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An Independently Tunable Tri-band slot antenna configuration

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Abstract* – *This paper will introduce a tunable tri-band slot antenna. This antenna can be tuned to a frequency range 650–960MHz and 1.5–2.6GHz. The aim is to design the frequency range for this antenna by making the antenna function for 4G Long-Term Evolution (LTE). It can also can for Wi-Fi, Bluetooth, Global Positioning System (GPS), if the system is designed for those functions. All the results in this paper are simulation results.

***Index Terms*— Reconfigurable antennas, reconfigurable architectures, system analysis and design, tunable circuits and devices, radio receivers, multiple band antennas, digital radio**

I. Introduction

Nowadays multi-band tunable antenna demand is increasing [1]. Therefore, making a tri-band tunable slot antenna is a sensible design by following the demand in the world. To achieve a good multi-band antenna, it should keep the antenna can tune independently. In addition, the antenna should fit on the size of the phone or a tablet. [2][3]

Many types of antenna can be tunable in a tri-band frequency range also it has been tested. For example, a square loop antenna operate at 2.37-2.67GHz, 3.39-3.58GHz and 4.86-4.98 GHz for WiMAX [4]. In [5], a three-slot antenna have three tuning range around 1.9, 3.7 and 5.5GHz.

Slot antenna is considered. Because this antenna has a simple structure and easy to mount on a ground plant. Which mean people can easy to reconfigure the design for more difference frequency.

The major part of this project is improved the design given from the start of project. The aim is remove the resonant point at 3.4GHz show on fig.2. Due to, doing the improvement of the antenna is easy to bring some side effect on the design. Therefor the design was created some addition specification on this project. Those are size, tunable range and complexity. To approach the specification, three design will be present in this paper. The first to the third design are antenna with filter, antenna with reflector and a folded slot antenna. These slot antennas all is design on a 50mm × 100mm FR4 PCB with a planar structure. To keep the improvement can work in fast, using simulation application is faster than other way. Therefore, all the work will work in the application call Computer Simulation Technology (CST).

The antenna is design on a double-side coated Printed Circuit Board (PCB) with size 100mm × 50mm× 1.6mm (L×W×H). The subtract dielectric constant is 4.3 and 0.025 loss tangent. In Fig.1 shows the antenna consist with one open-end slot and two close-end slot, the first slot and the second slot is perpendicularly to the second slot and the third slot respectively for reduce the mutual coupling. The longest slot is 26mm ×2mm (L×W) and 6 mm away with the short edge of the PCB. The second and the third slot is 15mm ×2mm, they also 1mm away to the first slot and the second slot respectively. Those slots driven by a 50 and 70Ohm combine strip-line placed behind on the PCB. The strip-line resistance is 50Ohm from the both end, but 70Ohm in the middle for feeding the second slot. The first, second and third slot are designed to resonate at 650-960 MHz, 1.5-2.2GHz and 2.2-2.4GHz respectively. In addition, 3.4-3.6GHz is in consideration. Those slots will provide three frequency bands when operating. Three tunable capacitor are design to tune those resonant frequencies separately. Those capacitors can be varactor diode or digital tunable capacitor. Varactor diode is a diode that can change the capacitance, when the voltage is change. During the capacitance is change the resonant frequency of the slot that connected will change. When the capacitance is increase, the slot will radiate at lower frequency, decrease capacitance for higher frequency. Using varactor diode and digital tunable capacitor can keep the circuit be simple to reconfigure and easy to study the design.

This prototype is given the parameter of the capacitance is 1.8, 3 and 2pF for the capacitor connect in first slot c1, capacitor connect in second slot c2 and capacitor connect in third slot c3. When changing the value of c1, c2 and c3 can tune the slot resonant frequency.

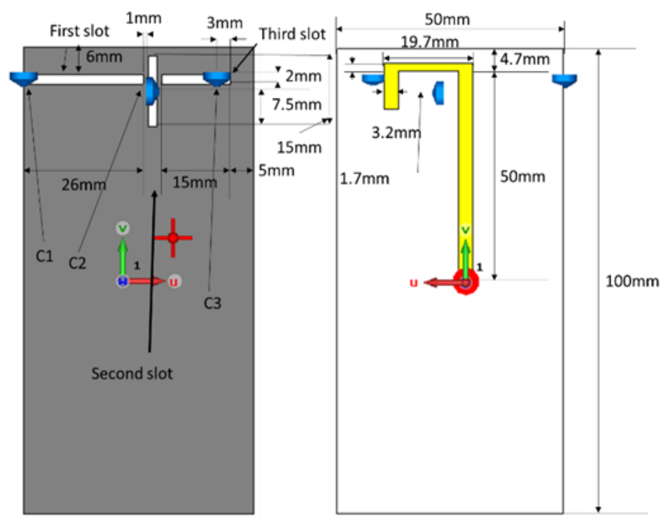


Fig 1: Prototype form the project given top (left) and bottom (right)

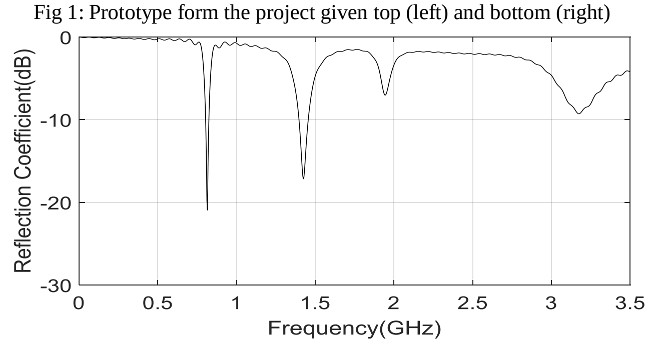


Fig.2: Reflection coefficient of the prototype (c1=1.8pF c2=3pF c3=2pF)

II. ECONOMIC, LEGAL, SOCIAL, ETHICAL AND ENVIRONMENTAL CONTEXT

The cell phone radiation effect on human body is a topic that has been researched for a long term already. According to [6] the experiment on mice shows the radiation actually can made a health cancer. However, the result is using mice to simulate human. So, it may need more study on that to prove the radiation will lead to cancer.

PCB is one of the element that ELSEE should consider. From [7] shows the solution for recycling PCB. It also mentions on the introduction that the PCB is contain heavy metal and poison material. Which this can harmful for the environment if people are not send the waste to a recycling facility. It also states the analysis of the economic evaluation for recycling PCB.

III. METHODOLOGY

This section will show the method to approach the specification mention in introduction.

A. CST program

Computer Simulation Technology (CST) is used for simulate the antenna design. CST is an application base on Maxwell's law to keep the result real. So that the university is using this application to simulate the realistic result and consider do the design can be manufacture or it needs an improvement.

To make sure the antenna design is accurate. It can increase the simulation particle in the design. This can set in the mesh view setting.

The majority to test the slot antenna is working. The reflection coefficient needs to be consider. When the Reflection Coefficient is lower than -5dB, generally the antenna is working but have some losses. When that is drop to -10dB that is mean the slot antenna is working well.

The reflection coefficient graph also can check the impedance matching. When using the CST both graphs were put in the same graph call S11. The graph of impedance matching can help the designer to design a circuit for impedance matching easily.

However, sometimes the graph from the reflection coefficient cannot give the full picture for the model. Because the graph is state the energy transmitted during the simulation. It can be a strip line resonation. To confirm the model is functional as predicted. It needs to be check by using surface current animate. This animate shows the energy flow. This also can give the idea where the energy flow to check the design is connect properly. In addition, read absolute value on surface current animate is easier to check the energy flow.

While using the CST to simulate model, it needs to add a discrete port or wave guide port for the port to determine power loss. This is the name of S11 comes from, port one in port one out. Using discrete port can tune the impedance to be 50ohm. In other word, reference impedance shows on result is 50. This can help people to determent the impedance matching on the antenna. Moreover, using discrete port can give a fast simulation but less accurate than the wave guide port. On the point of above, the wave guide port is load a longer time but more accurate. Because the wave guide port is feed in a surface. The waveguide port generally set six times the width of the strip line and five times the subtract thickness plus the ground plant thickness. In addition, the port bottom is attach to the ground edge. The method of above is used for micro strip line if using coaxial cable, it can choose the surface of the cable and put the wave guide port on the cable.

B. Antenna design

For a slot antenna, both close end of the slot represents short circuit and the middle of the slot represents open circuit. To achieve the strip line and the antenna impedance is matched. The strip line needs to move between the middle of slot and the end of slot. The slot length is represented half of the slot wavelength. In general, changing the slot size will change the frequency that generate from the slot. In this project, the tunable capacitor is added, so that the wavelength is not twice of the slot length. Furthermore, when the slot is open, the slot is not half of the wavelength.

To design the micro strip line impedance. It is proportion to the subtract dielectric constant and the width of the strip line. This can be follow by an equation. However, the CST has provided the calculator for the impedance in macro.

IV. RESULTS & EVALUATION

The first specification can be achieved by trying to filter, cancel and shift the signal at 3.6GHz. These three method has tested by three different design. Those designs designed to add a filter, reflector and folded slot respectively.

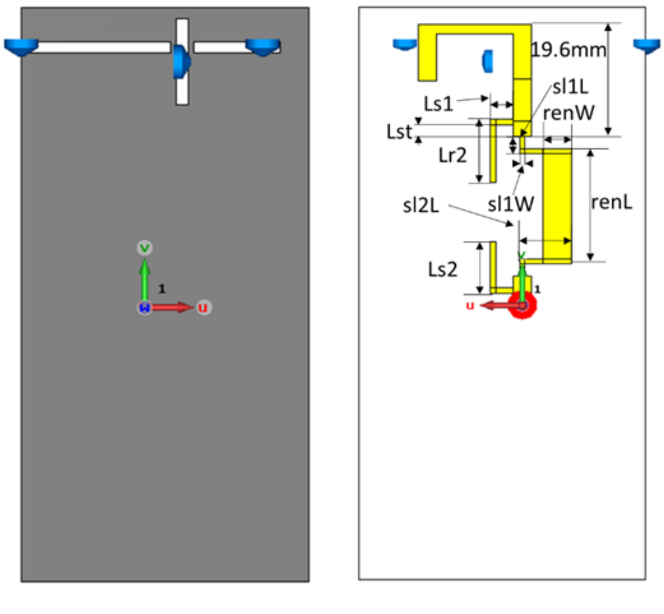
A. Antenna with filter

Fig. 3b shows the filter design and the parameter on table 1. This filter is come from [8], and it has been reconfigured to filter signal higher 2GHz. The filter was insert between the first slot and the feeding point, the strip line length is same as the prototype.

For the first design is aim to filter the signal that higher than 2GHz. From the appendix. B shows the result and the evaluation of the slot antenna with filter, it also included some result of the simple splitter. From those result shows, the filter can remove the resonant point and keep three slots working. The major problem is this design need a splitter that able to split a wide range frequency. However, to design a wide range frequency splitter, this will take a lot of time. In addition, the first design is too complication as Fig .3 shows.

Parameter name	length(mm)
Ls1	4
Lr1	4
Lr2	9
Ls2	11
Lst	2
sl1L	4
sl2L	12
sl1W	0.8
sl2W	0.8
renL	20
renW	5

Table 1: Filter parameter



(a) *(b)*

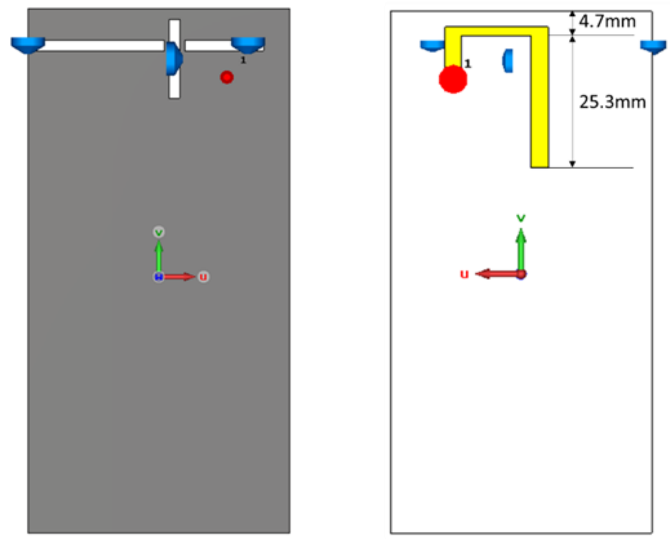
Fig.3: Filter with antenna Model

To sum up, rather than design a new splitter that work on this design, change the way to reach the specification is faster. The antenna with filter design shows the size of the strip line is going to be large, also the design is more complex. Although this design can be reach the specification easily, this design will make the design become complex and hard to reconfigure in future. From the point of above, the design needs to be simple.

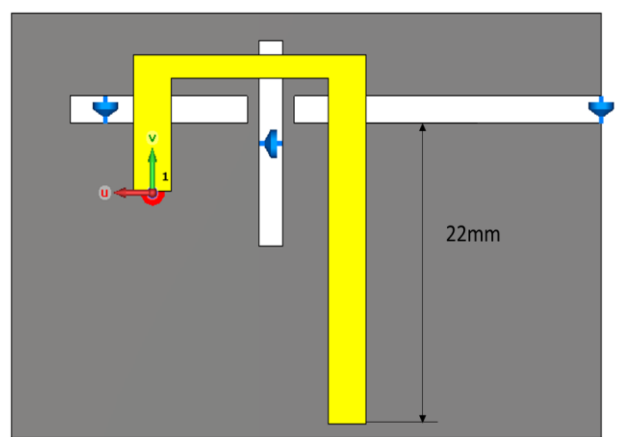
B. *Antenna with reflector result*

Therefor the second design shows on Fig.4, the design of antenna with reflector. The idea of this design is come from that when the strip line is reach the edge and nowhere to dissipate the energy, the energy will reflect. As the Fig.4 shows the distance between the strip line and the slot is 22mm. In other words, the strip line is a quarter wavelength of 3.4GHz. Therefore, the 3.4GHz signal will cancel at the first slot. Because the strip line is design to reflect the signal, so that the feed point is change to feed on the other side. After this, the positive peak and negative peak will collide on the first slot to achieve the signal cancellation on the design. Moreover, this design was keep most the design except the change that mention, it means the design complexity is not increase too much.

The second design shows from Fig.4 and the result of reflection coefficient shows on Fig.5. The resonant frequency around 3-3.5GHz is disappeared. Moreover, the result shows the antenna has three different resonant frequency, they are 0.81, 1.41 and 1.68GHz. These resonant frequencies are represent to three different slot radiation. As the Fig.6 shows the surface current on 0.81, 1.41, 1.68 and 3.6GHz. From Fig.6(a) can see the first slot is surrounding a red color. That is mean the slot is radiating, because when the slot antenna is generating wave the high peak and lower peak is on the top edge and bottom edge respectively. In addition, the surface current on Fig.6 is an absolute value measurement, so the figure can only show the red is surrounding on the slot. The first three figure from Fig.6 is showing the slot is functioning at the frequency shows on Fig.5. The final graph is checking will the first slot resonate while at 3.6GHz. It shows the strip line has resonate. While the strip line is resonating, the surface current at the first slot is small. The current is around 0.555A/m. Therefor the first slot cannot feed by the strip line, this is successful to stop the first slot radiate at 3.6GHz.



(a)



(b)

Fig.4: Antenna with reflector (a) top (left) and bottom (right) view (b) reflector location

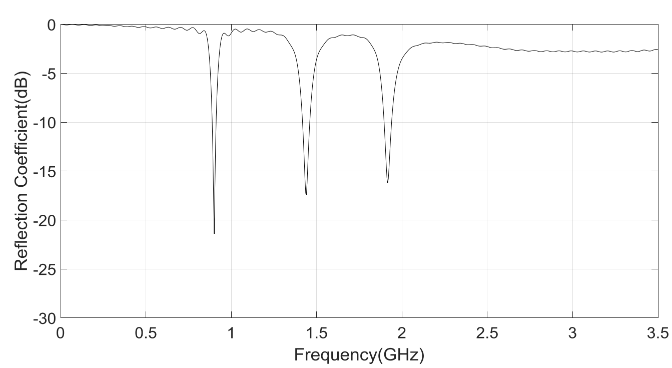
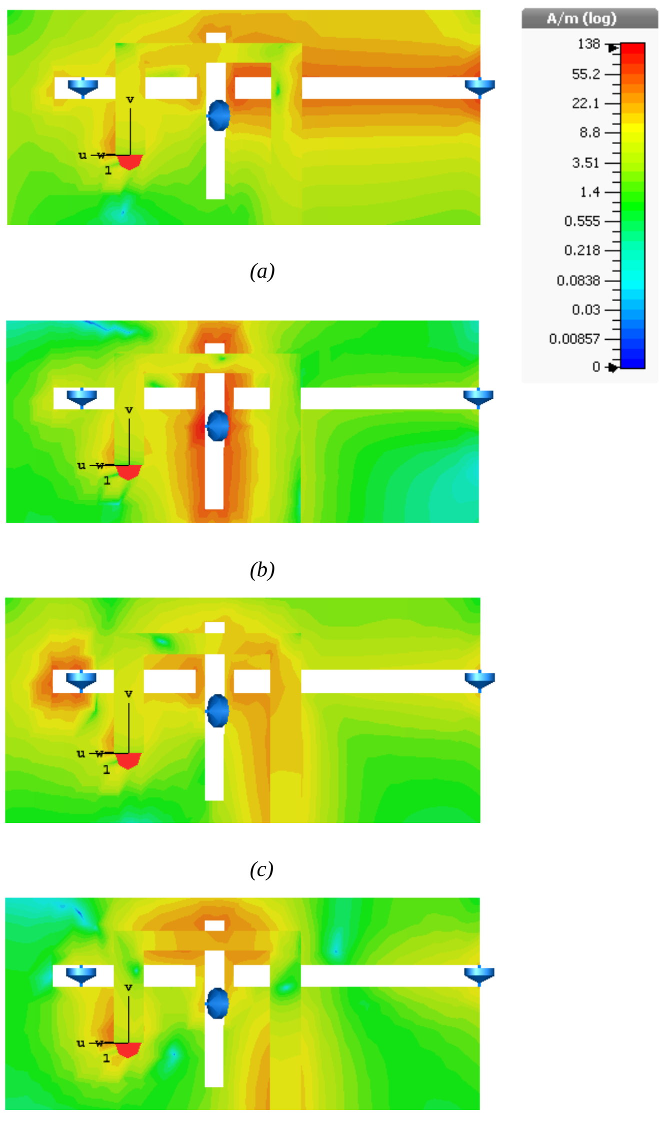


Fig.5: Second design reflection coefficient (c1=1.8pF c2=3pF c3=2pF)



(a)

(b)

(c)

(d)

Fig.6 : surface curent of the second design (a) 0.81GHz,(b)1.41GHz (c) 1.68GHz (d)3.6GHz (Right)Scale of the surface current.

