EXPERIMENTAL STUDIES OF SMALL ANTENNAS FOR MOBILE COMMUNICATIONS

by

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Abstract

With the recent advances of mobile communications, there have been frequent interests to develop small and low profile antennas for the further miniaturization of mobile telephone sets. Different types of small antennas has been constructed and tested which are aimed at the objectives : small, low profile, compact, low cost and easy to manufacture. The frequencies of interest including 900MHz band antennas for applications in cellular handheld phones such as for GSM (890, 935MHz), indoor cordless telephones such as the European CT1+(886, 931MHz) and 1.9GHz band antennas for applications in the 1.89GHz Digital European Cordless Telecommunications (DECT), and the 1.8GHz European future Personal Communication Services, the DCS1800 systems. Those systems have their own requirements in antenna characteristics, such as resonant frequency, bandwidth, etc..

A Meandering Inverted-F antenna with dimensions of less than $\lambda/6$ is designed and optimized for mobile communications applications. Two versions, a dielectric loaded version and a microstrip version are built and tested for wideband and narrow band use respectively. These antennas give excellent performance in VSWR (typically less than 1.02), wide bandwidth in the case of dielectric loaded version (greater than 9%), and omnidirectional far field radiation patterns and dual polarization sensitivity. This property play an important role in reducing multipath fading in urban areas.

The microstrip antenna presents good performance in narrow band mobile radio applications. It is the smallest antenna among the other designs with dimensions $\approx \lambda/10$. Measured results show that these

antennas are suitable for mobile communications, with omnidirectional far field radiation patterns and dual polarization sensitivity in all three planes of interest. Finally empirical formulas are noted to facilitate the design of the antennas with various operating frequencies, bandwidths, etc.

Contents

Acknowledgment

I would like to express my appreciation to my advisor, Dr. Albert K. Y. LAI, for his guidance and patience throughout the course of study at The Chinese University of Hong Kong. Also, my sincerest thanks to the pass and present members of the Microwave Laboratory of The Chinese University of Hong Kong for their useful discussions during my study. Special thanks for support and encouragement go to W. K. Yeung, Dickson T. S. Poon, Dr. K. M. Luk, Dr. K. W. Leung, Terry K. C. Lo, W. P. Tan, and K. W. Wong. Thanks also to my family for patience and understanding.

Lists of Illustration

Chapter 1

Introduction

In the hundred years since Heinrich Hertz made the first antenna, antennas have become an attractive research topic. Yagi-Uda antennas for television broadcast reception, small reflector antennas for direct broadcast reception, and monopole antennas on mobile telephone handsets can be seen in daily life.

With the recent advances in mobile communications, the need for small and low-profile antennas has greatly increased. In the 1990s Europe will introduce and further develop second generation mobile communication systems, such as GSM (Global System for Mobile telecommunications), DCS1800, DECT (Digital European Cordless Telecommunications), and ERMES (European Radio MEssaging System). These systems are able to provide several tens of millions of mobile radio users with cellular phones, cordless telephones and pagers. Other systems include wireless modem and fax on Type III PCMCIA cards, laptop computers and personal digital assistants (PDA) with built in wireless capability, wireless smart networks for control etc. Operation frequencies vary over a wide range, from 900MHz for the traditional mobile/cordless phone, to 1.9GHz for DECT. Portable radio equipment has rapidly reduced in size due to the development of VLSI and MMIC, but the antennas are still large compared to the equipment itself. Mobile telephone with a $\lambda/2$ whip antenna is a hindrance to user. One major problem faced by manufacturers and engineers alike is the availability of a miniature, conformal, omnidirection and dual polarized antenna with known or easily calculated input impedance that can be manufactured with ease, repeatability, and low cost. Consequently, there have been frequent interests to develop small and low-profile antennas for the further miniaturization of portable radio equipment[1.1].

Microstrip antennas [1.2] and inverted-F antennas [1.3] are typical low-profile antennas. Although microstrip antenna has its shorting coming of narrow bandwidth and low efficiency, the advantage of low-profile, small in size and light weight are the most attractive properties that researchers are interested in. The inverted-F antenna, which has already been used in mobile telephone handsets is one of the most promising [1.4, 1.5]. The inverted-F antenna typically consists of a rectangular planar element, ground plate, and short-circuit plate connect the rectangular element to the ground plate at one end. Basically, inverted-F antenna is a kind of short-circuit rectangular microstrip antenna with air substrate.

In general, small antennas suffer the disadvantages of narrower frequency bandwidth, radiation efficiency are low, and matching are difficult. As a result, small antennas having all the required characteristics are difficult to make. In this thesis, researches are made on small antennas which are suitable for applications in mobile radio equipment. Different types of small antennas has been constructed and tested which are aimed at the objective : small, low profile, compact and easy to manufacture. The frequencies of interest including 900MHz band antennas for applications in cellular handheld phones such as GSM (890, 935MHz), indoor cordless telephones such as the European CT1+(886, 931MHz) and 1.9GHz band antennas for applications in the 1.89GHz

Digital European Cordless Telecommunications (DECT), and the 1.8GHz European future Personal Communication Services, the DCS1800 systems.

In this thesis, two novel designs of small and low-profile antennas are studied. These are the Meandering Inverted-F antenna and the Meandering Posted Microstrip Antenna. Chapter 2 is devoted to the characteristics of the inverted-F antenna. Chapter 3 examines the characteristics of the meandering posted microstrip antenna. Chapter 4 concludes the research and points to future research directions.

1.1 References

[1.1] K. Hirasawa, "Small antennas for VHF and UHF mobile communications," National Science Foundation Workshop on Future Directions in Electromagnetic Research, Boston, July 1989, pp.199-201.

[1.2] J.Q. Howell, "Microstrip Antennas," *IEEE Trans. Antenna and Propagation*, Vol. AP-23, January 1975, pp. 90-93.

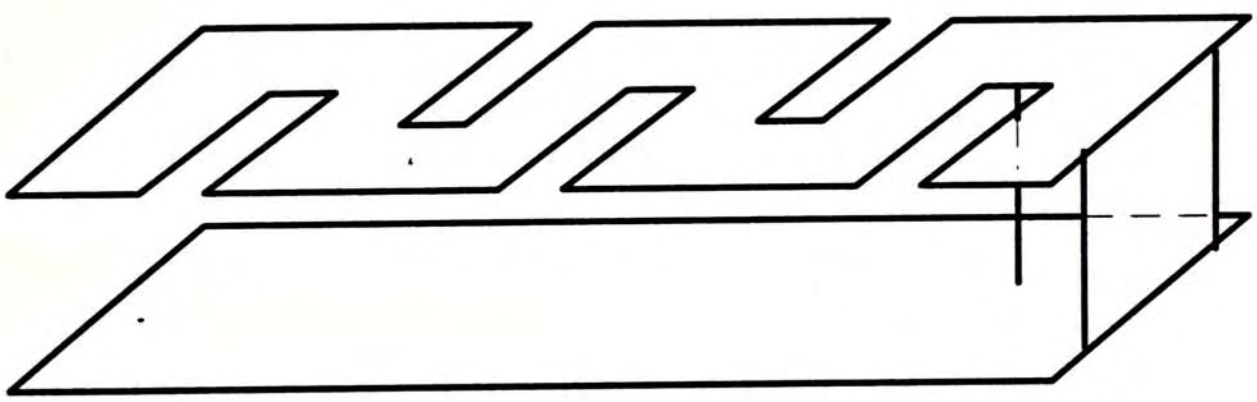
[1.3] J.R. James, K. Fujitomo, A. Henderson, and K. Hirasawa, *Small Antennas*, Research Studies Press, 1987, pp.116-151.

[1.4] T. Taga, K. Tsunekawa, and A. Sasaki, "Antennas for Detachable Mobile Radio Units", *Review of the ECL, NTT*, Japan, Vol. 35, No. 1, January 1987, pp.59-65.

[1.5] K.Qassim, "Inverted-F Antenna for Portable Handsets",*IEE Colloqium on Microwave Filters and Antennas for Personal Communication Systems*", pp. 3/1 - 3/6, Feb. 1994, London, UK.

Chapter 2

The Meandering Inverted-F Antenna



2.1 Evolution of the antenna

External antennas such as λ/2 monopoles and sleeve dipoles, are usually used in mobile telephone equipment. However, when portability is taken into account, these kinds of antennas are a hindrance to the user. It is desirable that the antenna be built-in type. Mobile radio units using built in planar inverted-F antennas has been reported [2.1]. Among existing built-in antenna schemes, the planar inverted-F antenna is one of the most promising candidates due to its compactness. In addition to portability, the planar inverted-F antenna exhibits sensitivity to both vertically and horizontally polarized radio waves [2.4].

The idea of the meandering inverted-F antenna was came from the transmission line antenna. Despite the relatively low radiation efficiency of transmission line antenna [2.2], the low aerodynamic drag achievable with transmission line antenna has enabled their use as VHF/UHF radiators on aircraft and rocket vehicles [2.3]. Transmission line antenna comes in a number of different geometry's although basically all are variations on a theme. Fig. 2.1 shows a particular simple antenna structure, the Inverted-L antenna (ILA).

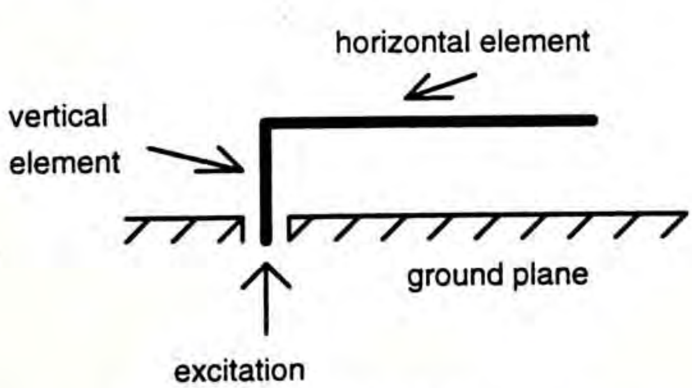


Fig. 2.1 Inverted-L antenna

ILA is a low-profile structure. It consists of a short monopole as vertical element and a wire horizontal element attached at the end of the monopole. The horizontal element usually has a length of about a quarter wavelength. It provides top-loading to the vertical monopole element. The ground plane is provided the antenna with an image component. The ILA has an inherently low impedance, since the antenna itself is a vertical short monopole loaded with a horizontal element. To increase the radiation resistance, another inverted-L shaped element is attached to the end of the vertical element. This turns out to the development of Inverted-F antenna (IFA).

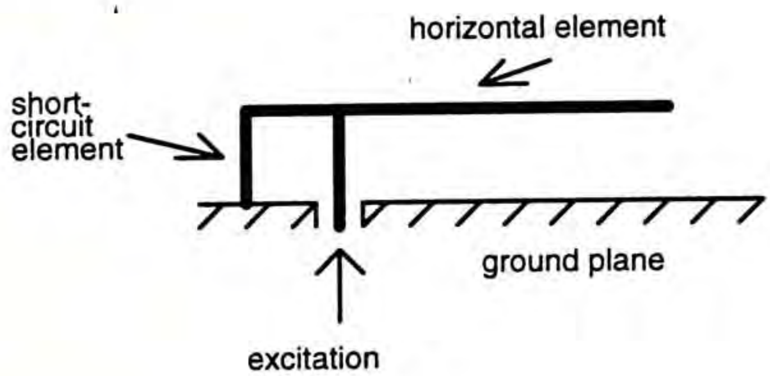


Fig. 2.2 Inverted-F antenna

The short-circuit element of an (IFA) play an important role to the input impedance. The dimension of the short-circuit element is adjusted so as to have an appropriate value to match load impedances, without using additional matching circuit. One main disadvantage of the IFA is narrow bandwidth (VSWR 2:1), typically only one percentage, or less of the centre frequency [4]. To widen the bandwidth, a modification to the horizontal wire element is useful. By replacing the wire element by a plate as depicted on Fig. 2.3, which becomes the Planar Inverted-F antenna (PIFA). The bandwidth can be increased to about 12% of the centre frequency with the dimensions given [5].

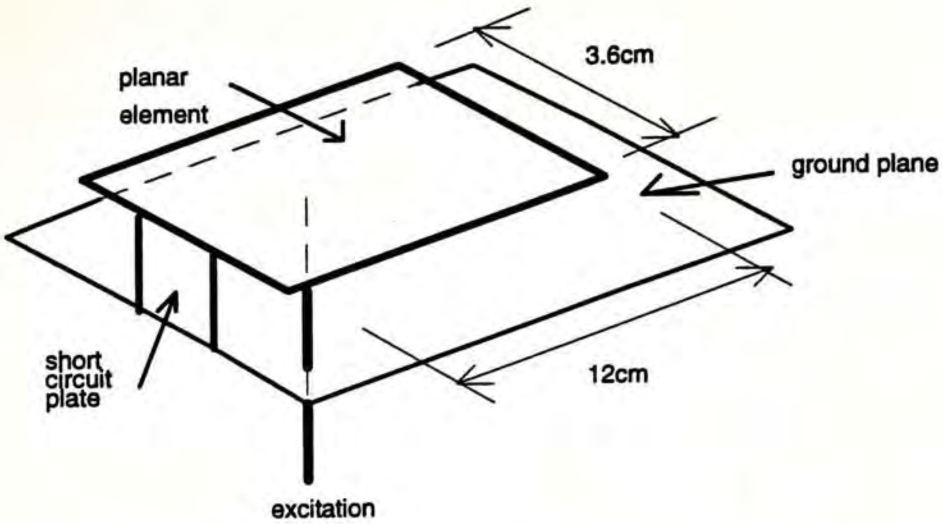


Fig. 2.3 Planar Inverted-F antenna

The antenna is resonated at about 1GHz. It is inevitable that the size of the antenna is too large to mount it onto a mobile phone.

If the planar element of the planar inverted-F antenna is replaced by a meandering line, as depicted in Fig. 2.4, the effective length of the antenna will be greatly increased. It is being proved that the new design has the characteristics of relatively larger bandwidth, better VSWR, and smaller in size than that of the planar inverted-F antenna. The shape of the radiating element of the meandering inverted-F antenna is similar to microstrip lines used in microwave circuits. Fig. 2.5 shows the PCB layout of the radio front-end of a 900MHz band mobile phone. Microstrip bends are required for the convenience of improving the usage of a given substrate area.

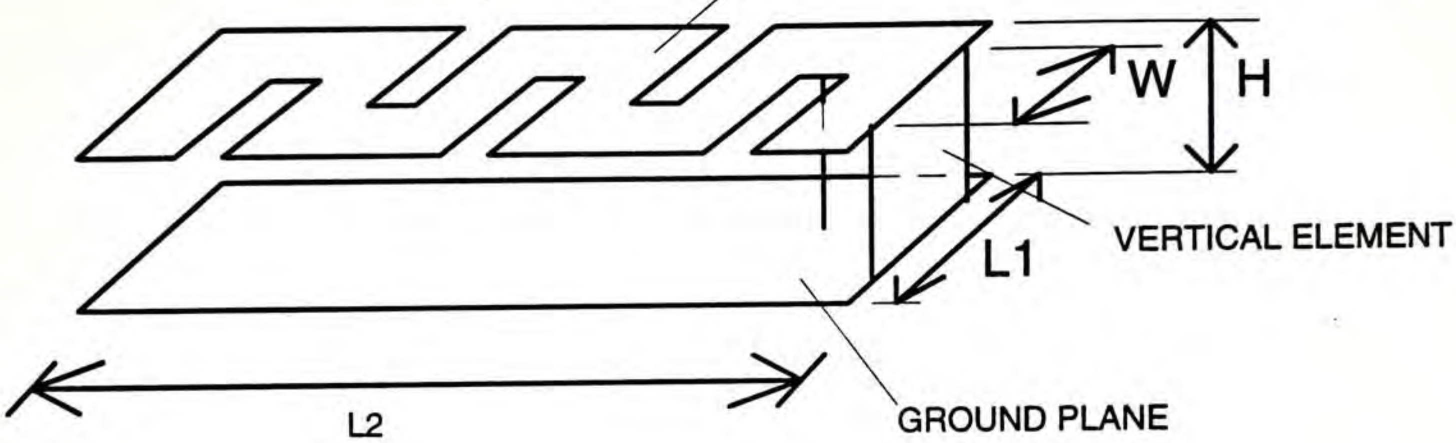


Fig. 2.4 Structure of the Meandering Inverted-F antenna

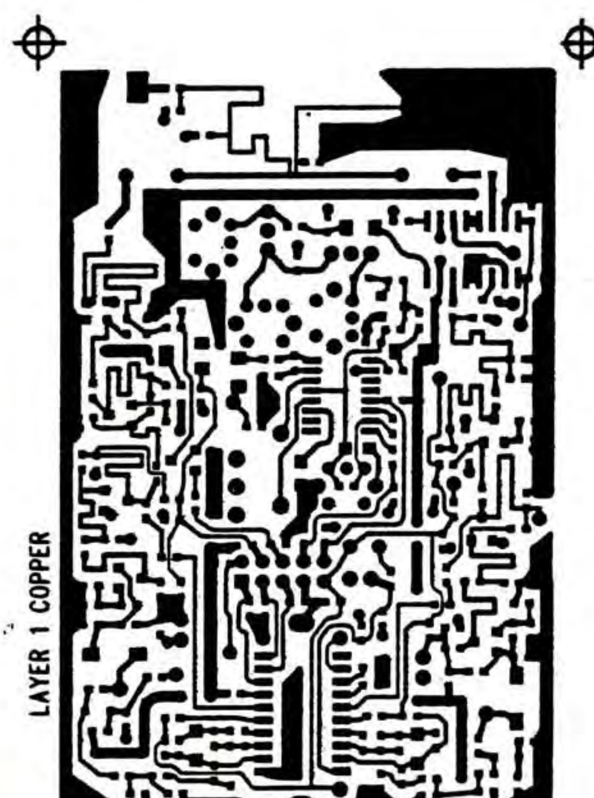


Fig. 2.5 PCB layout of a mobile phone (radio front-end)

2.2 The First Prototype

2.2.1 Geometry of the first prototype

The geometry of the first prototype is depicted in Fig. 2.6. The antenna is made by 0.3mm thick brass. The antenna is fed with a microstrip flange launcher and a short coaxial cable is connected from the centre conductor of the launcher to the radiating element of the antenna. The figures chosen is based on the dimension of a typical mobile phone handset.

