International Research Journal of Natural and Applied Sciences
Volume-2, Issue-4 (April 2015) ISSN: (2349-4077)

RADAR CROSS SECTION PREDICTION TECHNIQUES AND THEIR APPLICATIONS

Dr.Neeraj Tyagi

Deendayal Upadhyaya College, University of Delhi, Delhi-110007

ABSTRACT

Radar cross section (RCS) is estimated in terms of strengths of the incident and scattered electric fields and the range from the radar to the target. It is the reflective strength measurement of a target. Radar targets may be in the form of simple shapes such as spheroids, flat plates and the like and complex targets such as ships, aircrafts and insects. The reduction of RCS of complex targets enables their late detection by radar and adds an element of surprise. The RCS of complex targets therefore becomes a very significant design parameter. The objective of this paper is to review and discuss various RCS prediction methods for a complex target. The merits as well as limitation of each method have also been presented.

KEYWORDS: RADAR CROSS SECTION, COMPLEX TARGETS, SCATTERED ELECTRIC FIELDS, RCS

1.0 INTRODUCTION

RADAR stands for 'Radio Detection and Ranging'. Radar operates by transmitting electromagnetic wave into the surroundings and detecting the wave reflected by the objects .Radar cross section of aircrafts came into lime light when the U S government initiated a Department of Defense program known as the "Stealth Bomber". The stealth aircraft was alleged to be invisible to radar and very soon it was learned that technically the radar stealth was characterized by a low "Radar Cross-Section" (Brookner, Eli). Energy is scattered by the target in all directions, when it is illuminated by an electromagnetic wave. The scattered energy distribution depends upon the nature of incident wave as well as shape, size and composition of the target. The power '**scattered**' by an obstacle is measured in terms of radar cross section.. It is denoted by σ .Radar cross-section (σ). In terms of the incident and scattered electric fields strength and the range from the radar to the target is expressed as (Skolnik, 2008)

Radar cross section $\sigma = \frac{Lim}{R \to \infty} \frac{[E^S]^2}{[E^i]^2}$ 1.1

Where,

R = distance between radar and target

E^s = scattered field strength at radar

E^i = strength of incident field at target

Radar cross-section is very much dependent on the characteristics (i.e. echo properties) of typical radar targets. These include 'simple shapes' such as spheroids, flat plates and the like, and more 'complex' objects such as ships, aircrafts and insects.

2.0 CLASSIFICATION OF RCS PREDICTION METHODS

There are two kinds of RCS prediction methods namely (i) Exact methods and (ii) Approximate or High Frequency Methods.

IN exact class of methods there are methods based on Maxwell's Equations called classical methods and the methods based on integral equations called integral equation methods. These methods are also known as methods of moments (MOM). High frequency or approximate methods which are used for complex large targets comprises of Geometrical optics, Physical Optics, Geometrical theory of diffraction, Physical theory of diffraction and Equivalent currents (Jawad Khan,2012)

2.1 EXACT PREDICTION METHODS

Maxwell's equations can be manipulated to obtain a second order partial differential equation called wave equation involving only the electric or the magnetic field intensity vector. The solution of the wave equation yields the expressions for the total field everywhere in space and forms the basis for the classical methods. Maxwell’s equations were used with the vector Green's theorem by Stratton to obtain a set of scattered field equations which are known as Stratton Chu equations [1]. These equations happen to be integral equations. The Stratton Chu equation, in reduced form for perfect conductors, to compute scattered Electric field and scattered magnetic field are called electric field integral equation (EFIF) and magnetic field integral equation (MFIE).The solutions of these integral equations form the basis for integral equation methods for the prediction of RCS of simple targets.

