Design of a Small Form Factor Tri-Band PIFA Antenna for a Portable GSM System

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ABSTRACT

The PIFA antenna is one of the most widely used antennas in cell phones. It is compact in size; consumes low power and radiates high power. One of the major advantages of a PIFA antenna is that it can be designed for multiband applications using small dimensional structures. In our project, our primary objective was to design a planar inverted F antenna which is small in size and which will provide tri band coverage for GSM system. In our project the PIFA was designed to fit on an eye-glass frame designed specifically to support mobile application. We also present a complete architectural layout of the mobile phone in the eye-glass frame. We also analyzed the effect of various parameters on the performance of PIFA and tried to characterize their impact. To design PIFA we used the HFSS software which uses FEM (Finite element method). In the application section we provide a proposal of the eye frame mobile and briefly discuss different parts of our proposed eye frame mobile application.

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Above everything we thank our Almighty, Allah, for giving us the ability, knowledge, patience and energy to complete this commitment efficiently.

AUTHORIZATION PAGE

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1. INTRODUCTION

1.1. Thesis motivation

The growth of wireless mobile telecommunication is increasing day by day. Future wireless technology implementation will demand very small antenna in limited space. Today PIFA (Planner Inverted F Antenna) is widely popular in wireless technology application due to its small and robust form factor. Our thesis objective was to design such a small PIFA which we can place in an eye frame with ease along with other mobile components; in short we want to design a complete mobile system in an eye frame. It can potentially make our fast and complicated life easier and stylish, taking away the need to use a hand to hold the phone or any pockets to hold the device. Our main objective is to find the optimum geometry that can be placed in a small area which will support the PIFA antenna for standard GSM frequencies and also support the electrical circuitry and devices for the cellular phone. In our thesis we propose the eye frame mobile concept details and also provide architectural details of the eye frame mobile system. Our basic point is that this eye frame mobile system will only have circuits for transmission and receiving signal, minimized to reduce battery usage and circuit complexity; no special features for now such as video, mp3 and radio.

1.2. Literature review

In past, many research papers have been published on PIFA. In those papers analytical equations which relates to the performance of PIFA are not explicitly given. In previous papers researchers have presented PIFA antennas of different shapes using different effects such as coupling effect, source pin effect etc. This approach has allowed the development of antennas which meet GSM bands for mobile application. In Figure 1 we see one such antenna [1]. The PIFA antenna is generally used to reduce the area of patch. Here we also observe that use of capacitive load for tuning the resonance frequency. In Figure 2 we see another antenna which has two rectangular patches. One is located inside and the other is in the outside. Between the two patches there exists no physical contact but they are located very near to each other resulting in significant coupling effect. According to the paper, this coupling is responsible for higher bandwidth [2]. They also use multiple short pins. In another paper we see they design antenna patch which look like triangular shape. In many paper, we see researchers design to increase the bandwidth and the resonance frequency of the antenna. They also try to develop the equation for PIFA. In some review article [3] & [4] discuss about the multiband resonance frequency within a single antenna.

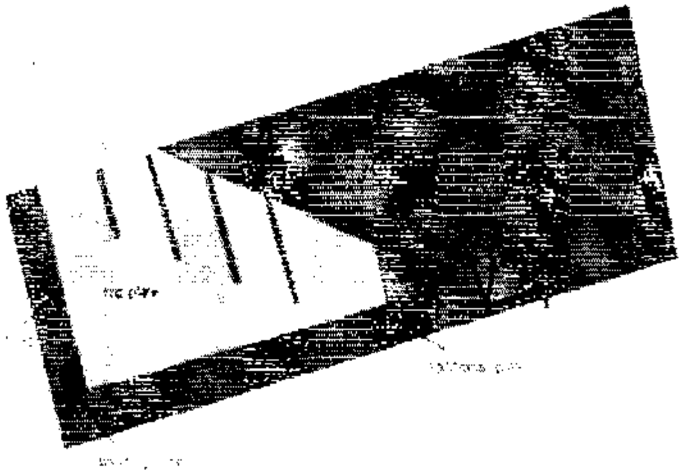

Figure 1: PIFA antenna by Kulkarni [1]

