# DESIGN AND FABRICATION OF A DOPPLER RADAR USING A MICROSTRIP PLANAR ARRAY ANTENNA

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**February, 2019**

# ACKNOWLEDGEMENTS

We would like to express a deep sense of gratitude and appreciation to all those who made it possible for us to do the project successfully. First and foremost we would like to express our heartiest gratitude towards our supervisors, Prof. Disala N. Uduwawala and Dr. Aruna Gunawardena, Department of Electrical and Electronic Engineering, University of Peradeniya. Without their wise counsel and guidance, it would have been impossible to do this project successfully.

Furthermore we would like to offer our appreciation to Mr. Ishan Chandrasiri, temporary instructor and non-academic staff, Department of Electrical and Electronic Engineering, University of Peradeniya for the support provided to do the project.

Last but not least, special thanks to our parents and friends for assisting us to do the project swimmingly.

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| | |
|---|---|
| HFSS | High Frequency Simulation Software |
| IF | Intermediate Frequency |
| RF | Radio Frequency |

# CHAPTER 1 Abstract

Microstrip antennas play a very important role in the today's wireless communication systems such as in military, satellite communication, 5G technology etc. Low profile, easiness of design and fabricate have made it ideal for most applications. In this project a 4x4 microstrip planar array antenna is designed and analyzed using the Transmission line model which gives a good physical insight. Two such identical antennas are used as the transmitting and receiving antennas in the Doppler radar circuit. The radar is designed to detect the speed of a vehicle moving at 50 kmph- 150 kmph within a range of 50- 200m.

Design and simulation of the patch antenna was done using HFSS software at 10.5 GHz. Feeder circuit of the radar was designed and simulated using AWR software by selecting the components which give 10 mW of transmitting power to the antenna. 5250 MHz frequency is generated by a VCO and is doubled using a frequency multiplier to the resonance frequency of the antenna, 10.5 GHz. A splitter was designed in AWR to split this signal to transmitter and to mixer. At the mixer, received signal is mixed with the transmitted signal. The resulting IF signal carries Doppler information. In order to measure the Doppler shift, an Arduino board is used and the speed is calculated. Speed will be displayed on a LCD display.

# CHAPTER 2 Introduction

An antenna is a transducer that converts radio frequency fields into alternating current or vice versa. Micro strip antenna or antenna array is a type of antennas, which is a thin metallic plate mounted on a dielectric substrate. Micro strip antennas are low profile. Therefore they can be used as an alternative for the heavy weighted antennas .Use of micro strip antennas has been spread in applications such as in high performance air crafts, space crafts, satellites, military based activities and mobile telephony, wireless local area networks etc.

The main objective of the project is to design and fabricate a Doppler radar using a micro strip planar array antenna. Doppler radar is designed to detect vehicles travelling above the maximum permitted speed. For radar, low profile and light weight of the antenna are highly essential properties which make the micro strip antenna idle for the purpose and it is also less expensive. In this project an antenna array is used instead of single antenna in order to increase the overall gain and two such identical antennas are used for transmission and reception.

As the first step of this project, calculations were done to design rectangular and square patch antennas with 10 GHz resonance frequency. For the simulation purposes HFSS software was used. Based on the calculations for single square patch antenna, 16-array antenna was designed. It was also simulated using HFSS software before fabrication. Fabricated 4x4 micro strip antenna array was tested using Network Analyzer.

Then as the next step, Doppler radar circuit design was designed using the AWR software. Using this software simulations was done using properties of the selected components.

This report consists of the design, analysis and testing of microstrip planar array antenna. And also the designed Doppler radar circuit with transmitting and receiver circuit.

# CHAPTER 3 Literature Review

## 3.1 Micro strip antenna

Often micro strip antennas are also referred as patch antennas .Usually radiating elements and feed lines are photo etched on the dielectric substrate .The radiating patch can be square , rectangular , dipole , circular , elliptical , triangular or any other configuration.

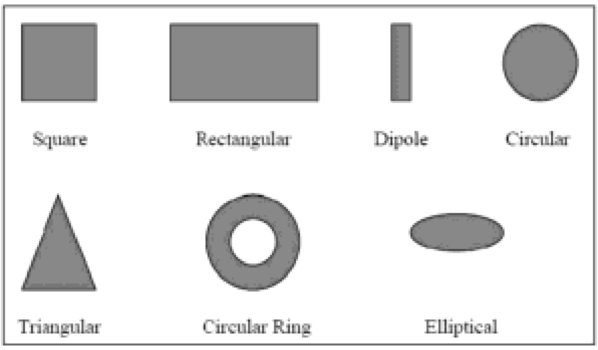



Figure 3.1 Shapes of Micro strip antenna

### 3.1.1 Feeding methods

There are many configurations that can be used to feed micro strip antennas.

But the most popular of them are;

1. Micro strip line
2. Coaxial probe
3. Aperture coupling
4. Proximity coupling

In this project micro strip line method was used.

Micro strip feed line is also a conducting strip .Compared to the patch, it is usually of much smaller width. The micro strip feed line is easy to fabricate, simple to match by controlling the inset position and rather simple to model.

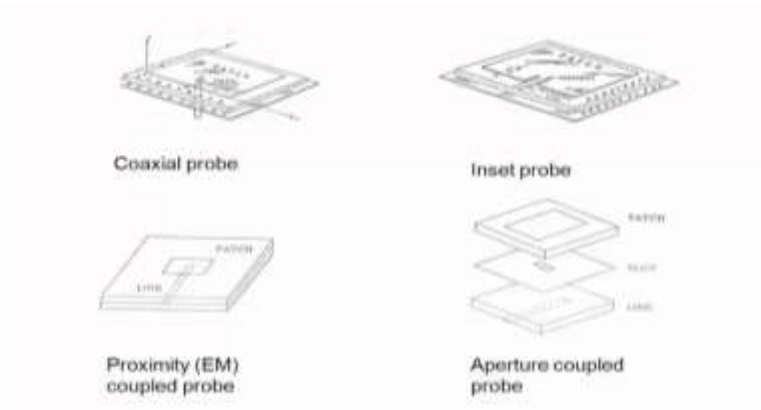
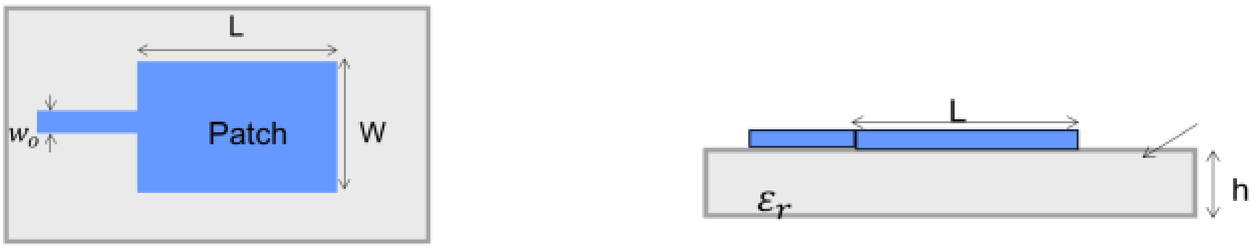



Figure 3.2 Feeding methods

Micro strip antenna is a thin metallic patch mounted on dielectric substrate. Below the dielectric substrate there is a ground plane.




(a) (b)

Figure 2.3 Micro strip rectangular patch antenna (a) Top view (b) Side view

Micro strip antenna has dielectric loaded cavities and they exhibits higher order resonances.

The resonant frequencies for the cavity is given by the following equation where m,n and p are the number of half cycle field variation along x ,y and z directions.

$$(f_r)_{mnp}=\frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{h}\right)^2+\left(\frac{n\pi}{L}\right)^2+\left(\frac{p\pi}{W}\right)^2} \quad (2\text{-}1)$$

μ ,ε ,h ,L and W are permeability, dielectric constant of the substrate, height of the substrate, length of the substrate and width of the substrate respectively.

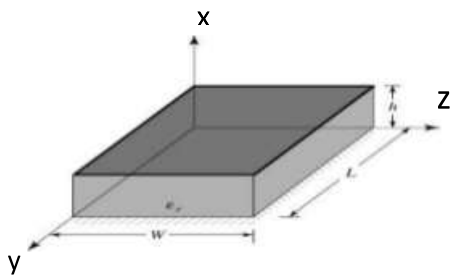



Figure 3.4 Micro strip patch antenna on 3D Cartesian plane

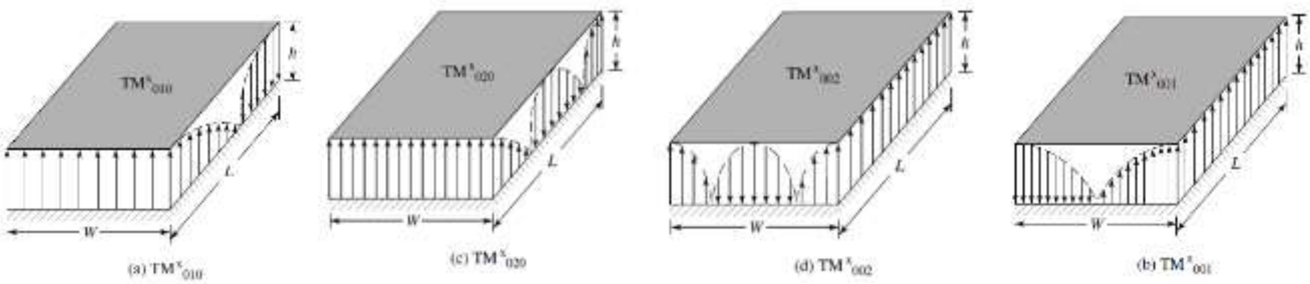


Figure 3.5 Field configurations for rectangular micro strip patch

In order to determine the dominant mode with lowest resonance we have to examine the resonant frequencies. Dominant mode is referred to as the mode with the lowest order resonant frequency. For all micro strip antennas h<<L and h<<W. If L>W> h, the mode with the lowest resonant frequency or the dominant mode is $TM_{010}$ whose resonant frequency is given by [1] ,

$$(f_r)_{010}=\frac{1}{2L\sqrt{\mu\varepsilon}} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \tag{2-2}$$

### 3.1.2 Analysis of a Patch Antenna

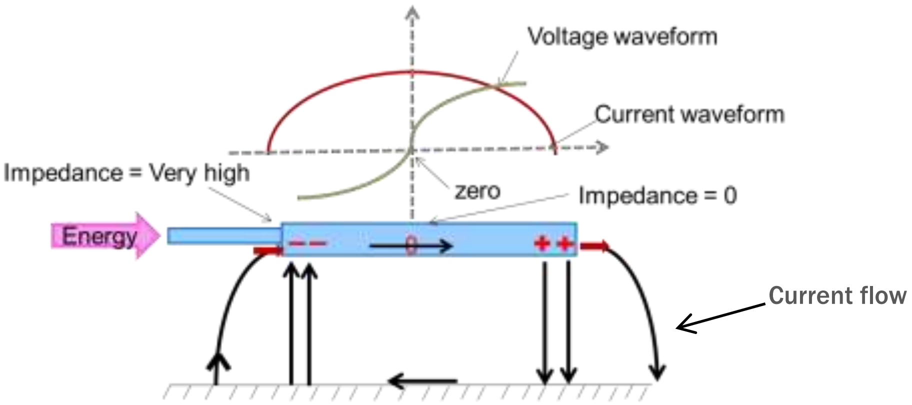



Figure 3.6 Demonstration of current and voltage pattern underneath a patch

Energy to the micro strip antenna flows through the transmission line from the source. Figure 2.6 shows the side view of a patch antenna. As the above figure shows at the right most corner, the patch terminates (open circuited).Therefore the current at that end is zero. If the length of the patch is ‘L’,

$$L=\frac{\lambda_d}{2} \tag{2-3}$$

where $\lambda_d$ is the wave length in dielectric medium. Therefore current is zero at the left most corner as it is at the half wave length. At the center of the patch, current is at its maximum. Patch can be considered as an open circuit transmission line as shown in Figure 2.7 and the formula for the reflection coefficient is (2-4),

$$\rho \text{ (Reflection Coefficient)} = \frac{Z_l - Z_g}{Z_l + Z_g} \tag{2-4}$$

where $Z_g$is source impedance and $Z_l$is load impedance, when the load end is open circuited reflection coefficient is equals to one. When reflection coefficient is 1, current and voltage have $90^0$ phase shift.

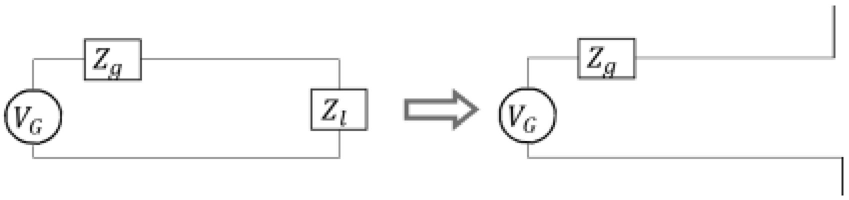



Figure 3.7 Open circuited transmission line

So that voltage value at the end points of the patch as shown in Figure 2.6, voltage underneath the patch is at its maximums where at the right end it is negative and at the other end it is positive. At the center of the patch, voltage reduces to zero.

Effect of fringing takes place at the ends of the patch. Fringing fields has horizontal components adding up in phase which give in rise in radiation. Current components in opposite direction cancel off. Therefore they do not responsible for radiation. But fringing fields do not cancel off. Therefore they contribute to the radiation.

When consider about the impedance of the patch , theoretically at the center of the patch impedance is zero and at the patch ends it a very high value. Therefore for an example if 50Ω feed point is required, then the micro strip line should feed into the patch at $y_o$ distance as shown in Figure 2.8.