2.1.1 Classical methods

Radar cross section analysis requires knowledge of the electric field intensity vector $\vec{E}$ or the magnetic field intensity vector $\vec{H}$ of the electromagnetic wave as the field interacts with a scattering body. Maxwell's equations are the fundamental laws governing electromagnetic phenomena. In a homogeneous, isotropic and source free region Maxwell's Equations are as follows:

$$\vec{\nabla} X \vec{E} + \mu \frac{\partial \vec{H}}{\partial t} = 0 \qquad 2.1$$

$$\vec{\nabla} X \vec{H} - \in \frac{\partial \vec{E}}{\partial t} = 0 \qquad 2.2$$

$$\vec{\nabla} \; . \; \vec{E} = 0 \qquad 2.3$$

$$\vec{\nabla} . \; \vec{H} = 0 \qquad 2.4$$

From these Equations, one can obtain the wave equations for electromagnetic fields, namely,

$$\overrightarrow{\nabla^2} E + k^2 E = 0 \qquad 2.5$$

and

$$\overrightarrow{\nabla^2} H + k^2 H = 0 \qquad 2.6$$

If λ is the wavelength in free space then the wave number k in the equations 2.5 and 2.6 is given by

$$k = 2\pi / \lambda$$

Equations 2.5 and 2.6 are the standard expressions for the wave equation. It is obvious from Equations 2.5 and 2.6 of wave that any component of the field vector will satisfy the scalar Helmholtz relation

$$\nabla V + k^2 V = 0 \qquad 2.7$$

Solving wave equation one can find the fields scattered by simple bodies [Knott, 1981]. The solution of Equation [2.7], is limited to simple bodies because a coordinate system has to be found for which the body surface coincides with one of the coordinates in order to solve the wave equation by separation of variable.

The solution of the wave equation, namely Equation 2.7 gives the total field everywhere in space, and typically the incident field is expanded in terms of elemental waves in the coordinate system used. When the scattered field is normalized with respect to the incident field, squared and then multiplied with the area of a sphere whose radius is equal to the distance to the observation point, we obtain the radar cross- section.

2.1.2 Integral equation methods

When more than one region of space are involved, the scattered field are obtained by using Stratton-Chu equations. These were obtained by Stratton by using Maxwell's equations along with the vector Green's theorem. This method is also called Method of Moments (MOM)

Region II

Sources

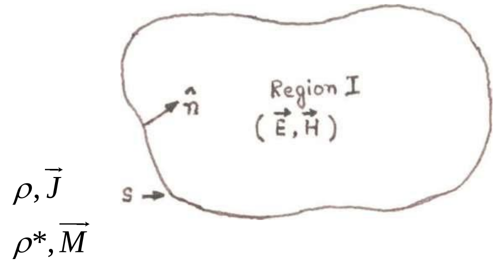

Figure: 2

Consider a situation where Region I is separated from Region II by a surface S as shown in Fig.2.

Assuming that there are electric and magnetic source currents and charges in each region, Stratton Chu equations give the field anywhere in Region I as the sum of a volume integral over the sources in Region I and a surface integral over the fields on surfaces caused by the sources in Region II. Stratton Chu Equations are (Silver, 1949).

$$\begin{aligned}\vec{E}^{S} &= \int_V (j\omega u \vec{j}\Psi - \overrightarrow{M} \times \vec{\nabla}\psi + \frac{1}{\in} e \vec{\nabla}\psi)\, dv \\ &+ \int_S [\, j\omega u\, (\hat{n} \times \overrightarrow{H}) + (\hat{n} \times \vec{E}) \times \vec{\nabla}\psi + (\hat{n}.\vec{E})\ \vec{\nabla}\psi)\, ds\end{aligned} \qquad 2.8$$

$$\begin{aligned}H^{S} &= \int_S (jw\varepsilon \overrightarrow{m}\psi + \vec{J} \times \vec{\nabla}\psi + \frac{1}{\mu} e\ \nabla\psi)\, dv \\ &- \int_S [\, j\omega\varepsilon\ (\hat{n} \times \vec{E}) - (\hat{n} \times \overrightarrow{H}) \times \vec{\nabla}\psi - (\hat{n}.\overrightarrow{H})\ \nabla\psi]\, ds\end{aligned} \qquad 2.9$$

Where the integral over the surface sums the contribution from each part of the scatterer, and

$\psi = \dfrac{e^{-ikr}}{4\pi R}$ Free space Green's function

$R = \left| \vec{r} - \vec{r}_S \right|$

ω = is the angular frequency of the time varying E_M field.

