Design of a Miniaturized Microstrip Antenna

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Nomenclature

Z_0 : Characteristic impedance

Z_{oe} : Even-mode characteristic impedance

Z_{oo} : Odd-mode characteristic impedance

Y_0 : Characteristic admittance

Y_{oe} : Even-mode characteristic admittance

Y_{oo} : Odd-mode characteristic admittance

θ : Electrical length

ω : Angular frequency

C : Capacitance

L : Inductance

S : Scattering parameter

B : Amplitudes of the scattered waves

T : Transmission coefficient

Γ : Reflection coefficient

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Abstract

With the rapid development of wireless communication technology, wireless communication terminals began to miniaturization and multi-direction. As wireless communications' import and export, antenna has a large affects on the performance of wireless communication systems. In most cases, the size of the wireless communication terminal is mainly determined by the size of the antenna.

This paper shows some methods for how to decrease the size of microstrip antenna. Especially, the method which is using the combination of parallel end-shorted coupled lines and capacitor is detail described. It is proven that antenna is fabricated with capacitive loading to reduce the resonant frequency of antenna, which is similar to reduce the size of antenna, and using parallel end-shorted coupled lines can also reduce the size of antenna. The antenna is fabricated on the FR4 epoxy glass cloth copper-clad PCB substrate having thickness 0.8mm and the dielectric constant is 4.4. The size of antenna is 28mm*14mm, and the center frequency is 1GHz. Simulated and measured results show that the return loss is greater than 15dB.

CHAPTER1 Introduction

In wireless systems, the antenna is the import and export of an electromagnetic wave. When as a receiving antenna, it is responsible for capturing the energy of electromagnetic which in the free space and changing to the time-varying current. When as a transmitting antenna, it is responsible for the time-varying current's radiating which is in the form of electromagnetic waves. Therefore, the antenna performance has a direct impact on the performance of the entire system.

With the development of wireless communication technology and the increasing emergence of a variety of communication standards, The function of wireless products is more and more complex, generally able to support multiple bands of different communication standards. The internal circuit of the wireless products also more complex. The space reserved for the antenna is less and less in the wireless terminal design, And to the functional requirement of the antenna become more and more. There is a wide variety of wireless products on the market, users have more options when choosing products. User not only satisfied with its performance to the requirement of wireless products, at the same time also to the appearance of products have higher requirements. Most users tend to buy the wireless products which are small volume and easy to carry. So both in technology and market , the wireless devices need to miniaturization. The height of the integrated circuit can keep up with the demand of wireless device miniaturization, the volume of the antenna is often become the bottleneck of wireless products volume reduction. Currently, Miniaturization, multiband and broad band are the important trend of the development of antenna design.

the thickness of the microstrip antenna dielectric substrate is small when compared with the wavelength, thus it itself implements one-dimensional miniaturization, into the category of electrically small antenna. Since microstrip line was proposed as a radiation device by DeschamPs,G,A in 1953, Microstrip antenna is widely used in wireless communication field because of its low profile, low weight, small volume and simple manufacturing. Such as used as the unit of aircraft conformal antenna array antenna and built-in antenna of the mobile phone. The traditional microstrip antenna is half wavelength structure, the practical application of the antenna need a smaller size. At the same time, the development of microwave integrated technology and the birth of a variety of materials of high performance, has prompted the miniaturization of microstrip antenna become one of the research hot in recent years.

1.1 The Concept And Characteristics Of Microstrip Antenna

Giving the microstrip antenna a complete definition is difficult[1-5]. Microstrip antenna can be divided into round, rectangular, circular, triangular, five angle etc based on the shape. According to the principle can be divided into resonant (standing wave) and non-resonant (traveling wave) microstrip antenna. Resonant microstrip antenna has a specific size, generally only work near the resonant frequency. However, the non-resonant microstrip antenna doesn't have the resonant size limit, and need to add matching load at the end of it to ensure the transmission of traveling wave. the microstrip antenna can be divided into three categories According to the structure characteristics: Microstrip patch antenna, slot antenna and microstrip travelling wave antenna.

Microstrip patch antenna is a kind of antenna that using a thin dielectric-slab, and attaching a thin layer of metal on one side of the dielectric-slab as the ground floor, making a metal patch on the other side by lithography and etching method, and feeding the patch by microstrip line or coaxial-cable. The shape of the patch can be rectangle, circle, triangle, five angle shape or other shapes. The rectangular and circular microstrip antenna is the most common. Microstrip slot antenna is constituted by microstrip feed and aperture on the floor. The shape of the slot is similar to the shape of microstrip patch, it can be rectangular (wide or narrow), circular or ring. Its main characteristic is to produce double or single directional diagram. Travelling wave microstrip antenna is composed of a substrate, the chain cycle structure on one side of substrate and the floor on the other side of substrate. At the end of the TEM wave transmission lines matched load, when antenna keeps travelling wave, it can be made the main bean shoot to any direction.

In general, Microstrip antenna working in the frequency from 100MHz to 1000MHz. Special microstrip antennas can be used in the 10Hz. Compared with the commonly used microwave antenna, microstrip antenna has the following advantages: small size, light weight, low profile, low manufacturing cost, easy batch production, can be achieved linear polarization and circular polarization by using Simple feed, easy to make double-frequency and dual-polarization antenna, feeder line and matching network can be manufactured with antenna structure. However, compared with conventional microwave antenna, the microstrip antenna also has some limitations: narrow band and associated tolerance problem, low gain, The high ohmic losses in feed array structure, the majority of the microstrip antenna radiation into the air, high performance array needs complex feed structure, The polarization purity is difficult to achieve, the additional radiation from the feed source and junction， low power capacity, using high dielectric constant substrate leads to the cross polarization and a narrow bandwidth.

we need to make the antenna smaller. Therefore, in this thesis, we introduce some methods to make the antenna smaller. And fabricate the antenna which is using the combination of parallel end-shorted coupled lines and capacitor.

1.2 organization of the thesis

The contents of the thesis are as follows:

Chapter 1 depicts the background and purpose and methods of how to reduce the size of antenna and the concept and characteristics of microstrip antenna.

Chapter 2 depicts some methods which can reduce the size of antenna.

Chapter 3 displays the simulated results by HFSS software and the experimental and measured results of fabricated antenna.

Chapter 4 is the conclusion of this research.

CHAPTER2 Miniaturized technology of microstrip antenna

The microstrip antenna has many advantages, for example, a low profile, easy manufacture, easy to design structure and many other advantages, A compact microstrip antenna achieved more and more attention and research.

Which work should be done of microstrip antenna miniaturization is reduce the size of microstrip antenna in fixed frequency. With the rapid development of mobile communication, various of microstrip antenna miniaturization methods appear. The main method is in the following: The short circuit loading technique can effectively reduce the size of the antenna in the fixed frequency. The design of the planar inverted F antenna and the planar inverted L antenna. Using The high dielectric constant substrate. Using meandering method which including patch meandering method and floor meandering method. And the method which we used to fabricate the antenna, this method is using the combination ofl parallel end-shorted coupled lines and capacitor.

2.1 Loading technique of microstrip antenna

The size of the antenna can be reduced effectively by loading. For half wave structure of the rectangular microstrip antenna, the current of the antenna form the standing wave between an open end and another open end, so there is a zero potential line between the two open end. If letting the place of zero line connect to the ground which become the short circuit, the standing wave structure which from the open circuit to short circuit will be formed, the result of this mothed is the antenna size can be reduce by half.

the main methods of microstrip antenna loading: Short circuit loading, resistive loading.

There are three commonly used methods of short circuit loading: shorting-wall loading, shorting-plate loading, shorting-pin loading. Fig.2.1 describes the Rectangular microstrip antenna structure of these three methods.

