ARRAY DESIGN OF SMART ANTENNA

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ABSTRAK

Pada masa kini, antena pintar telah semakin mendapat perhatian dalam peningkatan sistem komunikasi tanpa wayar. Matrik Butler 4 x 4 merupakan litar pasif yang akan membenarkan kita menerima alur yang utama dari antena tatasusunan kepada satu daripada empat alurnya. Matrik ini direka pada frekuensi 2 GHz dan stuktur mikrostrip dengan proses yang ditentukan. Matrik ini terdiri daripada beberapa pengganding hibrid, ‘crossover’, pengalihan fasa dan antena mikrostrip. Tujuan utama projek ini adalah untuk mengurangkan bilangan pengganding hibrid dan antena dari rekabentuk asal. Matrik ini direka dan disimulasikan dengan menggunakan ‘Advanced Design System’ dan dicetak pada papan litar bercetak FR4. Pengukuran yang akan diberi perhatian dalam projek ini adalah kehilangan suap balik, pengalihan fasa, gandaan antenna dan corak pancarannya. Keputusan rakabentuk yang baru akan berbanding dengan keputusan pada rekabentuk asal. Keputusan yang sama menunjukkan reakabentuk yang baru dapat mengganti rekabentuk asal.

ABSTRACT

Smart antennas have recently received increasing interest for improving of wireless system. The so-called 4x4 Butler matrix is a passive circuit which gives us the ability to get a main beam from an antenna array into the one of the four beam directions. The matrix is designed at 2GHz and implemented on a microstrip structure using conventional manufacturing process. The matrix consists of hybrid couplers, crossover, phase shifters and patch antennas. The main purpose of this project is to reduce the number of couplers and antennas in the matrix from the original design. The matrix is designed and simulated by using Advanced Design System (ADS) and implemented on FR4 PCB. The measurements that will concern in this project are return losses, phase shifts, antennas gain and radiation pattern. The new design's results will be comparing with the original and may prove the new design is operate in the same way.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Scientists studies based on indoor channel measurement campaigns have shown that highly directive antennas used at both the transmitter and receiver of communication system can reduce considerably the delay spread of the signal reaching the receiver while at same time improve signal gain.

The application of smart-antenna arrays has been suggested for mobile-communications systems, to overcome the problem of limited channel bandwidth, satisfying a growing demand for a large number of mobiles on communications channels. Smart antennas may help in improving the system performance by increasing channel capacity and spectrum efficiency, extending range coverage, steering multiple beams to track many mobiles, and compensating electronically for aperture distortion.

In this paper, a new Butler matrix is designed by using Advanced Design System and the phase difference of each output is considered. Besides that, a microstrip patch antenna with 180 degree phase different at the edge is designed and the parameters are measured. The results are compared with the original design's results. However, the results may slightly different with the original design due to some factors such as hardware fabrication and interference.

The dual fed patch antenna will connect to the output port of the butler matrix where the number of coupler in the matrix had been reduced. Then, it may be measured to obtain the parameters.

Therefore, the new design butler matrix is operated in the same way with the original design.

1.2 Project Objective

The objective of this project is to design a 4 x 4 Butler Matrix Smart Antenna which may reduce the number of coupler and antenna compare with the original design. The new design’s patch antenna is 180 degree phase shift at the edge. As it may replace the hybrid couplers function in the original design’s butler matrix and the number of coupler may reduced from four to two. Since there are two ports at each patch antenna, the number of antenna may reduce from four to two too. The simulation results of the new design are being compared with original design to prove the new design is workable

1.3 Project Implementation

To implement this project at frequency resonant 2.0GHz, there is two different stages. The first stage is designing the microstrip patch antenna. By using the theoretical equation, the width and the length is being calculated. Then, it is being design and simulated in the Advanced Design System (ADS) layout window. To obtain better result for return losses and phase shift, the design is optimized. Lastly, the antenna is sent for PCB fabrication. The return losses and phase shift is measured by using Network Analyzer. The antenna's radiation pattern is another parameter that needs to be considered. It is measured by connecting the hardware to vector analyzer as receiver antenna where a dipole antenna may transmit signal. The gain of the antenna is calculated by using Friss Equation and compare with the simulation result.

For the second stage is to design a 4 x 4 Butler matrix consists of four hybrids, two crossovers and two phase shifter. The dimension of the coupler, crossover and phase shifter is calculated by using Advanced Design System's LineCalc. Then, the schematic is drawn in ADS's schematic window. The designs are optimized to obtain better result which may consider the return losses and phase shift in certain frequency. The design is sent for fabrication and the measurement of the hardware is done by network analyzer to measure the return losses and phase shift at every output.

Lastly, I may design the combination of both antenna and butler matrix together. Two couplers are removed and the antenna is connected to the matrix. The simulation result is being optimized to obtain a result that is acceptable and similar to the original design. The design is fabricated and the return losses are measured. The radiation pattern and gain are considered too.

1.4 Report Organization

This report is divided into few chapters which may illustrate the project that had been done, this included the introduction of the project, theory, project implementation, measurement and testing.

The first chapter of this report introduces the project background, project objectives and how is this project being implemented. Chapter 2 is the literature review of this project. All the theories about the smart antenna, butler matrix, microstrip patch are illustrated in this chapter. Advantages and disadvantages of smart antenna are also written in this chapter.

Chapter 3 describes the design and simulation of this project. The setup and the software used for design and simulation are also discuss is this chapter. The theoretical equations are being used to calculate the dimension of the design. The simulation results are attached and discussed in this chapter.

