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Reducing Wing Observability to Radar using Microserrations at Leading Edge

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Key words: Radar Cross Section, Wing, Low Observable, Serrations, Leading Edge, Computational Electromagnetics

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Abstract

Serrations are found in nature on leading edge (LE) of bird wings and whale flippers. These serrations reduce flight noise and improve aerodynamic performance. This has inspired LE serrations to be incorporated in the design of wings and turbine blades. LE of wings can contribute significantly to observability of aircraft by radar due to LE diffraction of horizontally polarized incident electromagnetic (EM) waves. Serrations at wing LE can also be used to reduce observability to radar in such circumstances. In the present work method of equivalent currents is used to analyse the effect of microserrations on an infinitesimally thin metallic delta wing. It is shown that microserrations at wing LE can be effectively used to control the backscatter due to diffraction of EM waves at wing LE. LE serrations, in general, work by introducing a randomness in interaction of wing LE with incident fluid flow or EM field.

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Serrations on the leading edge (LE) of wings and flippers serve as flow control devices in nature. LE serrations on wings usually have two major roles. These relate to noise reduction and of enhanced aerodynamic (or hydrodynamic) performance. LE comb like serrations present in the wings of a barn owl is one of the three major adaptations responsible for its silent flight[1]. LE adaptation in the form of tubercles on flippers of humpback whales can delay onset of stall leading to superior performance in turn maneuvers[2]. There is an increasing tendency to mimic LE serrations observed in nature in wings and flippers for reducing noise and increased aerodynamic performance[3]. The role of wing LE serrations is mostly to generate stream wise vorticity in the incident flow. This has multiple consequences, including energizing the boundary layer and converting periodic or near-periodic wake at LE into random behaviour. The latter is thought to be responsible for eliminating tonal noise in wings with LE serrations as compared to that without when a wing interacts with oncoming gust[4].

The LE of a wing produces a noticeable glint in terms of visibility to radar, when it interacts with horizontally polarized EM field incident from on or near nose-on direction. The glint is a spike in the value of radar cross section (RCS), the quantitative measure of observability to radar, due to edge diffraction at LE involving horizontally polarized incident EM field. This is attributed to the presence of a major lobe in the Keller cone direction due to edge diffraction, of incident horizontally polarized EM wave at wing LE[5]. This glint is disadvantageous for contemporary combat aircraft designed with low observability to radar as a key design feature. In the current study we use small or microserrations at the LE of a common combat aircraft wing geometry to reduce this glint caused due to interaction with horizontally polarized EM field. As in the case of elimination of tonal noise in the interaction of a gust with wing geometry, the idea is to introduce element of randomness in the interaction of the LE with the incident field due to the presence of small serrations at the LE. Serrations are used to break up the continuous wing LE to reduce lobe intensity which is usually a function of the length of the straight uninterrupted LE[5]. In the interaction of EM waves with aircraft type configuration, backscatter contributions from edge type discontinuities are usually higher-order effects compared to pure specular returns, but can become important at the wing LE and the trailing edge (TE) for specific orientation and polarization of the incident field. A similar study was done previously to show the effectiveness of TE serrations in reducing the relatively prominent backscatter caused due to surface traveling waves interacting with edge discontinuity at the wing TE for vertically polarized EM field[6].

In the present study a thin metallic delta wing with LE sweep of 45 degrees also used in Refs. [6,7] is initially used to demonstrate the enhanced RCS due to horizontally polarized EM waves compared to vertical polarization for backscatter involving LE diffraction. This is done using both frequency domain based Method of Moments (MoM)[5] and time domain based Finite Volume Time Domain (FVTD)[8] methods. Both MoM and FVTD methods are full wave solvers for numerical solution of the Maxwell's equations. The delta wing with added micro-serrations and zero thickness is then analyzed using Method of Equivalent Currents (MEC)[5,9]. In high frequency regimes, MEC allows us to isolate and identify the contribution of LE diffraction by considering the LE to be infinitesimally thin. Full wave solvers like MoM and FVTD are not convenient and can be inaccurate or even fail in the presence of microserrations because of the very fine discretization required to resolve the geometry[10]. This is in addition to both full wave methods being computationally expensive at high frequencies and fine discretizations. Delta wings usually have thin LE to promote flow separation for generating additional vortex lift due to stable vortex systems on the upper surface of the wing. Thus, infinitesimally thin LE for calculation of RCS using MEC is a reasonable assumption for delta wing considered here. For a thin but finite thickness LE, as in Figure 1, the RCS analysis would require additional Physical Optics (PO) based formulation to take care of the specular contribution with edge diffraction effects computed using MEC as before.