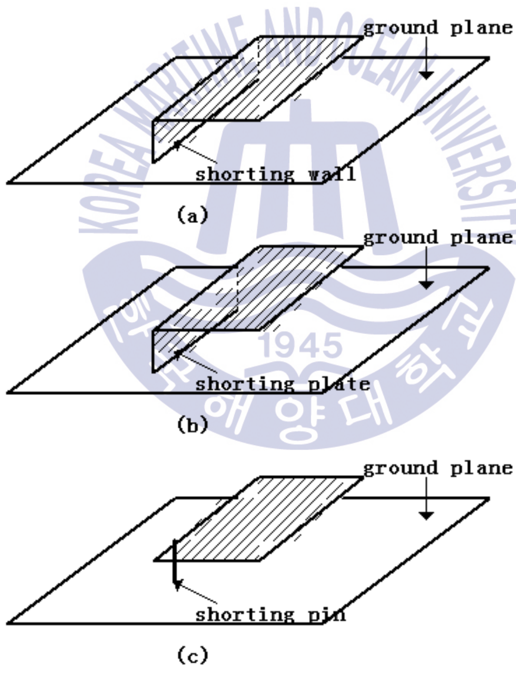


Fig 2.1 Rectangular microstrip antenna structure of short circuit loading

The Fig 2.1(a) is the microstrip antenna of shorting-wall loading. This is the antenna with the 1/4 wavelength structure. Compare with the rectangular microstrip antenna of half wave structure, Rectangular microstrip antenna with shorting-wall loading reduce half length. Fig 2.1(b) is the Rectangular microstrip antenna with shorting-plate loading. Fig 2.1(c) is the Rectangular microstrip antenna with shorting-pin loading. This two kings of structure is similar, the different of them is only the width of the short circuit structure.

There is a literature introduction that the resonant frequency of the circular microstrip antenna and the rectangular microstrip antenna which with short-pin loading is 1/3 of the antenna without loading. In the other words, for a fixed frequency, the size of the antenna is reduced by 89%[6][7]. Another literature introduction the size of the equilateral triangle microstrip antenna which with a shorting-pin loading was reduced by 94%[8].

2.2 Increase of dielectric constant

Generally, Microstrip antenna has a half-wave structure. the basic operating mode is TM_{10} or TM_{01}. For example, the rectangular microstrip antenna, For the rectangular microstrip antenna which using the thin substrate(h<<λ_g), The resonant frequency can be obtained by the formula:

$$f_r \cong \frac{c}{2L\sqrt[2]{\varepsilon_r}} \qquad (2.2.1)$$

c: The speed of light in vacuum L: The length of the rectangular patch ε_r: The dielectric constant of the substrate materials

From the formula (2.2.1), we can know that the resonant frequency f_r is inversely proportional to $\sqrt[2]{\varepsilon_r}$, So for a fixed frequency, using the high dielectric constant substrate can effectively reduce the size of the antenna.

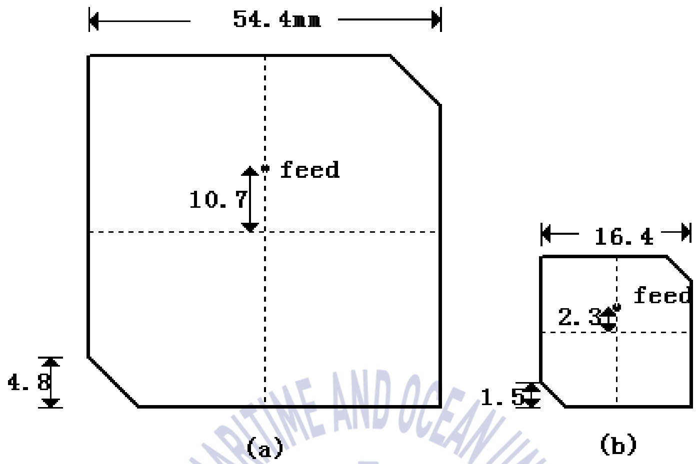


Fig 2.2.1 Different size of GPS antenna when using different dielectric constant substrate

Fig 2.2.1 is the microstrip antenna which used for GPS receiver's circular polarization angle[9]. (a) and (b) using the substrate materials with different dielectric constants, operating frequency of the antenna is the same 1575MHz. (a) is using the common microwave dielectric material $\varepsilon_r = 3.0$, h=1.524mm. (b) is using ceramic materials $\varepsilon_r = 28.2$, h=4.75mm. Antenna b adopted a thicker material than the antenna a in order to ensure enough circularly polarized bandwidth of antenna.

We can know form the Fig 2.2.1, the area of antenna b is only 10% of antenna a. This is the same of the calculation result of formula (2.1). So in a fixed frequency, using the ceramic substrate material instead of the common substrate material, the size of the antenna can be reduced 90%.

Thus, the high dielectric constant substrate is an effective antenna miniaturization method. But the high dielectric constant will decrease the antenna efficiency.

2.3 Meandering technology

Microstrip antenna meandering technology including patch meandering and the ground plane meandering.

Patch of meandering technology refers to the antenna miniaturization technology which through the excitation current path of patch which on the bent antenna surface. Through the slot method can make the current path on the surface of conventional shape patch antenna bending. This increases the effective length of the antenna patch, thus decrease the resonance frequency.

With the rectangular microstrip patch antenna as an example, Fig.2.3.1 draw a current distribution on surface of slot patch[9]. This figure show a rectangle patch that insert into the slit in its non-radiative edge. From this figure, we can see that the currents on the antenna surface are effective bending. So the effective length of current path which on the size fixed rectangular patch. The resonant frequency of the antenna will be a significant decrease. For a fixed frequency, the size of the antenna can be effectively reduced.

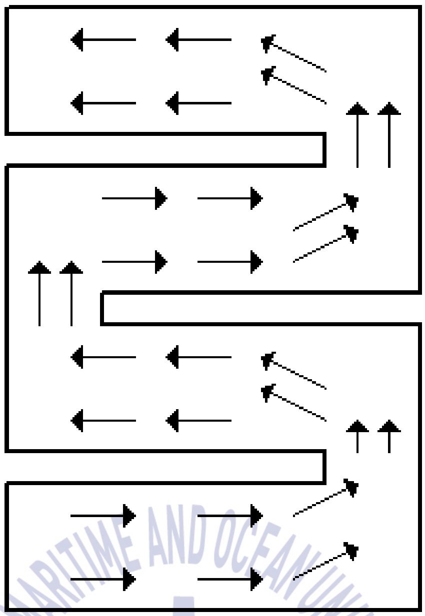


Fig 2.3.1 Schematic diagram of a rectangular microstrip patch antenna with the meander

The ground plane meandering technology refers to the antenna miniaturization technology which through slotting on the ground floor to realize the changing of current path. Slotting in the ground floor can reach the same effect with slotting in the patch. Keeping the shape of the antenna patch, slotting in the ground floor, can leed to the bending of the current on the patch. This can increase the effective length of the current path, reduce the resonant frequency. At the same time, because of the ground floor slotting caused a decrease in Q values of the microstrip antenna, bandwidth of antenna will increase accordingly.

If combine the loading technology and meandering technology effectively, the effect of the miniaturization of antenna is better. There are some references introduce that using the slotting and loading shorting pin method at the same time in the circular microstrip patch can greatly reduce the size of the antenna.[10]

2.4 Using the structure of PIF and PIL

Planar inverted F antenna(PIFA) and Planar inverted L antenna(PILA) Can be regarded as the microstrip antenna with air medium. PIFA can be regarded as the folding of the PILA. PIFA and PIAL has the advantages of small volume, wide band, high efficiency and so on. They can be viewed as a typical antenna which using the thickness of the substrate, low dielectric constant, short loaded . This can also realize the miniaturization of the antenna.