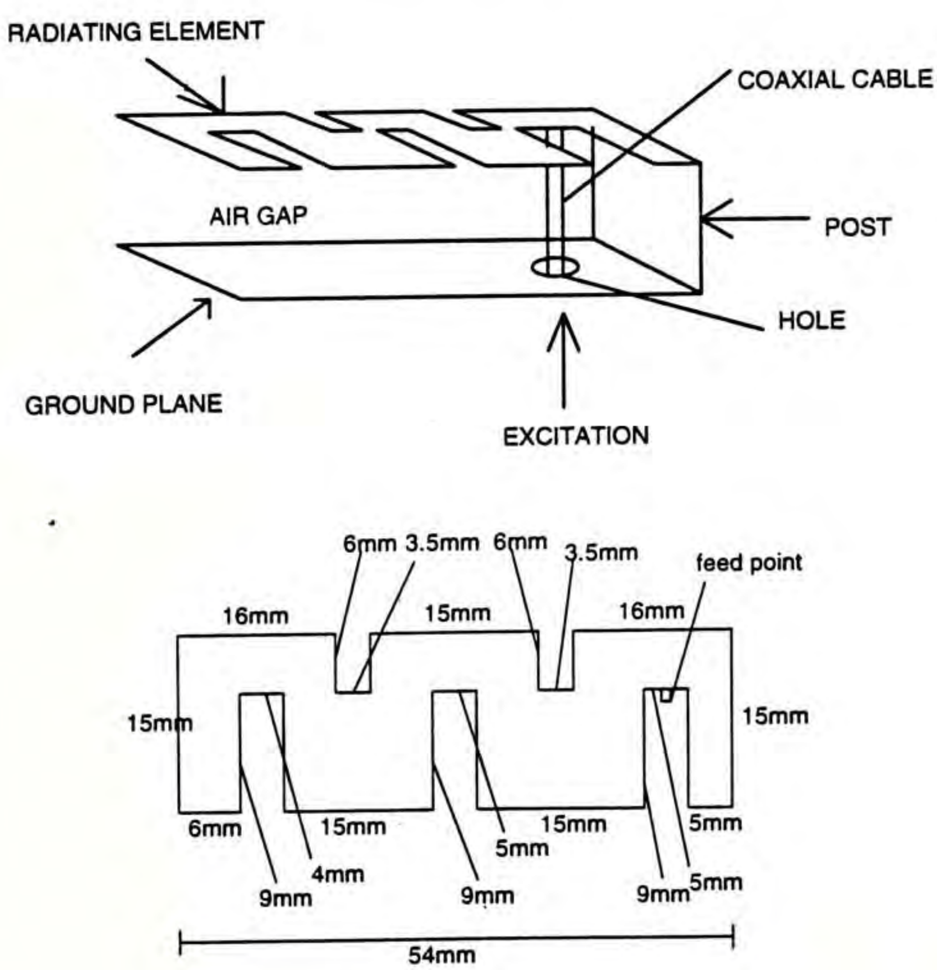


Fig. 2.6 Geometry of the first prototype

The frequency characteristics of the antenna is measured and the result is compared with a planar inverted-F antenna with the same outline dimensions. It can be seen that the replacement of the horizontal element from a flat plate to a meandering line is effective in making the resonant frequency lower. Parameters of the antenna that directly affect its operation frequency and bandwidth include : meandering patch length, vertical element (also called "post") height and width, and permittivity of the dielectric load between the radiating element and the ground plane.

2.2.2 Resonant Frequency

Fig. 2.8 shows the frequency characteristics of the meandering antenna. The results is measured on the HP8510C vector network analyzer and the antenna under test is put inside an compact range chamber at the Microwave Laboratory, Department of Electronic Engineering, The Chinese University of Hong Kong. The reason of putting the antenna under test onto a compact range chamber is to minimize proximity effects on the antenna characteristics. Since the antenna is small and low-profile, its characteristics are very sensitive to external environment. Fig. 2.7 shows the measurement set up.

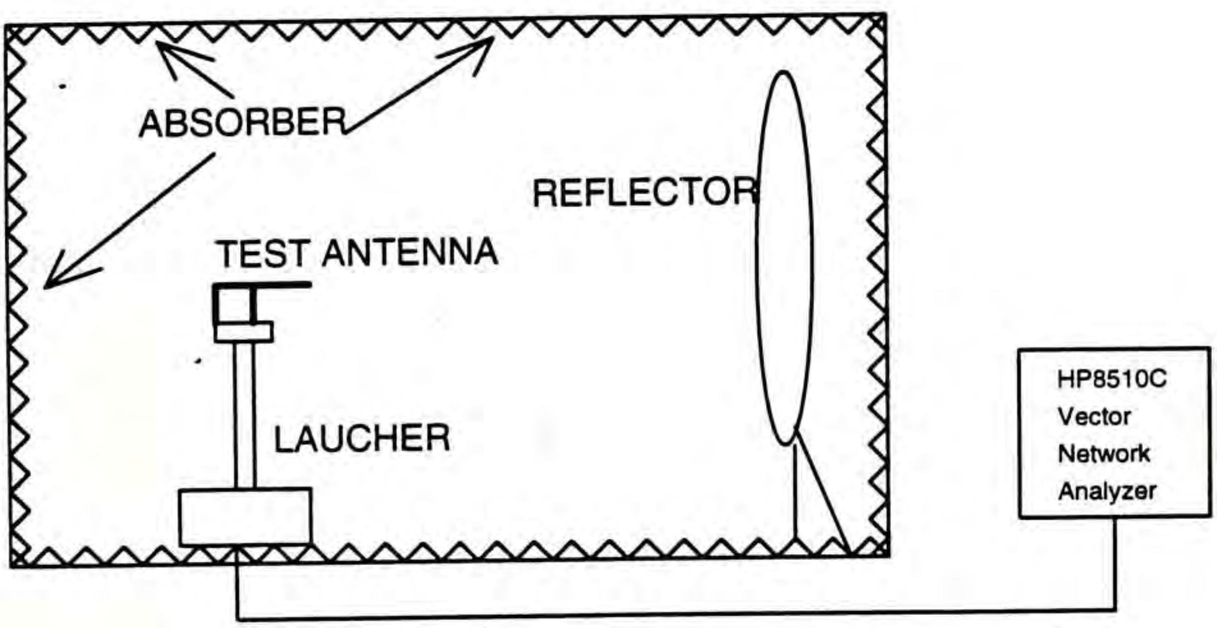
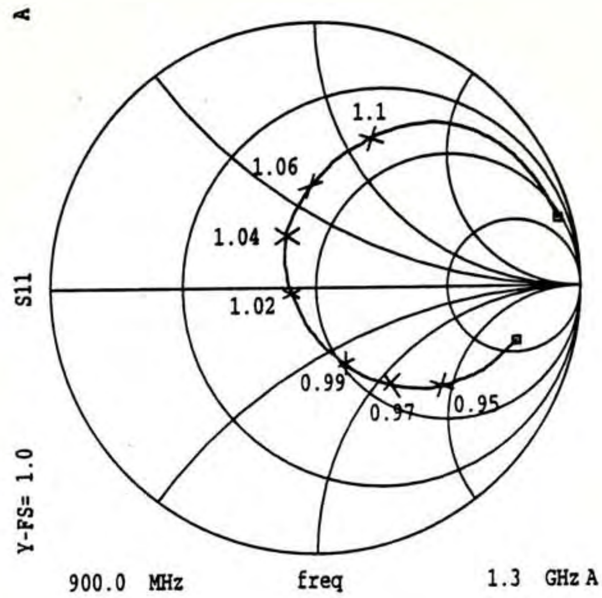
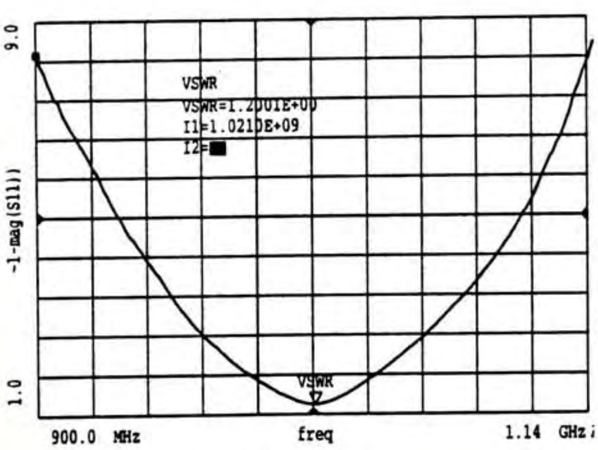


Fig. 2.7 Compact Range Measurement set up

For comparison, a planar inverted-F antenna with the same outside dimensions, i.e. the radiating element of the meandering antenna is replaced by a planar element with size of 54mm in length and 15mm in width. The frequency characteristics of the planar inverted-F antenna is shown in Fig. 2.9.

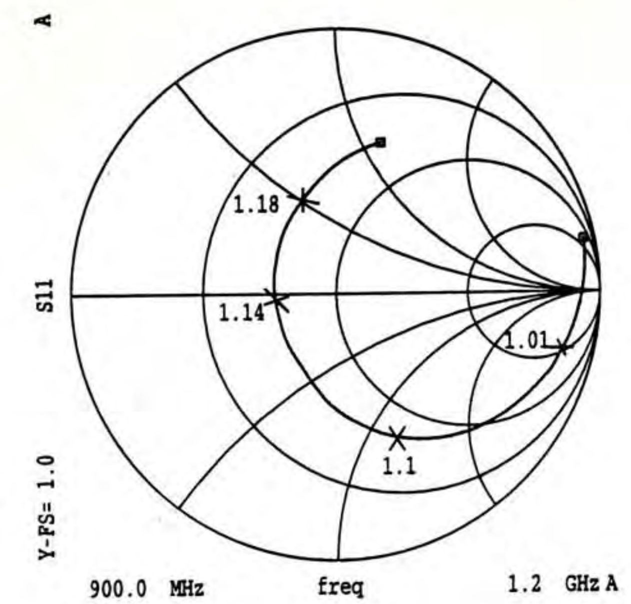


(a) Input impedance

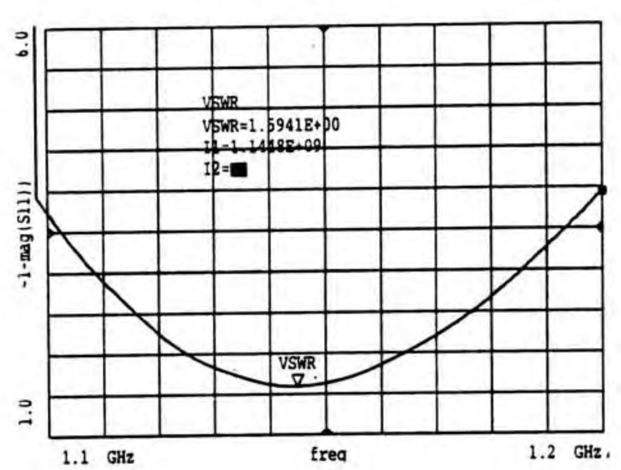


(b) VSWR

Fig. 2.8 Frequency characteristics of the first prototype



(a) Input impedance



(b) VSWR

Fig. 2.8 Frequency characteristics of a Planar Inverted-F antenna with the same outside dimensions

As seen from the measured data, the resonant frequency of the meandering antenna is 1.01GHz with VSWR less than 1.1. For the planar inverted-F antenna, the resonant frequency is 1.14GHz that is 130MHz higher than that of the meandering antenna. Its VSWR is fair and is greater than 1.5.

It has been shown that as the width of the short-circuit plate is set narrower, the effective inductance of the antenna increases. Thereby, the resonant frequency becomes lower. It turns out that the size of the antenna can be further reduced. Figure 2.10 shows the variation of resonant frequency of the antenna with respect to the width of the short-circuit plate with other parameters of the antenna are fixed. Figure 2.11 shows .the effect of the vertical element's height on the resonant frequency. Resonant frequency increase with the height of the height of the vertical element.

width of vertical element (mm)	resonant frequency (GHz)	% bandwidth (VSWR 2:1)
5	0.959	9.1
13	1.011	4.3
15	1.016	4.2

Fig. 2.10

height of vertical element (mm)	resonant frequency (GHz)	% bandwidth (VSWR 2:1)
5	1.024	9.3
7	1.031	7.6
9	1.038	6.3
11	1.042	4.9

Fig. 2.11

2.2.3 Bandwidth

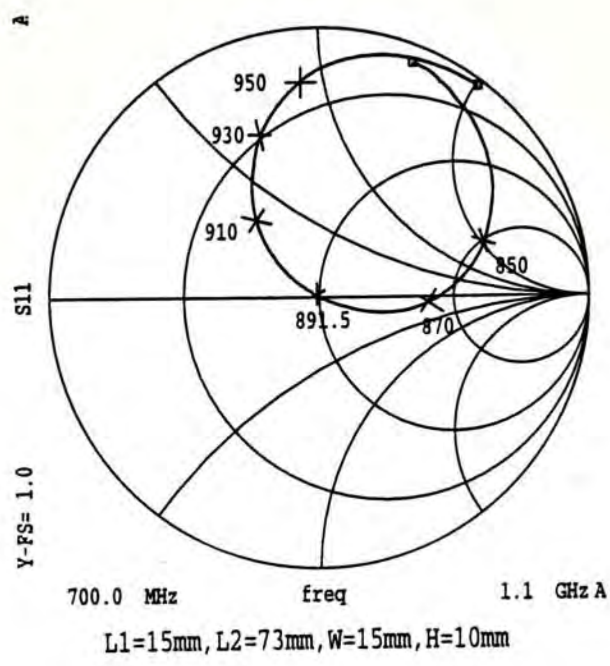
The bandwidth of the antenna increases as the width of the vertical element decrease, and decrease with the height of the vertical element increase.

By adjusting the size of the antennas, bandwidth from 5% to 9% of the centre frequency can be made. The bandwidth of meandering inverted-F antennas are several times greater than that of microstrip antennas which are more attractive low profile antennas for use in mobile communications.

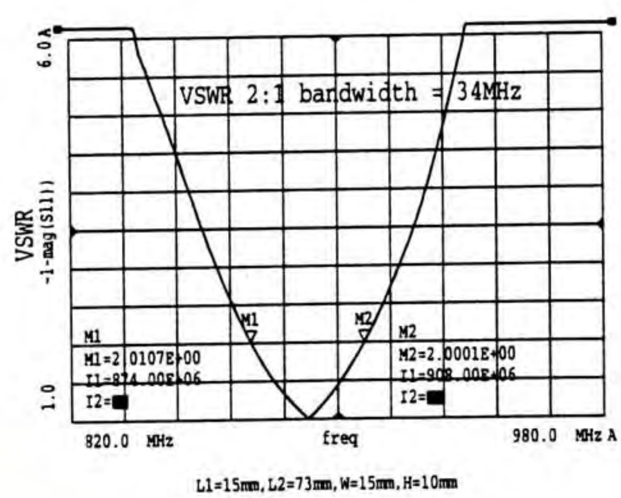
2.3 Antenna with a longer meandering line

The resonant frequency of the first prototype is around 1GHz. It is inevitable that it is not an appropriate antenna to use on 900MHz band mobile radios. In order to lower the antenna's resonant frequency, antennas with a longer horizontal element are constructed and tested. Figure 2.12 shows the antenna's frequency characteristics with different dimensions.

The results showed that if more bends are added to the meandering horizontal element, resonant frequencies of the antenna decrease. However, the drawback surely is the increase in antenna size.

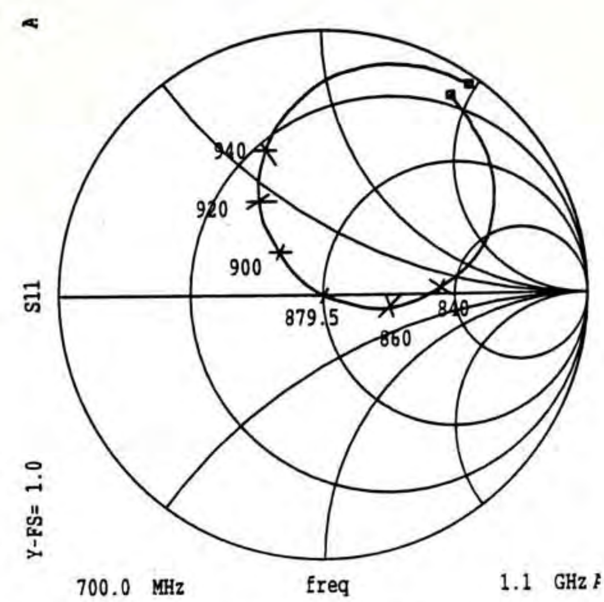


(a) Input impedance

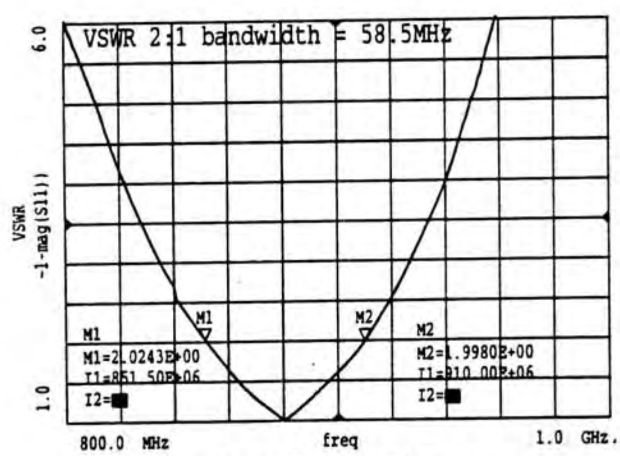


(b) VSWR

Fig. 2.12 Frequency characteristics of meandering antenna with longer horizontal element



(c) Input impedance



(d) VSWR

Fig. 2.12 Frequency characteristics of meandering antenna with longer horizontal element

2.4 Antenna loaded with dielectric substrate

Reinforced plastic material with dielectric constant ε_r of 2.3 is inserted between the antenna's horizontal element and the ground plate as depicted in Fig. 2.13.