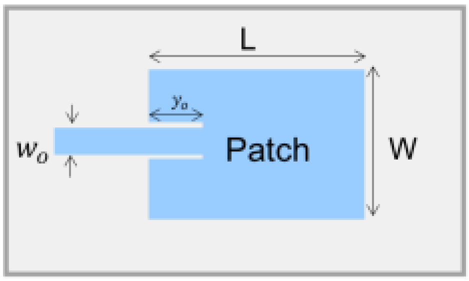



Figure 3.8 Feed point of the micro strip line

## 3.2 Methods of Analysis

There are many methods of micro strip antenna analysis; the most popular methods are transmission line, cavity and full wave models [1]. Transmission line model is the easiest method among the analyzing methods and it gives a good physical insight. In this method we assume that patch is a transmission line or part of a transmission line. But this method is less accurate and it is more difficult to model coupling.

Cavity model is more accurate compared to transmission line model and also it is more complex. This method also gives good physical insight and difficult to model coupling. In general full wave models are more accurate and very versatile, but they are the most complex models and give less physical insight.

In our project we have used transmission line model to analyze patch antenna and antenna array. Because it gives good physical insight and easy analysis.

### 3.2.1 Transmission line model

The transmission line model represents the micro strip antenna by two slots, separated by low impedance $z_c$ transmission line of length L as shown in the Figure 2.9.

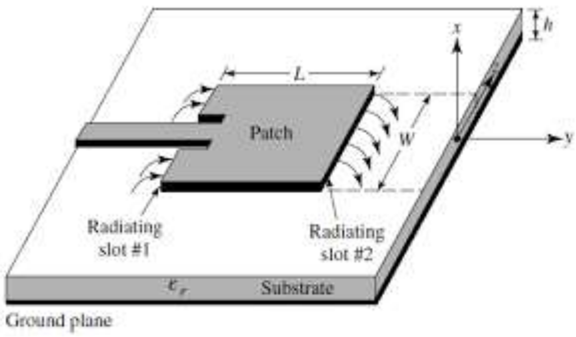



Figure 3.9 Micro strip antenna

When design is done using transmission line model special phenomenon that has an important effect on the accurate modeling and performance analysis of the patch antenna is considered. This is fringing effect. As the patch has finite dimensions along length and width, two radiating slots along the length L undergo fringing. Fringing effect depend on the ratio of the length of the patch to the height of the substrate (for E plane) and the dielectric constant of the substrate.

When, $L/h \gg 1$

Fringing is reduced [1].

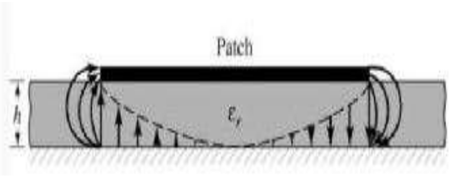



Figure 3.10 Side view of the patch

Typical electric field lines of the patch are shown in the Figure 2.10. As shown in the figure there are some electric field lines inside the substrate and some lines exist in the air. Due to fringing patch looks wider electrically compared to its physical dimensions. Also effective dielectric constant should be calculated because some waves travel through substrate as well as in the air. This can be calculated using equation (2-5). [1]

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{w}\right]^{-1/2} \tag{2-5}$$

W is the practical width of the patch.

Extended length electrically due to fringing can be calculated by equation (2-6).

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \tag{2-6}$$

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is

$$L_{eff} = L + 2\Delta L \tag{2-7}$$

### 3.2.2 Design of Rectangular patch antenna

Design procedure used in the project is shown below and it is extracted from the Antenna design book by Constantine A. Balanis [1].

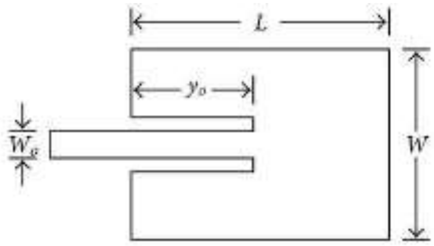



Figure 3.11 Dimensions of the patch

$f_r$ Resonant frequency

$\varepsilon_r$ Dielectric constant of the substrate

h Height of the substrate

W is the practical width of the patch. It can be calculated using equation (2-8).

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{2-8}$$

$v_0$ is the free space velocity of light

Effective dielectric constant and ΔL can be calculated using equation (2-5) and (2-6) respectively.

Then the actual length can be determined by fallowing equation (2-9).

$$L = \frac{v_o}{2f_r\sqrt{\varepsilon_{reff}}} - 2\,\Delta L \tag{2-9}$$

Characteristic impedance of the micro strip feed line is

$$Z_c = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_{reff}}}\ln\left[\dfrac{8h}{w_0}+\dfrac{w_0}{4h}\right] & \dfrac{w_0}{h} \le 1 \longrightarrow (1) \\ \dfrac{120\pi}{\sqrt{\varepsilon_{reff}}\left[\frac{w_0}{h}+1.393+0.667\ln\left(\frac{w_0}{h}+1.444\right)\right]} & \dfrac{w_0}{h} > 1 \longrightarrow (2) \end{cases} \tag{2-10}$$

Since the input impedance is known $w_0$ can be determined using equation (2-10).

When considering the input impedance of the antenna Figure 2.12 shows the Transmission line equivalent model.

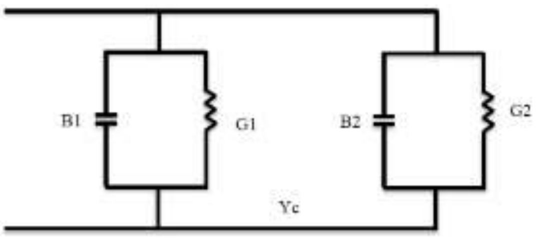



Figure 3.12 Transmission line equivalent model

Each radiating slot can be represented by a parallel equivalent admittance Y (with conductance G and susceptance B).

For slot #1:

$$Y_1 = G_1 + jB_1 \tag{2-11}$$

For slot #2:

$$Y_1 = G_2 + jB_2 \tag{2-12}$$

Since both slots are identical,

$$Y_1 = Y_2\,,\quad G_1 = G_2\,,\quad B_1 = B_2$$

$$G_1 = \frac{I_1}{120\pi^2} \tag{2-13}$$

Where,

$$I_1 = \int_0^{\pi} \left[\frac{\sin\left(\frac{k_o W}{2}\cos\theta\right)}{\cos\theta}\right]^2 (\sin\theta)^3 \, d\theta = -2 + \cos(x) + XS_i(X) + \frac{\sin(x)}{x} \tag{2-14}$$

Here,

$$X = k_0 W \tag{2-15}$$

$$S_i(X) = \int_0^{x} \frac{\sin\tau}{\tau} d\tau \tag{2-16}$$

Since the total admittance is real, resonant input impedance is also real,

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{2G_1} \tag{2-17}$$

When the mutual effects between the slots were taken into account equation (2-17) modifies.

$$R_{in} = \frac{1}{2(G_1 + G_{12})} \tag{2-18}$$

$G_{12}$ is the mutual conductance

$$G_{12} = \frac{I_{12}}{120\pi^2}$$

$$G_{12} = \frac{1}{120\pi^2} \int_0^{\pi} \left[\frac{\sin(\frac{k_0 W}{2} cos\theta)}{cos\theta}\right]^2 J_o(k_o L sin\theta) sin^3\theta \, d\theta \tag{2-19}$$

$J_0$ is the Bessel function of the first kind.

$$R_{in}\ (Y=Y0) = R_{in}\ (Y=0) \cos^2\left(\frac{\pi}{L} y_0\right) \tag{2-20}$$

Here $R_{in}(Y=0) = 0\Omega$ and $R_{in}(Y=Y_0) = 50\Omega$.

Then $y_0$ can be calculated using equation (2-20).

## 3.3 Doppler Radar

### 3.3.1 Doppler Effect

The Doppler- Effect is the apparent change in frequency or pitch when a frequency source moves either toward or away from the receiver, or when the receiver moves either toward or away from the source. This principle, discovered by the Austrian physicist Christian Doppler, applies to all wave motion.

The apparent change in frequency between the source of a wave and the receiver of the wave is because of relative motion between the source and the receiver. To understand the Doppler Effect, first assume that the frequency of a sound from a source is held constant. The wavelength of the sound will also remain constant. If both the source and the receiver of the sound remain stationary, the receiver will hear the same frequency sound produced by the source. This is because the receiver is receiving the same number of waves per second that the source is producing.

Now, if either the source or the receiver or both move toward the other, the receiver will perceive a higher frequency sound. This is because the receiver will receive a greater number of sound waves per second and interpret the greater number of waves as a higher frequency sound. Conversely, if the source and the receiver are moving apart, the receiver will receive a smaller number of sound waves per second and will perceive a lower frequency sound. In both cases, the frequency of the sound produced by the source will have remained constant.

### 3.3.2 Doppler Radar

- Doppler radar uses Doppler effect to measure speed of a vehicle at a distance by analysing the reflected microwave signal from the desired target. These systems operate by radiating energy into space and detecting the echo signal reflected from an object or target.

$$\Delta f\ (\text{Doppler shift}) = \frac{\text{Velocity of the Object} \times 2}{\text{Wave length}} \qquad (2\text{-}21)$$

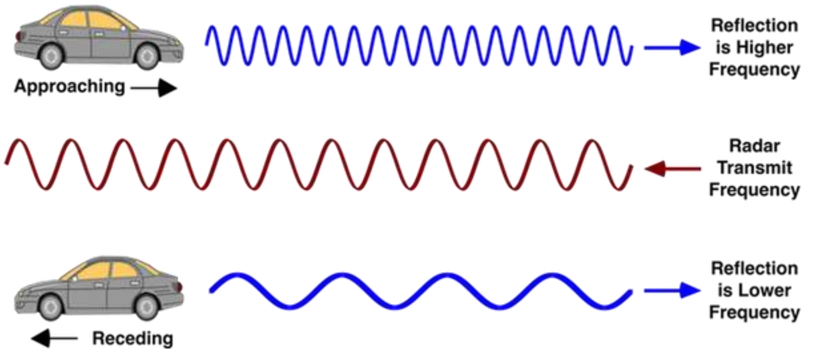



Figure 3.13 Doppler Effect

- Can perform at long or short distances and under the conditions of darkness, haze, fog, rain, and snow etc.
- Two identical 4x4 microstrip planar array antennas are used for transmission and reception of the radar system.

There are many applications where Doppler radars are used. Some of them are

- Police radar guns
- Weather Doppler radar
- Doppler Echocardiogram

In this project Doppler radar was designed to use as a Police Radar Gun.

**Specifications of the Police Radar Gun:**

| | | | |
|---|---|---|---|
| Maximum power transmitted | - | 10.23 | mW |
| Antenna Gain | - | 16.7157 | dB |
| Frequency | - | 10.525 | GHz |
| Free Space velocity | - | 3x $10^8$ | m/s |
| Max velocity of the target | - | 150 | kmph |
| Min velocity of the target | - | 50 | kmph |
| Wave length | - | 0.0285 | m |
| Radar cross section | - | 100 | $m^2$ |
| Range | - | 50- 200 | m |
| Oscillator Stability | - | 100 | ppm |

In the design operating frequency is 10.525 GHz. So the Radar operates in the X band. X band Police Radar guns are less vulnerable to extreme weather conditions.

Following Figure 2.13 shows the basic principle of working of a radar system.

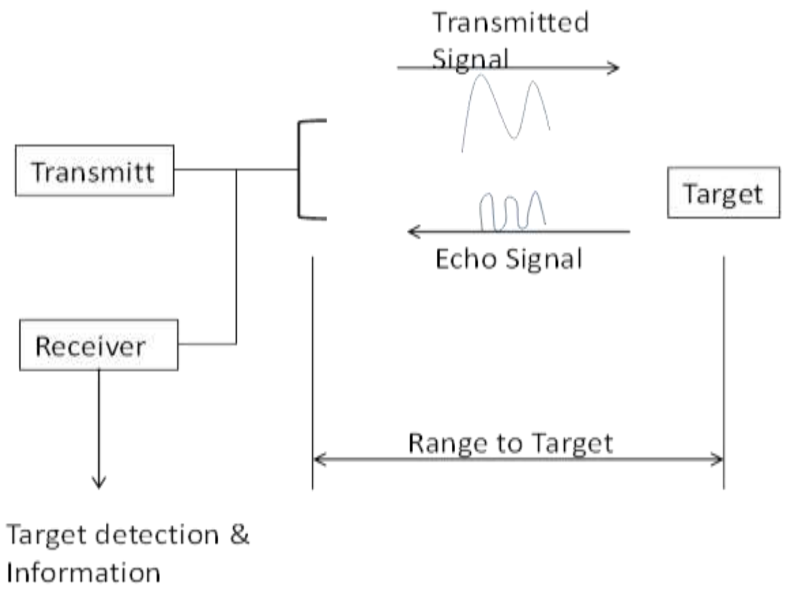



Figure 3.14 Basic principle of Working of a radar system.

