Investigation of Antennas for Car-to-Car Communication

Abdul Waqas

Karlsruhe, November 2008

Masters Thesis in Telecommunication

Examiner: Prof. Claes Beckman
Supervisor: Dipl.-Ing. Grzegorz Adamiuk, Dipl.-Ing. Lars Reichardt
Declaration

I hereby declare that this thesis is my own work and effort and that all sources cited or quoted are indicated and acknowledged by means of a comprehensive list of references.

Karlsruhe, 08.11.2009

Abdul Waqas
Dedicated to:

My Parents: Abdul Waheed and Shakeela Waheed

My Nephew: Ayan Shahid
Investigation of Antennas for C2C communication

Masters Thesis in Electronics and Telecommunication

submitted
by

Abdul Waqas
born 25-01-1980 in Haripur, Pakistan

Written at

University of Karlsruhe.

Advisor:
Started: ——
Finished: ——
Abstract

The road traffic density is continuously increasing. By the intensive use of automobiles, it comes to considerable difficulties and unpredictable events. The frequency of traffic obstructions, traffic jams and accidents will also increase in future. A solution for this problem would be that the driver would be supplied information when he is on the road. The information should be including about road and traffic conditions and also information about other vehicles, which in the near vicinity.

This kind of information sharing between vehicles is called C2C communication. Especially in Europe there are many projects which are working for different C2C communication applications, like [01].

Objective of this thesis is based on former works [02], which optimized the antenna positions for C2C communication by ray tracing simulation. The investigation of antennas for the C2C communication, two different approaches are taken into account, a narrow band, and broad band. Investigation of transparent material for broad band is also the part of this thesis.
# Contents

1 **Introduction**
   1.1 Motivation ................................................. 1
   1.2 Objective and Scope ........................................ 2

2 **Channel Characteristics**
   2.1 Narrow-band Analysis ....................................... 5
       2.1.1 Long-Term Fading ..................................... 5
       2.1.2 Short-Term Fading ..................................... 6
       2.1.3 Doppler Shift and Doppler Spread ....................... 7

3 **Simulation Results**
   3.1 LOS Scenario ............................................... 9
       3.1.1 Long-Term Fading ..................................... 10
       3.1.2 Short-Term Fading ..................................... 11
   3.2 NLOS Scenario .............................................. 12
       3.2.1 Long-Term Fading ..................................... 12
       3.2.2 Short-Term Fading ..................................... 14

4 **Measurements and Ray tracing results**
   4.1 Best Position for Antenna .................................. 15
   4.2 Monopole Antenna .......................................... 16
   4.3 Measurement setup .......................................... 17
   4.4 Measurement Track .......................................... 18
   4.5 Measurements ................................................ 19
       4.5.1 Long-term Fading ..................................... 19
       4.5.2 Short-term Fading ..................................... 21
5 Broad Band Antenna basics
5.1 Gain ................................................................. 23
5.2 Radiation pattern ................................................. 23
5.3 Matching ............................................................ 24
5.4 Polarization ......................................................... 24
  5.4.1 Linear Polarization .......................................... 24
  5.4.2 Circular Polarization ........................................ 25
  5.4.3 Elliptical Polarization ....................................... 25
5.5 Advantage of Broad band ....................................... 26
  5.5.1 Required Radiation pattern ................................. 27
5.6 Different Broad Band antennas ................................. 27
  5.6.1 Vivaldi Antenna .............................................. 28
  5.6.2 Bowtie Antenna ............................................. 28
  5.6.3 Bioconical antenna ......................................... 29
  5.6.4 Log-periodic antenna ...................................... 29
  5.6.5 Spiral antenna ................................................ 30
  5.6.6 Archimedean spiral antenna ............................... 30

6 Integration of broadband spiral antenna in to the car 35
6.1 Coplanar waveguide feeding .................................... 35
6.2 Positioning of antenna in to the Car ......................... 36
6.3 Transparent material ........................................... 37
6.4 Software .......................................................... 38
6.5 Previous Work .................................................... 39

7 Results 41
7.1 Four-Arm Spiral antenna PEC material centre feeding . 41
  7.1.1 Radiation pattern ........................................... 43
7.2 Four-Arm Spiral antenna Transparent material center feeding 46
  7.2.1 Radiation pattern ........................................... 47
7.3 Four-Arm Spiral antenna Transparent material back side feeding 50
  7.3.1 Radiation pattern ........................................... 51
7.4 Two-Arm Spiral antenna TP material side feeding .......... 55
  7.4.1 Radiation pattern ........................................... 56
7.5 Comparison ....................................................... 58
8 Conclusion and Future Analysis
  8.1 Conclusion ......................................................... 59
  8.2 Future Analysis .................................................... 60

List of Figures ......................................................... 62

List of Tables .......................................................... 67

Bibliography ............................................................ 69
Chapter 1

Introduction

1.1 Motivation

Suppose we are moving on highway, an accident that happened just a minute ago after certain distance to our moving place. We don’t have any chance but to rush towards the end of the resulting traffic jam and we can imagine our reaction when the end of the jamming is suddenly appears. We don’t have any chance to know about what’s going on with traffic after a few distances to us. Extreme traffic congestion sets in when vehicles are fully stopped for periods of time at the accident place and this will cause a huge traffic jam. Due to the accident the freeway is sporadic and there is an extensive line up of vehicles that are waiting the situation to regularize. If we get some electronic assist which already update us about the imminent situation and on behalf of this electronic assist we can slow down the car, long before the danger comes into sight. And we can be free from extensive line up of vehicles.

On a frosty morning, imagine if the car 30 meter ahead of you could somehow alert you to black ice on an off-ramp. You can slow down, and your car’s electronic stability system could even take preliminary steps to anticipate the situation. Witness C2C communication, the next step in safety technology. Its something experts in organizations from the Center for Automotive Research to economic consultancy Global Insight have mulled for years now, and theres even a federal program, called Intelligent Transportation Systems, to coordinate such efforts.[03]. Number of radio services are link with vehicles now days. Due to upcoming technology, the number of radio services for mobile application will increase. All these services should also be availables in vehicles. The different services are using several frequency bands as shown in Table [1.1].

One solution for to cover several frequency bands is, number of antennas. Atleast five antennas are required in a car, for key services. Number of antennas can facilitate us with many
<table>
<thead>
<tr>
<th>Service</th>
<th>Freq.[MHz]</th>
<th>Sat/Ter</th>
<th>Tx/Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVB-T</td>
<td>470-862</td>
<td>ter</td>
<td>Rx</td>
</tr>
<tr>
<td>AMPS</td>
<td>824-894</td>
<td>ter</td>
<td>Tx/Rx</td>
</tr>
<tr>
<td>GSM900/1800</td>
<td>890-960,1710-1880</td>
<td>ter</td>
<td>Tx/Rx</td>
</tr>
<tr>
<td>DAB-T</td>
<td>1452-1492</td>
<td>ter</td>
<td>Rx</td>
</tr>
<tr>
<td>GPS</td>
<td>1574-1577</td>
<td>sat</td>
<td>Rx</td>
</tr>
<tr>
<td>DECT</td>
<td>1880-1900</td>
<td>ter</td>
<td>Tx/Rx</td>
</tr>
<tr>
<td>UMTS</td>
<td>1885-2200</td>
<td>ter</td>
<td>Tx/Rx</td>
</tr>
</tbody>
</table>

Table 1.1: Different services and frequency bands.

services but on other hand we require sum of cabling which cause the problem of cost, weight and many other factors can come in a way. Additionally the demands concerning the design of a modern car become more complicated. Not only because of aesthetical reasons but also for aerodynamically reasons constancy and defacement. So keeping all these things in a mind, the best solution for this meet to a single antenna, being small as possible and conformably integratable in the car.

1.2 Objective and Scope

The thesis is divided in to two parts as show in Fig 1.1.

The first part contains the idea about the best position of antenna placement for C2C communication. The second part is containing the idea, to find a broad band antenna together with all necessary services which required now days. The objectives of the thesis are as follows:

1. Develope a monopole antenna for 5.9 GHz.

2. Take Measurements and analyse long and short term fading.

3. Define a possible broad band solution for car applications, (Bandwidth, services, antenna placment).

4. Evaluate Transparent material for broad band antenna.

IEEE 802.11 and 802.11x refer to a family of specification developed by IEEE for wireless local area network. 802.11 specify link between a wireless client and a base station or between two wireless clients. Air path is used for this link.
At beginning 802.11 applies to wireless local area network, in a range of 1 or 2 Mbps transmission, in the 2.4 GHz band, using either Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS). IEEE 802.11a was an extension to 802.11 that applies to wireless local area network for the range of 54 Mbps in the 5 GHz band, rather than FHSS or DSSS. Later on IEEE introduce IEEE 802.11p or wireless access in vehicular environments (WAVE). This was more less verification of IEEE 802.11a required to support Intelligent Transportation Systems ITS applications. The WAVE standards use a multi-channel concept which can be used for both safety-related and more infotainment messages. It includes data exchange linking high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of (5.85-5.925 GHz). For C2C communications the working frequency is 5.9 GHz and the bandwidth in Europe is 30 MHz. In USA some of the technical parameters are different like the bandwidth that is 70 MHz and it contain block of spectrum of 5.850 to 5.925 GHz band. IEEE 802.11p can use as the groundwork for (DSRC). DSRC label dedicated short range communication. And it provides communication between vehicle and the roadside specific location. To improve the safety and the production of the transportation system. DSRC provide medium range communication service intended to support both Public Safety and licensed Private oper-
ations over roadside-to-vehicle and vehicle-to-vehicle communication channels. DSRC contain operational frequencies and system bandwidth, but also allow for operational frequencies which are covered with in Europe by national regulation. 

