A new coplanar waveguide fed transparent antenna at 2.4 GHz

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***Abstract*—Antennas are used to deposit the transparent conductive film (AZO, ITO) which is used by antennas to radiate electromagnetic wave on transparent substrate in this paper. A Coplanar Waveguide fed transparent antenna is chosen in this process due to its omnidirectional radiation patterns and wideband. It is not only artistic but also works at 2.4GHz ISM (industrial, scientific, medical) band ($S_{11} \leqq -10$ dB).**

***Index Terms*—transparent antenna, CPW-fed AZO, ITO**·

I. INTRODUCTION

THE transparent antennas [1]-[3] which are fabricated by the transparent conductive films and substrates have a lot of potential in wireless communication systems and mobile devices in the future. It has characteristics of invisible and artistic then can be mounted on the devices and integrated with electric circuits. When attached on the device for wireless communication systems that it won't affect the appearance of the equipment due to its transparency. We could see through the devices from one side to another side and couldn't find out where it is just like glass due to its light-pervious.

Of course, the resistivity parameter should be the first to be considered. In previous researches, it indicates that the ITO (Indium Tin Oxide) and AZO (Aluminum-doped Zinc Oxide) had been used widely for the purpose. For the ITO target, it had been used to construct the radiation patterns, but this transparent material cause more pollution to the environment to be at potential risk. We might be able to replace the ITO one an AZO target to reduce this risk.

Second, we have to discuss the frequency for which the transparent antenna works for. The guided idea is the frequency band which it is free so that can be used anytime. The best choice is ISM (industrial, scientific, medical) bands.

Most of all, using the transparent antenna have potential in the RFID system and wireless power transmission system, the artistic technology cause the devices and equipments have no longer to be considered that how about its shape and outer appearance is due to its invisibility.

The RFID system has become one of the most potential industrial, because it is a low profile, low cost, and especially small size for valuable. This system basically consists of a read, write equipment and a tag (or transponder). The RF data can be transmitted between the tag and the read/write equipment by electromagnetic waves. It is easy to use when it attached to the object to be identified than bar code. It won't be abraded that it have no longer to touch the reader, and it can be identified over a hundred tags at the same time to cause more convenient. It not only increases the security but also the efficiency of tracking and identifying objects.

The wireless power transmission system is also popular in the recent years, the wireless charging system on the device just like electric toothbrush, iphone, even microstimulator in bio-medical implants. This system is also consists of the same elements like RFID system except the tags. The system transferred the RF power from the transmitted device to the received device by radiation. It had no longer to use wire to transfer the power. The traditional wire power transmission system had an impact by this technology in the future. How to increase the overall efficiency and conversion efficiency is the major study nowadays. In the paper, we had discussed these issues and implemented the whole design to realize.

II. ANTENNA PARAMETERS

A. Reflection Coefficient and Characteristic Impedance

Every transmission line has a resistance associated with it, and comes about because of its construction. This is called its characteristic impedance Z_0 . When the transmission line is terminated with an arbitrary load Z_L, in which is not equivalent to its characteristic impedance $Z_L \neq Z_0$, a reflected wave will occur [4]-[5]

$$\Gamma = \frac{V_r}{V_i} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (1)$$

where V_r is the reflected voltage, V_i is the incident voltage.

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B. Return Loss

Return loss is a parameter that waves are reflected leading to the formation of standing waves, when the transmitter and antenna impedance do not match, which is given by [6]

$$\text{Return Loss} = -20\log|\Gamma| \quad (2)$$

When the ratio obtained is 1, the connection is perfectly matched, and hence all the energy is transferred to the antenna prior radiation. To obtain a reasonably functioning antenna, the ratio should be less or equal to 1.5.

C. Bandwidth

The bandwidth of an antenna is defined by as the range of usable frequencies within which the performance of the antenna. The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the center frequency [6].

D. Radiation Patterns

An antenna radiation pattern (antenna pattern) is define as a mathematical function or a represented graphics of the radiation properties of a antenna as a function of space coordinates. The radiation pattern is determined in the far field region which is represented as a function of the directional coordinates.

An E-plane pattern is the magnitude of the normalized field strength which versus θ for a constant φ, and the H-plane pattern is the magnitude of the normalized field strength versus φ for $\theta = \pi/2$, in a spherical coordinate system.

E. Voltage standing-wave ratio

Maximum power transfer can only take place when the impedance of the antenna, Z_L, is matched to that of the transmitter, Z_0, which can be characterized by voltage standing wave ratio (VSWR), S

$$S = \frac{|V_{max}|}{|V_{min}|} = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (3)$$

III. ANTENNA DESIGN

The commercial program high frequency structure simulator (HFSS) [7] based on the finite-element method (FEM) is used for analyzing the behavior of proposed model and determining suitable values of parameters. Because the conductivity of ITO and AZO is usually changed by doping concentration of the mental element, as shown in Table. 1 and Fig. 2 illustrates the geometry and configuration of the proposed transparent antenna with ISM band operations in the WLAN communication devices by using CPW (coplanar waveguide) fed monopole model.