∈ = permittivity of the medium

μ = permeability of the region

ρ = volume density of electric charge

$\vec{J}$ = electric current density

$\rho*$ = volume density of fictitious magnetic charges

$\overrightarrow{M}$ = Magnetic current density

$\hat{n}$ = outward drawn unit normal to the surface S.

It is evident from equations 2.8and 2.9 that Stratton Chu equations prescribe scattered fields in terms of surface current source.

The total electric and magnetic fields are written in terms of incident and scattered fields,

$$\overrightarrow{E}^T = \overrightarrow{E}^i + \overrightarrow{E}^S$$
$$\overrightarrow{H}^T = \overrightarrow{H}^i + \overrightarrow{H}^S$$

The scattered E and H fields as given by the Stratton Chu –integrals (Knott and Senior), are

$$\overrightarrow{E}^S = \oint\!\!\oint_S [j\omega\mu(\hat{n}\times\overrightarrow{H})\psi + (n\times\overrightarrow{E})\times\vec{\nabla}\psi + (\hat{n}.\overrightarrow{E})\vec{\nabla}\psi]ds \qquad 2.10$$

$$\overrightarrow{H}^S = \oint\!\!\oint_S [j\omega\varepsilon(\hat{n}\times\overrightarrow{E})\psi - (\hat{n}\times\overrightarrow{H})\times\vec{\nabla}\psi - (\hat{n}.\overrightarrow{H})\vec{\nabla}\psi]ds \qquad 2.11$$

The tangential and perpendicular components of the surface field are interpreted as currents and charges [8].

$$\begin{aligned}
\vec{J} &= \hat{n}\times\overrightarrow{H}^T \\
\overrightarrow{M} &= \hat{n}\times\overrightarrow{E}^T \\
\rho &= \varepsilon\hat{n}.\overrightarrow{E}^T \\
\rho* &= \mu n.\overrightarrow{H}^T
\end{aligned} \qquad 2.12$$

For scattering from imperfect conductors, for example dielectric and magnetic bodies, we must consider both the electric as well as magnetic sources. But for the scattering from a perfect electric conductor, the total tangential electric field is zero at its surface. Therefore, magnetic currents or charges need not be considered as sources of the scattered Electric and magnetic fields.

Therefore, for a perfect conductor, Stratton-Chu integrals (Equations. 2.10and 2.11) reduce to

$$\begin{aligned}\vec{E}^{S} &= \int_{S}[\, j\omega\mu\ (\hat{n}\times\vec{H})\psi + (\hat{n}.\vec{E})\nabla\,\psi]ds \\ &= \int_{S}[\, j\omega\mu\ \vec{J}\psi + \frac{1}{\varepsilon}\vec{\nabla}\psi\,]\, fds\end{aligned} \qquad 2.13$$

$$\begin{aligned}\vec{H}^{S} &= \int_{S}[\hat{n}\times\vec{H})\times\vec{\nabla}\psi]ds \\ &= \int_{S}\vec{J}\times\vec{\nabla}\psi\ \ ds\end{aligned} \qquad 2.14$$

The equations 2.13 and 2.14 are known as the Electric Field Integral Equation (EFIE) and magnetic field integral equations respectively. These equations show that the scattered E field is due to electric currents and charges while the scattered H field is only due to electric currents.

To solve the above EFIE and MFIE for the computation of scattered fields, the method of moment given by Harrington (Harrington, 1961) is used. Once the scattered fields are computed the radar cross-section of the target can easily be estimated as indicated above.

The EFIF and MFIE are not yet in the form required to affect a solution. To do so, we must apply Equation, 2.13 to the surface of a perfectly conducting scattering body, for which we know that the tangential components of the fields are zero.

