UNIVERSITY OF MALTA
DEPARTMENT OF COMPUTERS & COMMUNICATION ENGINEERING

FINAL YEAR PROJECT
B.Sc. I.T. (HONS.)

Switched beam antenna array, Design and experiment

by

Joseph A. Zammit

Supervised by Mr A. F. Muscat

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Introduction

Digital beamforming is a technique that is being developed to utilize more efficiently the radio spectrum. With the advent of more radio services, such as mobile communications, remote operated devices, radar and telemetry, the radio spectrum is being overcrowded. Several solutions exist such as time division, multiplexing (TDM), frequency division multiplexing (FDM) and the allocation of higher frequencies. Another solution is to allocate user space for the time he needs to communicate. This is achieved using antenna arrays and the beamforming techniques. This gives the system several advantages such as higher output power due to the array and the option to reject interference. This has many uses in the military as an electronic counter measure (ECM) technique. For example suppressing the enemy's jamming equipment.

Patch antennas are a new type of antennas. They are cheap, lightweight and easy to manufacture. Other subsystems such as microwave amplifiers, transmission lines and filters may be mounted on the same board. This makes the manufacturing process much easier since it requires fewer steps.

When patch antennas and digital beamforming are used together, a powerful system emerges. This project investigates this possibility. The aim of the project is to build and test a small phased antenna array built using patch antennas. I would also determine the amount of phase shift that is needed to achieve a reasonable amount of beamsteering. The resulting antenna also had to be cost effective for its application.

The next section will describe how the project was carried out.

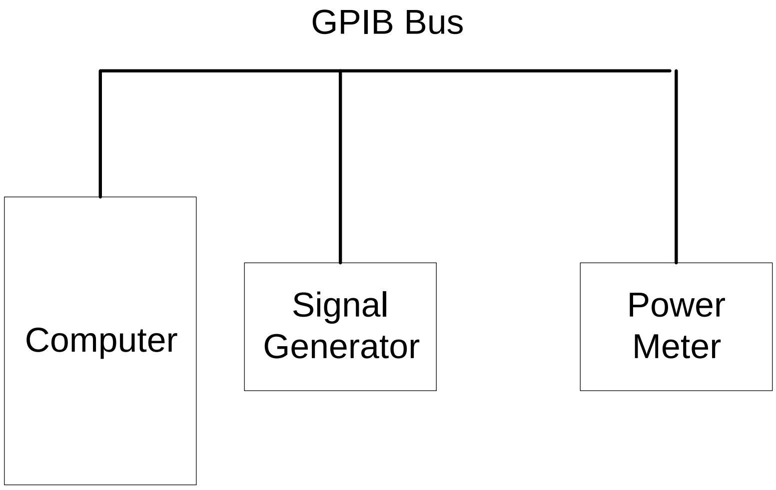
Project approach

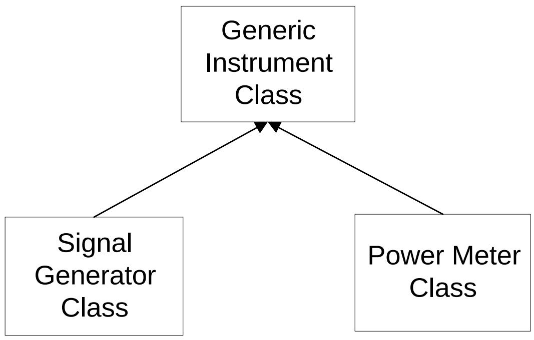
The project was implemented in a sequential fashion, as substantial amount of research was required at the beginning and at each stage.

Test facilities

Two automated test facilities had to be built before even the first patch antennas were designed. The laboratory is equipped with an HP442A power meter, 2 power sensors and an HP8648C signal generator. These instruments had a GPIB interface. The computer was equipped with a Keithley MetraByte GPIB interface card.