To consider the tuning range of the design. Appendix.A Fig.1 is showing the tuning test from each different slot. Appendix A Fig.1(a) shows the first slot is working well at 0.6-0.96GHz, when c1 was tune from 1.3-3.3pF. Moreover, the second harmonic resonant frequency is keep cancel during first slot is tuning at 0.6-0.96GHz. Those slots are not having any mutual coupling. However, the second slot and the third slot is not able to tune at 2-2.2GHz as the Appendix A Fig.1(b) and (c) shows. The second slot can work on 1.326-1.938GHz by tuning capacitance from 1.3 to 3.3pF. This is showing the second slot has a possibility to work in a lower frequency. The third slot on second design only can tune from 1.8-2GHz. Nonetheless, the third slot can tune around 3.4-3.6GHz when the capacitance is around 0.3-0.5pF. This is showing the third can be consider working in 3.4-3.6GHz rather than using the third slot radiate at 2.2-2.6GHz.

Overall, the second design is good for keeping the signal separate. Moreover, the resonant point of the second harmonic frequency from the first slot is cancel and the size is smaller than the prototype design. However, due to lake of the range tunable for the second slot and the size of the strip line, this design still need an improvement.

C. Folded slot antenna

From the specification that given. The second design is fit the specification well. Although the size of the second design is smaller than the prototype design. If the size of the third design become the smallest design, it helps the phone designer to have more flexibility to put the antenna in the phone. Moreover, the design is aim to evaluate to be a multiple slot antenna for 5G. If making a minimize size model, this will be helpful for further design, such as add more slot. Therefore, the third design was considered, folded slot antenna.

On the third design in micro strip line, the strip line feed for the first slot is change to feed 1mm away the c1. Therefor the first slot feed line is feed away than the original design, the 70Ohm strip line sl2 part is extended to 26.2mm × 1.7mm (L×W), this length is included to two 3.2mm strip line connection. So, if only measure the part of 70Ohm line is 19.8mm. The 50Ohm strip line feed for the first slot sl1 and the third slot sl3 except the connection part are 9 mm and 8.3 mm long respectively.

On the design of slot, the first slot is 22 mm long for the inner length and 30 mm long for outer length. The slot is double folded, the first folded at 13.5mm that bends down, second folded on 7.5 mm away the outer bend point 3.5 mm away the inner bend point that bend left. The second slot and the third slot and the strip lines for the third slot and second slot were shifted left 12.5mm.

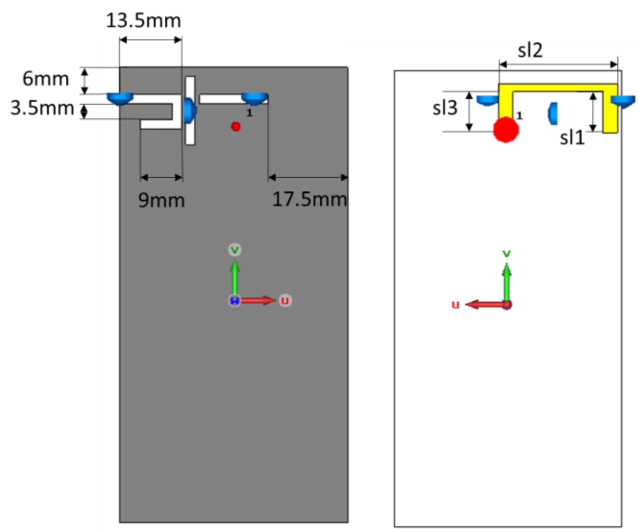


Fig.7: First slot folded antenna top (left) and bottom(right)

For the third design is aim to fold the first slot to increase the gap between the first harmonic frequency and the second harmonic frequency. The ideal situation is the second harmonic resonant frequency was shift to 4.2GHz. The majority limitation in this design is the first slot second harmonic frequency cannot shift to 4.2GHz. Because the problem of space and complexity. If the slot keep folded deeper to the slot end, the slot will be double feeding. When the first slot is double feeding, the design is become more complicate. Although the design can consider folding the first slot three or four times to avoid double feeding, but this will change the complexity also.

The result from Fig.8 shows the third design Reflection Coefficient, this result shows those slots are radiant at 0.81, 1.4 and 1.67GHz. Because the limitation of the tunable range, the third slot capacitance is change to c1=1.8pF, c2=3pF and c3=3pF. The Fig.9 shows the slot able to work at three difference frequency.

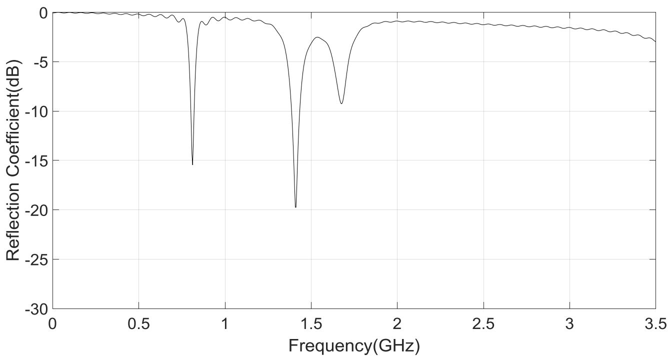
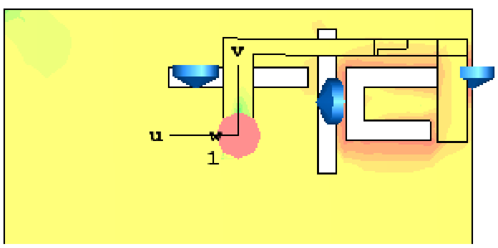
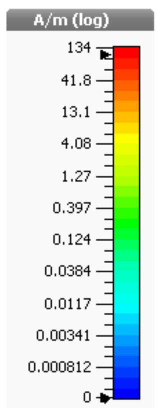
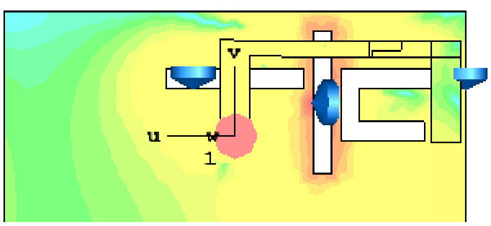


Fig.8: Reflection coefficient of the folded slot design

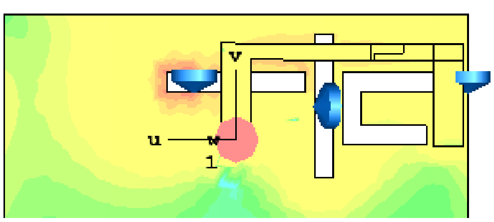




(a)



(b)



(c)

Fig.9 : Surface current of the third design(a) 0.812 GHz (b) 1.408 GHz (c) 1.676 GHz

The result of tuning capacitance. Appendix.A Fig.2 shows the first slot cannot work in a separate slot. From Appendix.A Fig.2, when the first slot capacitance change, the second harmonic resonant frequency shifted. Moreover, the third slot reflection coefficient was affect by mutual coupling. On the other hand, the second slot is working in a wide range frequency from 1.5-2.6GHz. Nonetheless, the third slot is working only few frequency ranges from 1.5-1.8 and 2.6GHz. This design has simulated the third slot to radiate around 3.4-3.6GHz. However, when the third slot antenna capacitance around 0.3-0.5pF, the reflection coefficient cannot show the third resonant frequency.

In conclusion, if ignore the third slot, the first slot and the second slot are fully functional. In addition, the size and the complexity of this design is small and simple. Because the strip line is shorter than before. Moreover, the first slot folded means the antenna became smaller. Furthermore, the design does not have any component add on the antenna, so the design complexity is not change.

V. Discussion

To discuss the project, the first improvement is far away worse than the second and the third improvement. Therefore, the major comparison in the project is the second design and the third design. Between both designs, it needs to consider the specification mentioned in the introduction. In size and tunable range of the third design is better. Because the second design have a long strip line also the tuning range shows at Appendix.A Fig.1 is not ideal. However, if consider above resonant frequency removal, the second design is doing a better job. Because the resonant frequency will not appear again when the first slot capacitance change or other relevant situation. In complexity, both look the same, because those designs are changed part of the design, but it has not add any circuit or component in to both designs. Nevertheless, consider the further improvement, the second design may better the third design. From the Reflection coefficient graph of the first slot shows on the second design and the third design. The third design resonant point has a potential to affect the signal at 3.4-3.6 GHz. Moreover, the design of folded slot has a limitation that mentioned on the result. If the antenna going to add more, the slot rotation angle may not enough for all slot. Overall, the second design has more possibility to work on more different frequency slot, but the third design may more suitable to work on three difference frequency.

VI. Conclusions

Finally yet importantly, this project is successful to remove or shift the resonant frequency at 3-3.5GHz by compare with the prototype design. However, those solutions have some limitation of the tuning range and size. From the prototype design and the result on above shows, this project has a lot of possibility to work in more different frequency range in one feed line. These simulation data can be reference to the remind project and accelerate the process. In addition, once this project is finished. This design fit the demand of the market require.

VII. Future Work

From second and third design, both design have their strength and weak point. To make the second design be better. It should increase the range of tuning frequency. Another design is increase the gap between first harmonic frequency and second harmonic frequency, also reduce the mutual coupling between the third slot and the first slot. Therefore, to improve the second and the third design, it can increase the 70 Ohm strip line length and rotate the third slot respectively. Because the result shows in section 4. The second design is worked by cancelling 3.6GHz wavelength by using the reflector, it is possible the wave length of 2-2.2GHz is cancelled at the second slot position. Viewing the third design result shown that the first slot resonant frequency shifting lead third slot frequency shift and the reflection coefficient is change also. So by rotate the angle between this three slot will improve the tuning range of this three slot antenna as the prototype design does for the first and the second slot.

. From the Appendix. A Fig.3 shows the second harmonic was shift to 3.9GHz, but when the strip line feed to the first slot length (sl1) change, the first slot Reflection Coefficient was decrease and the third slot Reflection Coefficient was increase. This may need to have a more testing to see do the mutual coupling can reduce by modify the strip line on the first slot.

VIII. References

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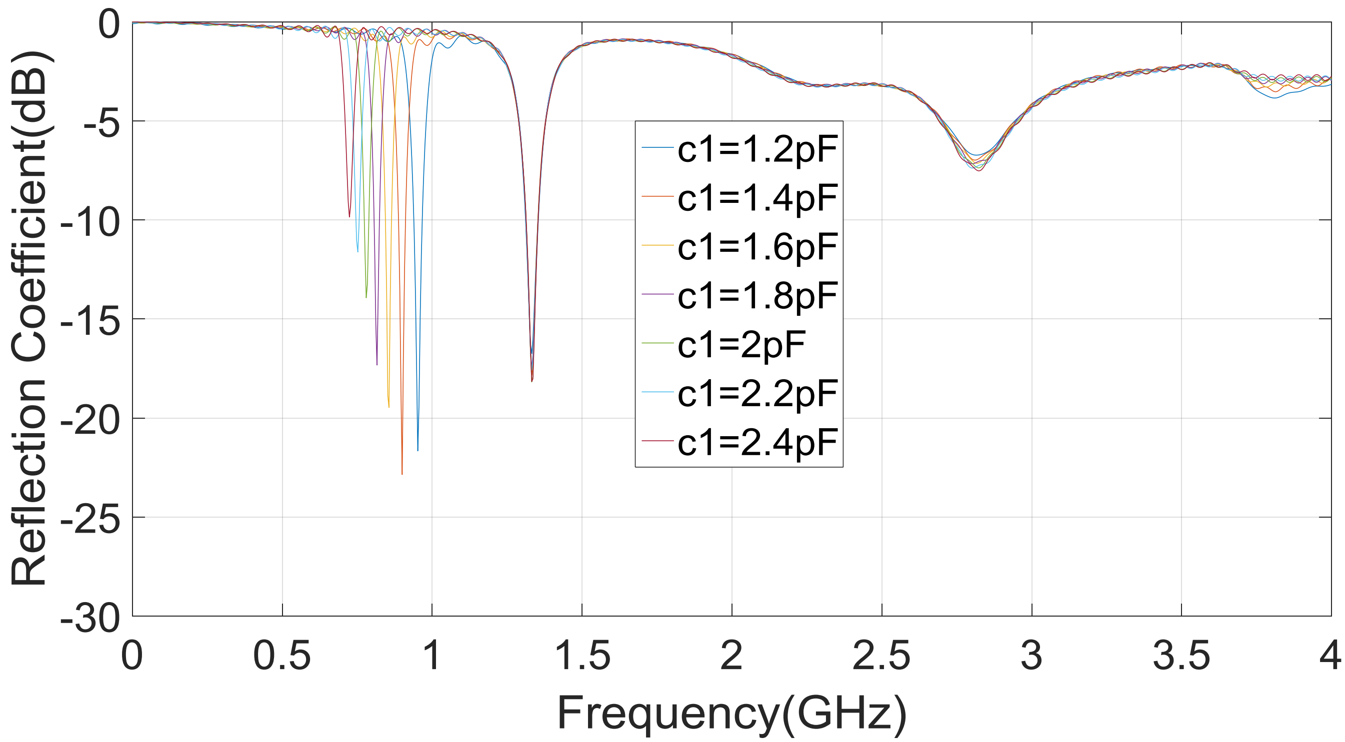
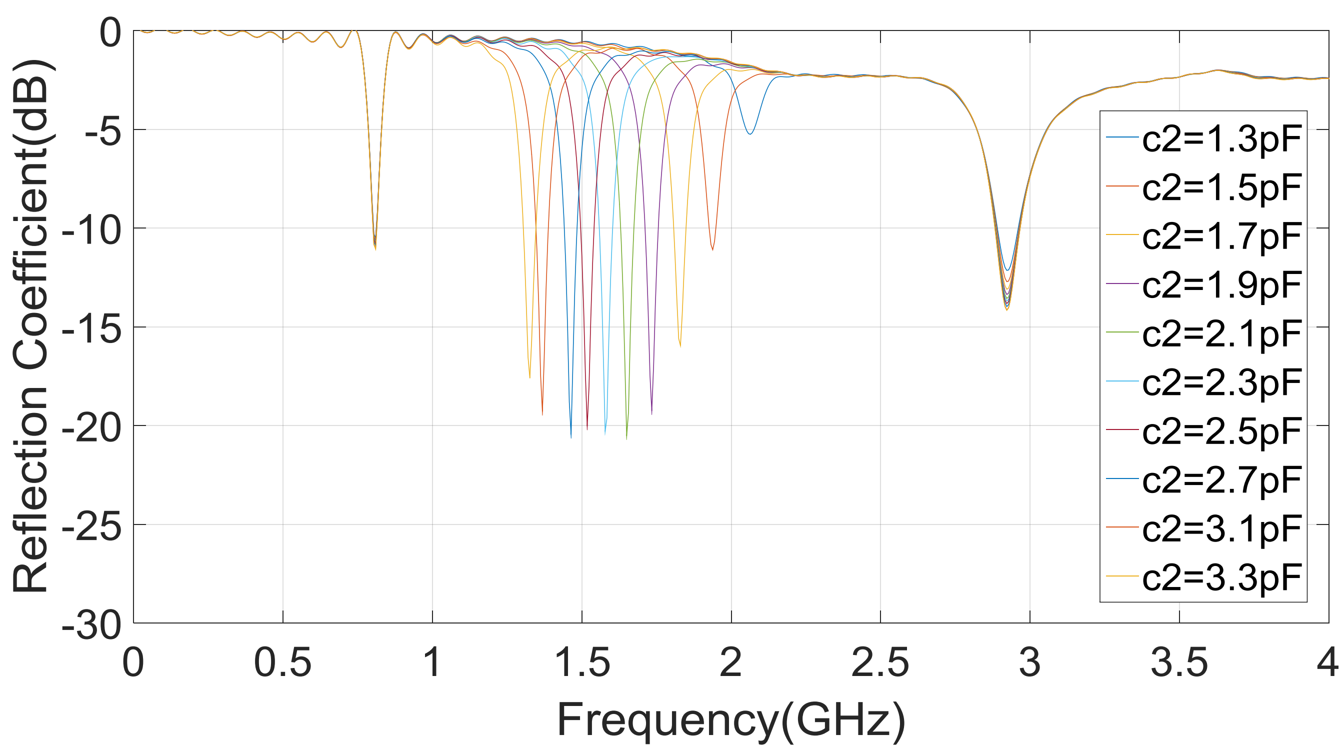
Appendix.A addition figure