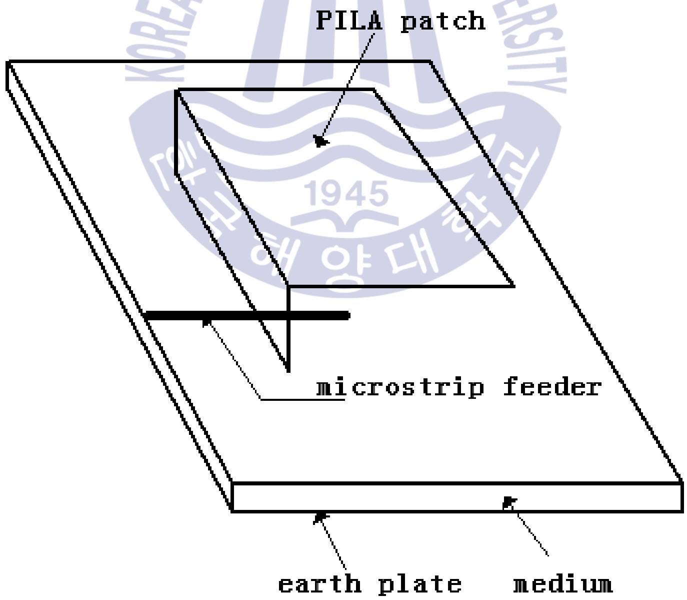


Fig 2.4.1 the FILA of microstrip line feeding

Fig 2.4.1 is the sketch map of PILA of the Microstrip line feeding[9]. The height of the antenna is less than $\lambda_0/10$, the PILA has strong radiation at $\lambda_0/4$, in order words, PILA can work in the 1/4-wavelength when keeping the same radiation characteristics with the ordinary half-wave radiation microstrip antenna. Thus, make the structure of the antenna reduce to 50% of the common antenna when keeping the frequency unchanged.

2.5 Using the end-shorted coupled lines

Using the end-short coupled lines instead of general patch can reduce the size of antenna. The size-reduction of the end-shorted coupled line is done here through a series of equivalent circuit transformation.

Firstly, $\lambda/4$ transmission line can be equated to a combination of lumped inductor and capacitors. Fig 2.5.1(a) and Fig.2.5.1(b) show it. The value of the capacitors can be know by comparing the ABCD matrices of the two circuits in the Fig2.5.1.

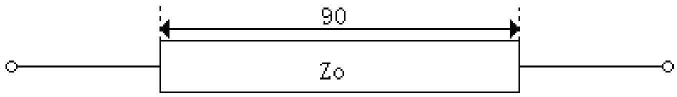
$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 0 & jZ_0 \\ j/Z_0 & 0 \end{pmatrix} \tag{2.5.1}$$

$$\begin{pmatrix} A' & B' \\ C' & D' \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ jwC_1 & 1 \end{pmatrix} \begin{pmatrix} 1 & jwL \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ jwC_1 & 1 \end{pmatrix}$$

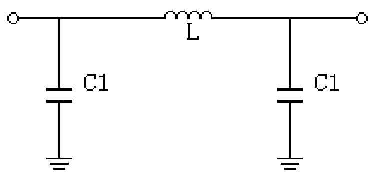
$$= \begin{pmatrix} 1 - w^2 C_1 L & jwL \\ jwL + jwC_1 - jw^3 C_1^2 L & 1 - w^2 C_1 L \end{pmatrix} \tag{2.5.2}$$

making $1 - w^2 C_1 L = 0$ and $jZ_0 = jwL$, we can calculate

$$C_1 = \frac{1}{wZ_0} \tag{2.5.3}$$



(a)



(b)

Fig 2.5.1 (a) the $\lambda/4$ transmission line; (b)distributed and equivalent lumped elements.

Then, replace the lumped inductor like Fig 2.5.2

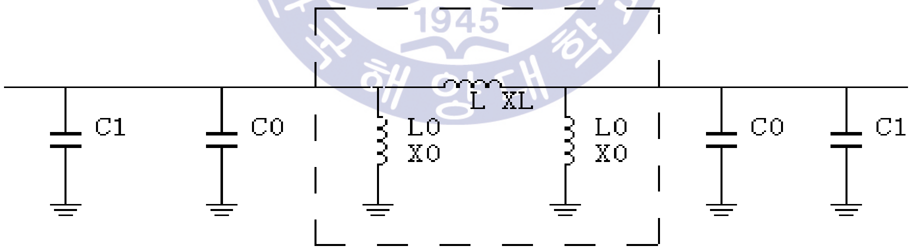


Fig 2.5.2 Equivalent circuit

The ABCD matrix of the dashed box PI network is :

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1+\dfrac{X_0}{X_L} & \dfrac{1}{X_0} \\ 2X_0+\dfrac{X_0^2}{X_L} & 1+\dfrac{X_0}{X_L} \end{pmatrix} \quad (2.5.4)$$

X_0=shunt impedance X_L=series impedance

Now, let's firstly look at Fig 2.5.3, that is an end-short couple line and its equivalent PI network.

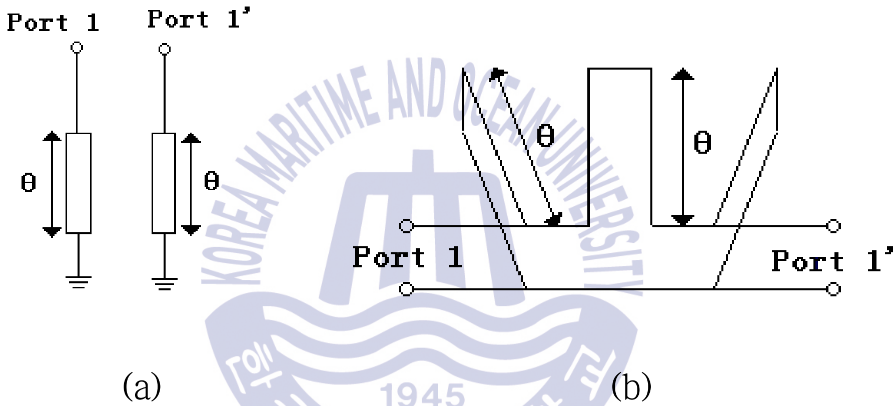


Fig 2.5.3 The end-shorted coupled lines(a) equivalent PI network (b)

The ABCD matrix of this PI network is:

$$\begin{pmatrix} A' & B' \\ C' & D' \end{pmatrix} = \begin{pmatrix} 1+\dfrac{Z_{0e}\tan\theta}{\dfrac{2Z_{0o}Z_{0e}}{Z_{0e}-Z_{0o}}tan\theta} & \dfrac{1}{j\dfrac{2Z_{0o}Z_{0e}}{Z_{0e}-Z_{0o}}tan\theta} \\ 2jZ_{0e}\tan\theta+\dfrac{jZ_{0e}^2\tan^2\theta}{\dfrac{2Z_{0o}Z_{0e}}{Z_{0e}-Z_{0o}}tan\theta} & 1+\dfrac{Z_{0e}\tan\theta}{\dfrac{2Z_{0o}Z_{0e}}{Z_{0e}-Z_{0o}}tan\theta} \end{pmatrix} \quad (2.5.5)$$

Z_{0e}=even-mode impedance Z_{0o}=odd-mode impedance θ=electrical length

Based on the equation (2.5.4) and (2.5.5), if the equations(2.5.6) and (2.5.7) are satisfied. Then the PI network in the dashed box of the Fig 2.5.2 would equal to the PI network in the Fig 2.5.3(b).