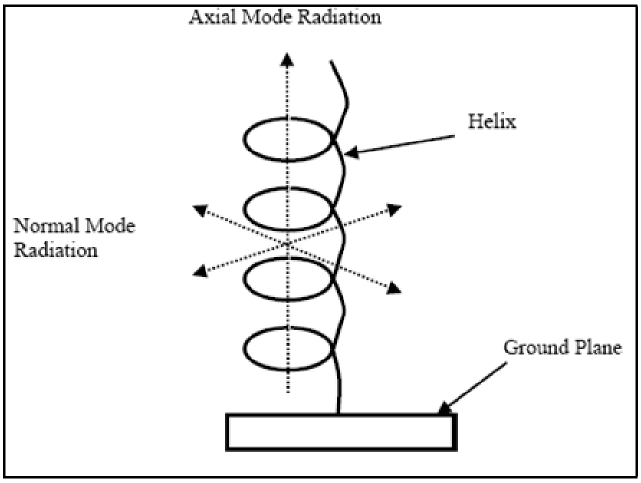


Fig. 1. The helical antenna

Our design concept comes from the helical antenna shown in Fig. 1. The helical antenna has two mode radiations: when the helical diameter is very small as compared to the wavelength, the antenna operates in the normal mode. However, when the circumference of the helix is of the order of a wavelength, then the helical antenna is said to be operating in the axial mode. And then we use the theoretical router to design the coplanar waveguide antenna. By adding the stub to the antenna, we find out that is better to match the input impedance between the fed and the antenna. Form Fig. 3 and Fig. 4, they indicate that the return loss of the simulation achieves -10 dB below.

TABLE I: PARAMETERS OF ANTENNA DESIGN
(thickness of substrate:1 mm; and thickness of film: 1 μm)

Case	Conductivity (S/m)	Area (mm^2)	Film	Substrate
(a)	1.0×10^6	10 × 15	ITO	Glass
(b)	1.0×10^5	10 × 15	AZO	Glass
(c)	1.0×10^6	10 × 15	ITO	Polyester
(d)	1.0×10^5	10 × 15	AZO	Polyester
(e)	1.0×10^6	20 × 30	ITO	Glass
(f)	1.0×10^5	20 × 30	AZO	Glass
(g)	1.0×10^6	20 × 30	ITO	Polyester
(h)	1.0×10^5	20 × 30	AZO	Polyester

