CHAPTER 7
CONCLUSIONS AND SCOPE OF FUTURE WORK

Future aircraft systems must have the ability to adapt to fend for itself from rapidly changing threat situations. The aircraft systems need to be designed to tackle dynamically threat in the form of Electronic Attack. In order to thwart the detection of operating frequency by the enemy and prevent the jamming of signals, it is necessary to design a frequency agile microstrip patch antenna. Such a reconfigurable patch antenna may be designed by employing multidielectric layers and a cover layers, placed directly on the surface of the aircraft. Impedance bandwidth, an important characteristic of microstrip patch antennas can be significantly improved by using multilayer dielectric configuration. The antenna thus, designed may be used for specific high-performance airborne applications and suitably be utilized for realization of frequency hopping. For large (azimuthal) angular coverage conformal arrays of these antennas can be mounted on singly curved cylindrical surface with low profile. The singly curved surface can also be used as an approximation of the shape of an aircraft wing, fuselage or external pods. Such a design is expected to facilitate the use of antenna in defence applications in radar and communication systems to avoid detection by enemy.

Chapter 1 of the thesis is devoted to introductory overview. In subsequent chapters of the thesis efforts have been made to design multidielectric microstrip patch antennas with a cover layer which are frequency agile, suitable for specific high-performance airborne applications and are conformable for mounting on singly curved cylindrical surface of an aircraft. The design performance analysis of such microstrip patch antennas and scope of further work are presented in the following sections of this chapter.

7.1 Main Design and Performance Analysis Contributions

Basic configurations of a microstrip patch antenna arrays, have been analyzed and an optimum frequency range of the patch antenna array has been presented in Chapter 2. It has been shown that for any planar array configuration desirable antenna characteristics can be obtained, depending upon element spacing. Further, the effects of surface waves and mutual coupling can be minimized by optimizing the inter
element spacing in both the planes. The antenna provides frequency close to the
designed operating frequency with an acceptable directivity and gain. When antenna
structure is closely spaced, the return loss improves in the $E$ plane. It has been shown
that with the increasing array spacing the gain of the antenna gets reduced
significantly.

Improved accuracy is obtained in the performance of a multidielectric layer antenna
with a superstrate layer over the substrate using conformal mapping techniques. The
design, developed in Chapter 3, eliminates the effects of inaccuracies that can have
compounding effect from the design stage to fabrication of multidielectric layer
microstrip antenna. The process has been successfully tested on both thin and thick
dielectric substrates having low permittivity. The antenna designed for given resonant
frequency has been observed to be in correspondence to the patch dimension with
high accuracy. The empirical relations derived can be used to predict the antenna
parameters including resonant frequency, return loss, power radiated, directivity and
gain for a multilayer microstrip antenna subjected to the limits for the thickness of the
superstrate layer (0.254mm-2.54mm). Gain of a multilayered structure increases as
the height of the cover layer is increased.

Using the design of microstrip patch antenna presented in Chapter 4, the antenna
losses are contained by controlling those quality factors which can have significant
impact on bandwidth for given permittivity and substrate thickness. It has been shown
that the impedance bandwidth of microstrip patch antennas can be significantly
improved by using multilayer dielectric configuration.

The gain bandwidth product is a constant, therefore an effort has been made to
improve the bandwidth of the patch antenna while ensuring desired radiation pattern.
Next, the effect of cover layer on impedance matching, Q factor hence bandwidth and
frequency correction is discussed. The Method of Moments and Finite Difference
Time Domain approach have been used for computation of the results presented in the
chapter. With the thickness of the superstrate layer limited to 0.254mm - 2.54mm., the
antenna parameters including resonant frequency, return loss, power radiated,
directivity and gain for a multilayer microstrip antenna can be predicted by using
empirical relations. It has been observed that the gain of a multilayered structure
increases as the height of the cover layer is increased.
Chapter 5 addresses to the design of antenna of future aircraft systems to fend for itself from rapidly changing threat situations. To overcome the threat under electronic warfare environment (Electronic Attack), airborne antenna systems need to be reconfigurable and functional to overcome intentional and unintentional electromagnetic disturbances. A novel design of frequency agile reconfigurable multidielectric microstrip patch antenna with a cover layer placed directly on the surface of the aircraft has therefore been presented in this chapter. Such an antenna can be used for specific high-performance airborne applications and suitably be utilized for realization of frequency hopping.

By choosing the cover layer parameters appropriately a significant increase in gain and antenna efficiency is achieved, enabling the cover to act as the part of antenna. This facilitates the use of antenna in defence applications to avoid detection by enemy. If the enemy detects the antenna operating at a particular frequency, we can switch over to another frequency to prevent the jamming of signals just by replacing the original cover layer by a new cover layer with different permittivity. Thus, the cover layer apart from shielding is utilized to make the antenna reconfigurable and hence frequency agile. The proposed design achieves frequency agility ranging from 0.5% to 18% with centre frequency set at 2.718 GHz.

