

C-BAND QUASI YAGI ANTENNA

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ABSTRACT

This thesis is concerned with investigations of types of broadband antenna elements namely quasi Yagi antenna. This antennas will be fabricated with a dielectric constant substrate material (FR4 with dielectric constant $\epsilon_r = 5.4$), substrate thickness of 1.6mm and design frequency of 4 GHz. The first part of the thesis deals with the theory behind microstrip antennas and transmission lines. An introduction to microstrip antennas is presented, followed by a literature review on microstrip design equations and background information with regard to microstrip broadband planar antennas. The three most commonly used broadband planar antennas are illustrated, namely the Microstrip Patch antenna, quasi Yagi antenna and Tapered Slot Antenna. In contrast to the microstrip patch, both the arrays of quasi Yagi antenna and the single-element quasi Yagi antenna radiates at the end-fire direction. As a result, both these antennas can achieve higher gain, lower side lobes and wider bandwidth compared to the conventional microstrip patch antenna. The second part of the thesis is concerned with design procedures and considerations for the antenna. The design for the antennas is aimed at obtaining wider bandwidth and better radiation patterns. Besides, a sensitivity analysis of the quasi Yagi antenna with respect to the design parameters is demonstrated in chapter 4 of this thesis. The simulation of the quasi Yagi is accomplished by using Advanced Design System (ADS) software. The simulation results showed that the quasi Yagi antenna is able to achieve at the desired frequency (4 GHz) that is in the C band frequency.

ABSTRAK

Tesis ini akan menerangkan penyiasatan ke atas antenna jalur lebar iaitu antenna quasi Yagi. Antenna ini akan difabrika dengan bahan substratum yang mempunyai dielektrik konstan (FR4 dengan dielektrik konstan, $\epsilon_r = 5.4$), ketebalan substratum 1.6 mm dan frekuensi rekabentuknya adalah 4 GHz. Bahagian pertama akan menerangkan teori tentang antenna mikrostrip dan talian penghantaran. Di samping itu, pengenalan kepada antenna mikrostrip akan dipersembahkan, ini diikuti dengan persamaan rekabentuk dan informasi latar belakang antenna mikrostrip jalur lebar. Ketga-tiga antenna jalur lebar akan digambarkan, iaitu antenna tampal, antenna quasi Yagi dan antenna riak tirus. Berbanding dengan antenna tampal, kedua-dua elemen tunggal dan tatasusunan quasi Yagi antenna menyinar pada arah hujung antenna. Oleh itu, kedua-dua antenna ini akan mencapai gandaan tinggi, cuping tepi kecil dan lebar jalur yang luas jika dibandingkan dengan antenna tampal mikrostrip. Bahagian kedua tesis ini akan menerangkan langkah-langkah dan pertimbangan untuk merekabentuk antenna tersebut. Rekabentuk antenna ini adalah bertujuan untuk mendapat lebarjalur yang luas dan bentuk radiasi yang lebih baik. Di samping itu, analisa kepekaan antenna quasi Yagi terhadap parameter rekabentuk akan ditunjukkan dalam Bab 4 tesis ini. Simulasi antenna ini akan dijalankan dengan menggunakan perisian Advanced Design System (ADS). Keputusan simulasi menunjukkan antenna quasi Yagi beroperasi pada frekuensi jalur-C iaitu 4 GHz.

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CHAPTER 1

THESIS OVERVIEW

1.1 Thesis Objective and Scope

The objective of this project is to design a C band quasi Yagi antenna which is operate in the range of frequency from 4 GHz to 8 GHz. Normally, antennas are designed for operation in one resonant frequency. In other words, antennas are normally operational only in one frequency. In recent years a lot of interest has been shown in spatial power combining methods to overcome: difficulties in generating high power levels from solid-state devices at millimeter-wave frequencies. Although oscillators and amplifiers can be spatially combined, most of the recent research activities have been devoted to amplifiers due to their more predictable design and a larger operational bandwidth. In order to obtain low manufacturing costs, tile and brick configurations of planar antenna arrays have attracted a lot of attention as suitable power combining structures. In these arrays antenna elements are located at the input and output ports of the individual amplifiers. The antenna element at the input receives the signal and passes it to the amplifier. The element at the output radiates the amplified signal. Power from the array is intercepted in free space by a receiving collecting antenna such as a horn antenna. Due to the fact that the tile configuration usually employs resonant type antenna elements, such as microstrip patch antennas, this type of power combiner is narrow-band in operation. The resulting operational bandwidth is usually smaller than that of individual amplifiers when they are tested without radiating elements. The motivation of the work presented in this thesis is to explore: new antenna elements arranged in the brick configuration to fully utilize the surplus bandwidth of transistor amplifiers. One possible choice, which has already been explored in, is to use a planar-type linear tapered slot antenna (LTSA). This antenna element, when properly designed, features large (multi-octave) operational bandwidth and because of an end-fire radiation characteristic it is suitable for inclusion as an element of a brick array.

Although this antenna element is compact and provides a suitable bandwidth to match individual transistor amplifiers its design strategy. It has not been well documented. This thesis investigates the effects of design parameters of the single-element quasi-Yagi antenna on its operational frequency and impedance bandwidth. The study identifies parameters most affecting the performance of this antenna. The presented findings should be of interest to the designers of the quasi-Yagi antenna for applications such as a spatial power combining and other wireless communications applications.

The antenna will be designed using Agilent's Advanced Design System (ADS) and simulated using its momentum simulator. Once the design of the antenna is completed, it will be fabricated onto a printed circuit board (PCB). Measurements of the antenna's characteristics such as its return loss, radiation pattern, gain, efficiency and input impedance will be done using the network analyzer, the vector voltmeter and signal generators in different testing environment and conditions. Then the similarities as well as differences will be compared and discussed.

1.2 Thesis outline

Chapter 1 gives a specific introduction to the objective and scope of the thesis. The outline of the structure of the thesis is also given.