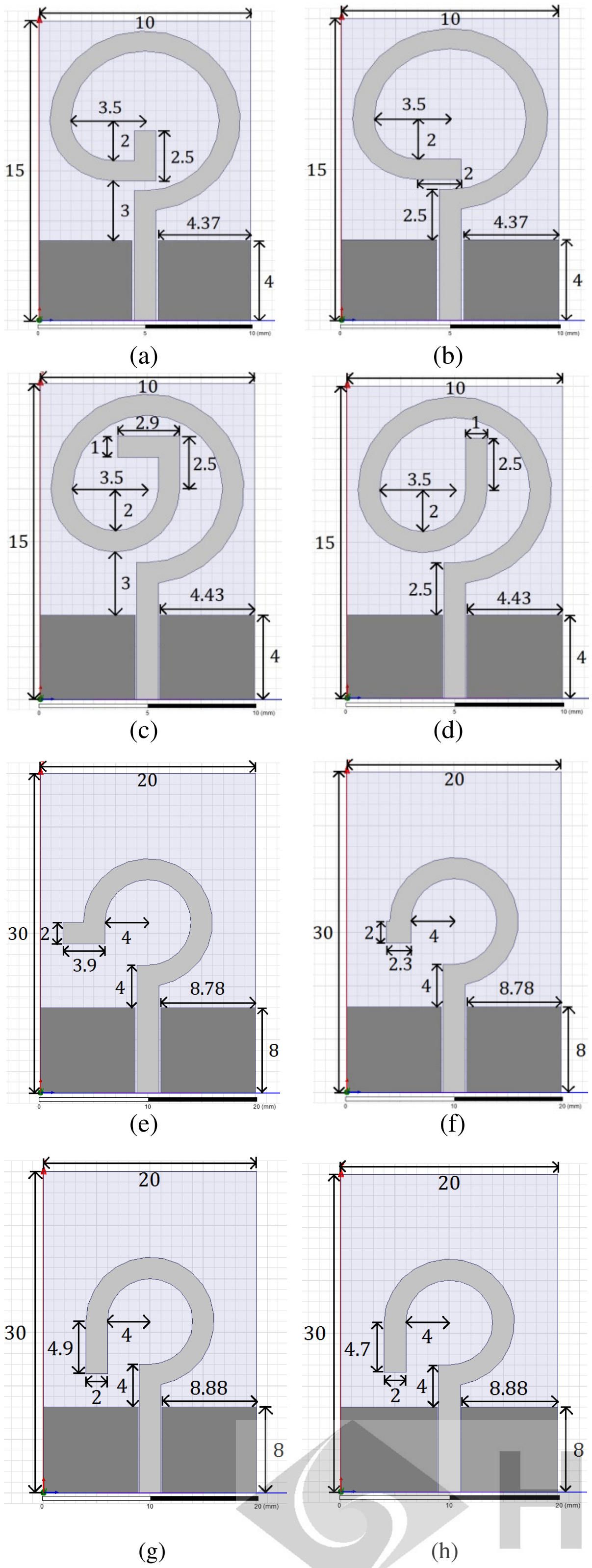


Fig. 2. Geometry and configuration of the proposed antennas

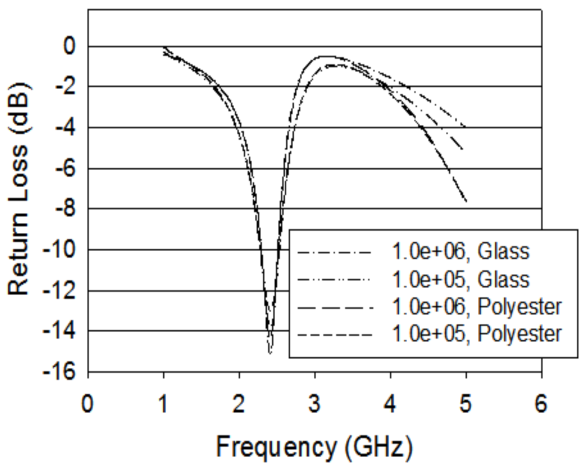


Fig. 3. Return losses of the antennas, the bandwidth is (a) 218 MHz (b) 256 MHz (c) 217 MHz (d) 239 MHz.

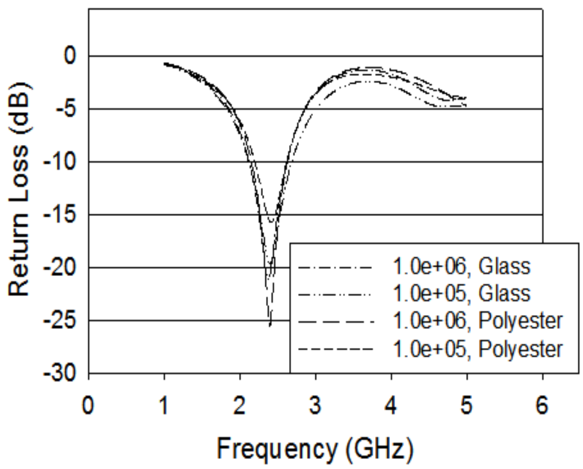
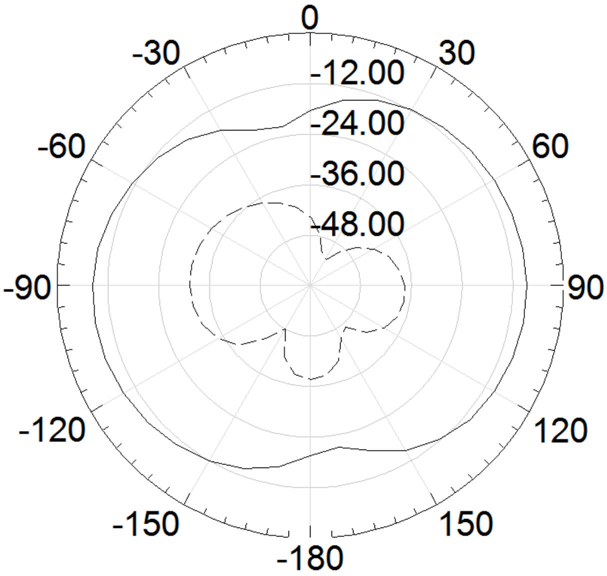


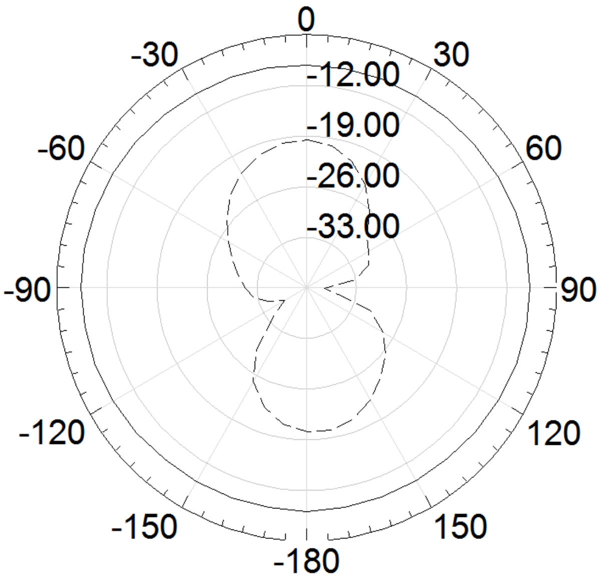
Fig. 4. Return losses of the antennas, the bandwidth is (e) 501 MHz (f) 567 MHz (g) 475 MHz (h) 420 MHz.

