WIDEBAND ACTIVE ANTENNA

by

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SYNOPSIS

The objective of this work is to develop novel antenna designs for bandwidth enhancement using passive and active log periodic techniques. The first part of the thesis describes the integration of amplifiers with single microstrip patch antennas. The antennas have been designed at centre frequencies of 2.1 GHz and 2.6 GHz. There are four different configurations of the antenna and amplifier. The second part describes the passive log periodic technique. Antennas with different numbers of elements have been modelled using microstrip lines and S parameter data from the single element. This data is extracted from the Momentum simulation and combined with the microstrip transmission line. The comparison between circuit and Momentum simulation shows very good agreement. The fabrication of the inset feed passive log periodic antenna has been done with four different numbers of elements: five, seven, nine and eleven. The centre frequencies of the antennas have been designed at 3 GHz with a bandwidth of 1.8 GHz for eleven elements LPA. The properties of the antennas such as bandwidth, gain, cross-polar isolation and half power beamwidth have been investigated and compared between different elements. The last part of the thesis is the integration of the amplifier with the log periodic antenna. The antennas have been designed with a bandwidth of 1 GHz with a centre frequency of 3 GHz. Five different configurations have been investigated. The first configuration involves the integration of a single amplifier at the input of the feed line of a five element LPA. The second configuration involves the integration of an amplifier in the middle of the five element LPA. The third configuration is a five element LPA with individual amplifiers in each element. In the fourth configuration, individual amplifiers and filters are integrated with five elements. The last configuration involves the integration of a single amplifier with a seven element LPA at the input to the feed line of the antenna The performance of these configurations have been investigated and compared in terms of bandwidth, gain relative to a passive LPA, cross polar isolation and beamwidth.

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Abbreviations

ACMSA	Aperture Coupled Microstrip Antenna
ADS	Advance Design System
AIA	Active Integrated Antenna
BPF	Band pass filter
BW	Bandwidth
DC	Direct Current
dB	decibel
ECMSA	Edge Coupled Microstrip Antenna
EIRP	Effective Isotropic Radiation Power
FDTD	Finite Difference Time Domain
FET	Field Effect Transistor
FEM	Finite Element Method
GaAs	Gallium Arsenide
HPBW	Half Power Beamwidth
I and Q	In Phase and Quadrature
IMPATT	Impact Avalanche Transit Time
LPA	Log Periodic Antenna
MESFET	Metal semiconductor field effect transistor
MPIE	Mixed Potential Integral Equation
MNM	Multiport Network Model
MoM	Method of Moments
MMIC	Monolithic Microwave Integrated Circuit
PLL	Phase Lock Loop
Q	Quality Factor
SWR	Standing Wave Ratio
SACMSA	Stacked Aperture coupled microstrip antenna
SDT	Spectral Domain Technique
TLM	Transmission Line Model
VSWR	Voltage Standing Wave Ratio

TABLE OF CONTENTS

1. INTRODUCTION

2 LITERATURE REVIEW

3 METHOD OF ANALYSIS FOR MICROSTRIP ANTENNA

4 DESIGN AND FABRICATION OF PASSIVE AND ACTIVE INTEGRATED ANTENNA

5 DESIGN AND FABRICATION OF LOG PERIODIC ANTENNA

6 DESIGN AND FABRICATION OF ACTIVE LOG PERIODIC ANTENNAS

7 ANALYSIS OF PASSIVE AND ACTIVE LOG PERIODIC ANTENNA

8 SUMMARY,CONCLUSION AND FUTURE WORK

CHAPTER 1: INTRODUCTION

1.1 Background to the study

Active antennas are promising devices for compact transmitters and receivers in microwave and millimeter wave radar, sensors and wireless communication applications. Integrated active antennas receive a great deal of attention because they can reduce the size weight and cost of many transmit and receive system. Passive and active devices can be configured to provide several functions at the terminals of the antenna. Active solid-state devices can be used to design active integrated antenna, oscillators, amplifiers, mixers etc. The integration of an active device on a microstrip antenna has led to a modification of conventional approaches, replacing waveguides, coaxial circuits and bond-wire interconnections, thereby reducing the overall size and weight of the system. It also finds many applications, which include bandwidth enhancement, gain enhancement, noise figure improvement, modulation, demodulation, beam steering and spatial power combining from active devices [1,2].

