Chapter 2

REVIEW OF THE PAST WORK IN THE FIELD

Methods for reducing Radar Cross Section (RCS) of objects have been investigated by many researchers both experimentally and theoretically for the last so many years. This chapter presents a chronological review of important research in the fields of RCS studies, RCS reduction techniques and fractal based scattering and radiating structures. This chapter is divided into two sections. The first section presents a review of RCS studies, RCS reduction techniques and its measurement techniques and the studies of fractal electrodynamics are reviewed in the second section.
2.1 RADAR CROSS SECTION STUDIES

The history of investigations on Radar Cross Section dates back to the early part of twentieth century. The results of the investigations were not published until World War II. From the end of the World War II till the present time, the radar response of specific targets has continued to be an area of considerable interest to many researchers, and great deal of work has been reported in the field.

The analysis and measurements on RCS of various objects are available in open literature [1-4]. Hu [5] had measured the RCS of a dipole antenna in the VHF range with the input terminals of the dipole shorted. The experimental results were compared with theoretical values.


E. H. Newman and Forria [7] presented a solution to the problem of plane wave scattering by a rectangular microstrip patch on a grounded dielectric substrate. The model does not include the microstrip feed, and thus does not include the so-called "antenna mode" component of the scattering. The solution begins by formulating an electric field integral equation for the surface current density on the microstrip patch.

D. Pozar [8] envisaged the problem of a rectangular microstrip antenna printed on a uniaxially anisotropic substrate. The effect of anisotropy on the resonant frequency and surface wave excitation of the antenna is considered, and the radar cross section (RCS) of the antenna is calculated. The RCS calculation includes the effect of the load impedance (antenna mode scattering). The derivation of the uniaxial Green's function
in spectral form, the associated moment method analysis for the input impedance and scattering of the microstrip patch, and the expressions for the far-zone fields of a source on a uniaxial substrate are presented.

D. R. Jackson [9] proposed a general formula for an arbitrary resonant conductive body within a layered medium, which shows that the body radar cross section is directly related to the radiation efficiency of the body.

A. Taflove and K. Umashankar [10] presented two disparate approaches—FDTD and MoM, the analysis and modeling of realistic scattering problems using these two methods are summarized and compared. New results based on these two methods for induced surface currents and radar cross section are compared for the three dimensional canonical case of a conducting metal cube illuminated by a plane wave.

D. Colak et al [11] presented a dual series based solution for the scattering of an H-polarized plane wave from a silted infinite circular cylinder coated with absorbing material from inside or outside. For both cases, numerical results are presented for the radar cross section and comparisons are given for two different realistic absorbing materials.

C. –G. Park et al [12] investigated the problem of transverse magnetic plane wave scattering from a dihedral corner reflector. Using the mode matching technique, the transmitted and scattered fields are expressed in the angular spectral domain in terms of radial waveguide modes.

D. A. Edward et al [13] presented the application of variational techniques to the electromagnetic scattering problem. It has been shown that these techniques can deal effectively with distorted structures and the case of orthogonal and nonorthogonal distorted dihedrals in some detail.
Harrison and Heinz [14] had derived a formula for the RCS of a solid wire, tabular and strip chaff of finite conductivity approximating one half wavelengths or less in length.

In the RCS analysis of coated metal plate by Knop [15], the thickness of the plate and that of the coating were assumed to be thin, and the size of the plate was large, so that physical optics approximation could be used.

Blore [16] had made experimental investigation for the effect of nose on backscattering RCS of grooves, cone spheres, double backed cones, double rounded cones and cone spheres.

Rheinstein [17] had carried out several series of rigorous numerical calculations of the backscatter cross sections of a conducting sphere with a thin lossless dielectric coating.

Senior [18] reviewed the analytical techniques available for estimating the backscattering cross section of a metal target with classification given on the basis of wavelength to dimension of the targets.

Blacksmith et al. [19] reviewed the history of radar cross section measurement. Crispin and Maffet [20-21] reviewed the RCS measurement methods for simple and complex shapes, with special attention being devoted to results rather than derivations of formulae.

The conditions of RCS measurement in terms of variations in the amplitude and phase of the incident field at the target, were discussed by Kouyoumijian and Petits [22]. A number of minimum range conditions were listed and discussed. The theoretical and measured data pertaining to background levels which can be achieved with conventional target supports were presented by Freeny [23].
Leipa and Senior [24] investigated the scattering of plane electromagnetic wave by a metallic sphere loaded with a circumferential slot in a plane normal to the direction of incidence. The slot was assumed to be of small width and the field scattered in any direction is obtained by the superposition of the field diffracted by an unloaded sphere, and the field radiated by excited slot. Numerical and experimental results of backscattering were also presented.

Corriher and Pyron [25] have presented a bibliography of articles on radar reflectivity and related subjects. The design of an extremely high range resolution FM/CW X-band radar and RCS measurements were illustrated by Alongi et al. [26]. The primary design objective was to provide the capability to measure RCS of scaled models with a range resolution equal to a small fraction of the target length. Millin et al. [27] presented a numerical technique for the determination of scattering cross section of infinitely long cylinders of arbitrary cross section.