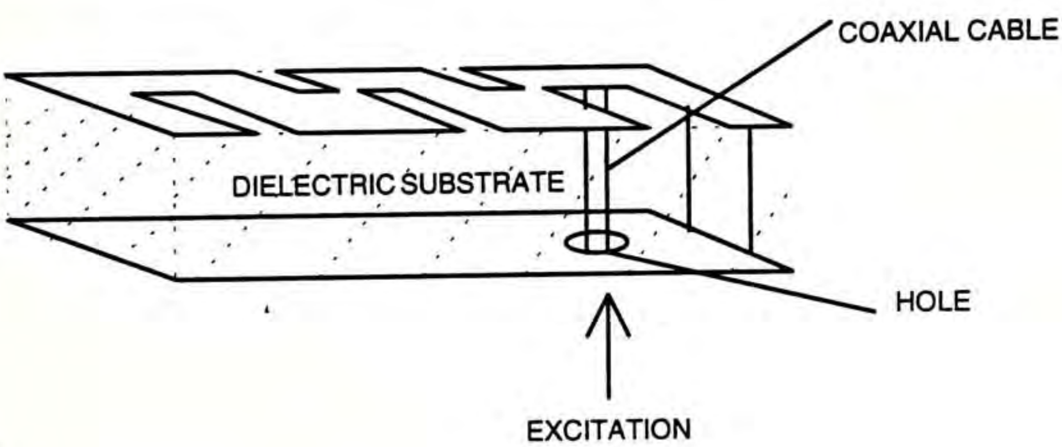


Fig. 2.13 Dielectric loaded meandering inverted-F antenna

Classical electromagnetic theory given that an electromagnetic wave travels through an uniform dielectric medium with relative permittivity of ε_r. The wavelength of the wave along the dielectric medium is given by

$$\lambda = \frac{\lambda_o}{\sqrt{\varepsilon_r}}$$

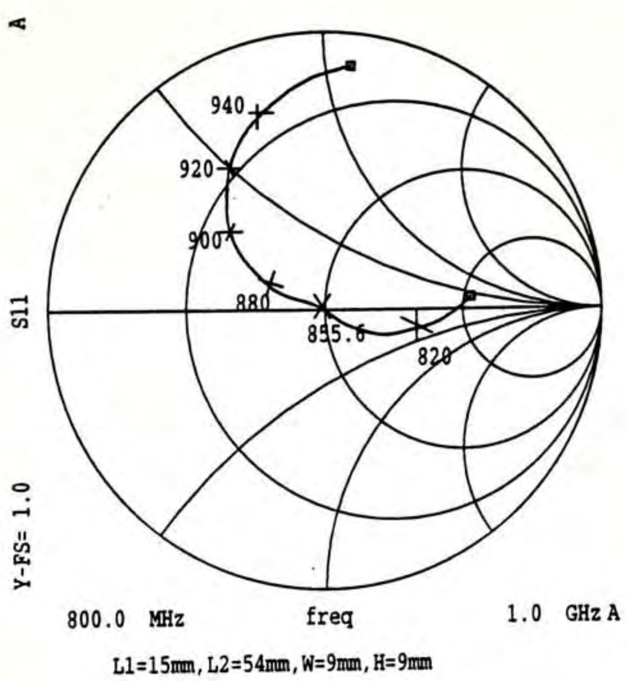
where λ is the wavelength along the transmission medium and λ_o is the free space wavelength. It turns out the effective wavelength is shorter than that in free space.

The dimensions of the dielectric loaded antenna are of the same as that of the first prototype as shown in Figure 2.6 but the vertical element with height and width of 9mm respectively. It is expected that the resonant frequency of the dielectric loaded antenna will be lower than that of the original design.

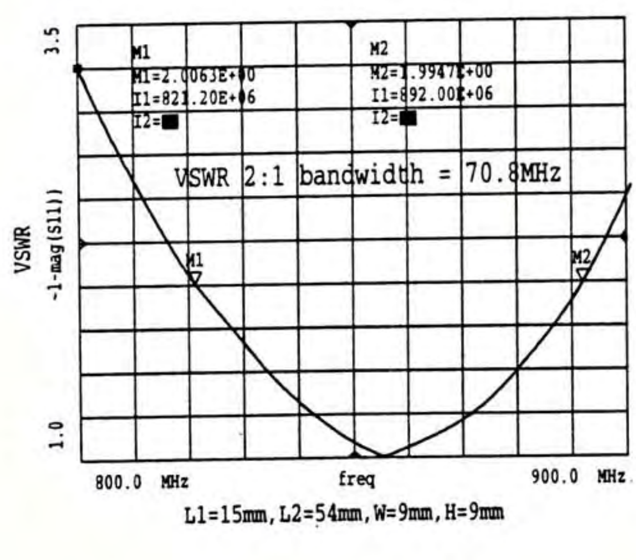
2.4.1 Frequency characteristics

Figure 2.14 shows the frequency characteristics The antenna gives excellent performance in terms of bandwidth and VSWR. Also in section 2.4.2 the radiation patterns of the antenna showed that it is very suitable for applications in mobile communications. The specifications of the antenna are summarized as follow :

centre frequency	:	855MHz
VSWR	:	1.005
VSWR 2:1 bandwidth	:	68MHz



(a) Input impedance



(b) VSWR

Fig. 2.14 Frequency characteristics of dielectric loaded antenna

2.4.2 Radiation pattern measurements

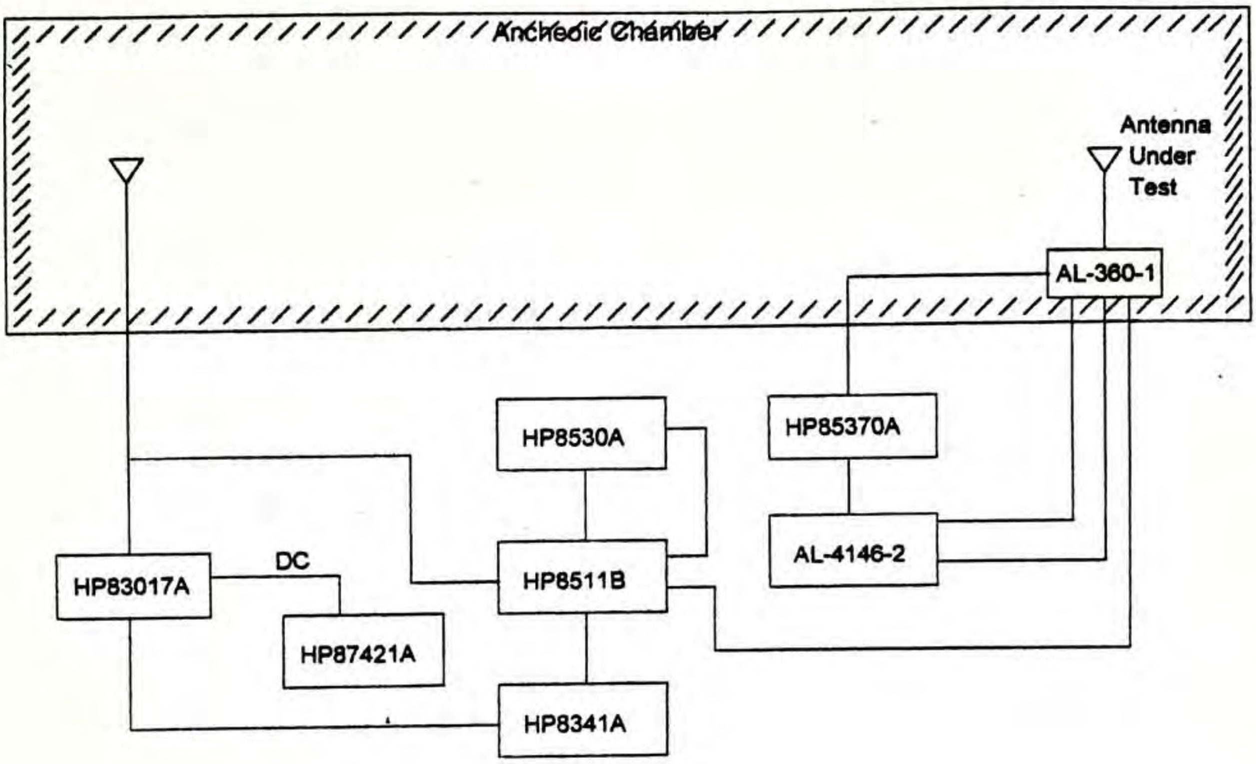
The far-field pattern of an antenna is one of the most important characteristics. The measurement is performed inside an anechoic chamber. The inside walls of the chamber are covered by high quality RF absorbers. The philosophy is to provide a non-reflecting environment like in free space, but external electromagnetic waves cannot go inside the chamber. Figure 2.15 shows the measurement set up.

The complete radiation pattern is a 3-dimensional pattern. Spherical coordinate system is used. Figure 2.16 shows the coordinate system used in the measurements. Patterns of the θ and ϕ components of the electric field (E_θ and E_ϕ) are measured as a function of ϕ along constant θ circles, where ϕ is the longitude or azimuth angle and θ is the zenith angle. These patterns are measured by moving and rotating the antenna under test. Then, six patterns are measured :

E_θ component of electric field in X-Y, X-Z, and Y-Z plane;

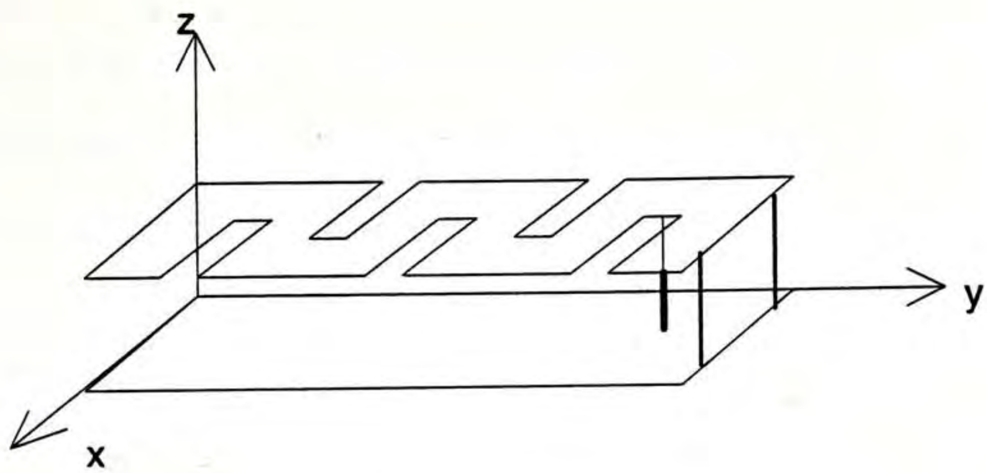
E_ϕ component of electric field in X-Y, X-Z, and Y-Z plane.

The frequency of measurement is selected as the resonant frequency of the antenna under test

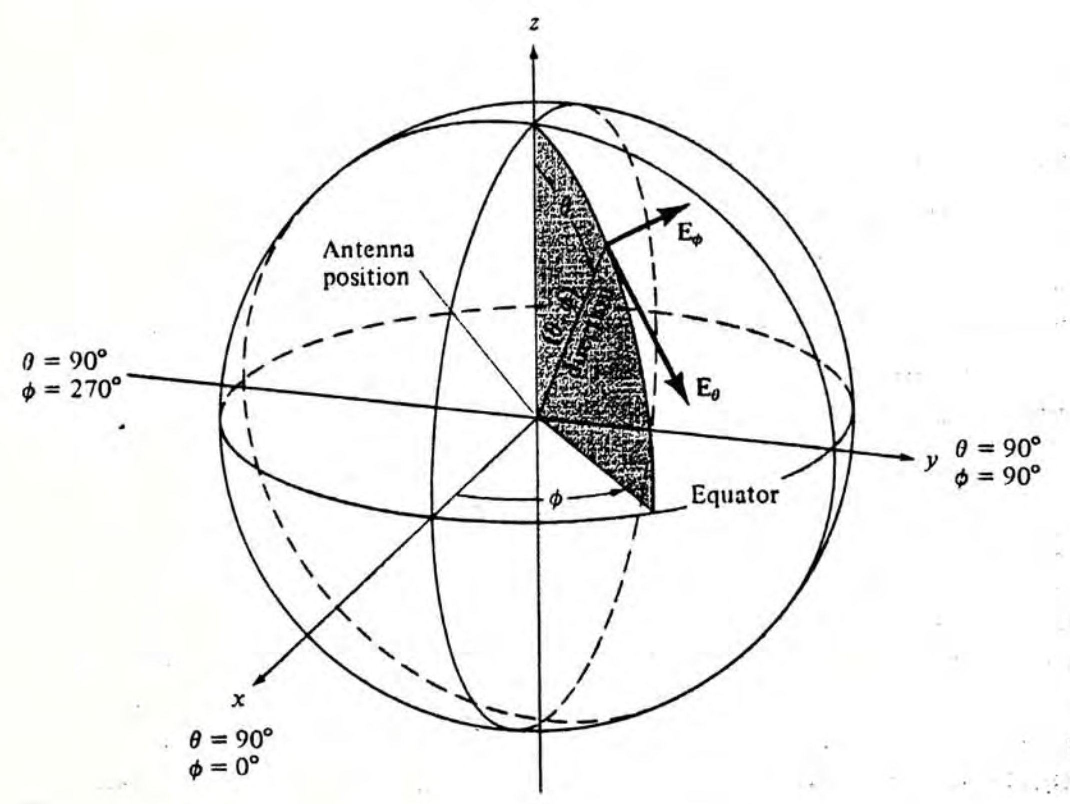


HP8530A	Microwave Receiver
HP8511B	Four Channel Frequency Converter
HP841A	Synthesizer
HP83017A	RF Amplifier
HP85370A	Antenna Position Encoder
Orbit AL-4146-2	Power Amplifier Unit for Positioner
Orbit AL-360-1	Azimuth Positioner

Fig. 2.15 Radiation patterns measurement set up



(a) antenna coordinate system



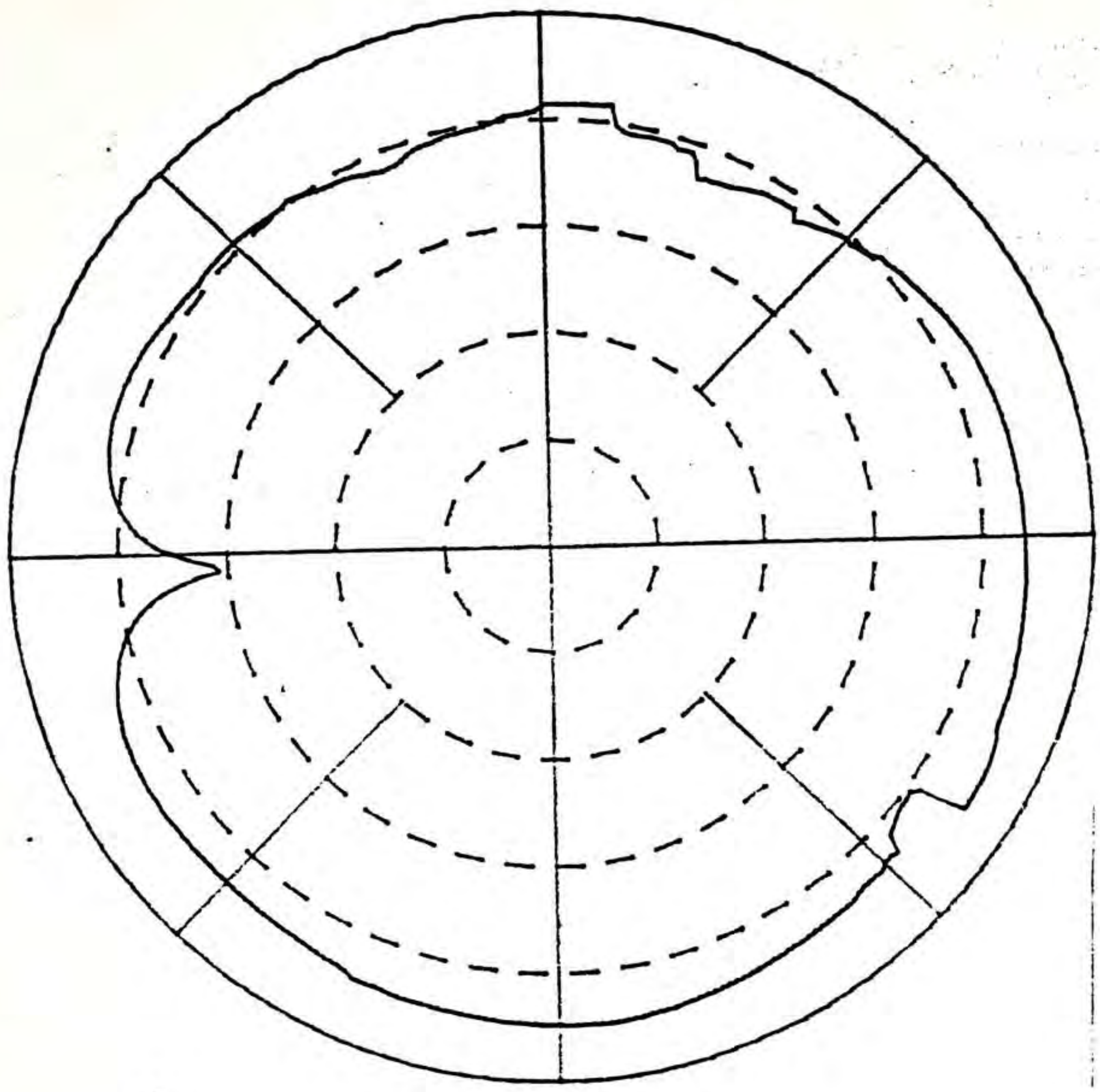
(b) Spherical coordinate system geometry

Fig. 2.16 Measurement coordinate system

2.4.3 Radiation Patterns

Fig. 2.17 to 2.22 shows the measured far-field radiation patterns of the antenna. Most of the nulls are less than 20dB, with only one 40dB null in ϕ polarization in the x-y plane. The radiation patterns of the antenna are almost omni-directional in all three planes X-Y, X-Z, and Y-Z. There are some ripples observed in the radiation patterns. It may caused by edge diffraction effect of the finite ground plane. It has both comparable E_θ and E_ϕ components. That means the antenna process both vertical and horizontal polarizations. Those are contributed by the vertical monopole and the meandering horizontal elements. It showed that the antenna is sensitive to both vertically and horizontally polarized radio waves, thereby the antenna is suitable for use with mobile radio equipment in which the antenna orientation is not fixed. As reported by Mishima and et al. [2.6], the cross-polarization characteristic of the antenna enhance the average received power in an urban city area. In an urban environment, where the radio waves may have random fluctuating distributions, compounding of both the vertical and horizontal polarizations can provide an averaging effect and improve the reception. The increase in average received power has the effect of lowering the probability of signal cancellation due to multipath fading. The effect play an important role in reducing multipath fading [2.6].

Since mobile radio antennas are operated in a land mobile propagation environment where random multipaths exist due to reflection, refraction, diffraction, and scattering of radio waves, estimating antenna gain using antenna directivity is not appropriate. Andersen and et al. have proposed a method to estimate the efficiency of mobile radio antennas [2.7]. The method estimate the average gain of mobile antenna by averaging the signal levels received while an operator walks along a selected route. With this method, the effective gain related to a reference antenna can be obtained. T. Taga and et al.[2.5] has proposed a pattern averaging gain method to estimate the average gain of mobile antennas in a multipath environment. This method employs wire grid analysis and gain estimation techniques to calculate the gain characteristics of planar inverted-F antenna's mounted on metal housing.



