Preliminary analysis and management of specular radar signature of SLN inshore patrol craft

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Abstract— *This paper fulfils the vacuum of research on Radar Signature Management of indigenously developed Inshore Patrol Vessels. It is analyzed considering the Specular Reflections and Outer Structural Characteristics. IPCs are utilized extensively for Inshore Patrolling tasks near to the coast lines, in lagoons and inland waterways. No studies have been carried out so far on the improvement of Radar Cross Section of this class of craft, being a very recent innovation to cater urgent requirements of the recent operations. Further the reduction of Radar Cross Section is important in surveillance tasks of Inshore Patrol Vessels, especially in anti smuggling and anti drug trafficking tasks. Finally we present the results of two of our best models, which gives out extremely low scattering effects from forward-aft and beam side directions.*

***Keywords*— Radar Signature Management, Radar Cross Section, Inshore Patrol Vessels**

I. INTRODUCTION

On successfully ending terrorism, we were to learn many lessons through numerous sacrifices. In this learning process innovativeness stands out to become paramount, now which should be directed to enhance national security through sustainable development. This is by finding innovative solutions to problems, which did not have much time to search into. This paper fulfils the vacuum of research on Radar Signature Management (RSM) of indigenously developed Inshore Patrol Vessel (IPC)s. It analyses the Radar Cross Section (RCS) of 'WaveRider' class SLN Inshore Patrol Craft considering the specular reflections and outer structural characteristics.

The RCS is a representative of geometrical objects of the ship concerned. When an electro-magnetic wave is incident on to a ship, the energy is scattered in all directions, where spatial distribution of energy is dependent upon the geometry of the ship. The RCS () could be defined as a ratio of reflected or scattered field to the incident field as follows:

Where:

$$\sigma = 4\pi \lim_{r\to\infty} r^2 \frac{|\vec{E}_R|^2}{|\vec{E}_I|^2} = 4\pi \lim_{r\to\infty} r^2 \frac{|\vec{H}_R|^2}{|\vec{H}_I|^2} \quad (1)$$

$\vec{E}_R$ – reflected or scattered electric field (V/m)

$\vec{H}_R$ – reflected or scattered magnetic field (A/m)

$\vec{E}_I$ – incident electric field (V/m)

$\vec{H}_I$ – incident magnetic field (A/m)

r - distance between the radar and the ship (m)

The RCS is expressed in , relative to one square meter as: . $\sigma(dBm^2) = 10 \log_{10} [\sigma(m^2)]$ The RCS of a ship can be typically represented as a product of three factors (Miacci and Rezende,2012):

σ = *Prjected Cross Section x Reflectivity x Directivity* (2)

Where the reflectivity is the intercepted radiated (scattered) power by the target; the directivity is the ratio between of the backscattered power into the radar's direction to the power that would have been backscattered, assuming isotropic scattering (Miacci and Rezende,2012).

The empirical formula for RCS of a ship is: (3); where f is the frequency in MHz and D is the full load displacement in kilotons (Skolnik,2008).

RSM is meant for the manipulation of the RCS, to gain the competitive advantage in view of optimal operational effectiveness. Reduction of RCS is important in surveillance tasks of IPCs, especially in anti smuggling and anti drug trafficking tasks. Further RSM is of paramount importance for a ship's survivability (Kim,2012), securing initiative and surprise as well as for the operational effectiveness in offensive as well as in defensive operations. High signature levels are principally undesirable as same provides information to the unwanted parties for detection, classification, identification, tracking and even homing guidance. The RCS is determined by solving Maxwell's Equations. The RCS could be calculated considering the ship as a static entity or also as a dynamic entity (Skolnik,2008), considering ships motion and actual oceanic environment. However for preliminary improvement of design and shaping of a craft, the consideration of a ship static case would be sufficient. O'Nell (O'Nell,1991) examines the naval application of RCS and its implications on the ships' designs from an operational point of view. In (Galle et al,1999) have provided a considerable overview on the naval RSM, covering operational benefits of achieving low RCS. The measurement and simulation techniques are also covered. The work also addresses the RSM aspects with an overview of the design process and future trends. (Khan et al,2012) also provides an overview of theoretical understanding and engineering approach to RCS reduction.