Chapter 2 reviews the massive theories behind the Yagi-Uda and microstrip antenna technology. This chapter begins with the basic characteristics of microstrip antennas and is continue by their feeding techniques/excitation methods. Then, various analytical evaluations of the antenna will be presented and the broadband operation of microstrip antennas will be researched. After that, the applications of the C band will be given in this chapter.

Chapter 3 will present the design process of the antenna in this project. The specification of the antenna will be determined and the various design parameters will be explained. And the design software- ADS will be introduced too. The layout of the design will be done using ADS's layout tool.

Chapter 4 will present the sensitivity of quasi Yagi antenna and the simulation

results and measurement results or experimental analysis from hardware testing on the fabricated antenna in the laboratory. Both the result from the measurement and simulation will be compared and discussed.

Chapter 5 will give the conclusion of the project. Recommendations will be suggested for future work as the continuation of this work.

1.3 Project Implementation

There are several steps or procedures in order to accomplish the project. Flow chart below shows the implementation of the project.

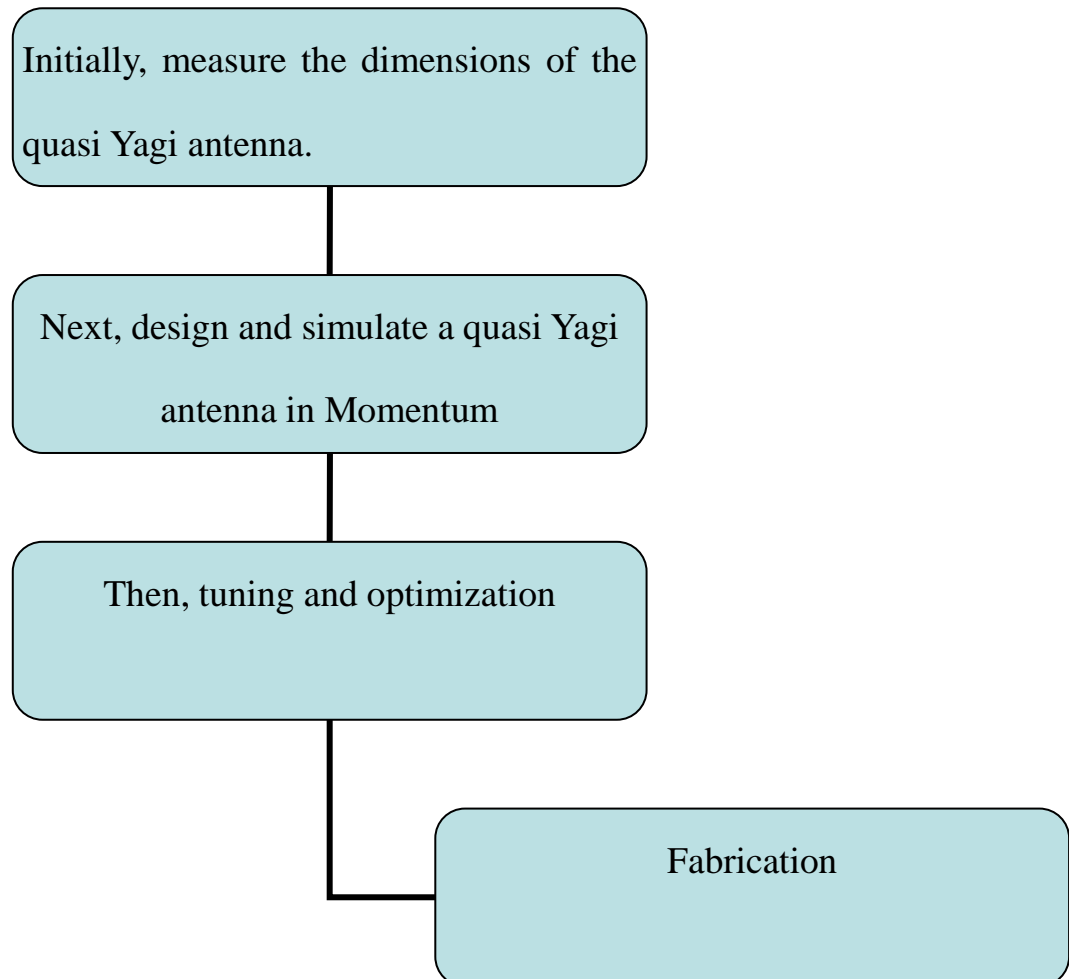


Figure 1.1 Implementation of design

CHAPTER 2

LITERATURE REVIEW

This chapter provides background information for the Yagi-Uda antenna. This chapter will also provide background information regarding the basic microstrip transmission line. The basic geometry of the microstrip line is illustrated, followed by an analysis of the microstrip electromagnetic field pattern. Furthermore, the different types of substrate materials used for microstrip antennas are listed. After presenting the historical development, the advantages and disadvantages of the microstrip antenna, a listing of the three various categories of microstrip antenna will be discussed, specifically the microstrip patch antenna, microstrip traveling-wave antenna and microstrip slot antenna. Besides, the excitation techniques used to excite microstrip antennas will be explained. Finally, this chapter will be end with the applications of C band.

2.1 Yagi-Uda Antenna

A Yagi-Uda antenna is familiar as the commonest kind of terrestrial TV antenna to be found on the rooftops of houses. It is usually used at frequencies between about 30MHz and 3GHz, or a wavelength range of 10 metres to 10 cm. (There are some obsessional amateur radio enthusiasts who construct Yagi-Uda antennas for the 80 meter wavelength band. This is rather impractical as spacing them from the ground by more than half a wavelength is difficult.) The rod lengths in a Yagi-Uda are about a half wavelength each, and the spacings of the elements are about 1/3 of a wavelength. [D.Jefferies 1999, 2000, 2002, 2004.]