The first part of the project was to interconnect these 2 instruments with the computer so that they could be remotely controlled. The C++ language was used for interfacing because it is an efficient and powerful language used by engineers. It was also used because it is the standard language in our department, thus allowing software portability and future extensions. Each instrument was wrapped in high level routines for ease of use. Classes were used for these high level wrappers. A base class is used to represent a generic instrument was created. It supports a limited set of instructions of the IEEE488.2 standard. The power meter and the signal generator were implemented as derived classes from this base class and any features to the particular instrument added. The resulting system is shown below:



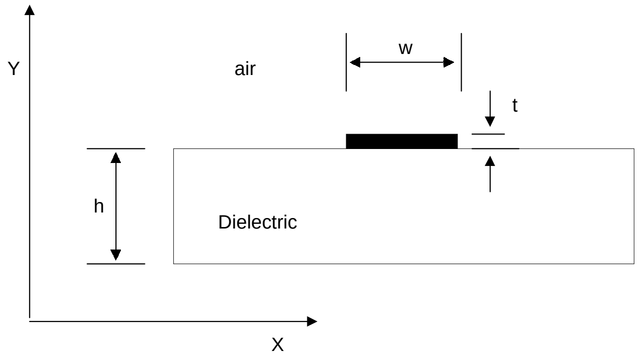


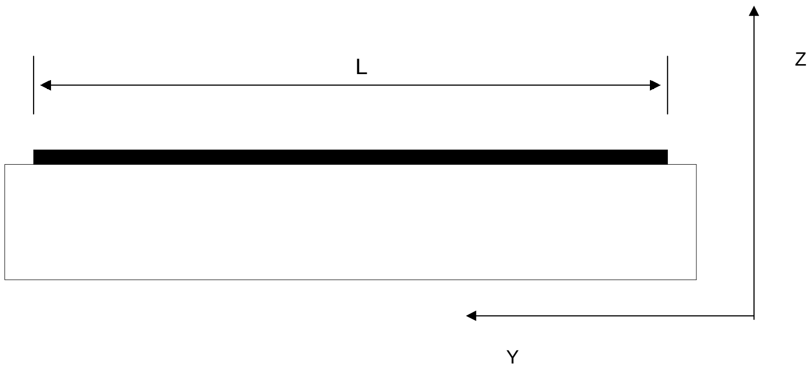
In order to plot the radiation pattern for the antenna, an existing facility was used. An existing facility was modified to suit the project requirements. A simple buffer from a printer port was designed and an assembly that allows an antenna to be placed on it together with a power meter was constructed so that the received power could be read and plot the radiation pattern. Some simple interfacing software was written to derive the stepper motor. As the design was very simple, it was not encapsulated in a class.

Microstrip layout techniques

As wavelengths become shorter, the circuit layout and dimensions become more critical. This is especially true for microwave frequencies and higher. As my previous knowledge on microstrip antennas was limited, I had to do a fair amount of reading and research on this topic. This would be important for the latter part of the project when the phase shifting circuitry was being designed.

A figure of a typical microstrip line is shown below:

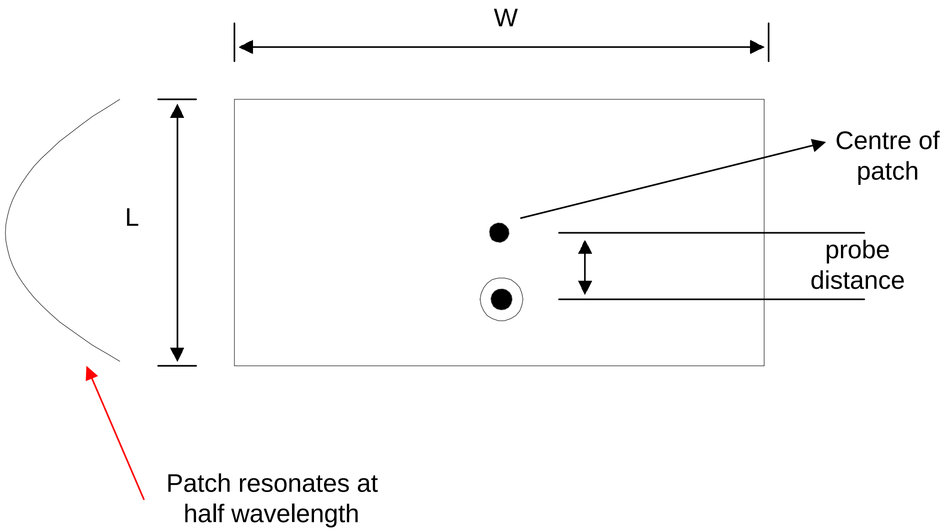




The impedence of a microstrip line is a function of the height of the line above the ground, the line width and the permittivity of the substrate being used. Usually the permittivity is replaced by the effective permittivity which takes into account that some of the microstrip`s electric field passes from the air to ground. The design of quarter wavelength transformers and power dividers was also read in order to get the maximum performance from the circuit. Finally, the effect of microstrip discontinuities such as 90^0 bends and series coupled gaps was researched as they were encountered in the project.

