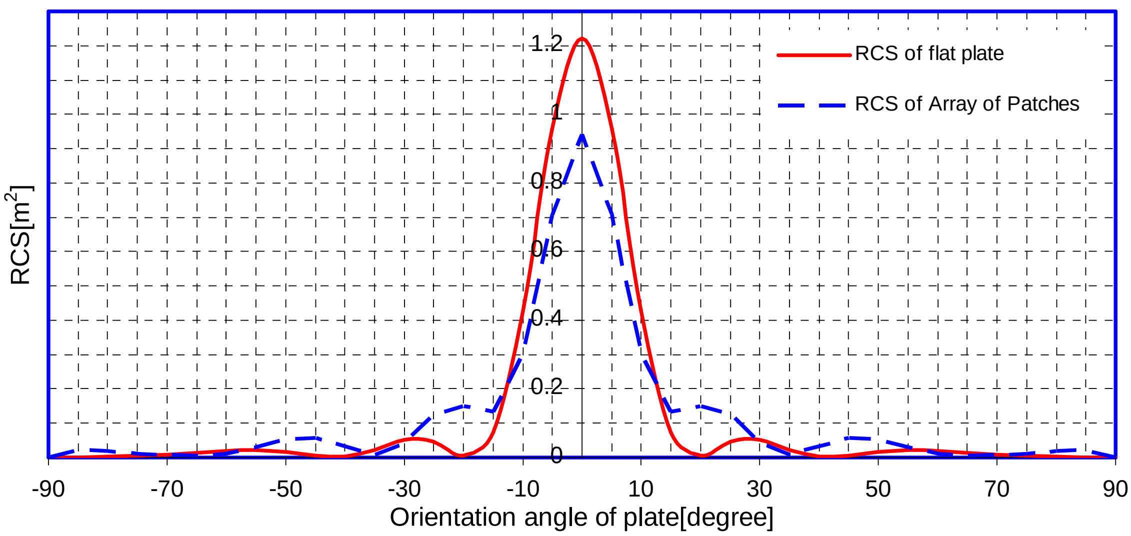


Figure (4): *RCS of array of patches 5×5 compared with RCS of flat plate at (f= 9.4 GHz)*

Figure (5) shows the RCS reduction of array of patches 3×3 with large separation compared with the flat plate at (f=9.4GHz). The reduction at normal incidence is equal to -6.6 dB.

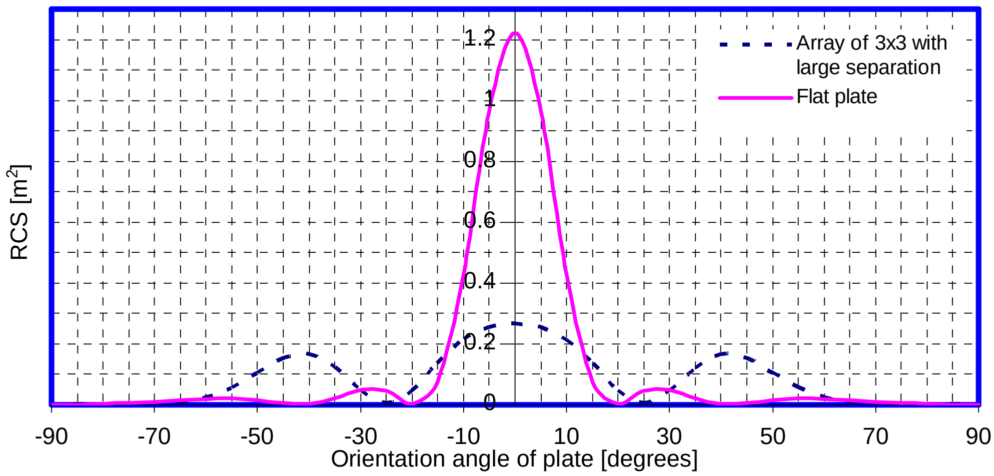


Figure (5): *RCS of array of patches 3×3 with large separation compared with RCS of flat plate at (f=9.4GHz)*

Figure (6) depicts RCS reduction of array of 3 patches at the edges compared with the flat plate at (f=9.4 GHz). The reduction at normal incidence is equal to -8.56 dB. The patches on edges make diffraction, in addition to cancellation.

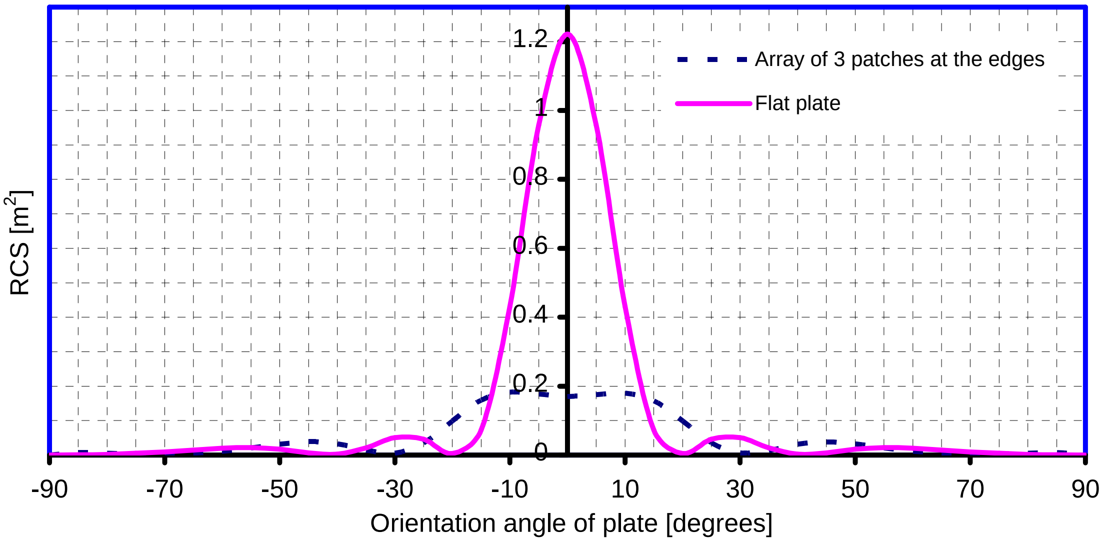


Figure (6): *RCS of array of 3 patches at the edges compared with flat plate at (f=9.4 GHz)*

