Lossy and Loss Free Material Research Taking Microstrip Patch Antenna Operating on the Band n261 as the Case

Hanwen Zheng [1]

[1]Department of Information, Beijing University of Technology, Beijing, China

*Corresponding author: zhenghanwen@emails.bjut.edu.cn

Abstract: The focus of this paper is to discuss the loss mechanism of the antenna and its effect on the antenna performance. This paper will follow the order of design basis, design idea, design content, and design results. Based on an antenna design for an n261 band, experiments are conducted in CST studio using different materials under lossy and lossless conditions. It includes 8 different sets of experiments. The lossy material will perform worse than the lossless material by processing the data through the program. When designing antennas, the performance of lossy materials will be worse. The material has a low tangential loss, and the loss of the antenna will be reduced. When designing an antenna, the antenna's performance should be measured comprehensively by S11, Z11, as well as radiation efficiency and electric field results, instead of looking at only one parameter. Meanwhile, microstrip antenna design can be used to design antenna arrays or multi-band antennas.

Keywords: Antenna, Loss Tangent, Lossy Material, n261.

1. Introduction

The basic patch antenna theory can be summarized in 3 steps: the microstrip model, the cavity model, and the integral equation method. The microstrip model is mainly used to solve the rectangular antenna [1]. This method used a coaxial probe bottom feed and tuned shorting pin. The generalized transmission line model is derived by considering the mutual coupling of the two gaps and the radiation from the other two sides in the conductance calculation. This method can be used for any patch shape with variable separation.

In recent years, there are several directions of antenna development. There are six main directions, which are broadband technology [5], circular polarization technology [6], multiple operating frequency technology [7], directional map control [8], feed technology [9], and medium coverage effect [10].

The miniaturized antenna is a new type of antenna with a smaller type. With the development of radar technology and integrated circuits, there is an increasing demand for miniaturized and portable antennas. A shorting post is used to make the antenna smaller. Introducing a capacitor in the resonant cavity can reduce the antenna size by at least 50%. Usually, microstrip patch antenna has the advantages of small size, low weight and easy fabrication. But the bandwidth of the patch antenna are always low, so a wideband antenna is needed. Changing the structure of conventional microstrip patch antenna can increase the bandwidth. vivaldi antenna also has ultra wideband performance. In addition, researchers placed two Vivaldi orthogonally to obtain dual polarization performance [13, 14]. Magnetoelectric dipole antennas have the advantage of broadband and stable beam. This antenna has a wider frequency band and stable pattern than a conventional dipole antenna. The dipolar antenna has the advantages of broadband, stable mode, small size, and easy fabrication. Researchers use two coupled dual-polarized antennas to make wider bandwidth [16]. This type of antenna has circular polarization and recent studies have used slots to make antennas with this polarization pattern.

A fabric antenna is a type of antenna that uses fabric as the antenna substrate. Its multi-planar structure can easily be combined with people's clothes [17]. Among them, the button antenna is shaped like a button and is always solid. Recent button antennas have a diameter of 16 mm and can operate in both 2. 4 GHz and 5 GHz dual bands.

This paper proposes an antenna design for the n261 band using the rectenna theory. The antenna performance parameters are discussed, and the chosen base material is investigated in depth. This paper finds the effect of lossy materials based on MATLAB data processing.

2. Methodology of patch antenna

2.1 Antenna performance parameters

Impedance The impedance of the antenna is equal to the impedance of the patch, which can be measured by the$Z_{1,1}$which is equal to $R + j * X$ (a complexity number). When designing the antenna, $Z_{1,1}$ can't always be 50Ω, so the waves that come from the microstrip transmission line will reflect and form a standing wave.

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

The reflection coefficient can be used to describe this reflection rate. And the S parameter is used to indicate Γ in another way which is:

$$S_{1,1} = -20log(|\Gamma|)dB \quad (2)$$

In the antenna design, the $S_{1,1}$ is the main factor that can reflect most of the performance of the antenna. For example, the bottom point of the $S_{1,1}$can indicate the operating frequency of the antenna, also the bandwidth can be seen by measuring the $S_{1,1}$ which is below $-10dB$.