IV. DISCUSSION

From Fig. 2 and Fig. 3, we notice that the conductivity of the conductive film is a great influence. By decreasing the conductivity, replacing the ITO one an AZO target, the bandwidth seems wider. The bandwidth is always wider that large area one than small area one. The substrate of glass is better than the polyester one, but the polyester one is usually low-cost. In the study, the environment factor is considered as a constant, so that the curves showed ideally. The input impedance is well matched as the -10-dB return loss bandwidth covers the ISM bands (2400 ~ 2484.5 MHz). The chosen patterns are shown below, where E-plane is dash line and H-plane is solid line.



(a)



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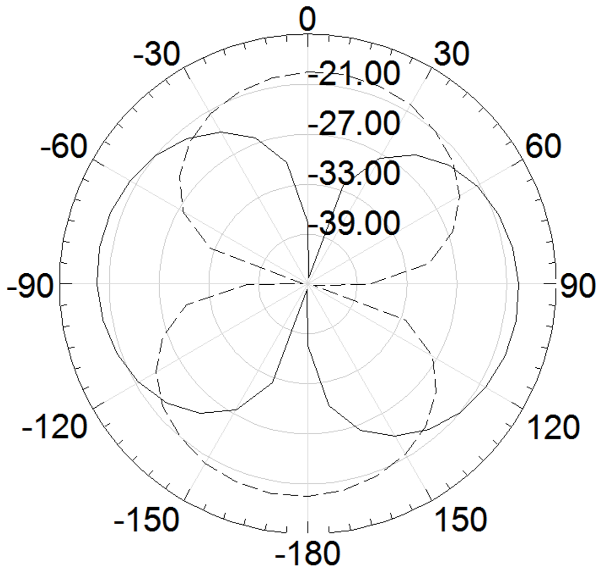


(c)

Fig. 5. Radiation pattern of the antenna design (a) at 2.40GHz (a) xy (b) xz (c) yz plane.

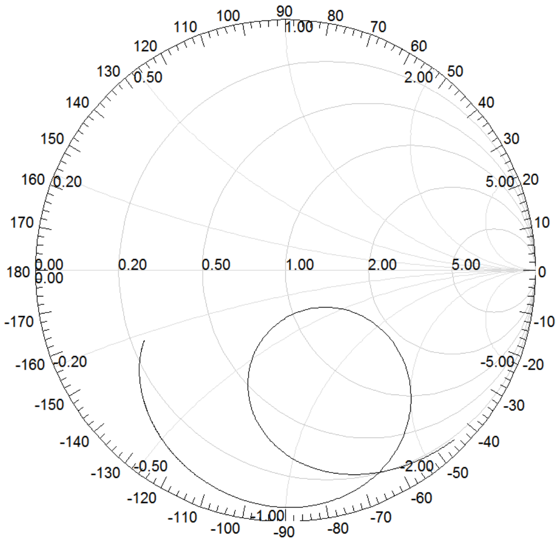
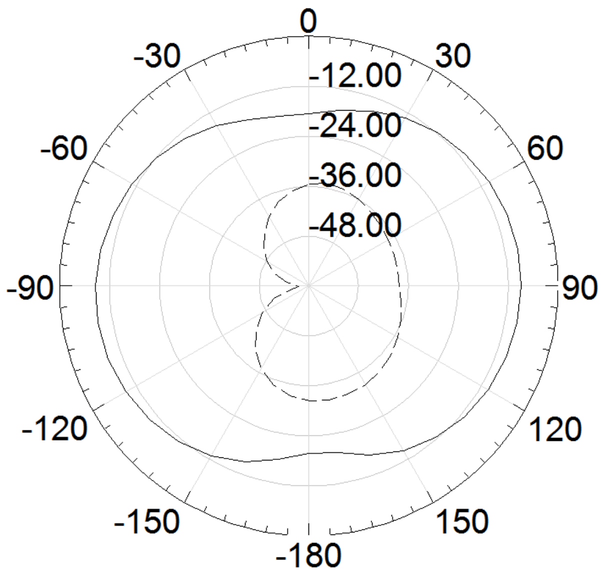
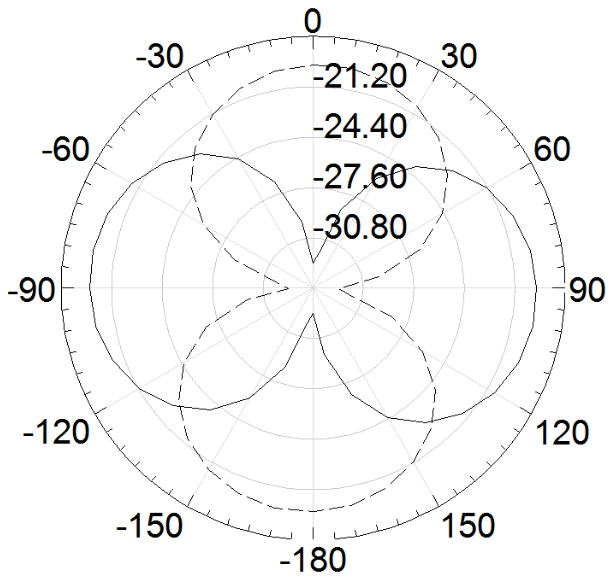