When we consider the observation point as on the surface, where the field values are known from the boundary conditions, the resulting forms for the EFIE and MFIE may be obtained as follows (Mitra, 1973)

$$\hat{n}\ \times\vec{H}^{T} = n\times(E^{i}+E^{S}) = 0 \qquad 2.15$$

and

$$\hat{n} \times \vec{H}^{T} = \hat{n}\times(\vec{H}^{i} + \vec{H}^{S}) = J \qquad 2.16$$

which leads to

$$\hat{n} \times \vec{E}^{i} = -\hat{n}\times\vec{E}^{S} = \hat{n}\times\int[i\omega\mu\vec{J}\psi + \frac{i}{\omega\varepsilon}\nabla.\vec{J}\psi]ds \qquad 2.17$$

$$\hat{n} \times \vec{H}^{i} = \frac{1}{2}\vec{J} - \hat{n}\times\int\vec{J}\times\nabla\psi \quad ds$$

2.18

Equs 2.17 and 2.18 thus the starting points for obtaining the unknown surface current density. Except for frequencies corresponding to interior body resonances, either form may be used. When the surface becomes very thin, such as for Wires, and thin Cylinders, the EFIE must be used because of the difficulty in adequately representing in MFIE for these cases. For closed smooth conductors, the MFIE is often applied.

The procedure required to find the unknown current density involve representing the unknown as a set of basic functions with unknown coefficients and defining weighing or testing functions, explicitly defining interaction matrix elements, inventing the matrix, specifying the polarization and direction of the incident field and calculating the resultant current density, computing the bistatic scattered field radiated by these induced currents.

Monostatic scattering patterns require more computation than bistatic patterns because the induced currents must be computed for each angle of incidence. However, scattering in only one direction needs to be computed, that being back toward the source of illumination.

Once the currents are known for a given excitation, the scattered fields due to these currents may be computed from EFIE or MFIE expressions. 2.13. Usually only the far field values are of interest and therefore, the far field Green's function gradients is used in the EFIE and MFIE to obtain [Ryan, and Peters, ,1970].

$$\vec{E}^{s} = \frac{i\omega\mu}{4\pi R}\ e^{ikR}\int_{S}[\vec{J} - (\vec{J}.\hat{R})]\ e^{-ikr}\ ds \qquad 2.19$$

$$\vec{H}^{s} = \frac{i\omega\varepsilon}{4\pi R} e^{ikR} \int_{S} \sqrt{\mu/\varepsilon}\,(\vec{J} \times \vec{R}) e^{-ikr}\, ds \qquad 2.20$$

Using equations 2.19 or 2.20the radar cross section may easily be calculated by the following expression

$$\sigma = 4\pi \lim_{R\to\infty} R^2 \frac{\left|\vec{E}^{S}\right|^2}{\left|E^{i}\right|^2} = 4\pi \lim_{R\to\infty} R^2 \frac{\left|H^{S}\right|^2}{\left|H^{i}\right|^2}$$

In integral Equation methods, Method of Moment (MoM) is applied in solving the integral equations. MoM is based on formation of interaction matrix, which becomes prohibitively large in high frequency regions. Consequently MoM cannot be used for large sized bodies.

Future trends in MoM applications are towards combining MoM with high Frequency Methods to obtain hybrid approach ches, thereby combining the best features of each method.