Patch antenna design

The microstrip patch consists of a shape of conducting material on a ground plane, fed by a microstrip line. Patch antennas were first introduced in the 1950` s in America. In this project, only rectangular patches were considered because of their design simplicity. The rectangular patch consists of length L and width W as shown below:



The rectangular patch resonates along its length L and radiates from the width W. For resonance at a particular frequency the patch length is half the wavelength. In reality, it is less because of the fringing fields at the edge of the patch. There is also a direct relationship between length L and width W. The less width W is the longer length L is. The patch antenna feed is as important as the design of the antenna itself. As all impedences must be matched for maximum power transfer, the degree of matching in antennas is an important design criteria. There are various methods of patch antennas feeds such as microstrip feed, probe feed and aperture coupling. In this project, probe feeding was chosen because of the simplicity of the circuit and match. The optimum match position is found by putting the probe at a distance $L/4$ from the patch center and at a width of $W/2$.

Simulations

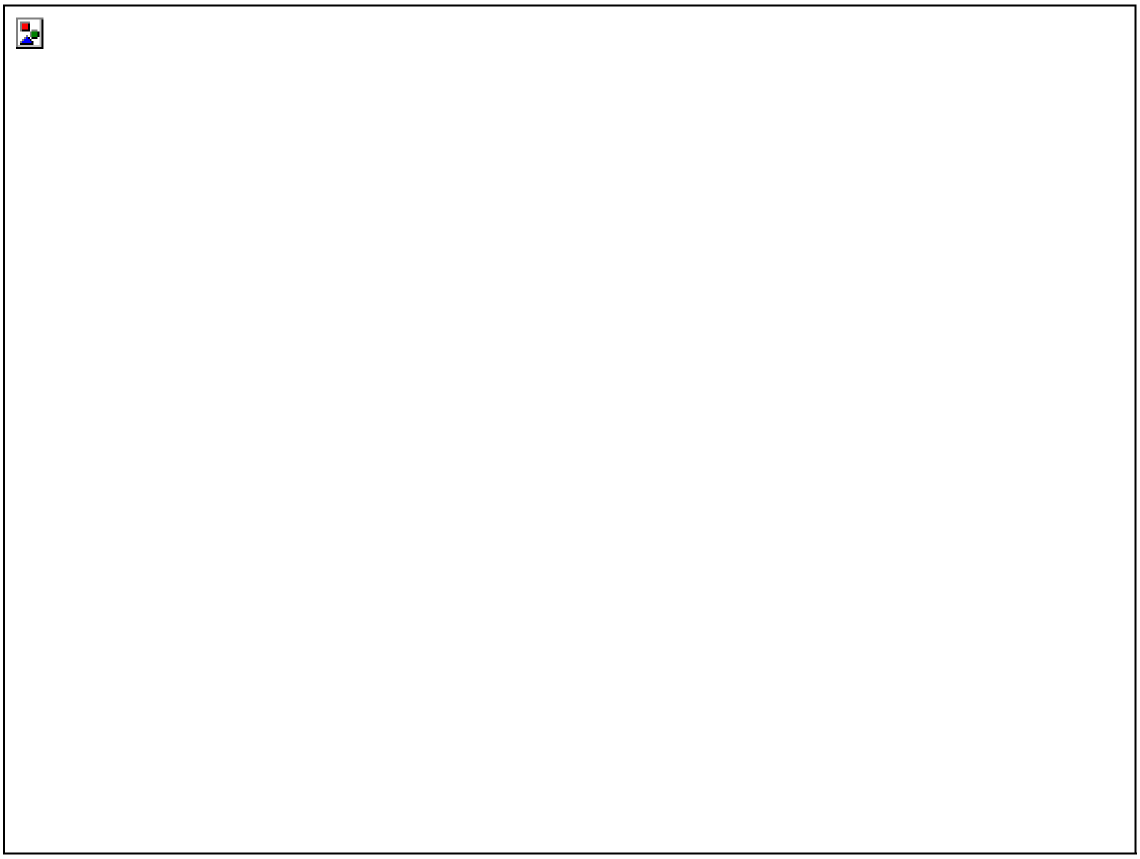
Before the patches were built, they were simulated using a Finite Domain Time Domain (FDTD) simulator developed in the department[1]. The FDTD simulator solves Maxwell's electromagnetic equations in a 3D space. The user specifies the point sources, the type of input pulse in order to calculate the reflection coefficient and radiation pattern. The results from the FDTD model are converted into the frequency domain to determine the variation of the source impedence with frequency, or the field radiation off the patch. The simulations were run using a 1mm scale on all axis. If a coarser scale were used, the result would be incorrect. The result of the simulations would then be compared to the actual results. In all cases the –10 dB beamwidth of the antenna was calculated.