Chapter 1 and 2 is based on basic informations. Chapter 3 is based on ray tracing simulation for LOS and NLOS. Chapter 4 describe whole measurement setup and measurements for C2C communication. Chapter 5 explain about different kind of broad band antennas and there advantages and disadvantages. Chapter 6 shows the best position for antenna in the car and transparent material. Chapter 7 contain on simulation of broad band antennas.
Chapter 2

Channel Characteristics

Channel is always characterised by different parameters, this chapter contains a description of the different parameters.

2.1 Narrow-band Analysis

In radio communication when the message bandwidth is less then coherence bandwidth, then it called Narrow-band. Narrow-band is analysed by the fading components (long term fading and short term fading).

2.1.1 Long-Term Fading

Long term fading behave in its statistical properties quite similar to a log normal processes. With such processes the slow fluctuations of local mean value of receive signal which is determine by shadowing effects can be reproduced. The channel transfer function $H_{TP}(t)$ can be divided into a short-term and a long-term fading component.

\[ |H_{TP}(t) = l(t)s(t)| \]  \hspace{1cm} (2.1)

The long-term fading component $l(t)$ is the result of averaging $|H_{TP}(t)|$ during the desired sample time $T_s$.

\[ l(t) = \frac{1}{T_s} \int_{t-T_s/2}^{t+T_s/2} |H_{TP}|(\varepsilon) d\varepsilon \]  \hspace{1cm} (2.2)

As it is shown in the Fig 2.1, the long-term fading is the slow change of the signal strength.
during a large time interval. If the amplitudes of the long-term fading are compared with high amplitude, this means high signal-to-noise ratios and this could conclude in wider ranges for a communication system, further distances or lower bit error rates. The long-term fading is caused by multi-path short-term by the interference.\[02\]

Figure 2.1: Long-term fading

2.1.2 Short-Term Fading

Received signal strength is formed by vector sum of various signals reaching the antenna and will have constant amplitude. When the object is moving and it is assumed that signal is received will be the vector sum of N reflected signals of equal amplitude which arrive at receiving antenna at random phase angle. This is accepted as a reasonable model for the cellular environment. Where there is not usually a direct line of sight path b/w transmitter and receiver, the addition of these component give rise to a resultant with amplitude (i-e envelope) which varies in a random manner. The short-term fading can be plotted by different forms, and in this case the Cumulative Distribution Function (CDF) is chosen, which provides the probability that the signal strength is equal or less than a certain value and indicates the probability of the deviation from the local mean value of the signal. Fig\[2.2\] shows CDF plot. CDF can be understood by Formula\[2.3\] The \( F_s(as) \) is the estimation of the short-term fading
2.1. Narrow-Band Analysis

Figure 2.2: Short-term fading

when the value of the short-term fading is smaller than a threshold as during an observation time $T_o$.\[02\]

$$F_s(\alpha s) = \frac{\Delta T_u(s(t) \leq s)}{T_o}$$ \hspace{1cm} (2.3)

The wider the CDF moves to the right for low probabilities the better for communications system and the less outages.

2.1.3 Doppler Shift and Doppler Spread

Robust and high-rate data transmission in highly mobile environments faces severe problems due to the time-variant channel conditions. Especially, synchronization, channel estimation and data recovery are affected. This situation is caused by the high Doppler shift and spread of signals between transmitter and a fast moving receiver. The Doppler shift is influenced by the relative velocity between the cars and the angle of arrival. The celerity with which the low pass transfer function $|H^TP(t)|$ is changed causes the Correspondent autocorrelation function which described by $|r_{hh}^t(\Delta t)|$ the calculation for during a sample time of $T_s$ is

$$r_{HH}^t(\Delta t) = \int_0^{T_s} (H^TP(t)) \ast H^TP(t - \Delta t) dt$$ \hspace{1cm} (2.4)
CHAPTER 2. CHANNEL CHARACTERISTICS

The Fourier transformation for the time variant autocorrelation function $|r_{hh}^t(\Delta t)|$ is the Doppler spectrum $S_{HH}(f_D)$:

$$r_{hh}^t(\Delta t) \overset{\circ}{\rightarrow} \bullet S_{HH}(f_D) = |H_D^{TP}(f_D)|^2 \tag{2.5}$$

$$H_D^{TP}(f_D) \overset{\circ}{\rightarrow} \bullet H^{TP}(t) \tag{2.6}$$

The measure of the Doppler spectrum $S_{HH}(f_D)$ in a determined moment $t = t_0$ is

$$S(f_D, t_0) = \sum_{n=1}^{N(t_0)} |A_n(t_0)|^2 \delta(f_D - f_D, n) \tag{2.7}$$

The Doppler spectrum is characterized by two different parameters, the mean Doppler $f_D$ and the Doppler spread $\sigma_{f_D}$. The mean Doppler is the average value:

$$\overline{f_D} = \frac{\int_{\infty}^{-\infty} f_D S_{HH}(f_D) df_D}{\int_{\infty}^{-\infty} S_{HH}(f_D) df_D}. \tag{2.8}$$

The Doppler spread is defined as two times the variation of the Doppler spectrum, if the Doppler spectrum is assumed as a probability density function.

$$\sigma_{f_D} = 2 \sqrt{\frac{\int_{\infty}^{-\infty} f_D^2 S_{HH}(f_D) df_D}{\int_{\infty}^{-\infty} S_{HH}(f_D) df_D} - \overline{f_D}^2} \tag{2.9}$$

The higher the value of the Doppler spread $\sigma_{f_D}$, the faster the changes in the channel and the more difficult would be to receive the transmitting signal correctly. If the Doppler spread is smaller than the bandwidth of the transmitted signal, most of the transmitted power will be in the band. [02]
Chapter 3

Simulation Results

This chapter is including the analysis of simulated scenarios. Two different kinds of scenarios are evaluated; LOS (line of sight) and NLOS (no line of sight), both are urban scenarios.

3.1 LOS Scenario

Urban scenario environment has a lot of buildings, and many park vehicles are modelled. Measurement is based on two vehicles, one with transmitter antenna and other with receiver antenna. Antenna is integrated under the car with omnidirectional radiation pattern. Fig 3.1 shows the urban scenario environment. If we compare with motoray, it has huge influence of traffic. This scenario is design same like measurement track which will discuss in next chapter.

Figure 3.1: LOS Scenario

Maximum velocity for both transmitter and receiver is 40 km/h. Distance between both cars start
CHAPTER 3. SIMULATION RESULTS

from 47.8 m and then it change with time, distance become close after each second and finally reached at 38.2 m. Distance change with respect to traffic.

3.1.1 Long-Term Fading

Long-term fading can be called as slow fading and it cause due to presence of large stationary obstacles that cause reflection, scattering and diffraction. Fig 3.2 shows the result of ray tracing simulation for long-term fading.

![Figure 3.2: Long-term fading for LOS case.](image)

Above Fig contain two graph, upper graph shows path loss in dB and lower graph show distance between two cars during 20 sec drive in simulation. Gray color in upper graph symbolize path loss between two cars and orange color in upper graph symbolize slow fading which is the average value of path loss. During 20 sec simulation, distance between both vehicles start from 47.8
m and then goes down till 38.2 m. A lot of buildings, and a lot of parked vehicles are modelled in this scenario. A receiver antenna received sum of reflecting signal from different surrounding object. At 12 sec, distance between two cars is near to 46 m, and the signal is constructive at this stage. At very next sec distance between two cars is reduced but path loss increase due to destructive interference. Average path loss retain between 80 dB to 90 dB, resultant path loss can work for real environment.

3.1.2 Short-Term Fading

Short term fading can also represent by fast fading. Short term fading transpire when receiver received multiple signals and cause rapid change in signal at receiver during a short interval. It has high probability to loss data if there is fast signal drop. Fast fading for LOS is shown in Fig 4.9.