Bandwidth Bandwidth is another basic parameter of an antenna. Bandwidth is used to describes the frequency range which an antenna is able to radiate or receive energy. Usually, the bandwidth required is a determining parameters when designing an antenna. Fractional bandwidth is common in patch antenna design. Fractional bandwidth is the ratio of absolute bandwidth to working frequency,which can be described by the equation below:

$$BW(\%) = \frac{f_{max} - f_{min}}{\frac{f_{max} + f_{min}}{2}} * 100\% \quad (3)$$

Efficiency The antenna's efficiency is another parameter that judges the antenna's quality. Because the antenna is a passive component which do not amplify the signal itself, the directivity can be judge by

$$D(\theta, \phi) = \frac{P(\theta, \phi)}{P_{total}}. \quad (4)$$

And for the gain of antenna, the equation is

$$G(\theta, \phi) = \frac{P(\theta, \phi)}{P_{isotrophic}(\theta, \phi)} \quad (5)$$

For the radiation efficiency can be measured by the equation below which is

$$\eta = G(\theta, \phi)/D(\theta, \phi) = \frac{P_{isotrophic}(\theta, \phi)}{P_{total}} \quad (6)$$

Far-field pattern Always, the far field is a feature to describe the electric field and the magnetic field (also known as E-field and H-field) in a larger scale which is quite away from the antenna. The researchers uses the intensity of each field to measure this feature. When the antenna is operating, the intensity of the fields will decrease with the increase of the distance.

The radio frequency wave goes through a waveguide. The wave has a wave pattern that can be mainly divided into two: TE and TM. In this design the researcher uses the TM mode.

In the farfield 3D graph, the $\phi = 90^{\circ}$ can view the electronic wave pattern. And in this view, the main lobe gain is equals to the gain of the antenna.

2.2 Antenna design

Proposed Geometry The antenna structure is shown in Figure 1.

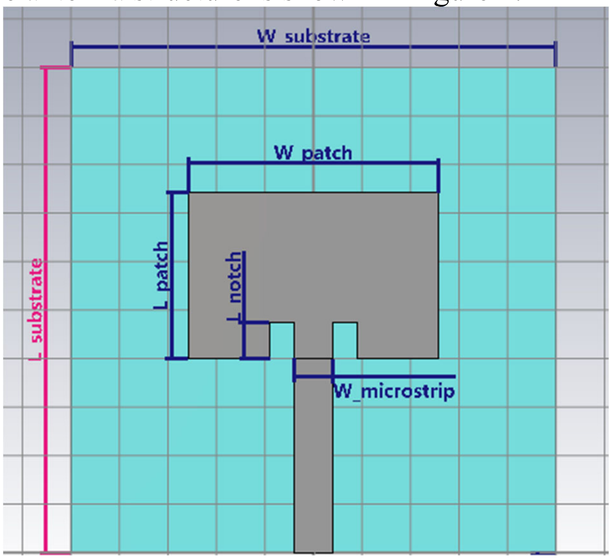

Figure 1. Antenna structure

The basic patch antenna's structure will be stated in this paragraph. The patch is combined with the ground to form a capacitor. The key component that helps the whole structure oscillate is the electromagnetic wave entering the nearby space to form an RF signal. Microstrip transmission lines on the PCB board help convert the original signal into the patch. The thin layer on the PCB board serves as the circuit's ground. The material used to make the PCB board should always have a width and length greater than the width and length of the patch. The thickness always has a certain value, provided by the material manufacturer and can affect the bandwidth.

Notches on the patch can reduce the impedance of the patch, which will help match the impedance of the transmission line. This paragraph states the basic structure of some complex designs. The quad-wave transformer serves the same purpose as the notch and helps to match the impedance of the patch and transmission line to each other. The slots are used to make the polarization circular. Some of them are U-shaped or H-shaped. Antenna arrays use more than one antenna to form an antenna array, which can have beam formation. The particular factor of the antenna always determines an array factor.

To design this antenna for n261, the patch and the microstrip transmission line are needed. The antenna should be able to cover some of the bandwidth of the n261, which is the operating frequency $f_0 = 28GHz$ bandwidth $BW_0 = 28.35 - 27.5 = 0.85GHz$ the fractional bandwidth $BW = \frac{BW_0}{f_0} = \frac{0.85GHz}{28GHz} \approx 3\%$.

Design the substrate When designing the substrate, the first is to choose the material. The Rogers RT5880 will be chosen in this design, with a dielectric constant of 2. 2. The Dielectric material will unexpectedly start to conduct current if the voltage across a dielectric material is too great or the electrostatic field is too intense, which is called dielectric breakdown. Also, rogers material is less likely to demonstrate a dielectric breakdown.

After choosing the substrate, the thickness of the substrate can be calculated by the substrate's dielectric using the equation below.

$$BW = \rho \frac{h}{\lambda_0} \sqrt{\frac{W}{L}} \tag{7}$$

The λ_0 in the equation is the wave length of the electromagnetic wave that conducts in the substrate which is $\lambda_0 = \frac{\lambda}{\sqrt{(\varepsilon_r)}}$. And the W/L is always be 1. 5 since the cross-polarization will be smallest when this ratio is 1. 5. And the ρ in this equation is a changing value and can be determined by this equation

$$\rho = \begin{cases} 200\ where\ 0.045 \le \frac{h}{\lambda_0\sqrt{\varepsilon_r}} \le 0.075 \\ 180 \qquad else \end{cases} \tag{8}$$