Phased arrays

After designing and testing the first antenna, dealt with in a later section, the design of the phased array began. I chose an array of 3 elements. The constraints were the size of each element and the final size of the ground plane which needed to hold all elements and still radiate effectively. The formula for an arbitrarily spaced and phased array is shown below.

$$F(\vartheta) \quad = \quad \left| \sum_{n=1}^{N} I_n \cdot e^{j \cdot k \cdot z_i \cdot \cos(\vartheta)} \right|$$

A simple simulation using isotropic sources and pattern multiplication was written using Matlab in order to evaluate the field patterns of the array. It ignored the effects of mutual coupling between the elements.



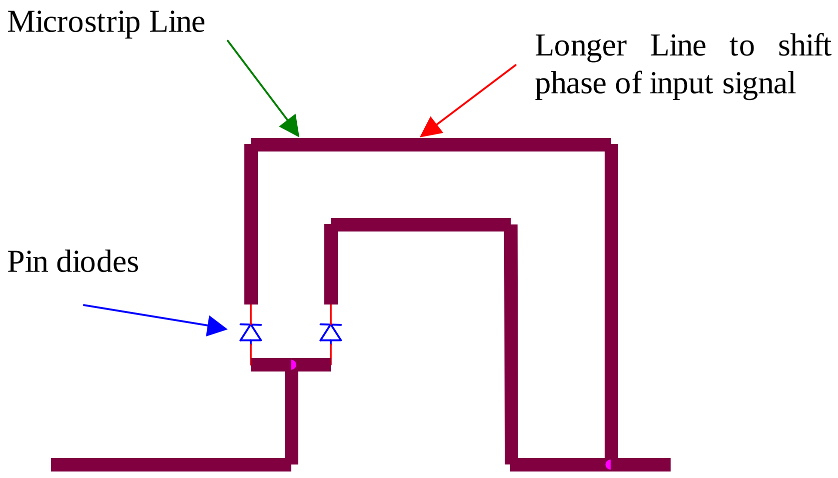
Shown below is the relative field pattern of the phased array, with no phase shift

Various phases were applied in order to see what phase shift was needed to achieve beamsteering. As this was a first design attempt I decided for a smaller amount of beamsteering typically of $\pm$ 15^0 to the main beam. The array elements were spaced half a wavelength apart from the minimum size for mutual coupling not to have a large effect on the array.

Pin diodes

These special types of diodes are used in microwave technology to act as electronic switches. Pin diodes have an intrinsic layer made up of silicon between the p and n layers.They have the special property that when forward biased in the microwave region, they act as a short circuit with only parasitic inductance and a small series resistance. If used at a lower frequency, determined by the width of the intrinsic layer the diode will act as a rectifier. When reverse biased, the diode will act as a capacitance in series with the package parasitic inductance. This places an upper bound on the frequency of the operation of the pin diode.

These diodes may be used to switch different lengths of transmission lines thus creating a relative phase shift between two microstrip lines. This is explained below:

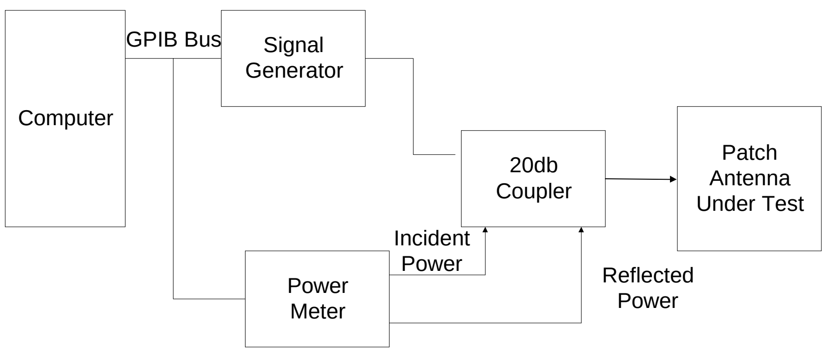


The upper transmission line is longer than the lower line by 45^0 . Thus if applied to an array I would have achieved our required phase shift to an array in order to steer the beam.