2.1.3 Merit & demerits of exact methods

The classical exact methods are restricted to bodies whose surfaces coincide with the coordinates of system in which the wave equation is soluable by the separation of valuable technique

MOM is preferable approach for scattering bodies in or below the resonant region. However in high frequency region, MOM is seldom applied because matrix size grows prohibitively large for even today's computers

2.2 HIGH FREQUENCY RCS PREDICTION METHODS

High frequency RCS methods are basically approximate methods as they involve some approximations in their formulation. These methods have been used to compute RCS of large complex obstacles in high frequency region (Duan et al ,1991;De Leeneer et al;Northam,1985). **1**

2.2.1 Geometrical optics

The geometrical optics (GO) approximation assumes that the radar energy is propagated along special trajectories known as rays. The ray optical field us is given by

$$u = A_e^{-ik_o s} \qquad 2.2.1$$

.where k_Q is the free space wavenumber.. The passage of the rays is determined by Fermat's principle, according to which the phase path length, S, must be an extremum. At points on a surface where n, the refractive index, is discontinuous the reflected and refracted rays are produced according to Snell's law. The variation of field amplitude, A, along a ray is determined by imposing the conservation of energy principle in a ray tube and its transformation by a reflection or refraction is determined by the Fresnel coefficients for reflection and refraction[Ryan, and Peters, 1970].

According to GO the far field RCS of a perfectly conducting body is

$$\sigma = \pi a_1 a_2 \qquad 2.2.2.$$

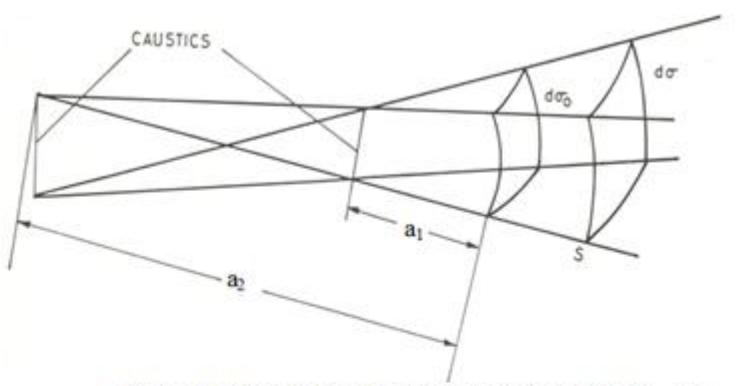

Figure 2.1: Wavefront with principal radi of curvature a_1 & a_2

Where a_1 and a_2 are the principal radii of curvature of the body at the specular point. The appropriate reflection coefficients must be used in the case of a dielectric body and multiple internal reflections have to be considered. It is evident from equation 2..2.2 that GO predicts infinite RCS for flat plates and cylinders. Further, geometrical optics approximates the scattered field only in the specular reflection direction and fails to account for fields which are diffracted from edges, vertices, corners or shadow boundaries. When the scattering phenomenon is dominated by specular returns, GO yields remarkably good results as in the case of backscatter from curved smooth surfaces having radii of curvature large as a function of a wavelength.

2.2.2 Physical optics

PO computes the field scattered from a target by assuming that the fields on the surface of the target are the GO surface fields. On every point on the geometrically illuminated side of the body, the surface induced current is taken to be the same as on an infinite target plane at that point, while in shadowed regions, the surface field is assumed to be zero. (Fang et al, 2008)

The surface current distribution on the target for perfectly conducting body is given by

$$\begin{aligned} J_{PO} &= 2\hat{n}\times H^{i} \text{ on the illuminated surface } \mathrm{S_i} \\ &= o \text{ on the shadowed surface} \end{aligned} \qquad 2.3.2$$

where $\hat{n}$ is a unit vector which is drawn normally and outwards from the body and H^i is the incident magnetic field. When surface current as given by equation 2.3.2 is substituted into the magnetic field integral, the PO approximation for the scattered magnetic field H^S may be obtained. The far scattered magnetic field is given by

$$H^{S} = \frac{ik}{4\pi}\frac{e^{-ikr}}{r}\int_{S_i} 2(\hat{n}\times H^{i})\times\hat{r}\; e^{ikr}.r'ds_{i} \qquad 2.3.3.$$

Where $\hat{r}$ and r are the unit vector and the distance from the origin to the field point respectively and r' is the radius vector from origin to the integration point and represents the integral over the illuminated surface S_i of the obstacle. The RCS of various simple shaped bodies using GO have been estimated (Blume and Kahl, 1987, Borzi, 2004).