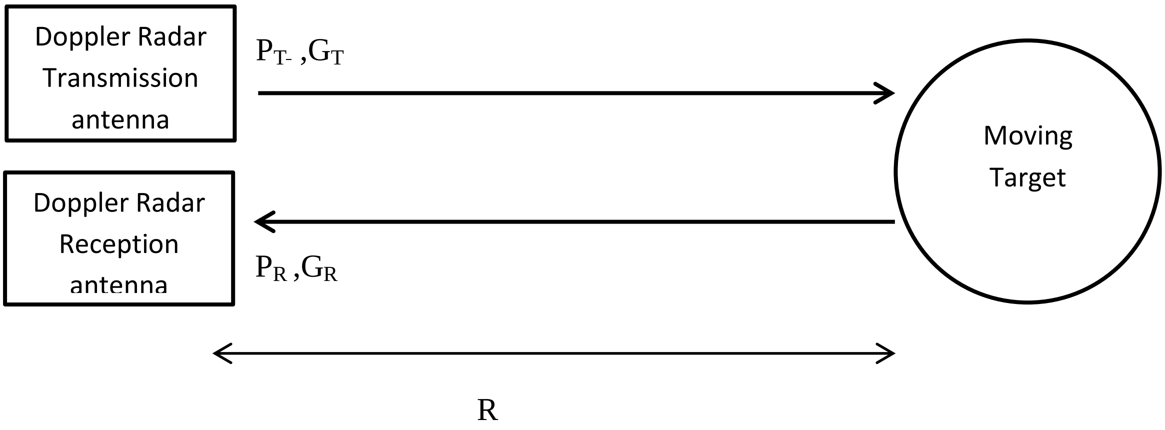



Figure 3.15 Receive power calculations

Power Density at the Target $$= \frac{P_T G_T}{4\pi R^2} \tag{2-22}$$

Power received at the Target $$= \frac{P_T G_T \sigma}{4\pi R^2} \tag{2-23}$$

Receive power at the Reception antenna $$P_R = \frac{P_T G_T \sigma A_e}{(4\pi R^2)^2} \tag{2-24}$$

Where the symbols $P_T$ ,$G_T$ ,$P_R$ ,$G_R$ , R, σ, $A_e$ denote the Transmitting power from the transmission antenna, Transmission antenna gain, Receiving power from the reception antenna, Reception antenna gain, Distance between the radar and the moving target, Radar cross section of a target and Effective aperture of the reception antenna respectively.

Radar cross section is defined as the cross sectional area of a uniform pattern that would give the actual power density at the receiving antenna.

Effective aperture $A_e$ $$= \frac{\lambda^2 G_R}{4\pi} \tag{2-25}$$

λ is the free space wave length.

# CHAPTER 4 Methodology

## 4.1 Design and calculations of a Rectangular Patch Antenna

Resonant frequency ($f_r$) = 10 GHz.

Dielectric constant of the substrate ($\varepsilon_r$) = 3.2

Height of the substrate (h) = 0.762mm

1. Determining W

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

$v_o$ –Free space velocity of light = $3*10^8$ $ms^{-1}$

$$w = \frac{3*10^8}{2*10*10^9}\sqrt{\frac{2}{3.2+1}}$$
$$=0.0103 \text{ m}$$
$$=\underline{\underline{1.04 \text{ cm}}}$$

2. Effective dielectric constant of the patch $\varepsilon_{reff}$ to account for the fringing effect

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{w}\right]^{-1/2}$$
$$= \frac{3.2+1}{2} + \frac{3.2-1}{2}\left[1+\frac{12*0.762*10^{-3}}{0.0103}\right]^{-1/2}$$
$$=\underline{\underline{2.9015}}$$

3. Extension of the length

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)}$$

$$\Delta L = 0.762*0.412\frac{(2.901+0.3)(\frac{10.3}{0.762}+0.264)}{(2.901-0.258)(\frac{10.3}{0.762}+0.8)}$$

$$=\underline{\underline{0.366 \text{ mm}}}$$

4. Actual length of the patch

$$L = \frac{v_o}{2f_r\sqrt{\varepsilon_{reff}}} - 2\,\Delta L$$
$$= \frac{3*10^8}{2*10*10^9\sqrt{2.895}} - 2*0.366*10^{-3}$$
$$=8.075*10^{-3} \text{ m}$$
$$=\underline{\underline{8.075 \text{ mm}}}$$

5. Calculating the width of micro strip line feed. ($w_0$)

Let's take ($w_0$/h) = x

$Z_c = 50\Omega$

h = 0.762mm, $\varepsilon_r = 3.2$

By taking equation (1) & (3)

$$50 = \frac{60}{\sqrt{\frac{3.2+1}{2} + \frac{3.2-1}{2}[1+12/x]^{-1/2}}} \ln\left[\frac{8}{x} + \frac{x}{4}\right]$$

X =2.53

Here x>1, so this condition is not compatible with the condition.

By taking (2) & (3),

$$50 = \frac{120\pi}{\sqrt{\frac{3.2+1}{2} + \frac{3.2-1}{2}[1+12/x]^{-1/2}}[x+1.393+0.667\ln(x+1.444)]}$$

X = 2.425

Here X > 1, this is compatible with the condition.

$$\frac{w_0}{h} = 2.425$$

$W_0$ = 0.762 * 2.425 mm

= 1.848 mm

6. Antenna input impedence

$$G_1 = \frac{I_1}{120\pi^2}$$

Where,

$$I_1 = \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 (\sin\theta)^3 \, d\theta$$

$$= -2 + \cos(x) + XS_i(X) + \frac{\sin(x)}{x}$$

$X = k_0 W$

$$S_i(X) = \int_0^{x} \frac{\sin\tau}{\tau} d\tau$$

**MATLAB code for finding $G_1$ and $G_{12}$**

```
f = 10^10;
Er = 3.2;
h = 0.000762;
v = 3*(10^8);
 w = (v/(2*f))*sqrt(2/(Er+1))
Ereff = (Er+1)/2+(Er-1)*(1+12*h/w)^(-0.5)/2
  a = w/h;
dL = h*0.412*(Ereff+0.3)*(a+0.264)/((Ereff-0.258)*(a+0.8))
 L = v/(2*f*sqrt(Ereff))-2*dL
W0 = h*0.4711
 % Finding G1
 k = (2*pi*f)/v;
X = k*w;
 syms x
Si   = int(((sin(x))/x),0,X)
SiX = sinint(76276372363661/35184372088832)
I      = -2 + cos(X) + X*SiX + (sin(X))/X
G1  = I/(120*pi*pi)
d=0.0001;
A=0;
x=0;
y=0;
f1 = (sin(k*w*cos(x)/2)/cos(x))^2*(besselj(0,k*L*sin(x)))*(sin(x))^3;
f2 = (sin(k*w*cos(y)/2)/cos(y))^2*(besselj(0,k*L*sin(y)))*(sin(y))^3;
for x=0:d:pi
    y=x+d;

A=A+d*((sin(k*w*cos(x)/2)/cos(x))^2*(besselj(0,k*L*sin(x)))*(sin(x))^3+(sin(k*w*cos(y)/2)
/cos(y))^2*(besselj(0,k*L*sin(y)))*(sin(y))^3)/2;
end

I12 = A
G12=I12/(120*pi*pi)
Rin=1/(2*(G1+G12))
```

Calculated parameters

$I_1$ =1.4518 A

$G_1$ = 0.0012 s

$I_{12}$ =0.7260 A

$G_{12}$ =6.1297*$10^{-4}$ s

$R_{in}$ =271.9235 Ω

Using the above calculated parameters rectangular patch antenna was designed and simulated using Ansoft HFSS (High Frequency Structure Simulator) software. The designed patch is shown in the Figure 3.1.

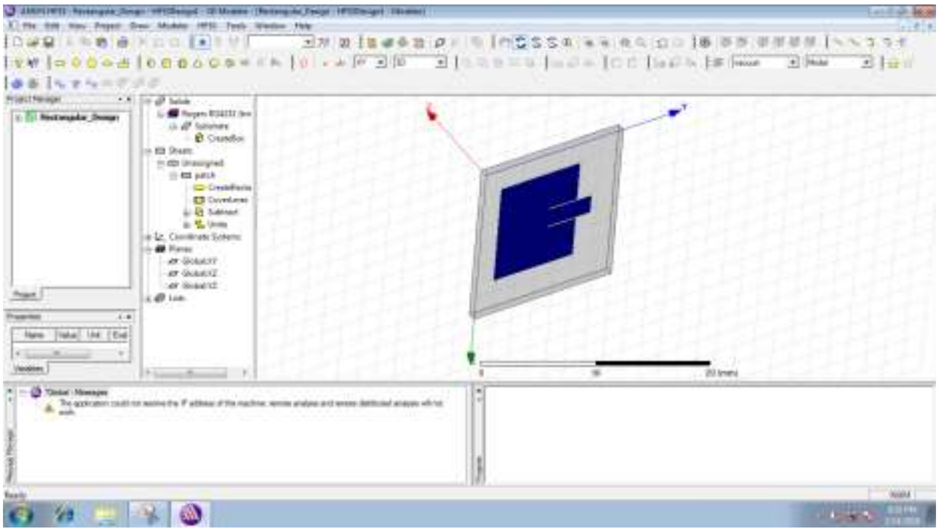


Figure 4.1 Designed patch in HFSS

## 4.2 Design and calculations of a Square Patch Antenna

Calculating the parameters of the square patch antenna is more similar to the calculations in the rectangular patch antenna. Only difference is, in a square patch length and width should be same (L=W). Equations used in the designing of rectangular patch antenna are used here by replacing W by L. Using the equations (2-5), (2-6) and (2-9) fallowing equation (3-1) can be deduced.

$$L = \frac{v_o}{2f_r\sqrt{\frac{\varepsilon r+1}{2}+\frac{\varepsilon r-1}{2}\left[1+\frac{12h}{L}\right]^{-1/2}}} - 2*h*0.412\frac{\left(\frac{\varepsilon r+1}{2}+\frac{\varepsilon r-1}{2}\left[1+\frac{12h}{L}\right]^{-1/2}+0.3\right)(\frac{L}{h}+0.264)}{\left(\frac{\varepsilon r+1}{2}+\frac{\varepsilon r-1}{2}\left[1+\frac{12h}{L}\right]^{-1/2}-0.258\right)(\frac{L}{h}+0.8)} \qquad (3\text{-}1)$$

**MATLAB code to solve the equation (3-1)**

```
syms L
      e=3.2;
      h=0.000762;
      fr=10^10;
      v=3*(10^8);
```

```
eqn=2*h*0.412*((e+1)/2+(e-1)/2*(1+12*h/L)^(-0.5)+0.3)*(L/h+0.264)
   /((((e+1)/2+(e- 1)/2*(1+12*h/L)^(-0.5)-0.258)*(L/h+0.8))
  -v/(2*fr*((e+1)/2+(e-1)/2*(1+12*h/L)^(- 0.5))^(0.5))+L==0;
Lsol=solve(eqn,L)
Lsol=vpa(Lsol)
```

Solutions of the code

```
>> one

Lsol =

 (200475859496093565881521840930066862342170720114986246200744805563077238779400473l7*root(z^11 + (22425600806802104970904628683675231272722
 (200475859496093565881521840930066862342170720114986246200744805563077238779400473l7*root(z^11 + (22425600806802104970904628683675231272722
 (200475859496093565881521840930066862342170720114986246200744805563077238779400473l7*root(z^11 + (22425600806802104970904628683675231272722
 (200475859496093565881521840930066862342170720114986246200744805563077238779400473l7*root(z^11 + (22425600806802104970904628683675231272722


Lsol =

                                                0.012388317063696541456945338229251
                                                0.0081500164033614926385458628738447
 - 0.00064240299787177885341694423999124 + 0.0000010576568643993563325070968764162i
 - 0.00064240299787177885341694423999124 - 0.0000010576568643993563325070968764162i
```

From the solutions 8.1mm was chosen as the length of the square patch.

W = L = 8.1mm

For calculating the microstrip feed line width equation (2-10) is used.

Let's take $(w_0/h) = x$

$Z_c = 50\Omega$

$h = 0.762\text{mm}$, $\varepsilon_r = 3.2$

From equation (2-5) for square patch antenna where $L=w_0$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1 + 12h/w_0]^{-1/2} \tag{3-2}$$

By taking equation (2-10) - (1) and (3-2)

$$50 = \frac{60}{\sqrt{\frac{3.2+1}{2} + \frac{3.2-1}{2}[1+12/x]^{-1/2}}} \ln\left[\frac{8}{x} + \frac{x}{4}\right]$$

X =2.53

Here x>1, so this condition is not compatible with the condition.

By taking (2-10)-(2) and (3-2),

$$50 = \frac{120\pi}{\sqrt{\frac{3.2+1}{2} + \frac{3.2-1}{2}[1+12/x]^{-1/2}}[x+1.393+0.667\ln(x+1.444)]}$$

X = 2.425

Here X > 1, this is compatible with the condition.

$$\frac{w_0}{h} = 2.425$$

$W_0$= 0.762 * 2.425 mm

= 1.848 mm

**MATLAB code to find the antenna impedance**

```
f = 10^10;
Er = 3.2;
h = 0.000762;
v = 3*(10^8);
L= 0.0081500164033614926385458628738447;

Ereff = (Er+1)/2+(Er-1)*(1+12*h/L)^(-0.5)/2

% Finding G1

k = (2*pi*f)/v;
X = k*L;
 syms x
Si   = int(((sin(x))/x),0,X)
SiX =sinint(7687353829374789/4503599627370496)
I      = -2 + cos(X) + X*SiX + (sin(X))/X
G1   = I/(120*pi*pi)
```

Solutions from the code

```
SiX =

    1.4536


I =

    0.9260


G1 =

   7.8182e-04
```

```
% Finding G12

d=0.0001;
A=0;
x=0;
y=0;
leff=v/(2*f*sqrt(2.901));
f1 = (sin(k*L*cos(x)/2)/cos(x))^2*(besselj(0,k*L*sin(x)))*(sin(x))^3;
f2 = (sin(k*L*cos(y)/2)/cos(y))^2*(besselj(0,k*L*sin(y)))*(sin(y))^3;
for x=0:d:pi
    y=x+d;
    A=A+d*((sin(k*L*cos(x)/2)/cos(x))^2*(besselj(0,k*L*sin(x)))*(sin(x))^3+(sin(k*L*cos(y)/2)/cos(y))^2*(besselj(0,k*L*sin(y)))*(sin(y))^3)/2;
end

I12 = A
G12=I12/(120*pi*pi)
Rin=1/(2*(G1+G12))
```

```
I12 =

    0.4591


G12 =

   3.8761e-04


Rin =

  427.5580

>>
```

Rin (Y=Y0) = Rin (Y=0) $\cos^2(\frac{\pi}{L}y_0)$

Substituting Rin (Y=0) & Rin (Y=Y0) = 50 Ω,

$$50 = \text{Rin (Y=0)} \cos^2(\frac{\pi}{L}y_0)$$

**MATLAB code to find $y_0$**

```
%Finding y0
syms y
eqn = Rin*(cos((pi/L)*y))^2-50==0;
Y0sol=solve(eqn,y);
Y0sol=vpa(Y0sol)
```

```
Y0sol =

 -0.0031695903884556011371682300102019
  0.0031695903884556011371682300102019
```

Calculated parameters of the square patch

| | |
|---|---|
| L | =8.15 mm |
| $\varepsilon_{reff}$ | =2.8551 |
| $G_{12}$ | =3.8761*10$^{-4}$ s |
| $R_{in}$ | =427.5580 Ω |
| $Y_0$ | =3.17 mm |
| $W_0$ | =1.848 mm |

Using the above calculated parameters square patch antenna was designed and stimulated using Ansoft HFSS (High Frequency Structure Stimulator) software. The designed square patch is shown in the figure 3.6.