Radar cross section of a rectangular flat plat was investigated by Ross [28]. The simple physical optics theory was used for predicting the near specular values of RCS but failed to account for polarization dependence. The calculations based upon the geometrical theory of diffraction showed excellent agreement with measured data except on edge on aspects.

Miller et al. [29] presented the monostatic RCS results for straight wires having lengths of multiple wavelengths. The numerical RCS values obtained from solving the Pocklington’s integral equation for induced current, fall within 1 dB of experimental measurements.

RCS of a perfectly conducting sphere coated with a spherically inhomogeneous dielectric was obtained using the geometrical theory of
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diffraction by Alexopoulos [30]. The result was compared to the second order approximation obtained by asymptotic theory.

Miller and Morton [31] have studied the RCS of a metal plate with resonant slot. RCS of a thin plate for near grazing incidence was studied by Yu [32] with three higher order diffraction techniques.

Rahmat Samii and Mittra [33] employed a new integral equation to calculate the current distribution on a rectangular plate, when illuminated by a plane wave. Numerical results were also presented for the RCS of a plate for different angles of incidences and different dimensions of the plate.

Lin et al. [34] experimentally and numerically investigated the RCS of a conducting rectangular plate. The numerical example also included the edge on incidence where physical optics and geometric theory of diffraction have failed.

Wier et al. [35] developed a technique for making RCS measurements over wide frequency bands. The Hewlett-Packard (HP) automatic network analyzer, which measures the scattering parameters at discrete frequencies over a band, has been adapted to obtain RCS measurements. Typically the background clutter, antenna cross coupling and system errors in the absence of target were reduced by the system measurement techniques to an equivalent value of -45 dBsm.

Mautz and Harrington [36] presented the computation of radiation and scattering of electromagnetic fields by electrically large conducting cylinders using geometrical theory of diffraction for the transverse electric case. The computation accuracy was checked by comparing the results to corresponding ones computed by a moment method solution to the H-field integral equation.
An accurate mathematical model for the backscattering from a loaded dihedral corner has been developed by Corona et al. [37]. This model employed a generalization of physical optics to loaded surfaces which takes into account the lighting of each face by rays diffracted by edge of other one.

Griesser and Balanis [38] predicted the backscattered cross section of dihedral corner reflectors which have right, obtuse and acute interior angles, using the uniform theory of diffraction (UTD) plus an imposed edge diffraction extension. Multiple reflected and diffracted fields up to third order were included in the analysis, for both horizontal and vertical polarizations.

Arvas and Sarkar [39] have considered the problem of determining the RCS of two dimensional structures consisting of both dielectric and conducting cylinders of arbitrary cross section. Both transverse electric and transverse magnetic cases are considered. The problem is formulated in a set of coupled integral equations involving equivalent electric and magnetic surface currents, radiating in unbounded media.

The low RCS measurement requires careful cancellation of the background reflections. The large size of the target tends to upset the background cancellation balance obtained in the absence of the target. So, when the cross section of the target is large, the target to background cross section ratio can be made large.

RCS reduction of dihedral corners, which are major scattering centers in radar signatures of ship and military ground vehicles, was studied by Knott [40]. A criterion was developed that gives the required corner angle as a function of RCS reduction desired and electrical size of corner faces.
The broadside RCS of a rectangular box was studied by Tsai [41] using the integral equation technique. Jones and Shumpert [42] presented the electromagnetic scattering behaviour of a perfectly conducting infinitesimally thin, spherical shell with circular aperture. The problem was formulated in terms of E-field integral equation. The calculated values of surface currents and RCS were presented and discussed for several cases of interest.

A scheme is presented by J. L. Volakis et al [43] for reducing the RCS of patch antennas outside their operational band without compromising gain performance. This is achieved by placing a narrow resistive strip (distributed loading) around the periphery of the patch which has minimal effect at the operational frequency of the patch. Results are presented using a finite element-boundary integral code demonstrating the effectiveness of this scheme over the traditional method of using lumped loads.

Keen [44] presented the development of a numerical technique for calculation of the RCS of any regular shape of corner reflector consisting of three orthogonal plates. A simple and accurate formula to calculate the backscattered RCS of a perfectly conducting hollow, finite circular cylinder with closed termination was proposed by Huang [45]. The radiated field from the cavity region was evaluated via, the Kirchoff approximation and the reciprocity theorem.

Le Vine [46] presented a solution for the backscatter RCS of dielectric disks, of arbitrary shape, thickness and dielectric constant. The result was obtained by employing a Kirchoff type approximation, to obtain the field inside the disk.
The application of the uniform asymptotic theory of diffraction to obtain an expression for RCS of curved plate was presented by Sanyal and Bhattacharyya [47]. Comparison with experimental results shows good agreement even for different small and intermediate radii of curvature of the plate.

An asymptotic high frequency estimation of monostatic RCS of a finite planar metallic structure coated with a lossy dielectric was made and compared with experiments in X band, by Bhattacharyya and Tandon [48].