![Figure 3.3: Short-term fading for LOS case.](image)

Fast term fading can explain by different forms, this graph explain CDF function, which shows the signal has equal value or less then define value, also it shows the probability of deviation from local mean value of signal. From the plot high fluctuation of signal can be seen. Maximum part of signal is away from 0 dB and variation goes to till -15 dB. It is high probability to loss the data.
3.2 NLOS Scenario

Second simulation is based on NLOS; it means one vehicle is moving in between transmitter vehicle and receiver vehicle. It is also urban scenario environment, lot of buildings and many cars are park at surrounding with huge influence of traffic. This scenario is model on the base of Measurement track. Fig 3.4 shows the urban scenario environment for NLOS.

![NLOS Scenario Diagram](image)

Figure 3.4: NLOS Scenario

Velocity of both cars, transmitter and receiver is 40 km/h. Distance between both cars start from 53.5 m initially and then it varies up to 57 m maximum. After short while distance decrease slowly and reached till 51.2 m between both cars transmitter and receiver. Through out the journey one vehicle remains in between both cars.

3.2.1 Long-Term Fading

As it is described before that Long term fading or slow fading cause due to presence of large stationary obstacles, that cause reflection, scattering and diffraction. Fig 3.5 shows Long term fading for NLOS case.

Plot contain 20 sec simulation which shows path loss, same like LOS plot, orange color shows average value and gray line shows total path loss. Initially path loss fluctuates between 75 dB
3.2. NLOS SCENARIO

to 90 dB. Due to distance decrease path loss reduces for short while, due to vehicle in between transmitter and receiver influence on signal strength. At maximum gap one peak of maximum path loss is shown, which emerge at 6 s. At very next moment, constructive signal appear and then with passage of time distance goes to decrease and path loss also decrease. From this conclusion can be done. NLOS has better result comparatively LOS, it could be happened due to constructive signal formulate by the reflection from vehicle in between, which plays positive role in this case. Also both cars, transmitter and receiver has gap of other cars and at the moment no car is moving on left side. While for LOS case, parallel cars are moving with transmitter and receiver cars on left side. This can effect on LOS case.

Figure 3.5: Long-term fading for NLOS case.
3.2.2 Short-Term Fading

Short term fading can be named as Fast fading, which is explain in Topic 3.12, rapid change in signal during short interval, Fig 3.6 shows the CDF plot for NLOS fast fading.

As shown in Fig, the probability of deviation from local mean value of signal, and also it can be seen that deviation is not so high. Maximum part of signal is closer to 0 dB, and maximum deviation goes to -5 dB amplitude, which is better then LOS case. In NLOS scenario left side of both cars (transmitter and receiver) is free from moving vehicles which makes goods effect.

Figure 3.6: Short-term fading for NLOS case.
Chapter 4

Measurements and Ray tracing results

4.1 Best Position for Antenna

Best place for antenna integration is also important consideration for C2C communication application. Because during vehicle movement signal can meet many factors which can influence on the signal, as its explain with detail in previous chapter. One of student has his research on this topic which is based on Ray tracing technique. Student has to find the place for integrating the antenna on car where the signal has high SNR. Fig 4.1 shows different position used for the work with mention height.

![Figure 4.1: Possible position for antenna](image)

‘BB’ and ‘BF’ shows back and front car bonnets, ‘ML’ and ‘MR’ shows left and right mirror, ‘B’ shows bottom of car and ‘R’ shows roof of car. Bottom shows 30 cm height from the earth, bonnet shows 60 cm, mirrors shows 90 cm and Roof shows 150 cm. 120 cm height which is not mentioned with capital letter, it is the glass part of the car. Fig 4.2 shows graph of ray tracing results. Scenario for such ray tracing is containing many cars park at surrounding also different elevation buildings are stand at surrounding. This graph is chosen from previous student work.
CHAPTER 4. MEASUREMENTS AND RAY TRACING RESULTS

This graph shows SNR according at define position and we can estimate suitable position for car. Bottom position has high SNR which makes it better position then others. The position at 120 cm has large shadow effect due to many obstacles. This place is not good for C2C communication, other places has also low SNR comparatively to bottom of car.

4.2 Monopole Antenna

A monopole antenna is good example for this application due to its omnidirectional radiation pattern. Monopole antenna formed by replacing one half of dipole. It has low input resistance which gives lower efficiency. Due to its omnidirection pattern, LOS can access from all sides. Fig 4.3 shows simulation result of 12.7 mm long monopole antenna which work at 5.9 GHz. Ground plane is 4 times lambda.
4.3 Measurement setup

Fig 4.4 shows block diagram for Measurements.

Transmitter side contain signal generator with attached monopole antenna under the car. Recommended 13 dBm power is transmitted through antenna. Receiver side contain antenna under the car with attached LNA 17dB gain for amplifying the signal. Signal goes to spectrum analyzer for measuring it in time domain. Spectrum analyzer is set to sweep time 4 sec with 8000 points. Due to Doppler spread 2000 Hz. Data is then feed to computer for analyzation. Fig 4.5 and Fig 4.6 show snaps of measurement setup install in cars. One car is equipped with Receiver setup, and other car is equipped with Transmitter setup.
4.4 Measurement Track

Fig 4.7 shows the GPS data for track, which is used for Measurements. It is a rectangular area in Karlsruhe, city of Germany. Track contains normal traffic and many buildings are surrounding to it. Red line on the track represent the receiver car and Blue line on the track represent the
transmitter car. Start point shows the beginning journey of cars and both cars have average speed of 40 Km/h. Weather used for this measurement is sunny day with normal temperature of 18 degree Celsius.

![Measurement track](image)

**Figure 4.7: Measurement track**

### 4.5 Measurements

This part explain the measurement for C2C communication at chosen track which is shown in Fig4.7. Different channel characteristics are analyzed in this section. Long term fading and Short term fading. Track is square, with number of park cars and also some cars are moving parallel with transmitter car and receiver car. Both sides of track has huge buildings. Whole measurement is based on LOS and NLOS.

#### 4.5.1 Long-term Fading

Long-term fading can be named as slow fading and it cause due to presence of large stationary obstacles that cause reflection, scattering and diffraction. Fig 4.8 shows the measurement result for long-term fading.

Initially distance between both cars is 30 meter, and it is LOS case. One side is full of buildings and other side with trees, at this time path loss is in between 75 dB to 85 dB. After certain time,
distance between both vehicles become enlarge and path loss also increased. At the same time one vehicle came in between of two cars. After 1 minuet both cars came on road but with huge gap. Then at 75 sec point, distance reduces to 38 meter and one vehicle retain in between. But path loss at that moment is reduced. After this traffic signal came and both cars stopped at this point for few seconds and many vehicles came in between both cars. Path loss increase up to 88 dB. At this point standing time on traffic signal is not included, just 1 sec at that point of traffic signal is included. After leaving the traffic signal, for certain time some vehicles remain in between them but distance between both cars was short and path loss was also decrease. At that moment it was straight road for 150 s to 200 s. After this once again distance increase for short while with some cars came in between both cars, this happened in the time duration of 201 s to 247 s. But again gap reduce slowly and reached at 20 meter and no vehicle is in between both cars, this journey was in between 248 s to end and at that time path loss decrease till 70 dB. Measurement plot and ray tracing plots for LOS and NLOS are not exact same but somehow same level of path loss can be seen. Gap between the cars cannot control on road due
to traffic, and road has friction which is not included in ray tracing simulation also antenna has bend radiation patterns, it is not exact on the corners so we don’t have perfect LOS for radiation pattern as it is shown in Fig 4.3. Actually antenna under the car can meet some pipes which can obstruct the signal. But still it works for C2C communication application.

4.5.2 Short-term Fading

Short term fading can be named fast fading. As it is describe before that short term fading cause when receiver received multiple signals and it cause rapid change in signal at receiver during a short interval. It has high probability to loss data, if there is fast signal drop. Fast fading for Measurement is shown in Fig 4.9.

![Figure 4.9: Short term fading for measurement setup.](image)

This graph explain Fast fading in term of CDF function, which shows the signal has equal value or less then define value, also it shows the probability of deviation from local mean value of signal. Measurement Plot for fast-term fading Fig 4.9 is almost same like NLOS plot for fast-term fading Fig 3.5. Signal has not so high deviation from mean value, maximum part of signal remain near 0 dB and maximum deviation goes to -6 dB. So fast fading component doesn’t effect too much in this case.
Chapter 5

Broad Band Antenna basics

This chapter will discuss in detail about the broad band antenna. In Telecommunication field Broad band technology is a concept in which number of frequencies can be include in a single method. Wider bandwidth has capacity to carry more information. A Single Broadband antenna is able to cover many narrow band services, which is an option for reduction of space needed for the radiators.

5.1 Gain

Gain is important consideration before choosing the antenna. The gain is a measure of how much of the input power is intense in a particular direction. It is expressed with respect to a hypothetical isotropic antenna, which radiates equally in all directions. Radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of $4\pi$ steradians.