Figure 1 show the metallic delta wing without serrations. The validation of the MoM in Multi Level Fast Multipole Method (MLFMM) form as well the FVTD method are carried out with available results in literature[6,7] at a frequency of 5 GHz. This frequency corresponds to wing span b = 8λ , where λ is the wavelength of the incident harmonic EM wave. The validation results were also presented in Ref. [6] , and are not repeated here. It is well known that the LE of a wing has a large contribution to the overall RCS for horizontal polarization for $b/\lambda >> 1$ due to diffraction at the wing LE[5]. Polar plots in Figures 2a – f compare the bistatic RCS at 2.5, 5 and 10 GHz, in the plane of the wing, for vertical and horizontal polarizations for nose-on incidence (0 degrees) and broadside incidence to the LE (-45 or 315 degrees). In all cases the horizontally polarized incident field results in a much larger RCS contribution especially at the monostatic point. This is uniformly true irrespective of the type of full wave solver used for the simulation.

To isolate LE diffraction contributions to the overall RCS, the delta wing is made infinitesimally thin and the LE contribution evaluated using MEC both for serrated and unserrated LE. Figure 3 shows the delta wing geometry with microserrations at the LE. The contribution to RCS due to edge diffraction of horizontally polarized EM wave at a straight LE is proportional to L^2, where L is the length of the LE[5]. Serrations in Figure 3, in-principle, seeks to break length L into smaller line segments to reduce backscatter. The LE serrations conceptually in the form of a cosine curve of wavelength λ_s and height 2h, in Figure 4a, is approximated for the current study as triangular serrations as in Figure 4b. The height 2h is expressed as a small fraction of the wing root chord C, while λ_s is a fraction of the wavelength of the incident harmonic wave λ. Full wave solvers will have difficulty in resolving LE serrations for 2h << C. The computational time would also be prohibitively large for such solvers given the very fine discretization required to adequately resolve the serrations. MEC, on the other hand, assumes edges to be formed by the intersection of two semi-infinite surfaces. The surface current generated on the edges also known as equivalent currents, are calculated based on diffraction coefficients, relative position of the edge with respect to observer and the incident electric field[5,9]. Once equivalent currents are calculated for individual serrations they can be summed up in the standard far field integral[11] and the RCS calculated. Figure 5 shows the validation of the MEC method for a metallic equilateral triangle with sides approximately 9λ and horizontal polarization with results in literature[12].

Results are shown in terms of monostatic plots obtained using the MEC method for serrated and unserrated infinitesimally thin delta wing in Figures 6 a – c for 12.5, 15 and 20 GHz. At these frequencies the wing span measures 20λ, 24 λ and 32 λ. The serration depth is taken to be only 2 % of the maximum wing chord to cause minimum disruption by the introduced LE serrations to the incident fluid flow. In this range of frequency and fixed serration depth, a serration wavelength $\lambda_s = 0.5\lambda$ shows the best performance with a reduction of around 10 dBsm at broadside ($\pm 45^0$) incidence as is shown in Figures 6a-c.. This reduction is RCS can be attributed to a breaking up of the LE and consequently of the major lobe formed by edge diffraction due to uninterrupted LE. In addition the serrated edge also results in multiple non-aligned scattering centers which scatters energy away from the monostatic point. However, for best performance the serration depths and wavelength of LE serrations need to be optimized rigorously for the operating range of frequencies.