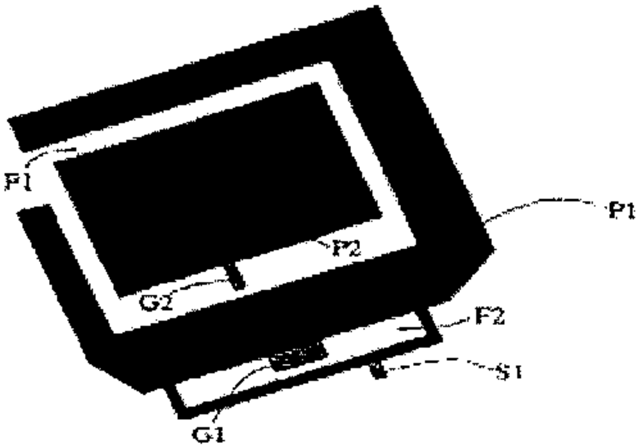

Figure 2: PIFA antenna by Pan--Lintfort [2]

2. BACKGROUND THEORY

2.1. Working principle of mobile system:

2.1.1. Mobile working principle

A cell phone is composed of several parts, such as the Power and energy management system, RF unit, Application processor, Audio and management system. Every part has its individual working principal and importance. In Figure – 3, we state the internal architecture of a typical cell phone.

RF Unit:-RF unit is build of an RF Processor and antenna, which is used to transmit and receive signal from MS to BTS. The RF processor controls all the processes including transmitting and receiving of signals, Bluetooth, WLAN, Infrared can be used to transmit and receive data in short distances between two devices. Digital signal processing is also done in this section.

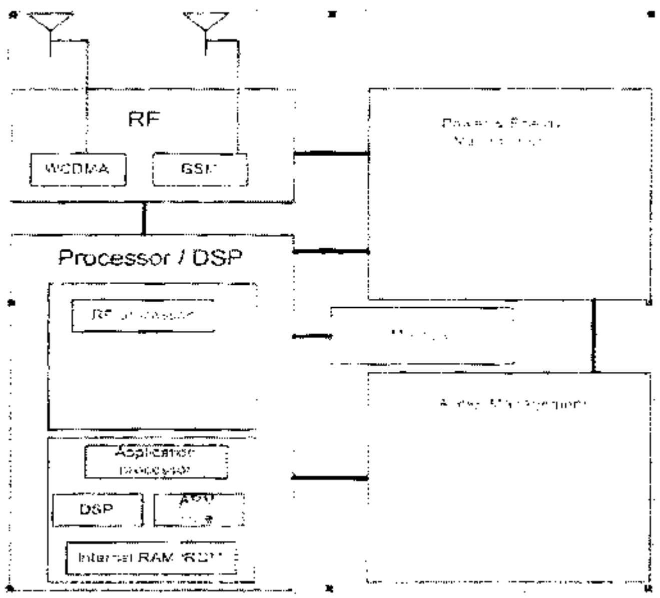

Figure 3: Internal architecture of Cell phone

Application processor: The application processor controls all the application which is used in cell phone. This part is composed of the DSP, ARM core, graphics or video accelerator and internal RAM. In the DSP (digital signal processing) section, audio or speech signal are processed to get digital data from analog signal. Analog signal are filtered, compressed and then converted to digital signals using ADC (analog to digital converter). ARM core is also known as the Advanced RISC Machine. Every mobile phone has at least one ARM core. ARM processor is suitable for low power consumer applications, such as the mobile phone. The function of the graphics or video accelerator is to generate and then show images to a display. RAM is used to store data and store data can be access in any order.

2.1.2. Power consumption area

Lifetime of the battery is one of the most important usage concerns for a mobile system. Power is needed to run cpu, memory chip, RF hardware, LCD display, mobile application and audio system [5]. Multimedia is a part of mobile application. In this part we use different type of players for audio and video playback and also to play graphical video games. All these applications consume significant amount of power running down the battery life time. Power and energy management system distribute power to different parts of a cell phone [6]. It works to provide better performance of the power supply to all part and it done this work very efficiently. To minimize power consumption, power reduction mechanisms are vital, such as the Low Power Processors, Energy Efficient Memory Schemes, Power Control Techniques for Displays and Power Management Unit [7].

