CHAPTER 1

INTRODUCTION

1.1 Background

The demand for wireless communications services is growing at an extensive rate all over the world. The intensive development and wide application of new generations of personal communication systems and wireless local systems, have increased the need for new antenna designs [1]. As the wireless communications networks expand, the number of both unwanted directional interferences and strong nearby sources increase, which degrade system performance. Optimal antenna arrays play an important role in the improvement of communications systems by providing increased coverage through antenna gain control and interference rejection [2, 3]. A system consisting of an array and a processor can perform filtering in both space and frequency to reduce the sensitivity of the system to interfering directional sources.

There are many requirements that new communications systems pose on antennas. The most common are low cost, low weight and compact designs with high-performance radiation and impedance characteristics. Therefore uplink and downlink antennas undergo a lot of modifications and performance improvement [1]. In many wireless communications systems, the signal-to-interference ratio (SIR) is improved by using multiple nulls in the directions of the interferences while maintaining omnidirectional coverage in the direction of the network users. The nulls in the radiation pattern may be used to reduce the interference from strong nearby sources as well as co-channel interference by introducing nulls in the directions of surrounding communication systems.

For the communication system considered in this thesis, the interferences are static and their directions of arrival are known. A non-adaptive antenna array is needed to provide the spatial filtering in a static wireless environment. Multi-path scenarios and space-time filtering via an adaptive array are therefore not addressed.

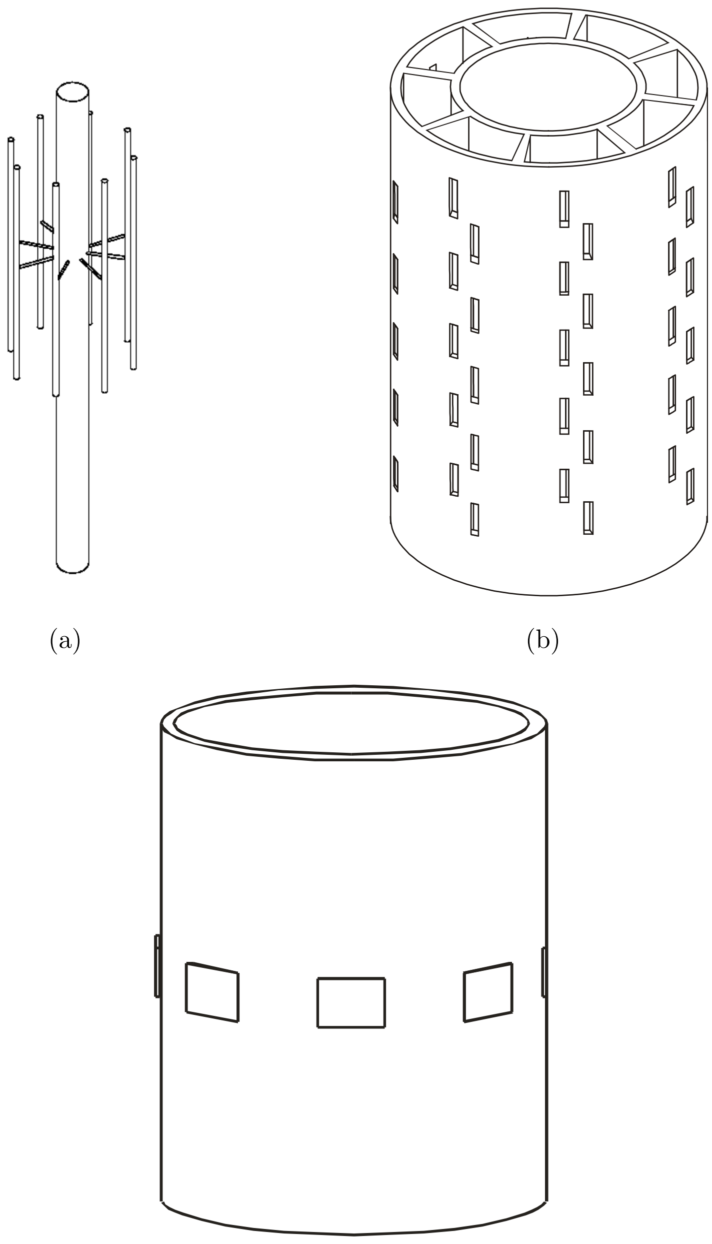
Omnidirectional arrays, such as cylindrical arrays, are the most suitable to provide the omnidirectional coverage and are capable of suppressing interferences when nulls are inserted in the radiation pattern. Some examples of cylindrical arrays are shown in Figure 1.1.