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Captions

Figure 1. Plain delta wing

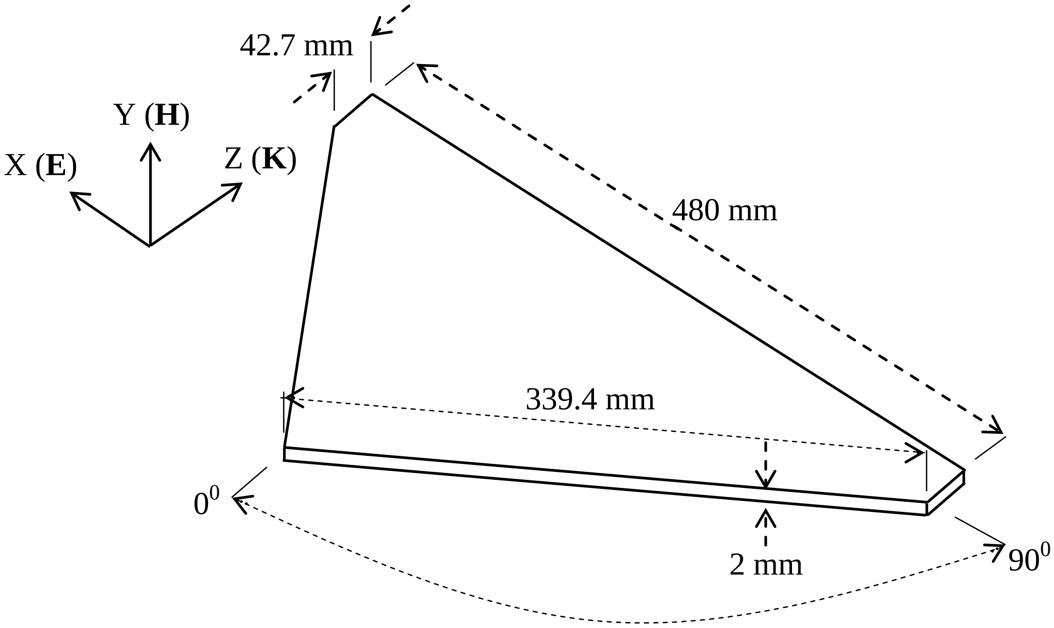
Figure 2. Bistatic polar plots, yaw plane, vertically polarized (VV) and horizontally polarized (HH) EM waves (a) 0^0 incidence, frequency 2.5 GHz, (b) -45^0 , 2.5 GHz, (c) 0^0, 5 GHz, (d) - 45^0 , 5 GHz, (e) 0^0 , 10 GHz and (f) -45^0 , 10 GHz.

Figure 3. Delta wing with leading edge serrations

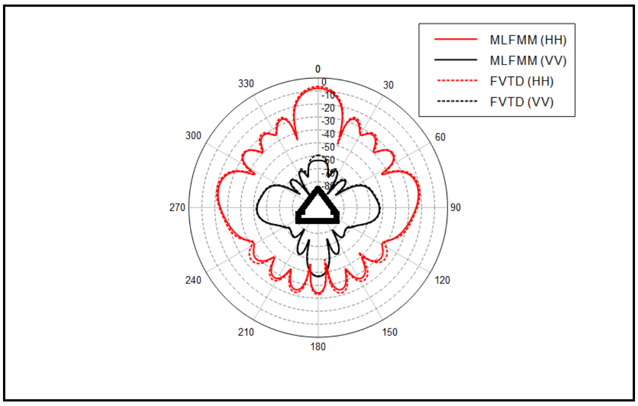
Figure 4. Geometry of serrations (a) cosine curve (b) cosine curve approximated by straight lines for actual geometry

Figure 5. Validation of MEC results, equilateral triangular plate

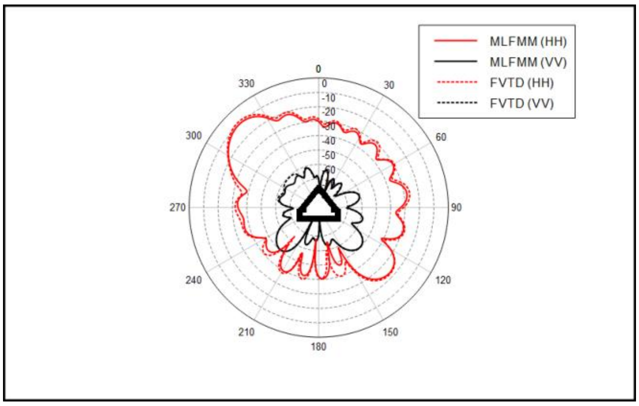
Figure 6. Monostatic RCS, LE serrated wing, HH polarization (a) 12.5 GHz, (b) 15 GHz and (c) 20 GHz



(Figure 1)



(a)