2.1.3. Audio management system

The audio management system supports the microphone and speaker. It manages the FM transition, SIM card. SD card. AV output. All these parts relate to one another

2.2. GSM band

GSM (Global system for mobile communication) is a standard for mobile communication. Now it is used worldwide. Over 70% of world telecommunication system is based on GSM. This standard is used by over 3 billion people in more than 212 countries worldwide. There are other standards for telecommunication but those are not used as much as GSM. GSM supported cell phone are cheaper and consumes lesser power then other telecommunication standard supported cell phones like CDMA. Also CDMA needs costlier BTS equipment, more complex network for soft handoff, more power control to manage near-far problem, orthogonal spreading sequence. and a hardware complexity and synchronization problem. Upgrade of GSM system is easier because it needs only software upgrade. It can also support large number of subscribers. In short, implementation of GSM infrastructure is easier and cheaper.

Table 1: The GSM standard [8]

System	Band	Uplink (MHz)	Downlink (MHz)	Channel number
T-GSM-380	380	380.2-389.8	390.2-399.8	Dynamic
T-GSM-410	410	410.2-419.8	420.2-429.8	Dynamic
GSM-450	450	450.4-457.6	460.4-467.6	259-293
GSM-480	480	487.8-486.0	488.8-496.0	306-340
GSM-710	710	698.0-716.0	728.0-746.0	Dynamic
GSM-750	750	747.0-762.0	777.0-792.0	438-511
T-GSM-810	810	806.0-821.0	851.0-866.0	Dynamic
GSM-850	850	824.0-849.0	869.0-894.0	128-251
P-GSM-900	900	890.2-914.8	935.2-959.8	1-124
E-GSM-900	900	880.0-914.8	925.0-959.8	975-1023,0-124
R-GSM-900	900	876.0-914.8	921.0-959.8	955-1023,0-124
T-GSM-900	900	870.4-876.0	915.4-921.0	Dynamic
DCS-1800	1800	1710.2-1784.8	1805.2-1879.8	512-885
PCS-1900	1900	1850.0-1910.0	1930.0-1990.0	512-810

Different standards use different types of modulation techniques, such as FDMA, TDMA and CDMA. In FDMA whole frequency band is divided into frequency non-overlapping sub-channel. For every user a frequency band is allocated. This technique was first implemented in the multiple access technique in cellular communication. In TDMA a single channel is shared with different users. Therefore, number of users and channel utilization will also increase. TDMA is implemented in second generation mobile communication. CDMA is known as third generation multiple access technology. A single 1.25 GHz frequency band is used for all users. Each user transmit signal with a unique code called PN sequence. Table 1 shows GSM specification followed worldwide. Different countries use different band of frequency in GSM system. Therefore, for common access we need multiband frequency support in cell phones. For this we can use multiband antenna or frequency tunable antenna [8]. In multiband there are different frequency bands which an antenna supports and in tunable antenna, the frequency of antenna can be tuned as required.