$$1+\frac{X_0}{X_L}=1+\frac{Z_{0e}\tan\theta}{\frac{2Z_{0o}Z_{0e}}{Z_{0e}-Z_{0o}}tan\theta} \qquad (2.5.6)$$

$$\Downarrow$$

$$X_0=Z_{0e}\tan\theta$$

$$\frac{1}{X_L}=\frac{1}{j\frac{2Z_{0o}Z_{0e}}{Z_{0e}-Z_{0o}}tan\theta} \qquad (2.5.7)$$

$$\Downarrow$$

$$X_L=\frac{2Z_{0e}Z_{0o}}{Z_{0e}-Z_{0o}}tan\theta$$

According to the equation(2.5.6) and (2.5.7),we can use the end-shorted coupled lines in Fig.3(b) instead of the circuits in the dashed box of the Fig.2.5.2. The circuit is like Fig.2.5.4:

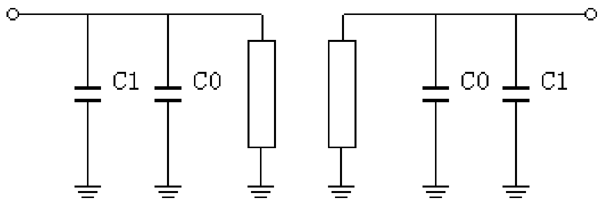


Fig 2.5.4 miniaturized $\lambda/4$ line with lumped capacitors and end-shorted coupled lines

Where $$C_0 = \frac{1}{wZ_{0e}\tan\theta} \quad (2.5.8)$$

We always use one capacitor C which is equal to the sum of C_0 and C_1,so the value of C is :

$$\begin{aligned} C &= C_0 + C_1 \\ &= \frac{1}{\omega Z_0} + \frac{1}{\omega Z_{0e}\tan\theta} \end{aligned} \quad (2.5.9)$$

Z_0=characteristic impedance of the $\lambda/4$ transmission line

Then, we can get the final circuit link Fig.2.5.5

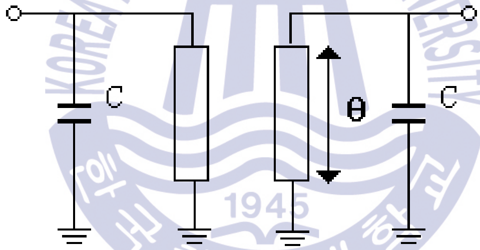


Fig 2.5.5 miniaturized $4/\lambda$ transmission line with capacitor C

Let's define the characteristic impedance of the end-shorted coupled lines as $Z' = \frac{2Z_{0e}Z_{0o}}{Z_{0e} - Z_{0o}}$ (2.5.10)

we can get

$$Z' = X_L \cot\theta \quad (2.5.11)$$

and $X_L = Z_0$,than

$$Z' = \frac{2Z_{0e}Z_{0o}}{Z_{0e} - Z_{0o}} = \frac{Z_0}{\tan\theta} \qquad (2.5.12)$$

With this method, the $\lambda/4$ transmission line can be made to be as short as a few degrees, resulting in a very compact circuit. the impact related to be imprecise inductor value has been eliminated since only lumped inductor is utilized.

CHAPTER 3 Design Simulation, Fabrication and Measurement

This chapter introduces the design procedure of a compact microstrip antenna. According to the above analysis, the couple lines with short electronic length and high characteristic impedance are required for miniaturized microstrip antenna. To validate the analytical results and demonstrate the design approach in a time-efficient way, the circuit parameters are converted to physical antenna structures and simulated by full-wave 3-D EM simulation tool Ansoft HFSS. In order to simplifying the fabrication procedure as easy as can be realized in author's laboratory room, the circuit is implemented on printed circuit board (PCB).

3.1 The Antenna Design

The antenna which we aim to design has the center frequency of 1GHz, and the characteristic impedance is 50Ω. Fig 3.1.1 is the schematic circuit diagram of the antenna.

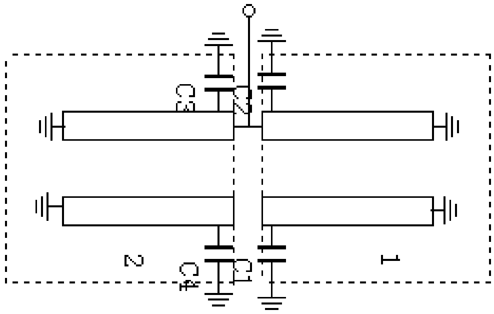


Fig 3.1.1 Circuit structure diagram

This is a shunt circuit, for the input impedance $Z_{IN}=50\Omega$,the characteristic impedance Z_{01} and Z_{02} which are in the dotted box 1 and 2 are all equal to 100Ω. From Chapter 2, we can know that the electrical length should be defined by ourself. there are variety of numerical value of the couple line. So there are many different results of antenna. The following table lists a set of data calculated through formula(2.5.9) and formula(2.5.12) for the interested readers. In this table, a quarter-wavelength transmission line working has been miniaturized to different length from 1 degree to 15 degree. By fixing Z_{oe} at 80 ohm, we can calculate the characteristic impedance of the end shorted coupled lines in dotted box 1 and 2 equal to 373.2Ω, and the odd mode impedance is 56Ω. At last, the lumped capacitor C can be calculate from Equation (2.5.12), $C=9pF$.

Table 1 A set of design at 1 GHz for reference

θ(Deg.)	Z'(Ω)	$Z_{0e}(\Omega)$	$Z_{0o}(\Omega)$	C(pF)
1	5729	80	77.83	115.57
2	2290.95	80	75.76	58.53

3	1908.12	80	73.81	39.55
4	1430.06	80	71.95	30.04
5	1143.00	80	70.18	24.33
6	951.47	80	68.48	20.52
7	814.44	80	66.86	17.79
8	711.54	80	65.31	15.75
9	631.38	80	63.83	14.15
10	567.12	80	62.39	12.87
11	514.46	80	61.02	11.83
12	470.46	80	59.70	10.95
13	433.15	80	58.42	10.21
14	401.09	80	57.19	9.57
15	373.20	80	56.00	9.01

Using the tool LineCala in microsoft Advanced Design System(ADS), we can get the length and width of the end shorted coupled line. Fig 3.1.2 is the calculation results.