Chapter 4 covers about the hardware fabrication and measurement results. The measurement is being taken by using some related instruments such as network analyzer and spectrum analyzer. The measurement results will be comparing with the theoretical results and it can be seen there are slight difference between the theoretical and hardware measurement results.

The report ended up with chapter 5 which is the discussion and conclusion of the project. Problems and suggestions are discussed in this chapter. The importance of the project is covered and discussion about the objectives of the project had been met is described.

The last page is appendices such as layout of the design and some unimportant results are attached.

CHAPTER 2: THEORY AND DESIGN OF SMART ANTENNA

2.1 Smart Antenna

2.1.1 Introduction

There has been a strong growth of number for mobile-communications users; this situation increases significantly the co-channel interference fading, which reduces the transmission quality and limits their performance. The application of smart-antenna arrays has been suggested to overcome the problem of limited channel bandwidth, satisfying a growing demand [10]. Smart antennas may help in improving the system performance by increasing channel capacity and spectrum efficiency, extending range coverage, steering multiple beams to track many mobiles, and compensating electronically for aperture distortion [6].

They also reduce delay spread, multipath fading, system complexity, bit error rate (BER), and outage probability. Delay spread occurs in multipath propagation environments when a desired signal, arriving from different directions, becomes delayed due to different travel distances. Delay spread and multipath fading can be reduced with an antenna array that is capable of forming beams in certain directions and nulls in others, thereby canceling some of the delayed arrivals [6].

Another important feature of a smart antenna system is its capability to cancel co-channel interference. Co-channel interference is caused by radiation from cells that use the same set of channel frequencies. Thus, co-channel interference in the transmitting mode is reduced by focusing a directive beam in the direction of a desired signal, and null in the directions of other receivers. It may also helps to reduce multipath reflections and the delay spread due to the array focuses energy in the required direction.

In the receiving mode, co-channel interference can be reduced by knowing the directional location of the signal’s source, and utilizing interference cancellation. However, the array provides compensation in multipath fading by adding the signals emanating from other clusters after compensating for delays, as well as by canceling delayed signals emanating from directions other than that of the desired signal [6].

Several terms are used to refer to the various aspects of smart antennas system technology, including intelligent antennas, phased arrays, SDMA (Spatial Division Multiple Access), spatial processing, digital beamforming, adaptive antenna systems, and others. Smart antenna systems are usually categorized as either switched-beam or adaptive antenna systems. Both of them communicate directionally by forming specific antenna-beam patterns. They direct their main lobe, with increased gain, in the direction of the users, and they direct nulls in directions away from the lain lobes. Different switched beam and adaptive smart antennas control the lobes and the nulls with varying degrees of accuracy and flexibility [6].

2.1.2 Switched-Beam Antenna System

The traditional switched beam antenna system has a fixed number of beams, from which one or more can be selected for transmission or reception. For this kind of system, an algorithm must be found to select the ‘best’ beam. This method is considered as an extension of the current cellular sectorization scheme, in which a typical sectorized cell site is composed of three 120-degree macro-sectors. The switched beam approach further subdivides the macro-sectors into several micro-sectors. Each micro-sector contains a predetermined fixed beam pattern, with the greatest gain placed in the center of the beam. Typically, the switched beam system establishes certain choices of beam patterns before deployment, and selects the beams that containing the strongest signals [6]. Besides that, another consideration is determined by the lowest BER (bit error rate) of the received signal. However, direct bit error measurement is not always possible as it may take too long to transmit a large number of bits to get an accurate measurement. An alternative is based on the RSSI (received signal strength indicator) value so that the beam with the strongest signal is selected. However, as a beam with a strong signal does not necessary mean that it has low BER reception due to multipath fading, the RSSI method will be inferior to the BER method in terms of performance. A more reliable criteria for beam selection will be based strongest SINR (signal to noise and interference ratio), where the ratio of the power of the desired signal to the power of all unwanted signals and noise is determined from a short pilot sequence for all beams. The beam with the highest SNIR is then selected. The choice of the beam is driven by RF or baseband DSP hardware and software, with the system switching between beams in different directions as the user moves in the cell. With the main beam directed with enhanced gain at the user, side lobes or nulls are formed in the directions of the other unintended users to provide spatial separation between users [7]. Figure 2.1 shows the transmit strategy of a switched beam antenna system.

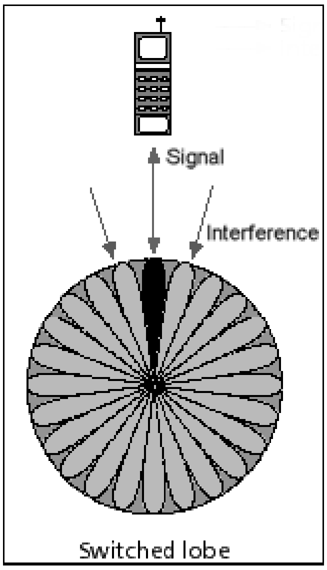

Figure 2.1: Transmit strategy of a switched beam antenna system

A performance improvement achieved when switched beam systems are used is interference reduction. A narrow main beam picks up less interference and offers increased directivity. Carrier to interference ratio (CIR) is increased, leading to an increase in user capacity and ranges for the same amount of transmit power used in traditional antennas systems. However, there are a few limitations to switched beam systems. The first limitation occurs when the interfering signal is around the center of the main beam while the user is away from the center and near the arc of the beam or the edge of the sector. Since the switched beam system does not distinguish between a desired signal and interfering signal, the interfering signal can be more enhanced than the user as it is nearer to the antenna, causing the link of the user to degrade. Another limitation can also occur due to the behavior of switched beam systems. Since the beams are predetermined, the signal strength varies when the user moves about the sector. This can cause signal strength to degrade rapidly before the user is switched to another micro-sector when moving towards the far azimuth edges of the beam [7]