So according to the equation (7) and (8), the equation can change into $\frac{h}{\lambda_0 * \sqrt{\varepsilon_r}} = \frac{BW}{\rho\sqrt{1.5*\varepsilon_r}}$ So the next thing to do is to use different value of ρ to get the value of the parameter $\frac{h}{\lambda_0 * \sqrt{\varepsilon_r}}$. The first value of ρ could be 180, the $\frac{h}{\lambda_0 * \sqrt{\varepsilon_r}} = \frac{3}{180\sqrt{1.5*2.2}} = 0.009 < 0.045$. If ρ is 200, the parameter of $\frac{h}{\lambda_0 * \sqrt{\varepsilon_r}}$ will be smaller, so $\rho = 180$. Substituting the $\rho = 180$ it into formula (7), the thickness of the substrate will be $h = BW * \frac{\lambda_0}{\rho}\sqrt{\frac{L}{W}} = 0.21\ mm$. Considering the fabricate of the Rogers RT5880, the thickness of the substrate will pick the nearest value which is 0. 252mm.

Design the patch As mentioned above, to minimize the cross-polarization, the patch's width and length ratio should be 1. 5:1. So the question is coming to designing the patch length.
The electric field under the patch is:

$$E_Z = E_o cos\left(\frac{m\pi x}{W}\right) cos\left(\frac{n\pi y}{L}\right) \tag{9}$$

The electric field has a resonant frequency which will be the center frequency of the patch antenna. The resonant frequency can be calculated by

$$f_{mn} = \frac{k_{mn}c}{2\pi\sqrt{\varepsilon_r}} \tag{10}$$

$$\mathrm{k_{mn}} = \sqrt{\left(\frac{m\pi}{W}\right)^2 + \left(\frac{n\pi}{L}\right)^2} \tag{11}$$

In this design, considering the simplest way to design the antenna, the m should be 0 and the n should be 1. So the equation of the frequency will be:

$$f_{01} = \frac{c}{2L\sqrt{\varepsilon_r}} \tag{12}$$

Also, considering the patch is not in an ideal condition, so the ε_r will be amended in to ε_{reff}. The equation will be $\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2}$. As a result, the patch length will be $L = \frac{c}{2f_{01}\sqrt{\frac{1+\varepsilon_r}{2}}} = 3.93mm$ and the width of the patch will be $W = 1.5L = 5.895mm$.

The real case will never stay the same like calculation. So the parameter sweep is required. Considering the patch width is 1. 5 times the patch length, scanning the length of the patch is enough.

Design the microstrip transmission line Considering the impedance match of the patch, $50\Omega$is a common number in the design. After designing the patch the microstrip transmission line should be designed. The impedance of the microstrip transmission line can be measured by the equation below.

For W/h<1,

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{W}}} + 0.04\left(1 - \frac{W}{h}\right)^2\right] \tag{13}$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}}\ln\left(8\left(\frac{H}{W}\right) + 0.25\left(\frac{W}{H}\right)\right) \tag{14}$$

Else,

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{W}}}\right] \tag{15}$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{H} + 1.393 + \frac{2}{3}\ln\left(\frac{W}{H} + 1.444\right)\right]} \tag{16}$$

The equation shows that the impedance of the microstrip transmission line is affected by the substrate's thickness, the patch's width, and the patch's length. After the calculation, the width of the microstrip transmission line will be 0. 80mm.

After designing the microstrip transmission line, the impedance can not be matched. As mentioned in 2. 1 and 2. 2. 1, the whole structure needs a notch or a quad wave transformer to match the impedance between the microstrip transmission line. The method uses the notch to have the impedance match in this passage. There's no mature equation to calculate the impedance of the patch, so a parameter sweep is needed to resolve the length of the notch(the width of the notch should be less than the width of the microstrip transmission line, so the width of the notch should be 0. 5mm) There is a table of the important parameters calculated above.

Table 1. Main parameters

Main parameters	**Value(mm)**
Patch Length	Need to sweep
Patch Width	1. 5* Patch Length
Width of the microstrip line	0. 80
Notch Length	Need to sweep
Substrate Thickness	0. 252
Notch Width	0. 5

2.3 Data Processing

Before the simulation, a field monitor is needed to be added, showing the simulation's 2-D and 3-D results. The E-field monitor shows the electric wave in the 3D space which has a certain frequency. H field monitor shows the H field pattern in the simulation. In this design, as mentioned in 2. 3. 3, the wave pattern is TM_{01}. And in the E field, there should be a standing wave in the patch, which as a trough in the middle of the patch. The E field graph will have a blue line in the direction parallel with the x-axis in the middle of the patch.