Antennas mounted on singly curved surfaces are an important class of conformal arrays for applications in which a large (azimuthal) angular coverage is required. These types of antennas can be used in radar and communication systems. The singly curved surface can also be used as an approximation of the shape of an aircraft wing, fuselage or external pods. The focus is on the mutual coupling and its influence on the radiating. A conformal microstrip antenna on a cylindrical surface with low profile has distinct advantage for applications related to fighter aircraft and spacecraft. Microstrip antenna and arrays conformed to curved surfaces viz. aerodynamic surfaces like supersonic aircraft or missiles, can be modeled approximately in the shape of a cylinder. In Chapter 6 Full-wave analysis has been adopted for the conformal microstrip antenna on a cylindrical surface. This analysis is more accurate and less complex computationally than Bessel and Hankel functions and Fourier integral approach.
Full-wave analysis, which is applicable to many structures, uses method of moments (MoM)/Greens function technique in the spectral domain. It has been employed for a probe-fed case with metallic ground cylinder & patch assumed to be perfect conductors by neglecting the thickness (<\lambda) with patch replaced by a surface current distribution. Probe has been treated as a line source with unit amplitude (feeding coax <<\lambda). The focus in the design has been on the mutual coupling and its influence on the radiating characteristics. Mutual coupling in arrays gives rise to deviations in antenna element-patterns compared with those of corresponding isolated elements. The microstrip elements used for these investigations were dual patch antennas fed by two coaxial probes and then combined quadratic patch antennas. A comparison is made between isolated conformal microstrip antennas and array-embedded conformal antennas results wherever necessary.

7.2 Further Scope of Research

With the advent of fighter aircraft technologies, new approaches for the development and integration of antenna systems need to be evolved. Advancements in the communication, navigation, and electronics warfare systems to new cutting edge technologies include the antenna which represents the interface between the transmitter and receiver. Optimizing the antenna characteristics can lead to considerable improvements in the overall system performance i.e. better accuracy, better aerodynamics, lighter weight, etc.

Challenges of the moment are the one regarding the antennas conforming to the desired shape of the parent body viz. aircraft or missiles. Antennas with radiating elements on the surface of a cylinder, sphere, or cone, may have their shape determined by a particular electromagnetic requirement such as antenna beam shape and/or angular coverage. Conformal antennas can be almost any geometry, although the main structure investigated is cylindrical, but spherical and conical microstrip antenna can conform to nose cone and canopy respectively of the aircraft or missile structures. A conical microstrip antenna is of particular importance in aircraft and missiles, portions of whose bodies are conical in shape. A circular microstrip antenna mounted inside or outside a conical ground plane, can be used to modify the radiation pattern of the microstrip antenna in the elevation plane.
Similar to the cylinder which is characterized by a singly curved surface, the cone can also be considered to be the same. Applications using conical surface can relate to the nose cone of streamlined fighter aircraft and airborne missiles. The conical surface offers wide-angle coverage and good aerodynamic performance. A small conical angle, however, poses problems with the installation of electronics in the tip region and the radiation performance in the forward direction is poor. The emphasis is on antenna element characteristics when a single element is fed, both isolated and in the array environment.

Microstrip-patch elements on a conical surface are a configuration of great potential interest. However, no mutual coupling data for this case have been found in the published literature. This may be due to the complexity of analyzing the near fields on a coated cone. There are very few references in the literature in which the radiation characteristics of microstrip-patch antennas on cones have been analyzed. The results found were obtained using a cavity model of the patch.

Also, conformal spherical antennas have attracted interest. A well-known example is the dome radar antenna. This antenna has a passive-transmission-type lens of hemispherical shape. What do radomes have to do with conformal array antennas? Radomes are usually thought of as dielectric shell structures protecting an antenna installation. If made of metal, a dense array of openings (slots) can provide the necessary transmission properties within a restricted range of frequencies. The result is a conformal frequency-selective structure (FSS). It is not an antenna, of course, but viewed from the outside it exhibits all the radiating characteristics of a curved antenna array of radiating elements, just like a conformal antenna.

The hemispherical surface provides an active area subtended by a conical angle of 120° be expected to be independent of the scan direction since we are dealing with a spherical surface. However, for scan angles larger than a certain value, in our case 30° from the zenith, the effective area decreases and is halved at the 90° scan limit based on our assumed maximum scan angle 60°. One alternative is to extend the sphere downward to make the effective area constant with scan.
The following considerations can lead to further study and investigation with integration of conical, spherical and cylindrical surfaces while achieving the desired specifications with minimum deviation in resonant frequency:

- The microstrip arrays mounted on a spherical surface have the advantages of wide-angle coverage. Such spherical microstrip arrays are usually designed to have radiation coverage over nearly a full hemisphere, which can find applications in ground station-to-satellite, aircraft-to-satellite, and satellite-to-satellite communication links.

- The conical microstrip array may be used to provide tracking antennas for high-speed missiles, where the front end of the missile makes a design using conventional planar microstrip antennas impractical. Other uses are in curved bodies that have conical or nearly conical surfaces. As for the conical microstrip array with typical geometry reports of related designs are relatively scanty.

- Results for $E$- and $H$-plane mutual coupling for cylindrical microstrip antennas and the curvature effects on the mutual coupling have been presented in the thesis. On the other hand, the curvature effects on the mutual coupling in the design and performance of microstrip antennas mounted on a spherical and the conical ground surface conforming to nose cone and canopy may be investigated.

- By following a theoretical formulation similar to that for the wide cylindrical microstrip line, the current density on the coupled lines may first be expanded in terms of combinations of known basis functions for modelling the surface current density on the coupled microstrip lines for numerical convergence. Since discontinuities in microstrip lines, caused by abrupt changes in the geometry of the strip conductor may generate radiating and surface waves, accurate characterization of the discontinuity characteristics of microstrip lines is desired.