Rembold [49] reported the measurement of RCS of a long metallic rod using continuous wave Doppler radar at 60 GHz. The derived expression for RCS demonstrates good agreement with the measured data. A continuous wave RCS measurement facility in the X band was described by Bhattacharyya et al. [50]. The set up was capable of automatically measuring the monostatic RCS over aspect angle ranging from 0 to +or − 180° for both parallel and perpendicular polarizations. The typical value of effective isolation between transmitted and received signal was of the order of 60 dB and dynamic range of 35 dB.

Corona et al. [51] studied the radiation characteristic of a 90° dihedral corner reflector and showed that it can be conveniently used as a reference target in experimental determination of RCS. The numerical model developed using physical optics and image method, has been improved by taking into account the rays diffracted by corner edges.

In 1987, Dybdal [52] reviewed the fundamentals of RCS measurements. The wide bandwidth electronic and digital signals processing capabilities encouraged the earlier objective of determining the RCS and have extended to include the developing techniques to distinguish different types of targets and modifying the target scattering properties.
Achievable accuracy and those factors that limited the accuracy were discussed.

Lee and Lee [53] calculated the RCS of a circular waveguide terminated by a perfect electric conductor. Geometrical theory of diffraction was employed for the rim diffraction and physical optics was employed for the interior irradiation.

Anderson [54] used the method of physical optics to calculate the magnitude of the reduction of RCS, which result from modest departures from orthogonality. The theoretical results were compared with experimental measurements which are found to be in very good agreement.

Welsh and Link [55] developed two theoretical models for RCS measurements of large targets consisting of multiple independent point scatterers.

The history of bistatic RCS of complex objects was presented by Glaser [56]. Beginning with the first radars before World War II, the discussion proceeds with current experimental and analytical modeling methods. Data were presented from experiments on cylinders and missiles.

Youssef [57] presented a summary of developments and verifications of a computer code, for calculating the RCS of complex targets. It is based on physical optics, physical theory of diffraction, ray tracing, and semi-empirical formulations. Wu [58] evaluated the RCS of arbitrarily shaped homogeneous dielectric body of revolution by surface integral formulation. Accuracy of the method was verified by good agreement with the exact solutions for the RCS of a dielectric sphere.

Mitschang and Wang [59] described hybrid methods incorporating both numerical and high frequency asymptotic techniques for
electromagnetic scattering problems of complex objects. Sarkar and Arvas [60] have presented an E-field equation for the computation of RCS of finite composite conducting and lossy inhomogeneous dielectric bodies.

RCS patterns of lossy dihedral corner reflectors were calculated using a uniform geometrical theory of diffraction for impedance surfaces by Griesser and Balanis [61]. All terms upto third order reflections and diffractions were considered for patterns in the principal plane. The dihedral corners examined have right, obtuse, acute interior angles and patterns over the entire $360^\circ$ azimuthal plane were calculated.

The problem of determination of the fields scattered by an infinite dielectric cylinder of arbitrary cross section, located at the interface between two semi-infinite dielectric media was presented by Marx [62]. The derivation of integral equations was given for transverse electric mode, for dielectric cylinder and for a perfectly conducting cylinder.

Pathak and Burkholder [63] have analysed the problem of high frequency electromagnetic scattering by open ended waveguide cavities with an interior termination, via three different approaches, modal, ray and beam techniques. Typically numerical results based on the different approaches were presented, and some pros and cons of these approaches were discussed.

The problem of electromagnetic scattering from a plate with rim loading for transverse electric (TE) and transverse magnetic (TM) polarizations was examined by Bhattacharyya [64], based on uniform geometrical theory of diffraction. An attempt was made to estimate the width of the coating around the edges which gives the same result as the plate of same size which is uniformly coated. Theoretical results were presented and discussed.
Penno et al. [65] examined the scattering from a perfectly conducting cube. The results presented were for a cube on the order of 1.5 - 3 wavelengths on edge, which is illuminated at broadside incidence. Hybrid iterative method was employed, which utilizes an initial approximation of the surface currents on the cube faces.

Tice [66] has presented an overview of RCS measurement techniques. In this review, the measurement radar was limited to ground based radar systems. Targets included operational full scale ships and aircrafts, full scale aircraft mounted on pylons and scale model of ships in water.

Choi et al. [67] have investigated the backscattering RCS of finite conducting cones using equivalent current concept based on uniform geometrical theory of diffraction. The discrete Fourier transform method was used to calculate the RCS of orthogonal and non-orthogonal dihedral corner reflectors by Shen [68]. The results obtained using the method compare favourably with measurements and predictions computed using the method of moments.

The RCS of a partially open rectangular box in the resonant region was investigated by Wang et al. [69]. Two dimensional numerical results were generated using the method of moment’s solution to the electric field integral equation. The dependence of the resonant behaviour on the box dimension, aperture size and incident polarization were interpreted in terms of the field distribution inside the cavity. Experimental data for a three dimensional box were also presented. They were consistent with the two dimensional simulation.

Blejer [70] presented the polarization matrix for a cylinder on a circular disk using the physical optics approximation. Multiple scattering
between the cylinder and the circular disk ground plane was obtained by invoking the image theory, and was expressed as a bistatic return from the cylinder and its image, due to the image field. Theoretical values were compared with experimental results.