Figure (7) shows the RCS reduction of array of 3×3 patches compared with the flat plate at (f= 9.4GHz). The reduction at normal incidence is equal to -10dB.

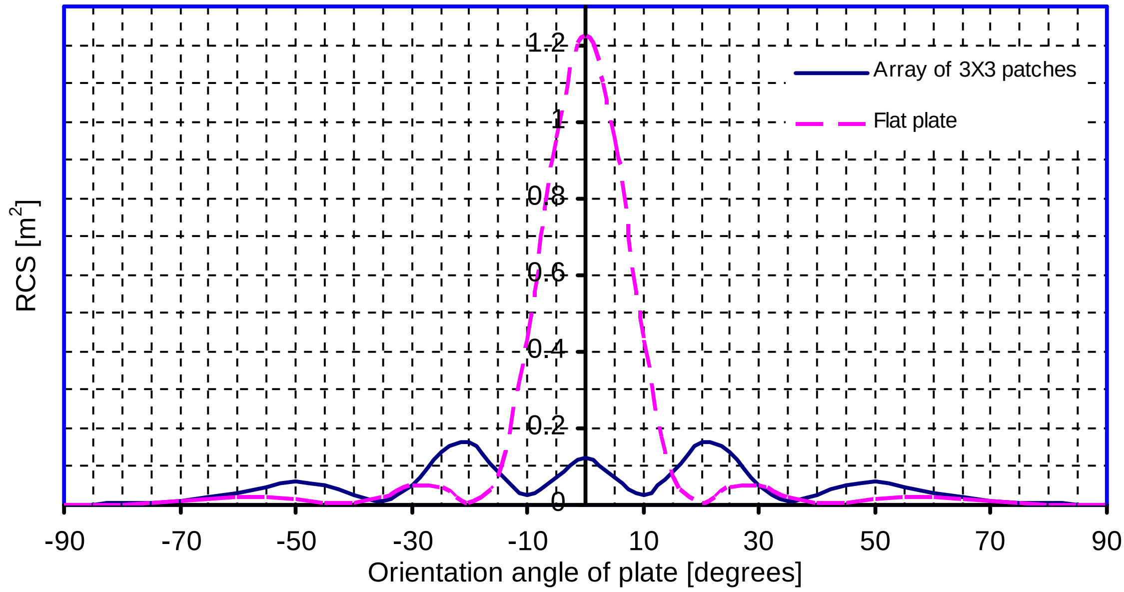


Figure (7): *RCS of array of 3×3 patches compared with flat plate at (f= 9.4GHz)*

Figure (8) illustrates the RCS reduction of array of 3×3 patches + corner compared with the flat plate at (f= 9.4GHz). The reduction at normal incidence is equal to -8.04 dB. Due to the patches in the corners, diffraction may occur in the corners, as well as cancellation, and hence better RCS reduction is obtained.

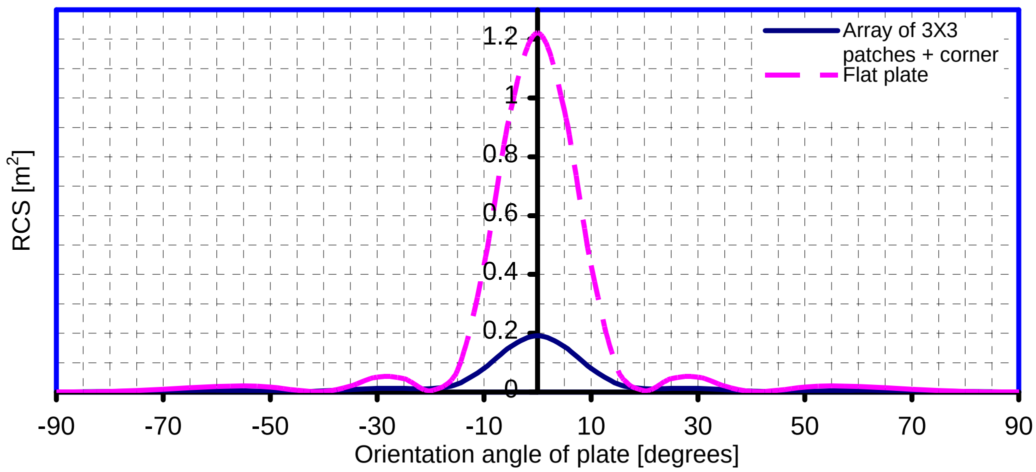


Figure (8): *RCS of array of 3×3 patches + corner compared with flat plate at (f= 9.4GHz)*

Figure (9) shows the RCS reduction of array of 3 patches around the surface compared with the flat plate at (f= 9.4GHz). The reduction at normal incidence is equal to -5.77dB.