2.1.3 Adaptive Array Antenna System

The other approach to smart antennas is the adaptive array antenna system. By adjusting to an RF environment as it changes, this technology can dynamically alter the signal patterns to optimize the performance of the wireless system. This system utilizes sophisticated signal processing algorithms to continuously distinguish among desired signals, multipath, and interfering signals as well as calculate the signal location. Its beam pattern is continuously updated based on the changes in both the desired and interfering signals location, similar to the way the brain collects the sound from both ears and combines it to hear better or even determine the direction of the sound. By forming nulls towards the unwanted users, this system also has the ability of the human brain to tune out unwanted noise and interference, focusing only at the desired signals on hand. Figure 2.2 shows an adaptive array antenna system focusing on the user and combining the effects of multipath to get a better signal while rejecting interference.

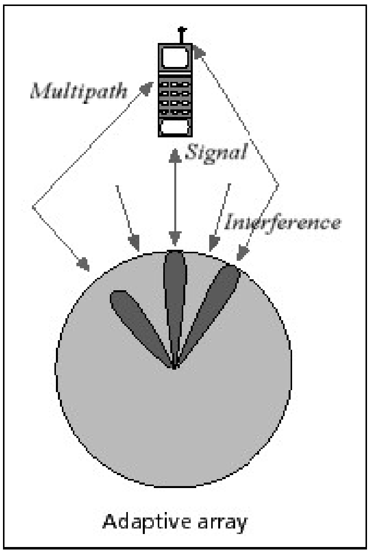

Figure 2.2 Transmit strategy of an adaptive array antenna system

An adaptive array antenna system performs better in terms of SNIR as its radiation pattern can be adapted to receive combined multipath signals. It can also monitor the user continuously by providing an effective antenna pattern with maximum gain in the user’s direction using known DOA algorithms, like *MUSIC* and *ESPRIT* [6].

2.1.4 Advantages and Disadvantages of Smart Antennas

The use of smart antennas will lead to many advantages which are not available when the traditional antennas are used in base station, namely:

- Increased range: coverage area increases as a result of the increased directivity and reduced interference that a single beam can provide. Switched beam systems can increase a base station’s range from 20% to 200%, compared to when sectored antennas are used. For an antenna array with ten elements used in a switched beam system, its range is almost doubled.

- Increased capacity: a reduction in interference (particularly in co-channel interference) comes with an increase in frequency reuse factor as the system does not transmit signals in all directions. Channel reuse patterns in cellular systems can be much tighter because the average interference resulting from co-channel signals in other cells is reduced; i.e. moving from a 7-cell to a 4- cell reuse pattern nearly doubles capacity.

- Reduced transmit power: as the system uses spatially selective transmission, less transmit power is radiated, reducing recent public worries over health issues originating from exposure to electromagnetic radiation. Battery requirements for handsets are also relaxed, increasing the talk time and reducing the size and weight of the handsets.

- Reduction in handoff rate: when the number of users in a cell using conventional antennas exceeds its capacity, cell splitting is used to create new cells. This leads to increased handoff due to smaller cell sizes. With smart antennas, more orthogonal beams are formed when there is an increase in the number of users.

- Reduced multipath propagation and delay spread: signal reflections must be within the narrow antenna beam at the base station and in the case of the adaptive array, multipath can actually be used to boost up the desired signal.

- BER improvement: a consequence of a reduction in co-channel interference and multipath fading also gives a reduction in BER for a given SNR, or a reduction in required SNR for a given BER. This eventually leads to higher data rates being used; paving the way for wideband cellular systems like Wideband-CDMA.

- On-demand location-specific services: on-demand services like roadside assistance, real-time traffic updates, tourist information and electronic yellow pages can be provided.

Clearly, the of advantages have shown why smart antennas have attracted so much interests in recent years, winning the hearts of cellular network planners and engineers. However, there is always a price to pay as increased complexity leads to higher equipment costs. It is now a question of whether the higher costs will be compensated for by the gains obtained in using this new technology. The disadvantages that should be considered are as follows:

- Transceiver complexity: as a smart antenna transceiver is more complex than a traditional base station transceiver, it will need more separate transceiver chains for each of the array antenna elements as well as accurate real-time calibration in each of them.
- Mobility management: when a new connection is to be set up or when an existing connection is to be handed over to a new base station, there is no angular information available to the new base station. In connection setup, some means have to be devised to enable the new base station to find the new user. In handover, the system needs some positioning information of the user to make the right decisions.

- Computational intensity: smart antennas require powerful and rapid numeric processors and control systems for computation. There is also a need for efficient algorithms for real-time optimizing and signal tracking.

It can be seen that the advantages outweighs the disadvantages, making the replacement of traditional antennas with smart antennas a viable option to consider. But still, we can try to avoid the disadvantages mentioned above when there is an alternative to do so: that is a complete switched beam smart antenna system can be implemented by using an RF beamforming network (namely a Butler matrix) together with a few other building blocks.