Experimental setups

Calculation of the reflection coefficient

In order to calculate the reflection calculation (S_{11}), the following setup was used:



The signal generator was swept through a range of frequencies. Channel A of the power meter was used to read the input power from the 20db coupler while Channel B was used to read the reflected power from the antenna under test. The reflection coefficient was calculated from this formula:

$$S_{11}\,(db) = P_{in}\,(dbm) - P_{ref}\,(dbm)$$

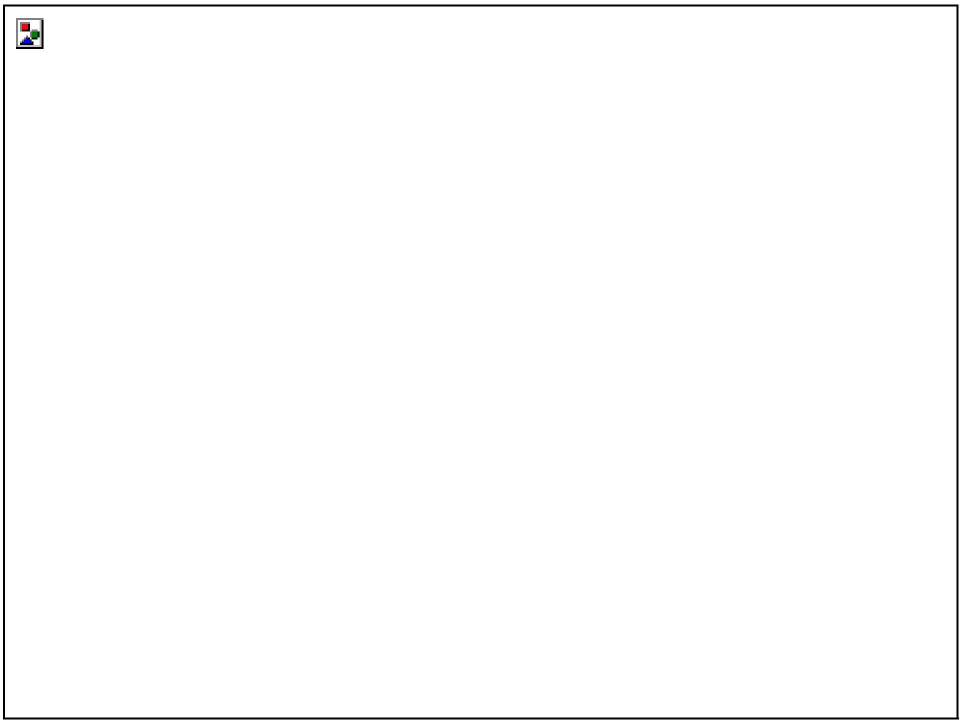
All measurements were made using the dB scale. The results were then plotted on a graph and compared with simulation results.

Radiation pattern measurements

A more elaborate experimental setup was needed to measure the radiation pattern. This measurement is ideally done in an anechoic chamber. This is a rectangular room with the walls lined with graphite loaded materials to absorb reflections. This is best approached by an outdoor test range with minimal object in the open space. The disadvantage of the outdoor test range is the weather. Until the writing of this report, the weather conditions in Malta were such that outdoor testing was impractical.

Current project progress

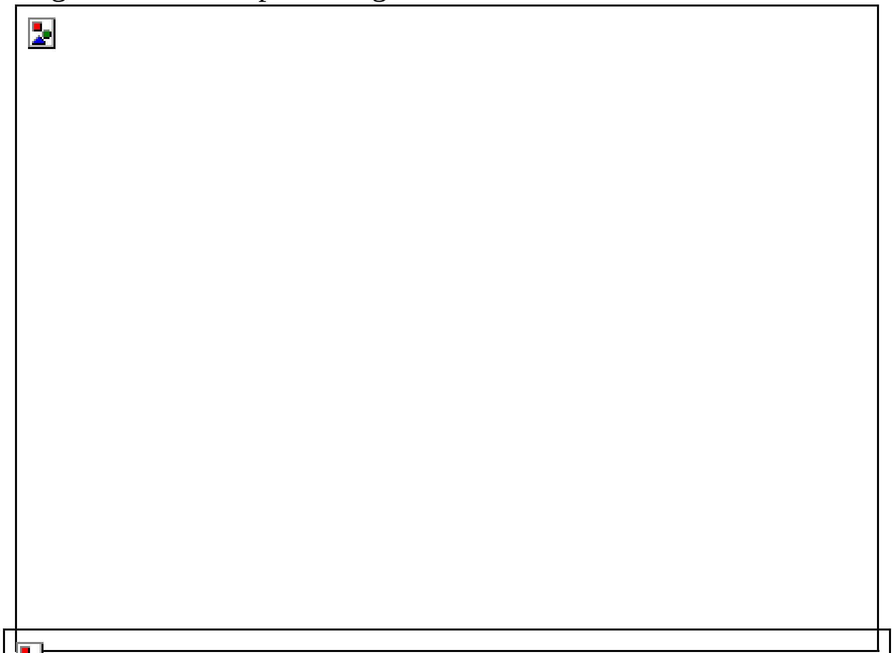
At the time of writing, the project in moving towards the last phase. A probe feed suspended patch antenna has been built and tested. Shown below is the s_{11} measurement of the patch antenna that is used to find the resonant position.