The non-physical discontinuity of the PO current gives rise to an erroneous contribution to the integral at the shadow boundaries. In the HF region, however, PO does yield good approximations to the scattered fields in directions not too far removed from the specular direction. Its main advantage over GO is that it is applicable to flat and singly curved surfaces. Like GO, PO does not show any depolarization in the back-scattered field. PO only satisfies the reciprocity theorem in the direction of specular scattering; accordingly, bistatic cross sections determined by PO are non-reciprocal except in the specular direction

2.2.3 The Geometrical theory of diffraction (GTD) and the Uniform theory of diffraction (UTD)

Geometrical theory of diffraction was proposed by Keller (Keller, 1957). Keller's GTD is an extension of GO in which diffracted rays considered with a generalization of Fermat's principle. Keller suggested that diffracted rays are generated whenever incident rays hit edges, corners or vertices of scattering surfaces or incident rays fall tangentially on smooth curved boundaries. He took into account the phase and the magnitude of these diffracted fields using Keller cone. However GTD fails in shadow boundary regions of transition as well as in reflection boundary regions. This problem could be solved by Uniform Theory of Diffraction (UTD).However both methods predict zero fields in direction not on the Keller cone. (Ryan, and Peters, 1970)

2.2.4 Physical Theory of Diffraction

Ufimtsev(Ufimtsev, 1957) extended PO by adding an additional surface current term to that used in PO to correct for non- planar surface. The total surface current on the scatterer is the sum of the "uniform" PO current and an additional "nonuniform" current which is derived from the appropriate canonical problem. Essentially the physical theory of diffraction (PTD) involves the evaluation of a surface integral. The major difficulty of PTD is that the resultant integral is not easily evaluated and it is confined to the directions of Keller cone.

The advantage of Ufimtsev's diffraction coefficients over those of Keller's is that they remain finite at reflection and shadow boundaries; however, like Keller's diffraction coefficients, they are valid only along the generators of a Keller cone. This limitation has been overcome by Mitzner (Silver, 1949) who derived diffraction coefficients, incremental length diffraction coefficients or ILDC, applicable in an arbitrary scattering direction and uniformly valid at reflection and shadow boundaries and at caustics.

2.2.5 Equivalent currents Method

In the description of HF scattering from edged bodies, GTD and UTD predict infinite fields when an infinite number of rays come together at a caustic. These infinities can be corrected by the use of equivalent currents (EC). Fictitious electric (I) and magnetic (I) currents are set up on the edge so as to produce the same far field as the edge. By comparing the far field due to the EC and the diffracted field from the edge the EC are

$$I^e = \frac{2i}{Z_O K}\,\frac{G^e(n,\phi,\phi_O)}{Sin^2\beta}\,E^i_{\tan} \qquad 2.3.4$$

$$I^m = \frac{2i}{Y_O K}\,\frac{G^m(n,\phi,\phi_O)}{Sin^2\beta}\,H^i_{\tan} \qquad 2.3.5$$

where $Z_0 = 1/Y_0$ is the free space impedance, $E^i_{\tan}$ and $H^i_{\tan}$ are the incident electric and magnetic field components tangential to the edge and $G^e(n,\phi,\phi_O)$ and $G^m(n,\phi,\phi_O)$ are given by the diffraction coefficients of GTD or UTD Alternatively, they can be derived from the application of PO for the surface contribution and PTD for the edge contribution. Unlike real currents, I^e and I^m depend on ϕ, the direction of observations. These EC are used in the far-field radiation integral around the corners of the edge to give the far-scattered field which is finite even at the caustics. The EC generate scattered fields in space, but equation 2.3.5 is really rigorous only in directions lying on the Keller cone. Knott and Senior [12] however, attempted to extend their applicability to directions not on the cone of diffraction by replacing $\sin^2\beta$ by $\sin\beta_i \sin\beta_S$ where β_i is the incident angle and βs is the scattering angle, arguing purely from symmetry considerations. Michaeli(Michaeli,A.,1984) developed more rigorously a set of EC that are applicable in arbitrary scattering directions but like the EC based on Keller's diffraction coefficients, Michaeli's solutions are singular along shadow and reflection boundaries. The relationship of Michaeli's EC and Mitzner's ILDC has been examined (Mitra,1973)