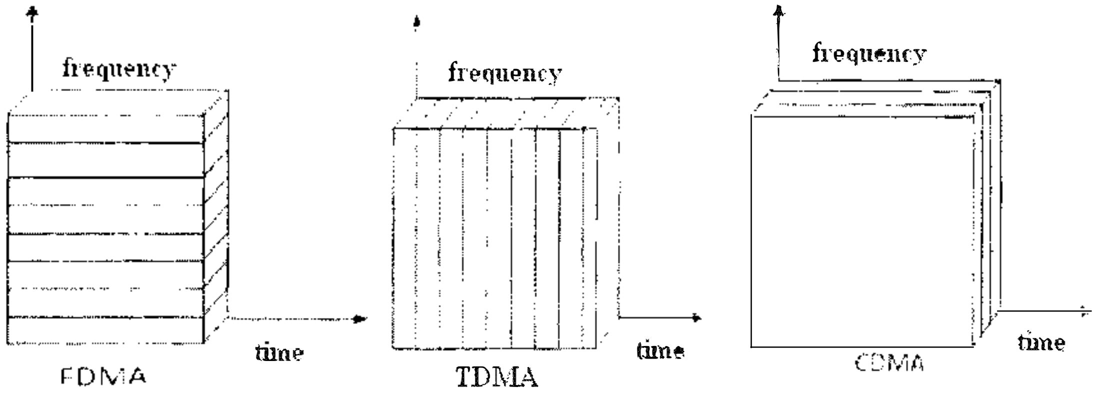

Figure 4: Overview of multiple access technologies

2.3. Different kinds of antenna

Of all antennas used in different communication systems, micro strip patch antenna or a PIFA is most widely used in cell phones. Figure 4 shows a general view of the micro strip patch antenna. This antenna has rectangular patch fabricated on a dielectric layer. Below the dielectric material is a ground plane. Figure 5 shows a PIFA antenna. The PIFA has the short pin which connects the ground plate with the patch, a feature which is not present in the micro strip patch antenna. In our patch micro strip patch antenna the feed pin is through a transmission line. But the feed pin of PIFA is situated to couple the input signal to the PIFA antenna. The primary advantage of PIFA is that the Micro strip patch is large. That is why PIFA is widely used in mobile devices.

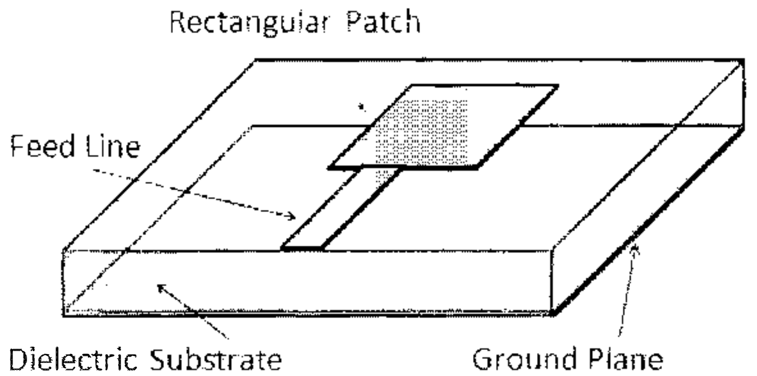

Figure 5: General micro strip patch antenna

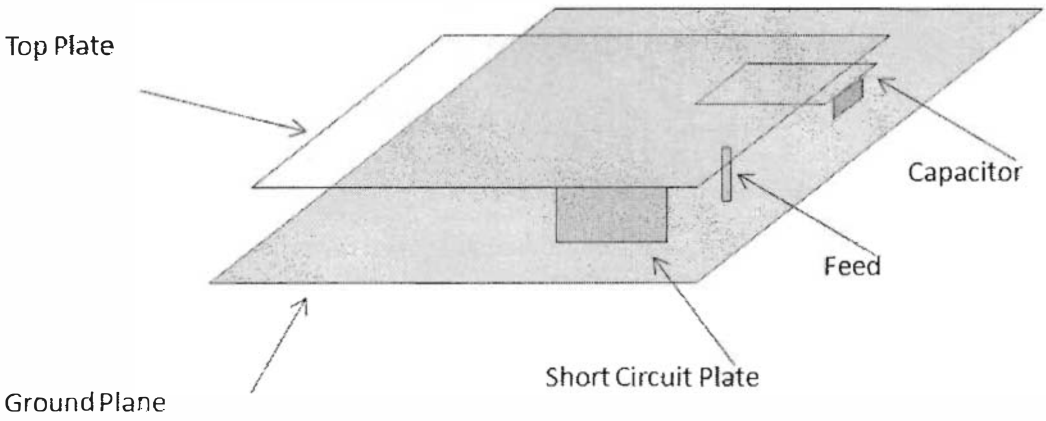

Figure 6: General PIFA structure

2.4. Design software - HFSS

HFSS (High Frequency Simulation Software) is a numerical tool which is used to model and simulate electromagnetic behavior of a structure. The primary advantage of this Ansoft software is that it performs analysis at high frequency in three dimensions. Here I can specify the material characteristics for each object and identify the input output ports and special surface characteristics. This software mainly generates the necessary field solution and port characteristics and S-parameters. This software can calculate resonance based on the geometry, materials and boundaries model of the structure. HFSS allows you to specify whether to solve the problem at one specific frequency or at several frequencies within a range. By using this software; we can perform the following analysis:

- 3D Full-wave Electromagnetic Field Simulation
- Basic electromagnetic field analysis - radiated near and far fields.
- Characteristic port impedance and propagation constant simulation.
- Generalized S-parameters and S-parameters renormalized to specific port impedances.