After having the simulation, the data should be exported from the CST into ASCII coding, which allows MATLAB to process the data. As mentioned in the 2. 2, the bandwidth, impedance, VSWR, radiation efficiency, total efficiency, E-field, H-field, far-field 3D graph, and far-field 1D graph. In this design, MATLAB is mainly use for processing data and plot it. The flow chart of processing the data is shown below:

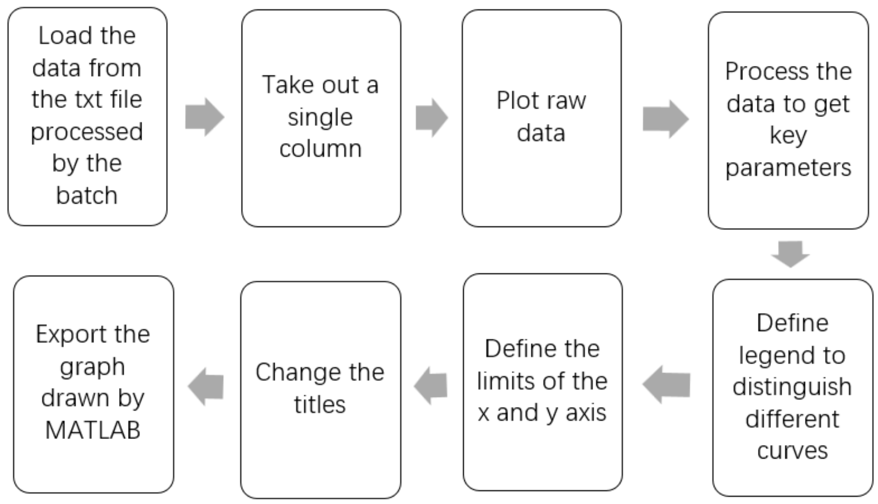

Figure 2. Flow chart of the MATLAB processing

2.4 Lossy material

The rise of the question When trying to use FR-4(loss free) to replace the Rogers RT5880 as the substrate of the antenna for 27. 5GHz to 28. 35GHz. The loss-free material has a very high $S_{1,1}$. The $S_{1,1}$ of the antenna cannot reach -10dB, where the antenna doesn't actually work. Meanwhile, when using the lossy FR-4 as the substrate, the antenna works very well with a 0. 715GHz of bandwidth in the $S_{1,1}$ graph, while all lossy materials have a larger bandwidth than the loss-free material.

Loss tangent The dielectric loss tangent is an important electromagnetic parameter to characterize the absorbing materials. It should be widely used in practice. If the loss depends on the conductance, the positive tangent of the dielectric loss Angle is determined by the complex dielectric constant. Study shows that the positive tangent of dielectric loss Angle is a function of temperature (T) and frequency (ω).

Resistive, dielectric, and magnetic losses are the three basic ways the losses are manifested [22]. The material's conductivity influences resistive losses. The skinning depth reduces as the medium's conductivity rises. A perfect conductor has an electrical and input impedance of 0, reflecting all electromagnetic waves. The material's dielectric constant is what generates the dielectric loss. The virtual portion of the material's dielectric loss will be at its maximum value when the external electromagnetic field's vibration frequency and the material's natural vibration frequency are in phase.

Preparing the experiment Considering the substrate's thickness and the patch's length, the microstrip transmission line's width should change when changing the dielectric constant. Considering the different materials used in the experiment, the author uses FR-4 (Dk=4. 3), Rogers RT5880 (Dk=2. 2), Rogers RT5870 (Dk=2. 33), Rogers RT6002 (Dk=2. 92). All the material is use in both loss free material, and the lossy material.

Table 2. Experiment setting parameters

Group	Material	Dk	tgδ	L_patch	w_microstrip	thickness
1	FR-4	4. 3	0	3. 62mm	3. 62mm	3. 62mm
2	Rogers RT5880	2. 2	0	2. 52mm	0. 75	0. 252
3	Rogers RT5870	2. 33	0	3. 13mm	0. 65	0. 252
4	Rogers RT6002	2. 94	0	3. 43mm	0. 2	0. 1
5	FR-4	4. 3	0. 025	3. 62mm	0. 8	0. 252

6	Rogers RT5880	2. 2	0. 0009	2. 52mm	0. 75	0. 252
7	Rogers RT5870	2. 33	0. 0012	3. 13mm	0. 65	0. 252
8	Rogers RT6002	2. 94	0. 0012	3. 43mm	0. 2	0. 1