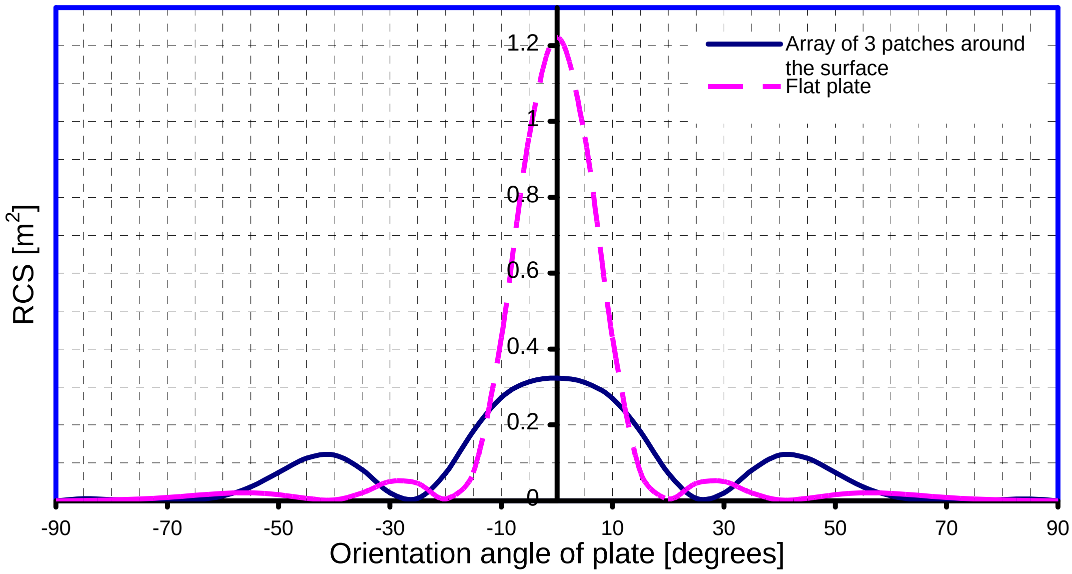


Figure (9): *RCS of array of 3 patches around the surface compared with flat plate at (f=9.4GHz)*

Figure (10) shows the RCS reduction of array of 5 patches compared with the flat plate at (f= 9.4GHz). The reduction at normal incident is equal to -2.44dB. The ratio of the patches area to flat plat area is small, then the reflection from the patches is smaller than the reflection from the plate, hence the cancellation is reduced. Consequently, the RCS reduction is low.

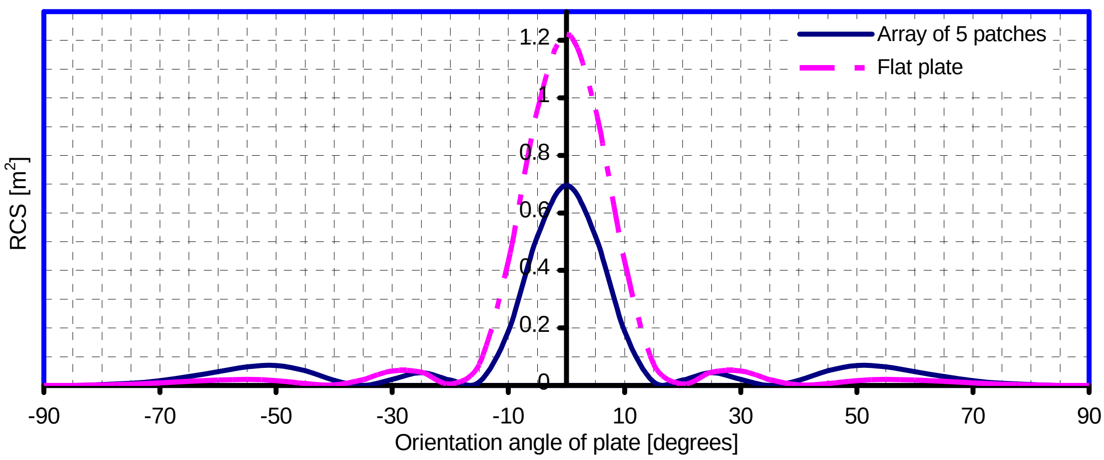


Figure (10): *RCS of array of 5 patches compared with flat plate at (f= 9.4GHz)*

Figure (11) shows the RCS reduction of array of 5 patches + corner compared with the flat plate at (f= 9.4GHz). The reduction at normal incidence is equal to -5dB. Due to the patches in corner, diffraction occurs, and then RCS reduction occurs due to diffraction in addition to cancellation.

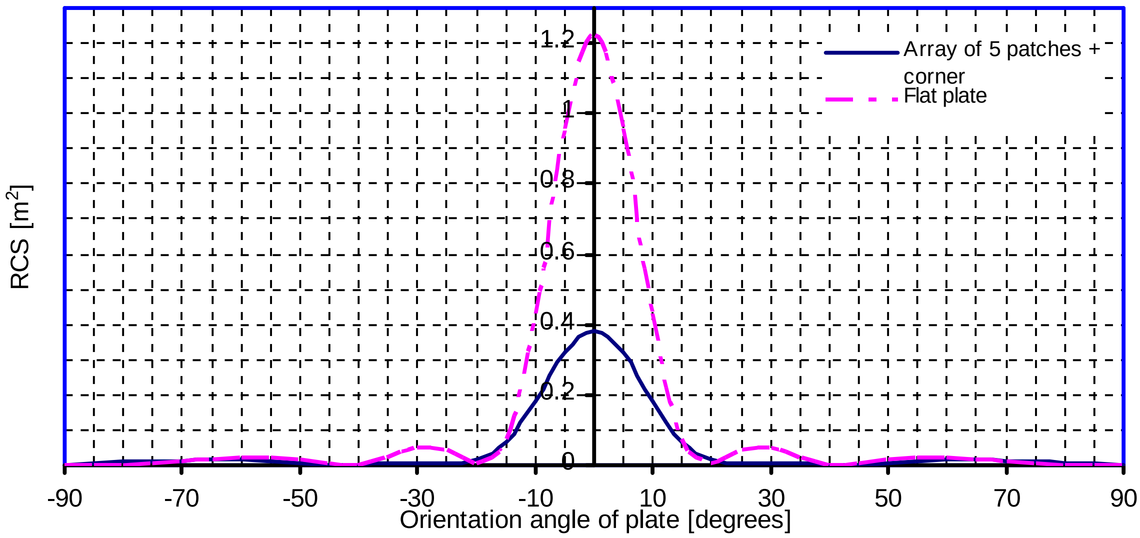


Figure (11): *RCS of array of 5 patches + corner compared with flat plate at (f= 9.4GHz)*