2.2 Hybrid Coupler

Hybrid coupler or quadrature hybrids are well known devices used for their ability to generate signals 90 degrees out of phase as its output [5]. An analysis of the quadrature hybrid implemented using transmission line as shown in Figure 2.2.1 can be carried out by the even-odd mode decomposition. Following this development, the analytical S parameters of this four-port network are:

$$S = \frac{-1}{\sqrt{2}}\begin{bmatrix}0 & j & 1 & 0\\ j & 0 & 0 & 1\\ 1 & 0 & 0 & j\\ 0 & 1 & j & 0\end{bmatrix}$$

The power applied at a port is evenly distributed between the ports located on the opposite side of the coupler. There is a 90 degree phase different between these two ports; the port close r to the input is leading in phase by 90 degrees. The port located on the same side as the input port is isolated since there is no power reaching it.

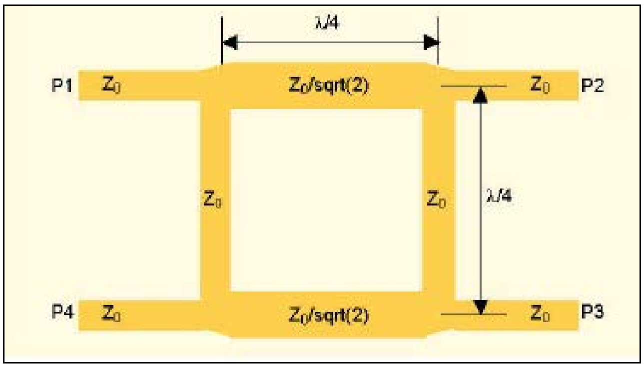

Figure 2.3: Quadrature hybrid built around transmission lines

Coupling and Directivity for these couplers are defined as:

$$Coupling = C = 10\log_{10}\left(\frac{\mathrm{P_{in}}\ \text{port 1}}{\mathrm{P_{out}}\ \text{port 3}}\right) = \text{-}20\log\beta\ dB,$$

$$Directivity = D = 10\log_{10}\left(\frac{\mathrm{P}_{out}\ \text{port 3}}{\mathrm{P}_{out}\ \text{port 4}}\right) = 20\log\frac{\beta}{|\mathrm{S}_{14}|}\ dB,$$

$$Isolation = I = 10\log_{10}\left(\frac{\mathrm{P_{in}}\ \text{port 1}}{\mathrm{P}_{out}\ \text{port 4}}\right) = \text{-}20\log|\mathrm{S}_{14}|\,dB$$

$$\mathrm{I} = (\mathrm{D} + \mathrm{C})\quad \mathrm{dB}$$

$$\text{Coupling factor, } \beta = |S_{13}|$$

2.3 Crossover

In the Butler matrix, the signal paths have to physically cross over while maintaining high isolation. These devices also known as 0 dB couplers, are an efficient means of crossing two transmission lines with a minimal coupling between them. This device is made as cascade of two hybrids as shown in Figure 2.4 yields the S parameters:

$$S = \begin{bmatrix} 0 & 0 & j & 0 \\ 0 & 0 & 0 & j \\ j & 0 & 0 & 0 \\ 0 & j & 0 & 0 \end{bmatrix}$$

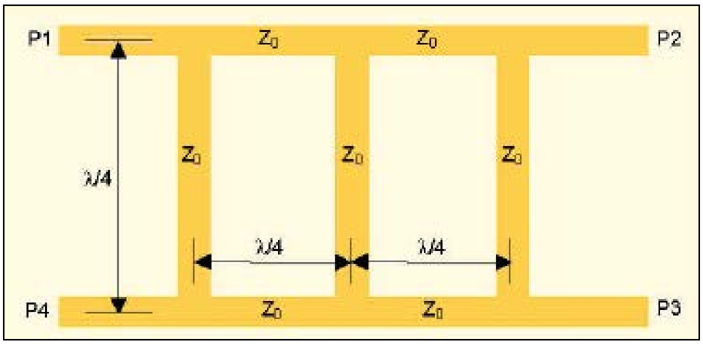

Figure 2.4: Crossover

2.4 Phase Shifter

The phase shifter was implemented using the transmission lines which is lengths introduce the required phase shift. Same with the hybrids and crossovers, the phase shifter will be implemented in transmission form. The phase shift θ associated to a transmission line of length is given by equation:

$$\theta = \frac{360^0}{\lambda} \bullet l$$

where , ε_{eff} is the effective permittivity of the substrate.

2.5 Microstrip Patch Antenna

2.5.1 Properties of a Basic Microstrip Patch

A microstrip patch antenna is a low-profile antenna that has a number of advantages over other antennas. It is lightweight, inexpensive, and easy to integrate with accompanying electronics where array performance could be enhanced. Figure 2.5 showed a basic inset-fed patch antenna is made up of a very thin metallic strip (patch) placed a small fraction above a ground plane. For good antenna performance, thick substrates whose dielectric constant ε_r is at the lower end of the dielectric constant range of $2.2 \leq \varepsilon_r \leq 12$ is desirable as they give a larger bandwidth and better efficiency. It will be used as the radiating elements to form an array for the Butler matrix in this thesis as it is the easiest to analyze compared to the rest of the patches (circular, triangle, ellipse, annular, disc sector and ring sector) [7].