(a)



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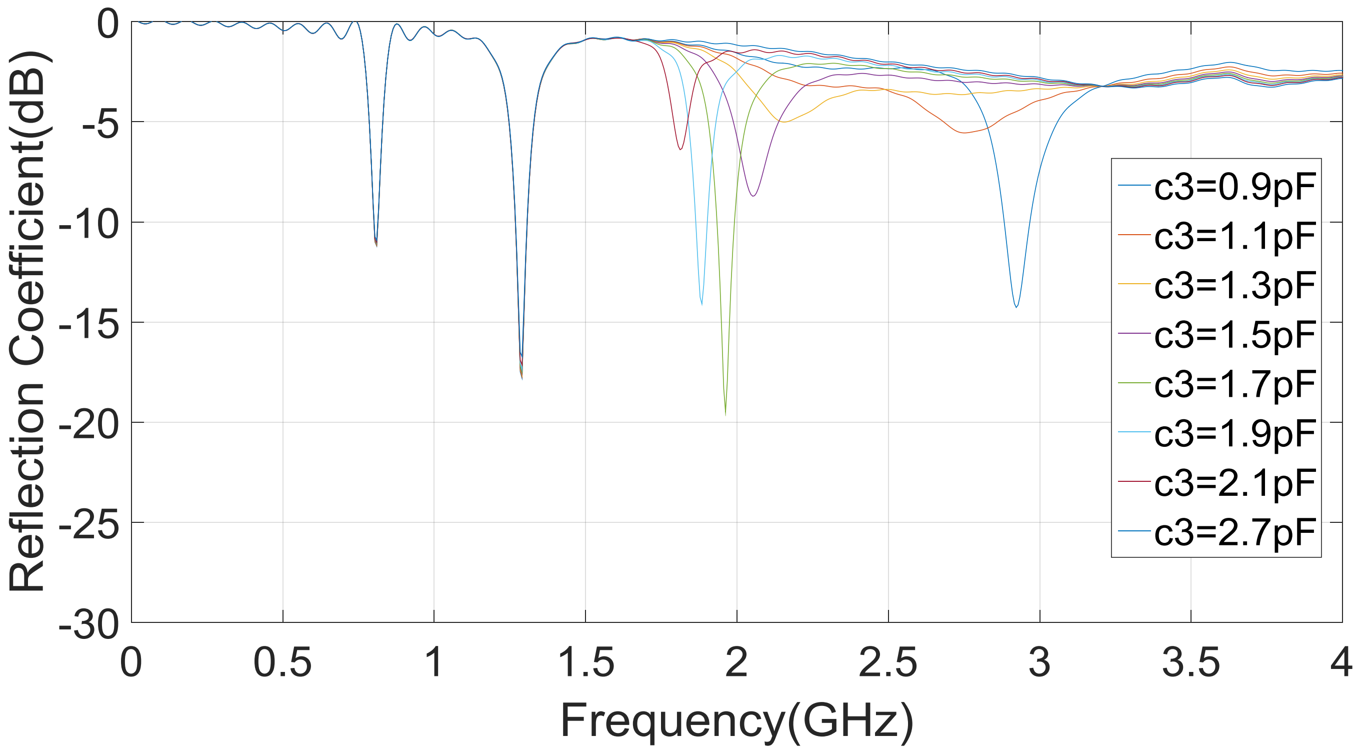

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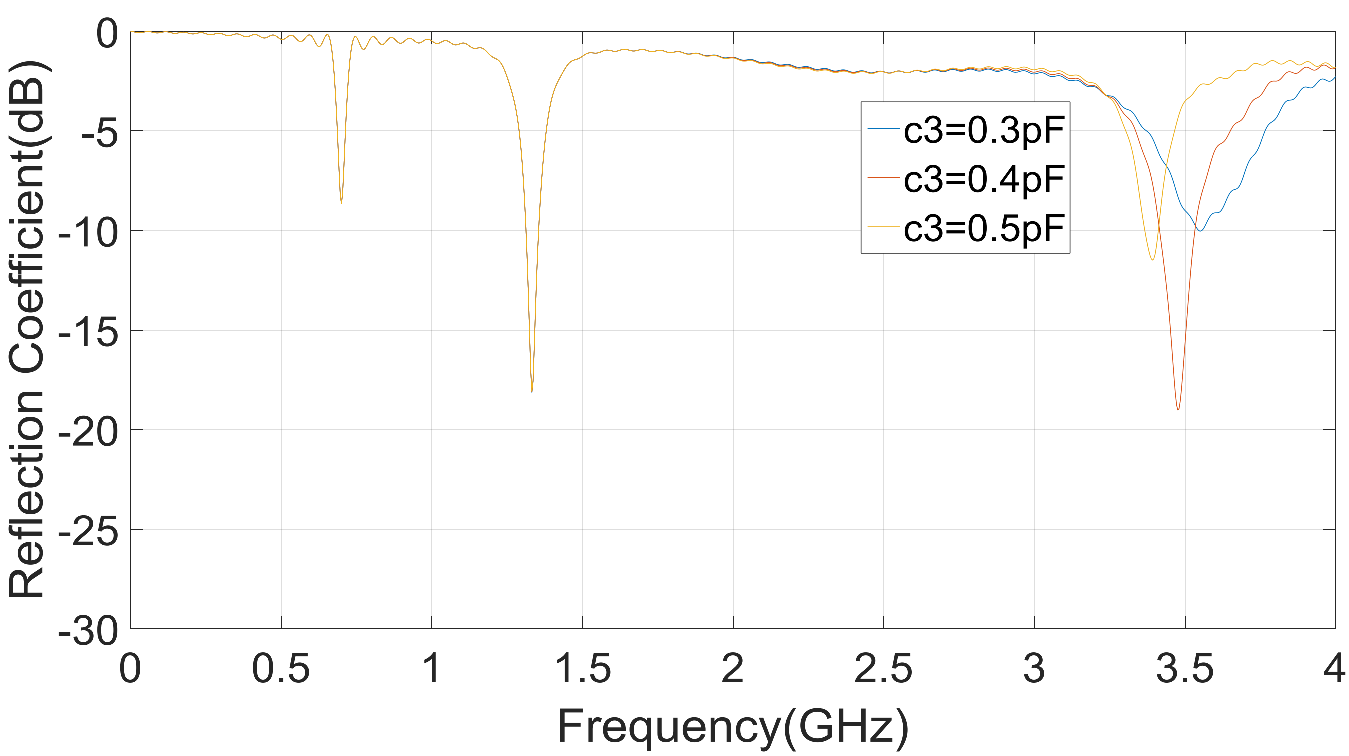
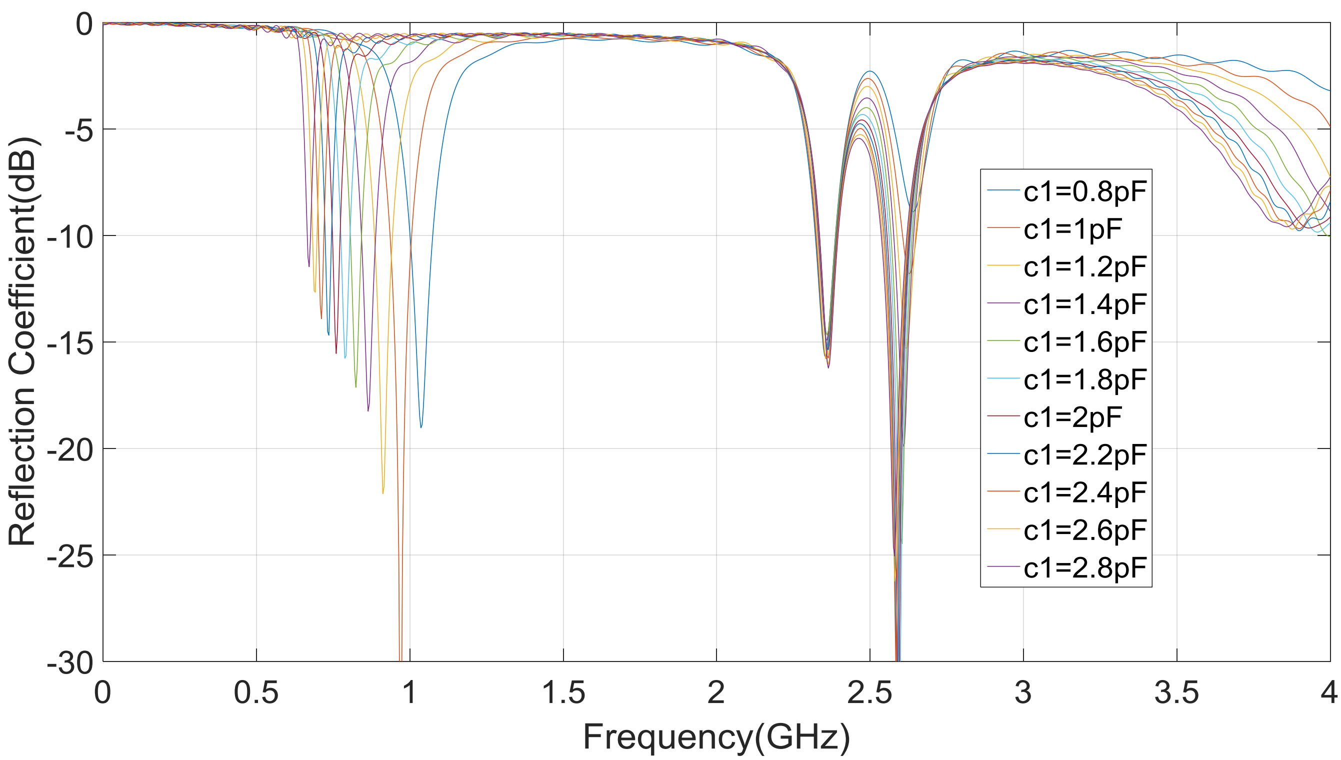
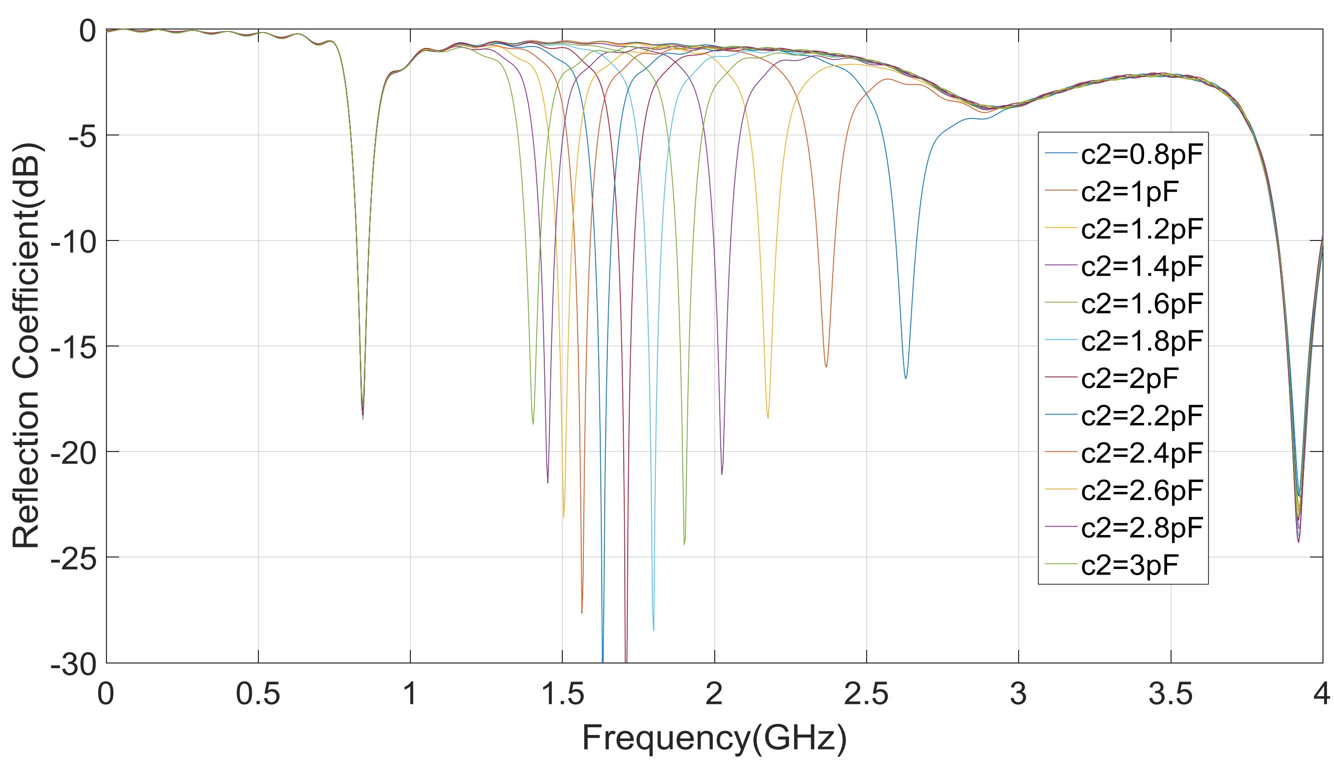


(d)

Fig 1: second design capacitance change (a) first slot (c1=1.2-2.4pF c2=3.5pF c3=1.15pF) (b) Second slot (c1=1.8pF c2=1.3-3.3pF c3=0.9pF) (c) Third slot (c1=1.8pF c2=3.35pF c3=0.9-2.7pF) (d) Third slot (c1=2.6pF c2=3.5pF c3=0.3-0.5pF)


0
-5
-10
-15
-20
-25
-30
Reflection Coefficient(dB)
0
0.5
1
1.5
2
2.5
3
3.5
4
Frequency(GHz)
c1=0.8pF
c1=1pF
c1=1.2pF
c1=1.4pF
c1=1.6pF
c1=1.8pF
c1=2pF
c1=2.2pF
c1=2.4pF
c1=2.6pF
c1=2.8pF

(a)


0
-5
-10
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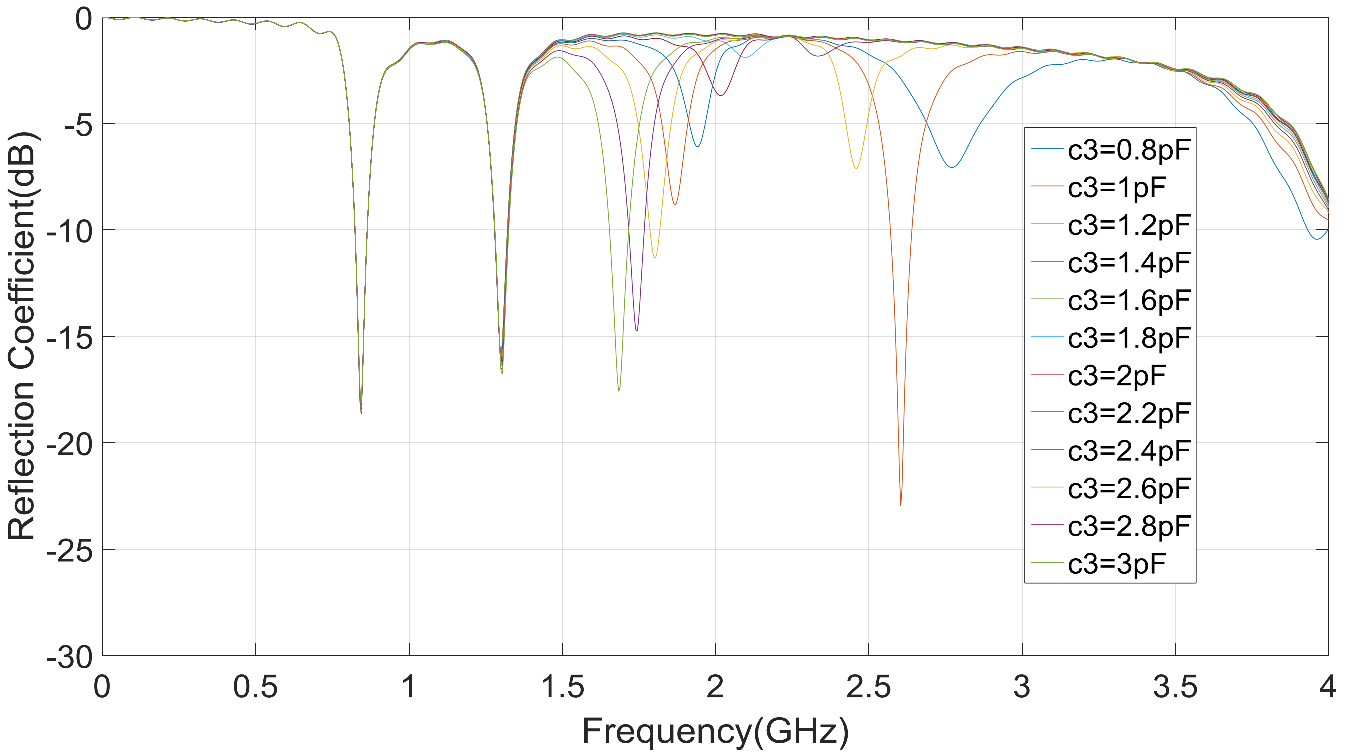
-20
-25
-30
Reflection Coefficient(dB)
0
0.5
1
1.5
2
2.5
3
3.5
4
Frequency(GHz)
c2=0.8pF
c2=1pF
c2=1.2pF
c2=1.4pF
c2=1.6pF
c2=1.8pF
c2=2pF
c2=2.2pF
c2=2.4pF
c2=2.6pF
c2=2.8pF
c2=3pF