5.2 Radiation pattern

The radiation pattern or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The following figure shows a rectangular plot presentation for radiation pattern.06
5.3 Matching

An antenna has different input impedance. May be it has input impedance as low as 15 ohm or as high as 1000 ohms. However, most transmitters have output impedance of 50 ohms or 75 ohms and transmission lines are only available in a limited number of characteristic impedance, so it is necessary to transform the antenna input impedance to the same value as the transmission line characteristic impedance. This process is called matching. There are a variety of matching techniques for antennas[07].

5.4 Polarization

Before installing or choosing any antenna, polarization is important contemplation. These can be distinguished many types of polarization, eg.

1. Linear Polarization.
2. Circular Polarization.
3. Elliptical Polarization.

5.4.1 Linear Polarization

Antenna is linearly polarized when electric field oscillates in one plane. There are two kind of linear polarization. When electric field is perpendicular to the earth surface it
5.4. **POLARIZATION**

denotes linear vertical polarization. Broadcast tower for Amplitude modulation is example for this. If electric field is parallel to the Earth’s surface it denotes to Linear Horizontal polarization. Television transmission is example for this. Fig 5.2 and Fig 5.3 shows linear vertical polarization and linear horizontal polarization.

![Figure 5.2: linear vertical polarization](image1)

![Figure 5.3: linear horizontal polarization](image2)

### 5.4.2 Circular Polarization

Antenna is circularly polarized when electric field oscillates in both horizontal and vertical plane as shown in Fig 5.4. The plane of polarization makes one complete rotary motion during each wave length. Circular polarization can also be classified with two kinds. (RHC) denotes, right hand circular polarization in which rotation occurs clockwise direction. (LHC) denotes, left hand circular polarization in which rotation occurs counter clockwise direction.

Circular polarization has many advantages comparatively linear polarization. Reflectivity, Phasing issue, Multi-path etc are common examples which makes circular polarization superior. [08]

### 5.4.3 Elliptical Polarization

Elliptical polarization is same like circular polarization with different amplitude in plane. Fig 5.5 shows Elliptical polarization.
5.5 Advantage of Broad band

As it is mentioned in chapter 1, now a days we want to integrate many services in a single car, like communication for personal, Broadcasting, Navigation etc. In future we can found complete office in a car due to latest services available. Suppose we are on a way and we are able to handle many issues while sitting in a vehicle, this thing makes life easier. Different services need different frequency bands. To do so we need number of antennas to handle all these services. Especially, if we want very basic services in our vehicle, then vehicle will be equipped with minimum four antennas. It cost money and many technical issues can come in front. Number of cables, spacing, electromagnetic compatibility also included in design criteria. Stability and destruction are also important things, that the antenna should be integrated ideally in a non visible place. By looking all these issues, best solution for all is that we should choose single antenna, which must cover the frequency range operating in all relevant radiation patterns. For the specified purpose a lot of research happen to make antenna smallest and enabling them for multi band operations. Some
5.6. DIFFERENT BROAD BAND ANTENNAS

approaches meet modified resonant antenna element like dipole, monopole. Monopole antenna is particularly suitable for GSM application. Window antenna combines for both application GSM and radio services together.

With the passage of time new services become invent like GPS, DAB, GSM. So, mention antennas are not enough to cover all these services. Some new approaches came forward like Fractional antenna, Microstrip patch antenna, slot antenna and PIFA antenna. These antennas can integrate on flat surfaces. Microstrip patch antenna can use for Radio services and TV. Patch antenna can used for Dual band service GSM 900 and GPS. PIFA antenna stands for mobile services GSM 900/1800. Slot antenna is suitable for mobile services and Navigation application. Fractional antenna can cover many services due to number of antennas integrated in a single panel.

5.5.1 Required Radiation pattern

Most appealing subject for broad band antenna in vehicle is to cover both terrestrial and satellite services. Antenna should radiate in front of car and also toward the sky. Fig 5.6 shows required radiation pattern from automobile which can cover both kind of services. To reach such variety of pattern is quite solid application.

![Figure 5.6: Required Radiation pattern](image)

5.6 Different Broad Band antennas

The number of broad band antenna comes out after research, each contains different characteristics according to there design and feeding technique. Some of them are describe
below with there advantages and disadvantages.

5.6.1 Vivaldi Antenna

The topic describes the characteristics of the Tapered-Slot Antenna (TSA). The Vivaldi antenna is a special type of TSA with an exponential flare profile. The Vivaldi antenna as shown in Fig 5.7 is a member of a class of periodic continuously scaled travelling-wave antenna structures. These antennas consist of a tapered slot etched on to a thin film of metal. This is done either with or without a dielectric substrate on one side of the film. Besides being efficient and light weight. Most attractive features of Tapered-Slot Antenna (TSA) are that, they can work over a large frequency bandwidth and produce a symmetrical end-fire beam with appreciable gain and low side lobes. Tapered-Slot Antenna (TSA) generally has wide bandwidth, high directivity and are able to produce symmetrical radiation patterns. Main problem of Vivaldi antenna is its radiation pattern. It is not suitable for vehicle to cover maximum services, because it radiate in end-fire direction. So due to its radiation parallel to the surface of antenna is not suitable for car applications.

![Figure 5.7: Vivaldi antenna](image)

$W_E$-Input slot width, $W_A$-Slot width at radiating area, $W_O$-Output slot width,

5.6.2 Bowtie Antenna

Bowtie antenna as it is shown in Fig 5.8 is a simple design. Broad-band bowtie antenna is made of bitrangle sheet of metal with a feed at its vertex. This kind of antenna is frequency
5.6. DIFFERENT BROAD BAND ANTENNAS

independent if it extended to infinity on both side. It has a finite gap between the feed points and a finite size which would result in limited bandwidth, however typically the antenna can be terminated without a significant effect on the pattern or the impedance. The experimental studies show that the distance to the image plane and the flare angle affect the bandwidth of the antenna. The antenna exhibits unidirectional radiation pattern with enhanced bandwidth, less back radiations and low cross polarization in the operational band. This antenna work better at low frequencies, but radiation pattern become unstable at higher frequencies, that’s why it could not be integrated in the car.

![Figure 5.8: Bowtie antenna](image)

5.6.3 Bioconical antenna

A bioconical antenna consists of a wire with the arrangement of two conical conductors. It has wide bandwidth in use for certain wide range of frequency, depending on its structure and feeding. It is frequency independent antenna. It also contains constant impedance at input. This antenna is bulky, that’s why it cannot be integrated in the car.

5.6.4 Log-periodic antenna

Log-periodic antenna contain multi element as it shown in Fig. It is unidirectional, narrow-beam antenna. Impedance and radiation characteristics are depended on logarithmic function of excitation frequency. The log periodic antenna is used in a number of applications, where a wide bandwidth is required along with directivity and a modest level of gain. The log periodic antenna can exist in a number of forms. The most common is the log
CHAPTER 5. BROAD BAND ANTENNA BASICS

Figure 5.9: Log-periodic antenna

Periodic dipole array (LPDA).\[13\] Antenna built with number of dipole elements. Typical example of this type antenna, provide the gain between 4 and 6 dB over a bandwidth of 2:1, while retaining SWR (Standing wave ratio) level of better than 1.3:1. With this level of performance it is ideal for many applications. Due to its radiation pattern parallel to antenna surface is not suitable for car application.

5.6.5 Spiral antenna

Spiral antenna is one major example of broad band antenna. Spiral antennas are travelling wave structures and are well-known for their wideband performance. This wideband feature of the spiral antenna makes it an attractive selection where a single antenna play vital role to send / receive over various channels. A bandwidth of 5:1 or 10:1 is easily obtained and stable input impedance is achieved through a self-complementary geometry.\[14\] Antenna gain and radiation pattern is another consideration of wideband antenna. Spiral antenna has a reasonable gain and radiation pattern for car. Three major kind of Spiral antennas are shown in Fig 5.10, Fig 5.11, and Fig 5.12. Three antennas are different with respect to there radiation pattern and there feeding techniques. In the sense of aesthetics, two-arm spiral antenna and four-arm spiral antenna will come under symposium.