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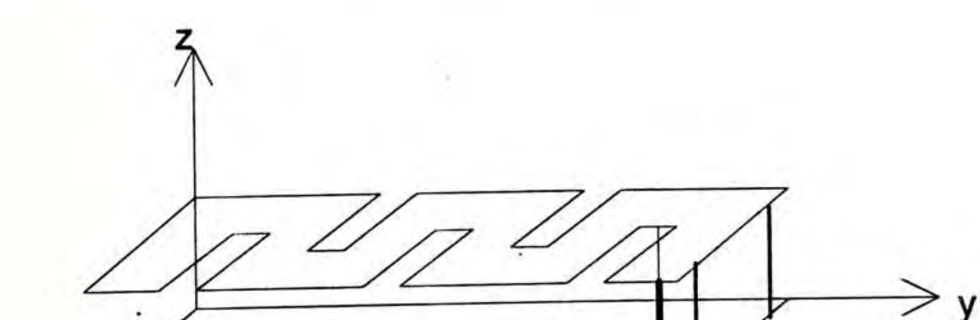
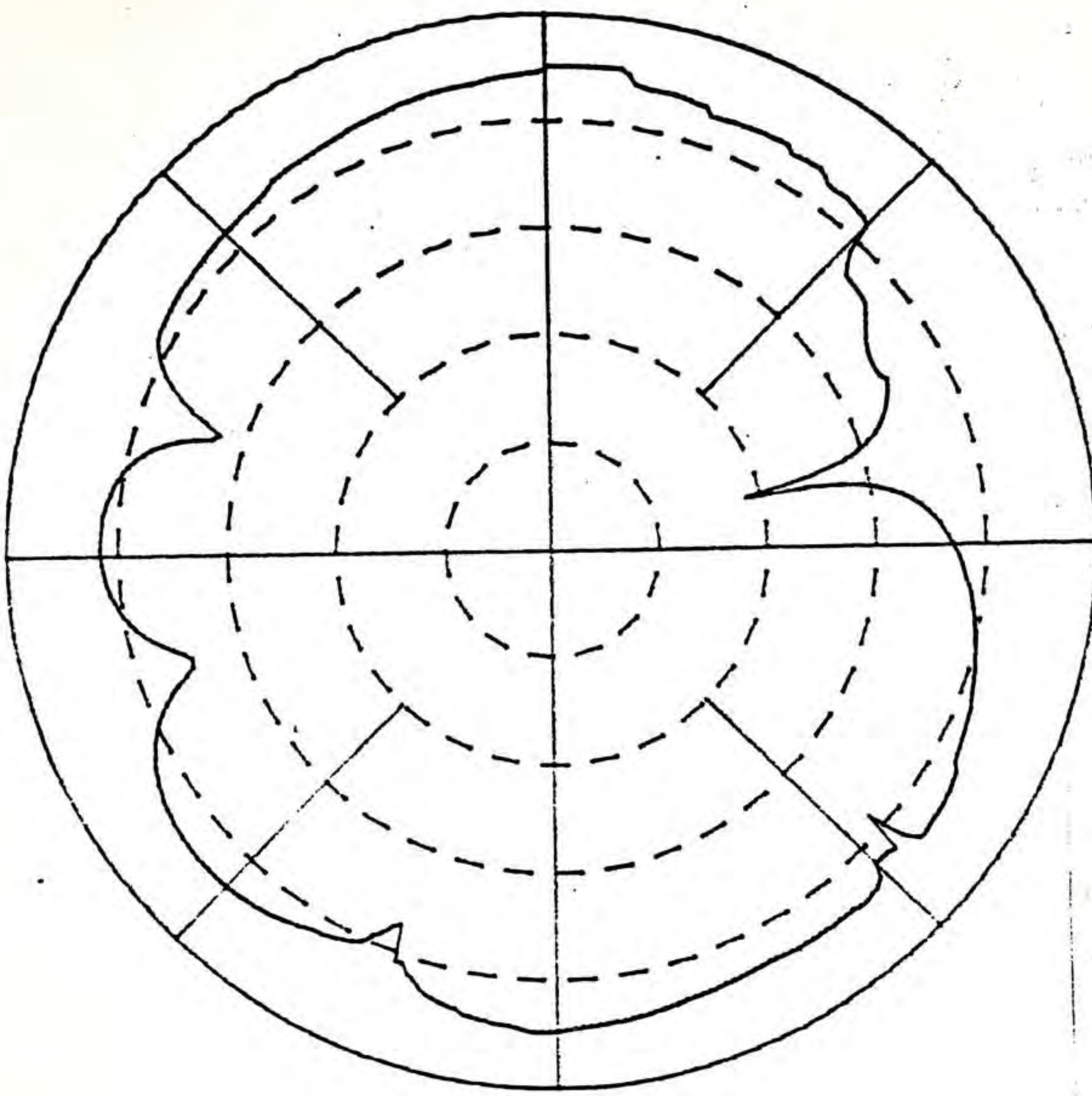


Fig. 2.17 Radiation pattern of E_θ component in X-Y plane



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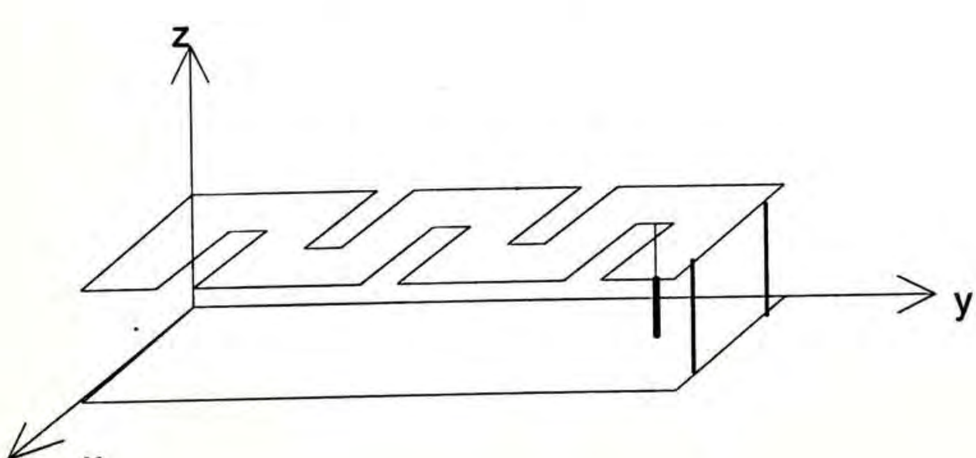
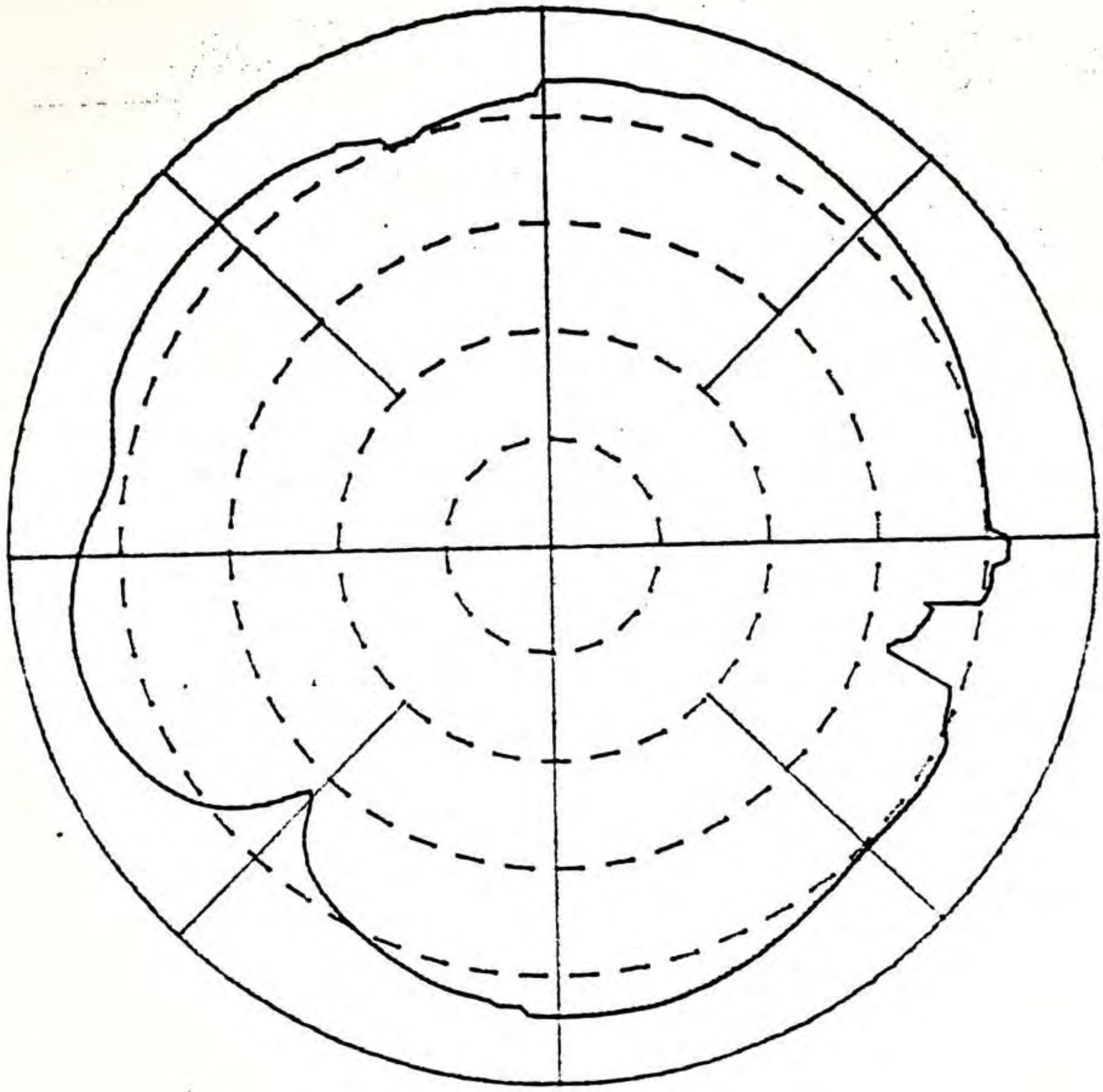


Fig. 2.18 Radiation pattern of E_ϕ component in X-Y plane



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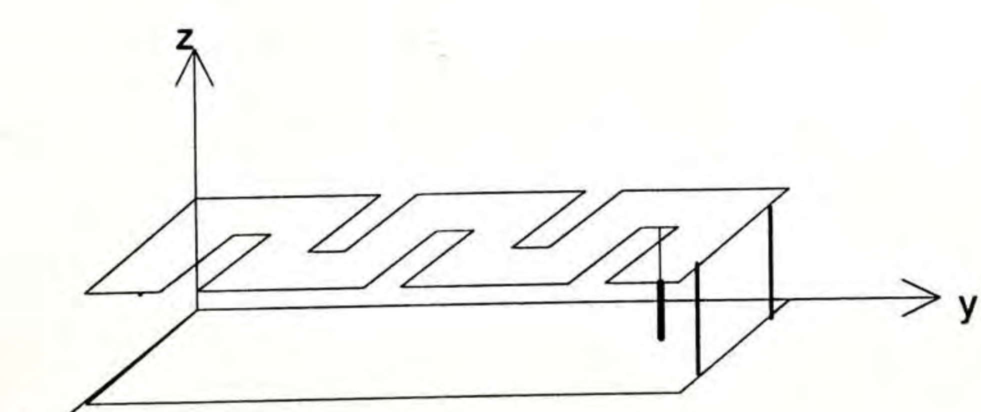
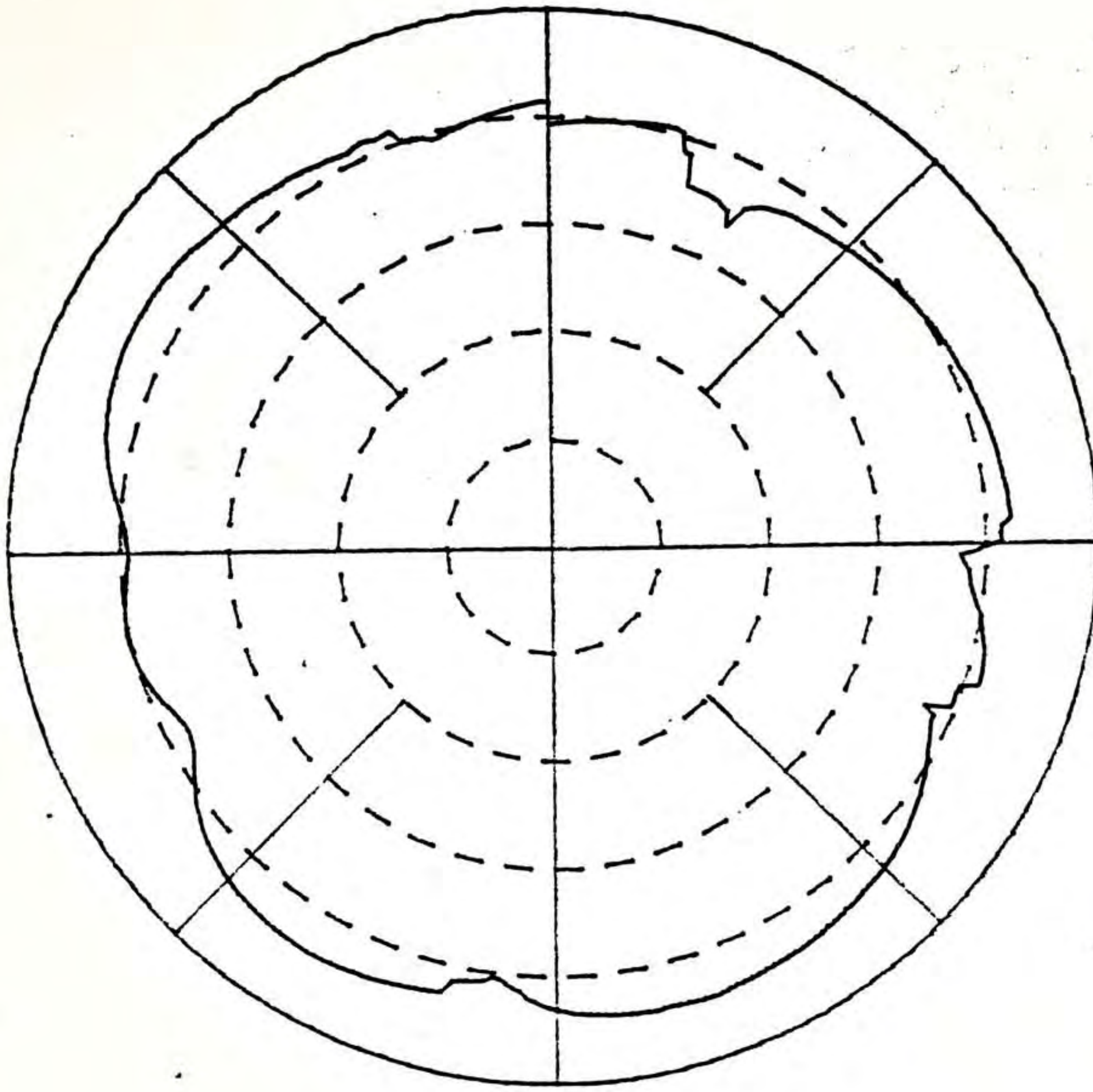


Fig. 2.19 Radiation pattern of E_θ component in X-Z plane



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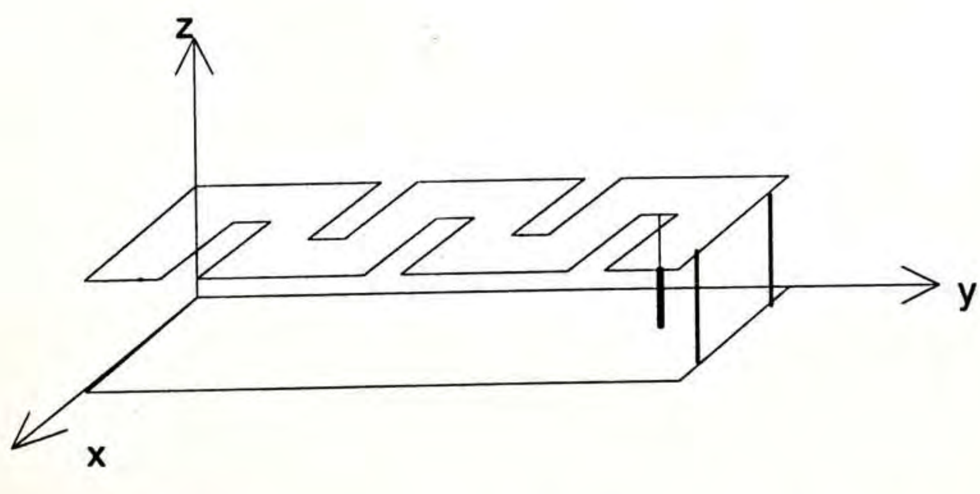
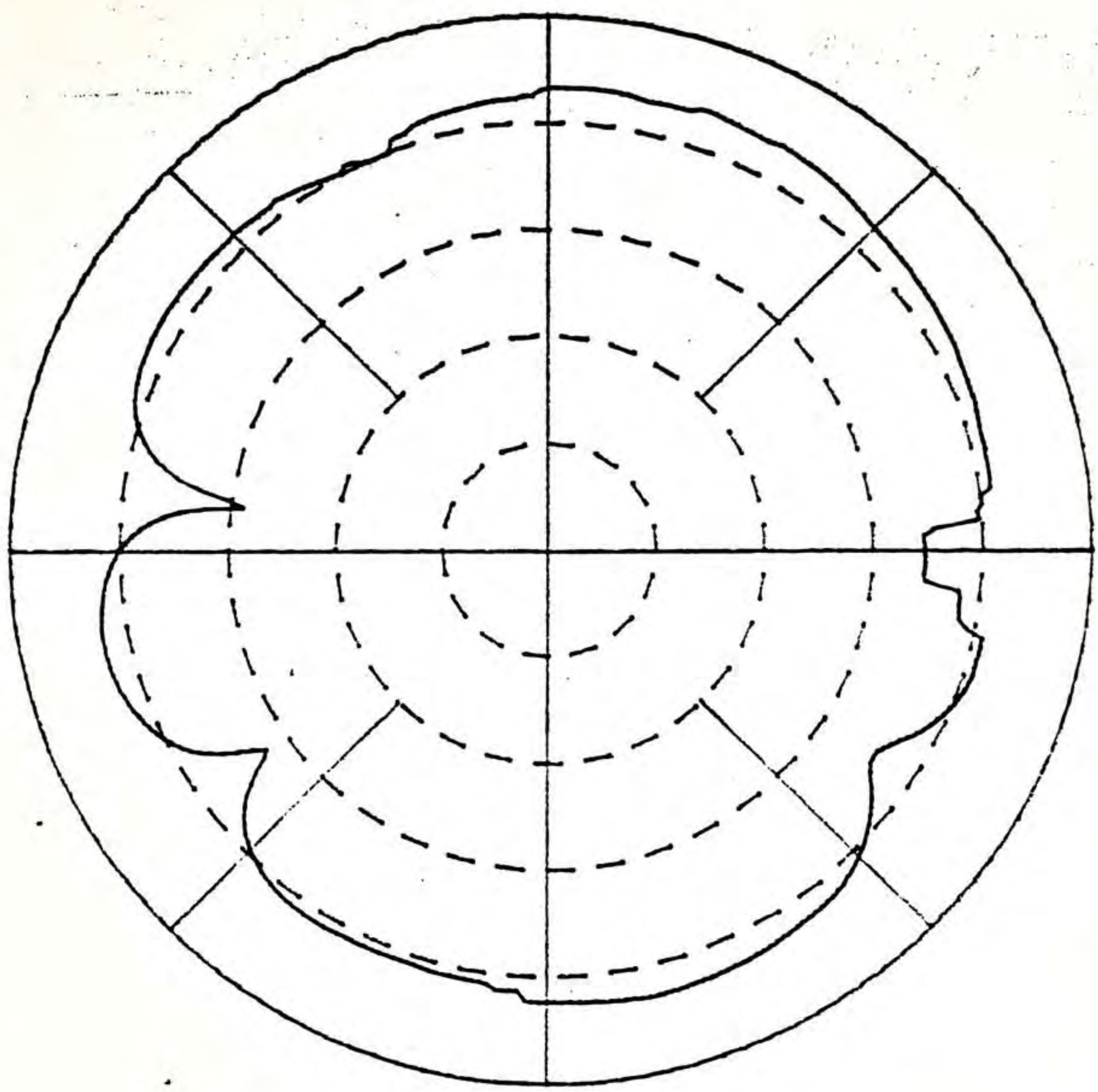