Goggans and Shumpert [71] presented the RCS of dielectric filled cavity backed apertures in two dimensional bodies for both TE and TM polarizations. The method of moment technique was employed to solve a set of combined field integral equations for equivalent induced electric and magnetic currents on the exterior of the scattering body and associated aperture.

Baldauf et al. [72] presented a general method for calculating the RCS of three dimensional targets. Following shooting and bouncing ray method, a dense grid of rays was launched from the incident direction towards the target. Each ray was traced according to geometrical optics theory including the effect of ray tube divergence, polarization and material reflection coefficient. At the point where the ray exits the target, a physical optics type integration is performed to obtain the scattered fields. The theoretical results were in good agreement with measured data.

Mongia et al. [73] reported the results of precise measurement of RCS of dielectric resonators of cylindrical and rectangular shape at resonance. The measured results were compared with those predicted by asymptotic theory.

The monostatic RCS spectra of rotating fan array, with tilted metal blades were investigated by Yang and Bor [74]. The high frequency theoretical treatment of slowly rotating and electrically large scatterer was based on the quasi-stationary method with the physical optics / physical
theory of diffraction technique. The agreement with the theoretical and experimental results was acceptable.

Trueman et al. [75] investigated the effect of wire antennas on the high frequency RCS of aircraft by comparing the RCS of strip, cylinder, and a rod with and without attached wire.

Mishra et al. [76] presented the precision measurements of RCS of simple rod and cylinder for all angles of incidence in a plane containing the long axis of the target. Fully automated RCS measurement setup used an HP series 9000, model 332 instrumentation controller for process control and data acquisition and processing. HP 8510 Network analyzer system with HP 8511A frequency converter as receiver front end was used to determine the scattered field amplitude and phase at many frequencies from 2 to 18 GHz. The extensive measured RCS data were used as a reference for validating numerical computations.

Rius et al. [77] presented a new and original approach for computing the RCS of complex radar targets, in real time 3-D graphics workstation. RCS of aircrafts were obtained through physical optics (PO), method of equivalent currents (MEC), physical theory of diffraction (PTD) and impedance boundary condition (IBC). A graphical processing approach of an image of the target at the workstation screen was used to identify the surface of the target visible from the radar viewpoint and obtain the unit normal at each point. The high frequency approximations to RCS prediction were then easily computed from the knowledge of the unit normal at illuminated surface of the target. This hybrid graphic electromagnetic computing results in real-time RCS prediction for complex targets.
RCS of rectangular microstrip patch on a lossy biased ferrite substrate was investigated by Yang et al. [78], based on a full wave integral equation formulation in conjunction with the method of moments. The RCS characteristics, especially the resonance behaviour of the patch, with various biasing conditions were studied and compared to the case of an unbiased ferrite.

Birtcher et al. [79] measured the RCS of a long bar (at X-band) and a scale model aircraft (at C-band) under the quasi plane wave illumination and cylindrical wave illumination and compared the results.

The RCS of a small circular loop made from YBCO high temperature superconductor were calculated as a function of applied magnetic field strength by Cook and Khamas [80]. It was shown that RCS is reduced as the magnetic field increases and that effect was more pronounced as the radiation distance decreases.

The RCS of several bodies proposed by the electromagnetic code consortium (EMCC) was calculated using transmission line matrix (TLM) method [81]. The results were in good agreement with experimental and moment method solutions, when TLM was used together with an appropriate boundary condition and a near to far zone transmission approach.

Grooves [82] have proposed an important class of boundary structures, having alternate areas of conducting and non-conducting materials, for control and direction of electromagnetic waves incident on them.

The solution for the problem of a plane wave incident obliquely on a parallel wire grid, which is backed by a plane conducting surface was
presented by Wait [83]. It was shown that, in certain cases, a resistive wire grid will absorb the entire incident wave.

The theoretical and experimental results for the reflection and transmission of uniform plane electromagnetic waves, normally incident on an ideal strip grating was presented by Primich [84]. The theory was based on the variational method, and measurements were made at normal incidence in a parallel plate region operating in 8 – 10 cm wavelength range.

Tadaka and Shiniji [85] presented a diffraction grating which was a new version of microwave passive repeater developed to improve the transmission qualities of links utilizing mountain diffraction. Principles and characteristics of diffraction gratings were given with test results.

Sigelmann [86] has studied the surface wave modes in a dielectric slab covered by a periodically slotted conducting plane. Sampling and variational methods were used to obtain surface wave modes.

Jacobson [87] described an analytical and experimental investigation of practical, two dimensional periodically modulated slow wave structures. The structure was a dielectric slab covered on one side by a perfectly conducting ground plane and the other side by perfectly conducting strips perpendicular to the direction of propagation.

Integral equations for currents induced on an infinite perfectly conducting grating for plane wave illumination were presented by Green [88]. These integral equations were approximated by matrix equations, which were readily solved for currents. From these currents the strengths of the grating modes were obtained.

A numerical solution for the problem of scattering of a plane wave by a dielectric sheet with an embedded periodic array of conducting strips
was presented by Lee [89]. The solution to the problem of scattering of plane wave by an infinite periodic array of thin conductors on a dielectric slab was formulated by Montgomery [90]. Numerical results were presented with experimental data.