5.6.6 Archimedean spiral antenna

The Archimedean spiral can also be recognized by the name Arithmetic spiral. It shows fixed point which is originating point and then vary rotationally with constant angular velocity from the fixed point to ending.
The input impedance of a self-complementary antenna can be found using Babinets principle, giving.\[15\].

\[
\frac{z_{metal}z_{air}}{4} = \eta^2
\]

(5.1)

where \( \eta \) represent the characteristic impedance of the medium surrounding the antenna. In free space antenna input impedance become

\[
z_{in} = \frac{\eta_0}{2} = 188.5\Omega
\]

(5.2)

Archimedean spiral Antenna length varies with constant angular velocity, so it become linearly proportional to angle \( \phi \) which can be describe with the following equation in relation

\[
r = r_0\phi + r_1andr = r_0(\phi - \pi) + r_1
\]

(5.3)

\( r_1 \) shows the inner radius of spiral. The proportional constant \( r_0 \) depend on the width of arm and it can be found by width of arm ’w’ and spacing between each turn ’s’, which for
a self complementary spiral is given by

\[ r_0 = \frac{s + w}{\pi} = \frac{2w}{\pi} \]  

(5.4)

the strip width can be evaluated by following equation

\[ s = \frac{r_2 - r_1}{2N} - w = w \]  

(5.5)

By considering antenna as a self complimentary space and width can be found as

\[ s = w = \frac{r_2 - r_1}{4} \]  

(5.6)

where \( r_2 \) is the outer radius of the spiral and \( N \) is the number of turns. The above equation describe for two-arm Archimedean spiral. Width of four-arm spiral, can be found with following equation

\[ w_{4-arm} = \frac{r_2 - r_1}{8N} \]  

(5.7)

and the proportionality constant

\[ r_{0,4-arm} = \frac{4w}{\pi} \]  

(5.8)

when the circumference of the spiral equals one wavelength then spiral start to radiate in that region, each arm of spiral is feed 180 degree out of phase, so when the circumference of the spiral is one wavelength and current at complementary or opposite points on each arm of spiral add in phase in the far field. The low frequency operating point of the spiral is determined theoretically by the outer radius and is given by

\[ f_{low} = \frac{c}{2\pi r_2} \]  

(5.9)

where \( c \) is the speed of light. Similarly the high frequency operating point is based on the inner radius giving

\[ f_{high} = \frac{c_o}{2\pi r_2} \]  

(5.10)

In practical the lower frequency will be greater than predicted by equation (5.9), due to reflection at the end of the spiral. The reflections can be minimized by using resistive
loading at the end of each arm or by adding conductivity loss to some part of the outer turn of each arm. Also, the high frequency limit may be less than found from (5.10) due to feed region effects [15].
Chapter 6

Integration of broadband spiral antenna in to the car

6.1 Coplanar waveguide feeding

The CPW mode is usually the desired mode in circuits based on coplanar lines, as it is a quasi-TEM mode. Coplanar wave guide is a simple conductor line which is separated from a pair of ground plane. Three lines are placed on a top of dielectric medium. Fig 6.3 shows coplanar wave guide with three lines. The line in the centre is used for conductor, and other two parallel lines are used for the grounds. In the diagram ’s’ shows the gap between conductor and ground lines, ’w’ shows width of conductor and ’L’ shows the length of conductor and ground lines. These parameters play important role for matching at input impedance. So these variables can be change according to input impedance.

The Spiral antenna can be used for automotive applications. As required services in the car it is necessary that antenna should radiate in two modes. One can cover terrestrial services and other can cover satellite services, and this can happened by using coplanar wave guide feed network in the centre of spiral. In the response, antenna will work in dual mode. Fou-rarm spiral is best choice for this work and coplanar transmission line is connected orthogonally to the spiral. Conductor line of coplanar will feed to, two-arms of spiral. These two-arms will become short after coplanar conductor line fed. And the ground lines of coplanar will fed to rest of two arms of spiral.

Fig 6.1 shows plus-and minus-signs, which means there is a 180 phase difference between adjacent arms. As the wave travels outward, the phase relation between opposite and 90
degree shifted positions remain constant. In order to currents in neighbouring arms are in phase, the electrical phase shift between geometrically 90 degree shifted positions has to be 180 degree. Therefore, radiation occurs at the radius (the hatched zone in Fig 6.1), where the circumference is two wavelengths. As currents on opposite arms are spatially in anti-phase, radiation toward the zenith (orthogonal to the spiral plane) is cancelled out, whereas the radiation maximum is toward an elevation of 40 to 50 degree\textsuperscript{[17]}. Fig 6.2 shows required radiation pattern in the response of coplanar wave guide feeding.

![Figure 6.1: Phase](image1)
![Figure 6.2: Required pattern](image2)
![Figure 6.3: Coplanar wave guide](image3)

### 6.2 Positioning of antenna in to the Car

The best place for such kind of radiation pattern is to choose the front glass of Automobile or rear glass of auto mobile. Fig 6.4 shows position of antenna in the car. If spiral antenna
6.3. **TRANSPARENT MATERIAL**

is placed at this position with coplanar wave guide feeding, then the radiation pattern at this position will be same like as in Fig [6.5]. One beam can cover the terrestrial services and the other beam can be good for satellite services.

![Antenna position](image1)

![Radiation pattern w.r.t position](image2)

Front glass has rear mirror so feeding network can hide with this mirror, and driver has also no interlude in driving. Same situation for rear mirror has to be, if the antenna is installing on rear mirror.

### 6.3 Transparent material

Aesthetic reason need to be consider, during car manufacturing. Antenna integrated in the car can spoil the look. Optical transparent antenna is one kind of solution to avoid this problem. Optical transparent antennas has many applications for wireless or automotive application. Transparent antenna can be integrated on glass of car. Optically transparent conductor is required for the fabrication of this kind of antenna. Transparent conductive material has transparency like glass. As a glass antenna for automobile is formed by arranging an antenna conductor in or on glass panel which constitute a window glass in mobile. Glass antenna has transparent conductive film as an antenna conductor is consider to be preferred for the reason that it doesn’t obstruct the visual field of driver and it doesn’t disturb the driver unlike conventional linear antenna conductor. Many
transparent conductive materials are available, which can be used for antenna design. ITO (Indium tin oxide) is a conductive transparent material which can work for antenna. It has low sheet resistivity and the high transparency. Due to high cost of this material we will not include it in this project.

Generally polymers are called insulator. However there is a special class of polymers—the intrinsically conductive polymers—that have conductivity levels between those of semiconductor and metal. Such kind of combination is completely new in electronic industry. This material can help in many electronic projects.

With poly(3,4-ethylenedioxythiophene) or briefly named PEDT or PEDOT - available under the trade name CLEVIOS- H.C. Starck has developed the latest generation of conductive polymers which are characterized by outstanding properties. Material has chemical name Poly (3, 4-ethylenedioxythiophene) poly (styrenesulfonate) aqueous dispersion [18]. The material which will be used for the fabrication of spiral antenna is called CLEVIOS P HC V4, which has conductivity of 400 S/cm. Physical data for CLEVIOS P HC V4 is shown in Table 6.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form</td>
<td>liquid</td>
</tr>
<tr>
<td>Odour</td>
<td>odourless</td>
</tr>
<tr>
<td>Colour</td>
<td>darkblue</td>
</tr>
<tr>
<td>Conductivity</td>
<td>min. 200 S/cm</td>
</tr>
<tr>
<td>Solid content</td>
<td>1.0 to 1.4</td>
</tr>
<tr>
<td>Viscosity</td>
<td>100 to 350 mPa·s</td>
</tr>
<tr>
<td>ph Value</td>
<td>1.5 to 2.5 at 20 ºC</td>
</tr>
<tr>
<td>Density</td>
<td>1 g/cm3 at 20 ºC</td>
</tr>
<tr>
<td>PEDT :PSS ratio</td>
<td>1 : 2.5 (by weight)</td>
</tr>
<tr>
<td>Temperature</td>
<td>approximately 100 ºC</td>
</tr>
</tbody>
</table>

Table 6.1: Physical Data Transparent material (CLEVIOS P HC V4).

### 6.4 Software

CST (Computer simulation technology) is used for simulation. CST is 3D Electromagnetic simulator software which is user friendly software. It is easy to use. This software has many applications, specially it contain static, stationary, low and high frequency problems, also devices with movement of charged particles.
6.5 Previous Work

There are many research happened on Spiral Antenna for car applications. One of them is [19]. In this project Spiral antenna is used for car application. Due to wide band antenna it cover max services. In this project Pec material is used as a conductor and coplanar wave guide is used for feeding. Roger 5880 is used for substrate. Fig6.6 shows matching for required frequencies.

![Figure 6.6: Matching of previous work](image)

Results show good matching for satellite and terrestrial services. Fig6.7 shows radiation pattern for satellite and terrestrial mode.

It works for both modes. Due to its physical design, antenna is placed at trunk of car, because need to hide antenna. According to design of antenna trunk is the maximum place for to hide antenna. But still it effects the design criteria of car. In my project I need to hide the antenna as much as I can. and also need to find different feeding techniques for make it hide from eye, also I need to find transparent material instead of Pec material.
Figure 6.7: Radiation modes of previous work
Chapter 7

Results

In this chapter, a spiral antenna is designed with PEC material and CLEVIOS P HC V4 conductive transparent material. Detail of this conductive transparent material is already defined in previous chapter. Spiral antenna is integrated in front glass of vehicle which make it hygienic. Coplanar wave guide is used for feeding antenna.