(b)



(c)

Fig.2 Reflection coefficient of changing capacitance on the third design (a) First slot (c1=0.8-2.8pF c2=1pF c3=1pF) (b) second slot (c1=1.5pF c2=0.8-3pF c3=0.6pF) (c) third slot (c1=1.5pF c2=3.5pF c3=0.8-3pF)

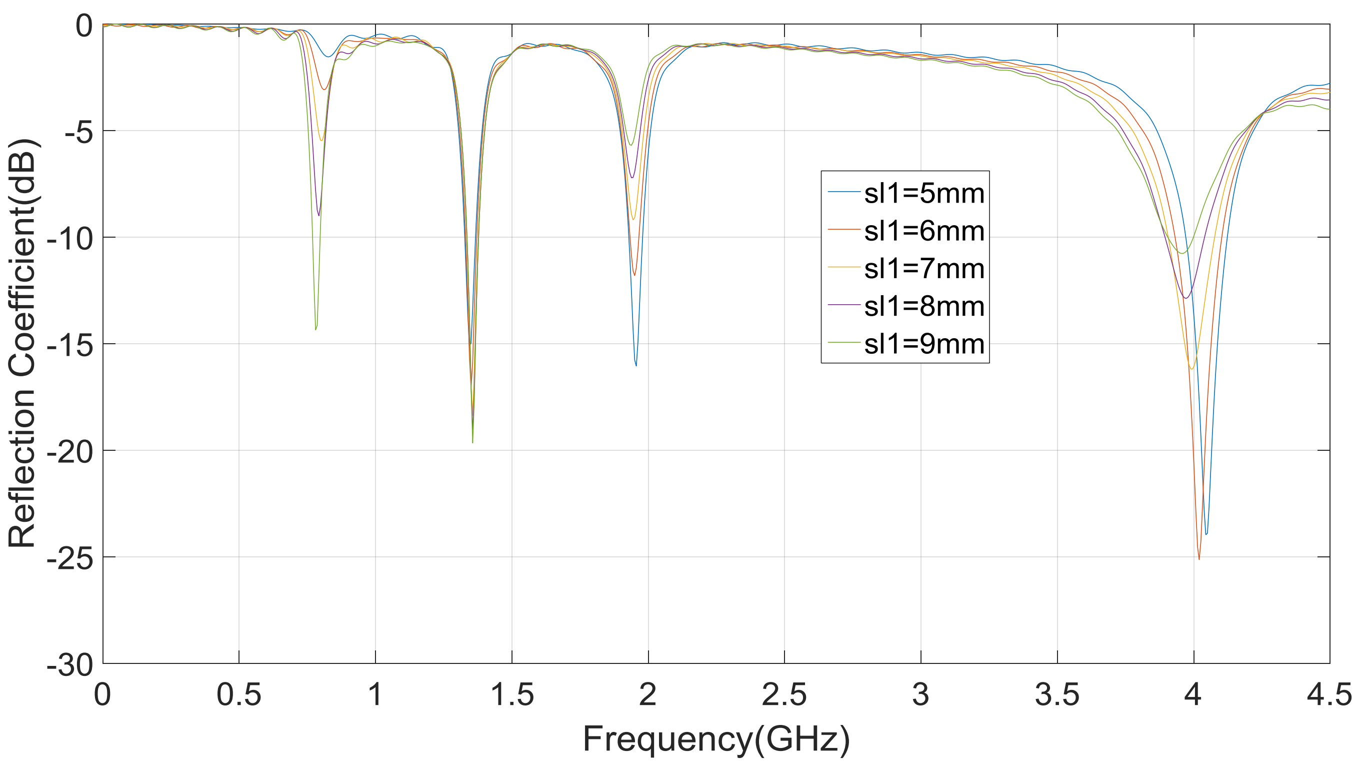


Fig.3: Reflection coefficient of changing sl1 on the third design

Appendix.B Interim Report

ANTENNAS WITH FILTERS

Contents

1. DESCRIPTION AND AIM OF THE PROJECT

This project aims to make a filter in an antenna composed of three slots operating at three separate frequency bands. The antenna is required to radiate signals in the frequency range 800MHz to 3000MHz covering the LTE mobile telephone bands. However, due to the lengths of the slots there are issues with overmoding of the longest slot antenna. The major problem is when the antenna needs to transmit the highest range of frequencies (3000MHz signal), 2 slots are activated at the same time (Figure 1.5). Because 2 slots are resonating at 3.18GHz, so the radiant pattern will have some holes. This is not good for a mobile phone antenna, because the mobile phone antenna should have a low directivity (omnidirectional). From the point of above the first slot should not radiant in 3.18GHz. So this project will develop Micro-strip filters to stop the high frequencies. In addition, those slots are designed to be adjustable around 0.7-3.5GHz.

Figure 1.1 is the prototype of the antenna.

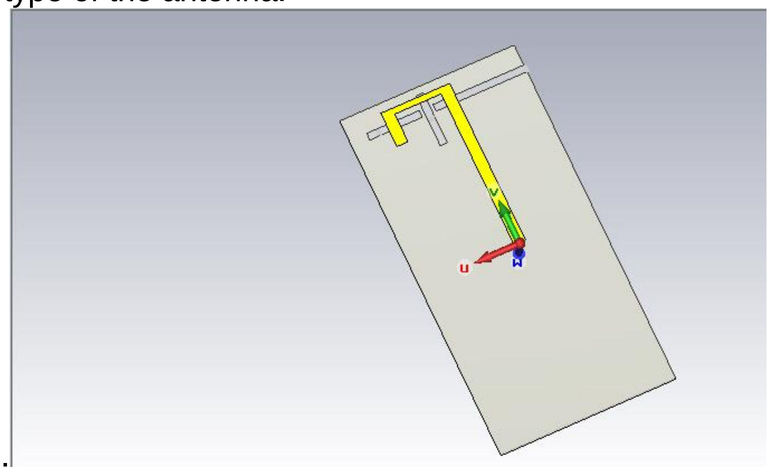


Figure 1.1: 3 slots antenna model

Figure 1.2-1.4 shows the antenna radiate at 0.812, 1.42 and 1.94GHz from the long to the short slot. Figure 1.5 shows both slots are resonating.

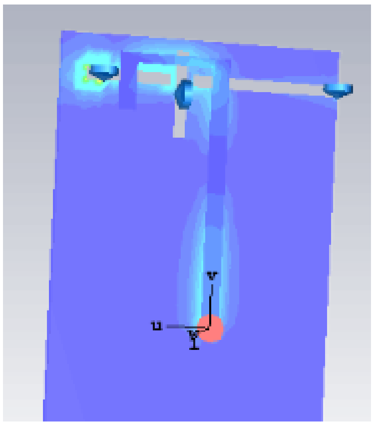


Figure 1.2: surface current in 1.94GHz

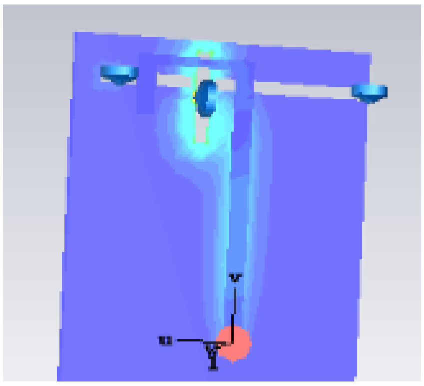


Figure 1.3: surface current in 1.42GHz

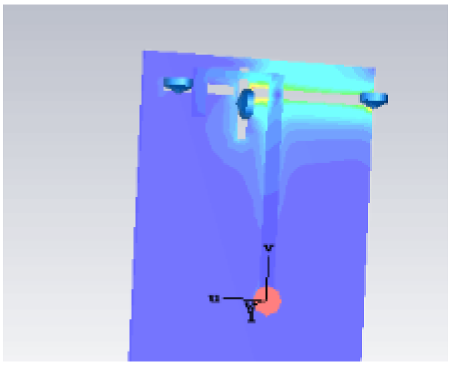


Figure 1.4: surface current in 0.812GHz

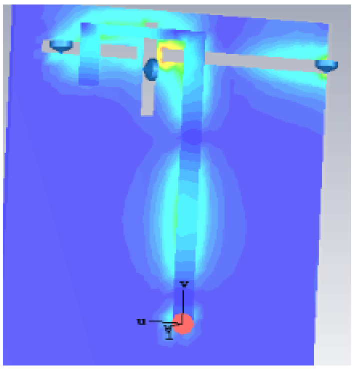


Figure 1.5: surface current in 3.18GHz

Here is the S11 graph which is represent to Figure 1.1 model. Also the graph shows 4 drops as you see. Those means the slot is activate at that frequency. The detail information of these frequency shows from Figure 1.2-4.

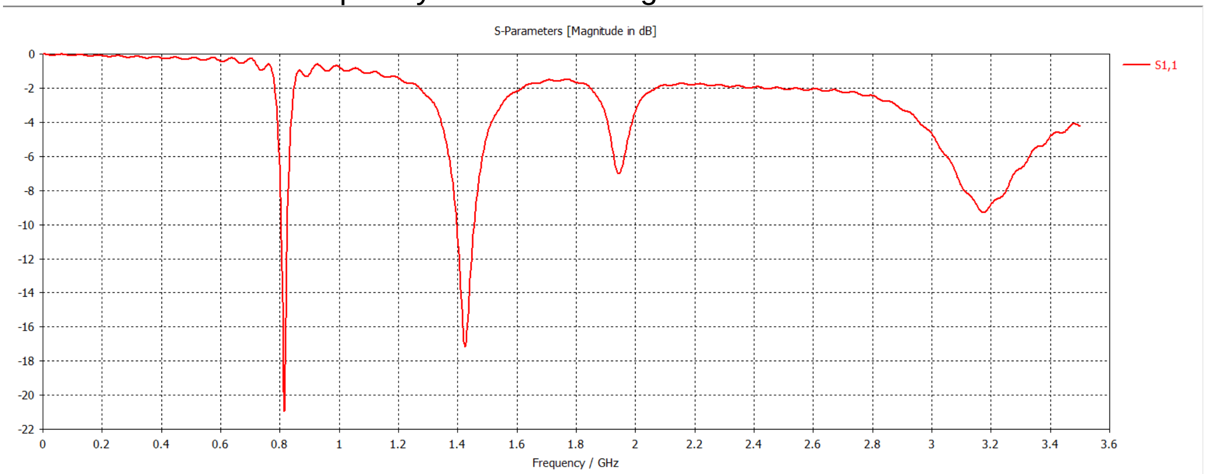


Figure 1.6: S11 of the Figure1.1 model

2. BACKGROUND

2.1 Slot antenna

Babinet's principle, this is the theory of the slot antenna. The slot antenna is appropriate to the dipole antenna design. However the slot is mount on a metal, the metal represent a ground. To make the slot antenna work, it needs substrate and micro-strip line. Send the signal to the micro-strip line, the line will feed to the slot. The length of the slot will resonant with half-wavelength of the frequency. Moreover the slot antenna radiant pattern is roughly omnidirectional. In other words the slot antenna is prefect for working on the phone, because the phone needs to receive a signal in any direction. [1][2][3][4]

2.2 Filter

The micro-strip filter is made of few lines of metal. Those lines are represent to capacitors and inductors to be a circuit that filters at different frequency. To know the value of inductance and capacitance in the filter. We need to measure the length of the metal lines that is 90 degree bend. When the line is longer the inductance is larger. Moreover the small gap between the lines are represent a capacitor. By measure the gap size, it can calculates the value of capacitance. So that the filter becomes a LC circuit to stop the signal pass in a high frequency.

2.4 Splitter

The splitter is a Y shape line which made by metal. That allows the signal to go to two different places. By using the splitter that helps the high frequency signal not reach to the 1st and 2nd slot but arrive to the 3rd slot. So that the 1st slot antenna not resonant at 3 GHz.

3. PROJECT SPECIFICATION

The project is required to adjust the 3 slots antenna not to resonate 2 slots at 2.5GHz to 3 GHz by using microstrip filter(s). In addition, the antenna is designed to self-adjustable frequency antenna by changing the capacitance in the slot. From the point of above, the filter designs to stop 2 GHz frequency. Also to make the 3rd slot radiant around 2-3 GHz, it needs a splitter to bring the signal to the slot, because one of the strip line is stopped the signal at 2 GHz.

The specification of the filter is ensure that the S11 (port 1(transmit) to port 1(receive)) and S12 (port 1 (transmit) to port 2 (receive)) is lower than -15dB in different frequency (S11 0.1GHz-2GHz, S12 2GHz-3.5GHz). When filtering 2GHz signal, the S11 and S12 parameter needs to rise from -10 to 0 dB (S12) and drop 0- -10 dB as fast as possible, (less than 500MHz). Because when the S11 is lower than -15dB at 0.1-2GHz means the signal is sending inside the device strongly. When S12 is 0dB, it means the port 2 is rejecting the signal at 0.1-2GHz. This can be ensure the signal is actually sending to the slot. When the signal frequency is 2-3.5GHz, this is the same saturation but opposite value apply to S11 and S12. The S11 needs to be 0, but S12 is less than -15dB.

When the signal is not filtering fast, it means the signal transfer is more unstable. Also the speed is slow, it will make the S11 and S12 not going to a good value like -5- -10 dB. So keeping smaller area to the band means smaller affect to the filter.

4. METHODOLOGY

4.1 Filter

4.1.1 Research from journal

The filter prototype comes from the journal. Figure 4.1.1-4.1.3 shows the circuit, model and S11 in the journal respectively. Figure 4.1.3 shows this filter stop 3GHz frequency signal. However the specification requires to stop 2GHz signal. So the filter needs to adjust the metal length of the design to have a perfect capacitance and inductance, which helps the filter to stop signal frequency at 2GHz. [2]

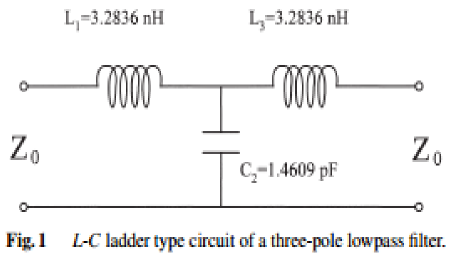


Figure 4.1.1: Low pass filter circuit

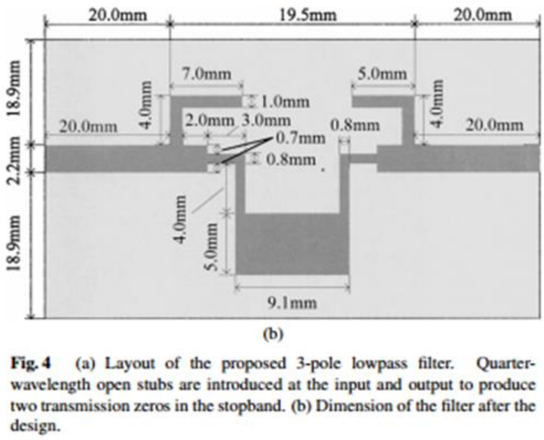


Figure 4.1.2: Low pass filter model

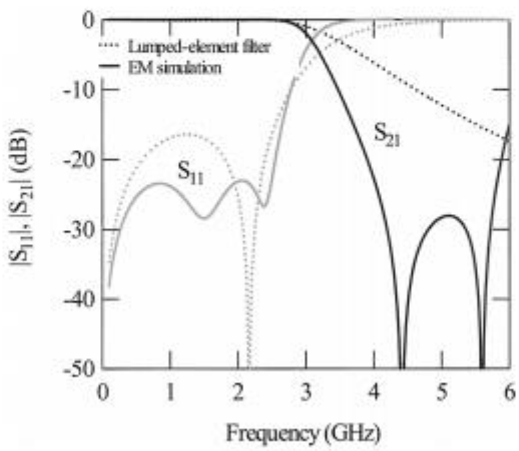


Figure 4.1.3: Low pass filter model S11

4.1.1 Cut off frequency design (adjustment)

From Appendix. A shows how to make the filter can stop the signal at 2GHz. From the result of simulation shows when sl1L, sl2L, renL, ls2, lr2 length is increase, the cut-off frequency is decrease. In addition, changing lst can decrease the cut-off frequency, but it increase S11 at 2GHz, which means when lst length is increase filter cannot transfer the signal below 3GHz perfectly. Figure A.2 shows the change of ls1 and lr1, when these parameter change, it gives a good S12 (drop lower) but result a bad S11 (rise higher). By consider all the result above lst, ls1 and lr2 were kept as the result from the journal. But adjust the sl1L, sl2L, renL, ls2, lr2 parameter to make the filter stop 2GHz frequency signal. These result is reasonable, because as figure 4.1.1 shows the filter is link to the inductor, and the capacitor is link to the ground. If the frequency is increase the capacitor will become short circuit than the signal is send to

the ground, else the signal will be pass to the other end. The action of increase renL is increasing the capacitance and make the short circuit frequency become low. The CST result is showing reasonable result as the circuit prefer. Also the length of sl1L and sl2L increase leads the frequency shift left more. This is the same saturation to increase the length of ls2 and lr2.
To make the filter S11 and S12 rise and drop faster. All possible combinations are tested in order to decrease the switching band (1.8-2GHz) range. Because the result is too many, so the result is not able to show in 20 pages report.