One of the principal disadvantages of the microstrip antenna in its basic form is its inherently narrow bandwidth. Significant research has been devoted to the bandwidth problem in recent years and many techniques have been suggested to achieve wider bandwidth [28 - 68]. The integration of the active devices is also limited due to the narrow bandwidth of single element microstrip patches. The antennas with physically wide bandwidth have been much sought after for several years. A wide bandwidth means that in some applications the antenna does not limit the system bandwidth and hence facilitates the use of filters, amplifiers, mixers oscillators and etc. Also in some applications wide bandwidth is the fundamental requirement such as in pulse compression radar and ground penetrating radar.

1.2 Objectives of the study

The objectives of this project are as follows:

- To design and fabricate the single layer microstrip patch antenna and integrate with active devices to further enhance the bandwidth performance of the antenna.
- To design, fabricate and analyse the performance of a new type of single layer passive log periodic antennas, using patch elements with inset feeds.
- To design, fabricate and analyse new configurations of log periodic antenna integrated with one or more amplifiers.

1.3 Thesis organization

The aim of this thesis is to develop novel configurations of passive and active log periodic antennas. Most of the antenna structures were experimentally developed and verified with Agilent Momentum (a full wave simulation) and Agilent ADS, a microwave circuit simulator. The thesis comprises eight chapters.

Chapter 2 introduces the microstrip concept, bandwidth definition and the relationship between the bandwidth (BW), quality factor (Q) and standing wave ratio (SWR). The different techniques to enhance the bandwidth of microstrip antennas are discussed. The integration of active devices with microstrip antennas is discussed with different types of application for wireless communication systems

Chapter 3 explores the methods used to analyse the microstrip antenna. The three methods discussed here are the most common methods used in this thesis. The first method is the transmission line model. This is the easiest but least accurate model for microstrip antennas. The second method is the cavity model. This model can be used for any shape of microstrip antenna. The last model is the Method of Moments (MoM), which has been used in the Agilent ADS Momentum simulator. This method used the numerical technique to solve Maxwell's integral equation in the frequency domain.

Chapter 4 describes the novel design for a single element microstrip antenna. In this design the transmission line model has been used for designing the microstrip antenna. The square patch antenna has been chosen for the design. Different configurations for integration are discussed in this chapter. Four different configurations for single element active integrated antennas have been designed. The performance of each configuration is analysed in terms of bandwidth (BW), cross-polar isolation, radiation pattern characteristics and gain relative to the dipole antenna.

Chapter 5 describes the design of a novel, passive microstrip log periodic antenna. The new design method has been described for this type of log periodic antenna using a microstrip circuit model and the S_{11} parameter of the individual patch antenna. In this method the first resonance frequency has been chosen and is scaled log periodically through the next frequency. A set of 12 scaleable patch elements with different dimensions has been studied. The circuit model of the log periodic antenna has been simulated using a circuit simulator and compared with the momentum simulator. Arrays with five, seven, nine and eleven elements have been fabricated and tested with the Network Analyser. The bandwidths of arrays with different numbers of elements have been compared from simulation and measurement results. The radiation pattern of each array has been measured at different frequencies in the anechoic chamber. The co and cross polarisation have been measured and the gain of the antenna has been measured relative to the dipole antenna.

Chapter 6 describes the different configurations of integrated active log periodic antenna (LPA). The first configuration is the direct integration between a five element LPA and an amplifier at the input of the feed line. The second configuration involves the integration of the amplifier in the middle of a five element LPA. The third configuration involves the integration of an individual amplifier with each element of the LPA. The amplifier is connected at the inset feed of the antenna. The fourth configuration is the integration of an individual amplifier, band pass filter and the antenna. The last configuration is the seven element LPA integrated with the amplifier at the input of feed line. The simulated and measured results have been plotted. The radiation pattern has been plotted for each configuration at different frequencies. The comparison in term of S_{21} has been analysed between the passive and active LPA. The co and cross polarisation for each configuration have been measured and the gain of the antenna is compared with the passive LPA.

Chapter 7 describes the comparative analysis of passive and active integrated LPAs. The passive LPA's analysed have five, seven, nine and eleven elements. The analysis of the active antennas is performed for each of the configurations described in chapter 6. The comparison for each active and passive configuration has been done in terms of bandwidth, radiation pattern, cross polarisation response and relative gain.

Finally conclusions to work described in the thesis are drawn and the scope of future work is outlined in chapter 8

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The basic structure of a microstrip antenna is given in figure 2.1. The upper surface of the dielectric substrate supports the printed conducting patch that is suitably contoured while the bottom surface is completely covered with metalization that serves as a ground. The microstrip antennas operate best when the substrate is electrically thick with dielectric constants in the lower end of the range, because they provide larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size. On the other hand thin substrates with high dielectric constants are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation coupling and lead to smaller element sizes, but they also lead to greater losses and smaller bandwidth in antenna applications. [20,26]

The radiating elements may be square, rectangular, thin strip (dipole), elliptical, circular triangular or any other configuration. Rectangular, square and circular are the most common shapes because of easy analysis and fabrication. Linear and circular polarization can be achieved with either single elements or arrays of microstrip [20].