7.1 Four-Arm Spiral antenna PEC material centre feeding

Fig [7.1] shows Four-Arm Spiral antenna, PEC material on glass substrate. Table [7.1] shows its parameters

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Symbol</th>
<th>Material</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Substrate</td>
<td>$\epsilon_r$</td>
<td>Glass</td>
<td>4.82</td>
</tr>
<tr>
<td>2</td>
<td>Conductor</td>
<td>$\sigma$</td>
<td>PEC</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Arm width</td>
<td>w</td>
<td>PEC</td>
<td>4mm</td>
</tr>
<tr>
<td>4</td>
<td>Space b/w Arms</td>
<td>s</td>
<td>PEC</td>
<td>4mm</td>
</tr>
<tr>
<td>5</td>
<td>Antenna size</td>
<td>l</td>
<td></td>
<td>216mm</td>
</tr>
<tr>
<td>6</td>
<td>CPW width</td>
<td>cw</td>
<td>PEC</td>
<td>2.7mm</td>
</tr>
<tr>
<td>7</td>
<td>CPW space</td>
<td>cs</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>CPW length</td>
<td>cl</td>
<td>-</td>
<td>6mm</td>
</tr>
</tbody>
</table>

Table 7.1: Parameter of PEC spiral antenna center feeding.
Fig 7.2 shows return loss at our desire services. Shaded area represent the matching of antenna for cover services. Shaded area in Fig 7.2 shows range in between 824 MHz to 2450 MHz, which cover GSM 1800/900, GPS, DABT, AMPS, WLAN, UMTS and DECT. Single shaded region shows at 5900 MHz, which is used for C2C communication application. According to define values in Table 7.1 for coplanar wave guide, reflections can minimize at input.
7.1.1 Radiation pattern

Fig 5.6 show the direction of radiation, which can be ideal for terrestrial and satellite services. Fig 7.3, Fig 7.4, and Fig 7.5 shows 3D radiation pattern of four-arm spiral antenna which covers different car services. Due to its dual pattern, and antenna position in front of glass it covers satellite and terrestrial services. At 5900 MHz radiation pattern is not stable, so C2C communication application doesn’t fit on it.

Figure 7.3: Radiation pattern of four-arm spiral antenn, PEC material, center feeding

Figure 7.4: Radiation pattern of four-arm spiral antenn, PEC material, center feeding
CHAPTER 7. RESULTS

Figure 7.5: Radiation pattern of four-arm spiral antenn, PEC material, center feeding

For more precise, 2D plot view of radiation pattern is shown in Fig 7.7 for GSM 1800 and Fig 7.8 for GPS application. In this plot Phi plane is at 90 degree and theta shows radiation pattern. Fig 7.6 shows 2D plane view of the car with antenna integrated on glass.

Figure 7.6: Car with 2D plane antenna
For GSM service main lobe has magnitude of 3.8 dBi and angular width [3dB] is 135.4 degree. For GPS application main lobe has magnitude of 3.8 dBi and angular width [3dB] is 135.4 degree.
7.2 Four-Arm Spiral antenna Transparent material center feeding

In this topic conductive transparent material (CLEVIOS P HC V4) came under investigation for antenna design. Transparent material which is described in Topic 6.3, will replace the PEC material in this simulation. Fig 7.9 shows transparent four-arm spiral antenna, integrated on front glass of car. This antenna is more hide comparatively four-arm spiral antenna PEC material due to its transparency. As previous design, this antenna is also fed by coplanar wave guide. Table 7.2 shows its parameters.

Table 7.2: Parameter of Transparent spiral antenna center feeding.

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Symbol</th>
<th>Material</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Substrate</td>
<td>$\varepsilon_r$</td>
<td>Glass</td>
<td>4.82</td>
</tr>
<tr>
<td>2</td>
<td>Conductor</td>
<td>$\sigma$</td>
<td>CLEVIOS P HC V4</td>
<td>400S/cm</td>
</tr>
<tr>
<td>3</td>
<td>Arm width</td>
<td>w</td>
<td>CLEVIOS P HC V4</td>
<td>4mm</td>
</tr>
<tr>
<td>4</td>
<td>Space b/w Arms</td>
<td>s</td>
<td>-</td>
<td>4mm</td>
</tr>
<tr>
<td>5</td>
<td>Antenna size</td>
<td>l</td>
<td>CLEVIOS P HC V4</td>
<td>216mm</td>
</tr>
<tr>
<td>6</td>
<td>CPW width</td>
<td>cw</td>
<td>PEC</td>
<td>2.5mm</td>
</tr>
<tr>
<td>7</td>
<td>CPW space</td>
<td>cs</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>CPW length</td>
<td>cl</td>
<td>PEC</td>
<td>10mm</td>
</tr>
</tbody>
</table>

Fig 7.10 shows return loss ‘$S_{11}$’ at our desire services. Comparatively, Return loss is almost same as in case of PEC material, so it work as a substitute of PEC material. Shaded area in Fig 7.10 shows range in between 824 MHz to 2450 MHz, which cover GSM.
7.2. **FOUR-ARM SPIRAL ANTENNA TRANSPARENT MATERIAL CENTER FEEDING**

Figure 7.10: Return loss of four-arm spiral antenna transparent material center feeding.

1800/900, GPS, DABT, AMPS, WLAN, UMTS and DECT. Single shaded region shows 5900 MHz which use for C2C communication. According to define values in Table 7.2 for coplanar wave guide, reflections can minimize at input.

### 7.2.1 Radiation pattern

Fig 7.11, Fig 7.12, and Fig 7.13 shows 3D radiation pattern of four-arm spiral antenna transparent material, which covers different car services. Due to its dual pattern, and antenna position in front of glass it covers satellite and terrestrial services. Radiation pattern is almost same as in PEC case. At 5900 MHz radiation pattern is not stable, so C2C communication application doesn’t fit it.

Figure 7.11: Radiation pattern of four-arm spiral antenna, transparent material, center feeding
Figure 7.12: Radiation pattern of four-arm spiral antenn, transparent material, center feeding

Figure 7.13: Radiation pattern of four-arm spiral antenn, transparent material, center feeding
7.2. **FOUR-ARM SPIRAL ANTENNA TRANSPARENT MATERIAL CENTER FEEDING**

For more precise view, 2D plot of radiation pattern is shown in Fig. 7.15 for GSM 1800 and Fig. 7.16 for GPS application. In this plot Phi plane is at 90 degree and theta shows radiation pattern. Fig. 7.14 shows 2D plane view of the car with antenna integrated on glass.

![Car with 2D plane antenna](image)

**Figure 7.14:** Car with 2D plane antenna

![2D Radiation pattern of four-arm spiral 'Transparent center feed' at 1797 MHZ.](image)

**Figure 7.15:** 2D Radiation pattern of four-arm spiral 'Transparent center feed' at 1797 MHZ.

![2D Radiation pattern of four-arm spiral 'Transparent center feed' at 1575 MHZ.](image)

**Figure 7.16:** 2D Radiation pattern of four-arm spiral 'Transparent center feed' at 1575 MHZ.
For GSM service main lobe has magnitude of 3.7 dBi and angular width [3dB] is 51 degree. For GPS application main lobe has magnitude of 2.5 dBi and angular width [3dB] is 57.6 degree.

7.3 Four-Arm Spiral antenna Transparent material back side feeding

In previous two simulations coplanar wave guide is used for antenna feeding in the centre. The length of coplanar wave guide is perpendicular to the antenna surface. This perpendicular feeding network can spoil the look of vehicle. Due to that reason this simulation explains the back side feeding network. In this feeding technique, three transparent conductor lines are feed via hole, from bottom of glass substrate. These transparent conductor lines are feed by coplanar wave guide at one side of antenna. So this makes 'L' kind of feed lines. In this way antenna is flat structure, and this type of prototype doesn’t spoil the look of vehicle, and also doesn’t obstruct the visual field of driver. Fig 7.17 shows Four-Arm Spiral antenna Transparent material back side feeding and Table 7.4 shows its parameters.