Figure (12) shows RCS for different structures of patches.

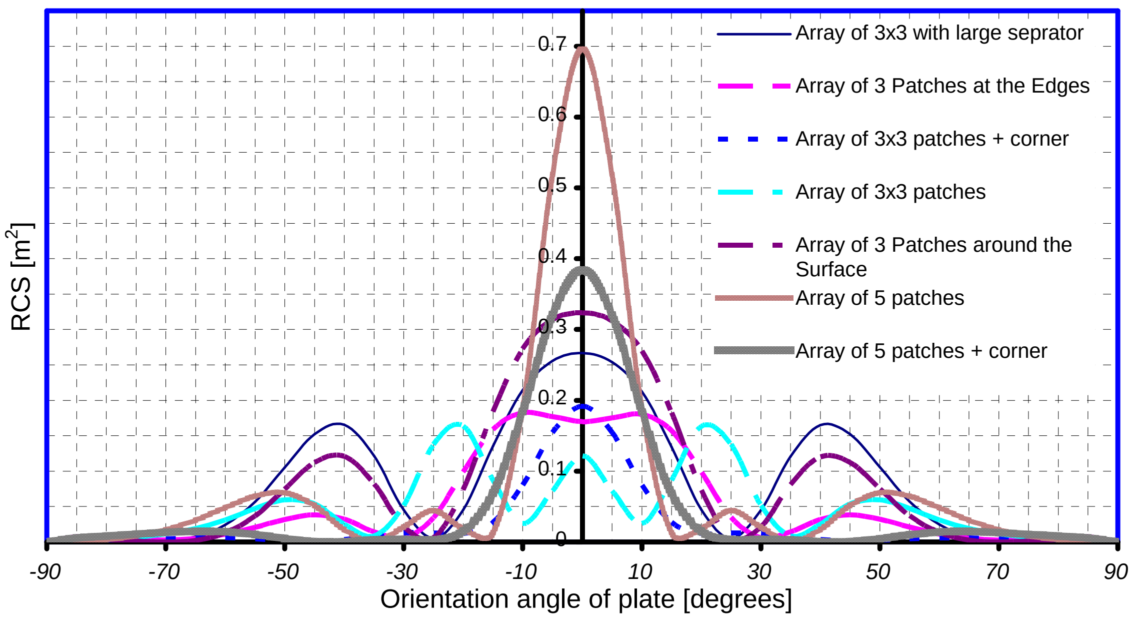


Figure (12): *RCS for different structures of patches*

Although the array of 3X3 patches gives the best result at normal incidence (angle 0), it gives a bad result at angles (22, -22). In addition, the array of 3 patches at the edges gives good results, but the curve of the array is flat over wide range of angles. The structures of array of 3X3 patches centre + corner gives the best results compared with the other structure at angle range (from -25 - 25).

The relation between the covered areas with patches compared to flat plate shows that when the ratio of the patches area to the flat plate area increases the reflection from the patches will be greater than the reflection from the plate and vise versa. Then, we get low cancellation, so that RCS reduction is low. There is an optimum number of patches, which cover optimum area, at which the reflection of ground plane is near to the reflection of the patches. The arrangement of optimum patches can be changed to improve the RCS reduction.

4. Effect of Polarization:

If we change the polarization of incident wave, no reduction occurs; RCS is same as flat plate. Figure (13) indicates the RCS of the flat plate compared with RCS of Co-polarization (horizontal polarization in the direction of the length of the patch (L)) and Cross-polarization.

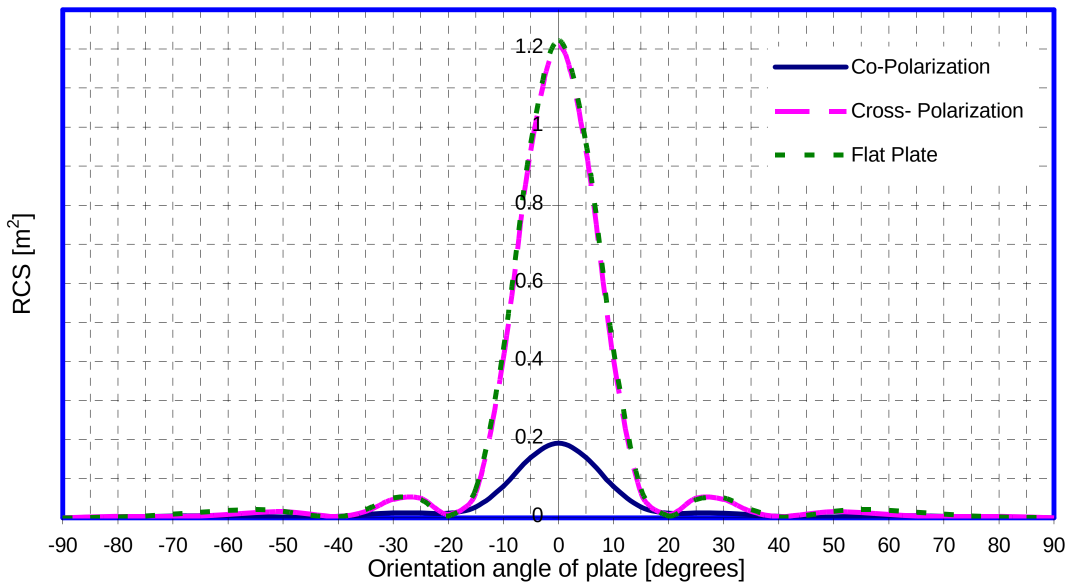


Figure (13): *RCS of array of patches with different polarization compared with flat plate at (f= 9.4 GHz).*