HFSS software analysis is based on the FEM (finite element method) numerical method. It is a numerical technique for finding approximate solutions of partial differential equations (PDE) and the integral equations. The approach either on eliminates the differential equation completely or renders the PDE into an approximating system of ordinary differential equations

3. PIFA ANALYSIS

3.1. Introduction of PIFA

The planar inverted F antenna (PIFA) is well-known in antenna designs. These antennas have reduced size compare to traditional micro strip antennas. This is because the resonance frequency for traditional micro strip antenna happens at half the wavelength, while the PIFA resonant frequency is achieved at quarter wavelength.

PIFA is an upgrade version of IFA (Inverter F antenna) which consists of a short feed with a monopole shown in Figure 6. To increase bandwidth wire is place by a planar horizontal plate and it is short circuited on the other end. The short circuit plate increases the effective length of current flow. PIFA consists of a rectangular planner element which also can be circular or rectangular (based on design) located above a ground plane, one or more short circuiting plate or pin and a feed. The short circuit pin of the PIFA plays a significant role. The length of the ground plane of the PIFA generally quarter ($\lambda/4$) of the operating wavelength. If the length higher than this we find increasingly multi lobed radiation patterns. If it is shorter than the overall performance degrades and tuning becomes difficult.

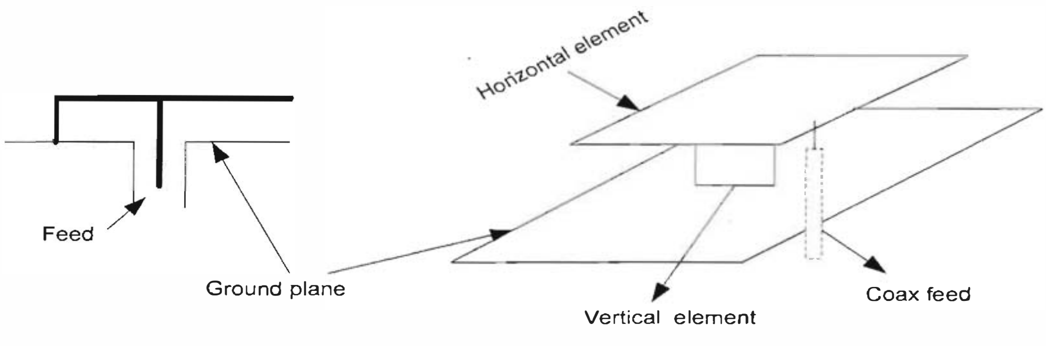

Figure 7: Upgrading of IFA to PIFA

3.2. Radiation efficiency

Radiation efficiency is a critical parameter for an antenna which measures the performance of the antenna system. In summary efficiency characterizes the amount of energy being transmitted in the far field region. It is the ratio of the radiated power in far field region and input power:

$$\text{Radiation efficiency, } \varepsilon = \frac{P_{radiation}}{P_{input}}$$

Where $P_{radiation}$ is the radiated power and P_{input} is the input power. If the input impedance of feed point is perfectly matched with the output impedance of top plate, then most of the power from the source will be transmitted into free space. The efficiency of the antenna is very dependent on the input impedance of the feed pin, which defines that how much power is transmitted out. To transmit the maximum power, the impedance of the feed pin and the impedance of the patch should be matched. The Voltage Standing Wave Ratio (VSWR) also characterizes the quality of impedance matching [9]:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}; \quad \Gamma = \frac{\text{Impedence of feed pin} - \text{impedence of Patch}}{\text{Impedence of feed pin} + \text{impedence of Patch}}$$

Where, Γ is the reflection coefficient. In this entire system the antenna performance is determine by the total radiated power (TRP). TRP is measured by the antenna gain without power absorption effect. The antenna gain, the antenna efficiency, and directivity are related by

$$\text{Efficiency} = \text{Gain} \times \text{Directivity}.$$

If gain is increased, then the antenna efficiency also improves. Thus we need to increase antenna gain to get higher efficiency. An antenna gain is increased by increasing the radiated power in the far field region. Antenna gets the 100% efficiency when antenna gain is equal to directivity. However, 100% radiation efficiency is not achievable because of environment losses, noise and the change of antenna characteristic [10].