![Four-Arm Spiral antenna Transparent material back side feeding](image)

Figure 7.17: Four-Arm Spiral antenna Transparent material back side feeding

Fig 7.18 shows return loss ’S11’ at our desire services. Comparatively, Return loss is better then the previous two cases. Shaded area in Fig 7.18 shows range in between 824 MHz to 2450 MHz, which cover GSM 1800/900, GPS, DABT, AMPS, WLAN, UMTS and DECT services. Single shaded region shows 5900 MHz which use for C2C communication. According to define values in Table 7.4 for coplanar wave guide, reflections can
7.3. **FOUR-ARM SPIRAL ANTENNA TRANSPARENT MATERIAL BACK SIDE FEEDING**

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Symbol</th>
<th>Material</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Substrate</td>
<td>$\varepsilon_r$</td>
<td>Glass</td>
<td>4.82</td>
</tr>
<tr>
<td>2</td>
<td>Conductor</td>
<td>$\sigma$</td>
<td>CLEVIOS P HC V4</td>
<td>400S/cm</td>
</tr>
<tr>
<td>3</td>
<td>Arm width</td>
<td>$w$</td>
<td>CLEVIOS P HC V4</td>
<td>4mm</td>
</tr>
<tr>
<td>4</td>
<td>Space b/w Arms</td>
<td>$s$</td>
<td>-</td>
<td>4mm</td>
</tr>
<tr>
<td>5</td>
<td>Antenna size</td>
<td>$l$</td>
<td>CLEVIOS P HC V4</td>
<td>216mm</td>
</tr>
<tr>
<td>6</td>
<td>CPW width</td>
<td>$cw$</td>
<td>PEC</td>
<td>3.5mm</td>
</tr>
<tr>
<td>7</td>
<td>CPW space</td>
<td>$cs$</td>
<td>-</td>
<td>0.6</td>
</tr>
<tr>
<td>8</td>
<td>CPW length</td>
<td>$cl$</td>
<td>PEC</td>
<td>10mm</td>
</tr>
</tbody>
</table>

Table 7.3: Parameter of Transparent spiral antenna back side feeding.

minimize at input.

![Graph](image)

Figure 7.18: Return loss of four-arm spiral antenna transparent material back side feeding.

### 7.3.1 Radiation pattern

Fig 7.19 and Fig 7.20 shows 3D radiation pattern of four-arm spiral antenna transparent material, which covers different car services. Label antenna has change radiation pattern relatively first two designs. This antenna has not exact dual mode radiation but if it is integrated in front glass of car it fit for all desire applications, GSM 1800/900, GPS, DABT, AMPS, WLAN, UMTS DECT and C2C communication. Radiation pattern change with
frequency and CPL can hide in roof. At 5900 MHz radiation pattern is not stable, so C2C communication application doesn’t fit it.

Figure 7.19: Radiation pattern of four-arm spiral antenna, transparent material, back side feeding
Figure 7.20: Radiation pattern of four-arm spiral antenna, transparent material, back side feeding
For more precise view, 2D plot of radiation pattern is shown in Fig 7.22 for GSM 1800 and Fig 7.23 for GPS application. In this plot Phi plane is at 90 degree and theta shows radiation pattern. Fig 7.21 shows 2D plane view of the car with antenna integrated on glass.

![Antenna](Image)

Figure 7.21: Car with 2D plane antenna

![Radiation Pattern](Image)

Figure 7.22: 2D Radiation pattern of four-arm spiral 'Transparent back feed' at 1797 MHZ.

Figure 7.23: 2D Radiation pattern of four-arm spiral 'Transparent back feed' at 1575 MHZ.

For GSM service main lobe has magnitude of 2.5 dBi and angular width [3dB] is 86.4 degree. For GPS application main lobe has magnitude of 3.6 dBi and angular width [3dB] is 126.2 degree.
7.4 Two-Arm Spiral antenna TP material side feeding

Last simulation explain Two-Arm spiral antenna. Transparent material (CLEVIOS P HC V4) is used for antenna. There are several methods of feeding a spiral antenna externally [20] - [21], but they all need a minimum metallic area, which is also not desired for car windows. An alternative, novel method of feeding the spiral antenna from outside is to extend one arm of two-arm spiral half a turn, so that the two arms form a two-wire transmission line. Via this transmission line, which has well-defined characteristic impedance, the spiral now can be fed. Fig 7.24. shows two-arm spiral antenna, and Table 7.4 shows its parameters. Discrete port is used for this simulation.

![Two-Arm Spiral antenna transparent material side feeding](image)

Figure 7.24: Two-Arm Spiral antenna transparent material side feeding

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Symbol</th>
<th>Material</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Substrate</td>
<td>$\epsilon_r$</td>
<td>Glass</td>
<td>4.82</td>
</tr>
<tr>
<td>2</td>
<td>Conductor</td>
<td>$\sigma$</td>
<td>CLEVIOS P HC V4</td>
<td>400S/cm</td>
</tr>
<tr>
<td>3</td>
<td>Arm width</td>
<td>w</td>
<td>CLEVIOS P HC V4</td>
<td>2.5mm</td>
</tr>
<tr>
<td>4</td>
<td>Space b/w Arms</td>
<td>s</td>
<td>-</td>
<td>2.5mm</td>
</tr>
<tr>
<td>5</td>
<td>Antenna size</td>
<td>l</td>
<td>CLEVIOS P HC V4</td>
<td>280mm</td>
</tr>
</tbody>
</table>

Table 7.4: Parameter of Two-Arm Spiral antenna transparent material side feeding.

Fig 7.18 shows return loss 'S11' at our desire services. Shaded area in Fig 7.18 shows range in between 824 MHz to 2450 MHz, which cover GSM 1800/900, GPS, DABT,
AMPS, WLAN, UMTS and DECT services. Single shaded region shows 5900 MHz which used for C2C communication.

Figure 7.25: Return loss of two-arm spiral antenna transparent material, side feeding.

### 7.4.1 Radiation pattern

Fig 7.26 shows radiation pattern of two-arm spiral antenna for different services. In this simulation radiation pattern is relatively change, if we compare it with the last three simulations. Good radiation pattern of this antenna can be seen in three services, GSM 900, GPS, and AMPS.

For more precise view, 2D plot of radiation pattern is shown in Fig 7.28 for GSM 1800.
and Fig 7.29 for GPS application. In this plot Phi plane is at 90 degree and theta shows radiation pattern. Fig 7.27 shows 2D plane view of the car with antenna integrated on glass.

Figure 7.27: Car with 2D plane antenna

Figure 7.28: 2D Radiation pattern of two-arm spiral 'Transparent side feed' at 900 MHZ.

Figure 7.29: 2D Radiation pattern of two-arm spiral 'Transparent side feed' at 1575 MHZ.
For GSM service main lobe has magnitude of 4.2 dBi and angular width [3dB] is 105.6 degree. For GPS application main lobe has magnitude of 5.8 dBi and angular width [3dB] is 133.7 degree.

### 7.5 Comparison

Spiral antenna is used in many applications, due to its wide band characteristics. There are many research happened on Spiral antenna for the car applications. Past research is mostly based on PEC conductive material and Roger 5880 is used as a substrate. One of research has Four arm spiral antenna with coplanar wave guide feeding for car[19]. Antenna gives better matching for both satellite and terrestrial services. The return loss for the terrestrial mode is better than -10dB from 670 MHz to over 5 GHz. This shows large input impedance bandwidth obtainable with this antenna. The return loss for the satellite mode is better than -10dB in the range from 1.3 GHz up to 2.2 GHz. So satellite services also can be covered in a broadband way.

Main idea in this project is to replace the PEC material with transparent conductive material, and glass is used as a substrate. All simulations in this Project has return loss better -10dB for both satellite and terrestrial services. But comparatively previous work, this project has less matching due to low conductivity of transparent material. Four-Arm Spiral antenna transparent material back side feeding has return loss better then -10dB in the range from 1 GHz to 1.6 GHz, which cover satellite service. Return loss for terrestrial services is also better then -10 dB in the range from 800 MHz to 5.9 GHz with exceptions of -8dB for some points.
Chapter 8

Conclusion and Future Analysis

8.1 Conclusion

In order to make a final conclusion about the best performing antenna position for C2C communications is under the car. Several aspects have to be taken into account, like the design considerations. Also a summary of each analyzed parameter will be done. Design considerations have to be taken into consideration also, as this will be very important in the implementation of the antenna. As there are some positions at the car, which are not so easy to locate an antenna. Antenna under the car can be safe. At the bottom of the car, there are no design restrictions and the designers will not have so many problems to locate a communication system device here. In Scenarios, LOS and NLOS antenna is placed under the car and urban environment is defined in simulation.

For LOS and NLOS case long-term fading is shown in Fig3.2 and Fig3.5. Signal losses can be seen at different points. NLOS shows less path loss comparatively LOS, it can go for NLOS case because no vehicle is moving parallel with both cars. But for LOS case some cars are moving parallel to both. For NLOS case one vehicle is in between both cars, it can make constructive signal at receiver side due to its reflection.

Short-term fading component can distinguish between LOS and NLOS case. For LOS case deviation from 0 dB is large. In this case rapid fluctuation can be seen and it has probability to lost the data. But for NLOS case deviation from 0 dB is not so large. So it has more chances to get signal at receiver.

Measurement results are morels same like NLOS case, due to maximum time, some vehicles in between. Path loss reached maximum 88 dB which was the worse case and
minimum path loss obtains 70 dB. Monopole antenna is not radiating exact in omni pattern. Radiation pattern is bended toward the earth, so signal can reach at receiver after ground reflection, this factor plays vital role in measurements. Earth surface is not smooth like we had consider in ray tracing simulation so fraction of earth surface is also involved in measurements.