Microstrip antennas, which the work in this thesis will focus on, are popular components in modern systems, since they are low in profile, light in weight and well suited for integration with microwave integrated circuits. They can also be made conformal to non-planar surfaces such as cylinders to form cylindrical arrays as shown in Figure 1.1(c).

This type of cylindrical array is also classified under conformal arrays of which the analysis and design can be divided into three areas [4]:

1. the analysis of the antenna element radiation pattern,
2. the array pattern analysis and synthesis to obtain the element excitations, and
3. the design of the radiators and the feed network to obtain the desired excitations.

The analysis of cylindrical microstrip patch antennas and arrays have been discussed in many publications [5–31]. The cavity model theory, method of moments, geometric theory of diffraction (GTD) and finite-element method have all been applied to obtain the resonant frequency, impedance behaviour and/or radiation pattern of a rectangular microstrip patch on a conducting cylinder. For electrically thin substrates, the cavity model has been shown to be sufficient to compute the characteristics of the patch antenna [23, 24, 29]. Hybrid modes are excited for electrically thick patches which require more accurate analysis methods [14]. When the radius of the cylinder is much larger than the operating wavelength, the effect of the curvature on the characteristics of the patch antennas may be neglected. For radii comparable to the operating wavelength, the input impedance, resonant frequency and radiation pattern of the patch antenna are effected by the curvature. The cavity model [13] and a commercial finite difference time domain (FDTD) analysis program have been used during the design of the radiating element to incorporate the influences of the curvature [30]. The FDTD analysis program can also be utilised where electrically thick patches are considered to improve bandwidth and gain performance.



(a) (b) (c)

Figure 1.1: Cylindrical arrays: a) dipole array, b) slotted waveguide array and c) microstrip patch array

Previously, cylindrical microstrip patch arrays were extensively used for omnidirecitonal coverage [9, 18] and the formation of beams in the far field radiation pattern [1, 32–40]. Many techniques for the introduction of nulls in the far field radiation patterns of cylindrical arrays can be found in the open literature [41, 43–55]. Lim [43] proposed the introduction of a single null into an omnidirectional pattern by approximating an abrupt phase reversal in the phase pattern of the array. This phase reversal in the specified direction of the null also minimised the null width. An orthogonal projection method was introduced by Vescovo [50, 51] to synthesise a desired radiation pattern for an equally spaced cylindrical array. Abele *et al* [53, 54] combined these two methods to synthesise multiple nulls in the omnidirectional pattern of a cylindrical array. An ideal null pattern with constant amplitude and an abrupt phase reversal at the desired location of each null was used in the orthogonal projection method. The null positions and depths could be controlled independently and some control could be exercised over the gain ripple and null width by utilising windowing functions.

All the above methods use radiating elements that are identical in radiation pattern, polarisation, gain and impedance. In conformal arrays, the elements, and consequently their radiation patterns, point in different directions and the element pattern cannot be factorised out of the array pattern to obtain an array factor [4, 56, 57]. Vescovo [56] also applied the projection method to an arc array of elements with directional radiation patterns. After a main beam was formed through the projection method, additional nulls were introduced in the pattern with null constraints to reduce the side lobe level.

The effect of mutual coupling between elements in an array is one of the most relevant problems in the synthesis of array antennas. Numerous methods to compute or represent the mutual coupling in linear and cylindrical microstrip patch arrays have been presented [17, 19, 24, 25, 29, 58–71]. The mutual coupling between the antenna elements modifies the element excitations and the driving input impedances of the antenna elements.

For arrays with wide band antenna elements and small mutual coupling between the elements, the measured radiation pattern characteristics may still be within the desired characteristics, although the mutual coupling was not taken into account during the design process of the array [32, 34–37, 39]. On the other hand, the consequent errors in the element excitations due to high mutual coupling may deteriorate the radiation pattern. This is especially true for a shaped or scanned beam, if the mutual coupling is not compensated for in the design process [72, 73]. For the accurate computation of the sidelobe levels in a beam pattern, the mutual coupling was taken into account by Bartolic *et al* [1].