Montgomery [91] analyzed the scattering of an infinite periodic array of microstrip disks on a dielectric sheet using Galerkin solution of vector integral equation. In 1979, he studied [92] the solutions of TE and TM scattering for an infinite array of multiple parallel strips. The solution was found using the perturbation form of modified residue calculus technique. Numerical results were presented and discussed.

By using microwave models of optical gratings, Tamir et al. [93-95] realized dielectric grating with asymmetric triangular or trapezoidal profiles that exhibit beam coupling efficiencies. The behaviour of leaky modes along microwave gratings show that, Bragg scattering approach provides simple design criteria for blazed dielectric gratings and broad band high efficient optical beam coupling devices.

Petit [96] presented the electromagnetic theory of plane grating, in which the integral methods and differential methods were studied in greater depth.

Kalhor and Ilyas [97] analyzed the problem of scattering of electromagnetic waves by periodic conducting cylinders embedded in a dielectric slab backed by a plane reflector using the integral equation technique. The results were compared with the limited numerical results available in the literature and indicate excellent agreement.

A method of analysis of strip gratings with more than one conducting strip per period was given by Archer [98] and that was then applied to a periodic twin strip grating with two unequal gaps.
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Formulae for ideal and good grating system were given by Xu-Jeadong and Guorui [99]. Some applications of the strip grating systems such as frequency filter, polarization rotators and impedance transformers were introduced and the principle design considerations of impedance transformers were discussed.

Kobayashi [100] investigated the problem of diffraction by a thick strip grating with the aid of Wiener-Hopf technique. Kobayashi [101-102] considered periodic parallel plate grating with dielectric loading, and the problem was analyzed with the same technique. The Wiener-Hopf equation was solved by decomposition procedure and then the modified residue calculus technique (MRCI) was applied to increase the accuracy of the solution.

Jose and Nair [103] have showed that the gratings can be used to simulate the effect of rectangular corrugations in conducting surfaces. The perfect blazing of reflector backed thin strip gratings to \( n = -1 \) spectral order for both TE and TM polarizations were compared with corrugated reflection gratings.

A fast convergent integral equation solution to the scattering problem of TE/TM plane wave by a one dimensional periodic array of thin metal strips on a dielectric substrate was described by Wu [104].

The development of reflector backed strip gratings exhibiting the properties like the elimination of specular reflection from a conducting surface for normal and near normal incidence was reported by Jose et al. [105]. This was achieved by using self complimentary strip grating which were not possible using conventional rectangular metallic corrugations.

Kalhor [106] analyzed the scattering of electromagnetic waves from a dielectric slab loaded with periodic array of conducting strips, using
mode matching technique. The fields were expanded in term of a suitable propagating and evanescent modes in various regions. He presented the variation of energy of significant scattered modes with various structure parameters for both polarizations of incident wave.

Kildal [107] defined artificially soft and hard surfaces for electromagnetic waves. Transversely corrugated surfaces and other alternative surfaces form soft surfaces and longitudinally corrugated surfaces from hard surfaces.

Kalhor [108] analyzed the diffraction of e.m. waves by plane gratings of finite extent and the results were compared with that of infinite extent to determine the minimum structure sizes that should be used in experimental measurements to obtain meaningful results.

The scattering and guidance of electromagnetic waves from a two dimensionally periodic metal grating structure were investigated by Wu and Chen [109]. The numerical results obtained were useful for the design of new devices in 2-D periodic structure, particularly in millimeter wave frequency range, such as antennas, filters, couplers and distributed reflectors.

Jin and Volakis [110] have discussed the scattering characteristic of an infinite and truncated periodic array of perfectly conducting patches on a dielectric slab. An approximate solution was presented for truncated array scattering based on the exact solution for the corresponding infinite array. The result was obtained numerically by solving for the patch currents via, a conjugate gradient fast Fourier transform technique. The scattering pattern of the finite array was then computed approximately by integrating the infinite periodic array currents over the extent of the given finite array.
A new robust approach for the analysis of strip gratings both of finite and infinite conductivity, for both TE and TM cases, was described by Naqvi and Gallagher [111]. The field distributions in the plane of the grating were expanded in a Fourier series, whose coefficients were derived as the solution to an infinite dimensional system of linear equations.

Aas [112] presented the concepts of artificially soft and hard surfaces, interpreted in terms of plane wave reflection properties of the surfaces, in particular the reflection phase angles for two orthogonal polarizations. Numerical results for corrugated and strip loaded surfaces were presented. The results indicate that strip loaded surface is the most promising candidate for hard surface. The advantage of strip loaded surface is that, when properly designed it can have a larger bandwidth while at the same time being thinner than corrugated surface.

Gedney and Mittra [113] have analyzed the problem of diffraction by a thick, conducting grating situated in an inhomogeneous dielectric slab, using the generalized network formulation, which combines the method of moment and finite element method. The solutions were presented for both TE and TM polarization.

Borkar et al. [114] presented the design procedure of a millimeter wave twist reflector, which is a polarization sensitive device consisting of unidirectional planar metallic grating supported on a dielectric substrate. The loss factor of the dielectric material has been accounted for the prediction of twist reflector performance. With the introduction of these corrections, experimental results were found to be in close agreement with the theory.