To overcome this problem we will design a square patch with dimension LXL, as shown in Figure (14)

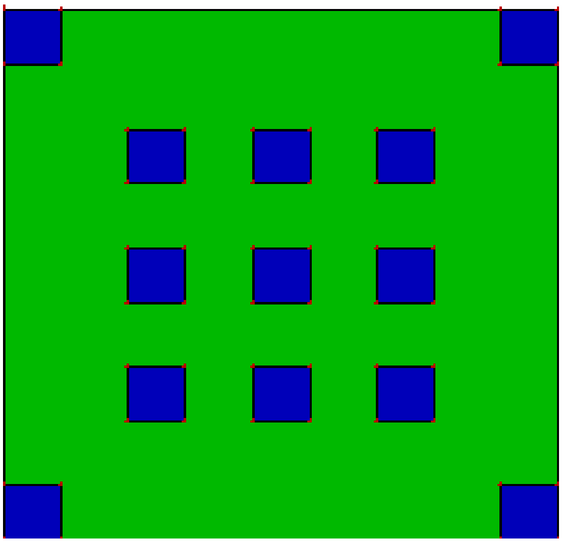


Figure (14): *Array of square patches 3×3 + corner*

Figure (15) indicates the RCS of the array of square patches 3X3 + corner at different frequencies. It is clear that RCS is minimum at frequency 9.4 GHz (design frequency).

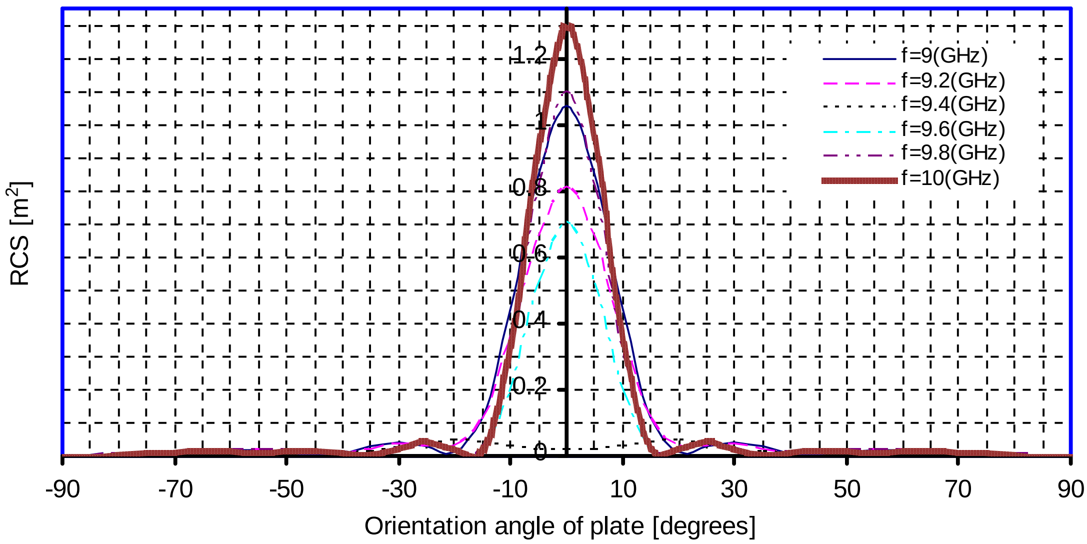


Figure (15): *RCS of array of square patches 3X3 + corner at different frequencies*

Figure (16) shows the relation between RCS of two arrays one of rectangular patches and the other of square patches for horizontal polarization (in direction of the patch length) of incident wave. It is clear that RCS is minimum at normal incidence for array of square patches but it has a maximum at angle 20°. The RCS of rectangular patch is max at normal incidence and decreases as angle increases.