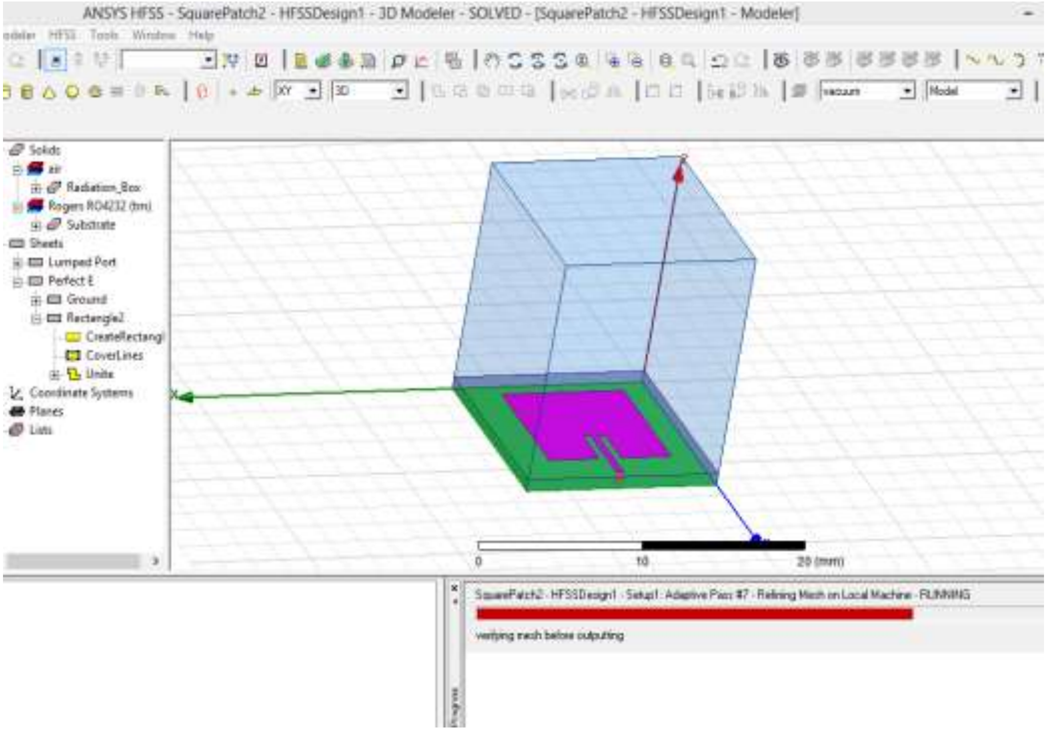



Figure 4.2 Designed square patch

## 4.3 Design and calculations of a 4×4 Square Patch Antenna Array

Array antenna was designed after simulating single patch antenna. Design of the array antenna is shown below [3].

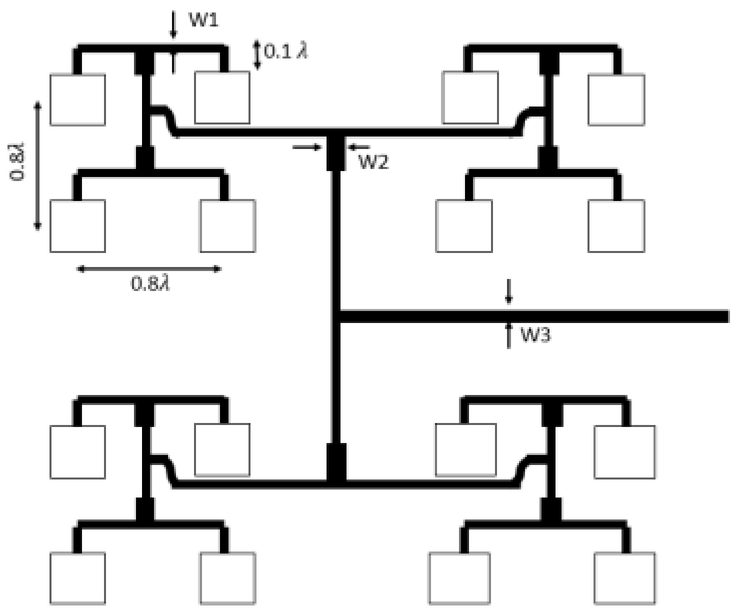



Figure 4.3 Rough sketch of the array design

W1 – Width of the micro strip line when impedance is 100 Ω

W2 – Width of the micro strip line when impedance is z' = $\sqrt{100 \times 50}$ Ω

W3 – Width of the micro strip line when impedance is 50 Ω

### 4.3.1 Calculations for Transmission line widths

Using the equation (2-10) (1) and (2-5)

Let's take $\frac{Wo}{h}$ = x from (2-15)

$Z_c$ = 100

h = 0.762mm

$\varepsilon_r$ = 3.2

$$100 = \frac{60}{\sqrt{\frac{3.2+1}{2} + \frac{3.2-1}{2}[1 + 12 \ / x]^{-1/2}}} \ln\left[\frac{8}{x} + \frac{x}{4}\right]$$

X = 0.6307

W1 = 0.6307 × 0.762

= <u>0.4806 mm</u>

Using equation (2-10)-(2)

$$\sqrt{100 \times 50} = \frac{120\pi}{\sqrt{\varepsilon reff}\, x{+}1.393.0.667\ln(x{+}1.444)}$$

X = 1.333

W2 = 1.333 × 0.762

= <u>1.01598 mm</u>

W3 = <u>1.848 mm</u> (This value was calculated in Chapter 3 Rectangular calculations)

### 4.3.2 Calculation for wavelength $\lambda$

$$V = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_r\mu_o\varepsilon_r\varepsilon_o}} = \frac{1}{\sqrt{\mu_o\varepsilon_o}} \times \frac{1}{\sqrt{\mu_r\varepsilon_r}}$$

$$= \frac{c}{\sqrt{\mu_r\varepsilon_r}}$$

In most mediums $\mu_r = 1$

<u>At free space</u>

V = f $\lambda$

Here, $\lambda = \frac{3\times10^8}{10\times10^9}$

$= 3\times 10^{-2}$

0.8 $\lambda$ = <u>24 mm</u>

At 100 Ω impedance,

$$\varepsilon_{reff} = 2.1 + 1.1\,(1 + \frac{12}{0.6307})^{-1/2}$$

= 2.3458

$$\lambda = \frac{3\times10^{8}}{\sqrt{2.3458}\times10^{10}}$$

= 0.01958 m

=19.58 mm

0.1$\lambda$ = 1.958 mm

At $\sqrt{50 \times 100}\Omega$ impedence

$$\varepsilon_{reff} = 2.1 + 1.1\left(1 + \frac{12}{1.333}\right)^{-1/2}$$

= 2.4478

$$\lambda = \frac{3\times10^{8}}{\sqrt{2.4478}\times10^{10}}$$

= 0.019174 m

= 19.174 m

### 4.3.3 HFSS Design

Since radar design needs two identical array antennas, design with two antennas is shown in the figure 3.4.

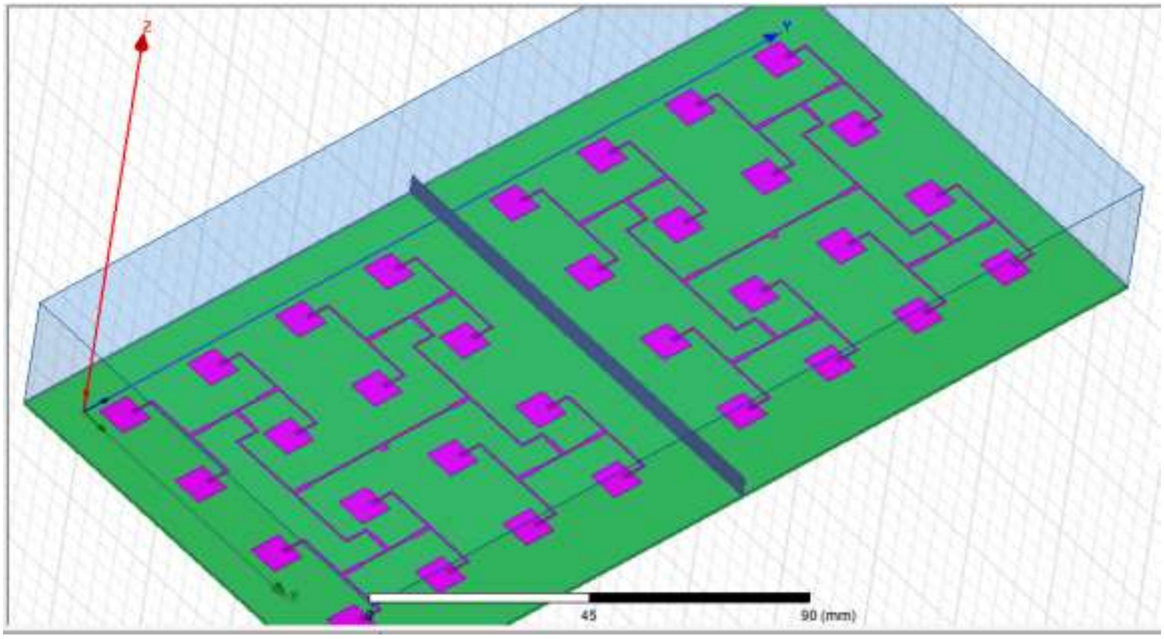



Figure 4.4 HFSS Design of the patch antenna array

Power of the receiving signal, reflected from the moving vehicle is much smaller compared to the transmitted signal. Therefore interference from the transmission antenna to the reception antenna will highly affect the readings. In order to isolate transmission and reception antenna, Aluminium isolator of height 16.1 mm is used in between two antennas. Height is chosen using trial and error method in HFSS.

### 4.4 Doppler Radar calculations

In this project same antenna is used for transmission and reception purposes. Therefore $G_T = G_R$

According to the radar specifications $P_T = 10$ mW

Receiving power at the transmitter varies according to the distance between the radar and the target.

Using equation (2-25).

$$A_e = \frac{\left[\frac{3\times10^8}{10.5\times10^9}\right]^2 10^{1.67157}}{4\pi}$$

$$= 3.051 \times10^{-3}$$

- When R = 50 m

  Substitute $A_e$ in equation (2-24)

  Radar cross section of a vehicle = 100 m$^2$

$$P_R = \frac{10\times10^{-3}\times10^{1.67157}\times100\times3.051\times10^{-3}}{(4\pi\times50^2)^2}$$

$$= 1.4512 \times10^{-11} \text{ W}$$

$$= \underline{\underline{-68.38 \text{ dBm}}}$$

- When R = 200 m

  Substitute $A_e$ in equation (2-24)

  Radar cross section of a vehicle = 100 m$^2$

$$P_R = \frac{10\times10^{-3}\times10^{1.67157}\times100\times3.051\times10^{-3}}{(4\pi\times200^2)^2}$$

$$= 5.6686 \times10^{-11} \text{ W}$$

$$= \underline{\underline{-92.465 \text{ dBm}}}$$

Sensitivity of the receiver = minimum input power for the proper operation

= $kT_oB$ + Noise Figure

= $10\log(kT_o)$ + 10log(Bandwidth) +Noise Figure

Frequency jitter $\frac{\Delta f}{f_o} \times 10^6$ = 100 ppm

$$\Delta f = \frac{100\times 10.5\times 10^{9}}{10^{6}}$$

$$= 1050000 \text{ Hz}$$

$$= \underline{60.211 \text{ dB}}$$

-68.38 dBm = -174 dBm + 60.211dB+ Noise Figure

Noise Figure = <u>45.409 dBm</u>

As the system overall noise figure is 45.409 dBm, components were selected in such a way that the total noise figures of the components do not exceed 45.409 dBm.