Fig. 2.20 Radiation pattern of E_ϕ component in X-Z plane



Scale : 20dB/division

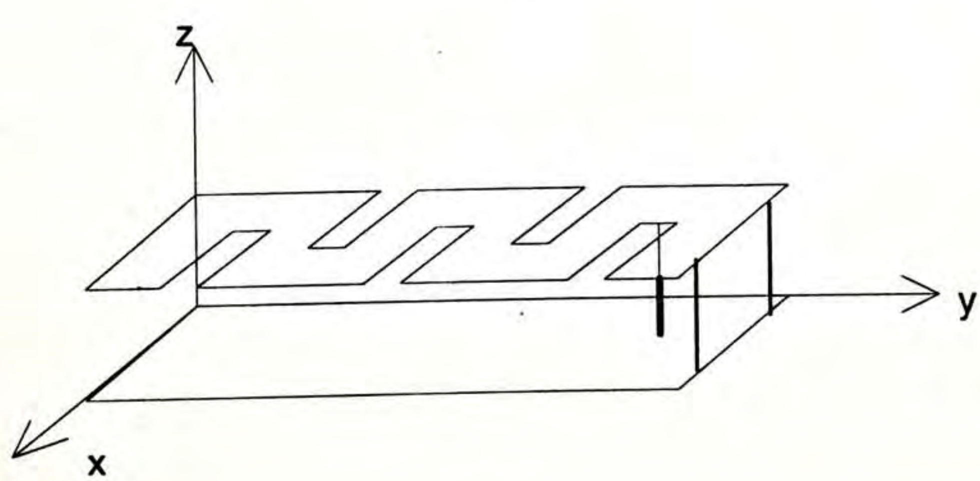
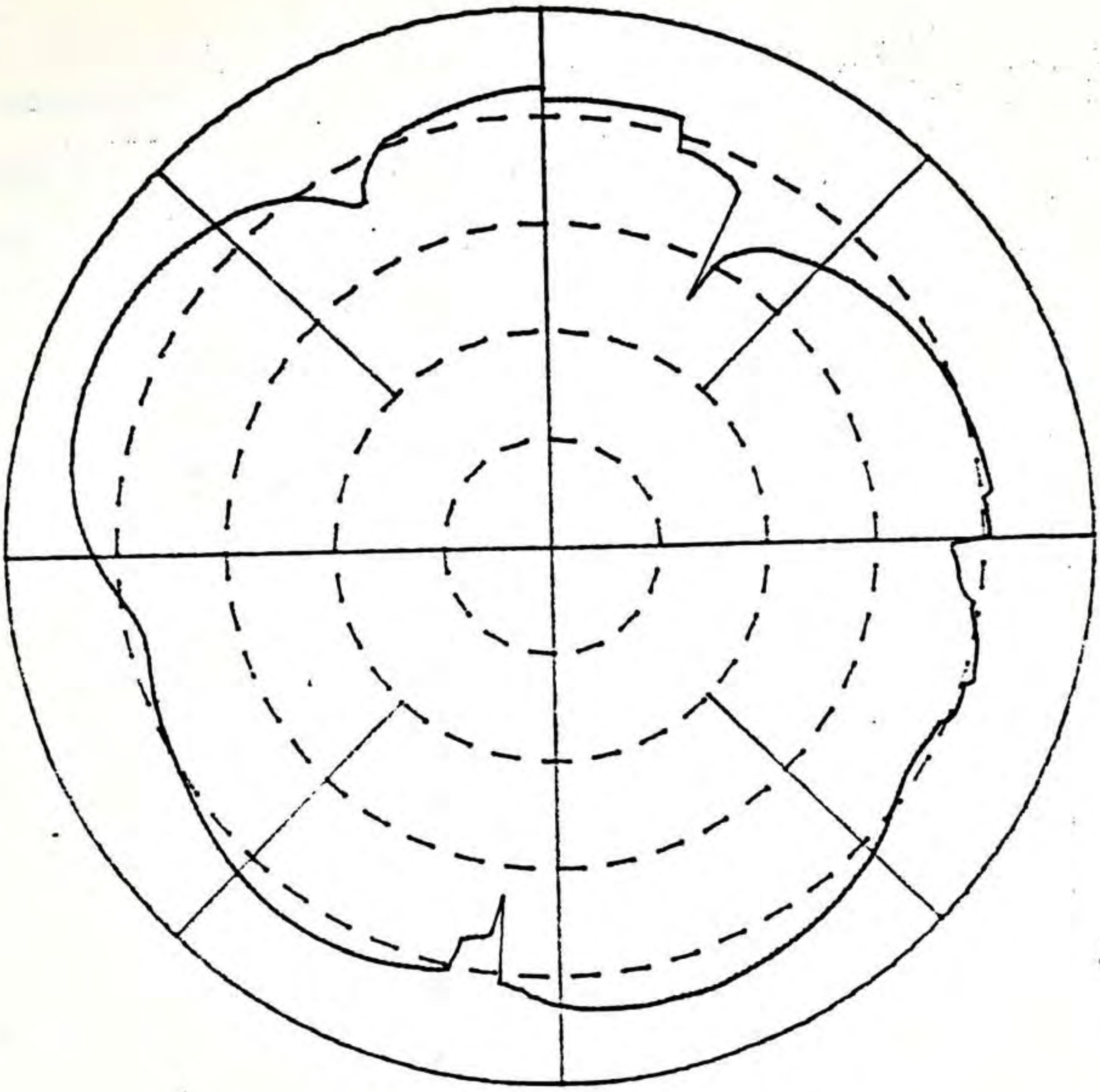


Fig. 2.21 Radiation pattern of E_θ component in Y-Z plane



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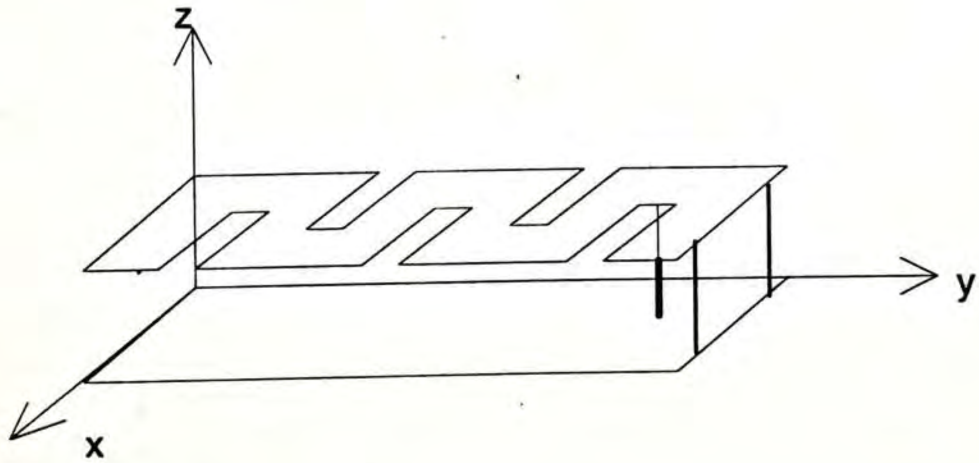


Fig. 2.22 Radiation pattern of E_ϕ component in Y-Z plane

2.5 The 1.9GHz Antenna

The resonant frequency of the meandering inverted-F antenna can be controlled by varying the length of the horizontal element, the width and height of the vertical element. An 1.9 GHz antenna is constructed and tested. The test antenna has a VSWR 2:1 bandwidth of 90 MHz and excellent VSWR of 1.03 at 1.9 GHz. It process both vertical and horizontal polarization and has approximate omni-directional far field radiation patterns. Figure 2.23 shows the dimensions of the horizontal element of the antenna. The width and height of the vertical element is 15mm and 9mm respectively. Figure 2.24 presents the frequency characteristics of the antenna.

The antenna is good for use in Digital European Cordless Telecommunications systems which are operating at 1.89 GHz and the allocated bandwidth is 20 MHz.

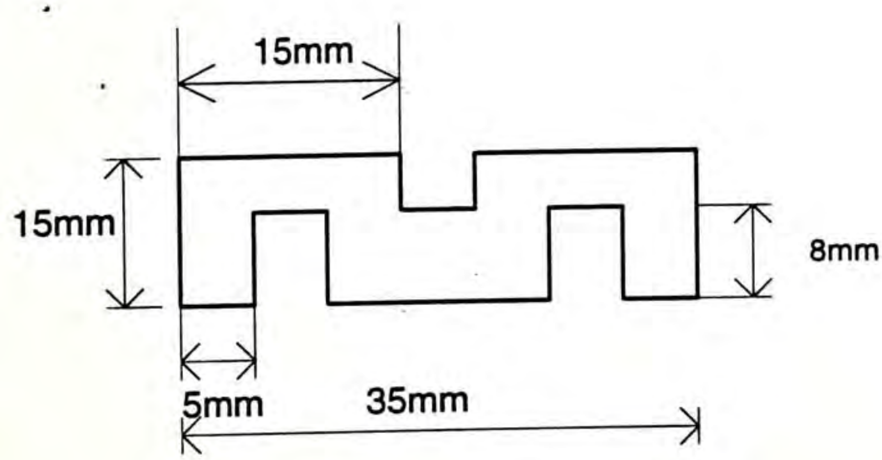
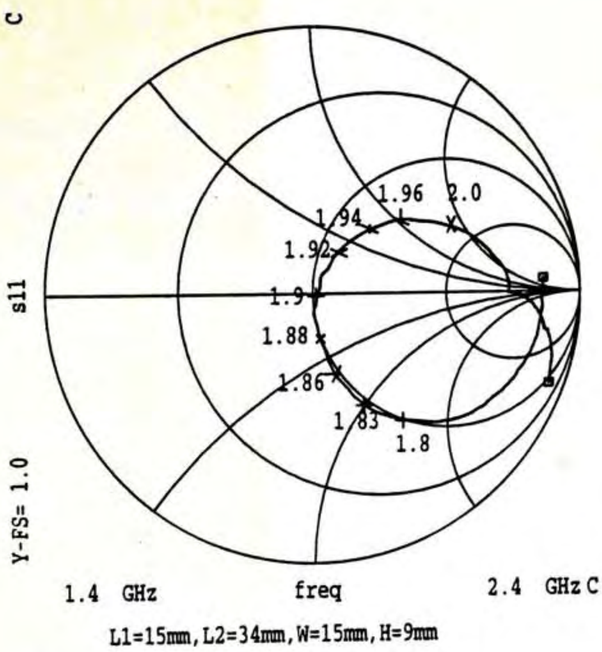
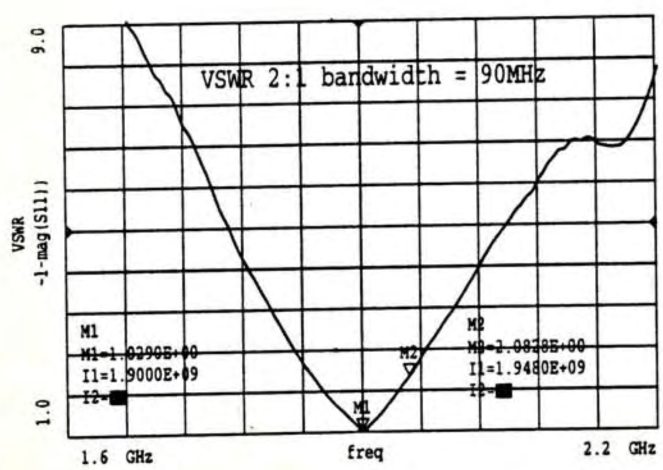


Fig. 2.23 Horizontal element of the 1.9GHz antenna



(a) Input impedance



(b) VSWR

Fig. 2.24 Frequency characteristics of the 1.9 GHz antenna

2.6 Summary

Novel meandering inverted-F antennas are constructed and tested. The antennas are low-profile and compact in size. The length of the radiating element (L) is the main parameter that affects the operating frequency of the antenna. The longer the length "L", the lower the operating frequency. On the other hand, the permittivity of dielectric load reduces the operating frequency by a factor of approximately $\sqrt{\varepsilon_r}$. The width and height of the vertical element are the parameters that control the bandwidth and the operating frequency. As the width of the vertical element is reduced, the bandwidth likewise increases with a reduction in operating frequency. On the other hand, as the height of the vertical is reduced, the bandwidth is increased with a slight lowering of the operating frequency. With different dimensions, the antenna can resonate at 900MHz band and 1.9GHz band. The VSWR at its resonate frequency is lower than 1.01, demonstrating the high efficiency of the antenna. The antenna process both vertical and horizontal polarization's sensitivity. The radiation patterns are approximately omni-directional. Taking these facts into account it can be said that the antenna is very attractive for mobile communications.

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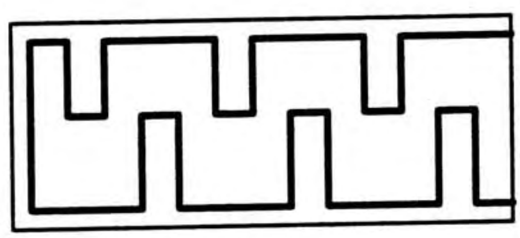
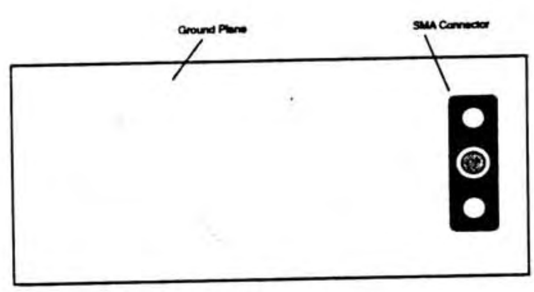
Chapter 3

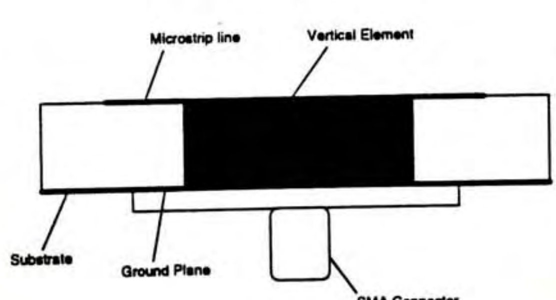
The Meandering Posted Microstrip Antenna



Top View



Bottom View



End view

3.1. Introduction

Microstrip antennas have the advantage of small size, light weight, low profile and low cost and are widely used in antenna applications. The basic geometry of a microstrip antenna consists of a conducting radiator patch printed onto a grounded substrate. The shape of the patch is arbitrary. Rectangular, circular, equitriangular, and annular designs are common in practice. Excitation can be achieved either with a coaxial feed, stripline, or aperture electromagnetic coupling.

Microstrip antenna is a type of planar antenna, first introduced in mid-1970s by Munsion and Howell [3.1, 3.2]. However, the original study of planar antennas, which utilize a stripline as a radiator or feeding system, began with the advent in stripline [3.3]. The features of microstrip antennas may be summarized as follows:

- low profile;
- low cost, actually it is a printed circuit board;
- clarity of radiation characteristics;
- light weight;
- easy to achieve dual frequency performance;
- suitable for MMIC fabrication.

In the following sections, the author will present the method of implementing the meandering inverted-F antenna concept onto printed circuit board. The test results showed that the new design makes the size of the antenna much smaller than that of a rectangular microstrip antenna with similar electrical characteristics.

3.2 Theory

In terms of electromagnetic field distribution microstrip structures are very complex, because they process three different inhomogeneities :

(a) The fields on printed microwave structures extend over imhomogeneous regions, formed partly of dielectric and partly of air. Waves propagating along the structure cannot be purely TEM and exhibit dispersion [3.5]. The dominant mode of microstrip line can be approximated by quasi-TEM.

(b) The microstrip line, partially covers the substrate : the boundary conditions that the fields must meet are not the same at all points on the air/dielectric.

(c) Radiated waves and surface waves on the air/dielectric substrate bounce back and forth, scattered by the edges, and they produce spurious coupling between elements.

An infinite straight transmission line propagating the dominant mode does not radiate. However, at every discontinuity higher-order modes are excited, some of which radiate part of the signal, and the line becomes an antenna.