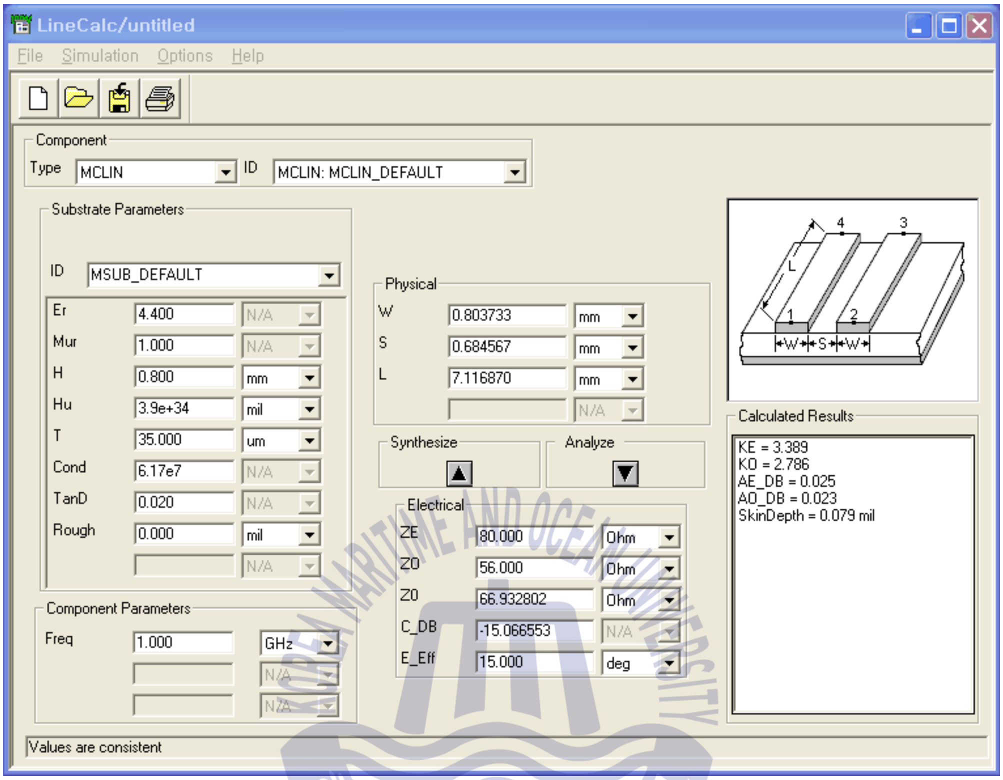


Fig 3.1.2 Detailed value of coupled lines calculated by ADS Linecalc

This microstrip antenna is fed by microstrip feed line. And the value of the feed line can be also calculated by the tool LineCala in the ADS. The calculation result is the width w=1.49mm. For the impedance of microstrip line is only decided by its width and in order to reduce the size of antenna, the length of microstrip line can be decided to h=6.89mm. The structure of the antenna is in the Fig 3.1.3 and the parameter of the antenna is in the Table 2

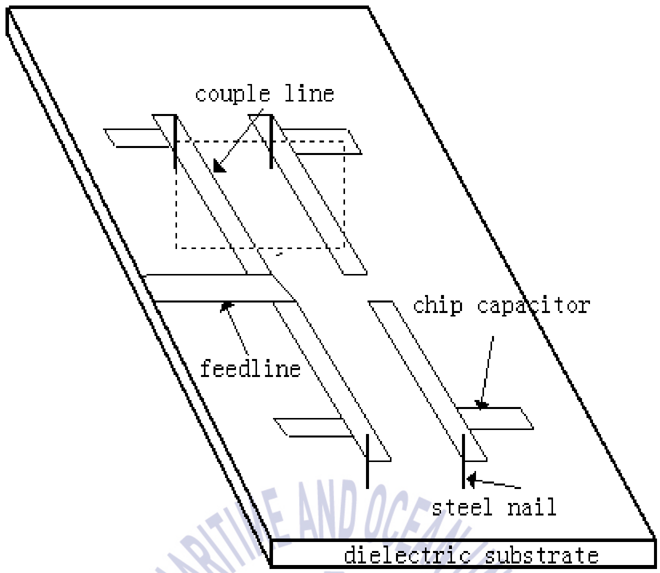


Fig 3.1.3 The structure of the microstrip antenna.

Table 2 The parameter of the antenna

Center frequency	1GHz
Substrate permittivity	4.4
Substrate thickness	0.8mm
Copper thickness	35um
Copper conductivity	6.17×10^7
Dielectric loss tangent	0.02
Length of coupled lines	7.117mm
Width of coupled lines	0.806mm

Slot of coupled lines	0.685mm
Capacitor	9pF
Ports impedance	50Ω
Circuit size	26mm *14mm

3.2 Full-Wave EM Simulation by HFSS and Optimization

HFSS is the industry-standard software for S-parameter and full-wave SPICES extraction and for the electromagnetic simulation of high-frequency and high-speed components. The model of the proposed antenna in HFSS is offered here in Fig 3.2.1

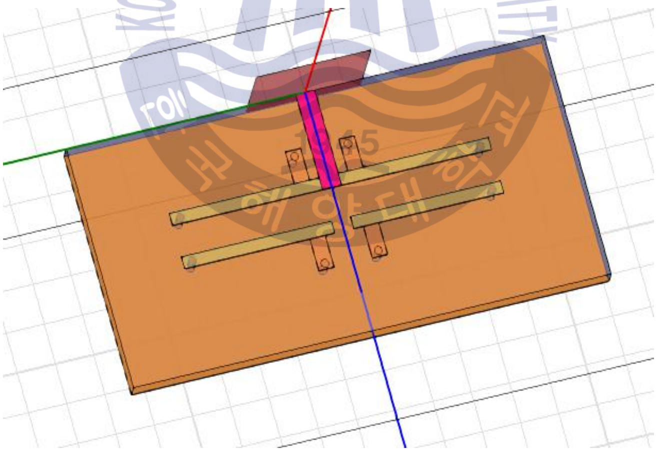


Fig 3.2.1 Microstrip antenna drawing in HFSS

The simulation result is in the Fig 3.2.2. We can find that the coupled line is miss matched. It is necessary to adjust. So this circuit needs a lot of modification before fabrication. This is the most difficult part of the paper, because many factors affects the result, such as capacitor, slot ,length and the width of the end shorted coupled lines, of course the feeding line has the effect to result.

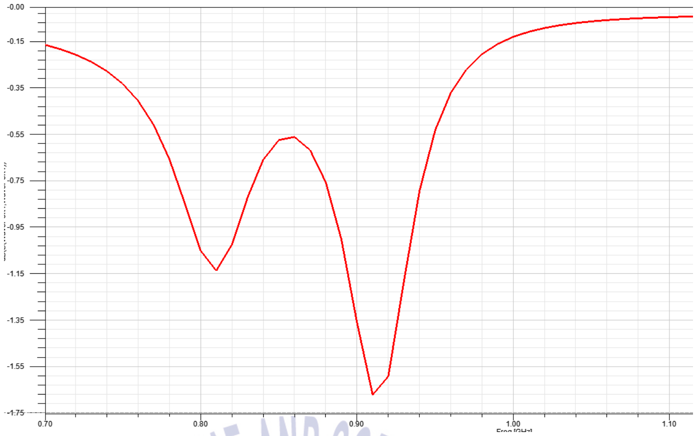
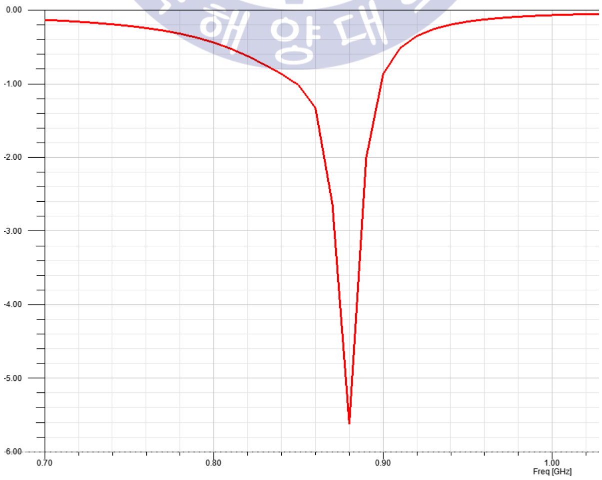
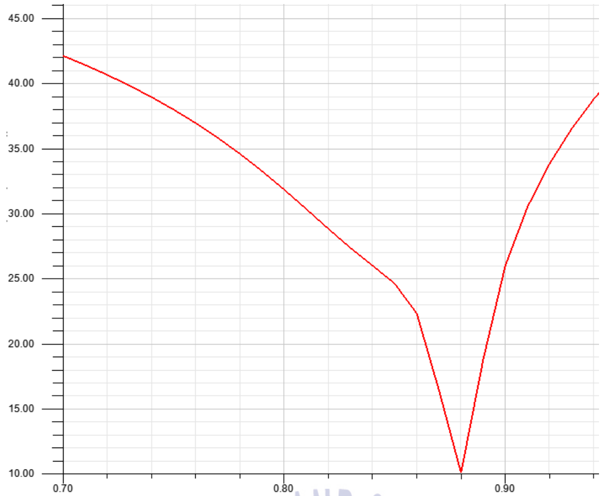


Fig 3.2.2 simulation result of the S_{11}

First of all, we should adjust the distance of the coupled lines. Through adjusting the slot, we can make the coupled line match. After simulating by HFSS, result is coming out. When the slot is more than 1.5mm, the coupled lines is matched. Fig 3.2.3 shows the result when the value of slot is 1.8mm.