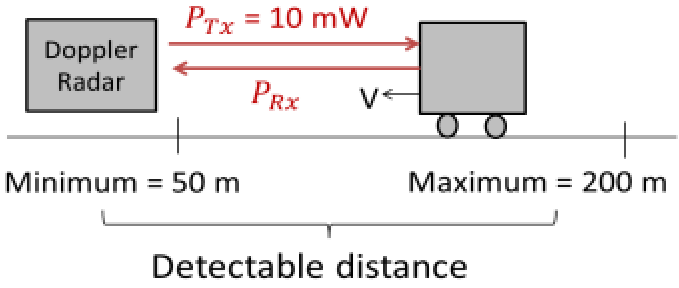



Figure 4.5 Specifications of the system

$$\Delta f \text{ (Doppler shift)} = \frac{\text{Velocity of the Object} \times 2}{\text{Wave length}}$$

$$50 \text{ kmph} \Rightarrow \Delta f = \frac{v\times 2}{\lambda} = \frac{50\times 10^{3}\times 10.5\times 10^{9}\times 2}{60\times 60\times 3\times 10^{8}} = \underline{972.22 \text{ Hz}}$$

$$150 \text{ kmph} \Rightarrow \Delta f = \frac{v\times 2}{\lambda} = \frac{150\times 10^{3} 10.5\times 10^{9}\times 2}{60\times 60\times 3\times 10^{8}} = \underline{2.916 \text{ kHz}}$$

$$\text{Resolution of the Radar} = \frac{2916 \text{ Hz} - 972.22 \text{ Hz}}{150\text{kmph} - 50 \text{ kmph}} = \underline{19.44 \text{ Hz/kmph}}$$

## 4.5 Block diagram of a Radar System

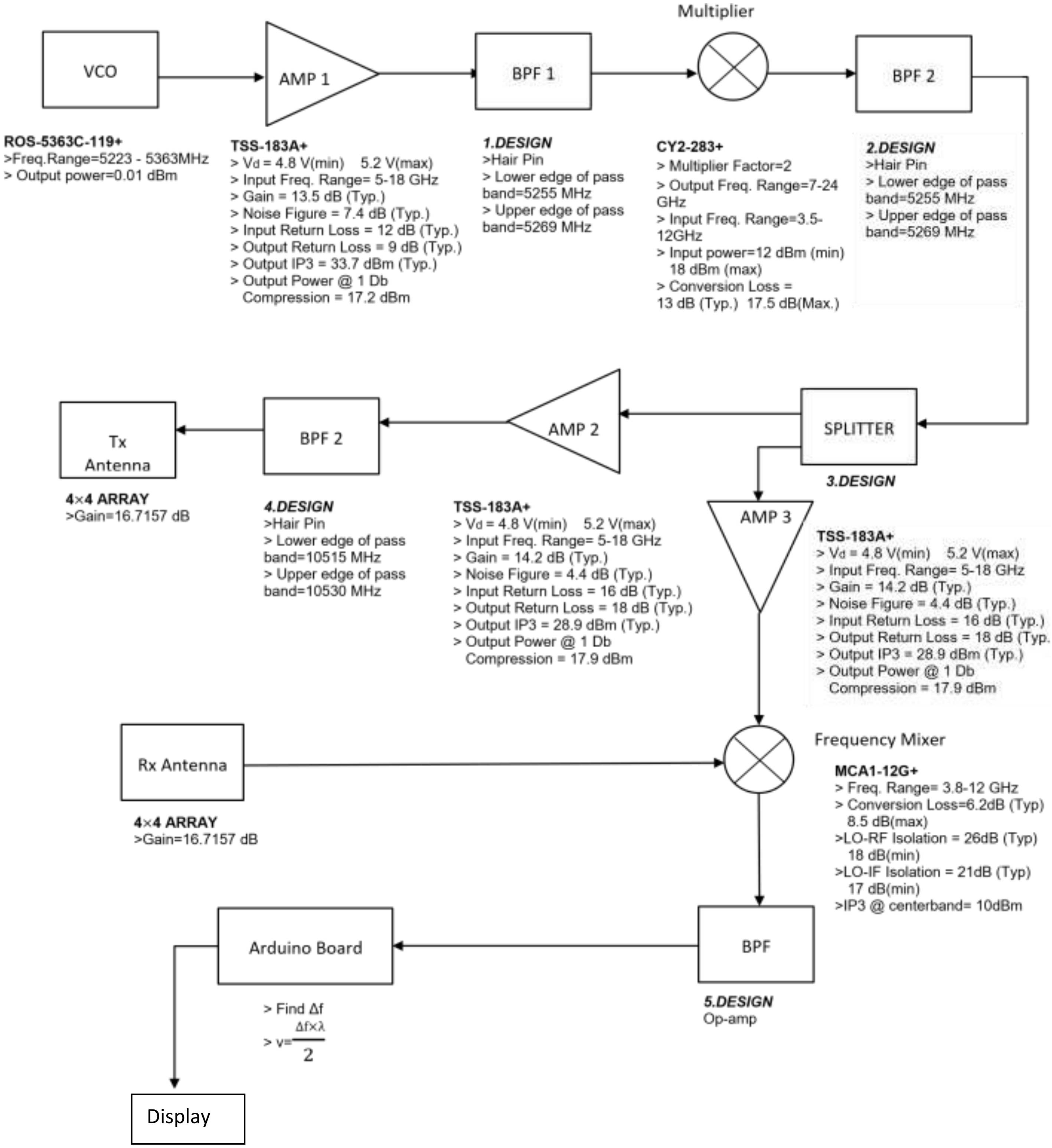



Figure 4.6 Block diagram of a radar

### 4.5.1 Radar design

Design and simulation of the radar and the layout design of the circuit are done using MWO AWR software by selecting the components which give 10 mW of transmitting power to the antenna.

For the two identical antennas two separated transmitter and receiver circuits should be designed. Transmitter circuit is shown in the figure 3.7.

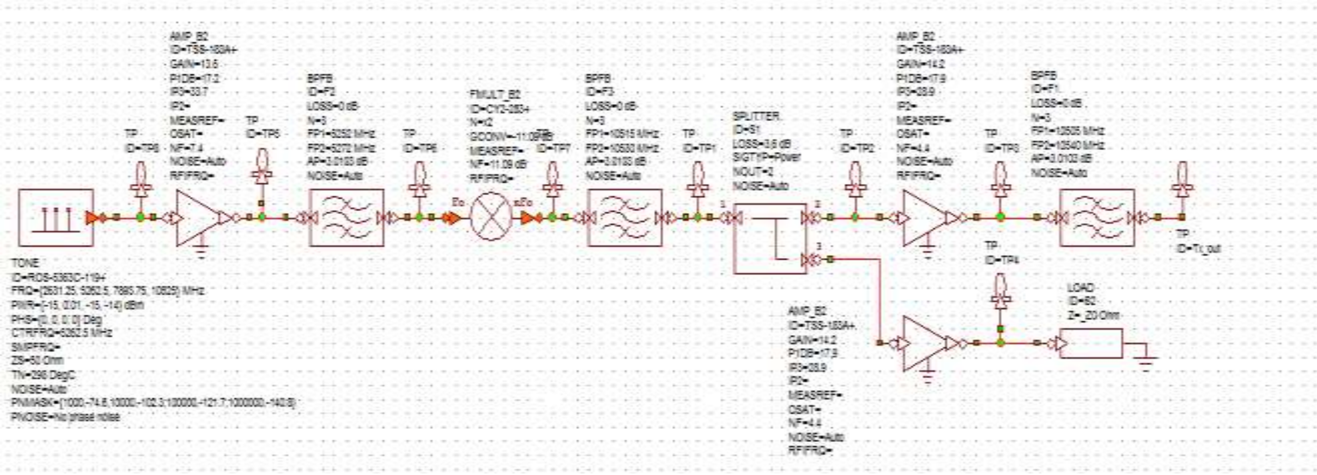


Figure 4.7 Transmitter circuit of the Doppler radar

5250 MHz frequency is generated by a VCO and is doubled using a frequency multiplier to the resonance frequency of the antenna, 10.5 GHz. A splitter was designed in AWR to split this signal to transmitter and to mixer. At each stage signal is amplified to achieve necessary power requirements of the components.

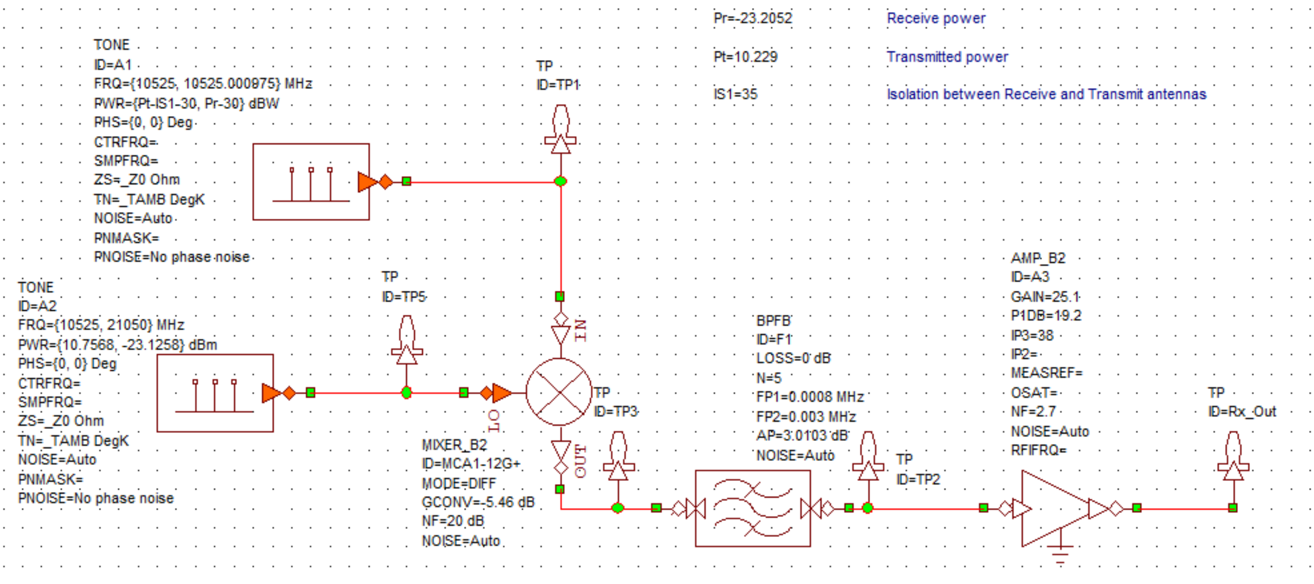



Figure 4.8 Receiver circuit of the Doppler radar

Received signal from the receiver antenna is mixed with the transmitted signal (separated from the transmitted signal in transmitter circuit) at the mixer. The resulting IF signal carries Doppler information.

## 4.6 Layout Design

### 4.6.1. Bandpass Filter Designs

Two bandpass filters were designed at 5250 MHz and 10.5 GHz. When designing the bandpass filters layouts were tuned in such a way that in simulation plots minimum reflection coefficients and maximum transmission coefficients occur at the resonant frequency.

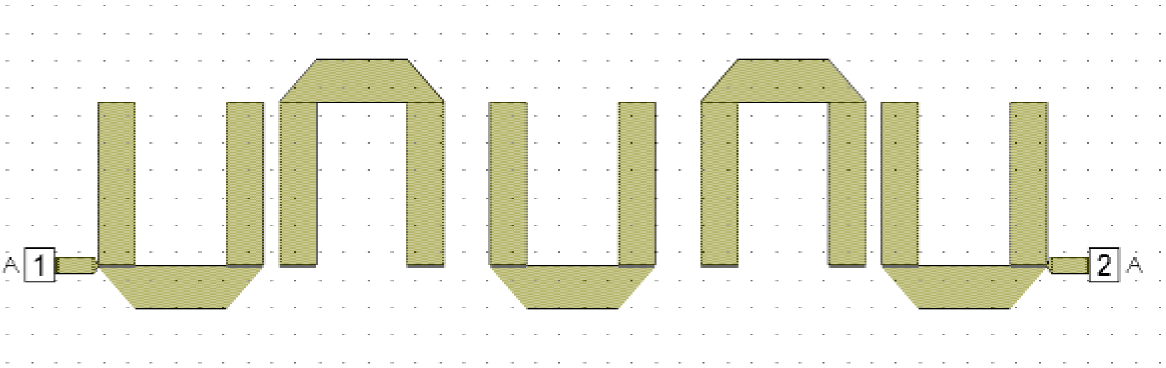



Figure 4.9 Layout of Hairpin structure Bandpass filter at 5250 MHz

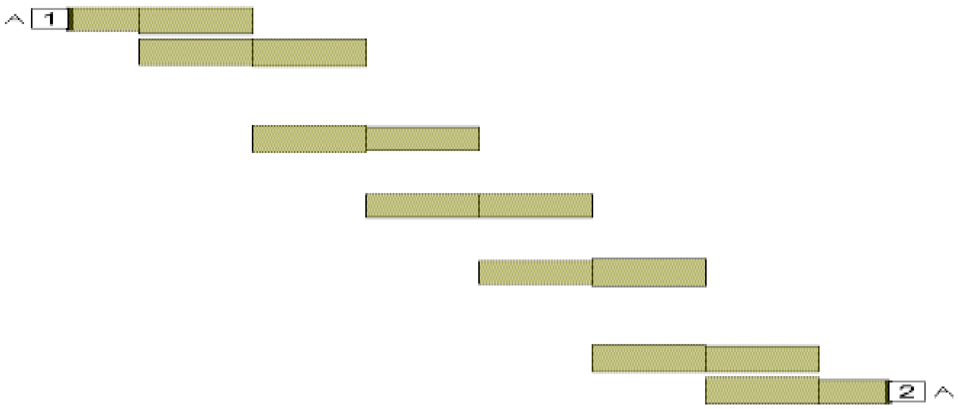
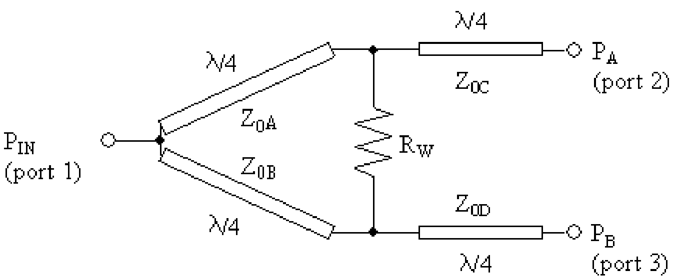



Figure 4.10 Layout of Edge coupled Bandpass filter at 10.5 GHz

### 4.6.2. Splitter Design

For the splitter design Wilkinson’s power divider is used. It splits an input signal into two equal phase output signals. Wilkinson relied on quarter-wave transformers to match the split ports to the common port. Figure of a Wilkinson’s power divider is shown below.