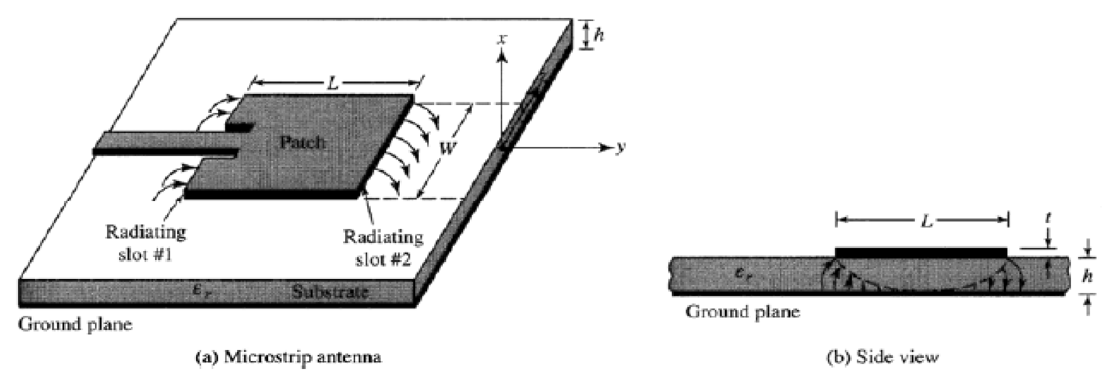

Figure 2.5: Microstrip patch antenna

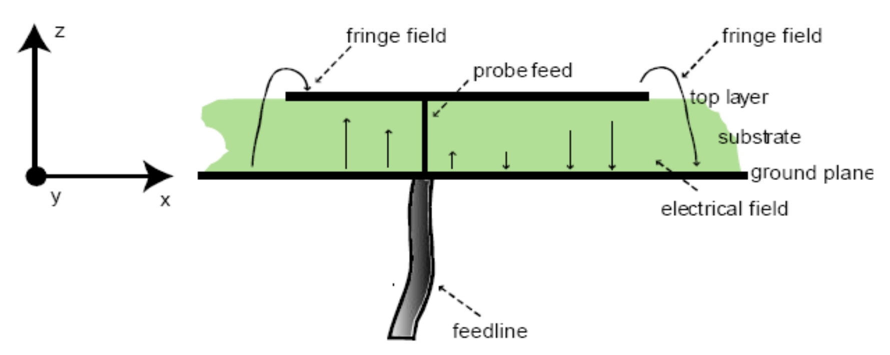

Figure 2.6: Feed probe and electrical field of microstrip patch antenna

The center conductor of a coax serves as the feed probe to couple electromagnetic energy in and/or out of the patch. The electric field distribution of a rectangular patch excited in its fundamental mode is also indicated as shown in Figure 2.6. The electric field is zero at the center of the patch, maximum (positive) at one side, and minimum (negative) on the opposite side. It should be mentioned that the minimum and maximum continuously change side according to the instantaneous phase of the applied signal. The electric field does not stop abruptly at the patch's periphery as in a cavity; Rather, the fields extend the outer periphery to some degree. These field extensions are known as fringing fields and cause the patch to radiate. Some popular analytic modeling techniques for patch antennas are based on this leaky cavity concept. Therefore, the fundamental mode of a rectangular patch is often denoted using cavity theory as the TM10 mode. TM stands for transversal magnetic field distribution. This means that only three field components are considered instead of six. The field components of interest are: the electric field in the z direction and the magnetic field components in x and y direction using a Cartesian coordinate system, where the x and y axes are parallel with the ground plane and the z-axis is perpendicular. In general, the modes are designated as TMnmz. The z value is mostly omitted since the electric field variation is considered negligible in the z-axis. Hence TMnm remains with n and m the field variations in x and y direction. The field variation in the y direction (impedance width direction) is negligible; Thus m is 0. And the field has one minimum to maximum variation in the x direction (resonance length direction); thus n is 1 in the case of the fundamental. Hence, the notation is TM10 [3].

A single rectangular patch when excited has a beam pattern as shown in Figure 2.7a). When more patches (in this case, eight) are lined up in a straight line and spaced λ/2 apart to form a linear array, a resultant beam as shown in Figure 2.7b). By changing the phase at each of the patches, we can move or steer the beam to a direction we desire. This is how the switched beam system would track a user that is moving in a cell. As each array has its own array factor and is a function of the number of elements, its geometrical arrangement, relative phase, relative magnitude and spacing. The total field of the array is given by the *product of the field of a single element at a selected reference point (usually the origin) and the array factor of the array.* This is also known as *pattern multiplication* for arrays of identical element [7]

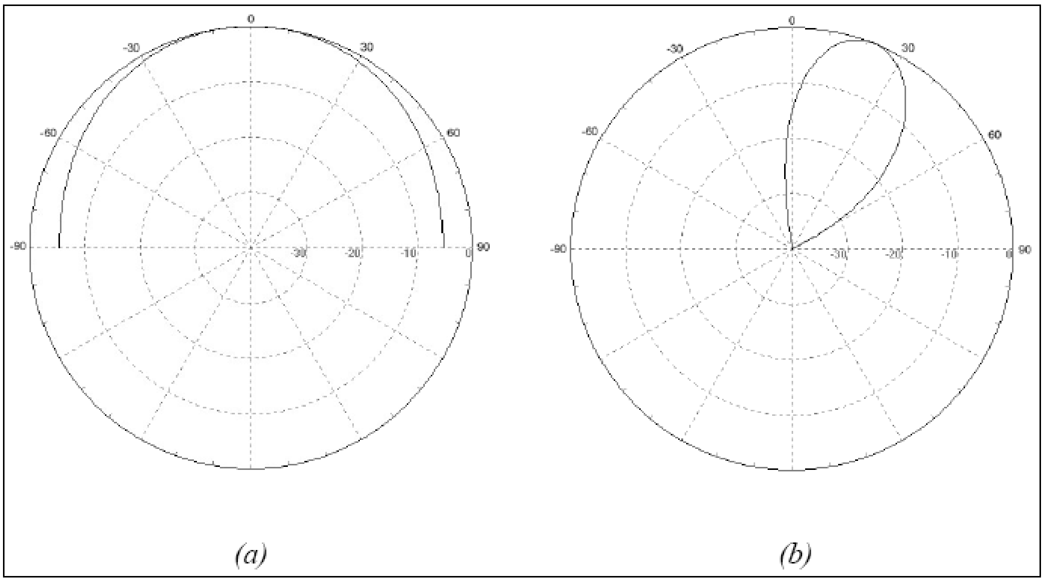

Figure 2.7: Beam patterns of a microstrip antenna with (a) N = 1 and b) N = 8.