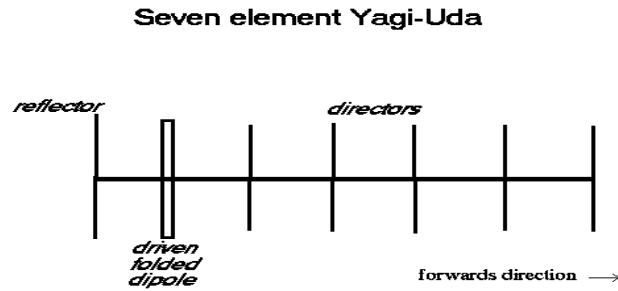


Figure 2.1: Diagram of a 7 element Yagi-Uda layout

There are three kinds of elements (or rods) mounted on a longitudinal connecting bar or rod. It doesn't matter if this connecting rod conducts, as it is orientated at right angles to the currents in the elements, and to the radiating electric fields; it supports little or no current, and does not contribute to the radiation. It does not matter what it is made of other than that it should have good structural properties. If it is made of conducting metal as are the elements, it can be connected electrically to the directors and to the reflector (but not to the driven element) without disturbing any of the properties of the antenna.

The three types of element are termed the *driving element*, the *reflector(s)* and the *director(s)*. Only the driving element is connected directly to the feeder; the other elements couple to the transmitter power through the local electromagnetic fields which induce currents in them. The driving element is often a folded dipole.

Many people believe that the gain of a Yagi-Uda rises proportional to the boom length, rather than the number of elements. These two criteria boil down to the same thing for "sensible element spacings". Clearly, taking the reductio-ad-absurdum of a three element yagi with indefinitely increasing element spacing, the gain will not rise as the spacing is increased, beyond a certain amount. On the other hand, placing a great many elements within a short boom length can plainly be seen not to increase the gain.

To broadband a Yagi-Uda, sometimes the individual elements are split into two in an approximation to a primitive "biconical antenna". An example is shown here; this shows part of a UHF television receive Yagi-Uda to cover a fractional bandwidth of

around 30 percent. It is vertically polarised.

Director

The directors present a capacitive impedance, acting like two lengths of open circuit transmission line each a little shorter than a quarter wavelength to a hypothetical generator at the centre formed from the "induced emf" set up by the impinging fields.

Reflector

The reflector has an induced current in it that contributes a wave in the backwards direction that just cancels the backward wave from the driven element. Only a little power is radiated backwards. The net power radiated by the reflector current has to go somewhere, so it appears as a contribution in the forward direction. The length and the spacing of the reflector have a strong influence on the residual backward radiation from the Yagi-Uda. Typically the reflector will be spaced by $1/8$ to $1/4$ of a wavelength, and the directors by about $1/3$ wavelength each.

2.2 Quasi Yagi Antenna

2.2.1 Uniplanar Quasi-Yagi Antenna

The Quasi-Yagi antenna shown in figure 2.2 (a) consists two dipole antennas, the director and the driver, a ground plane and a microstrip-to-coplanar strips (CPS) balun [10]. The director and driver of the antenna are placed on the same plane of the high dielectric substrate so that the surface waves generated by the antenna are directed to the end-fire direction. Coplanar strips are a uniplanar transmission line and a balun is usually desired to provide efficient transition between the CPS and the microstrip lines [11]. The ground plane is on the bottom side of the substrate. This antenna design is sense that the ground plane on the back of the substrate acts as a reflecting element [12]. In other words, the ground plane helps to reduce the surface wave traveling to the backside. The dipole elements of the antenna are strongly coupled by the surface waves which have the same polarization and direction as the dipole radiation fields [13]. As for the radiation direction of the Quasi-Yagi Antenna, it belongs to the general class of end-fire traveling-wave antennas. Shown in figure 2.2(b) is the end-fire radiation

characteristic of the Quasi-Yagi antenna.

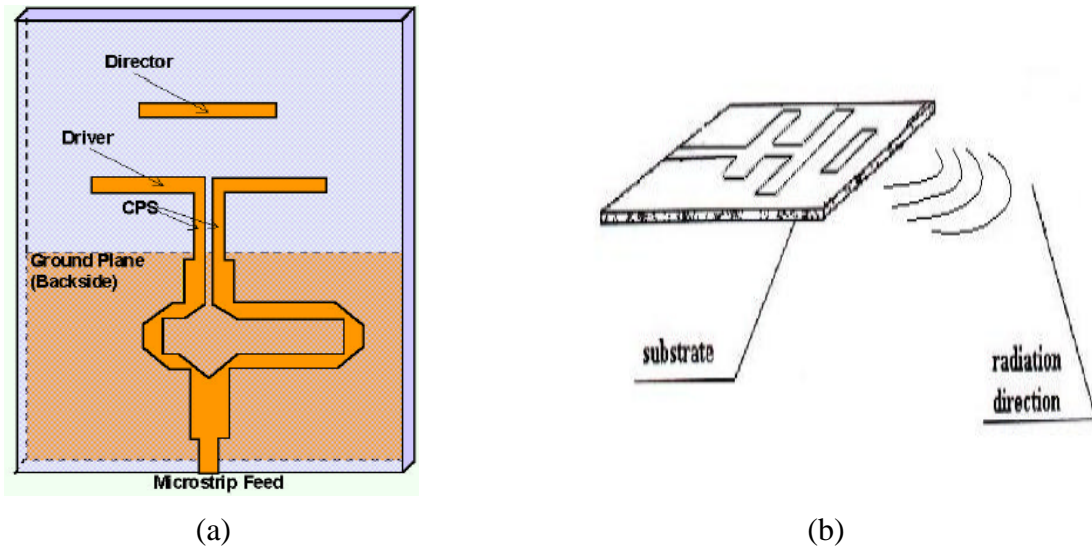


Figure 2.2: Uniplanar Quasi-Yagi Antenna And End-Fire Radiation Direction of Quasi-Yagi Antenna

2.2.2 Quasi-Yagi Antenna Array

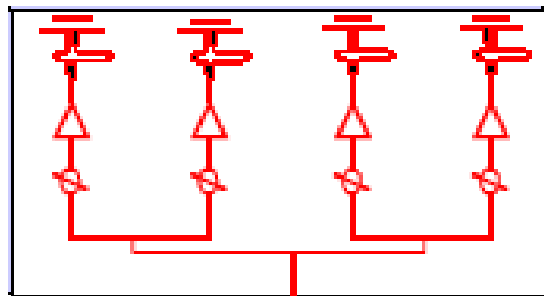


Figure 2.3: Quasi Yagi Antenna Array

The fully 2D phased array using the planar quasi-Yagi radiating element which delivers optimal array bandwidth and maximum scan angle. Based on the ensured $\lambda_0/2$ center to center spaced arrangement of elements, the developed four element array provides broadband operation and good radiation characteristics in terms of front-to-back ratio and cross polarization. The salient feature that the antenna is built on high permittivity substrate is attractive for monolithic integration with RF front-end circuitry such as GaAs or InP LNAs, which should greatly improve the overall efficiency of active phased arrays for high frequency applications.