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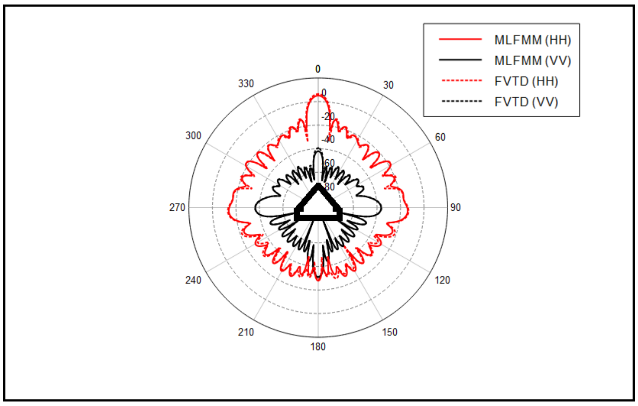

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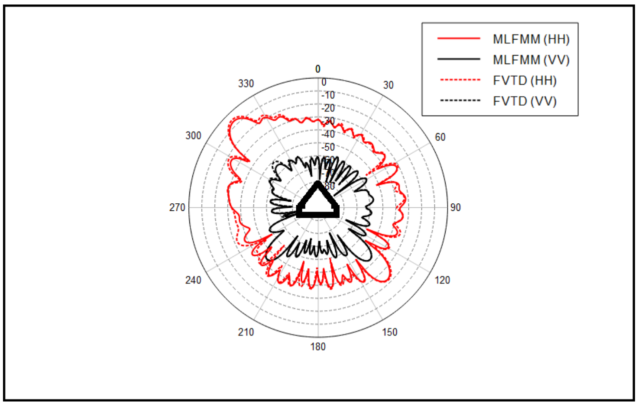

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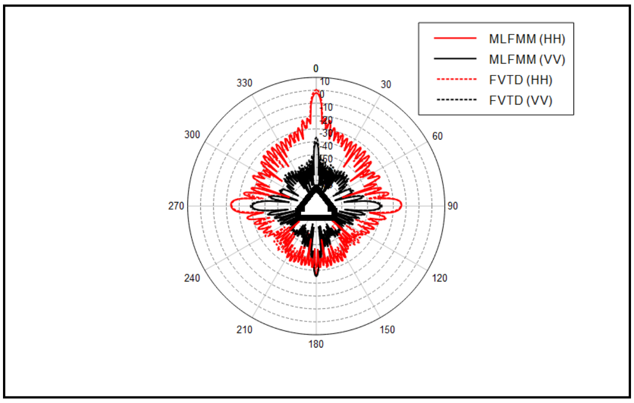

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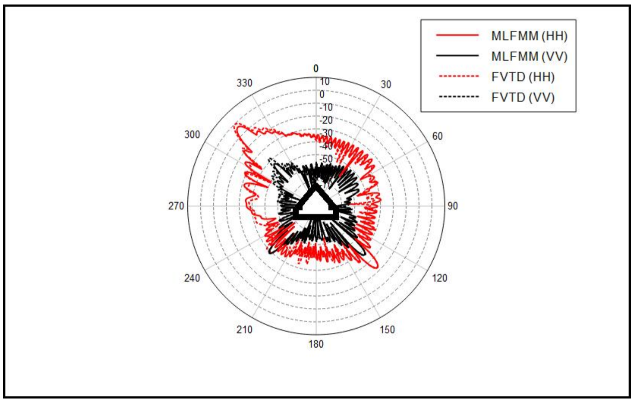
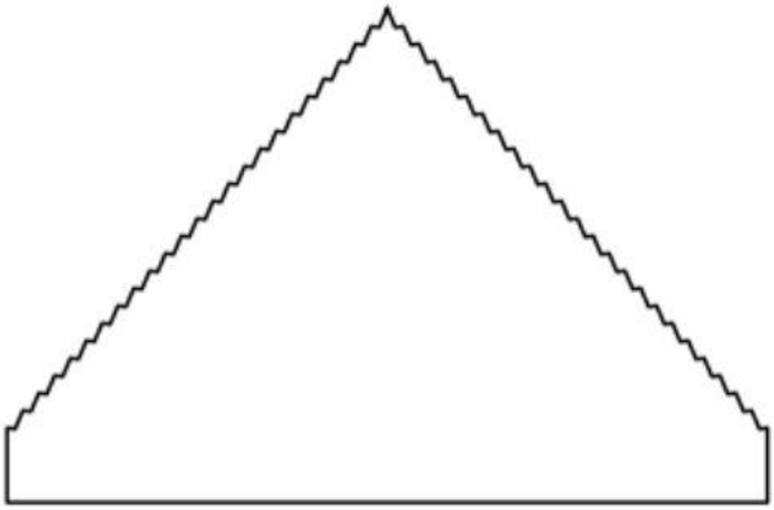