IPC is an indigenous design, developed in keeping the operational concepts of swarming and saturated deployment. The objectives of the development are minimization of danger faced by a single craft and, multiplication of fire power. The craft was extensively utilized in the asymmetric sea battles during last humanitarian operations, involving in a critical role in amphibious operations. The craft was also extensively deployed in past naval blockades as first line of defence (Fish,2009), (Seneviratne,2009). Due to low cost factor in production, in turn minimization of loss factor and ideality for multiplication, are salient features, which are also fundamental requirements in swarming. Improvability is easier on this class of craft due to indigenous technological based boat building process.

Wave Rider Class IPC Craft	
Length overall	14.85 m
Beam	3.39 m
Hull Material	Glass Reinforced Plastic
Draft at Ransom	0.65 m
author name	No
Weight	9.5 Tons

Table 1. Basic Specifications

I. MOTIVATION

IPCs are utilized extensively for Inshore Patrolling tasks near to the coast lines, in lagoons and inland waterways. No studies have been carried out so far on the improvement of RCS of this class of craft, being a very recent innovation to cater urgent requirements of the recent operations. Further the reduction of RCS is important in surveillance tasks of IPCs, especially in anti smuggling and anti drug trafficking tasks on which the craft is utilized at present.

As per (Fish) "the navy has returned to the traditional naval role of defending nation's maritime interests from internal and external threats. The main focus has been on having effective and efficient maritime and coastal surveillance, and the SLN is doing its utmost to keep the sea area free of piracy and armed robbery at sea." We need to maintain surveillance around the country and, hence, need ships and craft, surveillance equipment, and sufficient people to perform the task. Intelligence operations can play a key role in this endeavour. The SLN has to play an enhanced role in intelligence gathering and sharing with other agencies, locally and internationally, for the purpose of national and regional security. Hence a Research vacuum exists for the RSM of the aforesaid craft.

II. RESEARCH OBJECTIVE

To Analyze and propose hull and super structural amendments for SLN IPCs

A. Scattering Mechanisms

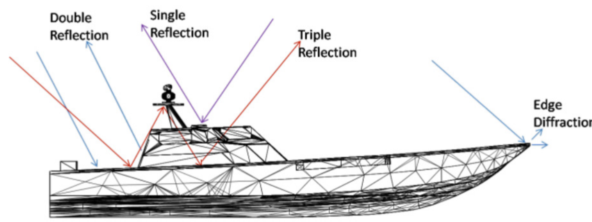

Fig 1. Scattering mechanisms of an IPC

B. RCS Reduction Techniques

Number of techniques are being applied for RSM (Kim,2012), (Norland and Skjerve), as follows:

1. Passive Cancellation
   Impedance Loading – Introduce an echo source, whose amplitude and phase can be adjusted to cancel another echo source.
2. Active Cancellation
   Active Loading- Target must emit radiation in time coincidence with the incoming pulse whose amplitude and phase cancel the reflected energy.
3. Radar Absorbing Material (RAM) s
   Reduce the energy reflected back to the radar by means of absorption and converting EM energy into heat.
4. Shaping
   Orientation of the target surfaces and edges to reflect the scattered energy in the directions away from the Radar.

Out of the above the Shaping has more potential for ships compared to air frames due to presence of dominant multiple bouncing and scattering effects occur in maritime environment (Khan et al, 2012). Further the shaping is comparatively an economical method. Shaping demands least maintainability requirements compared to other methods. Weighing factor of Radar Absorbing materials (RAM) is typically 1-8lb/ft^2. The water intrusion is another problem associated with RAMs (Marker). Thus the research was focused mostly on shaping related RCS contributions. This is due to the reason indicated above as well as due to high value of being aware, of design weaknesses of the original design. Further knowing the RCS performance will also provide a solid foundation to develop the tactical options for future operations.

III. EXISTING RESEARCH

(Kim et al, 2012) has proposed a method of determining dynamic RCS characteristics of a ship utilizing numerical methods and quasi static approach. Here the transfer function related to the ships motion is calculated by application of strip theory of which the result is a numerical model. By calculation of transfer function and pre defined ocean wave spectrum, the time domain ship responses are obtained. The RCS model is derived from data of hull shape, superstructure shapes. The conclusions are: the dynamic RCS values are lowers than that of static. The dynamic RCS is affected by type of ship, wave height, incident angle of radar and ocean waves. It has been also observed that RCS variations is rather less for horizontal polarization than that of vertical.