2.3 Microstrip Transmission Line

2.3.1 Basic Microstrip Line

The microstrip line is most commonly used as microwave integrated circuit transmission medium. Microstrip transmission line is a kind of "high grade" printed circuit construction, consisting of a track of copper or other conductor on an insulating substrate. There is a "backplane" on the other side of the insulating substrate, formed from a similar conductor. Basically, it comprised of a metal strip supported above a larger dielectric material and a ground plane. Looking at the cross-section of the microstrip transmission line, the track on top of the substrate will serve as a "hot" conductor, whereas the backplane on the bottom serves as a "return" conductor. Microstrip can therefore be considered a variant of a 2-wire transmission line.

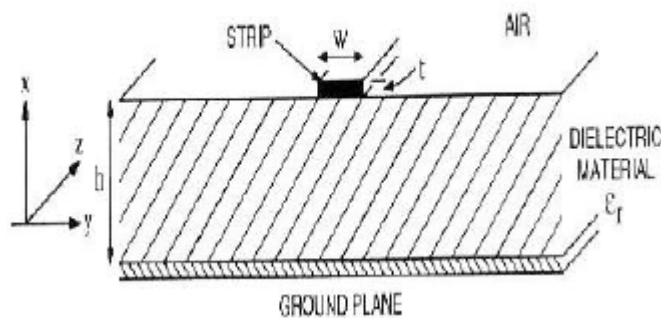


Figure 2.4 Structure of Microstrip Transmission Line

The general geometry of microstrip antenna is shown in figure 2.4 as above. The most important dimensional parameters in microstrip circuit design are the width w and height h (equivalent to the thickness of the substrate) [1]. Another important parameter is the relative permittivity of the substrate (ϵ_r). The thickness of the metallic, top conducting strip t and conductivity s are generally of much lesser importance and may be often neglected. The metallic strip is usually printed on a microwave substrate material.

2.3.2 Microstrip Field Radiation

If one solves the electromagnetic equations to find the field distributions, one will tend to find very nearly a completely TEM (transverse electromagnetic) pattern. This

means that there are only a few regions in which there is a component of electric or magnetic field in the direction of wave propagation. The field pattern is commonly referred to as a Quasi-TEM pattern. Shown in figure 2.5 is the electromagnetic field pattern of the basic microstrip transmission line.

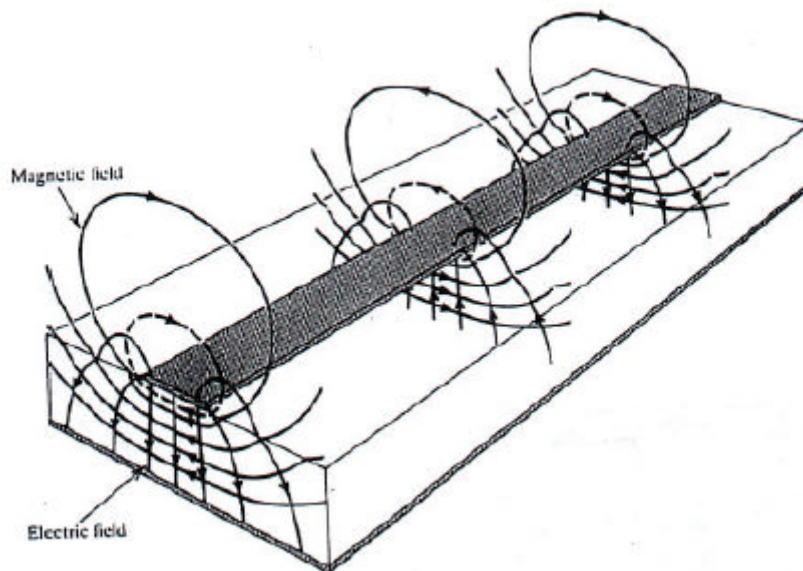


Figure 2.5: Electromagnetic Field Pattern of a Microstrip

2.4 Microstrip Antenna

Microstrip antennas become very popular in the 1970s primarily for space borne applications. Today they are used for government and commercial applications. These antennas consist of a metallic patch on a grounded substrate. The metallic patch can take many different configurations, as shown in Figure 2.6. And on the other side of a dielectric substrate has a ground plane.

This metallic patch can take many different configurations such as dipole, rectangular, circular, square, triangle, and others.

There are several advantages of using microstrip patch antenna:

- Low profile planar and non planar configuration which can be easily made conformal to host surface.
- Light weight and low volume.
- Low fabrication cost.

- Supports both, linear as well as circular polarization.
- Easy to integrated with MICs (microwave integrated circuits).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surface.

Meanwhile, there are some disadvantages of using microstrip patch antenna:

- Low efficiency
- Narrow bandwidth
- Low gain.
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antenna.
- Surface wave excitation.
- Low power handling capacity.

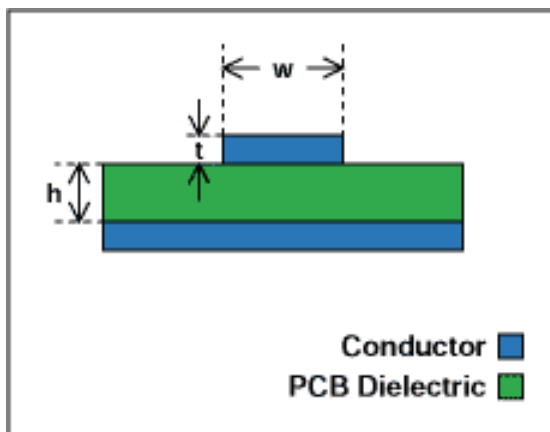


Figure 2.6: Microstrip patch

2.5 Basic characteristic

Due to their low-loss characteristics, metallic waveguides are still essential components in many microwave and millimeter-wave application systems. Since most modern solid-state and photonic devices are based on planar fabrication technology, waveguide transitions from microstrip, coplanar waveguide (CPW) and coplanar strips (CPS's) are critical for efficient integration of waveguide with planar circuits.