3.0 CONCLUSION

Various RCS prediction techniques have been discussed. The relative advantages and disadvantages of each prediction method are presented in detail. It has been concluded that not a single RCS prediction method is sufficient in itself to contain all type of practical problems. A hybrid approach by combining the best feature of each method is thus required. Computer software for low frequency methods as well as for high frequency methods are available for computation of the RCS. After the RCS prediction, design variations may be evaluated to reduce it further for complex objects and other military objects (Castelloe and Munson,1997,Broek et al,2005)

REFERENCES

Andersh D, Moore J, Kosanovich S, Kapp D, Bhalla R, Kipp R, Courtney T, Nolan A, German F, Cook J, Hughes J (2000).

Xpatch 4: The next generation in high frequency, electromagnetic modeling and simulation software. *IEEE, International Radar Conference*, Virginia, USA, 844-849.

A.Michaeli. (1985). Equivalent Edge Currents for Arbitrary Aspects of observation. *IEEE Trans. Antenna Propag., AP23*(3), 227.

Bhalla R. Ling H (1995). 3D Scattering Center Extraction from, XPATCH. *Antennas and Propagation Society International Symposium*, AP-S Digest, Albuquerque, USA, **4**, 1906-1909
.
Blume S, Kahl G (1987). The physical optics radar cross section of an elliptic cone. *IEEE Transactions on Antennas and Propagation*, **35**(4), 457- 460.

Borzi G (2004). Trigonometric approximations for the computation of Radar cross sections. *IEEE Transactions on Antennas and Propagation*, **52**(6), 1596-1602.

Broek BVD, Bieker T, Ewijk LV (2005). Comparison of Modelled to Measured High-Resolution ISAR Data. Netherlands Organization for Applied Scientific Research, Netherlands, TNO Report No. RTO-MP-SET-096.

C.E.Ryan, J. a. (1969, May). Evaluation of edge diffracted fields including equivalent currents for caustic regions. *IEEE trans.Antennaa Propags, AP-17*(3), 292-299.

Castelloe MW, Munson DC Jr. (1997). 3-D SAR imaging via high-resolution spectral estimation methods: experiments with XPATCH. *International Conference on Image Processing*, Washington DC, USA, **1**, 853-856.

Crispin JW Jr., Maffett AL (1965). Radar cross section estimation for simple shapes. *Proceedings of the IEEE*, **53**(8), 833- 848

De Leeneer I, Schweicher E, Barel A (1994). Analysis of the diffracting centers of a complex 3-dimensional structure.
Antennas and Propagation Society International Symposium,AP-S Digest, Seattle, USA, **3**, 2322-2324.

Duan DW, Rahmat-Samii Y, Mahon JP (1991). Scattering from acircular disk: a comparative study of PTD and GTD techniques *Proceedings of the IEEE*, **79**(10), 1472-1480.

E.F.Knott. (1981, april). A Tool for Predicting the Radar Cross Section of an Arbitrary Trihedral Corner",. *IEEE SOUTH EAST-CON 81 Conference* (pp. 17-20). HuntSville, ALABAMA: IEEE Publication 81CH1650-1.

E.F.Knott. (n.d.). *Radar cross section.* Dedham: Aztech House.Inc.610 Wasshington street Dedham,MA02026

Eli, Brookner. (n.d.). Norwood: Aztech House. MA02062.

Fang CH, Zhao XN, Liu Q (2008). An Improved Physical Optics Method for the Computation of Radar Cross Section of Electrically Large Objects. *Asia-Pacific Symposium on Electromagnetic Compatibility & 19th International Zurich Symposium on Electromagnetic Compatibility*, Singapore, 722-725.