(a)



(b)

Fig 3.2.3 (a) simulation result of S_{11} and (b) VSWR

We can find that VSWR=10, and the $S_{11} = 5.5dB$, and the resonant frequency is 0.88GHz. This result is show that the impedance matching is very bad. Then we should adjust the resonant frequency. the resonant frequency has changed to about 0.88Ghz, and the most important factor that affects resonant frequency is the value of capacitor. So I started from modifying capacitor values. According to the calculation results, the capacitor value is 9pF, however, in simulation, the resonant frequency has shifted from 1Ghz to 0.88Ghz, Change some values of the capacitors and finally find when the capacitor value reducing to 6.6pF, the resonant frequency can be moved back to 1Ghz. So capacitors of 6.6pF should be used to achieve a proper resonant frequency instead of theoretical 9pF. The simulation results is shown in Fig 3.2.3.

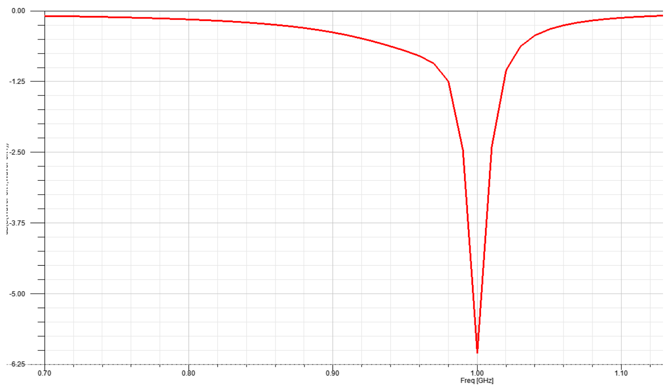
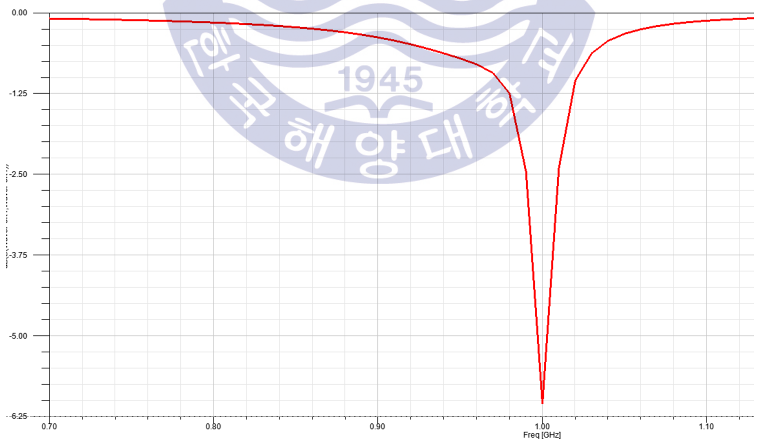
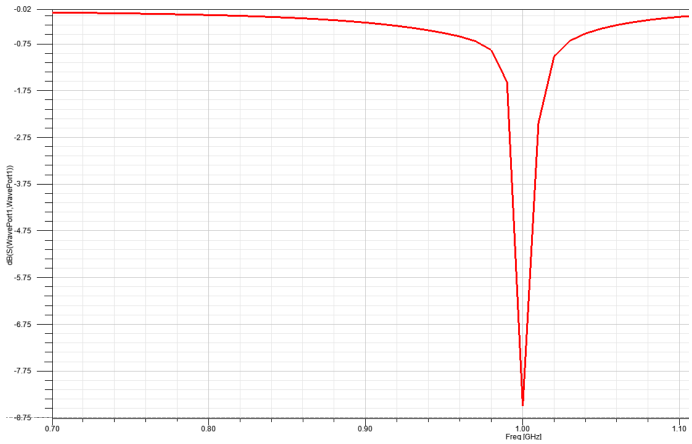


Fig 3.2.3 simulation result of S_{11} when C=6.6pF

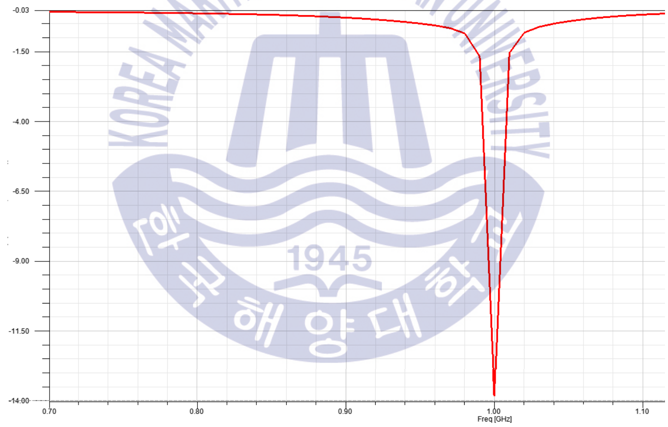
By changing the capacitor, the center frequency become 1Ghz, but the $S_{11} = 6.2dB$, the impedance of the antenna is still very bad which still need to modify. Adjust the advance of the slot can also increase the S_{11} and make the impedance matching. There are three kinds of simulation results are shown in the Fig 3.2.4.