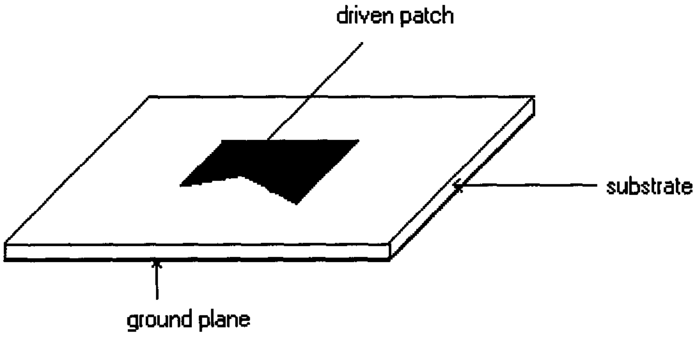


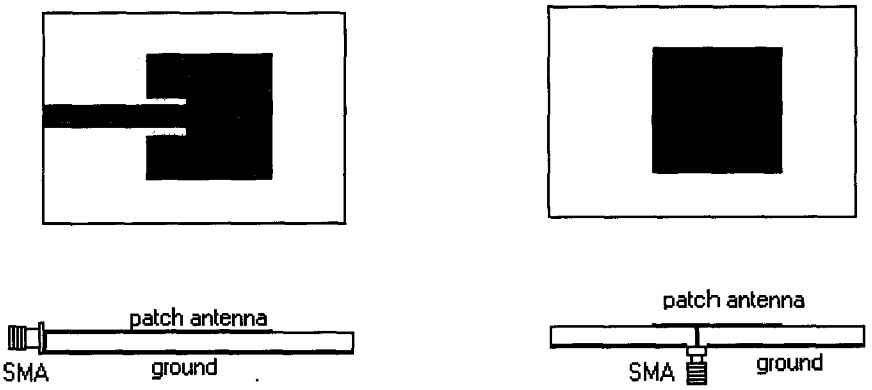
Figure 2.1 Contour of microstrip patch antenna

When the active devices are integrated directly into the antenna structure the antenna is called an active integrated antenna. Active integrated circuits at high frequencies are built on planar substrates with the antenna on the same substrate. The integration of the active device results in a smaller overall size and minimizes the connection losses and parasitic reactances between the antenna and circuit. Active antennas can be designed to perform more functions than the passive antenna, such as amplifying, oscillating, frequency tuning, frequency conversion and active diplexing [98,99]

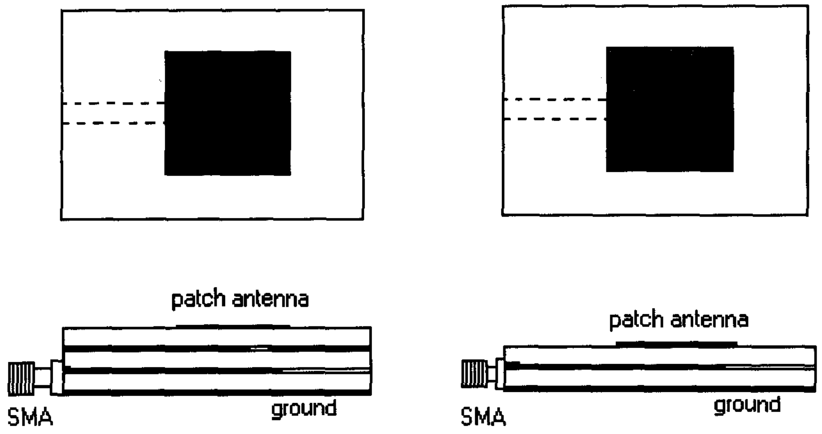
2.2 Bandwidth Definition

A limitation of microstrip antenna technology is the narrow bandwidth of the basic element. The bandwidth of a basic patch element is usually 1% - 3%. The bandwidth of the antenna can be increased by reducing the substrate permittivity (ε_r) or increasing its thickness (h). However there are two problems associated with increasing the substrate thickness. One of the problems is the radiation and reactance associated with the feed junction. The second problem is an increase in surface wave effects [20]. In order to avoid these problems, a number of different methods have been investigated to improve the bandwidth of the microstrip antenna. These methods will be discussed in the next section.