Probe fed suspended patch antenna

The diagrammatic interpretation is as follows. The graph minimum point is the resonant frequency of the antenna, in this case 2.03 GHz. The depth of the resonant frequency is a measure of the degree of matching in the antenna. In this case, this is –22 dB, which represents a very good match. The other diagram is a simulated patch using the FDTD simulator at a resolution of 1 mm. Both curves are in good agreement with each other but one can notice that a finer resolution may be needed for the FDTD simulation to match more closely the experiment.

The radiation pattern and the cross-polar pattern were also measured and their respective plots are shown below. These readings were taken in an indoor laboratory, as weather conditions outside would not permit any experiments. Although any interfering objects were removed from the laboratory, some reflection were still present and are shown as irregularities in the polar diagram, as shown:



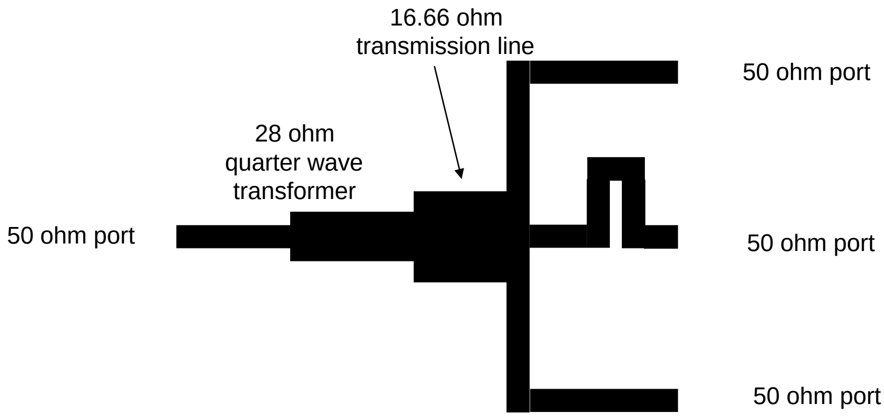
Again, these two graphs show that our experiments are consistent with the simulations.

Phased antenna feed design

This section is about the feed for the phased array in order to build the beamforming circuits. This final section of the project was broken down into 3 phases:

1. Building a feed for a 0^0, 0^0,0^0, phase shift.
2. Building a feed for a 0^0, 0^0, -45^0 phase shift. This would be tuned over for a -45^0, 0^0, 0^0 phase shift to test the antenna array.
3. Using pin diodes to create a switching network for the antenna array.

Phase 1 has been designed. It consists of a quarter wave transformer and 50 – 16.6 Ω and a power divider, feeding 3, 50Ω lines in parallel. The line lengths were compensated for give a 0 degree relative phase shift. A diagram of the feed system is shown below



Conclusions

In this project, the design of a switched beam antenna array was designed and implemented. Experiments were conducted to compare the design with the built antennas were conducted.

References

[1] Software written by A.F.Muscat
[2] A.F. Muscat and C.G. Parini *"Mutual Coupling in aperture fed antennas: Theory and Experiment* ", Queen Mary & Westfield College, London , UK

Books

[3] J.R James, P.S. Hall and C.Wood, *Microstrip Antenna* Theory and Design, Peter Perginus LTd,1981
[4] P.Bhartia, *Millimeter wave Microstrip and printed circuit antennas,* Artech House, 1991, pgs 9-41, pgs 125-176
[5] John Litva and Titus Kwok-Yeung Lo, *Digital Beamforming in wireless communications* , Artech House, 1996
[6] R.T Compton, *Adaptive Antennas, Concepts and performance* , Prentice Hall, 1998