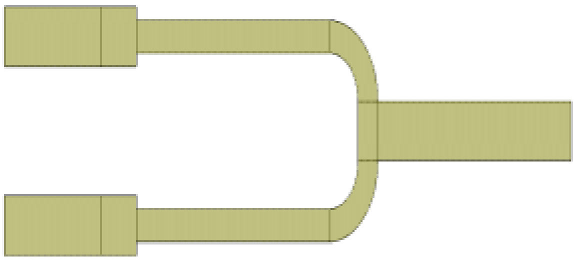



Figure 4.11 Layout of the Splitter

Figure 4.12 Wilkinson’s power divider

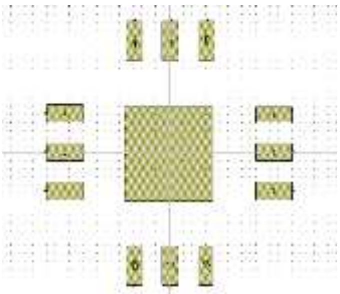


Figure 4.13 Layout of VCO

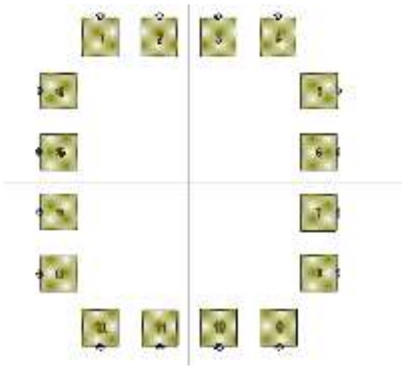


Figure 4.14 Layout of Doubler

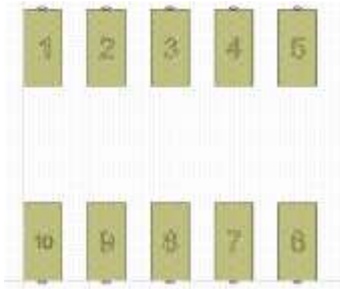


Figure 4.15 Layout of Mixer

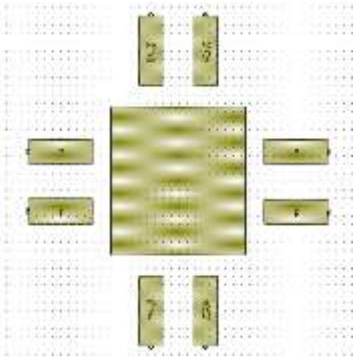


Figure 4.16 Layout of Amplifier 1

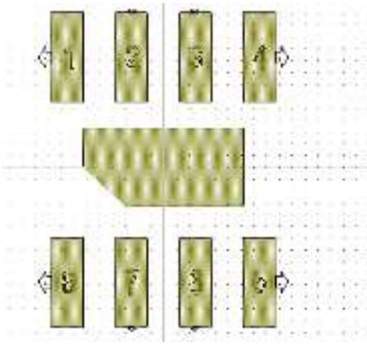


Figure 4.17 Layout of Amplifier 2

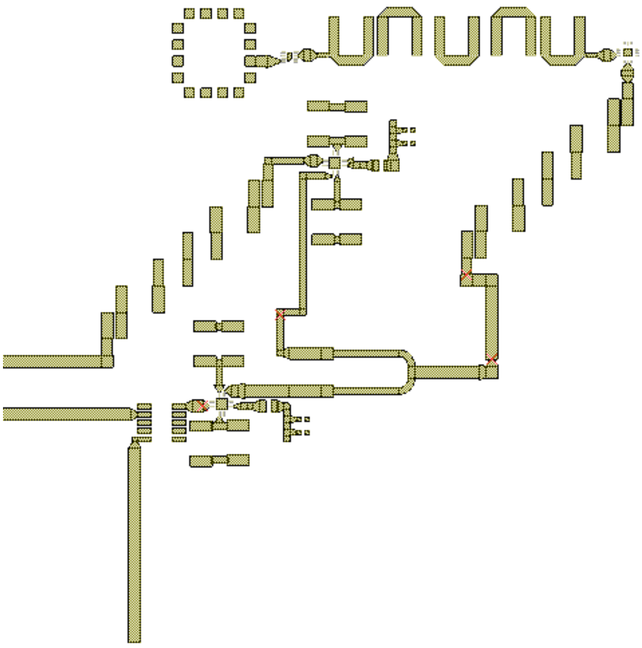


Figure 4.18  Layout of the radar circuit

# CHAPTER 5 Results and Discussion

## 5.1.1 HFSS Results

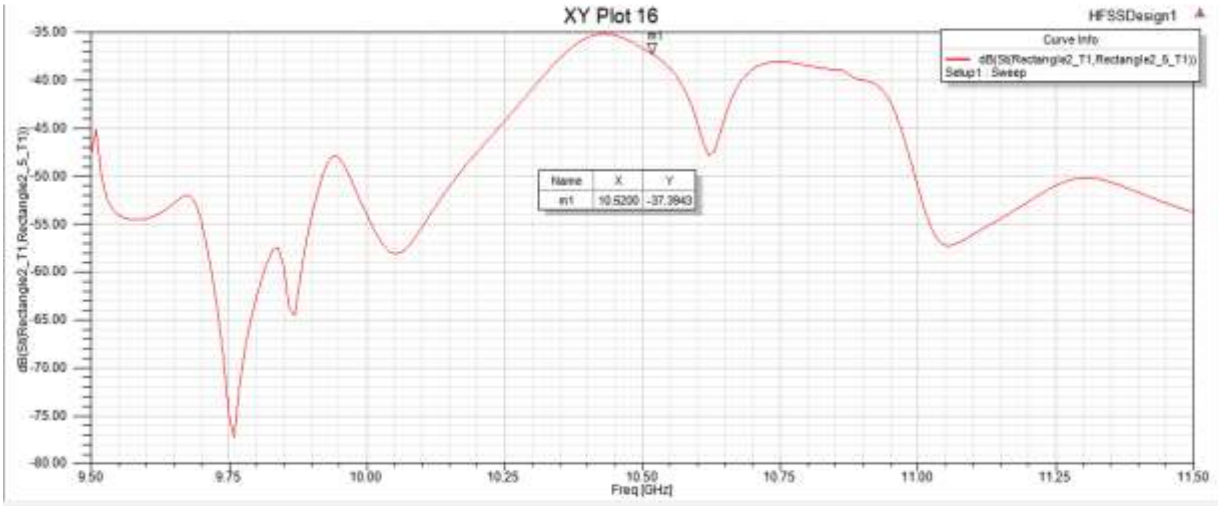



Figure 5.1 S12 plot of Antennas when isolator height = 7 mm

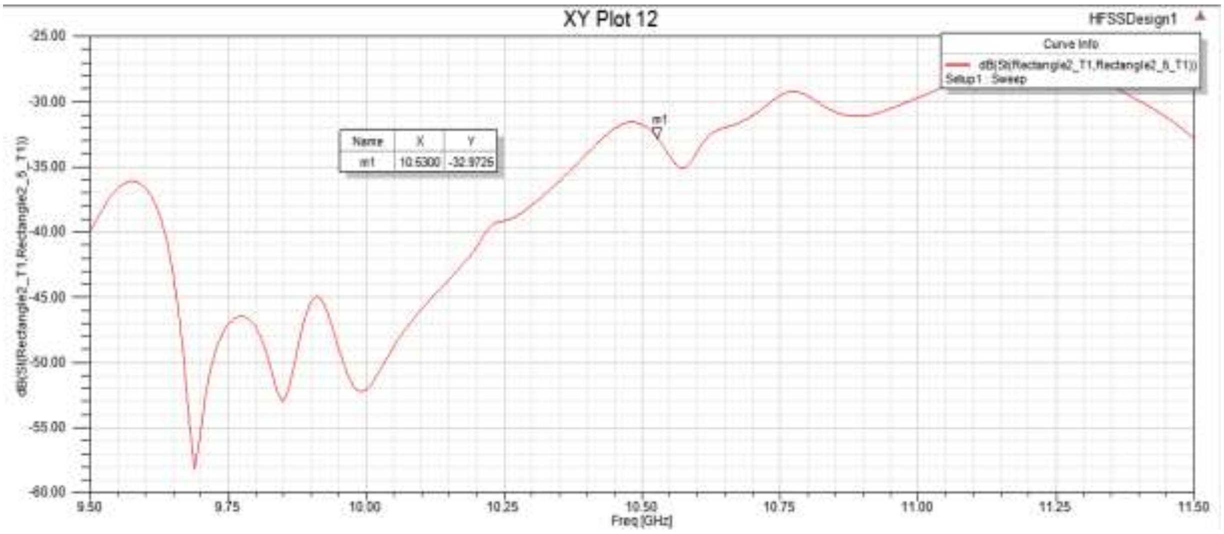



Figure 5.2 S12 plot of Antennas when isolator height = 16.1 mm

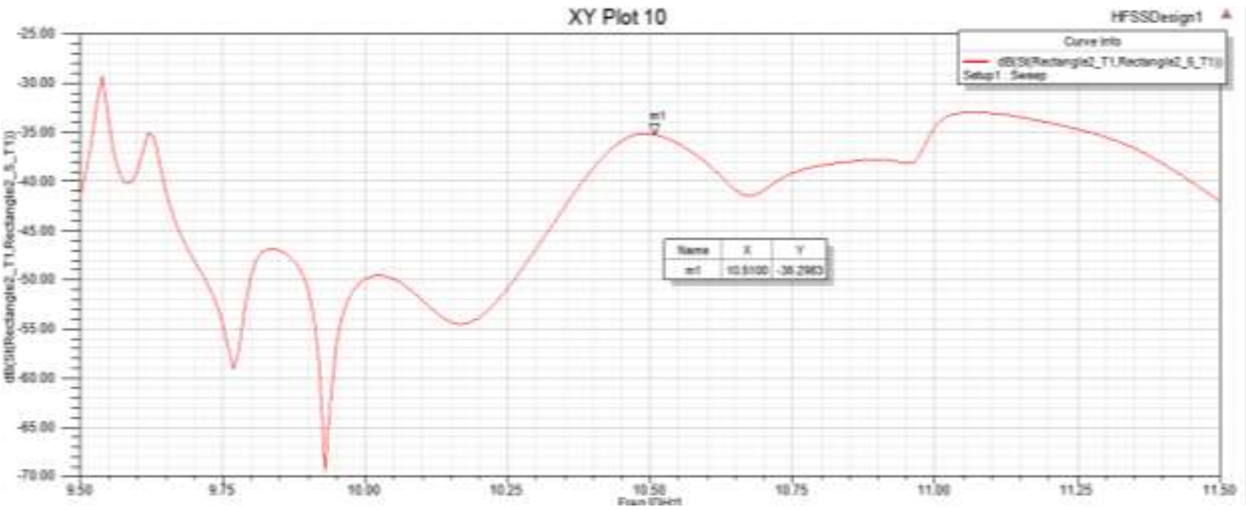



Figure 5.3 S12 plot of Antennas when isolator height = 22 mm

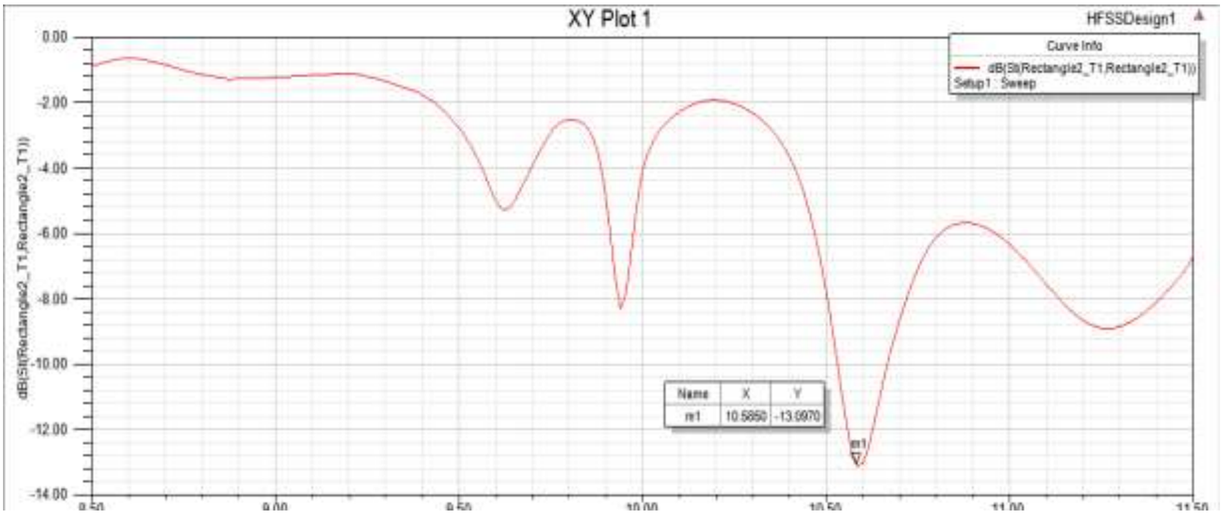


Figure 4.4: S11 plot of Antennas when isolator height = 7 mm

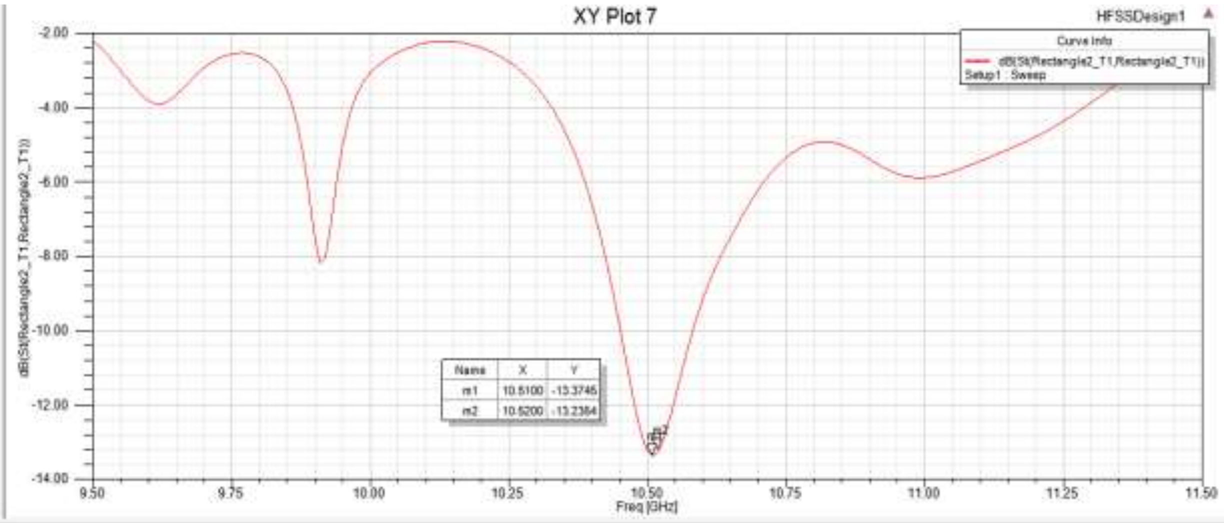


Figure 5.5: S11 plot of Antennas when isolator height = 16.1 mm

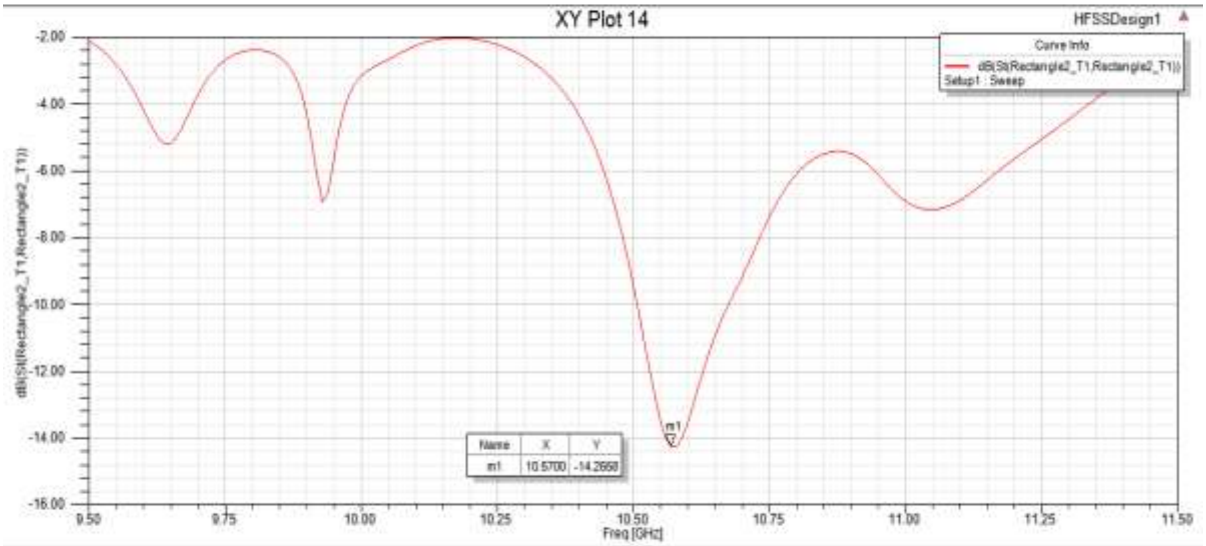


Figure 5.6: S11 plot of Antennas when isolator height = 22 mm

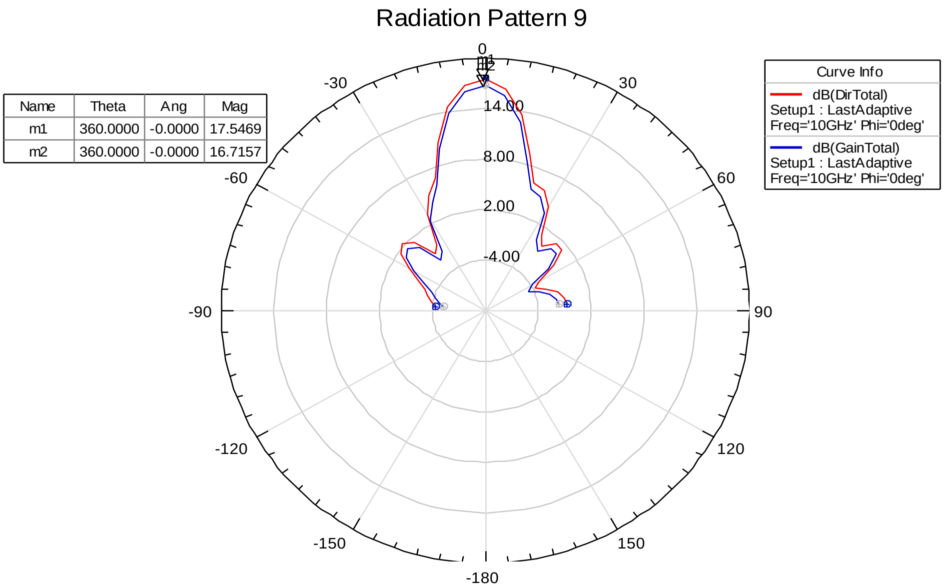



Figure 5.7: Gain and Directivity of Antenna Array

### 5.1.2 AWR Results

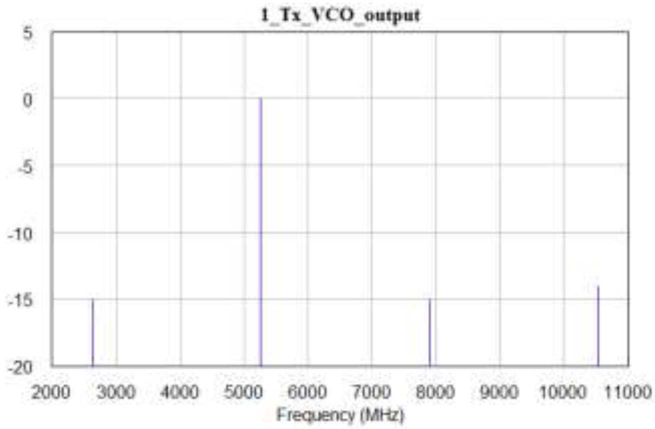



Figure 5.8: Frequency spectrum of the output of the Voltage controlled oscillator