3.3. Radiation Pattern

When electrical energy is propagated to an antenna, the antenna will convert this signal into electromagnetic wave and radiate the energy into outer space in a certain direction [11]. PIFA radiation pattern can be represented using three dimensional polar plots. A radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. For this we will measure how much power is radiated into the outer space in certain direction. This power variation is observed in the far filed region as a function of incident angle.

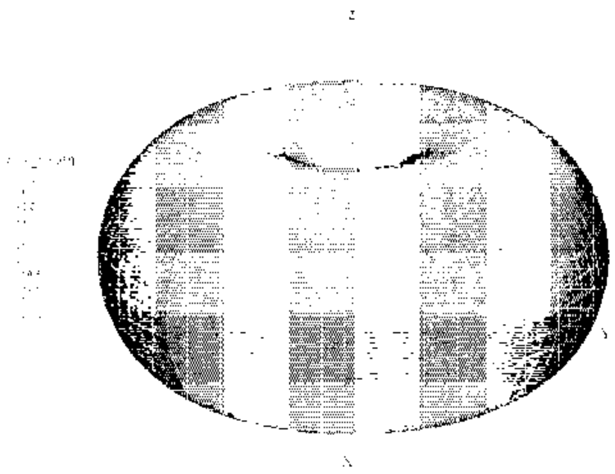

Figure 8: 3D Radiation Pattern

Radiation pattern is commonly referred to as the directional pattern. Radiation pattern is typically presented in the form of field on a spherical surface of constant radius around the antenna with the antenna being at the point of origin. Figure 8 is a three dimensional plot of a radiation pattern of the PIFA. which is a directional antenna. In our analysis of the PIFA. we have calculated the radiation pattern in the far field region. In Figure 8 we see that along the z-axis, i.e. radiation vertically over the antenna, very little power is transmitted. In the x-y plane which is perpendicular to the z-axis the radiation is maximum.

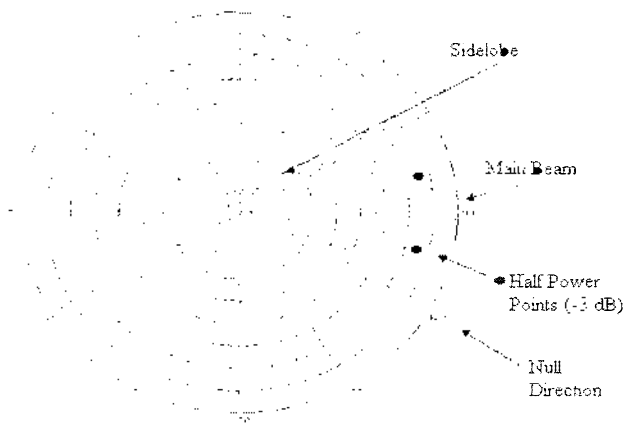

Figure 9: Polar Radiation Pattern

Figure 9 is the polar plot form of the radiation pattern. Here exist various lobes such as main lobe, side lobe, minor and back lobes. Here the main beam defines the direction of the maximum radiated power is shown in Figure 9. The side lobe defines the radiated power in undesirable direction. For the PIFA, the side lobes are significantly smaller than main lobe. The radiation pattern properties also include power flux density, radiation intensity, field strength, directivity phase. The angle over which the peak of the main beam of the radiation pattern decreases by 50% or -3dB is called the half power beam width. Null direction is when the magnitude of the radiation pattern decrease to zero which is negative infinity dB away from the main beam. From Figure 2 we see several Null directions.

3.4. Far Field Region

If the angular field distribution is normally independent of distance from the source that is called far field region. The source has a maximum overall dimension D. It is large compare to the wavelength. The far filed region is commonly taken from at distance greater than $2D^2/\lambda$ from the source where λ is the wavelength. Here the radiation beam is focused infinitely. This region is indicating by the radiated field. Here the electric field (E) and the magnetic field (H) are orthogonal to each other and propagation power can be modeled as plane waves. The far field region of an antenna. the angular field distribution is independent of distance from antenna. Here the outer boundary is infinite.