(a) slot is 1.8mm



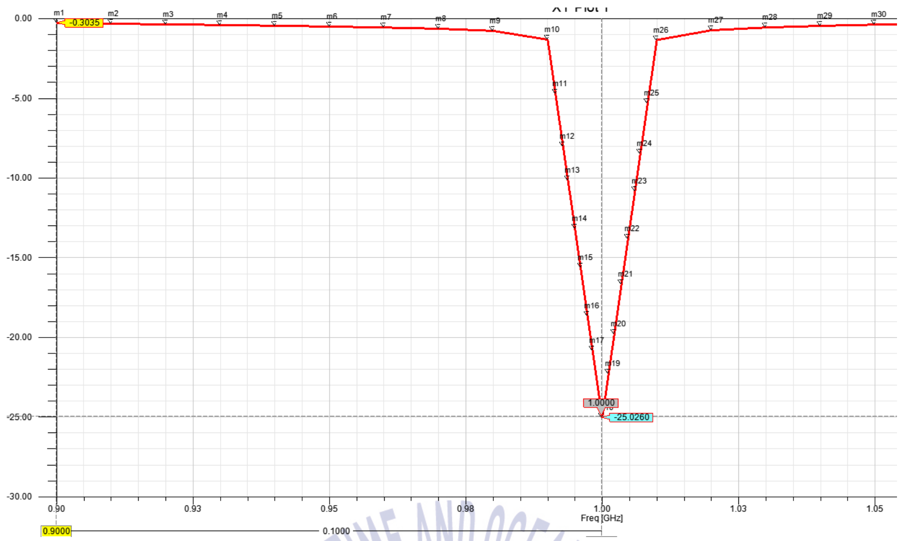
(b) slot is 2.1mm



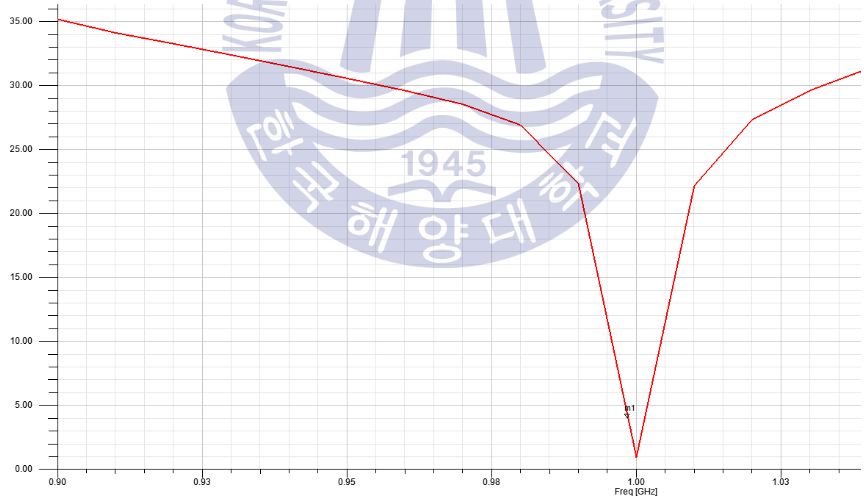
(c) slot is 2.4mm

Fig 3.2.4 simulation results of changing slot

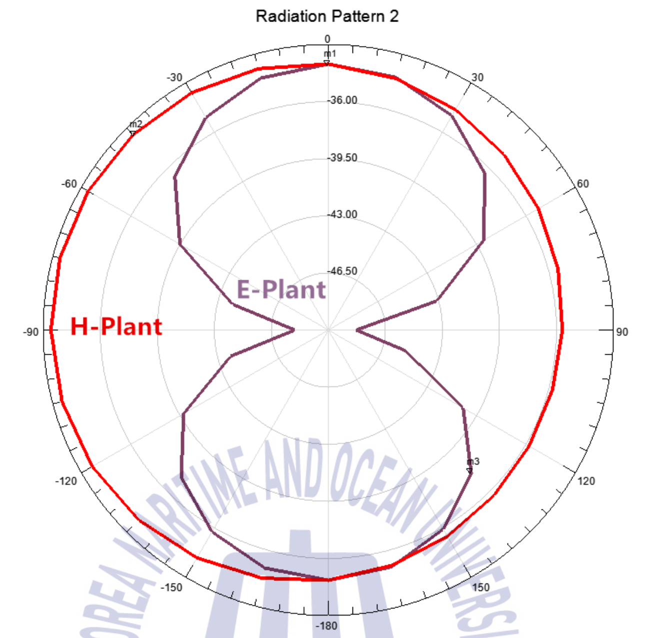
For this antenna is fed by the microstrip line, the microstrip line can produce the radiation and effect the result of antenna. then, adjust the length and width of the end shorted lines and the length of the microstrip is necessary. After optimizing, we get the better result which is shown in Fig 3.2.5



(a) simulation result of S_{11}



(b) simulation result of VSWR



(c) simulation result of E-plant and H-plant

Fig 3.2.5 simulation result of the final design antenna

From the simulation result, the bandwidth can be calculated. The resonant frequency is 1Ghz, and $S_{11}=25dB$, and the bandwidth $B=\frac{f_h-f_l}{f}*100\%=1.3\%$. For F=1 GHz, $\lambda=c/f=300mm$, then h/λ=0.0027. With this parameter, we can calculation the size and bandwidth of many other kinds of microstrip antenna. Like rectangular patch, circular patch, ring patch, triangular patch antenna. The calculation results are list in table 3. From the table 3 we can see that the size of coupled line antenna is about 10% of the circular patch and ring patch antenna, and bout 7% of the rectangular patch and triangular patch antenna. The bandwidth of the coupled line antenna is also better than the ordinary microstrip antenna.

Table 3 The calculation results for different kinds of antennas

Kinds	Size(mm^2)	10 dB BW(%)
coupled line	364	1.27
rectangular patch	5600	0.71
circular patch	3600	0.74
ring patch	5000	0.82
triangular patch	3600	0.75

3.2 Fabrication and Measurement

Each design parameter of this 1GHz antenna has been calculated and optimized in the above section. The Table 4 shows the final parameter of the antenna.

Table 4 Design parameters of the fabricated circuits

Center frequency	1GHz
Substrate permittivity	4.4
Substrate thickness	0.8mm
Copper thickness	35um
Copper conductivity	6.17×10^7
Dielectric loss tangent	0.02
Length of coupled lines	7.13mm
Width of coupled lines	0.87mm

Slot of coupled lines	2.63mm
Capacitor	6.6pF
Width of the microstrip line	1.49mm
Length of the microstrip line	6.89mm
Ports impedance	50Ω
Circuit size	26mm *14mm

For the reason that there are many elements may affect the results of the antenna, fabricating three antennas should be better. In our lab, there is no 6.6pF capacitor, so use the 7pF and 6.5pF and 6pF to instead of it. the fabricate antenna is shown in the Fig. 3.2.6

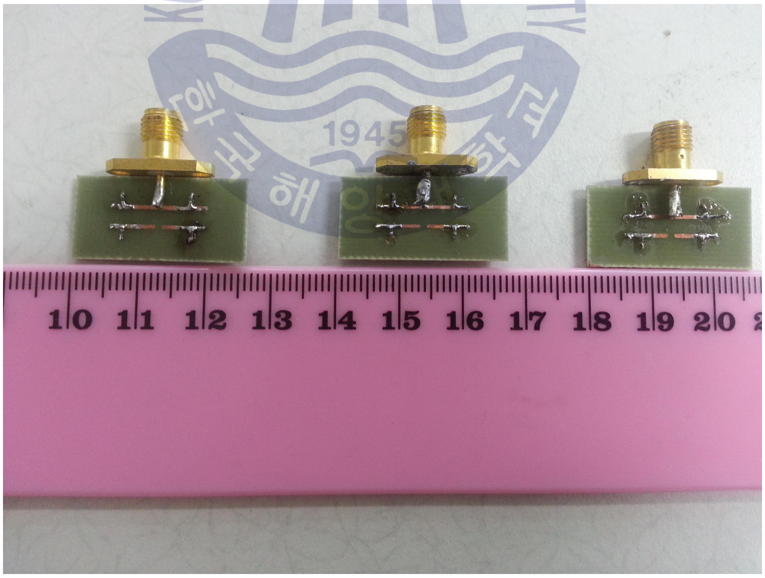
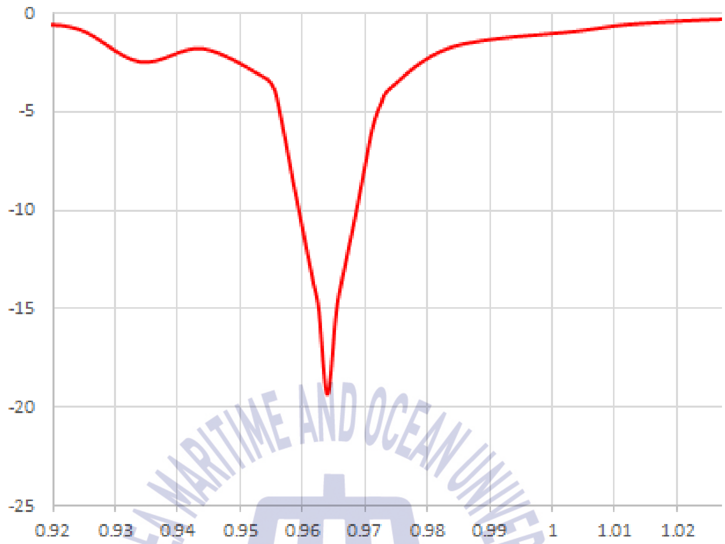
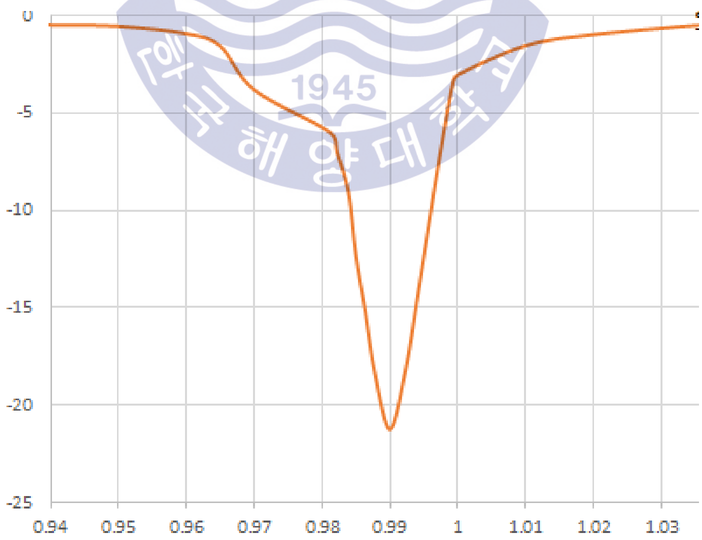