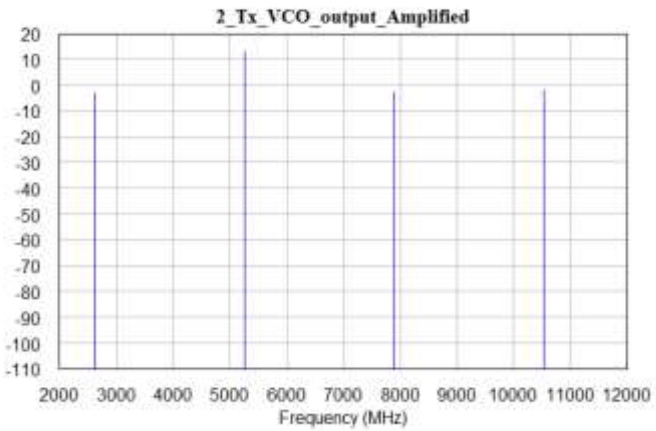



Figure 5.9: Frequency spectrum of the output of the VCO after amplification

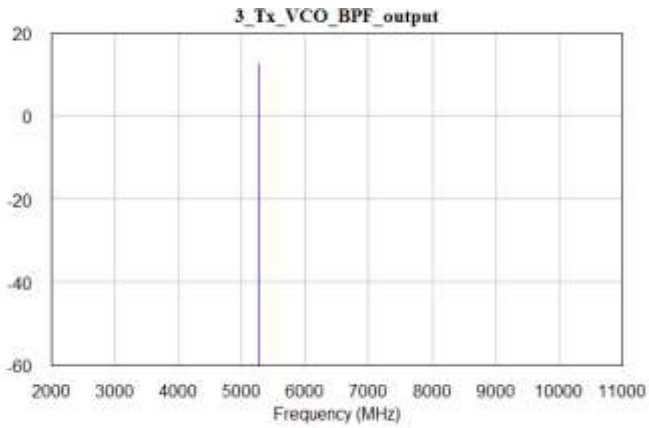



Figure 5.10: Frequency spectrum of the filtered output of the VCO

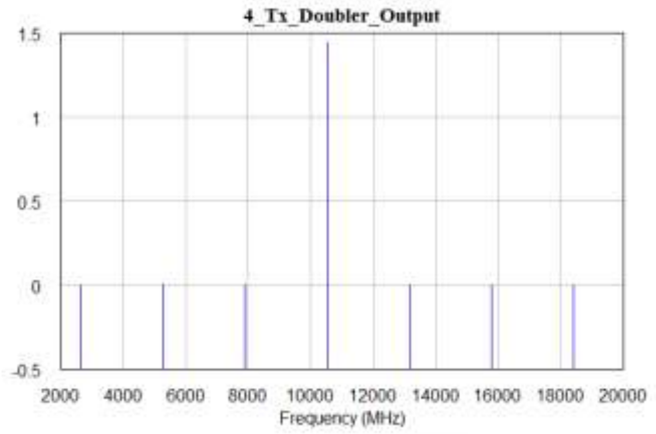



Figure 5.11: Frequency spectrum of the output of the frequency Doubler

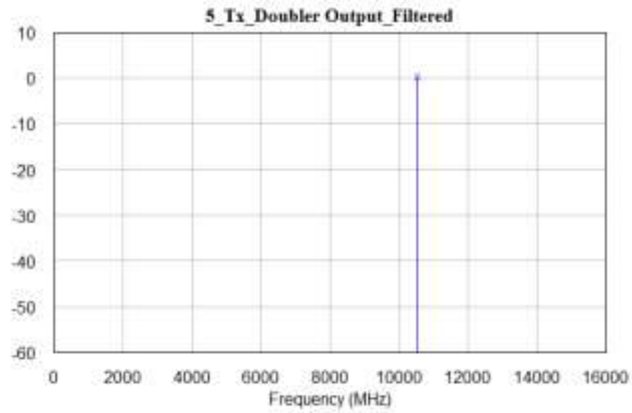



Figure 5.12 Frequency spectrum of the filtered output of the frequency Doubler

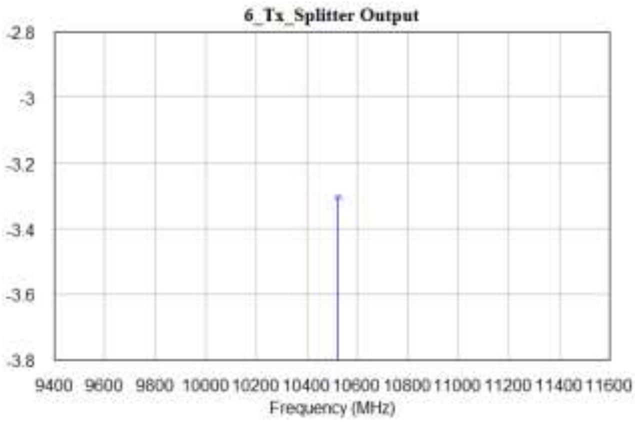



Figure 5.13 Frequency spectrum of the output of the Splitter

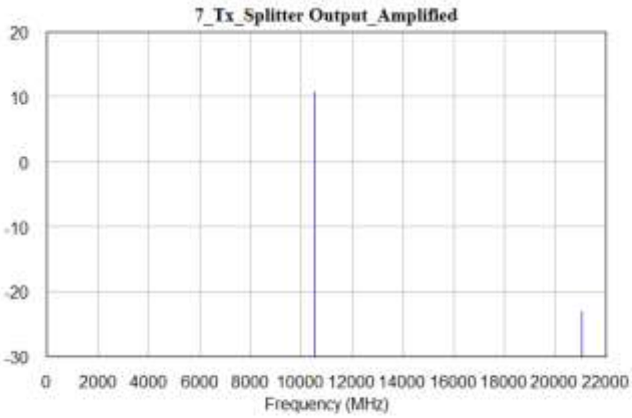



Figure 5.14 Frequency spectrum of the filtered output of the Splitter

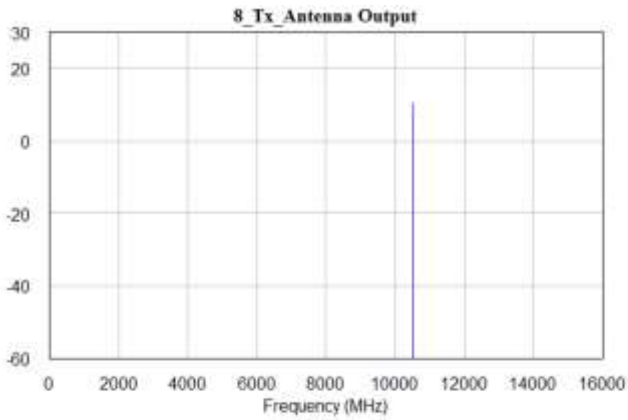



Figure 5.15 Frequency spectrum of the input to the transmission antenna

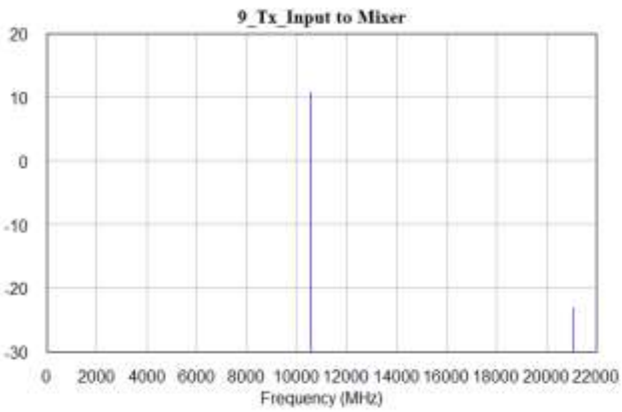



Figure 5.16: Frequency spectrum of the input of the mixer

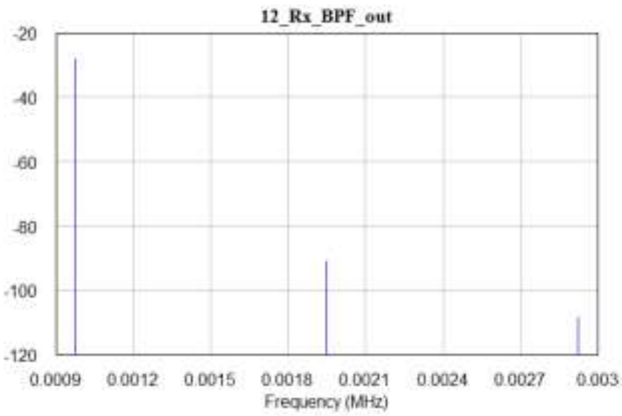



Figure 5.17: Frequency spectrum of the output of the Receiver

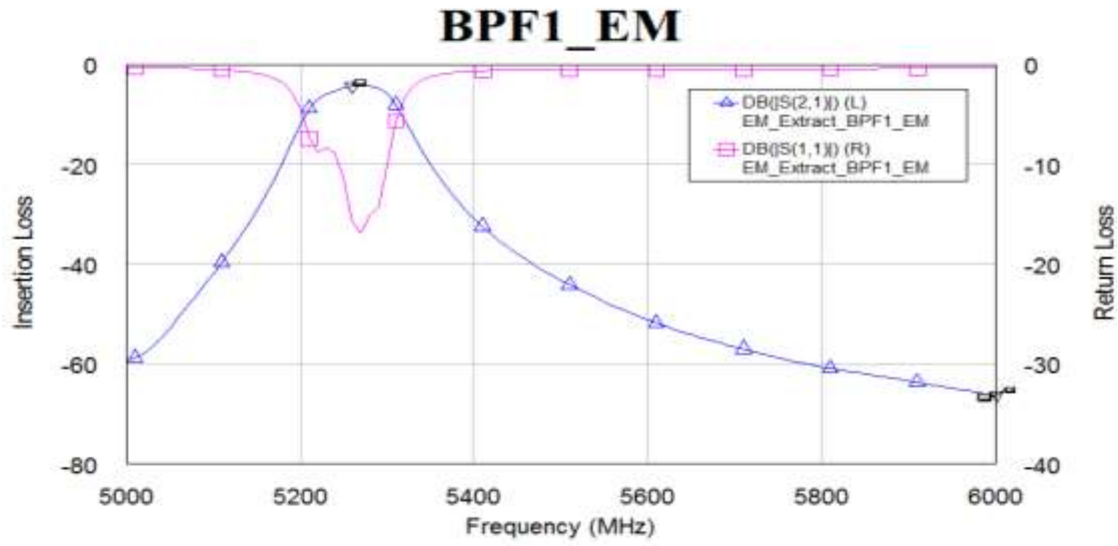



Figure 5.18 Reflection and transmission coefficient plot of hair pin bandpass filter at 5250 MHz

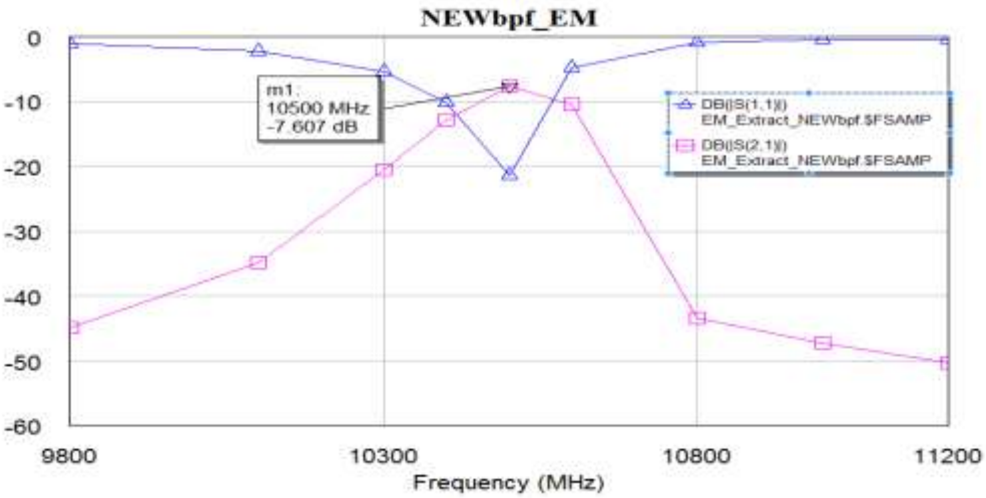



Figure 5.19 Reflection and transmission coefficient plot of edge coupled bandpass filter at 10.5 GHz

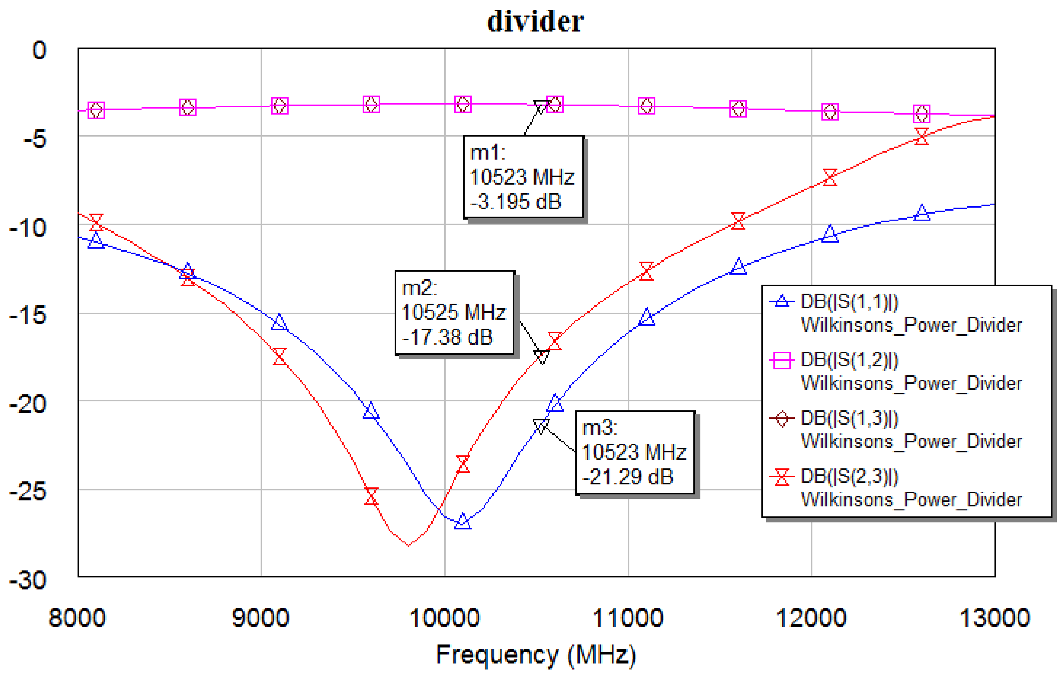



Figure 5.20: S11,S12,S13 and S23 parameter plots of the Wilkinson's power divider

Power and voltage levels at the mixer output are shown in the Table 5.1.

| | 50 kmph ( $\Delta f$=947.5 Hz) | 150kmph ( $\Delta f$=2.923 kHz) |
|---|---|---|
| 50 m ($P_r$=-23.205dBm) | > Power = -28.1107 dBm , 0.00154499 mW<br>> Voltage= 0.0124298 V , -38.1107 dBVpk | > Power = -28.1107 dBm , 0.00154499 mW<br>> Voltage= 0.0124298 V , -38.1107 dBVpk |
| 200 m ($P_r$=-34.9005 dBm) | > Power = -40.1519 dBm, $9.65627\times10^{-5}$ mW<br>> Voltage= 0.00310745 V, -50.1519 dBVpk | > Power = -40.1519 dBm, $9.65627\times10^{-5}$ mW<br>> Voltage= 0.00310745 V, -50.1519 dBVpk |

## 5.3 Discussion

Receive power of the reflected wave which is bounced off from the moving target varies according to the distance between the reception antenna and the target. At 50 m receive power is -68.38 dBm and at 200 m receive power is -92.465 dBm. Therefore it can be observed that the receive power and the distance to the target are inversely proportional to each other.

Doppler shift varies according to the speed of the vehicle. At 50 kmph Doppler shift is 972.22 Hz whereas at 150 kmph it is 2.916 kHz. This is the dynamic range of the mixer output.

After considering these facts separate circuits were designed for transmission and reception in AWR software and simulations were done. In transmission circuit VCO ( Voltage Controlled Oscillator ) is used to generate 5250 MHz frequency signal. VCO output frequency spectrum is shown in Figure 5.8. Then a power amplifier is used amplify the output power of the VCO to match with the input power requirement of the doubler. Figure 5.10 shows the filtered output of VCO which will be input to the doubler. For this Hairpin band pass filter at 5250 MHz was designed in AWR software. It's reflection coefficient (S11) and transmission (S12) plots are shown in Figure 5.18.Hairpin structure was designed in such a way that the minimum reflection coefficient and maximum transmission coefficients occur at 5250 MHz.

At the doubler the frequency is multiplied to 10.5 GHz. At the output of the doubler edge coupled bandpass filter at 10.5 GHz was designed in AWR as hairpin structure does not support high frequencies like 10.5 GHz. It's simulation results are shown in Figure 5.19.According to the results it's minimum reflection coefficient and maximum transmission coefficients occur at 10.5 GHz.

After the doubler splitter is used to split the signal to transmitter and to the mixer. Wilkinson power divider was designed in AWR as the splitter. It's simulation results are shown in Figure 5.20.Splitter output to the transmission antenna is amplified by a power amplifier in order to compensate the power loss in the circuit and to give the desired output power of 10mW from the antenna. In between this amplifier and the transmission antenna edge coupled band pass filter at 10.5 GHz is used to filter out the desired signal at 10.5 GHz by removing unwanted frequency components at the transmission antenna input as in Figure 5.15. Splitter output to the mixer is also amplified to meet the input power requirement of the mixer.