(f)

(Figure 2)



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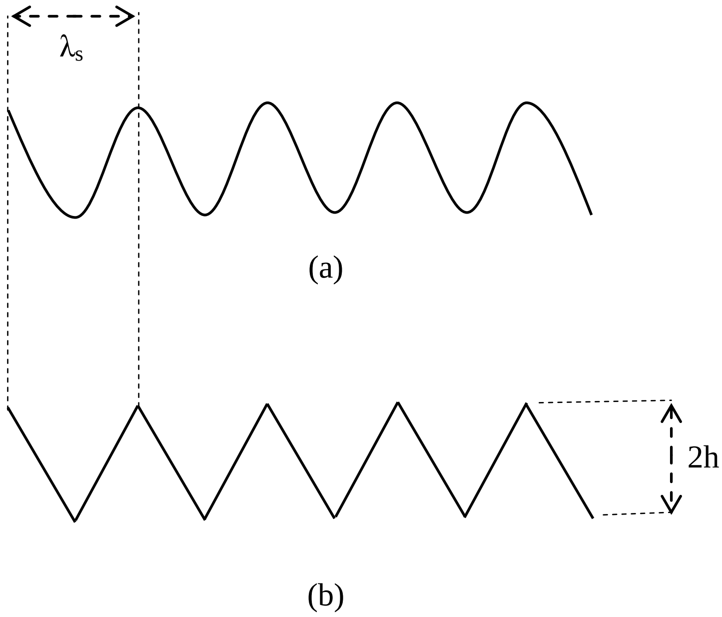
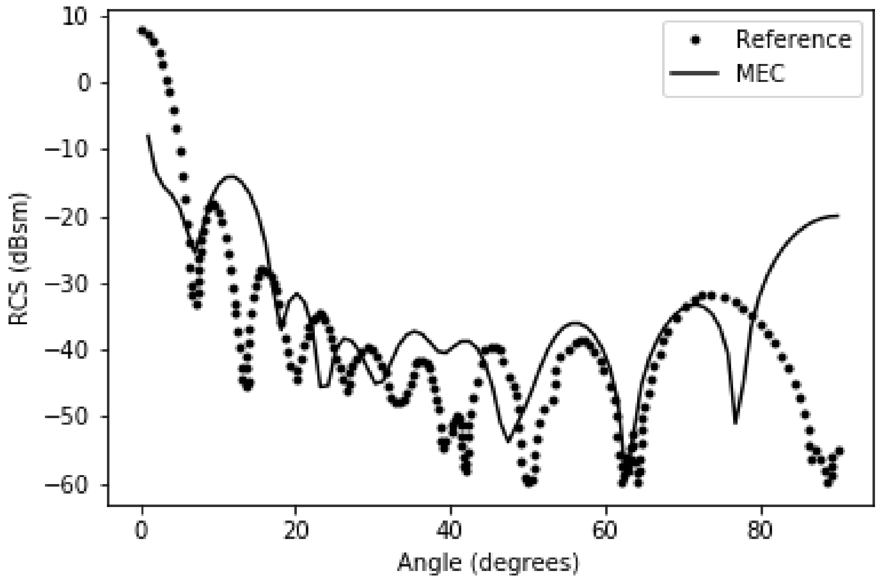
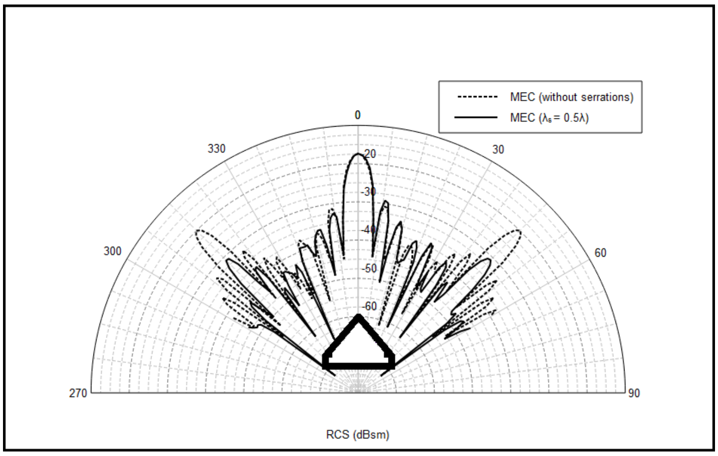