3. Results

3.1 Parameter sweep

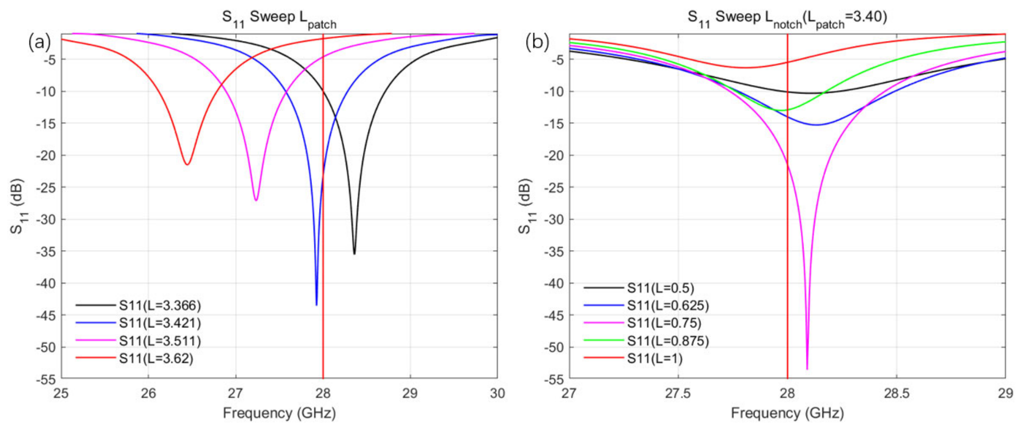

Figure 3.(a) Length of the patch as the parameter . (b) Length of the notch as the parameter.

The red line in the figure 3 (a-b) shows the center frequency of n261 (28 GHz)

As mentioned in 2. 2. 3, according to equation (12), the center frequency will be moved by the increase of the length of the patch. So figure 3 shows the best parameter for the patch and the notch length. As mentioned in 2. 2. 1, the impedance of the patch is related to how deep the microstrip transmission line is connected with it. And $S_{1,1}$ can indicate if the patch impedes match the microstrip transmission line. A notch is one way to let the transmission line connect to the patch but not on the edge of it, so the length of the notch shows the deepness of the transmission line is connected with the patch. Figure 3 showed that the transmission line would match the patch at the 0. 75mm point. The accuracy can only reach 0. 05 mm, so the length of the patch and the notch should be 3. 40mm and 0. 75mm.

3.2 Near field result

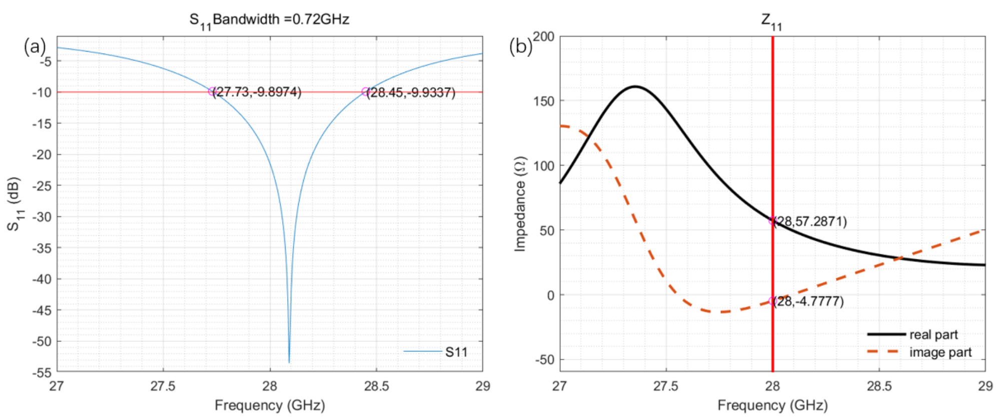

Figure 4.(a) $S_{1,1}$ of the designed antenna (b) $Z_{1,1}$(impedance) of the designed antenna

The $S_{1,1}$ shows how much energy the port has reflected from port 1. The more energy propagated into the free space, the less energy is reflected back. According to the equation (1) and (2), $|\Gamma|$ will be larger than 0 if the patch impedance (which acts like a circuit load). As mentioned in 2.1.1, the impedance of the patch and the impedance of the transmission line is very close, $|\Gamma|$ will be very close to 0. This is called impedance match. When the impedance of the patch is much larger or smaller than the impedance of the transmission line, the $|\Gamma|$ will be close to 1. Looking back to equation (2), $S_{1,1}$ will reflect this feature of $|\Gamma|$. When $|\Gamma|$ close to 0, the $S_{1,1}$ will be very small, when $|\Gamma|$ close to 0, $S_{1,1}$ will be close to 0. As a result, $S_{1,1}$ will reflect the pattern of the impedance mismatch, which leads to low radiation energy. Most of the energy will be lost by reflection when the impedance is a mismatched.

Figure 4.(a) shows that the antenna's bandwidth is 0. 72GHz. The red line in figure 4 shows the antenna's impedance when working at the operating frequency, which is $57.29 - j4.78\Omega$.