Gimeno et al. [115] presented a numerical model to analyse a system formed by the cascade connection of slanted strip grating plates, to
rotate the polarization of a linearly polarized wave. General criteria of design were presented and four plates 60° polarizer was designed in the 7–8 GHz band. Good agreement was found between theoretical and measured results.

Jose et al. [116] presented a method for RCS reduction of metallic cylinders using strip grating technique. The RCS of a cylinder with periodic strip loaded dielectric surface was determined experimentally and it is compared with the reference target having the same dimensions. Typical reduction of 30-40 dB was reported. The RCS measurements were made using HP 8510B network analyzer along with test set. The measurement principle was based on the time gated signal which is differentiated according to their time of arrival. This signal was analyzed using the network analyzer, which is configured to make swept frequency RCS measurements in the time domain with required corrections.

Ajaikumar et al. [117] studied the effect of rectangular strips on a dielectric slab on the RCS of dihedral corner reflector for TE polarization. The strip grating technique was found to be more effective in the RCS reduction of corners for normal incidence. Typical reduction of 40 – 50 dB was achieved but only over narrow frequency range.

Hong and Zhu [118] presented a mixed technique for calculating the RCS characteristics of a dielectric coated conducting cylinder loaded with metallic strips, for TE wave incidence, the technique was based on the Spectral Domain Method (SDM), Conjugate Gradient Method (CGM) and Fast Fourier Transform (FFT). Numerical results were presented which shows the RCS can be effectively controlled by adjusting the period or spaces between the strips.
Kell and Pederson [119] compared RCS measurements in narrow band continuous wave system and on short pulse system. They also presented data for one model target.

Knott [120] had shown that the deformation of metallic flat plates into cylindrical segments reduces the large specular echo but does not necessarily reduce the mean cross section by more than 1 dB or so.

Ebbeson [121] has given the results of an analytical and numerical investigation of TM polarized plane wave scattering from an infinite fin-corrugated surface. The surface was composed of infinitely thin, perfectly conducting fins of spacing $\lambda/2 < a < \lambda$. Specular reflections from this ideal surface were completely converted to backscatter in a direction opposite to the incident wave when the fin period and height were properly chosen. A procedure for the design and performance prediction of a finite fin-corrugated surface composed of finitely thick fins were also described.

John et al. [122] described a bistatic RCS measurement technique. It used the variation of CW null balance approach, resulting in rapid measurement time. A network analyzer and process computer were incorporated into the existing image ground plane system to improve the bistatic capability and flexibility.

Jull and Ebbeson [123] proposed the use of corrugated surfaces to reduce interfering reflections from buildings. Numerical examination was made for infinite comb grating under H-polarized plane wave illumination with grating space between $\lambda$ and $\lambda/2$ Model measurements at 35 GHz on finned surfaces of finite size under non plane wave illumination are given to verify whether the surfaces behave essentially as predicted for the infinite comb.
Jull et al [124] reported that perfect blazing of reflection gratings to the n = -1 spectral order for both TE and TM polarizations is possible with rectangular grooves with angle of incidence in the range 19.5° to 59.4°. Design dimensions were verified experimentally at 35 GHz.

Heath and Jull [125] described that corrugations could completely convert specular reflection from a conducting surface to backscatter. They showed that this was possible with rectangular groove surface profile for either TE or TM polarizations or for both simultaneously. Numerical and experimental results were illustrated for a surface, designed for plane wave incidence at 50° from the normal.

An experimental investigation of the scattering from crossed gratings of square pyramids was conducted by Cai et al. [126]. They have provided examples of the use of equivalent singly periodic grating surfaces as a guide to the design of crossed grating surfaces.

Jull et al [127] presented a numerical analysis of thin corrugated strips with rectangular groove profiles, dual blazed to n = -1 spectral order. It has shown that, high efficiency gratings remain efficient as the number of grating elements is reduced to as few as two, provided that incidence is not near grazing. Numerical results show that the main effect of reduced grating size is a broadening of the diffracted beam, which can be predicted from a simple formula.

The fundamental of radar cross section measurements was reviewed by Robert B. Dybdal [128]. Measurement facilities including the present research activities on compact range techniques are then described. Those factors that limit the accuracy of RCS measurements are discussed.
T. Mathew et al. [129] demonstrated a trapezoidal strip grating surface that eliminates specular reflection over almost the entire X-band frequency range for TM polarization.

D. S. Stephen et al. [130] reported the elimination of specular reflection over a wide range of aspect angles for TE polarization by a strip grating surface of two dimensional periodicity.

They also [131] proposed simultaneous elimination of specular reflection and backscattered power from a plane metallic surface by simulated corrugated surfaces of constant period and variable strip width for TM polarization.

T. Mathew et al. [132] developed a simulated corrugated surface that eliminates specular and backscattered power simultaneously for both TE and TM polarization.

The RCS of a finite-size ground plane with perforated triangular apertures has been characterized by Kathleen L. Virga [133]. The results of the monostatic RCS computed by the method of moments surface patch formulation for a plane wave incident on finite size plates with two widely spaced and two closely spaced apertures have been presented.