In (Redada et al, 2006), it has presented a comparison of near and far field analysis of a wedge structure, painted by an incident wave field from a line source or a plane wave. The authors have analysed the effect of cap parameters on the maximum radiation of the line source as well as on the sharp edge behaviour for an incidental plane wave. An analysis of different modelling methods for determination of RCS of surface ships is presented in (Charris and Torres,2012). The authors considered the contribution of different factors of vessel construction for the RCS. This work also analyses the different methods and software available to access the RCS. The work identifies proper handling of shapes in designing of hull and super structure leads to significant reduction of RCS. In (Norland and Skjerve), it is endeavoured to compare high range resolution imaging method and inverse synthetic aperture radar imaging method for identification of the scattering points on large targets. The comparison is presented both in real and simulated targets.

The works (Martin,2009), (Cakir et al), (Kobayashi et al), (Eliking et al,1995) provides an overview of techniques utilized in measurement of RCS. (Martin et al,2009) provides a comparative overview of differentiation of results of measured RCS, as per the technique used for the measurement. The conclusion is that simultaneous methods should be utilized to obtain a precise value of RCS. In (Cakir et al), it is presented a parallelized method of RCS and antenna simulation. Numbers of improved options are also discussed. A software predicting code based on high frequency asymptotic technique is discussed in (Kobayashi et al). The technique is based on physical optics and physical theory of diffraction, which are based on electromagnetic surface and edge currents. The code determines cross polarized field for polarimetric analysis of radar remote sensing imaging and decomposition. The code is also capable of Doppler analysis, hence could be applied for non cooperative target recognition. (Elking et al,1995), provides a review of a software called Computer Aided Design Drafting SCAttering. The aforesaid code could handle both faceted and curved geometries.

In (Gallman, 2009), it has provided the factors which affect any target to be detected by radar, from the practical point of view. The presentation starts from ideal condition and extended to various sea, climatic and visibility conditions. Finally it covers the subject of radar reflectors briefly. (Zaman and Matin, 2012) presented a physical optics based method for the calculation of RCS of shell shaped projectile, with a detailed analysis of the said method. On pointing out the drawbacks for prediction of the surface current density near the shadow boundaries accurately, a Fourier transform based filtering method is proposed. Finally it is stated that results of the proposed with the similar results found in literature. The details of angle and frequency resolved bistatic RCS measurements at Terahertz radar frequencies are presented in (Iwaszczuk et al, 2010). The time domain method was followed for determination of total RCS as well as particular elements of the model. An algorithm called filtered back projection is used to reconstruct two dimensional visualizations of all scattering points.

A comprehensive review of radar absorbing materials are given in (Saville, 2005), covering history, fundamental concepts and available types of materials. Applications of glass reinforced plastic are covered in (Taby et al,2001). Development details of an electrically conductive glass fibre reinforced epoxy resin are presented in (Kupke, 1998). The electrical conductivity is achieved adding carbon black as conductive filler into the epoxy matrix. In (Ismail), it is presented the details of a study of frequency selective surfaces on RCS. The conclusion states that the best performance on RCS reduction due to angle of incidence, minimum reflection response and lower surface current distribution could be achieved at 75^{o} incident angels. Study on optimum corner reflectors in both the theoretical and experimental aspects is given at (Sarabandi and Chiu,1996). A new class of self illuminating corner reflector is also introduced. An actual case study in design and fabrication of RCS reduction cover using a special type of polyester is presented in (Elbakly). The results state the achievement of 96% reduction of the scattering of the radar waves.

IV. METHODOLOGY

'Waverider' class was selected for testing. An extensive qualitative analysis of RSM shaping feature design of the craft was performed with the variation of number of shaping parameters. In turn a large number of 3D simulation models was generated as a result of a former. PC based simulations for Radar Cross Section was carried out for 'S' and 'X' Radar bands.

A. Simulation Parameters

Surface Roughness and Standard Deviations were taken as 1/10 of the wavelength of each Bands (contributes to the diffuse scattering component of RCS). Correlation Distance – average distance (m) at which deviations become uncorrelated was taken as 5. Incident wave polarization: TM-Z (this is vertical polarization where magnitude vector is transverse to the Z axis or vertical). The other parameters are shown in Table 2.

Dielectric Constant	4
Loss Tangent	0.019
X Band Frequency	9410 MHz
S Band Frequency	3050 MHz

Table 2. Simulation Parameters

V. RESULTS

The results of the simulation are depicted in figures 1 to 7. No data of optimal shapes of generated craft designs were included here due to obvious restrictions and also maintaining confidentiality.