Null filling and null position errors also occur during null synthesis due to the mutual coupling [53, 74]. Various authors have presented techniques to compensate for the mutual coupling effect on a synthesised array pattern [54, 72–86]. At the array feed port, a mismatch occurs due to coupling [87], which may significantly degrade the performance of narrowband arrays. The driving impedances of the antenna elements resulting from radiation pattern correction methods remain unequal and the design of the feeding and matching network can be complicated. Another solution is to alter the individual element geometries physically in order to have equal driving impedances for the required element excitations [88, 89]. This method causes the feeding network to be much simpler.

1.2 Contributions

In this thesis, a cylindrical microstrip patch antenna array is investigated as an antenna to provide an omnidirectional radiation pattern with nulls at specified angular locations to suppress interference from directional sources. The null synthesis for the cylindrical microstrip patch array is presented by discussing the above three mentioned areas of array analysis and design.

Three null synthesis methods are described and used to provide the omnidirectional array pattern with nulls using the radiation characteristics of the cylindrical microstrip patch antenna elements. The desired element excitations are obtained from:

- the extension of the orthogonal projection method to incorporate the radiation patterns of the cylindrical microstrip patch antenna elements [90–92],
- the implementation of the objective weighting method for null pattern synthesis, and
- the application of a constraint optimisation method for the synthesis of null patterns with specified characteristics [92].

In addition, the implementation of the cylindrical microstrip patch array is investigated by:

- studying the effect of the mutual coupling on the desired null pattern [93, 94], and
- applying a technique to compensate for the mutual coupling between the cylindrical microstrip patch antenna elements to obtain the desired excitations [93,94].

1.3 Methodology

The null synthesis technique of Abele *et al* [53] is extended to incorporate the directive radiation patterns of the cylindrical microstrip patch elements. Using this method, an optimal pattern that minimises the squared pattern error with respect to the ideal pattern is obtained. The orthogonal projection method may not give an amplitude pattern with the desired characteristics (null depth, null width and ripple in the omni-region) for certain array configurations. Instead of only minimising the array pattern error, a multi-objective optimisation approach is followed [95–97]. The objective weighting method, previously applied in other fields of computational electromagnetic problems [96, 97], is used to improve the amplitude pattern characteristics of the cylindrical patch arrays.

Previously, constrained optimisation techniques were used to obtain beam patterns for circular and arc arrays [45, 52]. As a third null synthesis technique, a constraint optimisation method is applied to obtain a constrained pattern with the desired amplitude pattern characteristics. The optimal pattern is used as the starting value for the optimisation. The influence of the array attributes, such as the number of array elements and the inter-element spacing, on the characteristics of the amplitude patterns obtained from the null synthesis methods, is also studied.

In the last part of the array synthesis,the implementation of the cylindrical microstrip patch arrays is investigated. The influence of the mutual coupling on the characteristics of the null patterns of the cylindrical patch arrays is investigated utilising simulations and measurements. In a mutual coupling compensation technique, Chen [88, 89] varied the lengths and radii of the dipoles in linear and planar arrays to obtain the desired radiation patterns as well as equal driving impedances for the dipoles. This compensation technique is used to provide matched and equal driving impedances for all the patch antenna elements given a required set of excitations. The driving impedances are corrected by adjusting the lengths and feeding points of the individual patches. Utilising the compensation technique, the impedances of the microstrip patch antennas in both the planar and cylindrical arrays are designed to be 50 Ω for the desired element excitations. The consequent improvements in the bandwidth and reflection coefficient of a linear patch arrays are discussed. The resulting amplitude pattern for the compensated cylindrical microstrip patch array is also compared with the amplitude pattern before the compensation, to observe the improvements in the pattern characteristics.

1.4 Layout of thesis

The relevant background to the null synthesis and mutual coupling compensation for a cylindrical microstrip patch array is given in Chapter 2. An overview of the characteristics of the cylindrical patch antenna element, the null synthesis techniques, the mutual coupling effects and coupling compensation techniques is given. In Chapter 3, a null synthesis technique is adapted and extended for a cylindrical microstrip patch array. Results of the null synthesis techniques are shown and compared for different array geometries. A technique to compensate for the mutual coupling in both planar and cylindrical arrays is discussed and applied in Chapter 4. Both simulated and measured results are shown. Chapter 5 presents the conclusions of the study.