A rectangular microstrip antenna is depicted on Figure 3.1. The antenna will radiate most efficiently when its length is any integer multiple of a half-wavelength. However, to avoid multiple mode operation, the lowest mode of

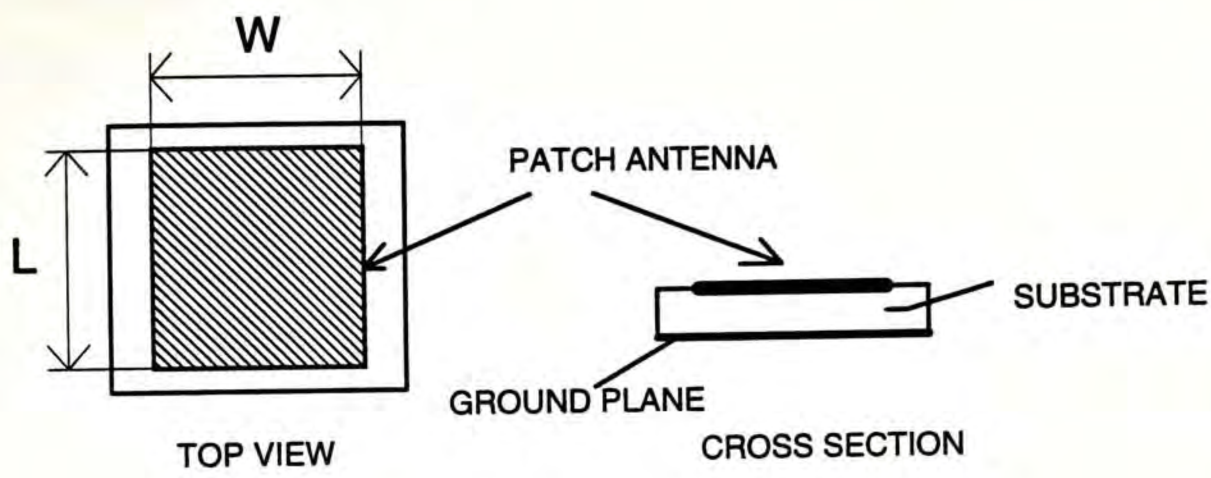


Fig. 3.1 Rectangular microstrip patch antenna

operation is chosen. In practical, the patch antenna must be less than one-half wavelength long to account for fringing fields from the ends of the patch. This gives the length of the patch antenna to be,

$$L = \frac{\lambda g}{2} - 2\Delta leo \qquad (3.1)$$

where

L = effective length of the patch antenna

$\lambda g = \frac{\lambda o}{\sqrt{\varepsilon_{eff}}}$ = guided wavelength

Δ_{leo} = the effects due to edge fringing [3.5]

ε_{eff} = effective dielectric constant [3.5]

λ_o = free space wavelength

Both Δ_{leo} and ε_{eff} are dependent on the relative dielectric constant and the patch width W. The patch can be set to any width. However, in order to achieve maximum efficiency and allow conductance curves to be used [3.4], the antenna width W is chosen to be

$$W = 0.3\lambda_o \qquad (3.2)$$

RT/Duroid 5870 laminates with $\varepsilon_r = 2.33$ and thickness of 0.7874mm are used, at 900MHz, the length of the patch antenna, as given by equation 3.1,

$L \cong 10cm$

and the width of patch antenna, as given by equation 3.2

$W \cong 9cm.$

Radiation from a microstrip line is desirable effect in the design of microstrip antennas. Radiation power calculations generally follow the approach of Lewin [3.7]. The power radiated from a discontinuity, P_{rad}, for an incident power of P_{in} is given by

$$\frac{P_{rad}}{P_{in}} = 2\pi\frac{\eta_o}{Z_o}[\frac{h}{\lambda_o}]^2 F(\varepsilon_r) \qquad (3.3)$$

where $\eta_o \approx 376.7\Omega$ is the intrinsic impedance of free space and $F(\varepsilon_r)$ is a factor that is to be determined for each type of discontinuity [3.7].

The power radiated from the open-circuit termination of a microstrip line can be modeled in terms of a shunt conductance, G_{rad}, across the open circuit. Ideally, $G_{rad} \ll 1/Zo$ and the voltage across it is essentially that across a perfect open circuit, namely

$$V_{oc} \approx 2V_{in} = 2\sqrt{P_{in}Z_o} \qquad (3.4)$$

where V_{in} is the voltage of the wave incident upon the open circuit. Thus

$$Grad = \frac{P_{rad}}{V^2{}_{oc}} = \frac{1}{4Zo}\frac{2\pi\eta_o}{Zo}\left\{\frac{h}{\lambda o}\right\}^2 F(\varepsilon_r) \quad [7] \qquad (3.5)$$

$$= \frac{60\pi^2}{Zo^2}\left\{\frac{h}{\lambda o}\right\}^2 F(\varepsilon_r) \qquad (3.6)$$

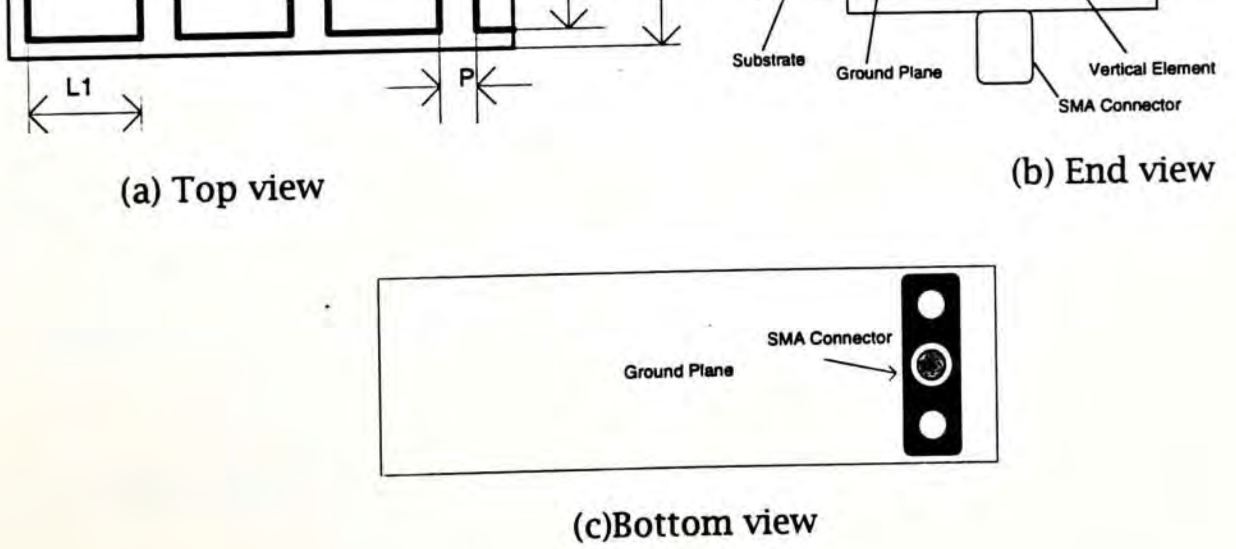
It turns out that the radiation power is related to h, the height of substrate, frequency, characteristic impedance (line width) and ε_r.

3.3 Meandering Inverted-F antenna implemented on PCB

3.3.1 Geometry for the antenna

Basically, the antenna is a type of microstrip antenna with one end of the radiating element shorted electrically. Figure 3.2 shows the geometry of the antenna. The radiating element is a meandering microstrip line. The antenna is fed with a microstrip flange launcher and a short coaxial cable is connected from the centre conductor of the launcher to the radiating element of the antenna. The dimensions of the first prototype are as follows :

L	:	32mm;	W1	:	19mm;
P	:	2mm	W	:	15mm;
L1	:	7mm;			
L2	:	34mm;			
L3	:	15mm			



(a) Top view

(b) End view

(c)Bottom view

Fig. 3.2 Geometry for the Meandering Microstrip antenna

3.3.2 Microstrip bends

Consider a microstrip bend with uniform lines leading up to the two reference planes as illustrated in Fig.3.3a. The corner, between planes R_1 and R_2, may be modeled by the T-network in Fig.3.3b. Here, L_c accounts for the current and stored magnetic energy and C_c for the charge and stored electric energy. The corner also affects the current and voltage distributions in the uniform connecting lines. These disturbances, however, can be considered as a part of the corner segment and thus lumped into the equivalent circuit in Fig.3.3b. In evaluating these disturbances to the uniform connecting lines in the theoretical analysis, auxiliary planes are introduced some distance away from the corner reference planes. At these planes, it is assumed that the fields and currents are identical to those of the uniform transmission line and are not affected by the presence of the bend. $L_c$and C_c in Fig.3.3b have been evaluated by Metran, R. [3.9] and P. Silverter et al. [3.10] respectively.

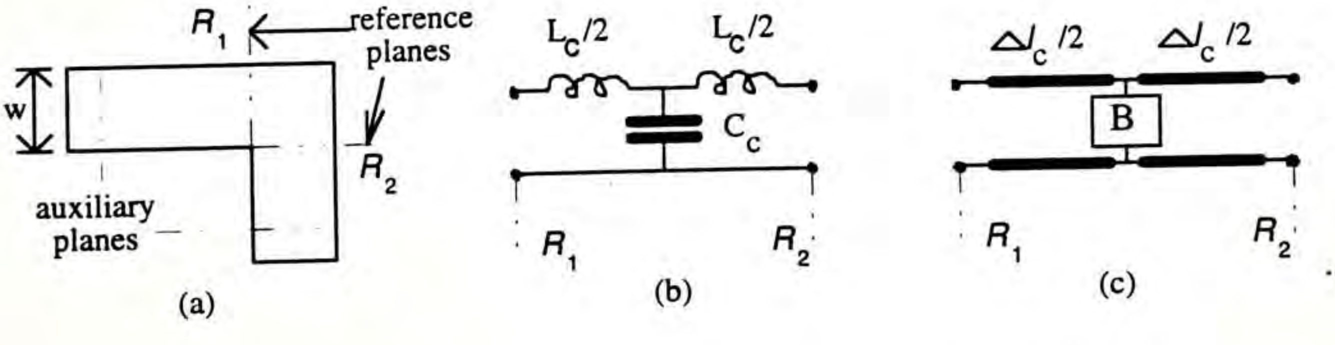


Fig.3.3 The geometry of a microstrip bend and its equivalent circuits

The characteristic impedance of a lossless transmission line is given by

$$Z_o = \sqrt{\frac{L}{C}}$$

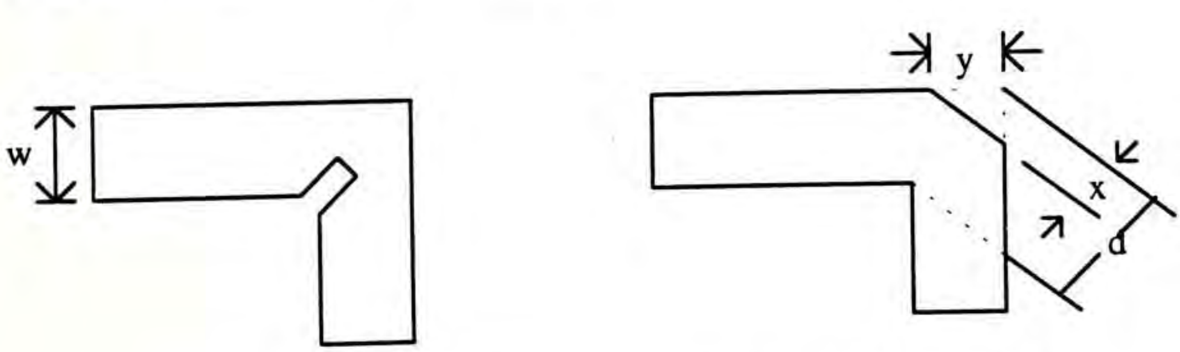
At a microstrip corner, the region between the two reference planes has inductance and capacitance values, L_c and C_c respectively. Thus, with the corner dimensions small compared with the microstrip line wavelength, the characteristic impedance of the corner section of line is

$$Z_{corner} = \sqrt{\frac{L_c}{C_c}}$$

with an equivalent line length, not necessarily of a 50Ω line, of

$$\Delta l = \frac{c}{\sqrt{\varepsilon_{eff}}}\sqrt{L_c.C_c}$$

It turns out that Z_{corner} for the geometry of Fig.3.3a is significantly less than Z_0. Thus the corner may be considered to have either insufficient inductance or excessive capacitance. It is therefore necessary to either increase the corner inductance with a narrow slit in the line [3.11] or reduce the corner capacitance in a symmetrical manner, as illustrated in Fig.3.4, in order to obtain a low reflection from the corner. Reducing the corner capacitance has been the preferred technique [3.12], as it is both dimensionally less sensitive in practice, i.e. easier to construct, and more suitable for theoretical evaluation.



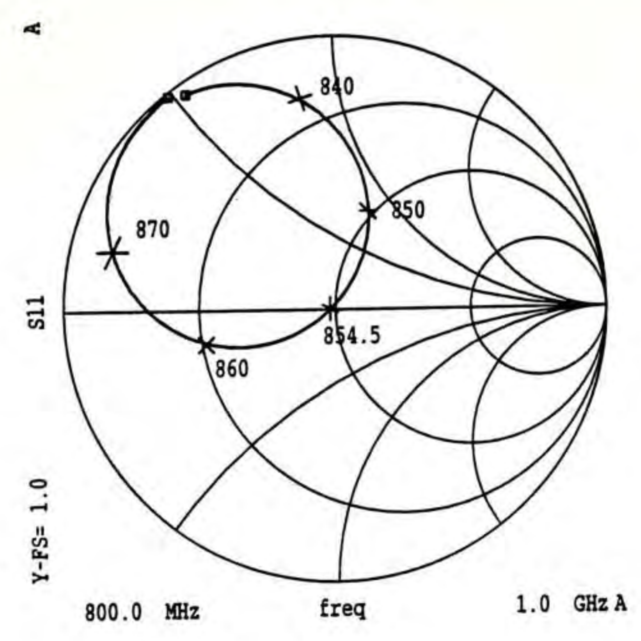
(a) increased inductance (b) decreased capacitance

Fig.3.4 Compensation techniques for a microstrip corner

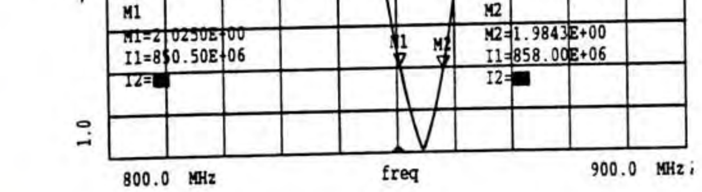
3.3.3 Frequency characteristics

Figure 3.5 shows the frequency characteristics of the test antenna. The antenna resonate at 854.5 MHz and having an excellent VSWR of 1.02. The bandwidth of the antenna is relatively narrower than that of the meandering inverted-F antenna. The VSWR 2:1 bandwidth is 7.5 MHz or 0.87% of the centre frequency whilst for the meandering inverted-F antenna is about 6% of the centre frequency. The measurement results showed that the antenna's characteristics are well agreed with that of microstrip patch antenna. In next section, the radiation characteristics of the antenna is presented.

Although the bandwidth of the antenna is relatively narrow, it is good for applications in the digital 2nd-generation cordless telephone (CT2). CT2 operates at 864-868 MHz which require a frequency bandwidth of 4 MHz [3.13].



(a) Input impedance



(b) VSWR

Fig. 3.5 Frequency characteristics of the Meandering Microstrip antenna

3.3.4 Implementation of the microstrip antenna with different line width

Antennas with different line width are constructed and tested (see Figure 3.6).. Line of 1.5mm, 2.0mm, and 2.5mm are measured. The result is shown in Figure 3.7.

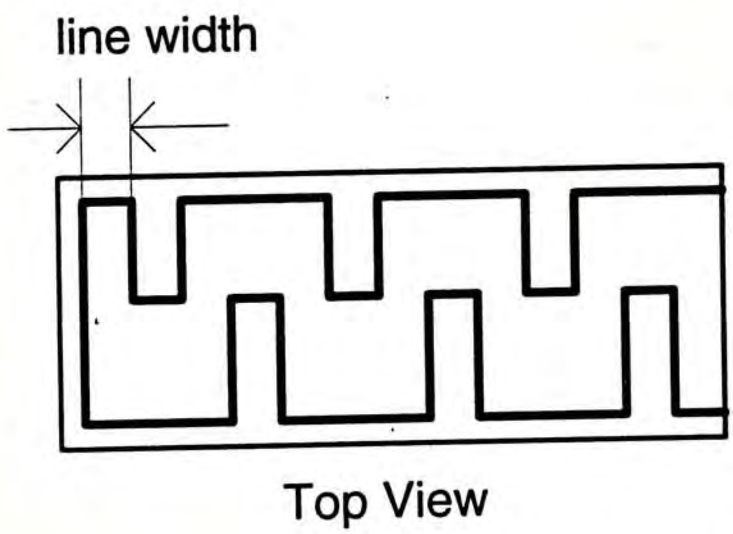


Fig. 3.6 Definition of line width

As seen from the figure, resonant frequency of the antenna decrease with the line width but as an expense of worse return loss. As the line width go narrow, the impedance of the line will become higher (section 3.3.2), and radiation efficiency will get lower.