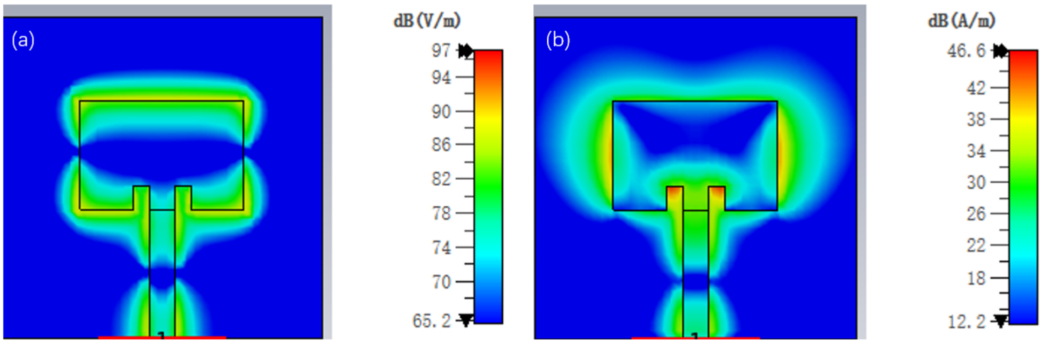

Figure 5.(a) E-field of the designed antenna (b) H-field of the designed antenna

Figure 5 shows the E field and H field in dB. As shown in the legend, the dark part of the figure has lower energy. According to the 1 and 2.2.3, using the cavity model in the paper [2] the EM wave have a pattern of TM_{01}, which means that there is only an electric field transverse to the direction of the EM wave propagation. In TM_{01} pattern, there should be a stand wave in the middle of the patch which is reflected in the figure 5.(a). The blue line in the middle of the patch shows the wave pattern in the patch operating in the mode of TM_{01}.

Figure 5 shows the antenna's E-field with a blue line in the middle of the patch. That indicates that the patch's electric wave has the operating mode of TM_{01}.

3.3 Far field result

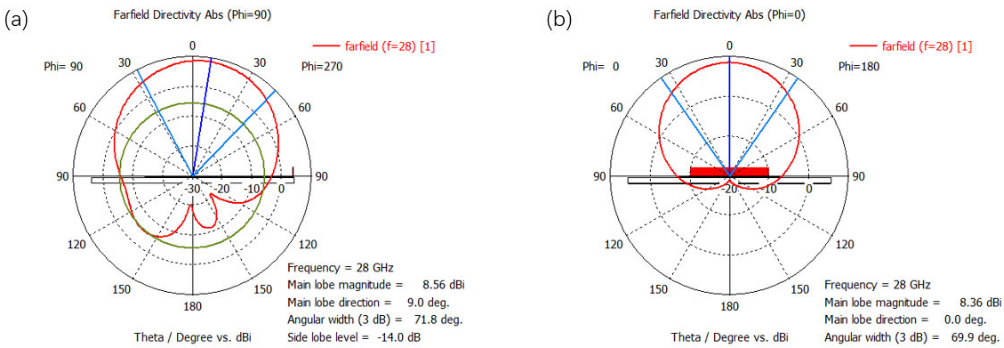

Figure 6.(a) E-plane of the designed antenna. (b) H-plane of the designed antenna

Figure 6.(a) and (b) show the polar plots of the far-feld patterns in the E-plane and H-plane at the resonant frequency of 28GHz.

According to 3.2, the electric wave is oscillating in the $\phi = 90°$ direction. The 1-D plot of the farfield plot can indicate the electric field in the free space. Fig 6.(a) shows that the main lobe angle is 71.8° which has a wide band operating region and works in a unidirectional mode. According to this feature, this antenna can also make the antenna array. Fig 6.(b) showed that the magnetic field in the direction of $\phi = 0°$. Also, the angle of the main lobe is 69.9°, which is unidirectional. Figure6 also shows that the antenna's gain, according to 2.1.4, should be measured in the E-plane. So the main lobe gain is 8. 29dBi.