Fig 3.2.6 the fabrication antenna

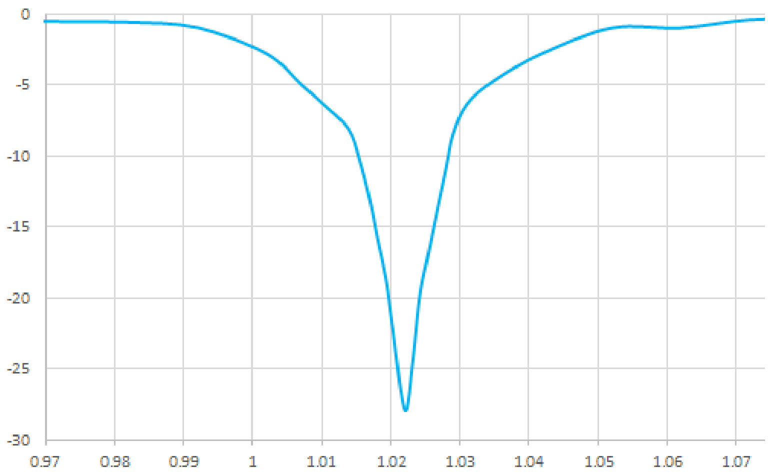
Using the Vector Network Analyzer(VNA) to measure the parameters of the antennas. The results are shown in the Fig 2.3.7



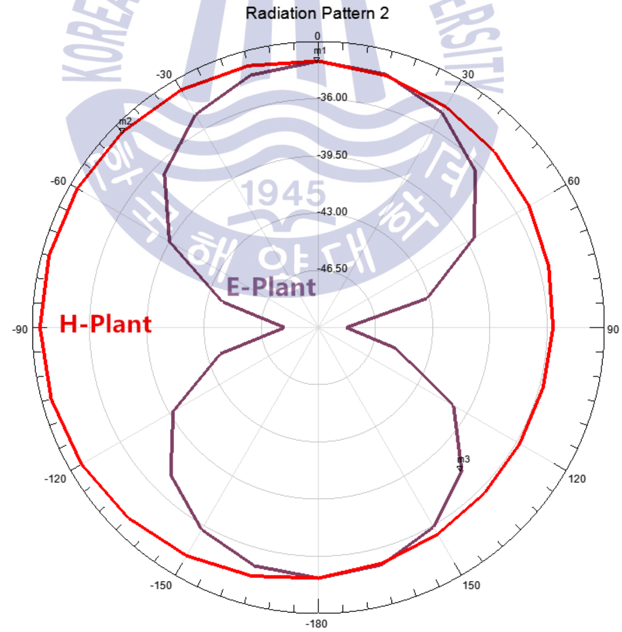
(a) C=7PF



(b) C=6.5pF



(c)C=6pF



(d)

Fig 3.2.7 The measuring result

Compare with the simulation result, we can find that all the resonant frequency of the fabricated antennas are shifted. The reason is that the lumped capacitors value of the fabrication antenna is different with the simulation antenna. The value of the S_{11} and bandwidth is similar to the simulation result.

Using the same structure to Design another small antenna at 500MHz with the dimensions of 26mm*14mm. Change the value of capacitor to 25.5pF. And adjust the slot, we can get the simulation result as Fig 3.2.8. We can find that the impedance match is very well. And the bandwidth is equal to 11Mhz. This result showed that, This method enables us to achieve a perfectly matched antenna with a fairly high efficiency for a given arbitrary center frequency.

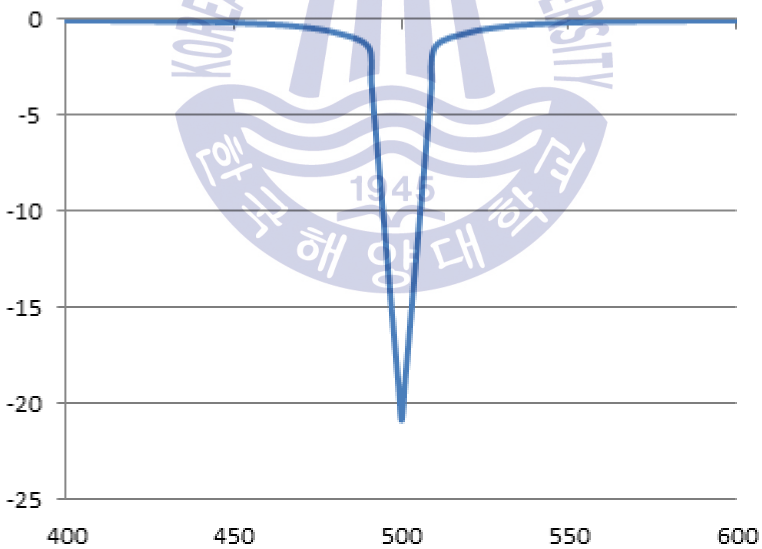


Fig 3.2.8 simulation result of s-parameter

Table 5 shows the comparing result with some other miniaturization antenna.

Table 5 Compare with the different kinds of antennas

type	author	frequency	size	10dB BW	S_{11}
inductor loading	REZA AEADEGAN	300MHz	55mm*55mm	0.5Mhz	25
capacitor loading	Maximilian C.Scardelletti	3.7Ghz	29mm*40mm	1GHz	35
coupled line	In-Ho Kang	1Ghz	26mm*14mm	13MHz	25

CHAPTER 4 Conclusion

In this thesis, we carry out the design theory and procedure for a novel enhanced microstrip antenna for extremely miniaturization utilizing the combination of parallel end-shorted coupled lines and diagonally shorted coupled lines both with shunt lumped capacitors. Compare with other microstrip antenna, the proposed microstrip antenna takes up a much smaller circuit area. This is because the electrical length of the coupled lines that determines the size of antenna can be reduced to just a few degrees, with the help of lumped capacitors. The measurement responses agree well with simulation result curves. This kind of microstrip antenna can be easily fabricated, and the size of the antenna is very small, it is likely to become even more attractive and competitive in the future.

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