4.2 Splitter

4.2.1 Splitter prototype

This section will describe about splitting the signal in two. By using a splitter to send the signal to different strip lines, than the strip lines feeds different slots, those slots will receive different frequency range and radiant. Generally, the splitter is required be a 50 Ohms and 100 Ohms design. However, this is a sample that for understanding the behaviour and give an idea with a simple design. After fully understand the circuit and behaviour, the model will designed the splitter send from 50 Ohms strip-line to 100 Ohms strip-line.
The model from Figure4.2.1 can split quiet well, the result shows in Figure 4.2.3 as the S11 parameter.

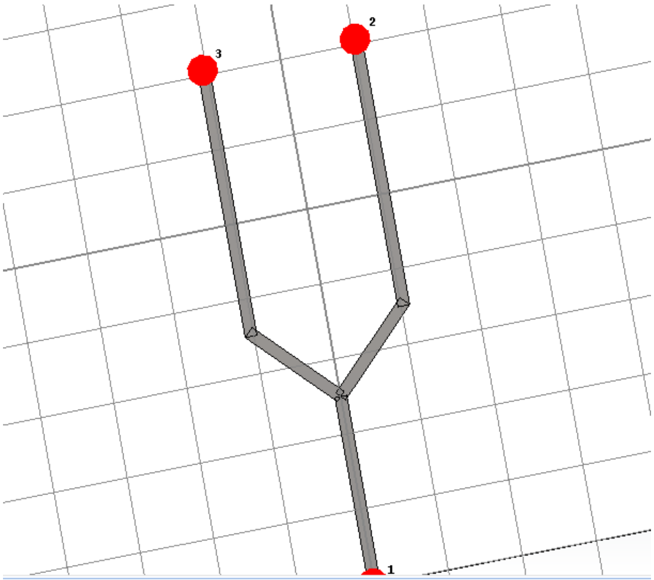


Figure 4.2.1: Splitter model (without filter)

Figure 4.2.2 shows the splitter simulation result. Because it is difficult to see each different parameter, so figure 4.2.3-4.2.5 is the different S parameter result.

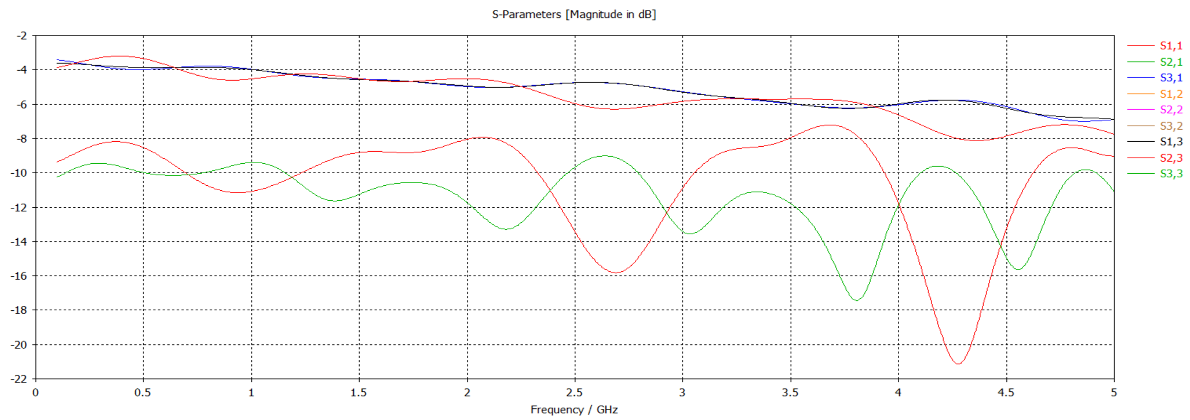


Figure 4.2.2: Splitter result (All)

Figure 4.2.3 shows the S11, S22 and S33. S22 was covered by S33, this is reasonable because S22 and S33 is symmetric, so that the S parameter have a similar saturation to transfer the signal.

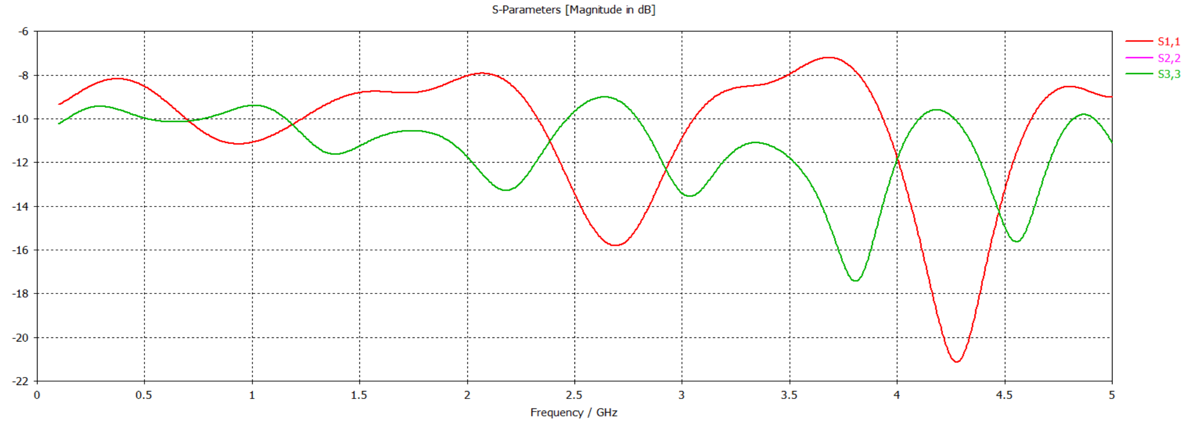


Figure 4.2.3: Splitter result (S11 22 33)

Figure 4.2.4 shows the parameter of S12 21 13 and 31 these all value is represent to port 1 transfer. In addition, these parameter is quiet similar, which mean the splitter is not lead the signal have any huge tolerance between both lines. Figure 4.2.5 shows the S32 and S23 parameter. These parameter not actually need to be consider, but this is another way to prove the splitter is splitting signal well.

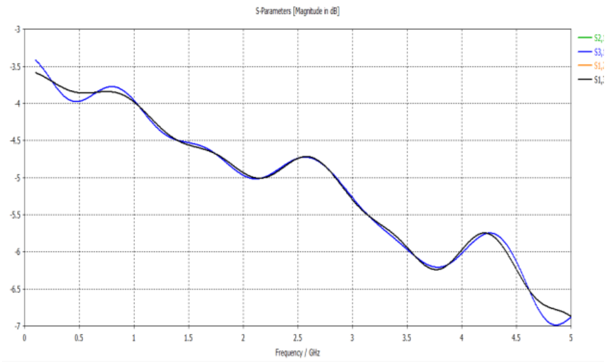


Figure 4.2.4: Splitter result (S12 21 31 13)

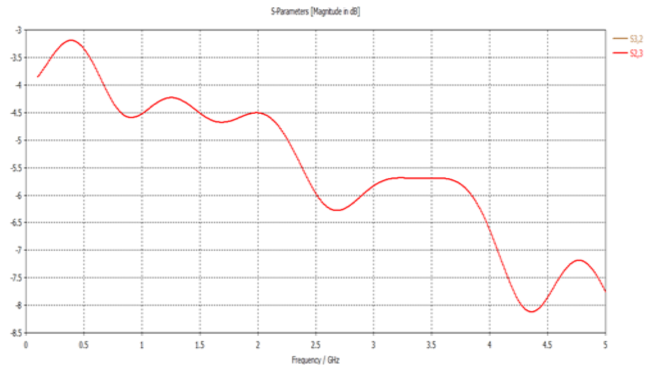


Figure 4.2.5:Splitter result (S32 23)

4.2.2 Splitter with filter

By looking the S11, S13 and S12 shows the signal is split. However when the frequency is around 2.5-3GHz, the filter is sending the signal back to port 1, this leads the signal sending to port 2 in 2.2 and 3.3 GHz become smaller, it shows from the Figure 4.2.9 parameter S12. The adjustment of the filter reflection will do in the coming session from the schedule (Configure a feeding network for the 3 slot antenna design). Figure 4.2.6 shows the filter is added to the splitter model. Figure 4.2.7 shows the S parameter by simulate figure 4.2.6 model. To make those value read easily. Figure 4.2.8-10 is screen S13 31 32 33, S21 12 and S11 22 33 respectively.

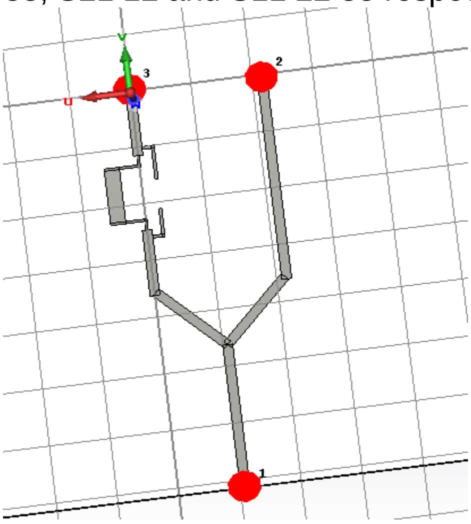


Figure 4.2.6: Splitter Model (with filter)

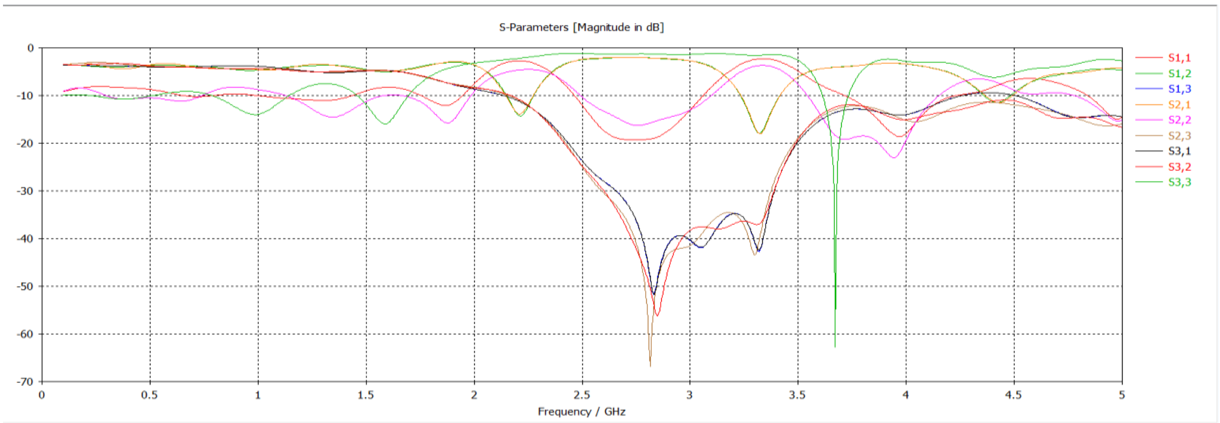


Figure 4.2.7: Splitter result (with filter) (All)

Figure 4.2.8 shows the S13 is good (-30dB) after 2GHz. Also the S13 shape is similar to Figure 5.1.2(S12).

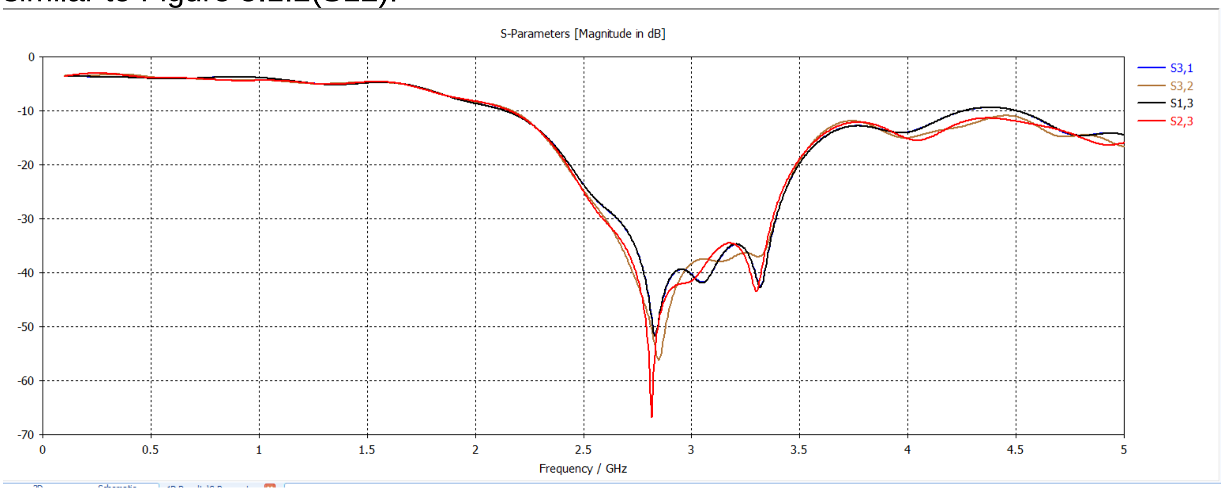


Figure 4.2.8: Splitter result (with filter) (S31 32 13 23)

Figure 4.2.9 shows the splitter is absorb the energy but there have stronger S12 and S21 in 2.2 and 3.3 GHz.

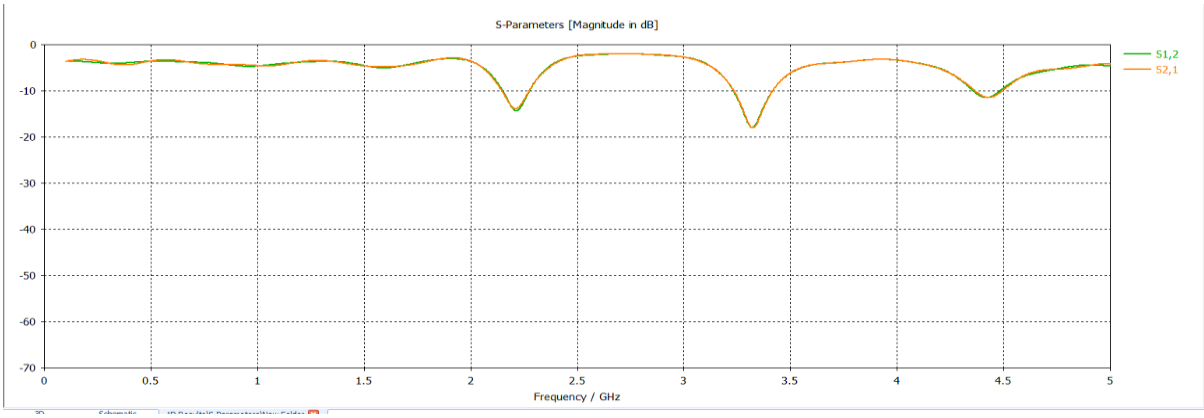


Figure 4.2.9: Splitter result (with filter) (S12 21)

Figure 4.2.10 shows the signal transmit reaction S11 and S22 is getting a similar result, S33 is getting the reflection around 2-3GHz, because the filter is reject the frequency between that frequency.

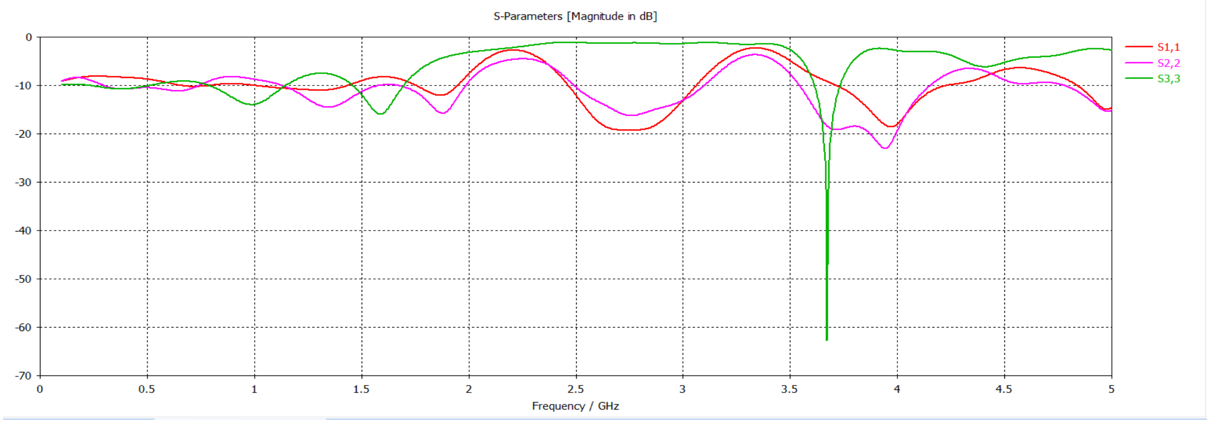


Figure 4.2.10: Splitter result (with filter) (S11, 22, 33)

4.2.3 Splitter applied to the antenna

On the other hand, while the splitter is applied to the antenna (Figure 4.2.11-12) this makes the antenna radiant frequency different. The interesting thing is when the length of P1-P2 (Figure 4.2.11) is different, it has a difference radiant/resonant frequency.