Jawad Khan,Wenyang Duan and Salma Sherbaz,(2012),Radar cross section prediction and reduction for Naval Ships,J.Marine.Sci.Appl,11,191-199

J.B.Keller. (1957). Diffraction by aparture. *J.App.Phy.*, 426-444.

Jernejcic RO, Terzuoli AJ Jr., Schindel RF (1994).Electromagnetic backscatter predictions using XPATCH. *Antennas and Propagation Society International Symposium*, AP-S Digest, Seattle, USA, **1**, 602-605.

Kadrovach BA, Wailes TS, Terzuoli AJ, Gelosh DS (1996). Codesign model for Xpatchf optimization. *Antennas and Propagation Society International Symposium*, AP-S Digest, Baltimore, USA, **3**, 1882-1885.

Kingsley S, Quegan S (1999). *Understanding Radar Systems*. SciTech Publishing, Mendham, NJ, USA, 1-24.
Knott EF (1985). A progression of high-frequency RCS prediction techniques. *Proceedings of the IEEE*, **73**(2), 252- 264.

Lee SW, Ling H, Lu C, Moore J (2005). CrossFlux: a method for hybridizing Xpatch and other codes. *Antennas and Propagation*
Society International Symposium, Washington DC, USA, 1A,2-5.
MI, Skolnik. (n.d.). *Introduction to radar systems.* McGrawHill book company.

Moore JT, Yaghjian AD, Shore RA (2005). Shadow boundary and truncated wedge

Northam DY (1985). Modeling of Electromagnetic Scattering from Ships. Advanced Techniques Branch Tactical ElectronicWarfare Division Report, NRL Report 8887, Washington, D.C.USA.

P.Ia.Ufimtsev. (1957). Approximate computation of a plane electromagnetic waves at certain metal bodies:pt1 Diffraction patterns at awedge and a ribbon. *Zh. Tekhn.Fiz(USSR)*, 1708-1718.

R.F.Harrington. (1961). *Time Harmonic Electromagnetic Fields.* New York: McGraw Hill.

R.F.Harrington. (1968). *Field computation by Moment Method.* NewYork: MacMillan.

R.Mitra. (1973). *Computer Techniques for Electromagnetics.* Oxford: Pergamon.

S.Silver. (1949). *Microwave theory and design,MIT Radiation Laboratory Series,Vol.2.* NewYork: McGraw Hill.

Senior, E. K. (1984). Equivalent currents for a Ring Discontinuity. *IEEE Trans. Antenna Propag, AP23*(3), 252-258.

Skolnik MI (2008). *Radar Handbook, Third Edition*. McGraw-HillCompanies, New York, USA, 1.1-1.24 and 14.1-14.46.

Sundararajan P, Niamat MY (2001). FPGA implementation of the ray tracing algorithm used in the XPATCH software. *IEEE*
Midwest Symposium on Circuits and Systems, Ohio , USA,Vol.1, 446-449.Suttie WK (1992).

Wang YX, Ling H (1999). Radar signature prediction using moment method codes via a frequency extrapolation technique.
IEEE Transactions on Antennas and Propagation, **47**(6), 1008-1015.

Wu TK (1989). Radar cross section of arbitrarily shaped bodies of revolution. *Proceedings of the IEEE*, **77**(5), 735-740.

Xiang YC, Qu CW, Su F, Yang MJ (2010). Active cancellationstealth analysis of warship for LFM radar. *IEEE 10thInternational Conference on Signal Processing*, Beijing, China,2109-2112.

Youssef NN (1989). Radar cross section of Complex targets.*Proceedings of the IEEE*, **77**(5), 722 - 734.

Yuceer M., Mautz JR, Arvas E (2005). Method of momentssolution for the radar cross section of a chiral body of
revolution. *IEEE Transactions on Antennas and Propagation*,**53**(3), 1163-1167.