3.4 Dielectric constant experiment result

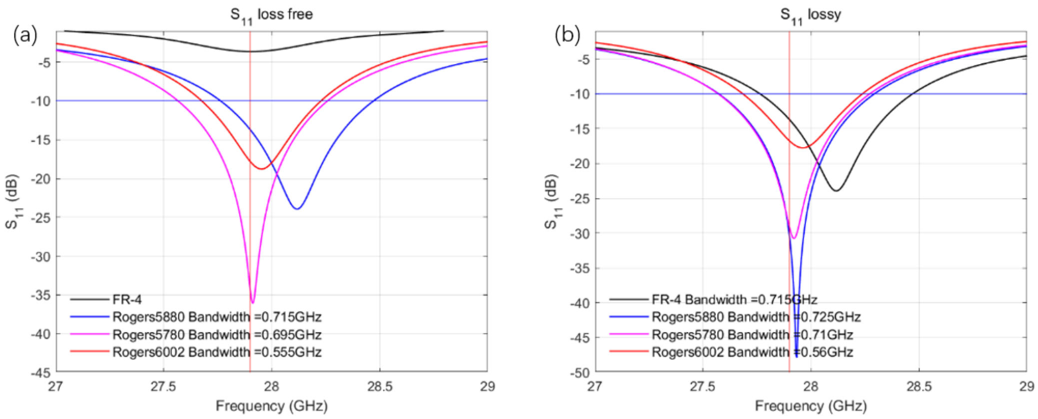

Figure 7(a). $S_{1,1}$ of the loss free material. (b) $S_{1,1}$ of the lossy material

Figure 7(b) shows that the lossy material has a larger bandwidth than the loss free material. There is the result of the experiment:

Table 3. Primary Results

Group	Dk	δ_E	Bandwidth(GHz)
1	2. 2	0	0. 715
2	2. 33	0	0. 695
3	2. 94	0	0. 555
4	**4. 3**	**0**	**No bandwidth (0)**
5	2. 2	0. 0009	0. 725
6	2. 33	0. 0012	0. 71
7	2. 94	0. 0012	0. 56
8	**4. 3**	**0. 025**	**0. 715**

Table 3 shows the details of the bandwidth shown in the figure. 7(a-b). Different groups can infer different results. For groups 1-4, considering the dielectric loss is all 0, the only thing that affects the bandwidth is the dielectric constant, so the conclusion could be that with the gain of the dielectric constant.

For the same materials of the lossy version and the loss-free version, like groups 2 and 6, groups 3 and 7, groups 4 and 8, the conclusion will be that increasing the bandwidth will make the bandwidth from the $S_{1,1}$ graph look higher.

Also, the bandwidth ratio is the same when the loss tangent is the same and when the ratio of the dielectric constant is the same. The rate of the bandwidth of groups 2 and 3 is 1.264, and the rate of the bandwidth of groups 6 and 7 is 1.267. The little difference would be accepted since the sample point is not large enough. This showed that the loss tangent is independent of the dielectric constant.

Considering the FR-4 material have a huge bandwidth difference, the following research will focus on the FR-4 material.

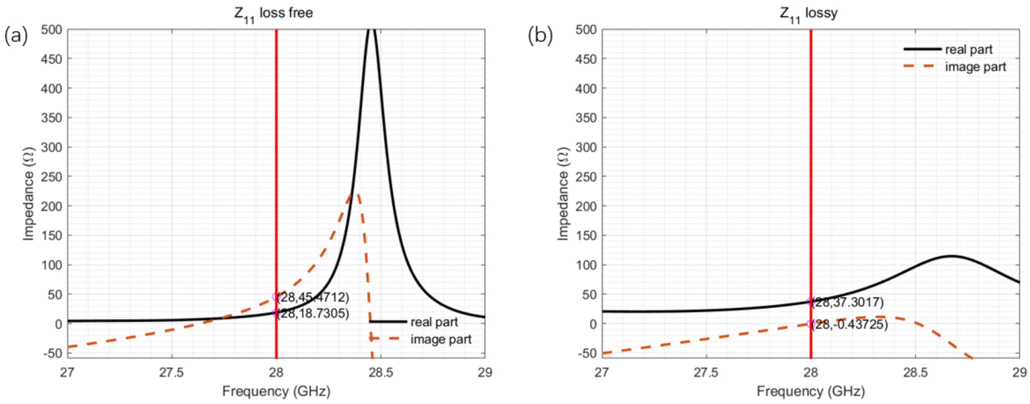

Figure 8 (a). $Z_{1,1}$ of the loss free material. (b) $Z_{1,1}$ of the lossy material

3.2 indicate that the impedance is related to the $S_{1,1}$. To find the fundamental result why lossy materials have a better performance in the $S_{1,1}$, the impedance must be analysed.

As figure 8.(a) and 8.(b) showed, the lossy material's impedance is lower overall than the loss-free material's impedance. To find the cause of this phenomenon, the patch model must be revived. As mentioned in the passage [1] and [2], the circuit model of the antenna can be reguarded as below:

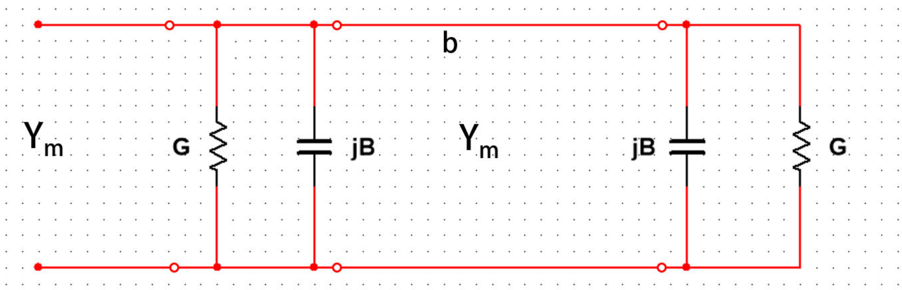

Figure 9. Equivalent circuit model

Having the lossy material is like changing the circuit's load, since the loss-free material is considered as nothing in the circuit. The impedance change can be generalized in mainly 2 ways: reducing the imaginary part of the antenna and real part. Reviewing 2.4.2, the paper [21] and [22] showed that the resistance loss lies in the resistance change, which is the change of the real part. The dielectric loss lies in the repolarization of the dielectric which is the change of the imaginary part. So the loss type can be determined, which is both resistance loss and dielectric loss.

The impedance of the lossy material is much lower than the impedance of the loss-free material.

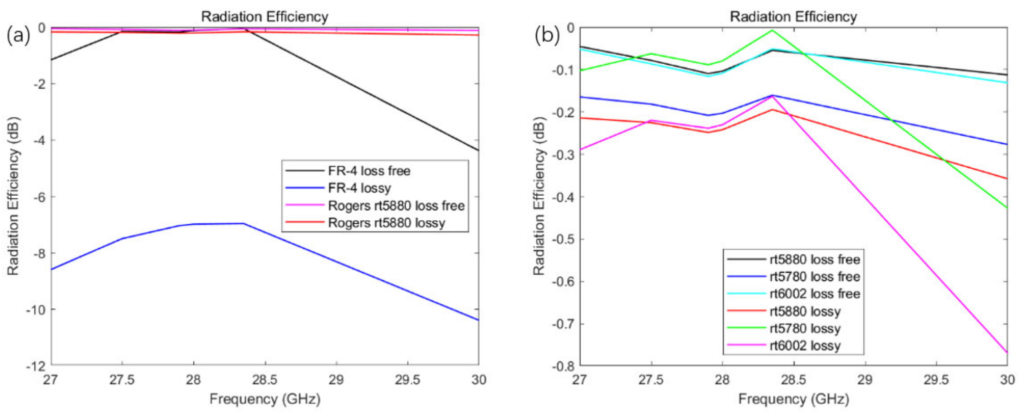

Figure 10. (a) Radiation efficiency. (b) Radiation efficiency

Figure 10. (a-b) show lossy materials have much less radiation efficiency than the loss-free materials. According to the previous part, lossy material acts like another circuit load in Figure 9. Like the circuit, some energy will be lost in the load. The radiation efficiency shows that the energy does not use for propagating the EM wave. The energy is much more absorbed by the material and turned into loss, possibly due to heat.

There is a list of the means of the difference between loss-free and lossy material.

Table 6. Radiation efficiency loss

Material	Loss tangent	Difference in Rad. Effi
FR4	0. 025	6. 9022
Rogers RT5880	0. 0009	0. 1151
Rogers RT5870	0. 0012	0. 1563
Rogers RT6002	0. 0012	0. 1907

Table 6 shows the difference in radiation efficiency will increase when the loss tangent increases. As mentioned, the difference in radiation efficiency indicates how much the substrate loses in radiating the EM wave, so the higher difference refers to the higher loss. Also, as mentioned in the previous part, the loss tangent is independent of the dielectric constant, so the disturbance in a difference of dielectric loss can be excluded. As a result, materials with higher loss tangents will have a lower radiation efficiency when using the lossy material. Researchers should always be concerned about this point when designing the antenna since it will somehow change the performance of the antenna and will make it worse.

4. Conclusion

3. 2. 1 shows that the patch designed has met the basic requirements of an antenna with 0. 72GHz of bandwidth and 8. 29dBi of gain works in the operating mode TM_{01}. Reviewing the definition of $S_{1,1}$ is important. $S_{1,1}$ shows how much energy reflects by port 1, whether the energy is absorbed by the substrate or propagated into the free space. The radiation efficiency shows that lossy materials have lower energy propagating into the free space. Loss tangents have three main types. This design has the resistance type, which will absorb energy and turn it into heat. As a result, the port's energy is turned into heat.

To sum up, the conclusion can be in two parts. The first part is that when designing the antenna, only the loss-free material can use $S_{1,1}$ to measure the bandwidth. $S_{1,1}$ in the lossy material will have a large deviation when the loss tangent is high, which indicates if the antenna is working is the far field plot and the radiation efficiency, so always pay more attention to the whole result but not to one special structure. The second part is the lossy material will have worse performance, but the performance will be better with the decrease of theδ_E. But the price will be higher with the decline in the δ_E. As a result, when designing the antenna, designers should find a balance between the cost and the loss tangent they choose.

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