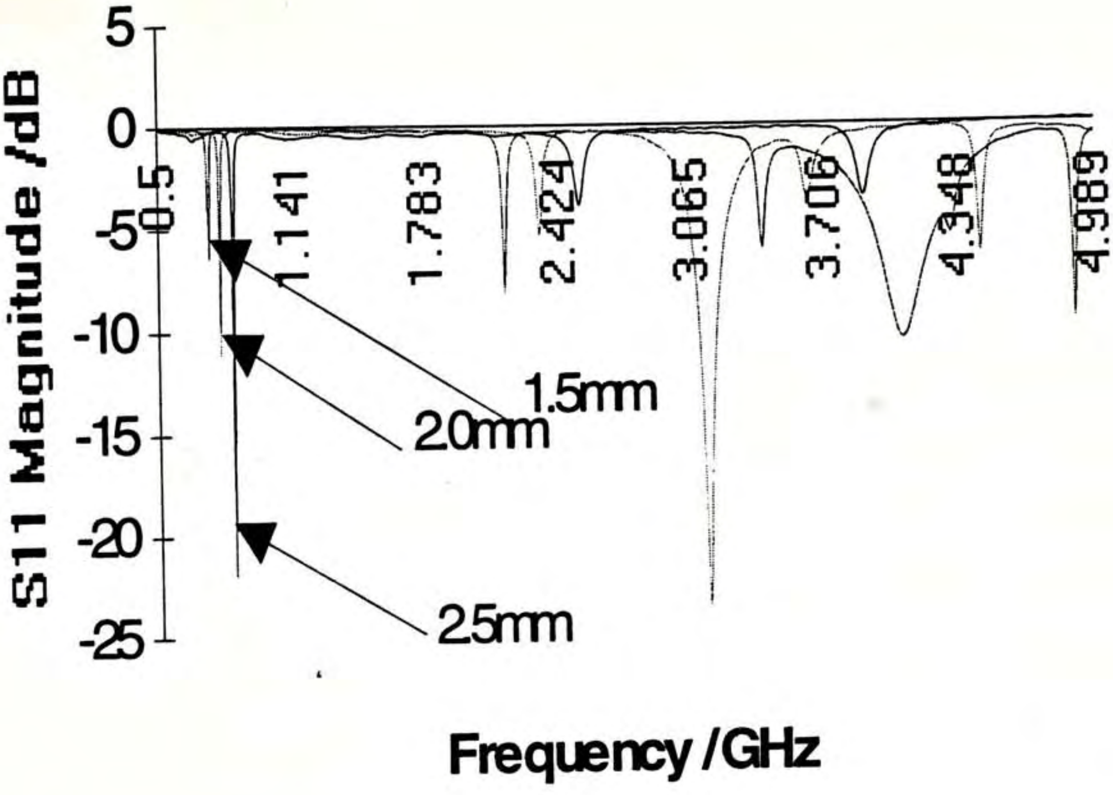
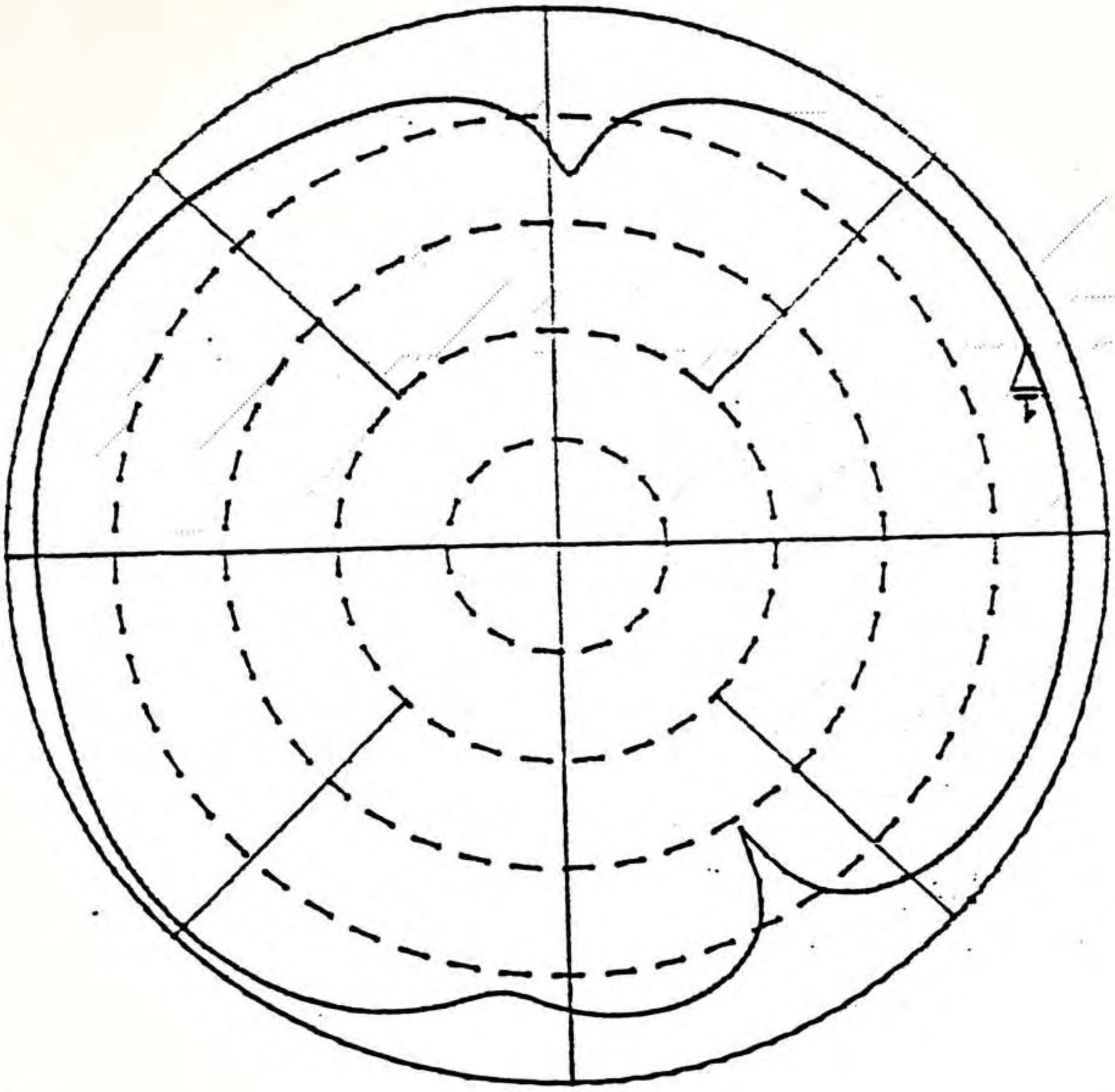


Fig. 3.7 Resonant frequency as a function of line width

3.3.5 Radiation patterns

Figure 3.8 through 3.13 presents the far field radiation patterns of the antenna. The coordinate system used in the measurements is the same as before. Most of the nulls are less than 20dB. Other than that, the radiation patterns of the antenna are approximately omni-directional in all three planes. Among the three planes of interest, the strongest radiations is on the x-y plane, it is nearly 10 dB stronger on average. It has comparable E_θ and E_ϕ components. That means the antenna process both vertical and horizontal polarizations and are contributed by the vertical post and the meandering horizontal elements. It showed that the antenna is sensitive to both vertically and horizontally polarized radio waves, thereby the antenna is suitable for use with mobile radio equipment in which the antenna orientation is not fixed.



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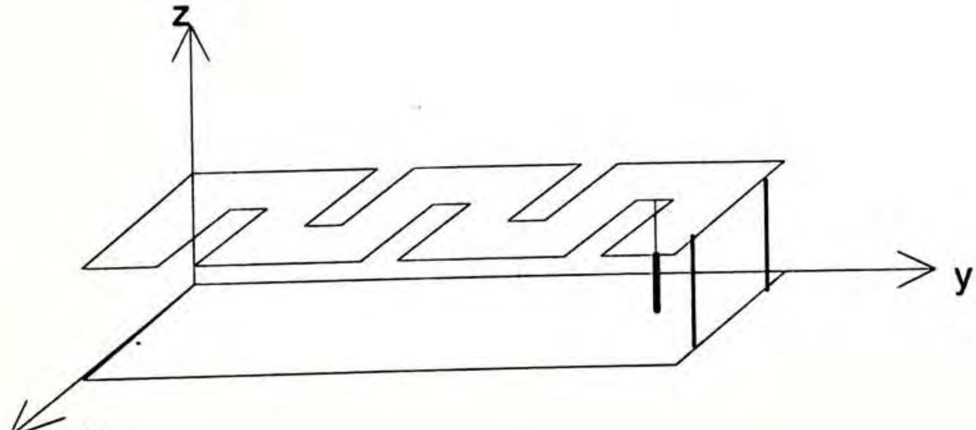
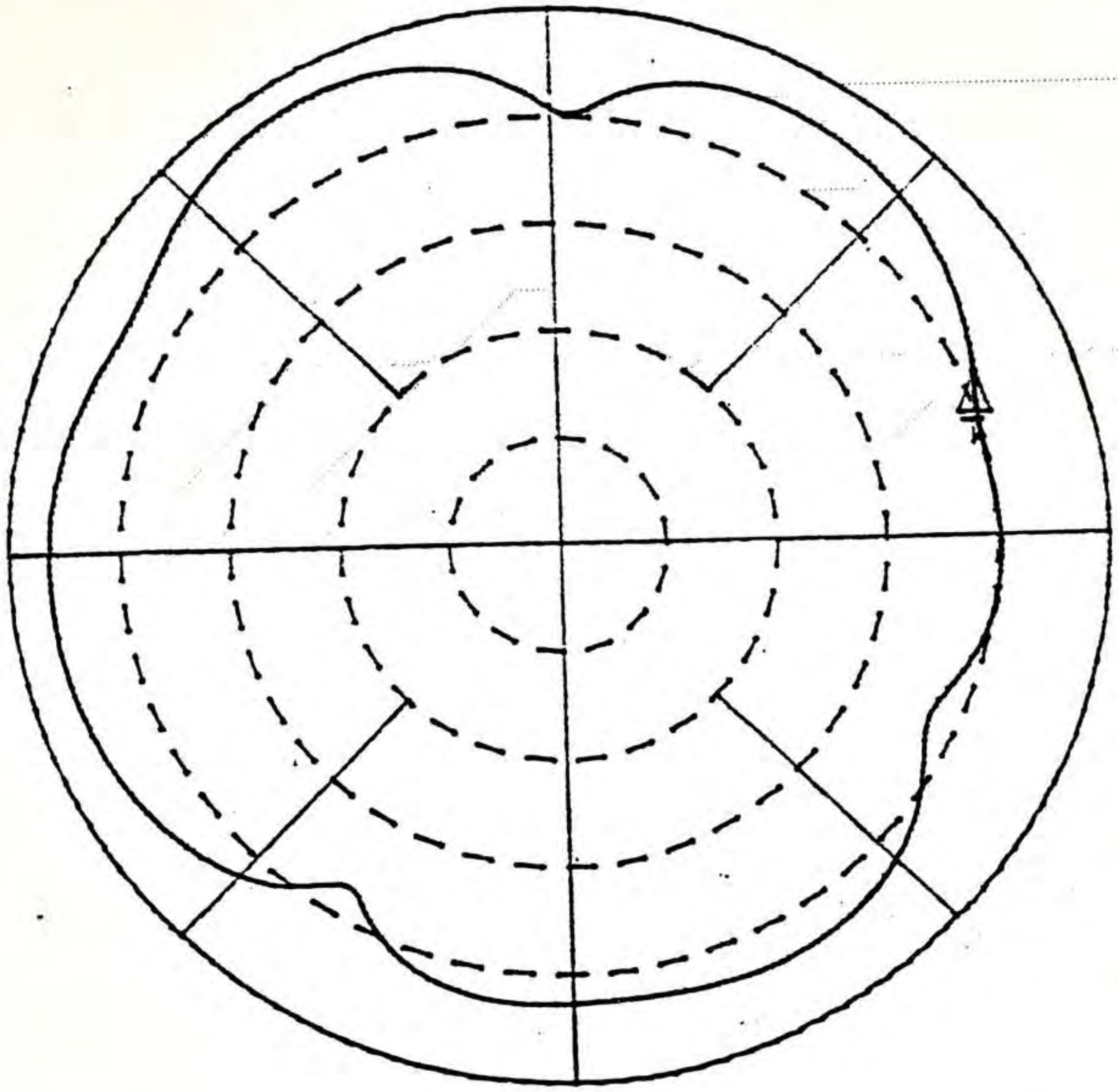


Fig. 3.8 E_θ component in X-Y plane



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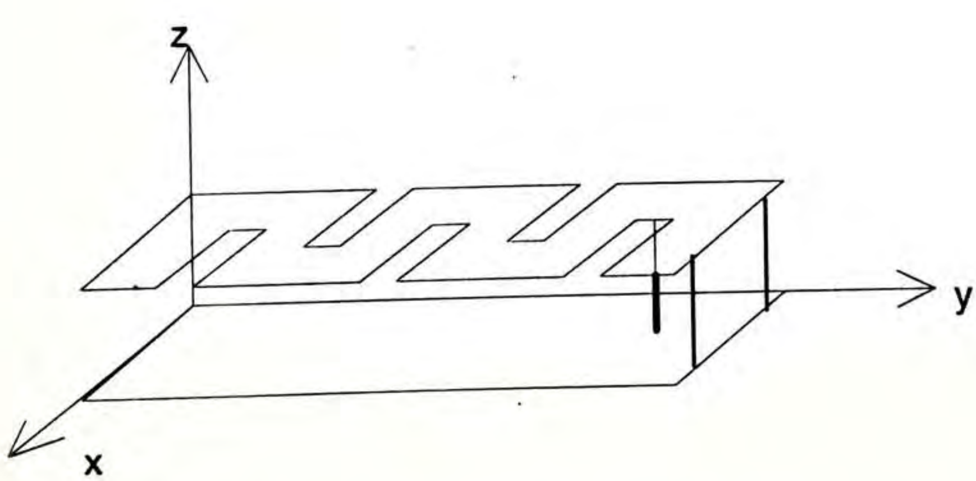
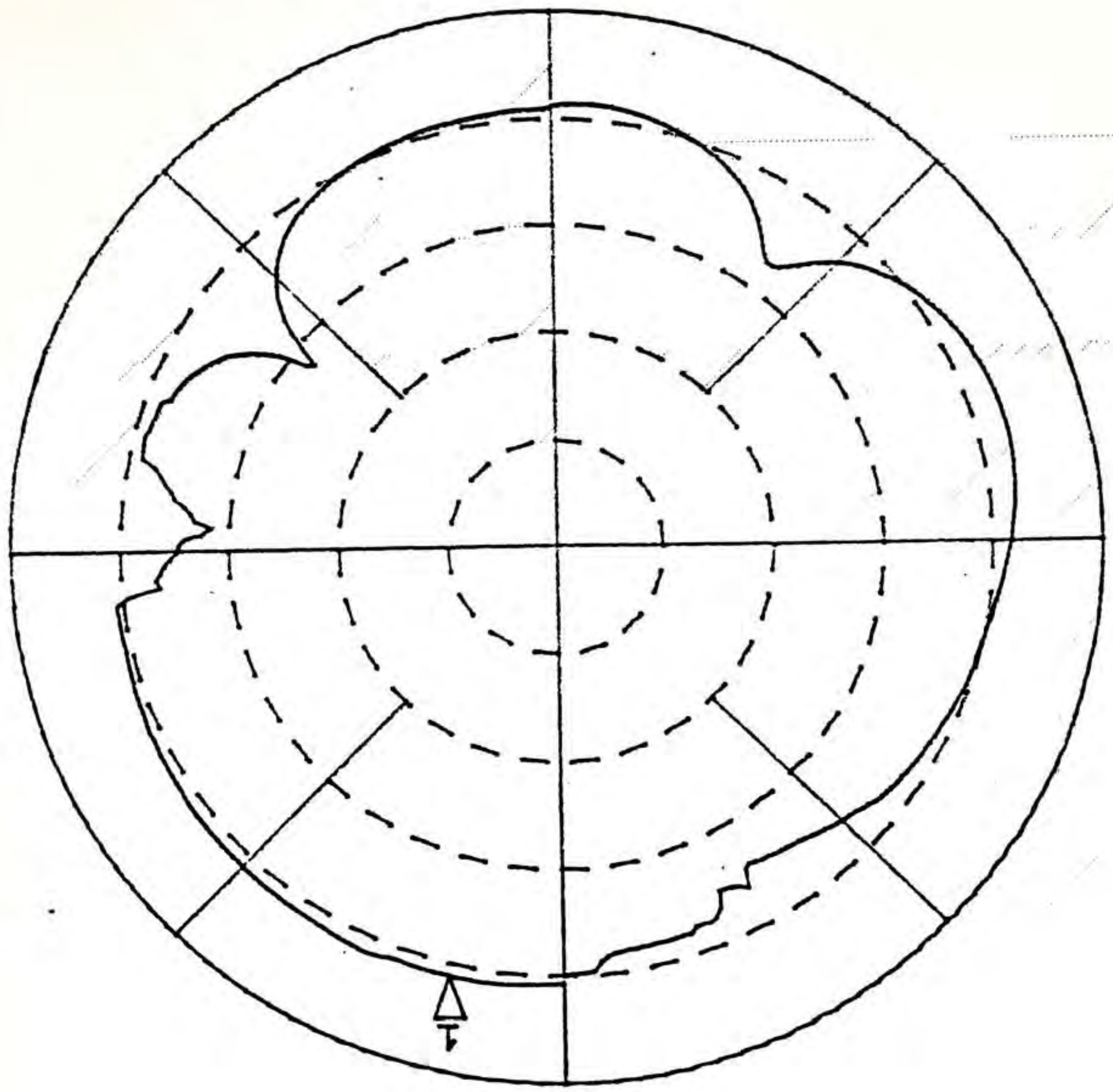


Fig. 3.9 E_ϕ component in X-Y plane



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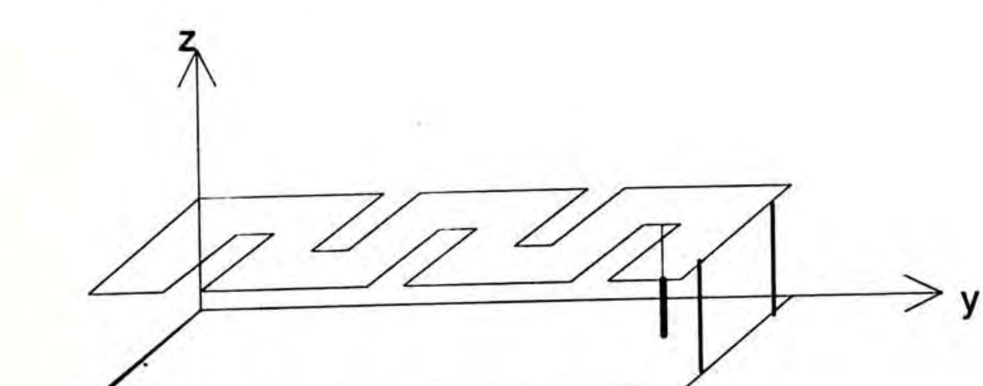
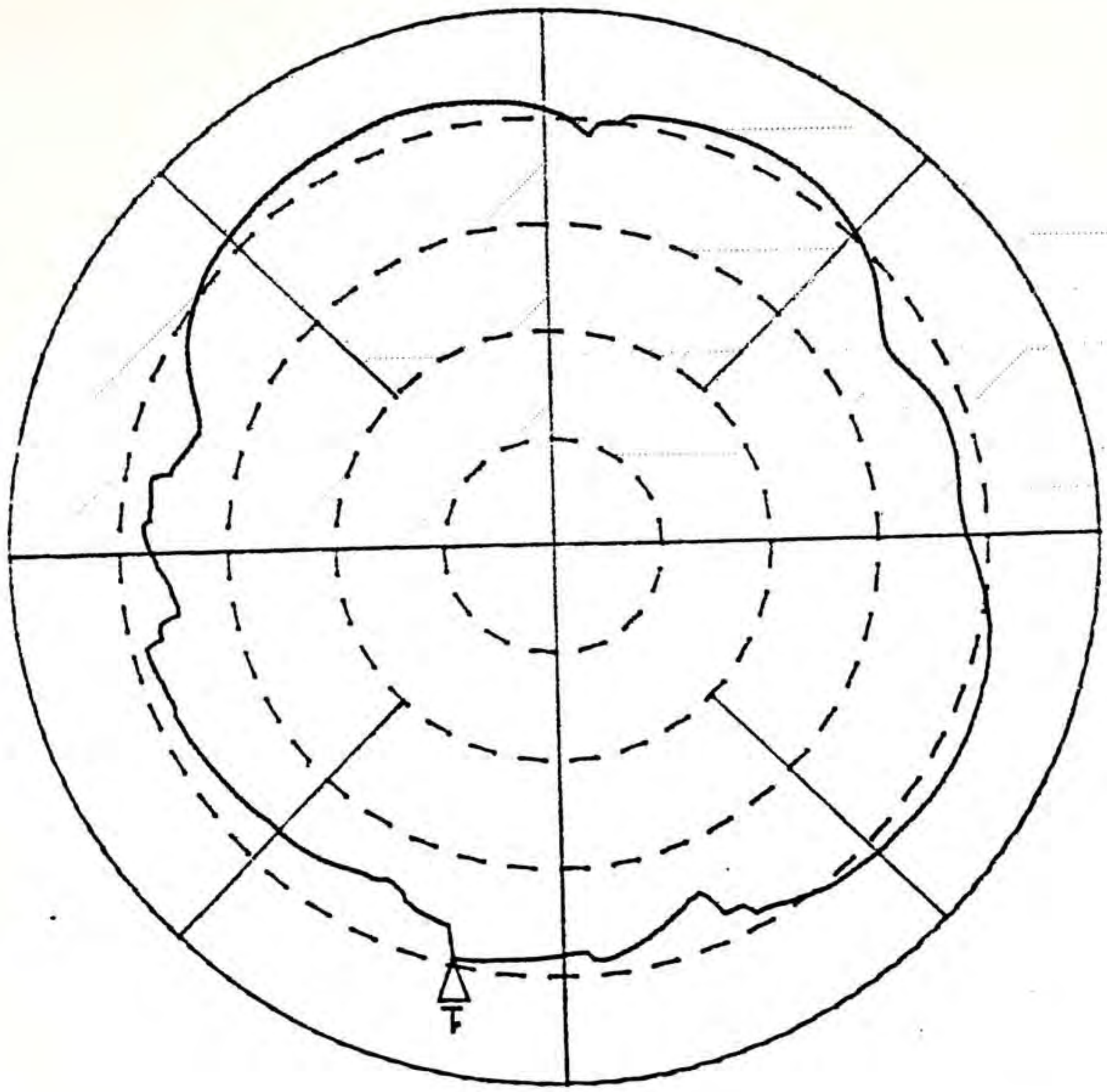