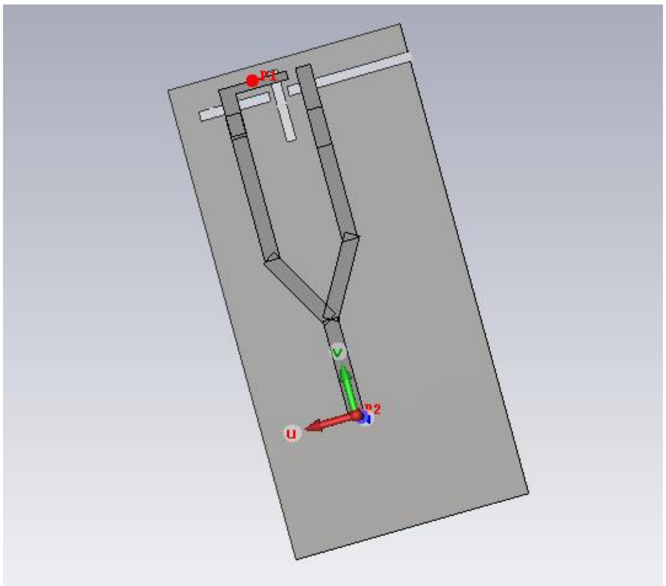


Figure 4.2.11: Splitter with antenna model

Figure 4.2.12 shows the blue line (distance =56) is the closest result by compare to Figure 1.6. The distance actually is changing the strip line that is feeding the slots.

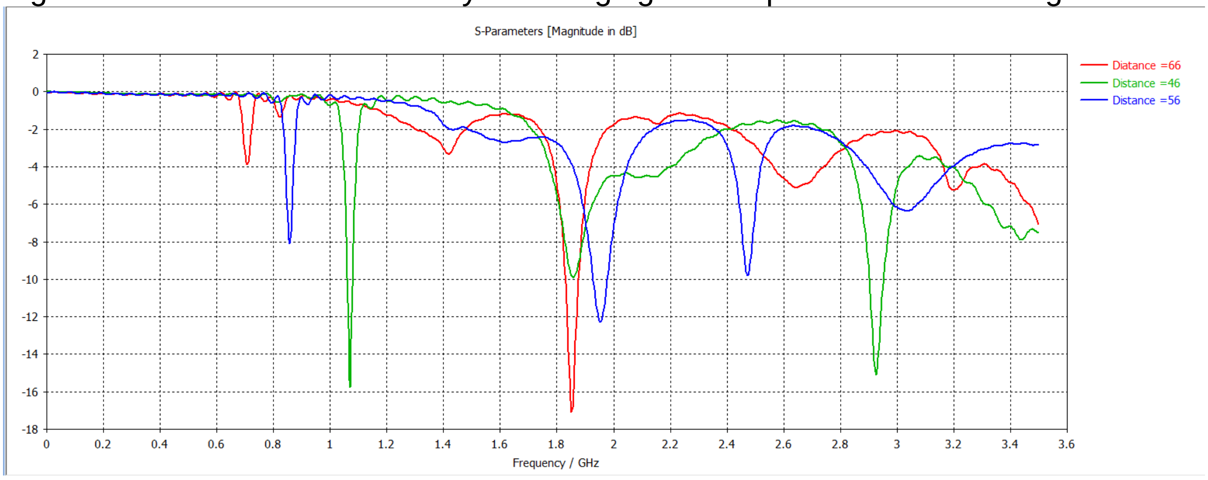


Figure 4.2.12: Splitter with antenna result (distance = P1 to P2 Y-axix length)

5. RESULT

5.1 Filter design (Final)

The view of above. The filter parameter is designed to the table 5.1. This makes the filter stop 2 GHz as a low pass filter.
Figure 5.1.1 shows the final model of the band pass filter.

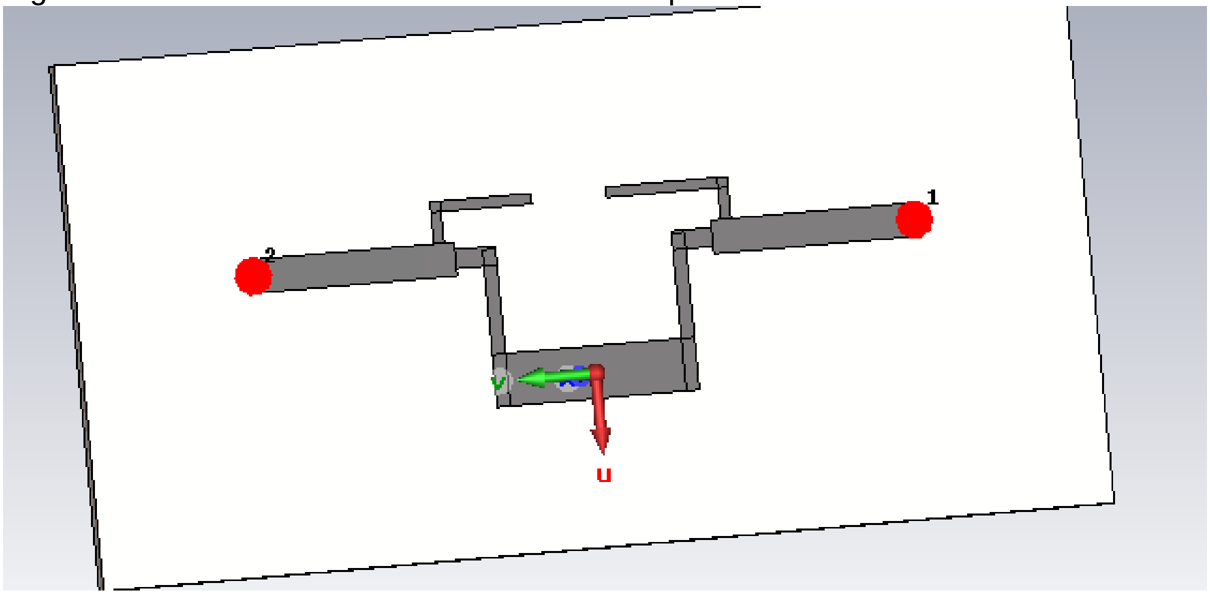


Figure 5.1.1: Band pass filter model in cst

Figure 5.1.2 shows the cut off frequency is around 2.2GHz and S11 is around -15 to -20dB. Moreover, the cross area is 411 MHz, it start with 1.8624 to 2.2738GHz. Also it shows the S12 and 21 goes back up to -15 at 3.4GHz, this means the filter is filter 1GHz band.

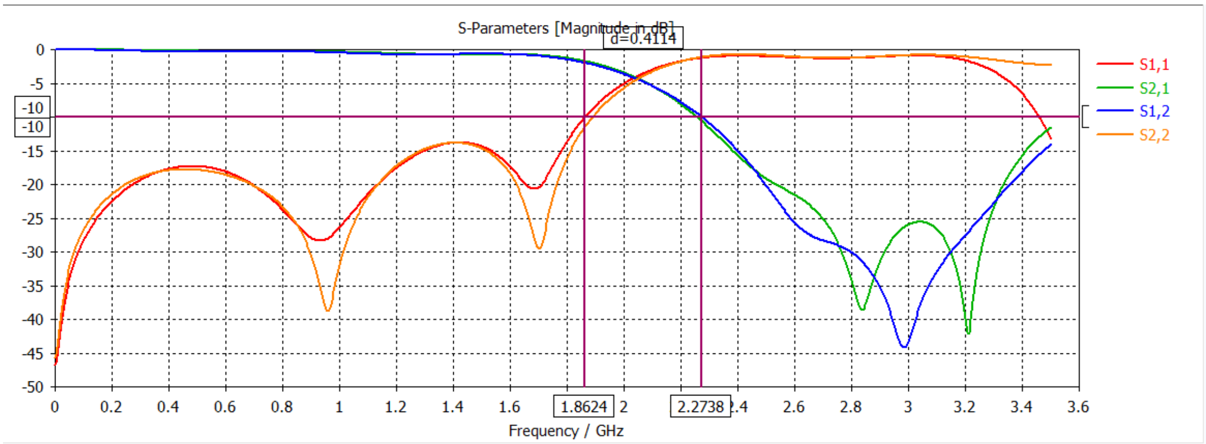


Figure 5.1.2: Final S11 in the filter simulation base on Figure 8 model

Figure 5.1.3 shows the Filter model with some addition parameter add, because some parameter is not shown.

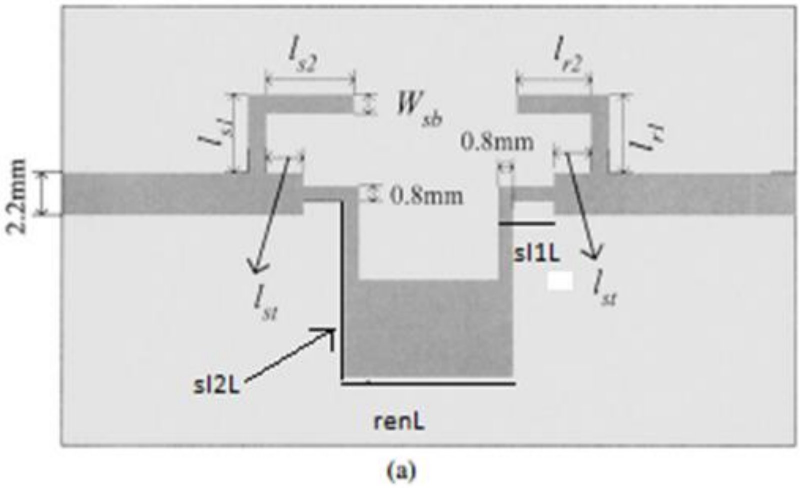


Figure 5.1.3:Filter model and some addition parameter name

Parameter name	length(mm)
Ls1	4
lr1	4
lr2	9
ls2	11
lst	2
sl1L	4
sl2L	12
sl1W	0.8
sl2W	0.8
renL	20
renW	5

Table 5.1: Parameter of the filter

5.2 Applied the filter to the antenna

The filter is applied to the slot antenna. The reason of putting the filter close to the slot is the strip line will resonate when the strip line is too long. These resonation will affect the quality of signal. From the point of above, the strip needs to be short as the original design.

Figure 5.2.1 shows the filter model when it is applied to the slot antenna. The result is shown in Figure 5.2.2. It is filtered the signal in frequency 2.8-3.5 GHz by compare to Figure 1.6.

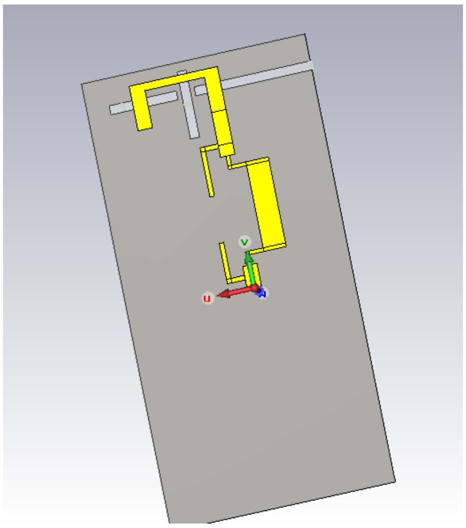


Figure 5.2.1: Strip line with filter model

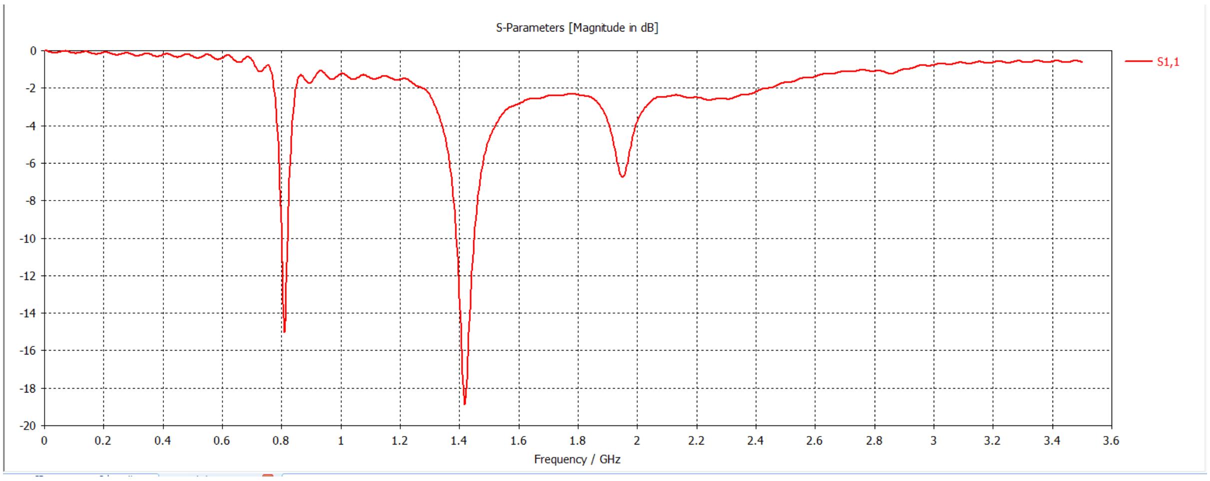


Figure 5.2.2: Strip line with filter S11

From the Figure 5.2.3-6 shows the radiant signal around in 0.8, 1.4, 1.9 and 3.2 GHz these surface current show 3 slots is working and stop the current in the filter while the frequency is 3.2GHz.

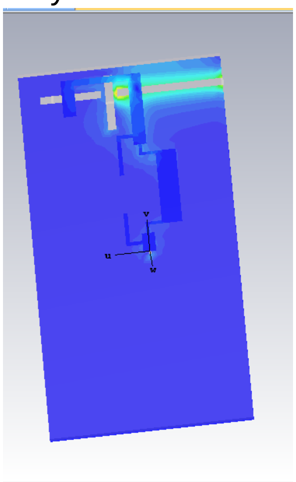


Figure 5.2.3:Surface current in 0.812GHz

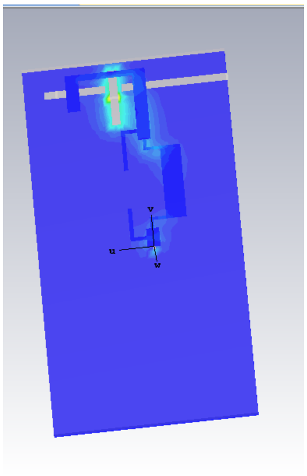


Figure 5.2.4:Surface current in 1.42GHz

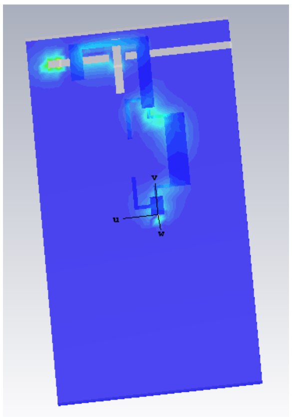


Figure 5.2.5:Surface current in 1.94 GHz

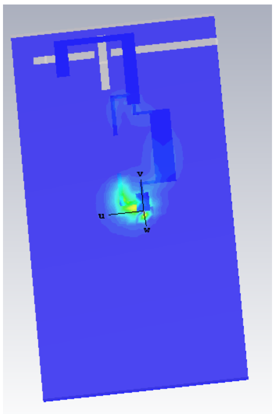


Figure 5.2.6: Surface current in 3.18 GHz

Figure 5.2.7 is the model of strip line length increase until reach the bottom of the substrate.

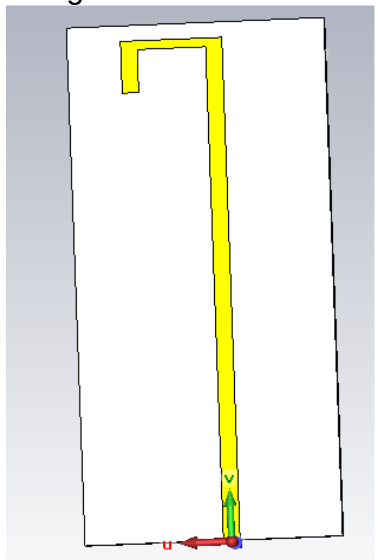


Figure 5.2.7: Full length strip line

Figure 5.2.8 shows the strip line length increase, the line will resonate around 2-3GHz (see Figure 5.2.8).