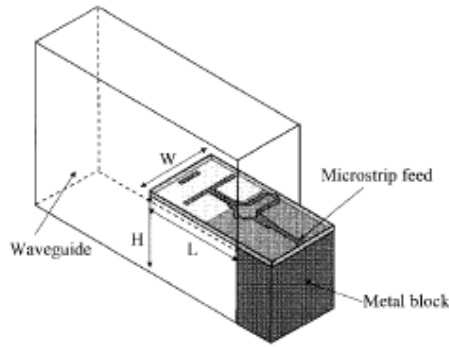


Figure 2.7: Proposed microstrip-to-waveguide transition using quasi-Yagi antenna.

We have recently developed and demonstrated a novel CPS Yagi-like antenna , which has the compactness of a resonant-type antenna ($< \lambda_0 / 2$) and yet achieves very broad bandwidth.

Figure 2.7 shows a schematic diagram of the proposed quasi-Yagi antenna, which consists of a printed dipole director, and a driver dipole fed by our previously reported microstrip-to-coplanar strip transition as a broadband balun. The transition can be realised easily by designing an impedance matched T-junction and delaying one side of the microstrip line by half wavelength at the desired frequency ($L_3-L_2= \lambda_g/4$). This result in a predominantly odd mode in the coupled microstrips, which can be subsequently transformed into the balanced coplanar strips (CPSs) required to feed the driver dipole. The unique feature of this antenna design, however, is the use of the ground plane on the back side of the substrate as its reflecting element. This results in a very compact and simple structure which can be easily integrated with any microstrip-based RF circuitry. In fact, the prototype antenna as will be shown below is designed and built on high dielectric constant ($\epsilon_r= 5.4$) FR4 substrate.

2.6 Feeding techniques

There are several configurations that can be used to feed microstrip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling and proximity coupling feeding. As researched by Schaubert [1995] and Balanis [1997], their respective construction, advantages and disadvantages are summarized in table 2.1 below.

Table 2.1: Advantages and disadvantages of feeding techniques

Techniques	Construction	Advantages	Disadvantages
Microstrip line	A conducting strip with much smaller width compared to the patch	<ul style="list-style-type: none"> - monolithic - good polarization - easy to fabricate - simple to match - simple to model 	<ul style="list-style-type: none"> - High spurious of radiation for thick substrates. - must be insert or use transformer to match impedance - narrow bandwidth
Coaxial probe	The inner conductor of the coax (eg. SMA connector) is attached to the radiating patch while the outer conductor is connected to the ground plane.	<ul style="list-style-type: none"> - easy to fabricate - easy matching by probe location - low spurious radiation - can be used with plated vias for multilayer circuits 	<ul style="list-style-type: none"> - narrow bandwidth - difficult to model for thick substrates - impedance is highly inductive for thick substrates
Aperture coupling	Two substrates separated by ground plane	<ul style="list-style-type: none"> -independent choice of substrates for feed and radiators -no spurious radiation from feed - no via connectors - easy to model 	<ul style="list-style-type: none"> - multilayer fabrication required - narrow bandwidth - difficult to fabricate
Proximity coupling	Similar to Aperture coupling with overlapping substrate and patch	<ul style="list-style-type: none"> - no DC contact between feed and radiating patch - low spurious radiation - can have large effective thickness for patch substrate and much thinner feed substrate - easy to model - several degrees of freedom available for matching/tuning - higher bandwidth 	<ul style="list-style-type: none"> - Multilayer fabrication required. - difficult to optimize

2.7 Types of Microstrip Antennas

Microstrip antennas can be differentiated by more physical parameters than any conventional microwave antennas. In fact, microstrip antennas may be of any geometrical shape and any dimension. However, the three basic categories of all microstrip antennas are: microstrip patch antennas, microstrip traveling-wave antennas and microstrip slot antennas. The following sections will briefly describe the basic characteristics of all the three antennas.

2.7.1 Microstrip Patch Antennas

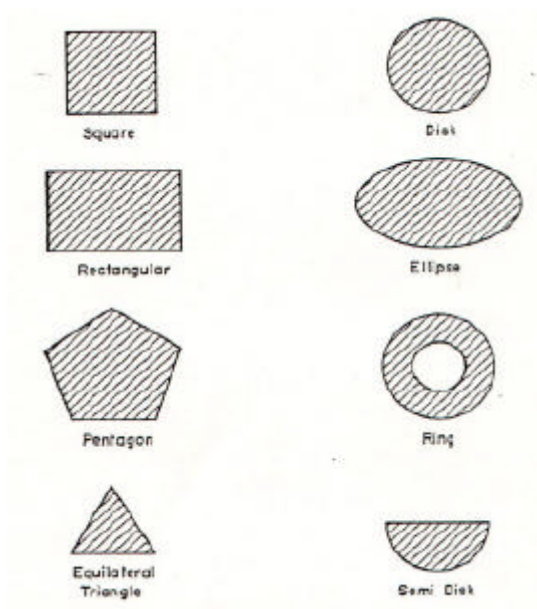


Figure 2.8: Various patch patterns used for Microstrip Patch Antenna

A microstrip patch antenna consists of a conducting patch of any planar geometry on one side of a dielectric substrate with a ground plane on the other side. There are practically an unlimited number of patch patterns for which radiation characteristics may be calculated. Shown in figure 2.8 are the various patch patterns used for microstrip patch antennas.