2.5.2 Element width and length for patch design

The design of a rectangular patch requires its dimension, width (*W*), length (*L*) and height (*h*), its effective dielectric constant (ε_r) and an approximation relation for the normalized extension of length (ΔL) to be derived and specified in meters

$$W = \frac{c}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}}$$

C= speed of light at $3 \times 10^8 m/\sec$

$f_r =$ resonant frequency of the microstrip antenna

ε_r = relative dielectric constant of the substrate

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}}$$

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}$$

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L$$

Patch width has a minor effect on the resonant frequency and radiation pattern of the antenna. It affects the input resistance and bandwidth to a larger extent. A larger patch width increases the power radiated and thus gives decreased resonant resistance, increase bandwidth, and increase radiation efficiency. With proper excitation we may choose a patch width W greater than the length L without exciting undesired modes. The patch width should be selected to obtain good radiation efficiency if real estate requirements or a grating lobe are not overriding factors. It has been suggested that $1 < \frac{W}{L} < 2$.

The patch length determines the resonant frequency. It is a critical parameter due to the inherent narrow bandwidth of the patch.

2.5.3 Fundamental Specification of Patch Antenna

a) Radiation Pattern

The patch's radiation at the fringing fields results in a certain far-field radiation pattern. This radiation pattern shows that the antenna radiates more power in a certain direction than another direction. The antenna is said to have certain directivity. This is commonly expressed in dB.

An estimation of the expected directivity of a patch can be derived with ease. The fringing fields at the radiating edges can be viewed as two radiating slots placed above a ground-plane. Assuming all radiation occurs in one half of the hemisphere, this results in 3 dB directivity. This case is often described as a perfect front to back ratio; all radiation towards the front and no radiation towards the back. This front-to-back ratio is highly dependent on ground plane size and shape in practical cases. Another 3 dB can be added since there are 2 slots. The slots are typically taken to have a length equal to the impedance width (length according to the y-axis) of the patch and a width equal to the substrate height. Such a slot typically has a gain of about 2 to 3 dB (simple dipole). This results in a total gain of 8 to 9 dB.

The rectangular patch excited in its fundamental mode has a maximum directivity in the direction perpendicular to the patch (broadside). The directivity decreases when moving away from broadside towards lower elevations. The 3 dB beamwidth (or angular width) is twice the angle with respect to the angle of the maximum directivity, where this directivity has rolled off 3 dB with respect to the maximum directivity. An example of a radiation pattern can be found below.

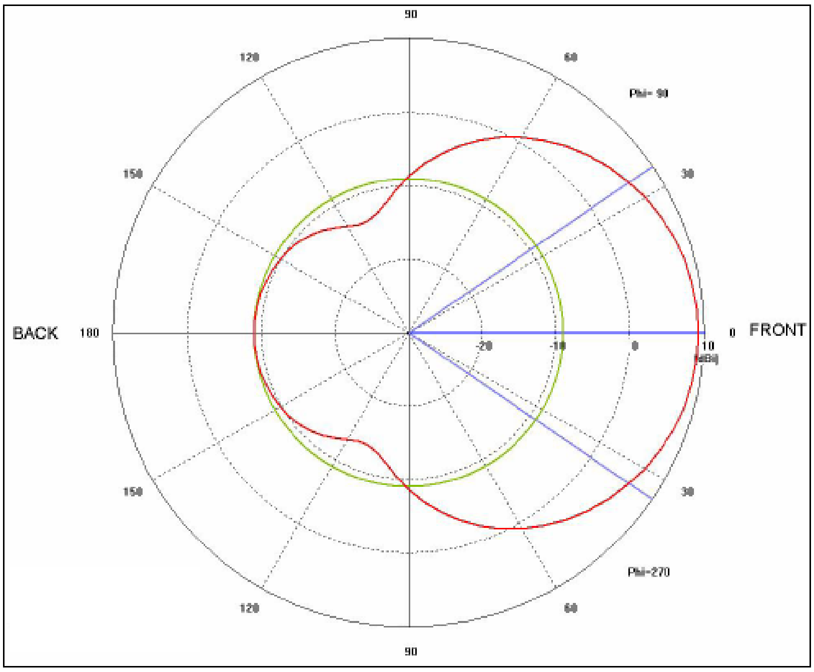

Figure 2.8: Radiation pattern of microstrip patch

So far, the directivity has been defined with respect to an isotropic source and hence has the unit dB*i*. An isotropic source radiates an equal amount of power in every direction. The antenna directivity is specified with respect to the directivity of a dipole. The directivity of a dipole is 2.15 dB*i* with respect to an isotropic source. The directivity expressed with respect to the directivity of a dipole has dB*d* as its unit [3].

b) Antenna Gain

Antenna gain is defined as antenna directivity times a factor representing the radiation efficiency. This efficiency is defined as the ratio of the radiated power (Pr) to the input power (Pi). The input power is transformed into radiated power and surface wave power while a small portion is dissipated due to conductor and dielectric losses of the materials used. Surface waves are guided waves captured within the substrate and partially radiated and reflected back at the substrate edges. Surface waves are more easily excited when materials with higher dielectric constants and/or thicker materials are used. Surface waves are not excited when air dielectric is used. Several techniques to prevent or eliminate surface waves exist, but this is beyond the scope of this article.