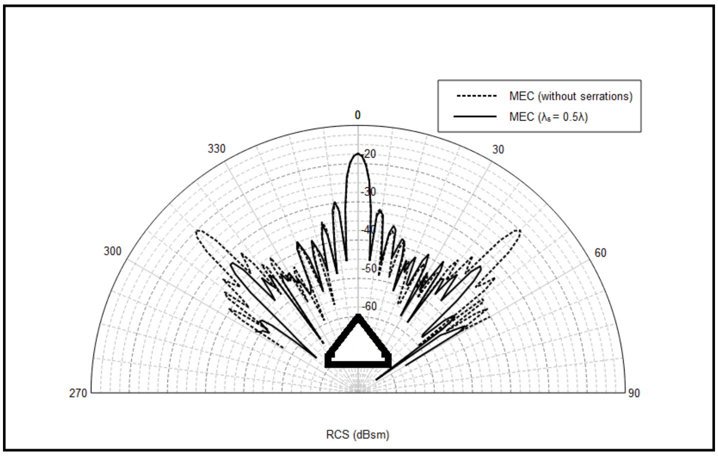
(Figure 4)


Reference
MEC
RCS (dBsm)
Angle (degrees)
10
0
−10
−20
−30
−40
−50
−60
0
20
40
60
80

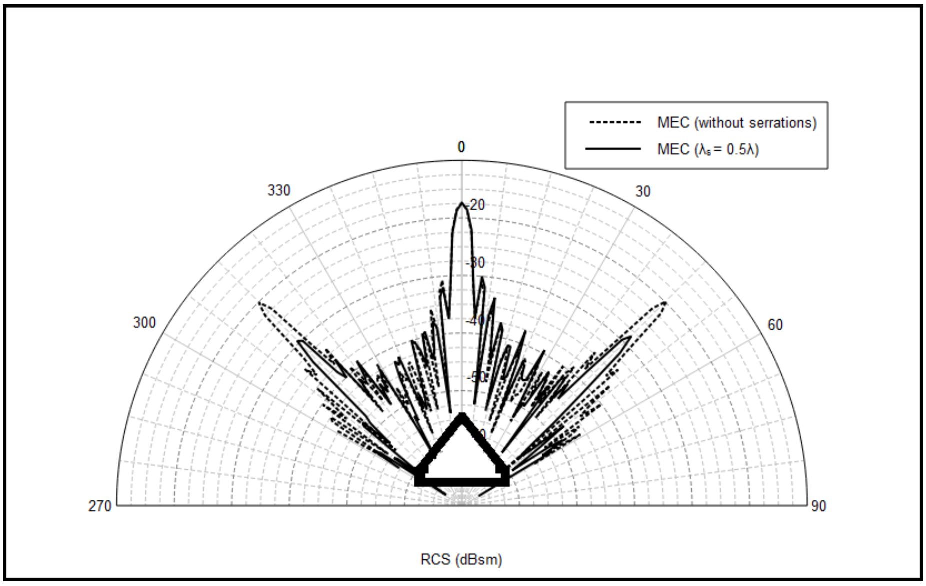
(Figure 5)


MEC (without serrations)
MEC (λs = 0.5λ)
0
330
30
300
60
270
90
-20
-30
-40
-50
-60
RCS (dBsm)

(a)


MEC (without serrations)
MEC (λs = 0.5λ)
0
330
30
300
60
270
90
-20
-30
-50
-60
RCS (dBsm)

(b)


MEC (without serrations)
MEC (λs = 0.5λ)
0
330
30
300
60
270
90
-20
-30
RCS (dBsm)

(c)

(Figure 6)