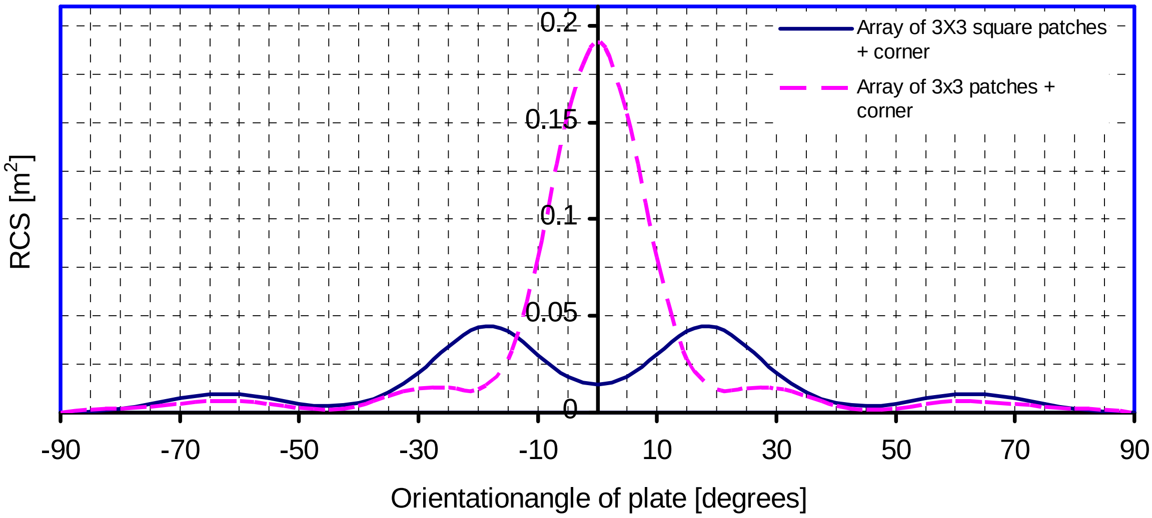


Figure (16): *RCS of two arrays of patches rectangular and square patch at (f=9.4GHz)*

5. Effect of Height of Substrate:

Changing the height of substrate the design of patch will change, we can obtain the following:

For h1= h/2 = 0.3935 mm, L = 10.558 mm

For h2 =2h = 1.574 mm, L = 9.69 mm

For h3 = 3h = 2.361 mm, L = 9.053 mm

Figure (17) shows RCS of array of 3X3 + corner square patches at different heights.

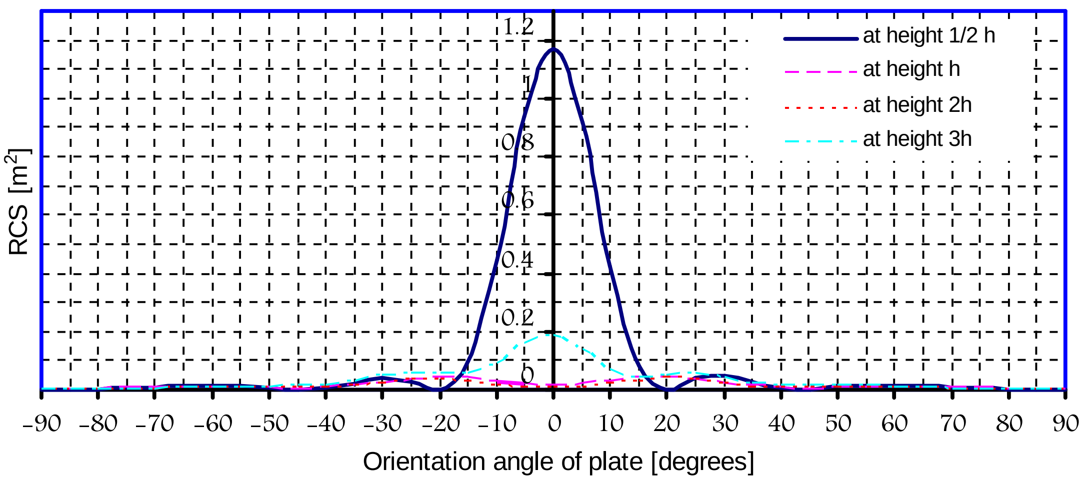


Figure (17): *RCS of array of 3X3 + corner square patches at different heights at (f=9.4GHz)*

As illustrated in Figure (17), we can find that when the height changes the RCS changes because the height change leads to change in the patch dimensions and the phase of reflected wave from the ground plate. The heights of substrate of 0.787 mm and 1.574 mm are optimum, for a great wave cancellations, and great RCS reduction. As height of the substrate increases, the dimensions of patches decrease, and vise versa. Then, there is an optimum height of the substrate, which gives optimum dimensions of the patch, and hence a good cancellation, which leads to better RCS reduction.

6. Effect of Dielectric Constant of Substrate:

Changing the dielectric constant of substrate the design of patch will change. We can obtain the following,
For εr = 1.2, L = 13.659 mm
For εr =3.2, L = 8.5817 mm

Figure (18) indicates RCS of array of 3X3 + corner square patches at different dielectric constant

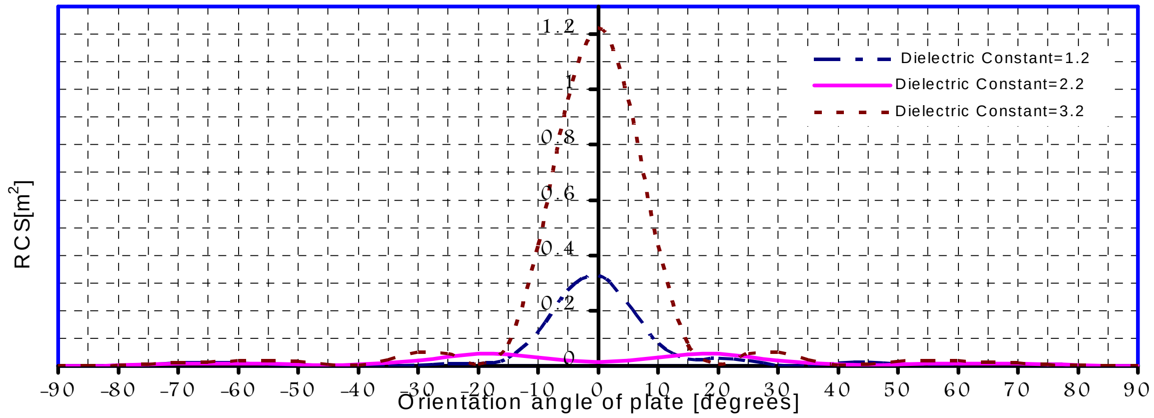


Figure (18): RCS of array of 3X3 + corner square patches at different dielectric constant at (f=9.4GHz)

As shown in Figure (18), one can find that when the dielectric constant of the substrate changes the RCS changes because the dielectric constant change leads to change in the patch dimensions and the phase of reflected wave from the ground plate. The dielectric constant of substrate of 2.2 is optimum, for a great wave cancellations, and great RCS reduction. As dielectric constant of the substrate increases, the dimensions of the patches decrease, and vise versa. Then, there is an optimum dielectric constant of the substrate, which gives optimum dimensions of the patch, and hence a good cancellation, which leads to better RCS reduction.