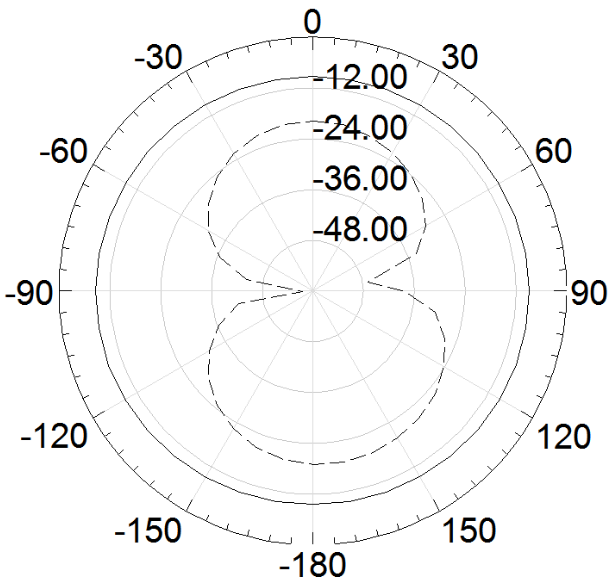
Fig. 6. Smith chart of the antenna design (a) at 2.40GHz, and its input impedance (RX) is 1.0146-0.3588i.



(a)



(c)



(b)

Fig. 7. Radiation pattern of the antenna design (c) at 2.40GHz (a) xy (b) xz (c) yz plane.

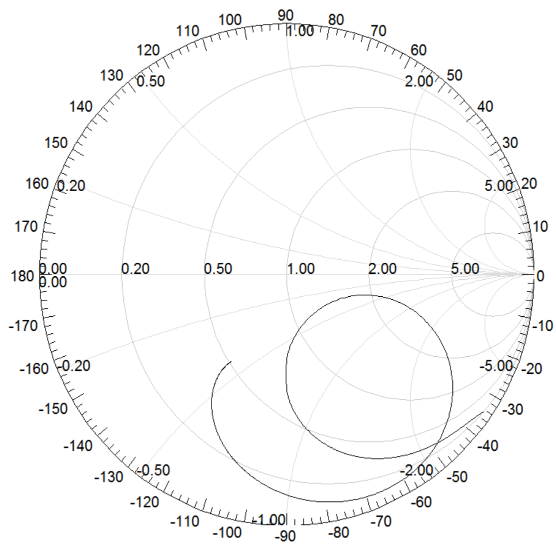
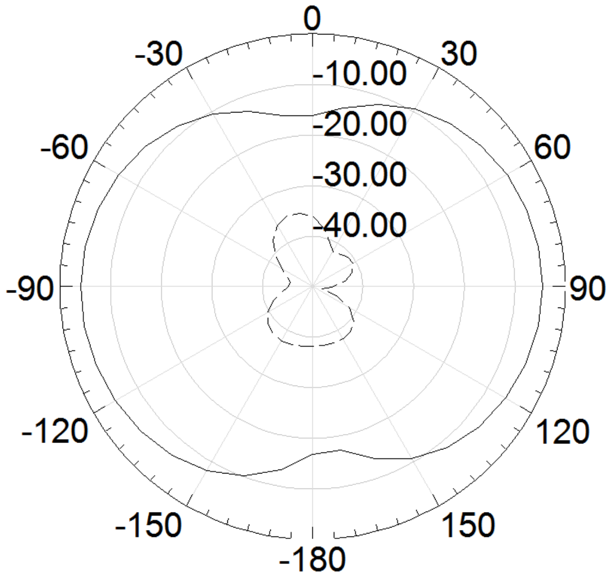
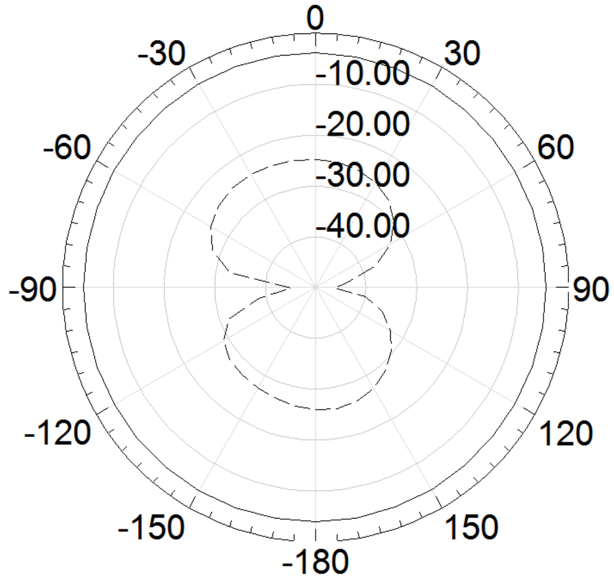