2.7.2 Microstrip Traveling-Wave Antennas

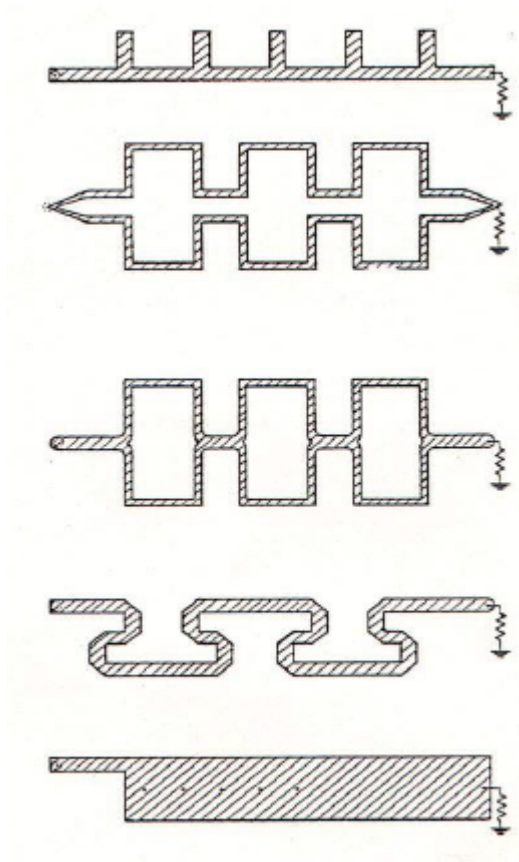


Figure 2.9: Microstrip Traveling-Wave Antennas

Microstrip traveling-wave antennas consist of chain-shaped periodic conductors or an ordinary long TEM line which also supports a TE mode, on a substrate backed by a ground plane. The open end of the TEM line is terminated in a matched resistive load. Due to the fact that the antennas support traveling waves, their structures are designed so that the main beam lies in any direction from broadside to endfire. The main aim of this thesis is to understand and analyze such traveling-wave antennas, namely the Linearly Quasi-Yagi Antenna. Shown in figure 2.9 above are the various configurations for the microstrip traveling-wave antennas.

2.8 Excitation Techniques

There are many techniques used to feed or excite microstrip antennas. But, microstrip feed will only be briefly discussed in the following. Matching is normally required between the feed line and the antenna. The reason for this is because the

antenna input impedances is different from the normal 50-ohm line impedance. Matching can be achieved by correctly choosing the position of the feed line. On the other hand, the position of the feed may also affect the radiation characteristics.

2.8.1 Microstrip Feed

As shown in figure 2.10 are the centre microstrip feed and off-centre microstrip feed antenna arrangements. The position of the feed point will determine which mode is excited. After deciding the size of the antenna element, the matching procedure will be as follows. The center-fed antenna patch is etched together with the 50-ohm feed line. The input impedance is measured and a matching transformer is designed. After reconstructing the antenna, it is then incorporated to the matching section between the antenna element and the feed line. However, if the antenna geometry supports only the dominant mode, the microstrip feed line can be placed towards a corner in order to achieve a good match.

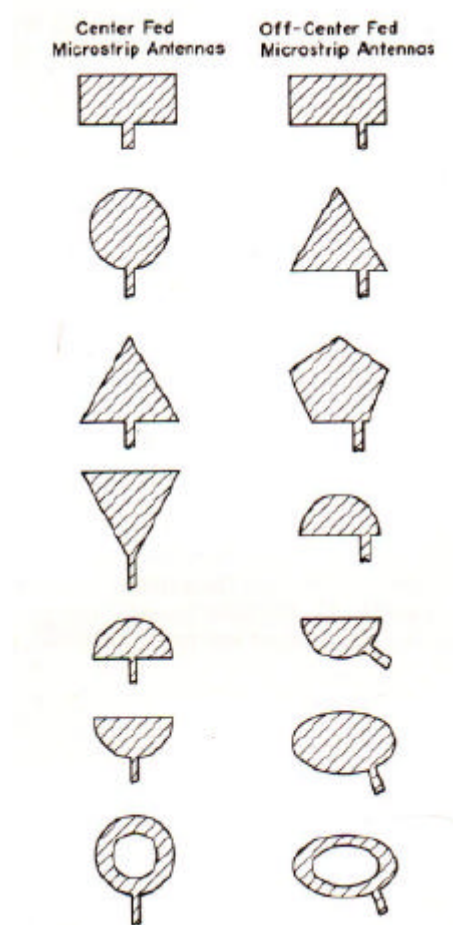


Figure 2.10: Microstrip Line Fed Antennas

Normally, the antenna mode can be excited in a lot of methods. If the field differs along the width of a rectangular patch antenna and the feed is shifted across the width, the input impedance will change. Although the change in feed position may affect a small shift in resonant frequency (due to change in coupling between feed line and antenna), the radiation pattern will remain unchanged. The shifts in resonant frequency can be compensated by altering the antenna dimensions slightly.

2.9 Applications

2.9.1 Satellite TV

Satellite television is television delivered by way of communications satellites, as compared to conventional terrestrial television and cable television. In many areas of the world satellite television services supplement older terrestrial signals, providing a wider range of channels and services, including subscription-only services.

The first satellite television signal was relayed from Europe to the Telstar satellite over North America in 1962. The first geosynchronous communication satellite, Syncom 2 was launched in 1963. The world's first commercial communication satellite, called Early Bird, was launched into synchronous orbit on April 6, 1965. The first national network of satellite television, called Orbita, was created in Soviet Union in 1967, and was based on the principle of using the highly-elliptical Molniya satellite for re-broadcasting and delivering of TV signal to ground downlink stations. The first domestic North American satellite to carry television was Canada's geostationary Anik 1, which was launched in 1973. ATS-6, the world's first experimental educational and Direct Broadcast Satellite, was launched in 1974. The first Soviet geostationary satellite to carry Direct-To-Home television, called Ekran, was launched in 1976.

2.9.2 Television receive-only

C band is highly associated with television receive-only (TVRO) satellite reception systems. C band usually provides better video quality and is less affected by rain attenuation than the K_u band. Television receive-only, or TVRO is a term used in North

America to refer to the reception of satellite television from FSS-type satellites (Fixed Service Satellite), generally on C-band analogue; free-to-air and unconnected to a commercial DBS (Direct broadcast satellite) provider. TVRO systems rely on feeds being transmitted unencrypted and using open-standards, which heavily contrasts to DBS systems in the region.