Antenna gain can also be specified using the total efficiency instead of the radiation efficiency only. This total efficiency is a combination of the radiation efficiency and efficiency linked to the impedance matching of the antenna [3].

c) Polarization

The plane wherein the electric field varies is also known as the polarization plane. The basic patch covered until now is linearly polarized since the electric field only varies in one direction. This polarization can be either vertical or horizontal depending on the orientation of the patch. A transmit antenna needs a receiving antenna with the same polarization for optimum operation. The patch mentioned yields horizontal polarization, as shown. When the antenna is rotated 90°, the current flows in the vertical plane, and is then vertically polarized. A large number of applications, including satellite communication, have trouble with linear polarization because the orientation of the antennas is variable or unknown. Luckily, there is another kind of polarization circular polarization. In a circular polarized antenna, the electric field varies in two orthogonal planes (x and y direction) with the same magnitude and a 90° phase difference. The result is the simultaneous excitation of two modes, i.e. the TM10 mode (mode in the x direction) and the TM01 (mode in the y direction). One of the modes is excited with a 90° phase delay with respect to the other mode. A circular polarized antenna can either be right-hand circular polarized (RHCP) or left-hand circular polarized (LHCP). The antenna is RHCP when the phases are 0° and -90° for the antenna in the Figure 2.9 when it radiates towards the reader, and it is LHCP when the phases are 0° and 90°.

From this, it is clear what needs to be done in order to get circular polarization, namely:

· Split the signal in two equal parts.

· Feed one signal to a horizontal radiator and the other to a vertical radiator (in this case, each radiator is a pair of radiating edges of the patch antenna is indicated in Figure 2.9).

· Change the phase of one of the signals by 90°.

· Splitting the signal in half can be done with a Wilkinson power divider or similar splitter. If a square patch is fed with two feed points as depicted in the Figure 2.5.2.2, a vertical and a horizontal radiator are created concurrently. By creating the 90° delay in one of the signal lines and connecting each signal to one feeding pin of the patch, a circularly polarized antenna is created.

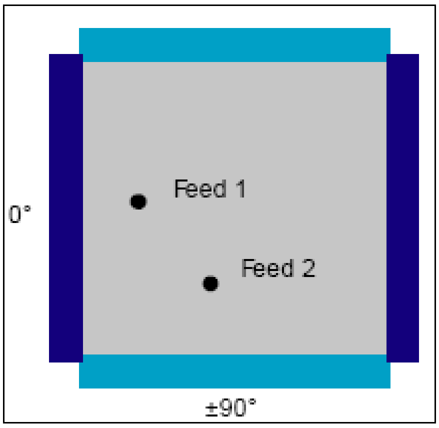

Figure 2.9: Patch fed with 2 feed point

Though this works well, the splitter and delay line take up valuable board space, and they also tend to radiate and degrade radiation pattern. Another approach is to see the patch as a parallel RLC resonant circuit. This means a phase shift that changes versus frequency is present, as shown in the following plot:

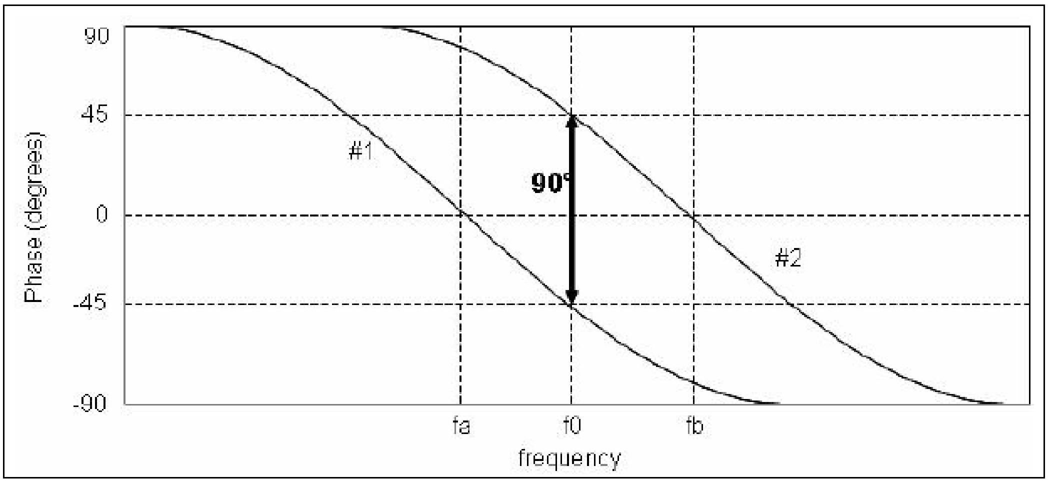

Figure 2.10: Phase shift vs frequency

Since there are two resonances, fa and fb (two modes), there are two RLC circuits. When the corresponding resonance frequencies are slightly different, there is a small frequency band where the phase difference of the two RLC circuits is 90°. Thus circular polarization can be achieved by building a patch with two resonance frequencies in orthogonal directions and using the antenna right in between the two resonances at f0. It is important that the two modes are excited equally strong and with a 90° phase difference. A number of ways exist to implement this, but cutting two corners off the element -- the so-called corners truncated patch -- is a technique widely used in GPS antennas (see figure below). Note, however, that this technique inherently has a lower circular polarization bandwidth than the double fed patch, whose polarization bandwidth is mainly limited by the splitter-phase shifter bandwidth.