7. The structure of array of patches on a large Plate:

In this section, the structure of array of patches on the large plate is discussed. There are three methods to apply the array structure of patches on a large plat. In the first one, the structure is repeated as shown in Figure (19). In The second one, the structural area is increased. In addition, the spacing between the patches and the edges and also, between the batches themselves are kept identical as the original structure shown in Figure (14). Due to the increasing of the structural area, the numbers of patches are increased because the patches size and spacing are not changed. Figure (20) shows this suggested structure. The third one is the same as the second one but instead of keeping the same space between the patches and the edges, the ratio of the distance between the patches and the edges of structure to the length of the edge of structure are kept identical as shown in Figure (21).

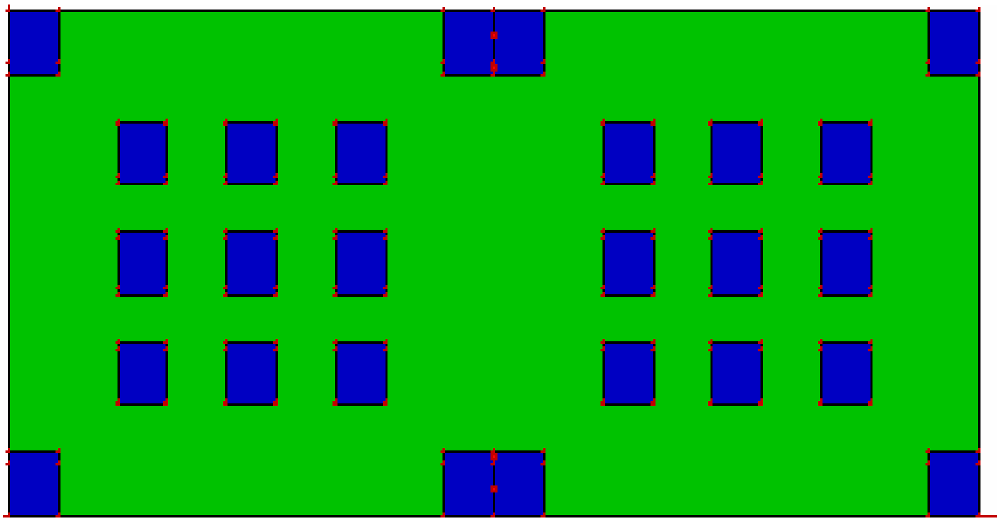


Figure (19): *The new structure by repeating the original structure*

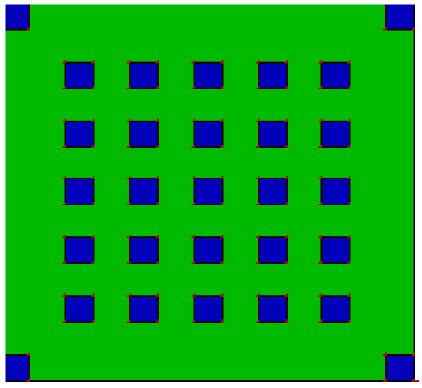


Figure (20): *Array of 5X5 of plate 15X15 cm^2*

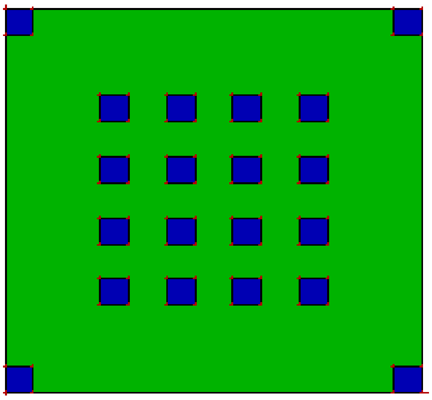


***Figure (21):** Array of 4X4 of plate 15X15 cm^2*

Figure (22) Shows the RCS of the two structures shown in Figure (20) and Figure (21) compared with RCS of flat plate 15X15cm^2. It is clear that RCS reduction for array of 4X4 at normal incidence compared with flat plate is equal to -9.9 dB, RCS reduction for array of 5X5 at normal incidence compared with flat plate is equal to -9.65dB, and then the two structures give us nearly the same results at normal incidence.

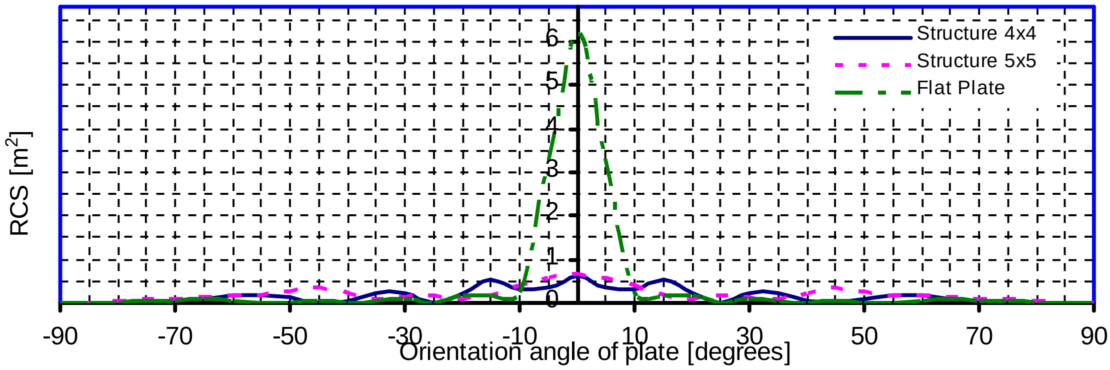


***Figure (22):** RCS of two structures of array of patches of plate 15X15 cm^2*

compared with flat plate at (f=9.4GHz)