A modified mode matching technique that uses the segmentation method to analyse the scattering properties of a dual periodic strip grating is presented by D. S. Stephen et al. [134].

Polarimetric radar cross sections were measured for two large Bruderhedral at 35 and 93 GHz [135]. The overall spread in the measured RCS was 2 dB. It was found that the absolute RCS as well as the dependence of the RCS on elevation angle could be significantly altered by a slight misalignment of the Bruderhedral.
The transmission line modeling (TLM) method is applied to determine the radar cross section of very thin conducting targets under critical illumination that are included in a benchmark of thin plates proposed by the electromagnetic code consortium (EMCC) for validation of low-frequency electromagnetic computational codes [136].


H. Mosallaei and Y. Rahmat-Samii [139] presented a modal/GA technique for RCS reduction in a wide-band frequency range for planar, cylindrical, and spherical conducting structures. Using the GA method, RCS of these structures is reduced more than 27dB by designing an optimized RAM coating. In addition, it is shown that the optimum RAM coating designed for a planar structure can also reduce the RCS of the cylindrical and spherical structures effectively.

A comparative study on target identification using RCS signature of an aircraft in both the frequency domain and the range domain is proposed by Chan [140].

Smith [141] demonstrated a technique for measuring the RCS of 2D diffracting sources. The measured and predicted diffraction RCS of a conducting halfplane edge and a gap in an otherwise infinite conducting plane are presented. The technique may be used to measure the diffraction coefficient of an impedance discontinuity.

P. Corona et al [142] analyzed the electromagnetic backscattering by a perfectly conducting dihedral corner reflector with sinusoidal profiles characterized by different periodicity values.
An application of the theory of open electromagnetic problems by circuitual analysis is presented by Penaranda [143] for the reduction of radar cross sections of homogeneous cylinders without need for other dielectric media.

V. Losada et al [144] proposed Galerkin’s method in the Hankel transform domain (HTD) to the determination of the RCS of unloaded nstacked circular microstrip patch antennas fabricated on a two-layered substrate which may be made of a uniaxial anisotropic dielectric, a magnetized ferrite or a chiral material.

Richard Norland [145] showed how the assumption that specular backscattered reflection pattern of the flat plate reduces the induced multipath error is constrained by the radar wavelength, geometric parameters and by the plate dimension.

Misran et al [146] compared the performance of a concentric ring reflectarray element backed either by a solid metal ground plane or a frequency-selective surface. Simulated and measured results showed that the ‘in-band’ reflection phase response of the two structures is similar; however, the periodic surface reduces the ‘out-of-band’ reflectivity of the antenna by more than 4 dB, thereby decreasing its RCS profile to these signals.

A. E. Serebryannikov and A. I. Nosich [147] developed a generalized model to study the TE-polarized plane wave scattering by coated and uncoated slotted circular cylinders of nonzero thickness and by a filled and empty circular cylinders with sectoral cuttings.

Peixoto et al [148] investigated the RCS reduction of dihedrals by shaping and by application of Radar Absorbing Material (RAM).
2.2 FRACTAL ELECTRODYNAMICS

The blend of fractal geometries and electromagnetics is called fractal electrodynamics. A good reference on the basics of fractal geometry, especially on how they pertain to the field of electrodynamics is described by D. L. Jaggard in [149]. Fractal geometry was first defined by Benoit Mandelbrot [150], to define many perplexing geometries found in nature. A very good reference for fractal antennas as elements and array can be found in [151] by D. H. Werner and R. Mittra.

J. Romeu and Y. Rahmat-Samii [152] proposed that the multiband properties of self-similar fractals can be advantageously exploited to design multiband frequency selective surfaces. It is shown that the self similarity of the Sierpinski dipole translates into a dual-band behaviour of a FSS made by arraying a two iteration Sierpinski dipole.

C. Puente-Baliarda et al [153] studied the multiband behaviour of the fractal Sierpinski antenna.

D. H. Werner et al. [154] discussed about the recent developments in the field of fractal antenna engineering, with particular emphasis placed on the theory and design of fractal arrays.

C. T. P. Song et al. [155] introduced a parallel feed staked fractal antenna using square Sierpinski and diamond Sierpinski carpet, which are suitable for applications in picocell environments for the operating bands of GSM, DECT and WLAN systems.

G. J. Walker and J. R. James [156] proposed the concept of fractal volume antenna in order to increase the degree of design freedom associated with fractal antenna elements and hence improve their input matching characteristics.
Z. Du et al [157] analysed the square microstrip fractal patch antenna in a Sierpinski carpet and the effects of its elements. They proposed that the multi-band frequency operation of the antenna resulted from the driven element and not from the parasitic fractal elements.

D. H. Werner and D. Lee [158] proposed a technique for the design of multiband and dual polarized frequency selective surfaces that is based on the use of fractal screen elements.

D. H. Werner and P. L. Werner [159] explained the fundamental relationship between self-similar, that is, fractal, arrays and their ability to generate radiation patterns which possess fractal features. The theoretical foundation and design procedures are developed for using fractal arrays to synthesize fractal radiation patterns having certain desired characteristic. A family of functions, known as generalized Wierstrass functions, are shown to play a pivotal role in the theory of fractal radiation pattern synthesis.