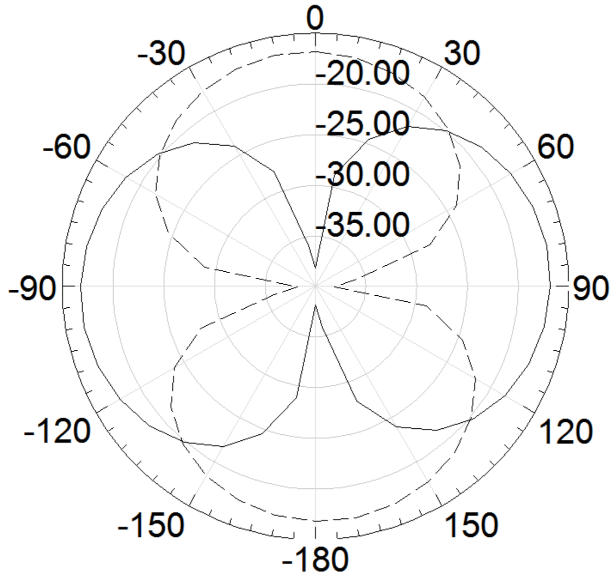
Fig. 8. Smith chart of the antenna design (c) at 2.40GHz, and its input impedance (RX) is 1.1616-0.3288i.



(a)



(b)



(c)

Fig. 9. Radiation pattern of the antenna design (e) at 2.40GHz (a) xy (b) xz (c) yz plane.

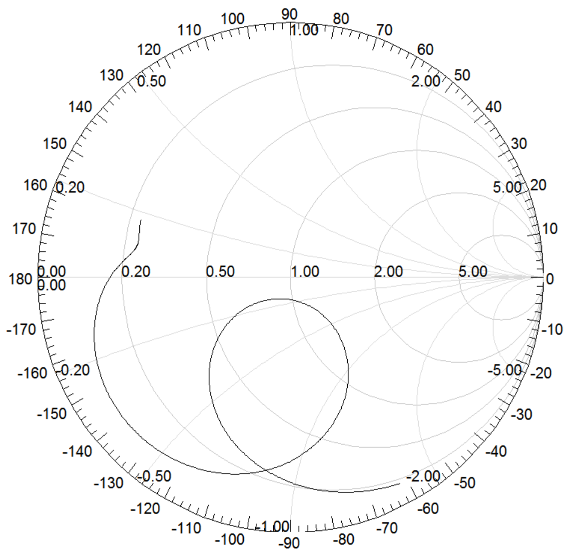
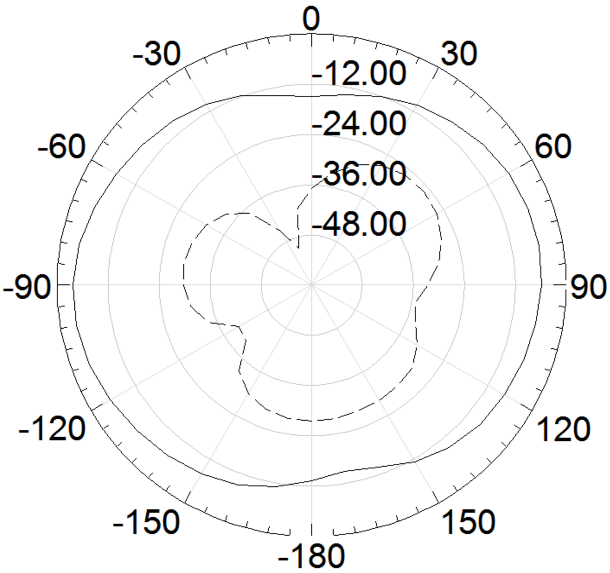
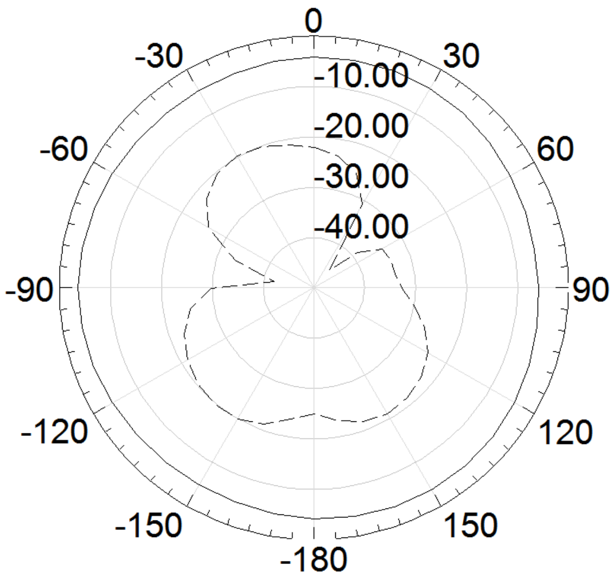


Fig. 10. Smith chart of the antenna design (e) at 2.40GHz, and its input impedance (RX) is 1.0197-0.1892i.