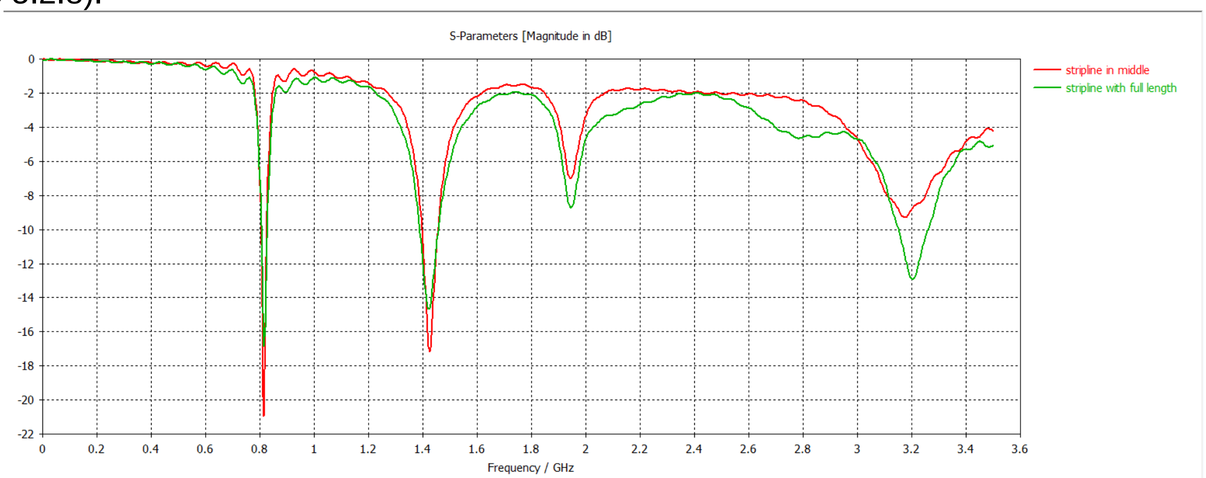


Figure 5.2.8: Full-length strip line (green) compare half-length strip line (red) S11

6. DISCUSSION AND CONCLUSIONS

By designing the filter and splitter so far, the Filter is able to stop 2 GHz frequency. However the splitter cannot apply to the antenna, because of the size and design of the antenna. When the splitter mount on micro-strip line, the design is change to two lines and both lines may interrupt each other, although this is not significant. Also if the line length is as long as Figure 5.2.7, the antenna frequency will change and resonate in around 2.8 - 3GHz frequency. So the splitter design may need to be change for matching this antenna design. Moreover the design of the micro-strip line position may need to change to produce a better feed to the slot, because the design is changing. For some additional information, university cannot produce the PCB recently. So that the PCB needs to be manufacture from factory. This will take around 15 days if that choose the cheapest plan [5], and it costs around £50 to manufacture. However the project is decided not to manufacture the antenna. The reason of not to produce the antenna is the PCB manufacture factory may delay the PCB if that have some accidental. Also the PCB needs to deliver to the university, this may take risk of the project delay.

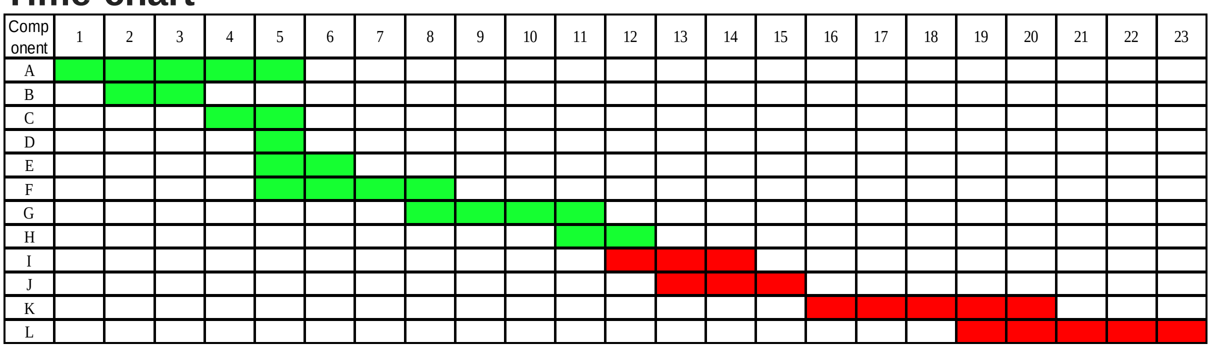
7. MILESTONE EVALUATION AND FUTURE WORK

The project is added to design a splitter to help the antenna which can radiate at 0.8 1.4 and 1.94 GHz without resonating. So the Time chart is changed. However the chart is designed the project is end at week 18 in last report because the 5 weeks is designed for some extra event. So the project is able to be extended for designing the splitter. Moreover, the group is decided not to manufacture the antenna, so the antenna will not be produce and replaced by redesign antenna, splitter and filter by simulation to optimise antenna performance unwanted resonances. From session 6 have mention the project will not produce antenna at the end, so the budget is £0 right now.

Project Schedule:

A.–Background research
B.–Understand how to use CST
C.– Have a clear idea of designing a slot antenna
D.– Report 1
E.– Research types of micro-strip filters
F.– Design micro-strip filter to stop 2000 MHz
G.–Design splitter to make 3 slots working
H.– Report 2
I.– Configure a feeding network for the 3 slot antenna design
J.– Simulate performance of complete antenna/filter system
K.– redesign antenna, splitter and filter by simulation to optimise antenna performance unwanted resonances
L.– Final report

Time-chart



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[5] http://www.pcbtrain.co.uk/resources/pcb-technical-capability/
PCB design requirement and order access date: 9/02/2017

APPENDIX. A FILTER PARAMETER CHANGES

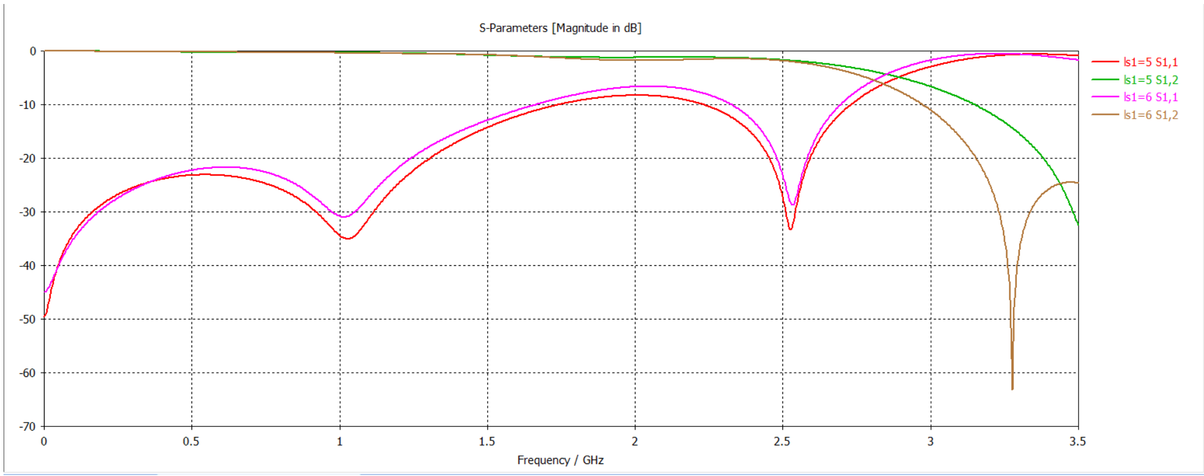


Figure A.1: Change the parameter of the filter [symmetric ls1 and lr1] (S1)

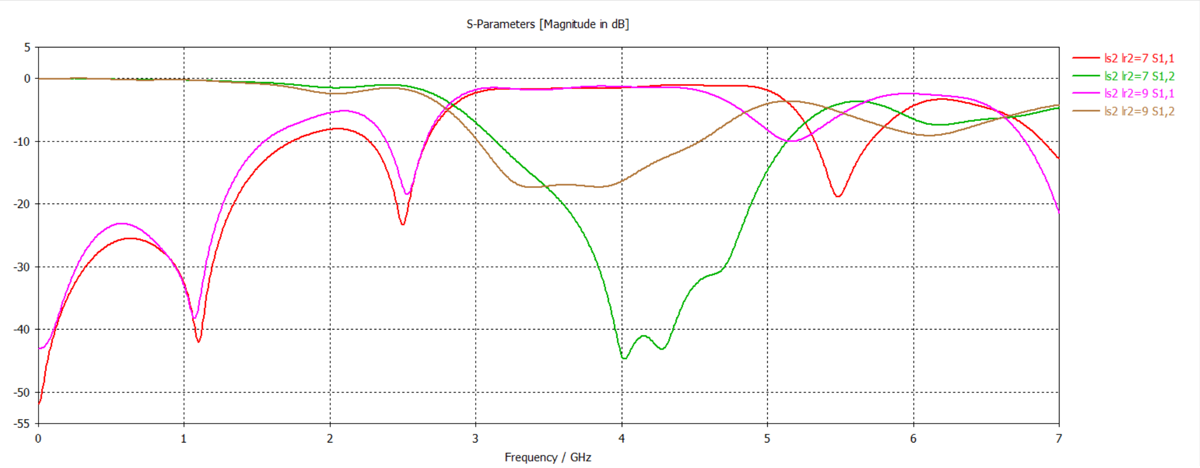


Figure A.2: Change the parameter of the filter [symmetric ls2 and lr2] (S1)

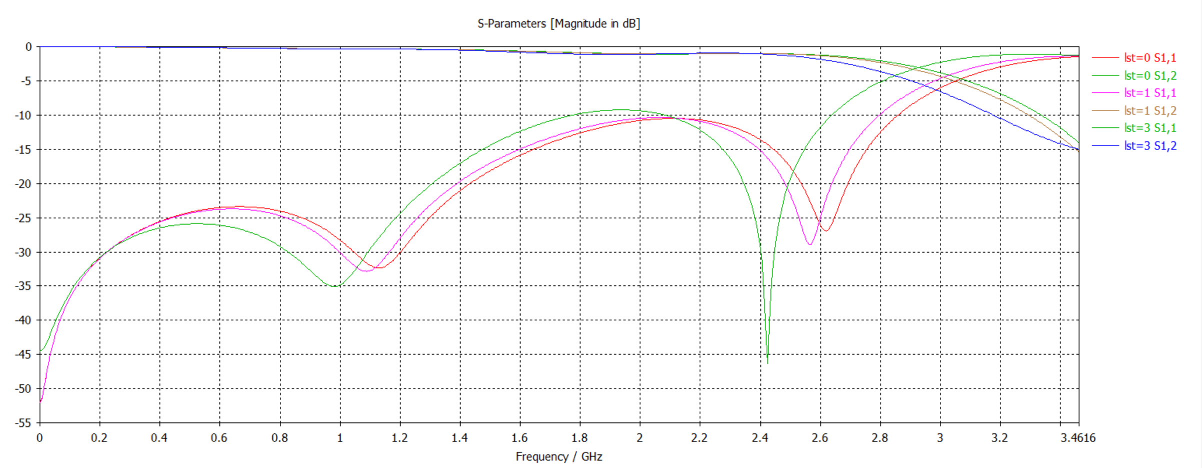


Figure A.3: Change the parameter of the filter [lst] (S1)

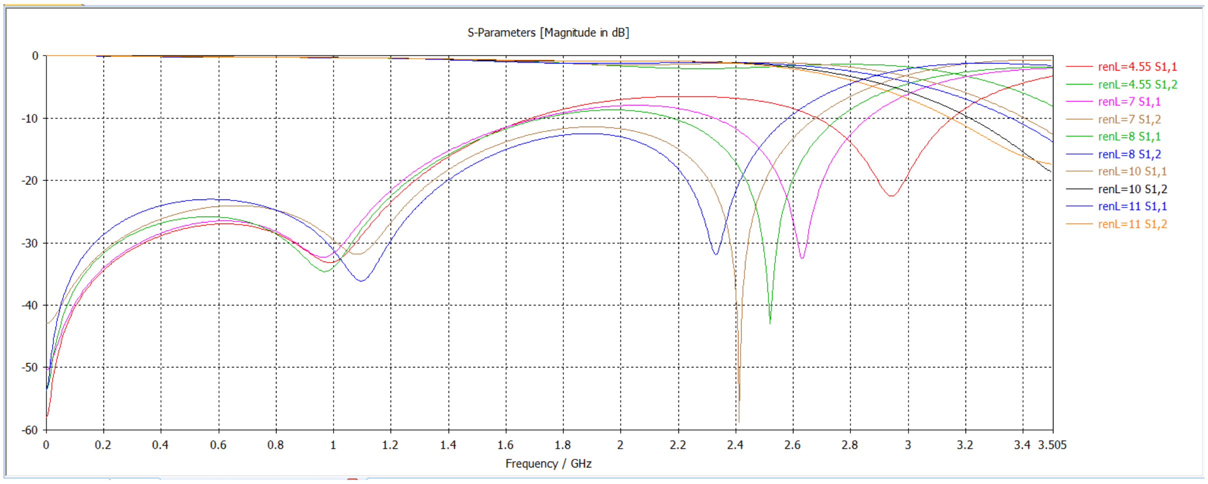


Figure A.4: Change the parameter of the filter [renL] (S1)

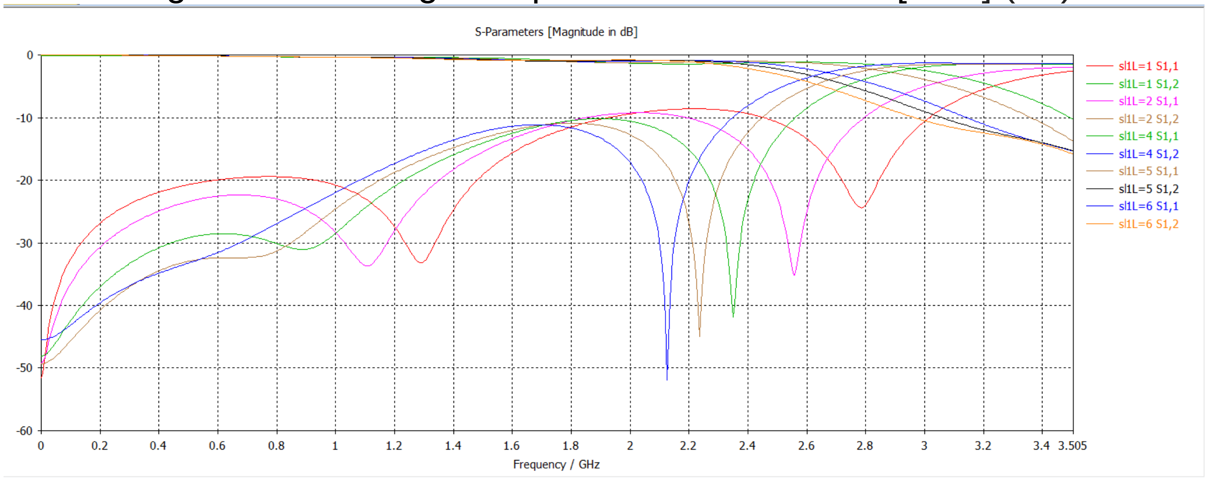


Figure A.5: Change the parameter of the filter [sl1L] (S1)

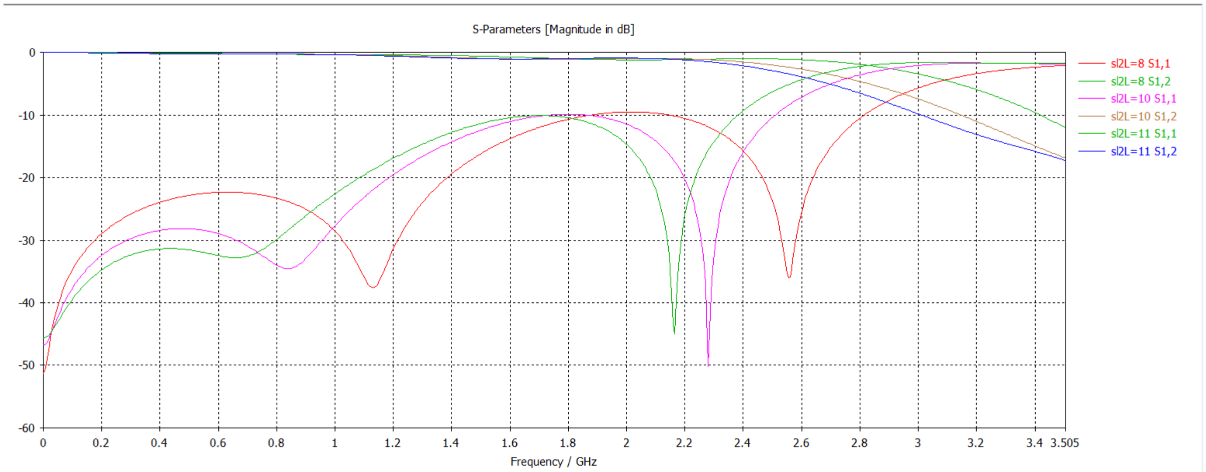


Figure A.6: Change the parameter of the filter [sl2L] (S1)

APPENDIX. B RISK ASSESSMENT

The University Of Sheffield.

Faculty of Engineering

Electronic and Electrical Engineering

General Risk Assessment : Unique ID 010133

Task or Activity : Doing the simulation for the antenna with using computer

Valid until 16th November 2017

Persons At Risk : Staff/Postgraduates/Undergraduates/Other (null)

Name : Kei Hong Chan

Supervisor : Prof Richard Langley

Location : Portobello (B09)

No Out of Hours Working Allowed

If ANY changes are made to the task or activity described on this form please create a new Risk Form.