Different kind of broad band antennas are discussed. Some of them are rejected due to there radiation pattern and structure. Spiral antenna can work for multitude radio services and can help for automotive applications. Four-arm spiral fed with a coplanar transmission line, in the response both terrestrial services and satellite services covers. Position for antenna in the car is important consideration, and I had found that front glass of car, works better for dual mode radiation. Radiation can be seen at both side of antenna, so if antenna is integrated inside the car, still it can work.

Simulations shows that transparent conductive material has good approach for automotive application, like PEC material. Four-arm spiral antenna feed through back side can also work for automotive and all necessary services can cover by this. Integration of Four-arm spiral antenna feed through back side is easy to integrate on glass.

Two-arm spiral antenna which is intended to be integrated in the front glass of car. The proposed novel external feeding structure allows feed this antenna frequency-independently. The pattern change with frequency and is reliant on the location on the car. Due to high gain it has edge compare to other simulations.

8.2 Future Analysis

In this project work two scenarios are set and then analyze different channel characteristics. Scenario is based on measurement track. It will be very interesting to have the results and conclusions for other scenarios and measurements. Urban scenario is used for this project, motorway scenario and measurements could be interesting.

In this project monopole antenna is used under the car but some other antennas can also be analyzed with different radiation pattern. Finally, it will be important to analyze diversity-systems. In order to combine different antenna positions as transmitters or receivers. The results will be better, as if an antenna position is not performing so well in a certain moment, if there is another antenna located in another position at the car, this will improve the behaviour of the whole system.

Second part is based on broad band antenna with PEC and transparent material. It is based
8.2. FUTURE ANALYSIS

on simulations, so it could be more interesting if prototype is installing on the car and then analyze the radiation pattern. Also some other positions for antenna on the car can be analyze. In this project work the analysis is done in front glass of car for antenna integration, so another interesting improvement will be to analyze other position of car for antenna integration. Irregular radiation problem at 5.9 GHz frequency can be fixed in future work. Some other broad band antennas can also be used for analyzing transparent material.
List of Figures

1.1 Block Diagram of objective. ........................................... 3

2.1 Long-term fading ....................................................... 6
2.2 Short-term fading ....................................................... 7

3.1 LOS Scenario ........................................................... 9
3.2 Long-term fading for LOS case. ................................... 10
3.3 Short-term fading for LOS case. ................................... 11
3.4 NLOS Scenario ........................................................ 12
3.5 Long-term fading for NLOS case. ................................. 13
3.6 Short-term fading for NLOS case. ................................. 14

4.1 Possible position for antenna ................................. 15
4.2 Signal to noise ratio for different antenna positions. ........ 16
4.3 Monopole antenna Radiation Pattern .......................... 17
4.4 Block diagram of measurement setup ..................... 17
4.5 Transmitter setup ................................................. 18
4.6 Receiver setup ...................................................... 18
4.7 Measurement track .............................................. 19
4.8 Long term fading for measurement setup. ................. 20
4.9 Short term fading for measurement setup. ............... 21
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Rectangular plot of Radiation Pattern</td>
<td>24</td>
</tr>
<tr>
<td>5.2</td>
<td>linear vertical polarization</td>
<td>25</td>
</tr>
<tr>
<td>5.3</td>
<td>linear horizontal polarization</td>
<td>25</td>
</tr>
<tr>
<td>5.4</td>
<td>Circular Polarization</td>
<td>26</td>
</tr>
<tr>
<td>5.5</td>
<td>Elliptical Polarization</td>
<td>26</td>
</tr>
<tr>
<td>5.6</td>
<td>Required Radiation pattern</td>
<td>27</td>
</tr>
<tr>
<td>5.7</td>
<td>Vivaldi antenna</td>
<td>28</td>
</tr>
<tr>
<td>5.8</td>
<td>Bowtie antenna</td>
<td>29</td>
</tr>
<tr>
<td>5.9</td>
<td>Log-periodic antenna</td>
<td>30</td>
</tr>
<tr>
<td>5.10</td>
<td>Two-arm spiral antenna</td>
<td>31</td>
</tr>
<tr>
<td>5.11</td>
<td>Four-arm spiral antenna</td>
<td>31</td>
</tr>
<tr>
<td>5.12</td>
<td>Conical Spiral antenna</td>
<td>31</td>
</tr>
<tr>
<td>6.1</td>
<td>Phase</td>
<td>36</td>
</tr>
<tr>
<td>6.2</td>
<td>Required pattern</td>
<td>36</td>
</tr>
<tr>
<td>6.3</td>
<td>Coplanar wave guide</td>
<td>36</td>
</tr>
<tr>
<td>6.4</td>
<td>Antenna position</td>
<td>37</td>
</tr>
<tr>
<td>6.5</td>
<td>Radiation pattern w.r.t position</td>
<td>37</td>
</tr>
<tr>
<td>6.6</td>
<td>Matching of previous work</td>
<td>39</td>
</tr>
<tr>
<td>6.7</td>
<td>Radiation modes of previous work</td>
<td>40</td>
</tr>
<tr>
<td>7.1</td>
<td>Four-arm spiral antenna PEC material</td>
<td>42</td>
</tr>
<tr>
<td>7.2</td>
<td>Return loss of four-arm spiral antenn, PEC material</td>
<td>42</td>
</tr>
<tr>
<td>7.3</td>
<td>Radiation pattern of four-arm spiral antenn, PEC material, center feeding</td>
<td>43</td>
</tr>
<tr>
<td>7.4</td>
<td>Radiation pattern of four-arm spiral antenn, PEC material, center feeding</td>
<td>43</td>
</tr>
<tr>
<td>7.5</td>
<td>Radiation pattern of four-arm spiral antenn, PEC material, center feeding</td>
<td>44</td>
</tr>
<tr>
<td>7.6</td>
<td>Car with 2D plane antenna</td>
<td>44</td>
</tr>
<tr>
<td>7.7</td>
<td>2D Radiation pattern of four-arm spiral ’PEC’ at 1797 MHZ</td>
<td>45</td>
</tr>
</tbody>
</table>
7.8 2D Radiation pattern of four-arm spiral 'PEC' at 1575 MHZ .......................... 45
7.9 Four-arm spiral antenna transparent material center feeding. ....................... 46
7.10 Return loss of four-arm spiral antenna transparent material center feeding. .... 47
7.11 Radiation pattern of four-arm spiral antenna, transparent material, center feeding ................................................................. 47
7.12 Radiation pattern of four-arm spiral antenna, transparent material, center feeding ................................................................. 48
7.13 Radiation pattern of four-arm spiral antenna, transparent material, center feeding ................................................................. 48
7.14 Car with 2D plane antenna ................................................................. 49
7.15 2D Radiation pattern of four-arm spiral 'Transparent center feed' at 1797 MHZ. ................................................................. 49
7.16 2D Radiation pattern of four-arm spiral 'Transparent center feed' at 1575 MHZ. ................................................................. 49
7.17 Four-Arm Spiral antenna Transparent material back side feeding ........... 50
7.18 Return loss of four-arm spiral antenna transparent material back side feeding. 51
7.19 Radiation pattern of four-arm spiral antenna, transparent material, back side feeding ................................................................. 52
7.20 Radiation pattern of four-arm spiral antenna, transparent material, back side feeding ................................................................. 53
7.21 Car with 2D plane antenna ................................................................. 54
7.22 2D Radiation pattern of four-arm spiral 'Transparent back feed' at 1797 MHZ. ................................................................. 54
7.23 2D Radiation pattern of four-arm spiral 'Transparent back feed' at 1575 MHZ. ................................................................. 54
7.24 Two-Arm Spiral antenna transparent material side feeding .................. 55
7.25 Return loss of two-arm spiral antenna transparent material, side feeding. ... 56
7.26 Radiation pattern of two-arm spiral antenna, transparent material, side feeding ................................................................. 56
7.27 Car with 2D plane antenna .................................................. 57
7.28 2D Radiation pattern of two-arm spiral 'Transparent side feed' at 900 MHZ. .................................................. 57
7.29 2D Radiation pattern of two-arm spiral 'Transparent side feed' at 1575 MHZ. 57
List of Tables

1.1 Different services and frequency bands. ........................................... 2

6.1 Physical Data Transparent material (CLEVIOS P HC V4). ............... 38

7.1 Parameter of PEC spiral antenna center feeding. .......................... 41

7.2 Parameter of Transparent spiral antenna center feeding. ............... 46

7.3 Parameter of Transparent spiral antenna back side feeding. .......... 51

7.4 Parameter of Two-Arm Spiral antenna transparent material side feeding. . 55
Bibliography