(a)



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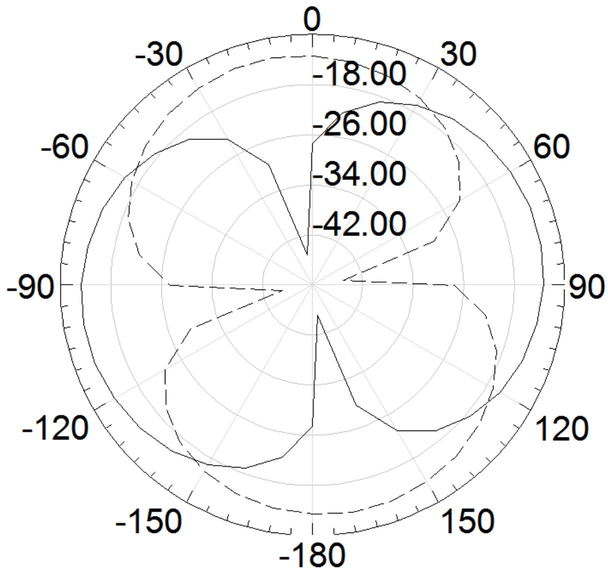


(c)

Fig. 11. Radiation pattern of the antenna design (g) at 2.40GHz (a) xy (b) xz (c) yz plane.

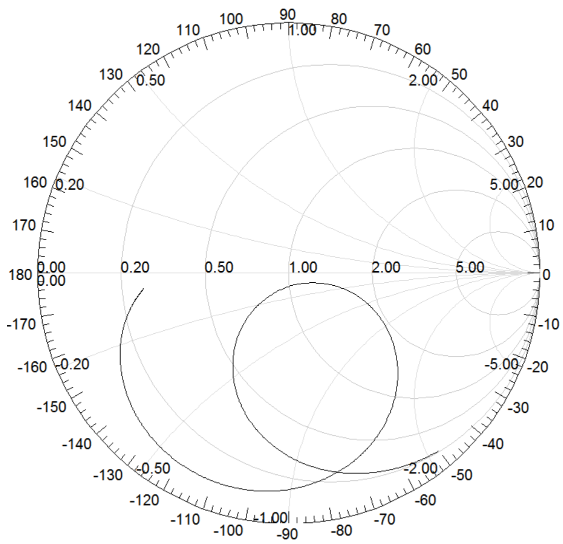


Fig. 12. Smith chart of the antenna design (g) at 2.40GHz, and its input impedance (RX) is 1.0425-0.1010i.

TABLE II: INPUT IMPEDANCE AND VSWR OF ANTENNA DESIGN

Case	Input impedance	VSWR
(a)	1.0146-0.3588i	1.4257
(b)	1.0793-0.4310i	1.5201
(c)	1.1616-0.3882i	1.4737
(d)	1.2060-0.4622i	1.5790
(e)	1.0197-0.1892i	1.2069
(f)	0.9675-0.2031i	1.2321
(g)	1.0425-0.1010i	1.1132
(h)	0.8759-0.2862i	1.3935

From Table. II, the full fed impedance is all 50Ω, and then the input impedances of the antenna are almost well-matched to the input impedances of the fed, VSWR ≤ 1.5, this discover will help us to fabricate our ideal antennas.

V. ANTENNA FABRICATION

After we finish HFSS simulation, we prepare to fabricate our antenna sample. The process is shown below.

A. Sample Description

We use glass as the substrate and the ITO/AZO as the target for the deposition by RF sputtering.

B. Clean the glass

We use acetone, isopropyl alcohol, and DI water to clean the glass in the shaker step by step.

C. Dry the glass

We use air gun to remove all liquids from the glass.

D. Coat photo resist

We put the coated glass in the spin coater, and then press the "PUMP" button to check the glass which is held by the punp. Finally, we cover over the coater and press the "START" button by using parameter of 4500 rpm / 30s and 1000 rpm / 10s.

E. Soft bake

After coating, we put the glass on the oven to soft bake at 100℃ in 3 minutes.

F. Alignment and exposure

After baking, we put the glass on the tray of the stepper and align the mask with the glass, and then starting exposure.

G. Development

We develop the glass by using developer solution in 1 minute 40 seconds, and then put the glass in the DI water to clean. Finally, we use air gun to dry the glass.

H. Final baking

We put the glass on the oven at 100℃ in 7 minutes.

I. RF Sputtering deposition

First, we open the power of the sputter, and prepare to deposited RF sputtering our entire samples. Second, we press the switch of the chiller. The parameter of the sputter will be shown in the next subsection. Third, we lock the sample on the panel and put it and the ITO or AZO target in the sputter after breaking vacuum, and then start to vacuum. Wait for sputtering process time. When it finished, we break vacuum and take the sample and target out. Finally, we vacuum again.

J. Parameters of the sputter

- Target: ITO/AZO
- Substrate: Glass
- Substrate temperature: Room temperature
- Sputtering power: 100W
- Gas pressure: 1×10^{-2}
- Sputtering time: 120 minutes
- Gas flow ratio: Ar 20 sccm
- Thickness: 0.3μm

K. Remove photo resist and dry the sample

We use acetone, isopropyl alcohol, and DI water to remove the photo resist, and then put the sample in the shaker to remove until the photo resist is all disappear. After removing, use air gun to remove all liquids from the sample.