At the mixer, received signal is mixed with the transmitted signal. In order to get the Doppler shift from the mixer output, frequency range of 972.22 Hz to 2.916 kHz will be filtered.

Power of the receiving signal, reflected from the moving vehicle is much smaller compared to the transmitted signal. Therefore interference from the transmission antenna to the reception antenna will highly affect the readings. In order to isolate transmission and reception antenna, Aluminum isolator is used in between two antennas. Height is chosen using trial and error method in HFSS. According to Figure 5.1, Figure 5.2 and Figure 5.3 it can be observed that when isolator height increases a better isolation occurs between transmission and reception antennas. But the resonance frequency in each instant varies as shown in Figure 5.4, Figure 5.5 and Figure 5.6. When the isolator height is 16.1 mm the resonance frequency is 10.5 GHz. Therefore, 16.1 mm was selected as the optimum isolator height.

According to Figure 5.7, $4\times4$ patch antenna array has a narrow beam width. This is highly appropriate for this project because an antenna with better directivity can focus to a single target.

# CHAPTER 6 Conclusion and Further Improvements

Doppler radar uses Doppler Effect to measure speed of a vehicle at a distance by analysing the reflected microwave signal from the desired target. These systems operate by radiating energy into space and detecting the echo signal reflected from an object, or target. They can perform at long or short distances and under the conditions of darkness, haze, fog, rain, and snow etc. Two identical 4x4 microstrip planar array antennas are used for transmission and reception of the radar system.

In our project the antenna was designed such that maximum power transfer occurs at 10.5 GHz. In the process of designing antenna, initially single patch antenna, then 2x2 array antenna and finally 4x4 array antenna was designed. From this it was seen that antenna beam width has narrowed in antenna array compared to single antenna. This emphasis single antennas have better coverage while antenna arrays have better directivity. Since array antenna was designed for Doppler radar it's always preferable to have a better directivity than a coverage.

Prior to the designing radar circuit, speed range and the distance range of the Police radar gun was determined. Variations of the distance range affect the received power of the radar. So the reception circuit was designed accordingly. Speed range affects the Doppler Effect, hence the dynamic range of the filter at the output of the mixer.

Transmission circuit and the Reception circuit of the Doppler radar was designed using two identical 4x4 array antennas. Antenna was designed at 10.5 GHz which is in X band. X band Police radar is less vulnerable to extreme weather conditions. And 4x4 array is more directional. So 4x4 microstrip planar array antenna is more suitable for a designing of Doppler radar.

For further improvements, we can implement the display part using Arduino board. By taking frequency difference from the mixer output, and using Doppler equation we can calculate the speed of the particular vehicle. Using Arduino and 7 segment display board we can display the speed of the vehicle.

And also, we can improve this to detect speeds of more than one vehicle. So we can detect more vehicles with high speeds.

By increasing the range of the radar, we may able to detect speeds of vehicles from far.

## References

[1] Constantine A. Blanis, “Antenna Theory Analysis and Design ,Second Edition”, Singapore: John Wiley & Sons (ASIA) Pte Ltd, 2002, ch.14 , pp 722-751.

[2] Merrill I.Skolnik, “Introduction to Radar System, Third Edition”, New York: McGraw-Hill Companies, 2001, ch 1, pp 7-9

[3] Ely Levine, Gabi Malamud , Shmuel Shtrikman, David Treves, “A study of Microstrip Array Antennas with the Feed Network”, IEEE Transaction on Antennas and Propagation, Vol. 37,No.4, April 1989,pp 430