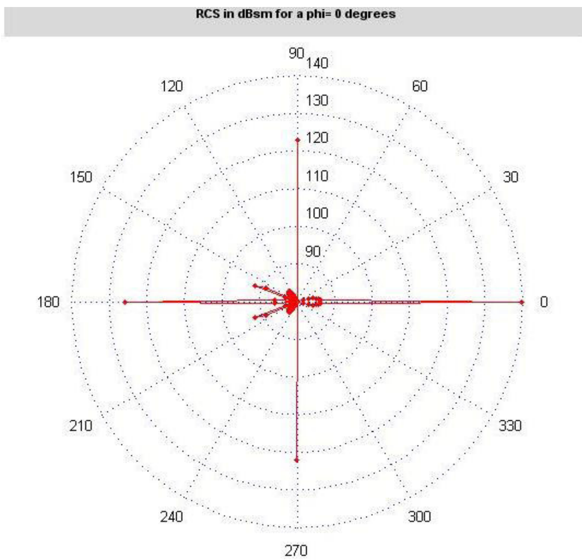

Fig 2. RCS of Original Craft in S band

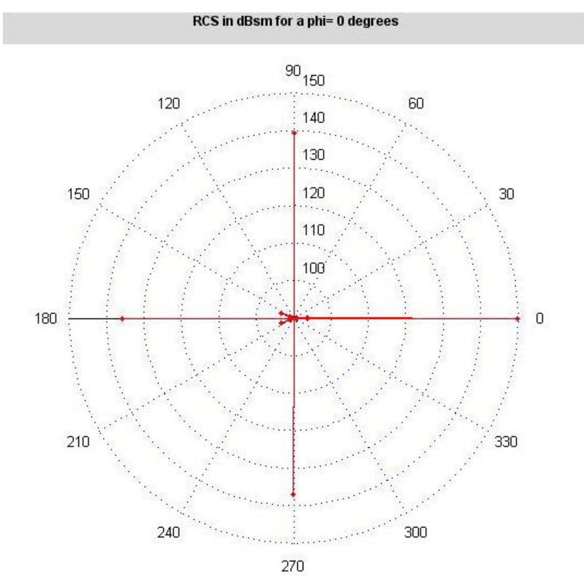

Fig 3. RCS of Original Craft in X band

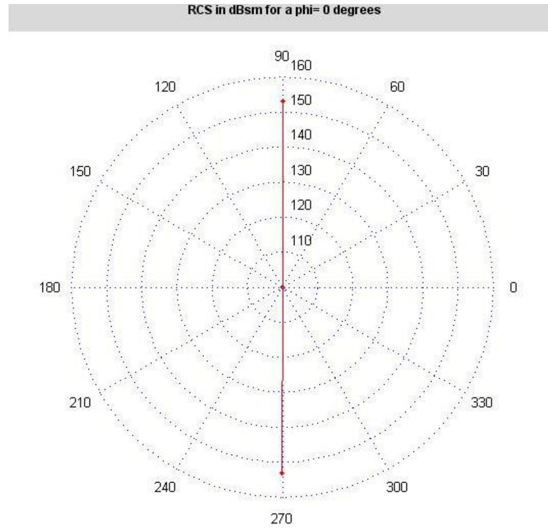

Fig 4. RCS of Proposed Model A in S band

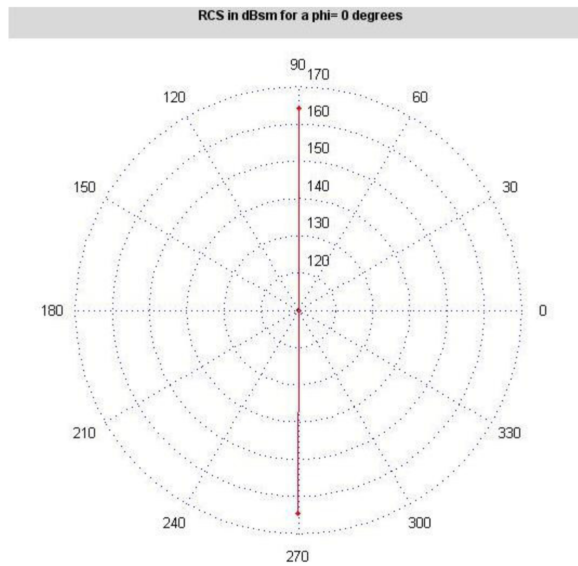

Fig 5. RCS of Proposed Model A in X band

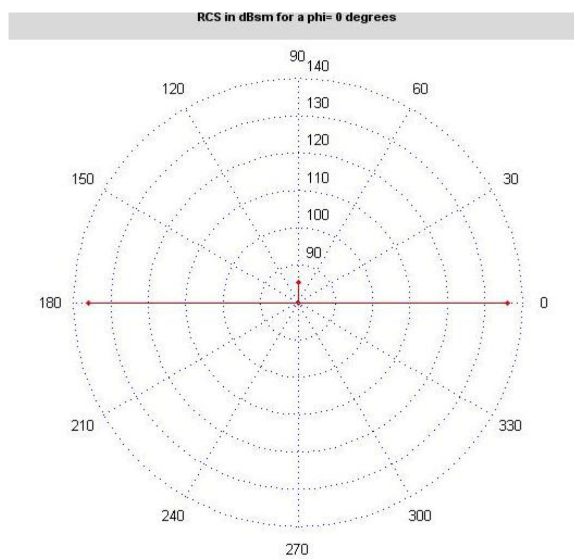

Fig 6. RCS of Proposed Model B in S band

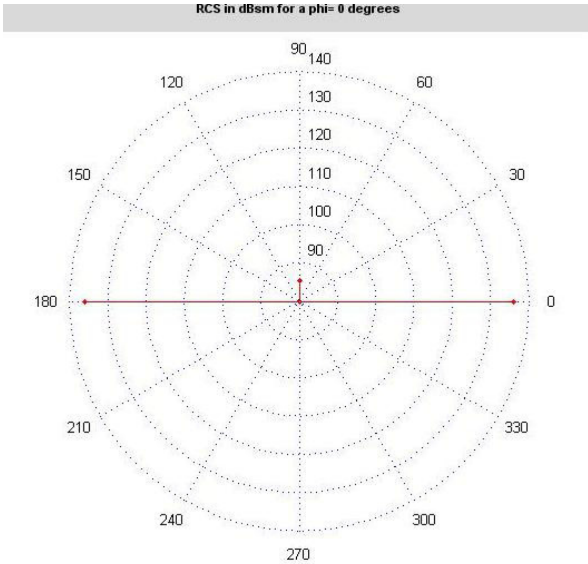

Fig 7. RCS of Proposed Model B in X band

VI. DISCUSSION

The basic shaping design observed in original craft (Figures 2-3), denies it, the critical aspects of stealth performance. In the results of proposed model A (Figures 4-5), it is well understood the effect of optimum shaping, that we have achieved very minimum level of reflections from forward and aft surface reflections towards the radar in both S and X bands. The improvement of very minimum reflections from beam side could be observed in proposed model B (Figures 6-7) in both S and X bands. The lessons learnt during the optimization process of the Shaping of the craft are: the surface normals should always be pointed away from outside radars as feasible. The specular component is a frequency independent parameter. However scattering lobe width is a variable of the frequency. Further purely vertical/horizontal superstructure wall surfaces are not favourable for maintenance of optimum level of RCS. The maximum intensity of the diffracted lobe from an edge observed is to be increased with a particular edge length.

VII. CONCLUSIONS

In conclusion this study has carried out through physical optics simulation across two frequency bands. There is no fundamental barrier exists in shaping design of the Waverider class Inshore Patrol Craft except the radar mast and the radar scanner/transceiver assembly. The radar is required to be replaced with dome type outdoor unit. This precludes its development into a very low observable design we have proposed. The conclusions are: the surface normals should always be pointed away from detecting radar as feasible, hence preventing radar waves not reflected back towards the most likely elevation of the transmitter concerned. The specular component is a frequency independent parameter. However scattering lobe width is a variable of the frequency. Further purely vertical/horizontal Superstructure wall surfaces are not favourable for optimum level of RCS. The maximum intensity of the diffracted lobe from an edge observed is to be increased with a particular edge length.

VIII. FUTURE RESEARCH

The aforesaid findings are planned to be further tested on numerous other software platforms especially to validate our designs against commercial and industrial benchmarks. It is also intended to extend these findings to be incorporated in a future craft design subjected to continuous analysis. Further the methodology and lessons learnt from this research work will be utilized to manage the radar signature of other classes of ships.

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