8. Measurement RCS of Array of Patches in the large Plate (5X5):

To measure the RCS of a metallic plate, change the orientation angle of the plate and measure the reflected wave voltage on the scope. The RCS is then determined using the formula:

$$\frac{\sigma_1}{\sigma_2} = \frac{V_1^2}{V_2^2} \qquad (1)$$

Where: σ1 is the maximum radar cross section at normal incidence.

$$\sigma_1 = \frac{4\pi a^2 b^2}{\lambda^2} \quad (2)$$

Where a & b are the dimensions of the plate

then we can measure RCS of an array of patches 5X5 of plate 15X15 cm^2 by using equation (1), we can get RCS relative to a reference point (at normal incidence for flat plate).Figure (23) shows the RCS of the array of patches 5X5 of plate 15X15 cm^2 compared to the flat plate.

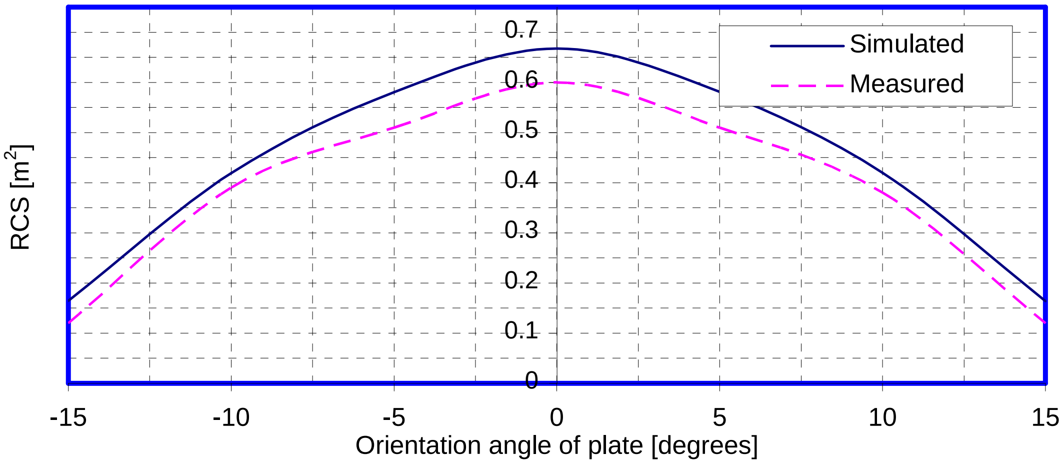


Figure (23): *RCS reduction of array of patches 5×5 in plate 15×15 Measured and Simulated at (f=9.4GHz).*

It is shown that from Figure (23) the slope of two curves are nearly equal, but the peak values (at normal incidence) are different. This difference may be due to that the peak value of the measured curve is calculated from formula (2) which may be invalid for small plates.

9. Conclusion

This paper introduces a technique for the RCS reduction by using array of patches. The patch is designed at a required frequency and arranged on the flat plate with different structure by which the reflected wave from the flat plate is interfered with the reflected wave from the patches. Due to the different phase shift between these waves it might cancel each other, and hence reduce the reflected backscattered field to the radar, resulting in reduction in RCS of the object seen by the radar at this frequency. The patches on the corners cause diffraction in addition to the reflection. A good RCS reduction is obtained by using an arrangement of array of 3×3 patches at the centre of plate and 4 patches on the corners of that plate. There are an optimum number of patches, which cover optimum area, at which the reflection from the ground plate is near to the reflection from the patches. The arrangement of optimum patches can be changed to improve the RCS reduction. The RCS reduction can be optimized further by changing the height and dielectric constant of the substrate.

References:

[1] Knott, E. E., J. F. Shaeffer, and M. T. Tuley, *Radar Cross Section,* Artech House, 1993.

[2] Francois, Lechevalier,"*Principles of Radar and Sensor signal processing"*, Artech house, Boston, London, 2002

[3] Hossein, Mosallaei, and Y. Rahmat-Samii, "*RCS reduction of canonical targets using genetic algorithm synthesized RAM,*"IEEE Trans. on Ant. and Prop., Vol. 48, 1594–1606, Oct. 2000.

[4] Michielssen, E., J.-M. Sajer, S. Ranjithan, and R. Mittra, "*Design of lightweight, broad-band microwave absorbers using genetic algorithms,"* IEEE Trans. on MTI. Vol. 41, 1024–1031, 1993.

[5] Weile, D. S., E. Michidssen, and D. E. Goldberg, "*Genetic algorithm design of Pareto optimal broadband microwave absorbers*," IEEE Trans. on Electromagnetic Compatibility,Vol. 38, 518–525, 1996.

[6] H.F.Harmuth, "*Antennas and Waveguides for Non Sinusoidal Waves*", New York, Academic press, 1984.

[7] I.J. Bahl and P. Bhartia, "*Microstrip Antennas*" ,Artech House, Dedham, MA, 1980.

[8] Constantine A. Balanis "*Antennas Theory Analysis and Design*", Second Edition, John Wily & Sons, INC., New York ,1997..