L. Connect the sample with SMA connector

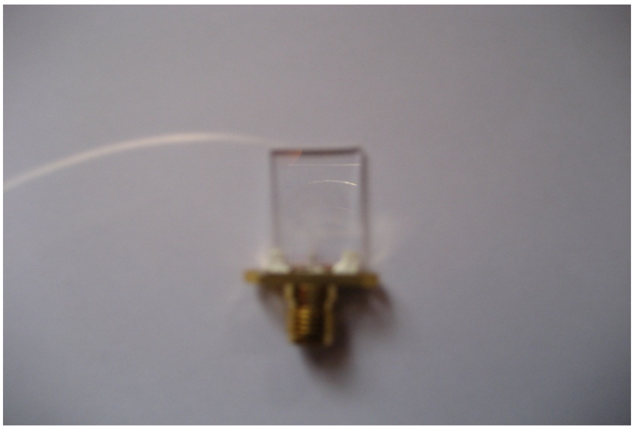
We use the sealant to hold the glass with the SMA connector first, and then wait for about 10 minutes. After holding, add the Ag inks to the antenna fed and ground with SMA connector.

M. Sample baking

We put the sample on the oven to bake at 150℃ in 1 hour 30 minutes to finish the process.

VI. RESULTS AND DISCUSSION

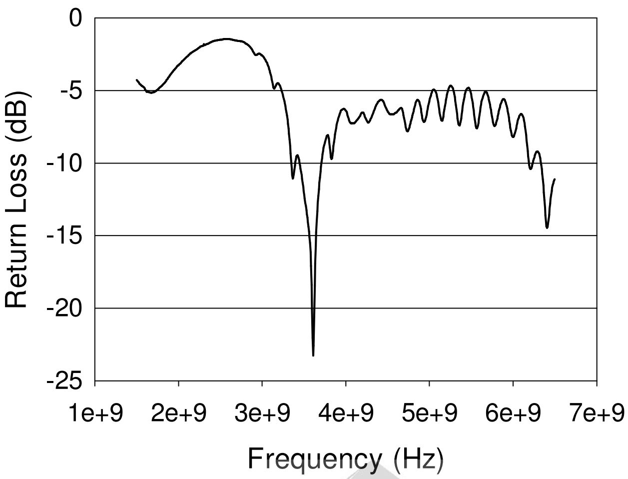
The chosen antenna samples are shown below. Their pattern come from Case (a) and Case (b). We use RF network analyzer to measure our sample, and the result is shown in Fig.14 and Fig. 16.



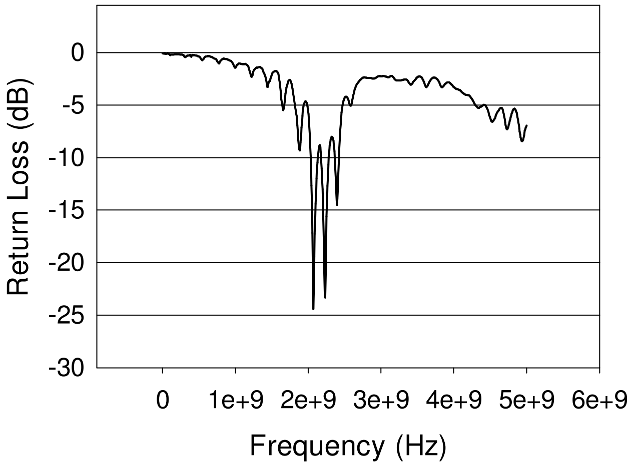
(a)

(b)

Fig. 13. Photographs of antenna samples: Case (a) and Case (b).



(a)



(b)

Fig. 16. Measurements of the return loss for Case (a) and Case (b).

From above, the stub will cause the central frequency shift to the high level. Comparing of the simulation, the Case (b) matches well due to well-matched impedance between the fed and the antenna. On the other hand, the return loss of Case (a) locates at 3.65 GHz. If we modify the antenna length of the ITO film, we assume that it will match the simulation. Considering of environment factors, it will influence all measurement to mismatch the simulation. The sample of Case (a) by using AZO film can use widely from about 2G to 2.55G for ISM band applications. We will improve the antenna design to get more efficient transparent antenna in the future.

VII. CONCLUSION

In this paper, we study all the parameters and characteristic of a transparent antenna, and using the knowledge to derive the dipole, monopole and microstrip model of the antenna. We select CPW-fed due to its fabrication easily. By using the HFSS software, these ideal transparent antennas are achieved.

From the results of simulation, we notice that replacing the ITO one an AZO target and its area causes wider bandwidth, and glass is better than the polyester one. The input impedances of antenna are almost well-matched.

Finally, we try to fabricate our transparent antenna samples. From the measurement, we notice the mismatch from the simulation due to the antennas stub, we can modify the stub to match the simulation.

Although a sample is mismatch, we also get a better one to match well the simulation, this sample can use widely from 2G to 2.55G for ISM band applications.

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