Fig. 3.10 E_θ component in X-Z plane



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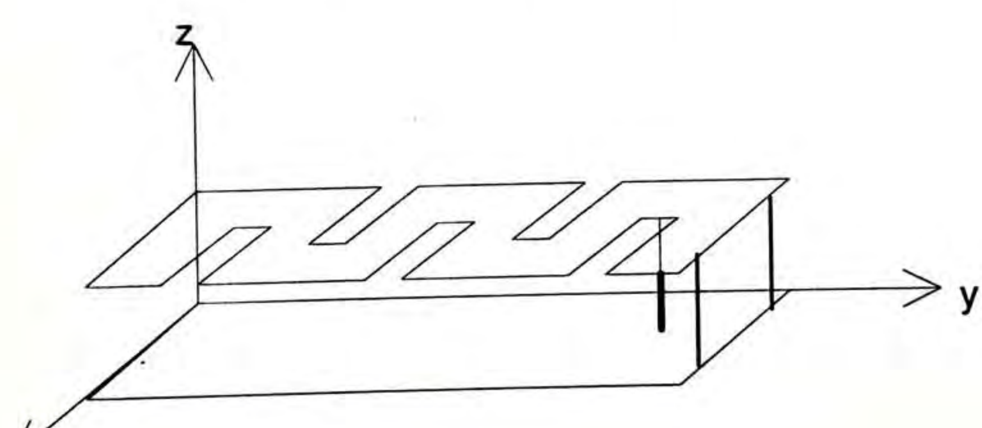
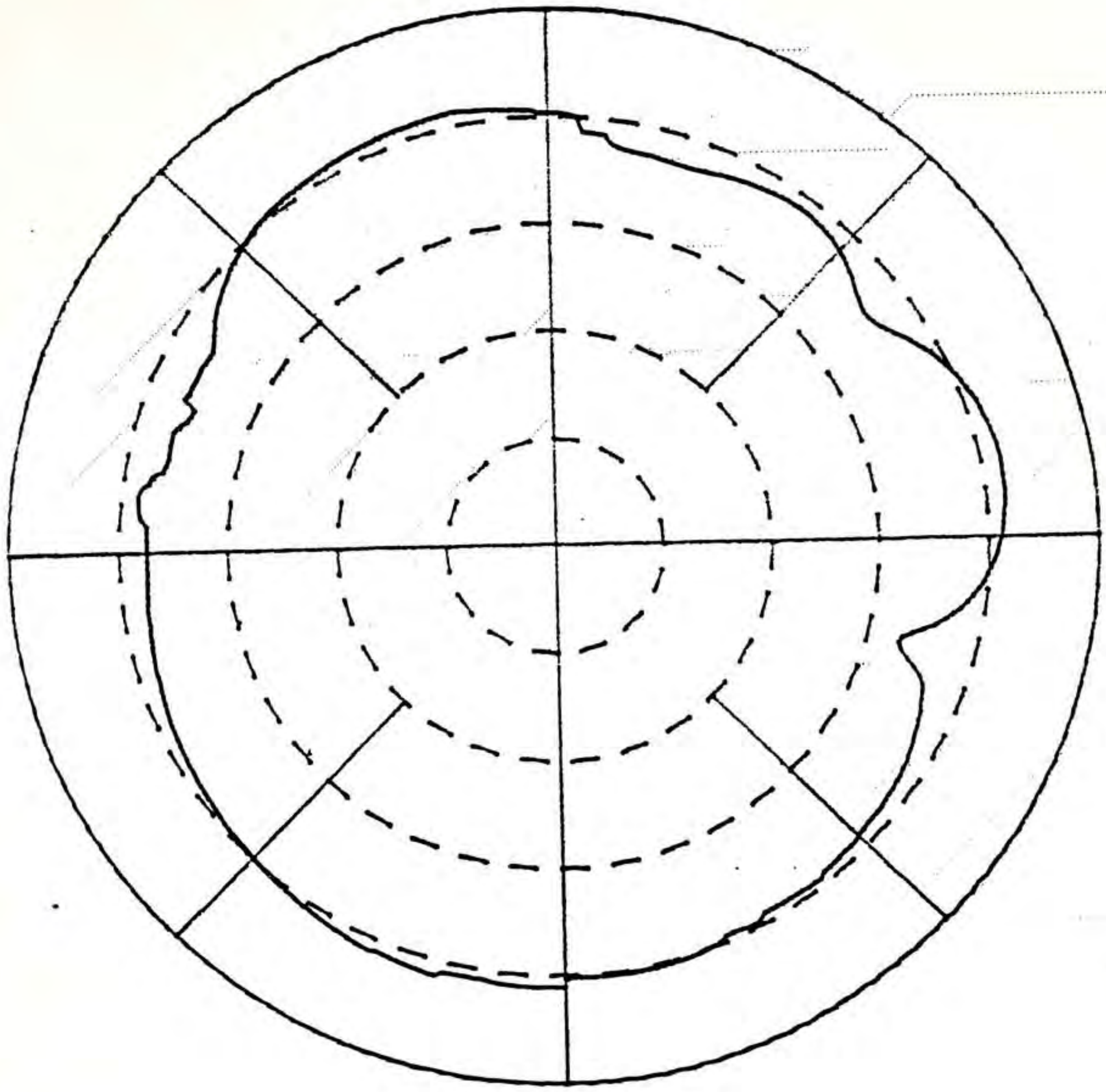


Fig. 3.11 E_ϕ component in X-Z plane



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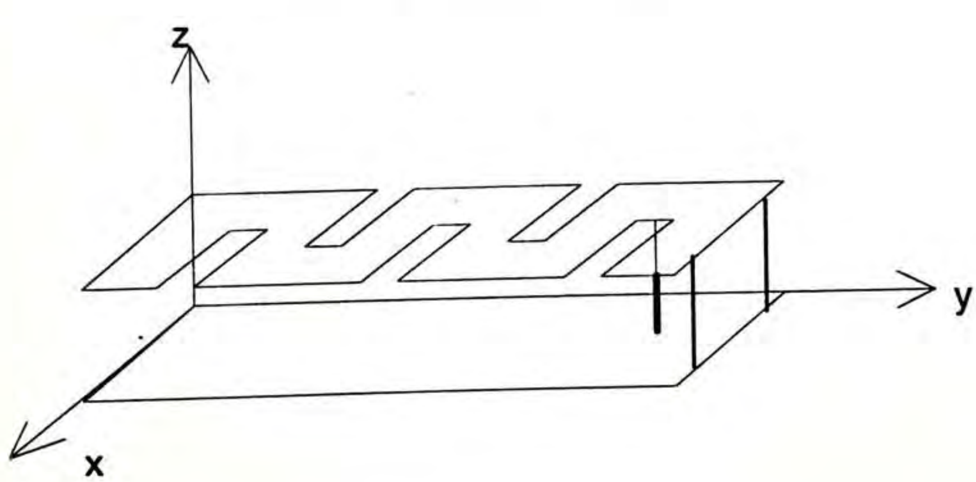
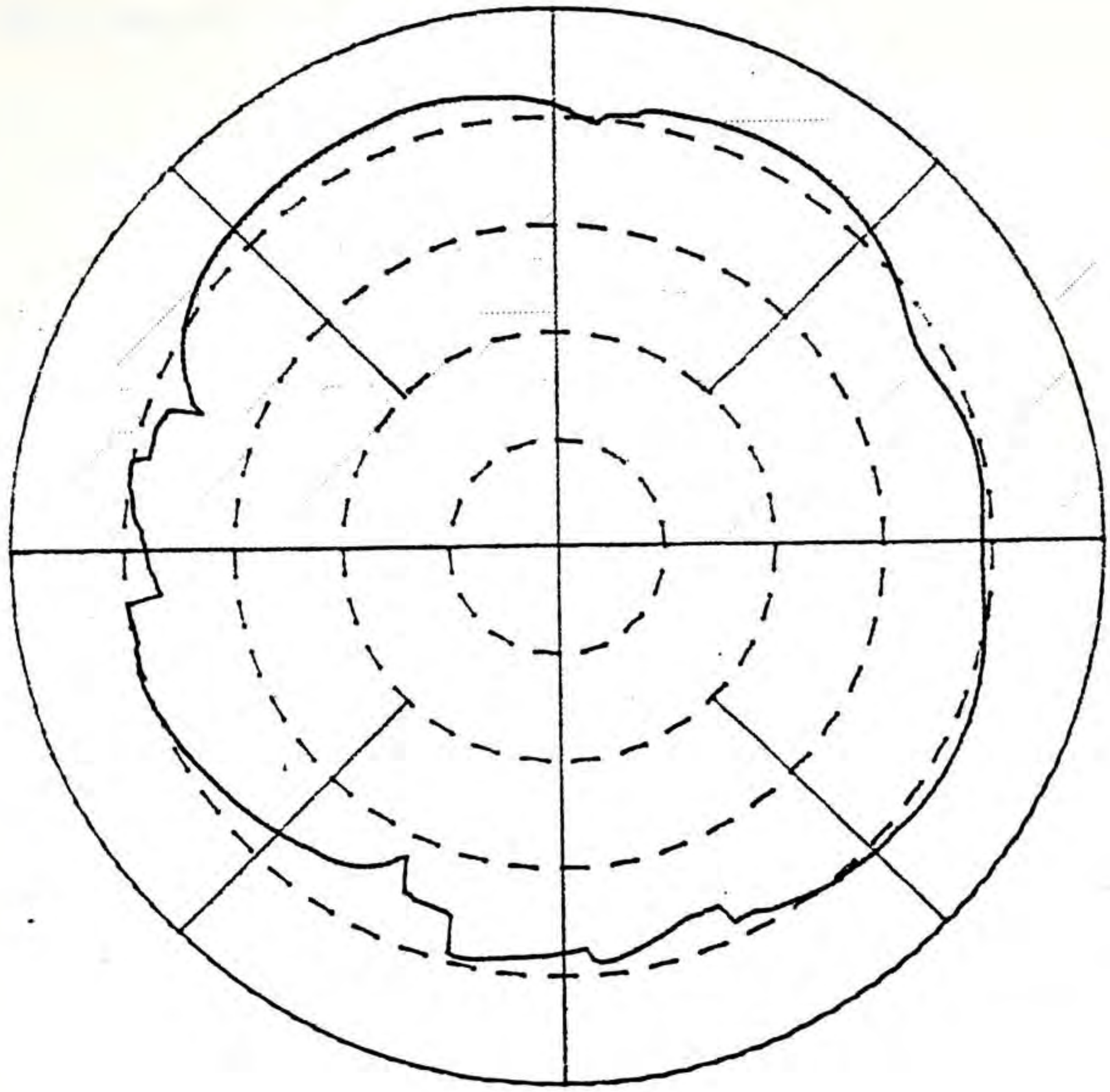


Fig. 3.12 E_θ component in Y-Z plane



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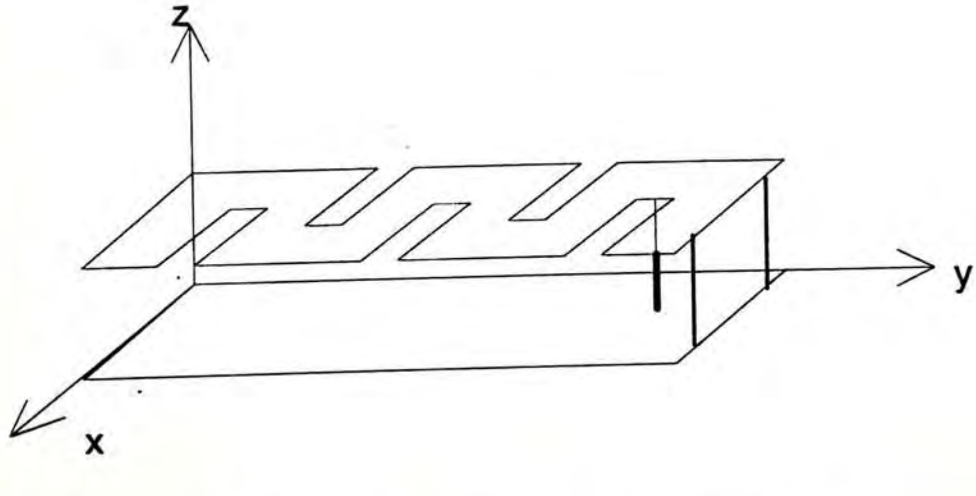

Fig. 3.13 E_ϕ component in Y-Z plane

3.4. Physical realization

When a design has been analyzed and optimized, one of the most critical parts of the design process must still be carried out : its physical realization. Before moving on to the photolithographic process, one must draft the pattern of the upper conductor, and then cut the mast.

A commercial CAD system [3.8] is used to layout the microstrip lines accurately as defined by their physical dimensions. The layout is then used to generate photo films. A photosensitive lacquer is deposited on RT/Duroid 5870 laminate. Several processes may be used to do this :

(a) Dipping : the PCB is entirely dipped into the lacquer, and then pulled out at a constant speed. The thickness of the layer depends on the withdrawal speed and on the viscosity of the photoresist. This process generally yields rather thick layers, with a bulge on the lower edge.

(b) Spraying : The photoresist is sprayed on the structure through a nozzle. It is difficult to obtain a constant thickness in this manner.

The photographic mask is then exposed to ultraviolet radiation. By developing in a suitable chemical, either the UV-exposed part of the photoresist layer (positive photoresist) or the non exposed part (negative photoresist) is removed. The unwanted metal is removed by etching. The laminate is exposed to an acid that dissolves the metal but does not affect the remaining photoresist.

When the previous steps have been carried out, the remaining photoresist is removed by a concentrated alkaline solution.

The techniques described realize `thin film' circuits, practically used for most microwave circuits. The `thick film' approach, in which a paste is deposited through a silk screen, is not accurate enough for high frequency circuits.

The vertical short circuit elements can be realized by drilling via plate through holes at the end of the microstrip line to the ground plane as depicted in Figure 3.14.

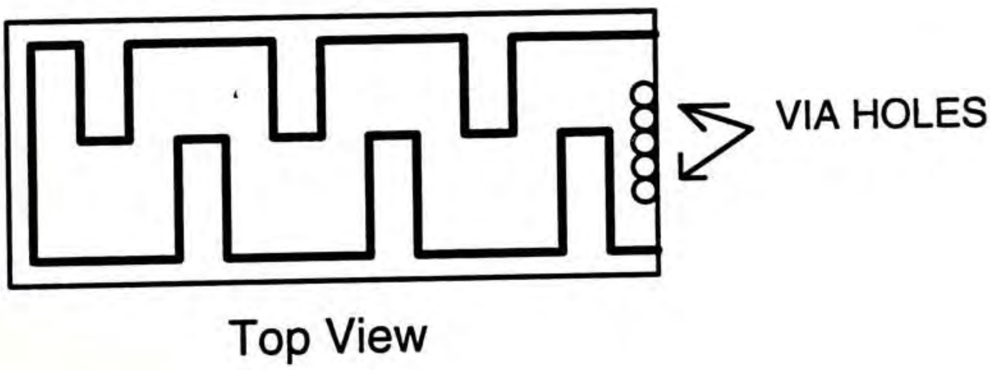

Fig. 3.14 Realization of short circuit element by via plate through holes

3.5 Summary

Meandering posted microstrip antennas with one end electrically shorted are constructed and tested. The antenna gives excellent VSWR at 900MHz band. Although its bandwidth is only 0.85% of the centre frequency, the antenna is suitable for the 2nd generation cordless phone (CT-2) which requires only 4MHz bandwidth. The far-field radiation patterns of the antenna are approximately omni-directional and are sensitive to both vertical and horizontal polarizations. This feature makes the antenna very suitable for mobile communications.

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Chapter 4

Conclusions

This thesis has been devoted to the design of small antennas for mobile communications. Different types of small antennas has been constructed and tested which are aimed at the objectives : small, low profile, compact, low cost and easy to manufacture. The frequencies of interest includes 900MHz band antennas for applications in cellular handheld phones such as GSM (890, 935MHz), indoor cordless telephones such as the European CT1+(886, 931MHz) and 1.9GHz band antennas for applications in the 1.89GHz Digital European Cordless Telecommunications (DECT).

Starting with the inverted-F antenna, a small and low-profile meandering inverted-F antenna has been developed. The antenna performs with excellent VSWR at 900MHz band. Its omni-directional radiation properties and its sensitivity to both vertical and horizontal polarizations makes the antenna very attractive for mobile communications.

Starting with the first prototype, the antenna characteristics are studied through numerous experiment on different size and different dimensions of the antenna. Dielectric load help to decrease the size of the antenna further. Reinforced plastic has been used as a substrate, which low down the resonant frequency of the antenna from 1GHz to about 850MHz. These studies lead to empirical results which are useful for further investigation on the antennas.

With the meandering inverted-F antenna as a foundation, the concepts has been applied to printed circuit antenna. That becomes the meandering posted microstrip antenna. Meandering Posted Microstrip Antennas with dimensions ≈ $\lambda/10$ are constructed and tested. This kind of microstrip antenna presents good performance in narrow band mobile radio applications. It is the smallest antenna among the other designs.

Analytical techniques such as finite difference methods and wire-grid model may be used to formulate the design procedures of the antennas. Finite difference method is particularly useful in analyzing microstrip structures. Wire-grid model is an appropriate method for analyzing antenna characteristics mounted on metal cases with dimensions comparable to wavelength.

Finally, the author hopes that this work will contribute to the design of small antennas for mobile communications equipment.