There are many configurations that can be used to feed microstrip antennas. The most popular are the microstrip line, coaxial probe, aperture coupling and proximity coupling. The different feeding techniques have different bandwidths. In these types of feeding the proximity coupled and aperture coupled have bigger bandwidth compared with the microstrip line and coaxial feeder. These are shown in figure 2.2.



(a) Microstrip line feed **(b) coaxial feed**



(c) Aperture coupled feed **(d) proximity coupled feed**

Figure 2.2 Typical feed for microstrip antenna

The bandwidth of the antenna is defined [21] as the range of frequencies, over which the performance of the antenna with respect to some characteristic conforms to a specific standard. The bandwidth of the antenna depends on patch shape, resonant frequency, dielectric constant and the thickness of the substrate. Several definitions of the antenna bandwidth are discussed below

Impedance Bandwidth: The impedance variation with frequency of the antenna element results in a limitation of the frequency range, over which the element can be matched to its feed line. Impedance bandwidth is usually specified in terms of a return loss or maximum

SWR typically less than 2.0 or 1.5 over a frequency range. Conversion of bandwidth from one SWR level to another can be accomplished by using the relation between bandwidth (BW) and quality factor (Q)[21]:

$$Bandwidth = \frac{S - 1}{Q\sqrt{S}} \tag{2.1}$$

where S = standing wave ratio

Q = quality factor

SWR (S) can be defined in terms of the input reflection coefficient as

$$S = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{2.2}$$

Γ is the reflection coefficient at the feed point of the antenna. It can be defined in terms of input impedance (Z_{in}) of the antenna and (Z_o) the characteristic impedance of the feed line. It is given by

$$\Gamma = \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \tag{2.3}$$

Pattern Bandwidth: Over the operating frequency range of a microstrip element, the pattern and gain vary with frequency according to the electrical size of the patch element. Placing elements in an array environment introduces new frequency dependence according to the electrical spacing between elements and the frequency variation of the amplitude and phase of the excitation applied to each element by the feed network. The beamwidths, sidelobe level and gain of an antenna all vary with frequency. If any of these quantities is specified as a minimum or maximum, the pattern bandwidth can be defined.

Polarization or Axial Ratio Bandwidth : The polarization properties (linear and circular) of an antenna are usually preferred to be fixed with frequency. Specifying a maximum cross-polar or axial level can be used to define this bandwidth.

2.3 Relationship between Quality factor and Bandwidth

The quality factor (Q) and bandwidth (BW) are interrelated; therefore there is always a trade off between them in arriving at an optimum antenna performance. The quality factor is a figure of merit that is representative of the antenna losses. Typically there are four losses associated with the microstrip antenna. The losses are radiation, conduction, dielectric and surface wave. The total quality factor Q_T can be written as [4]

$$\frac{1}{Q_T}=\frac{1}{Q_{rad}}+\frac{1}{Q_c}+\frac{1}{Q_d}+\frac{1}{Q_{sw}} \qquad (2.4)$$

where

Q_T = total quality factor

Q_{rad} = quality factor due to radiation losses

Q_c = quality factor due to conduction losses

Q_d = quality factor due to dielectric losses

Q_{sw} = quality factor due to surface waves

For very thin substrates the losses due to surface waves are very small and can be neglected. However for thick substrates they need to be taken into account. For other losses there are approximate formulas to represent the quality factors of the various losses [4]. These can be expressed as

$$Q_c = h\sqrt{\pi f \mu \sigma} \qquad (2.5)$$

$$Q_d = \frac{1}{\tan\delta} \qquad (2.6)$$

$$Q_{rad} = \frac{2\omega\varepsilon_r}{hG_t/l}K \tag{2.7}$$

f	resonance frequency
μ	permeability
ε_r	dielectric constant
h	is the thickness of the substrate
$\tan\delta$	is the loss tangent of the substrate material
σ	the conductivity of the conductors associated with the patch and ground plane
G_t/l	the total conductance per unit length of the radiating aperture and

$$K = \frac{\iint area|E|^2\,dA}{\oint_{perimeter}|E|^2\,dl} \tag{2.8}$$

E	electric field

For a rectangular aperture operating in the dominant mode TM_{010}

$$K = \frac{L}{4} \tag{2.9}$$

$$G_{t/l} = \frac{G_{rad}}{W} \tag{2.10}$$

L	patch length dimension
W	patch width dimension

Q_{rad} is inversely proportional to the height of the substrate and for very thin substrate is usually the dominant factor

Another approach that can be used for Q_{rad} and Q_{sw} is from the power radiated [20]
The radiation Q is then

$$Q_{rad} = \frac{2\pi f W_e}{P_{rad}} \tag{2.11}$$