The quality of the circular polarization is commonly quantified as the axial ratio (AR), expressed in dB. A 3 dB axial ratio is considered sufficient for most applications. From the outline given previously, it is clear that the axial ratio varies with frequency and has an optimum (0 dB) right in between the resonance frequencies of the two excited modes. However, it is not noticeable in the previous outline that the axial ratio varies with elevation as well. The axial ratio is mostly optimal at broadside (in the direction of z-axis) and degrades towards lower elevations (away from z-axis). The degree of degradation is highly dependent on the antenna geometry. Most antenna vendors only specify one axial ratio value or an axial ratio variation versus frequency, and they don’t say anything about axial ratio variation versus elevation.

Another way of expressing the quality of circular polarization is showing the co-and cross-polar radiation patterns. The co-polar radiation pattern is the radiation pattern of the wanted polarization, and the cross-polar radiation pattern is the radiation pattern of the unwanted opposite polarization [3].

d) Bandwidth

Another important parameter of any antenna is the bandwidth it covers. Only impedance bandwidth is specified most of the time. However, it is important to realize that several definitions of bandwidth exist -- impedance bandwidth, directivity bandwidth, polarization bandwidth, and efficiency bandwidth. Directivity and efficiency are often combined as gain bandwidth.

Impedance bandwidth/return loss bandwidth

This is the frequency range wherein the structure has a usable bandwidth compared to certain impedance, usually 50 Ω.

The impedance bandwidth depends on a large number of parameters related to the patch antenna element itself (e.g., quality factor) and the type of feed used. The plot below shows the return loss of a patch antenna and indicates the return loss bandwidth at the desired S11/VSWR (S11 wanted/VSWR wanted). The bandwidth is typically limited to a few percent. This is the major disadvantage of basic patch antennas [3].

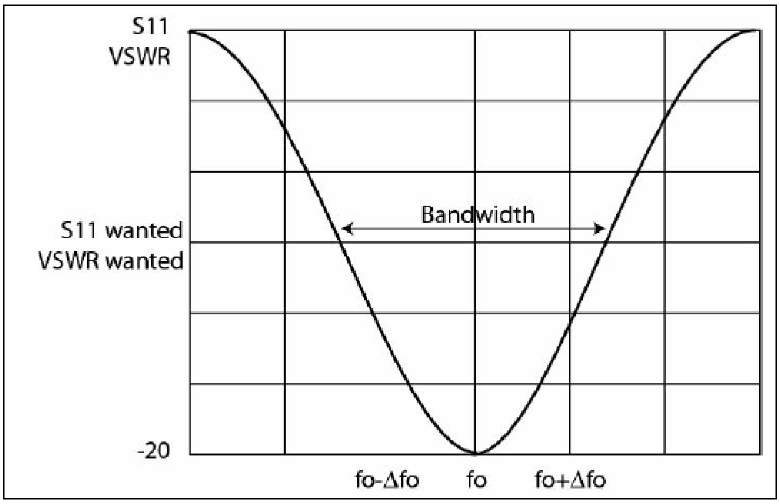

Figure 2.11: Bandwidth of a patch

2.6 Butler Matrix

2.6.1 Introduction

Butler matrix is a passive feeding N x N network with beam steering capabilities for phase array antennas with N outputs connected to antenna elements and N inputs or beam ports. N must be an integer power of 2 ($N = 2^n$ where n is a positive integer) to form a network and creates a set of N orthogonal beams in space by processing the signal from the N antenna elements of an equi-spaced linear array. These beams are pointing in direction θ governed by the following equation:

$$\sin\theta_i = \pm\frac{i\lambda}{2Nd}, i = 1,3,5....(N-1)$$

The corresponding inter-element phase shift with spacing d= $\frac{\lambda}{2}$ is

$$\alpha_i = \beta d \sin\theta_i = i\frac{\pi}{N}$$

Where $\beta = \frac{2\pi}{\lambda}$ the wave number and d is is the distance between the output antenna ports.

A total of $\frac{N}{2}\log_2 N$ hybrids and $\frac{N}{2}\log_2(\frac{N}{2})$ phase shifters are required for this network. Figure 2.12 shows a schematic diagram of a 4 x 4 Butler matrix consist of four 90^0 3-dB hybrids, two crossovers and two 45^0 phase shifters

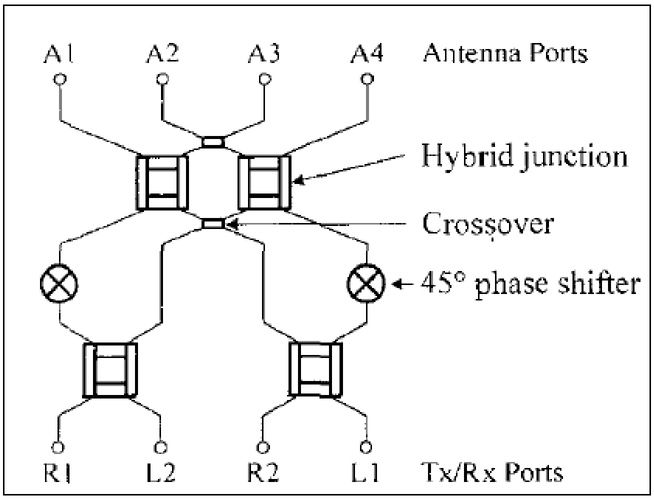

Figure 2.12: 4 x 4 Butler matrix block diagram