Summary

This chapter has presented the characteristic and the advantages of microstrip antennas. Various feeding techniques were described and stated to give the antenna designer different options while designing an antenna. There are several methods to get the position of microstrip feeding. The position of the feed point will determine which mode is excited. Finally, the applications of the C band antenna will be presented.

CHAPTER 3

DESIGN OF ANTENNA

This chapter gives a literature review relating to the quasi Yagi antenna design. It will start by introducing Agilent's Advanced Design System (ADS) design software. Before fabricating the antenna onto microstrip, it will be used as the initial step to make sure the design is aimed to the objective of the project. Then it will be followed by providing the design formulas for calculating the effective dielectric constant, followed by the derivations for free-space wavelength and guide wavelength to find the dimension of the antenna.

3.1 Overview of Advanced Design System for design

Agilent's Advanced Design System (ADS) has a Computer-Aided Design (CAD) layout tool and a full-wave electromagnetic simulator called Momentum simulator. The antenna had been designed by using layout of ADS and simulated to get the behavior of the design. Then, it will be fabricated onto the printed circuit board (PCB).

Momentum Simulation, Optimization, and Visualization

Momentum is used for predicting the performance of multilayer high-frequency circuit board, antennas, hybrids, multichip, and integrated circuit. It is an electromagnetic simulator that computes S-parameters for general planar circuit, including microstrip, slotline, stripline, coplanar waveguide, and other topologies. It enables us to simulate when a circuit model range is exceeded or the model does not exist. It may identify parasitic coupling between components. Besides, it can analyze and verify the design automation of circuit performance. Nevertheless, ADS can visualize current flow and 3-dimensional display of far field radiation.

Momentum optimization varies geometry parameters automatically to help us achieve the optimal structure that meets the circuit or device performance goal.

Meanwhile, momentum visualization provides a 3-dimensional perspective of simulation results, enabling you to view and animate current flow in conductors and slots, and view both 2 D and 3 D representations of far field radiation patterns.

3.2 Antenna Specification

3.2.1 Fundamental Frequency selection

According to Wikipedia, the free encyclopedia, an antenna or aerial is an electronic component designed to transmit or receive radio waves. More technically, an antenna is an arrangement of conductors designed to radiate (transmit) an electromagnetic field in response to an applied alternating voltage and the associated alternating electric current, or to be placed into an electromagnetic field so that the field will induce an alternating current in the antenna and a voltage between its terminals. My antenna namely quasi Yagi antenna is operating at C band, which is from 4GHz – 8GHZ.

3.2.2 Antenna parameter

Resonant Frequency

The resonant frequency is related to the electrical length of the antenna. This is usually the physical length of the wire multiplied by the ratio of the speed of wave propagation in the wire. Typically an antenna is tuned for a specific frequency, and is effective for a range of frequencies usually centered on that resonant frequency. However, the other properties of the antenna (especially radiation pattern and impedance) change with frequency, so the antenna's resonant frequency may merely be close to the center frequency of these other more important properties. Antennas can be made resonant on harmonic frequencies with lengths that are fractions of the target wavelength. Some antenna designs have multiple resonant frequencies, and some are relatively effective over a very broad range of frequencies. The most commonly known type of wide band aerial is the logarithmic or log aerial but its gain is usually much lower than that of a specific or narrower band aerial.

Gain

In antenna design, gain is the logarithm of the ratio of the intensity of an antenna's radiation pattern in the direction of strongest radiation to that of a reference antenna. If the reference antenna is an isotropic antenna, the gain is expressed in units of dBi (decibels over isotropic). For example, a dipole antenna has a gain of 2.14 dBi. Often, the dipole antenna is used as the reference, in which case the gain of the antenna in question is measured in dBd (decibels over dipole).

Bandwidth

The bandwidth of an antenna is the range of frequencies over which it is effective, usually centered on the resonant frequency. The bandwidth of an antenna may be increased by several techniques, including using thicker wires, replacing wires with *cages* to simulate a thicker wire, tapering antenna components (like in a feed horn), and combining multiple antennas into a single assembly and allowing the natural impedance to select the correct antenna. Small antennas are usually preferred for convenience, but there is a fundamental limit relating bandwidth, size and efficiency.

3.2.3 Substrate selection

As discussed previously in chapter 2, microstrip will suffer from very narrow bandwidth (less than 0.5%), low efficiency, and poor radiation pattern due to the triggering of unwanted surface wave when it has high dielectric constant, ϵ_r . Thus, we had selected the low dielectric constant in order to get broadband antenna to aim the objective of the design. To get a broadband antenna, the thickness, h of the substrate is required to be big enough. But, if we are using the thick substrate, it may make the antenna heavy and bulky. After considering all factors, I decided to use the fiberglass substrate (also known as FR4). The height of it is 1.6 mm and dielectric constant is 5.4. The details of the substrate will be attached in the Appendix B.1.

3.2.4 Effective Dielectric Constant

The effective dielectric constant ϵ_{eff} is usually not equal to the dielectric constant ϵ_r for a non-uniform structure. For a uniformly filled structure such a strip line, coaxial line, or parallel plate, the effective dielectric constant is equal to the dielectric constant of the material ($\epsilon_{\text{eff}} = \epsilon_r$). However, for microstrip structures, it is necessary to calculate the effective dielectric constant of the structure. Firstly, assume two extreme cases for the effective dielectric constant. Shown below in figure 3.1 are two cases whereby the width of the microstrip w is much greater than the thickness of the substrate ($w \gg h$) in the top diagram and in the bottom diagram, width w is much smaller the thickness of the substrate ($w \ll h$) [1].