D. L. Jaggard and A. D. Jaggard [160] examined the radiation pattern from a new fractal array, the cantor ring array. They also studied the case of thinned uniformly excited elements, and found that for large fractal dimension and low lacunarity, the Cantor ring array is considerably better than the periodic array, and appears to have lower sidelobes or a large visible range for a given sidelobe level than similar random arrays for number of elements less than or equal to hundred.

Y. Kim and D. L. Jaggard [161] presented a novel method of random array synthesis. It has been demonstrated that quasi-random arrays posses the ability to control the sidelobe of the radiation pattern.

Using Sierpinski gasket as an example A. Lakhtakia [162] showed that the paraxial Fraunhoffer-zone diffracted field of a self-similar fractal screen exhibits self-similarity.
C. Peunte-Baliarda [163] described a novel approach to the design of frequency independent systems based on fractal structures. The effort has been focused in describing a technique to design low side-lobe and multiband arrays, which has always been difficult due to the sensitivity of most current design techniques to variations on the operating wavelength.

X. Sun and D. L. Jaggard [164] investigated the reflection and transmission properties of finely divided fractal layers. They observed the behaviour of electromagnetic or optical waves normally incident upon generalized Cantor bar fractal multilayers for various fractal dimensions and stages of growth.

D. H. Werner et al. [165] proposed a technique for generating sum and difference pattern using Sierpinski carpet based fractal subarrays.

M. Lehman and M. Garavaglia [166] obtained the input impedance and the reflectance for a multilayer structure with periodic and fractal distribution and demonstrated how it shows a self similar behaviour according to the type of the structure.

D. L. Jaggard and Y. Kim [167] introduced the concept of band limited fractals and used to describe the diffraction of electromagnetic and optical waves by irregular structures. They demonstrated it through the example of plane-wave diffraction by a fractal phase screen of finite extent.

D. L. Jaggard and X. Sun [168] considered the scattering of electromagnetic waves from perfectly conducting fractal surfaces. The surface was modeled by a multiscaled bandlimited continuous fractal function. They analytically developed a generalized Rayleigh solution for electromagnetic wave scattering from such fractal surfaces. After examining the convergence of Rayleigh systems, they numerically
calculated the coupling strengths and related the angular scattering energy
distribution to the fractal descriptors of the surface.

E. Jakeman [169] investigated on the scattering by a
corrugated random surface with fractal slope. Wu and Hu [170] studied the
phase transitions on more complex Sierpinski carpets. Variations of the
critical exponents with various geometric factors and the scaling of resistor
networks are examined.

Reflection and transmission properties of polyadic fractal
superlattices are formulated, solved analytically, and characterized for
variations in fractal dimension, lacunarity, number of gaps, stage of
growth, and angle of incidence by A. D. Jaggard and D. L. Jaggard [171].

D. L. Jaggard and X. Sun [172] investigated and characterized the
reflection and transmission properties of finely divided fractal layers.

The surface impedance of two thin metallic films of different fractal
structures realized on printed circuits have been measured in free-space
over the frequency range 10 GHz to 20 GHz by E. Troncet et al [173]. A
modeling scheme based on Maxwell's equations and Fresnel's diffraction
theory is proposed.

C. Puente Baliarda et al. [174] presented a model that explains the
behaviour of the Sierpinski fractal antenna. The model is applied to predict
the behaviour of the Sierpinski fractal antenna when the flare angle is
modified and its validity is assessed by comparing its predictions with
measured data.

D. H. Werner and S. Ganguly [175] has presented a comprehensive
overview of recent developments in the rapid growing field of fractal
antenna engineering.
J. P. Gianvittorio et al [176] designed frequency selective surfaces using the iterative techniques of fractals which exhibit two or three stop bands depending on the number of iterations.

F. Chiadini et al [177] highlighted the self-similarity features of the frequency dependent reflection coefficient of a dielectric cantor prefractal obtained by applying cantor set construction to the optical layer lengths.

L. Zhou et al [178] studied the reflective properties of a small dielectric plate covered with fractal like metallic pattern generated by a particular type of space filling curves. They observed both experimentally and theoretically that the plate could reflect electromagnetic waves in a multitude of frequencies, generated from a near field monopole antenna.

C. T. P. Song et al [179] demonstrated a novel method for designing a wideband quasi-log periodic monopole antenna based on the principles of the fractal Sierpinski gasket and circular disk monopole.


D. H. Werner et al [181] proposed a methodology for exploiting the self-similarity and symmetry in the geometrical structure of fractal arrays to develop fast algorithms for calculating the impedance matrix and driving point impedance.

From the above review of past work in the field, it is clear that many researchers have studied the scattering properties of strip gratings and to reduce RCS of targets using strip grating technique. No work has been reported for reducing RCS of a target using fractal based metalo-dielectric structure. This thesis is the outcome of the investigations carried out to reduce the RCS of targets by applying Metallo-Dielectric Structures
Review of the past work done in the field

(MDS) based on fractal geometries on the target surfaces. The scattering characteristics of simple targets like flat plate, dihedral corner and cylinder loaded with MDS are investigated.