Hazard Type	Risk of Injury & Details	Control Measures	Risk Rating
Display Screen Equipment (Computers)	Potential for soft tissue injury to back, neck, shoulder, arm,wrist, hand from poor posture for a prolonged period of time. Risk of headaches and eyestrain.	All workstations are provided with an adjustable chair. Workstation to be adjusted to suit user to give correct posture. Laptop use to be kept to a minimum. Take regular breaks (5 minutes per hour). Further guidance is available from the Health and Safety Executive (HSE) http://www.hse.gov .uk/pubns/priced/hsg90.pdf and http://www.hse.gov.uk/pubns/indg36 .pdf	1
Electrical	Electric shock or burns from faulty or inappropriate use of electrical equipment.	All electrical equipment (including personal items i.e. Laptops, chargers etc) should be PAT tested at least annually - check items are labelled and in date. If an item is not labelled, contact staff in the Electronic Workshop. Visually inspect equipment before use - check for	2

Electrical		signs of damage. Report defects i.e. discoloured sockets, damaged cable/equipment to technical staff immediately. Defective equipment to be labelled and taken out of use immediately. DO NOT ATTEMPT TO REPAIR IT YOURSELF. Training available in use of equipment where necessary.	2
Vapours and Fumes	Soldering activities produce vapours and fumes that may cause eye and nose irritation, damage to the air passages and respiratory problems.	Soldering to take place in well ventilated area. Read COSHH form for soldering activities. Extraction units provided for use while soldering. Safety glasses must be worn whilst soldering.	1
Manual Handling	Risk injuries to back, feet, hands, fingers etc from handling heavy/bulky objects eg equipment etc.	Recommend that students do not lift loads of greater than 5kg. As technical staff for advice/assistance if required. Use a suitable trolley to move items where appropriate. Heavy items to be stored/accessible at waist height. For loads heavier than 5kg, contact technical staff to assist.	1
Fire & Burns	If trapped, could suffer fatal injuries from smoke inhalation/burns. Soldering - burns to hands and fingers from hot work piece or the soldering iron.	Safety talks include details of emergency procedures. Know location of nearest safe exit from building - back of the room have door go straight forward Know where assembly point is - St. George's Church Yard Know how to raise the alarm - either breaking the glass of an emergency call point or shouting fire, or by telephoning the University's Emergency Control Centre Fire Alarms tested weekly in all buildings. Ensure soldering iron is replaced in its holder when not in use. Switch off when not in use. Keep work area tidy and free from combustible	2

Fire & Burns		items i.e. paper, textiles etc First Aid assistance is available from trained staff. Names are printed inside first aid boxes for listed on the EEE Safety pages, along with locations of all First Aid boxes.	2
Electric,Magnetic & Electromagnetic Fiel ds (100 KHz to 300 GHz)	Time-varying electric, magnetic and electromagnetic fields 100kHz to 300GHz May cause burns internally and externally, damage to eyes,	Training provided by authorised/competent person Supervision by supervisor or other designated competent person. Operating procedures in place. Power limited so the chance of burns is minimal. Restricted access to chambers. For free space measurements, avoid line of sight exposure. Appropriate signage to be used where required	1

Key		
High Risk	Medium Risk	Low Risk

Ian Wraith (i.wraith@sheffield.ac.uk)

Appendix.C PID

THE UNIVERSITY OF SHEFFIELD **Department of Electronic and Electrical Engineering** **3rd Year Individual Project** **Project Initialisation Document**			
Student Name	Kei Hong Chan		
Project Title	Antennas with filters		
Supervisor	Richard J Langley	**Second Marker**	

Description and aims of Project:

This project aims to make a filter in an antenna composed of three slots operating at three separate frequency bands. The antenna is required to radiate signals in the frequency range 800MHz to 3000MHz covering the LTE mobile telephone bands. However, due to the lengths of the slots there are issues with overmoding of the longest slot antenna. The major problem is when the antenna needs to transmit the highest range of frequencies (3000MHz signal), 2 slots are activated at the same time. This project will develop Micro-strip filters to stop the high frequencies exciting the longest slot antenna.

Literature review:

The project relates to the Communication Electronic. The project needs to understand what antenna is and how it works. For example understanding antenna radiation pattern, gain of the antenna, what design (material, shape) will affect antenna performance etc.

1.1 Antenna radiation pattern

This is a pattern shows how the signal transmits from the antenna, Different antenna shape, size can affect the shape of pattern. Figure 1 shows the patch antenna shape. The red colour means the antenna have higher directivity at that point (1.2).

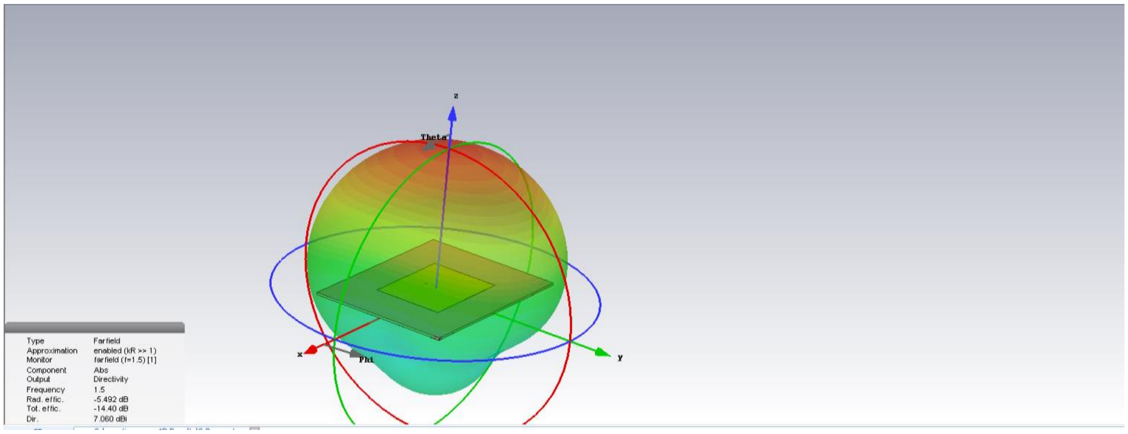


Figure 1: Radiant pattern in a patch antenna

1.2 Directivity

Directivity is a parameter showing direction of signal transfer, on the other word its mean the receiver can receive signal easily in the red area. For a mobile phone antenna, it generally requires a low directivity antenna, because it can to receive signal from everywhere easily. On the other hand, it is good to use a high directivity antenna for controller.

2.1 Slot antenna

Slot antenna a of the project. The slot antenna is an antenna with a slot on the ground plant, you can see the subtract from the slot. In Figure 2 shows the slot antenna with ground plant, subtract and micro-strip line. [2][3][4]

2.2 Micro-strip line

The micro-strip line is a line that can feed to the slot and make the slot to generate signal. The impedance (Z_0) of the antenna is related to the width of the micro-strip line, the thickness of subtract and the material of subtract [2].

2.3 Slot

The size of the slot can change the wavelength (frequency) of the antenna. Moreover, the slot and the micro-strip line position can make the antenna to have more harmonic band (Figure 3).

2.4 S-Parameter

Figure 3 shows a simulation loaded by (Computer Simulation Technology) CST, which is a part of the parameters of the antenna. This parameter can show the range of frequency to be achieved by figure 2 antenna. When it is lower than -10 dB in the graph that means the antenna starts to work in that frequency.

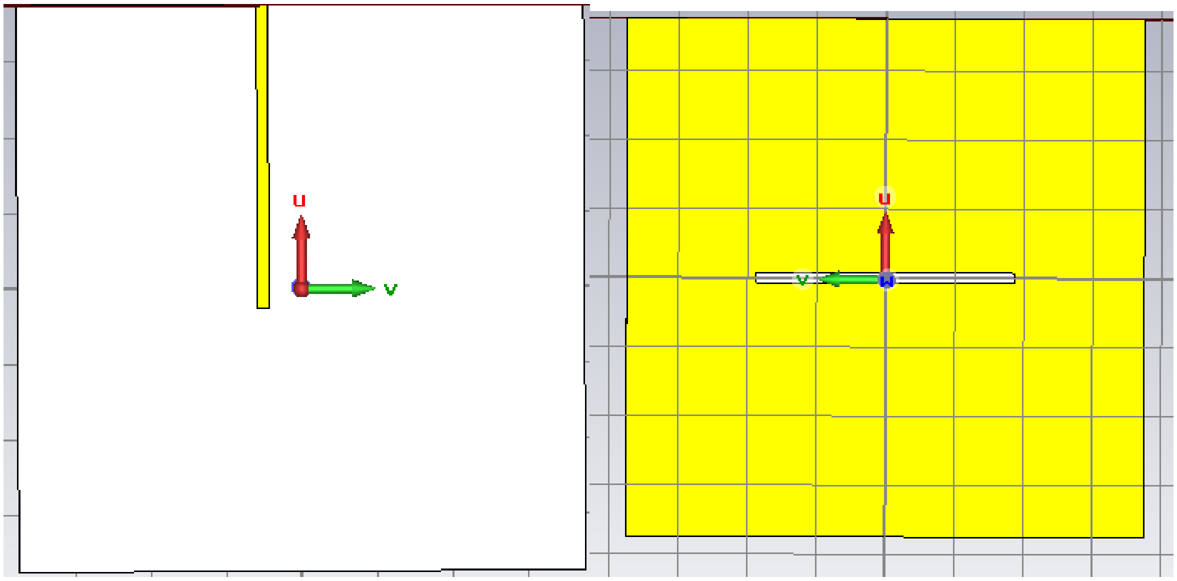


Figure 2: Slot antenna (left back, right front)

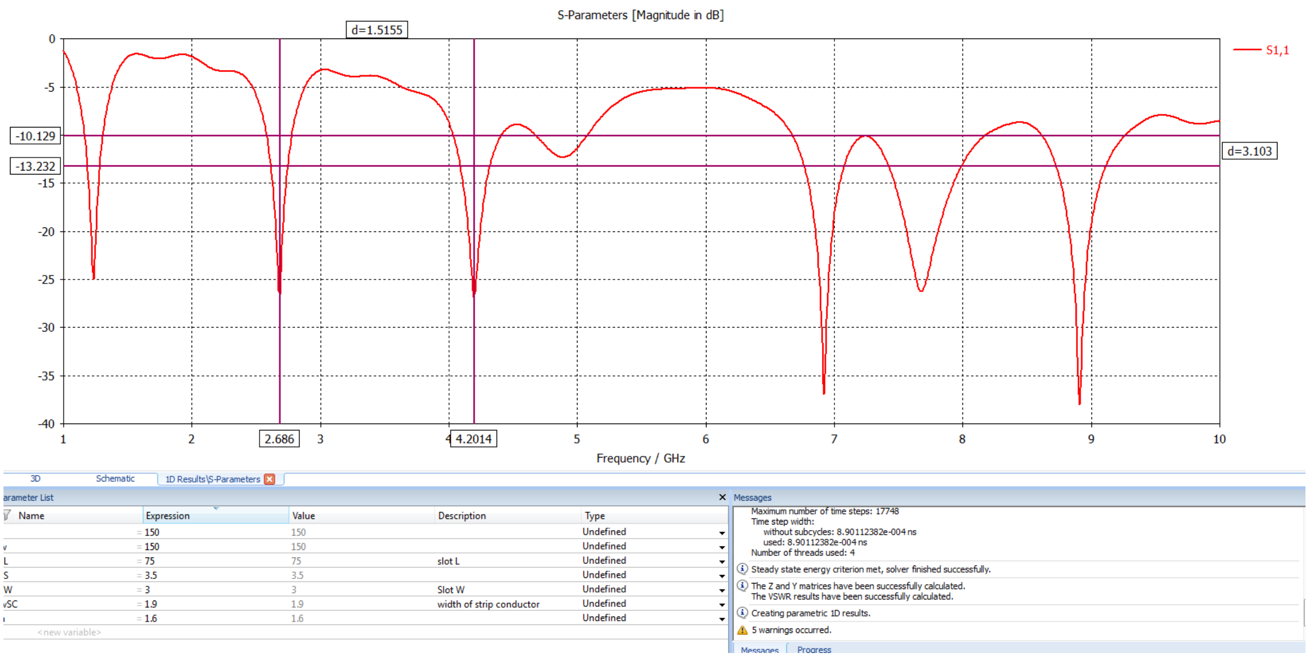


Figure 3 : S-parameter from Figure 2 antenna

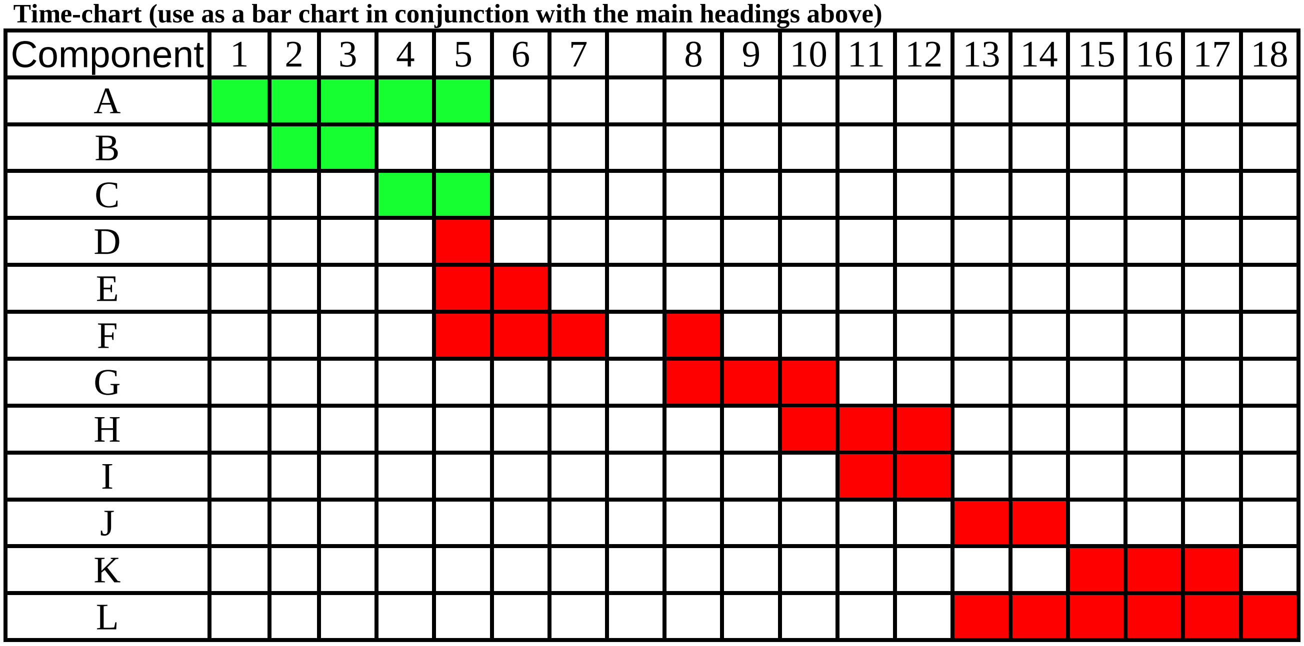
Project Specification:

- **Understand how to use CST**
- **Have a clear idea of designing a slot antenna**
- **Research types of microstrip filters**
- **Design microstrip filter to stop 2500-3000 MHz**
- **Configure a feeding network for the 3 slot antenna design**
- **Simulate performance of complete antenna/filter system**
- **Manufacture antenna**
- **Measure antenna in anechoic chamber**
- **Final report**

Project Schedule:

A – Background research
B – Understand how to use CST
C – Have a clear idea of designing a slot antenna
D – Report 1
E – Research types of microstrip filters
F – Design microstrip filter to stop 2500-3000 MHz
G – Configure a feeding network for the 3 slot antenna design
H – Simulate performance of complete antenna/filter system
I – Report 2
J – Manufacture antenna
K – Measure antenna in anechoic chamber
L – Final report

Time-chart (use as a bar chart in conjunction with the main headings above)



References:

[6] Robert S. Elliott, "Antenna Theory & Design" , Books & eBooks, pp. 79 – 110 , 2003

[7] Thomas A. Milligan "Modern Antenna Design", Books & eBooks, pp. 285 - 335 , 2005

[8] Xuehui Guan, Zhewang Ma,Peng Cai,Tetsuo Anada,and Gen Hagiwara "A MICROSTRIP DUAL-BAND BANDPASS FILTER WITH REDUCED SIZE AND IMPROVED STOPBAND CHARACTERISTICS" , Journal, 19 July 2007

[9] Mustafa K. Taher Al-Nuaimi and William G. Whittow "On The Miniaturization of Microstrip Line-Fed Slot Antenna Using Various Slots" IEEE Trans. Antennas and Propagation Conference (LAPC) , 2011 Loughborough , Journal, Nov. 2011

[10] Oteng Gyasi Kwame , Wen Guangjun , Senior Member, IEEE, Xue Xiao Lin , Muhammad Abdul Basit "Bandwidth Enhancement of a Microstrip-Line-Fed Printed Rotated Wide Slot Antenna With Tuning Stubs" , IEEE Transactions on Antennas and Propagation ,pp. 1712 – 1716 , 31 January 2012

[11] Deep K Chauhan and FalguniRaval , 2016, "Design Of Microstrip Low Pass Filter" Online Access: http://ijiere.com/FinalPaper/FinalPaperDesign%20Of%20Microstrip%20Lowpass%20Filter170720.pdf [Accessed 26 October 2016].

Risk Register:

Risk Number	Description of Risk	Mitigation of Risk	Risk evaluation (L/M/H)	Chance of risk occurring (L/M/H)
1	Loss of data (USB key)	Multiple back-ups in multiple locations	M	L
2	Potential for soft tissue injury	Take regular breaks (5 minutes per hour).	L	L
3	Electric shock	Defective equipment to be labelled and taken out of use immediately.	M	L
4	Time-varying electric, magnetic and electromagnetic fields 100kHz to 300GHz	Power limited so the chance of burns is minimal.	L	L
5	Electromagnetic - less than 100kHz	Us low power/low voltage for project work only	L	L

<table>
<tr><th colspan="2">FOR COMPLETION BY SUPERVISOR</th></tr>
<tr><td>Does the project require ethical approval? As with PGR projects you must obtain ethical approval if required. For more information see: https://www.shef.ac.uk/ris/pgr/code/ethical</td><td>YES NO
Delete as applicable</td></tr>
<tr><td colspan="2">I agree that this specification is of a satisfactory standard for the student to continue with the project.

Supervisor’s Signature: Date:</td></tr>
</table>