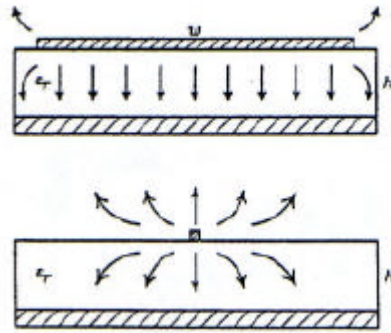


Figure 3.1: Extremely wide ($w \gg h$) and extremely narrow ($w \ll h$) microstrip lines

Looking at the diagram, for the case of $w \gg h$, most of the fields are confined under the strip and the circuit performs like a parallel plate. Hence, the effective dielectric constant for $w \gg h$ is approximately equal to the dielectric constant. As for the case of $w \ll h$, half of the fields are in the air and the remaining half is in the dielectric substrate (assuming $\epsilon_r = 1$). As a result, $\epsilon_{\text{eff}} \approx 1/2 (\epsilon_r + 1)$. Therefore, the range of the effective dielectric constant is:

$$1/2(\epsilon_r + 1) \leq \epsilon_{\text{eff}} \leq \epsilon_r \quad (3.1)$$

However, equation (3.1) is only a rough estimate of the range of the effective dielectric

constant. In order to calculate the exact value of ϵ_{eff} , it is necessary to assume a strip thickness $t = 0$. After assuming negligible strip thickness, the derived formulas for the effective dielectric constant is shown below as equations (3.2) and (3.3).

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\left(1 + 12 \left(\frac{h}{w} \right)^{-1/2} + 0.04 \left(1 - \frac{w}{h} \right)^2 \right) \right], \text{ for } \frac{w}{h} \leq 1 \quad (3.2)$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \left(\frac{h}{w} \right)^{-1/2} \right), \text{ for } \frac{w}{h} \geq 1 \quad (3.3)$$

Where

ϵ_{eff} = effective dielectric constant

ϵ_r = dielectric constant to substrate

h = height of dielectric substrate

w = width.

3.2.5 Wavelength

For any propagating wave, the velocity is given by the appropriate frequency wavelength product [1]. In free space, $c = f \lambda_0$ and in the microstrip, the velocity is $v_p = f \lambda_g$. Since the effective dielectric constant ϵ_{eff} is given by

$$\epsilon_{eff} = \left(\frac{c}{v_p} \right)^2 \quad (3.4)$$

Equating equation (3.4) with the two above-mentioned equations will result in

$$\epsilon_{eff} = \left(\frac{\lambda_0}{\lambda_g} \right)^2 \quad (3.5)$$

or,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{eff}}} \quad (3.6)$$

where λ_0 is the free-space wavelength.

3.2.6 Quasi-Yagi Antenna Calculations

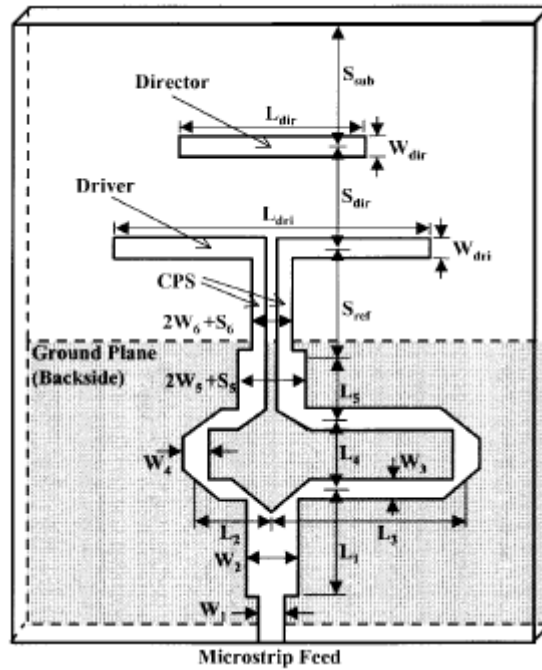


Figure 3.2: Quasi-Yagi Antenna

Width

The width is important to the power efficiency, antenna impedance and bandwidth. The width is also depending on the operating frequency and the substrate constant. The equation is showing as below:

$$\begin{aligned}
 w &= \frac{1}{2f_r \sqrt{\epsilon_0 \mu_0}} \sqrt{\frac{2}{\epsilon_r + 1}} \\
 &= \frac{1}{2 * 4 * 10^9 \sqrt{\epsilon_0 \mu_0}} \sqrt{\frac{2}{5.4 + 1}} \\
 &= \underline{0.02095 \text{ m}}
 \end{aligned}$$

Effective dielectric constant (ϵ_{eff})

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \left(\frac{h}{w}\right)\right)^{-1/2}$$

$$= \frac{5.4+1}{2} + \frac{5.4-1}{2} \left(1 + 12 \left(\frac{0.0016}{0.02095}\right)\right)^{-1/2}$$

$$= 6.2456$$

$$\lambda_0 = \frac{c}{f} = \frac{3 * 10^8}{4 * 10^9}$$

$$= \underline{0.075m}$$

c = speed of light = $3.0 * 10^8$ m/s

f = design frequency = $4.0 * 10^9$ Hz

Thus, the wavelength,

$$\epsilon_{eff} = \left(\frac{\lambda_0}{\lambda_g}\right)^2$$

Or,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{eff}}}$$

$$= \frac{0.075}{\sqrt{6.2456}}$$

$$= 0.03001m$$

$$= \underline{30mm}$$

It can obtain reasonably good initial dimensions for the length of the director element

being $\lambda_g / 2$, where: [14]

$$L_{dir} = \frac{0.03001}{2}$$

$$= 0.015m$$

$$= \underline{15mm}$$

After many interactions, through trial and error method it has been found that the optimized dimensions of the antenna are, units in millimeter:

$$L_{dri} = \underline{86.35 \text{ mm}}, W_1 = W_3 = W_4 = W_5 = W_{dir} = \underline{3.97 \text{ mm}}, W_6 = S_5 = S_6 = \underline{1.87 \text{ mm}},$$

$$L_1 = \underline{20.39 \text{ mm}}, L_2 = \underline{9.07 \text{ mm}}, L_3 = \underline{32.38 \text{ mm}}, L_4 = \underline{11.32 \text{ mm}}, L_5 = \underline{8.13 \text{ mm}}, \quad S_{ref}$$