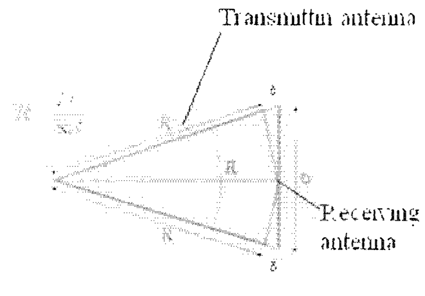

Figure 10: Far field measured from an antenna

$$R \geq \frac{2.5D^2}{\lambda}$$

Where, R is the radius of an antenna, λ is the wavelength and D is dimension of an antenna. For radiation to be far-field. here assume δ is less than 1/20 of wavelength.

3.5. Directivity

The amount of energy transmitted in a particular direction depends on directivity and the efficiency of an antenna. Directivity is a fundamental antenna parameter. It measures the ability of the antenna to focus its radiated power in a certain direction. An antenna that radiates equally in all directions would have effectively zero directivity or 0 dB. Based on the directivity, antenna can be divided into Omni directional and directional. PIFA antenna is a directional antenna. This is because PIFA antenna primarily radiates in either one or two direction. In such way directional antennas radiate energy in the shape of lobes (beams) that extend into space or far field region. The goodness of directivity of the antenna measures the narrowness of the radiated beam. Antenna will have high degree of directivity when the beam is narrow in either horizontal or vertical plane. To get high directivity, an antenna is designed basically to radiate in one plane. It also depends on the antenna application. Directivity is the maximum power to its average value ratio over a sphere. Basically directivity is calculated using this equation.

$$D = \frac{4\pi}{\Omega_A}$$

Here, D is antenna directivity, 4π is solid angle in steridians. and Ω_A is the solid beam angle.

3.6. Electric field distribution

A property that describes the electric energy density in a space surrounded by electrically charged particles is as known electric field. This electric field exerts a force on other electrically charged objects. Electric fields follow the superposition principle.

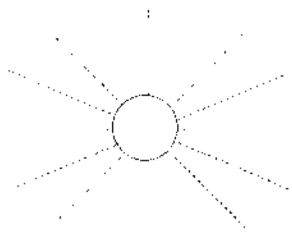

Figure 11: Electric field distribution

If more than one charge is present, the total electric field at any point is equal to the vector sum of the respective electric fields that each object would create in the absence of the others. The electric field is defined as the force per unit charge that would be experienced by a stationary point charge at a given location in the field.

$$E = \frac{F}{q}$$

Here F is the electric force, q is the charge. In a space with a single charge, electric field reduces by a factor of the distance, as one move away from the source charge. On the antenna, electric field is maximum at the edge. From the edge of the plane electric filed is propagated in the air.

3.7. Current field distribution

The current distribution of an antenna is another important parameter. The per unit area flow of conserved charge is Current density. The charge is the electric. Current density is important to the design of electrical and electronic systems as the distribution of flow of charge:

$$\mathbf{J}(\mathbf{r},t) = qn(\mathbf{r},t)\mathbf{v}_d(\mathbf{r},t) = \rho(\mathbf{r},t)\mathbf{v}_d(\mathbf{r},t)$$

J(r,t) is the current density vector at location r at time t

n(r,t) is the particle density in count per volume at location r at time t

q is the charge of the individual particles with density n

ρ(r,t) = qn(r,t) is the charge density

vd(r,t) is the particles' average drift velocity at position r at time t

The current is fed at a point on the antenna and then it is distributed to the antenna plane. The distribution may not be equal at every point. It also depends on the conductivity of the plane.

4. SMALL PIFA DESIGN & ANALYSIS

4.1. PIFA for GSM band

GSM (Global system for mobile) is standardized which is followed all over the world. We state in section 2.2 about the GSM bands and their usage criteria. In Our Project we target to design a tri band small form factor antenna which support the 900, 1800 & 1900 MHz Band with Uplink and Downlink frequency which we state in section 2.2. PIFA means planner inverted F antenna. General shape of this antenna is F. Here we first design a PIFA which is shown in Figures 12 and 13 with its frequency spectrum.

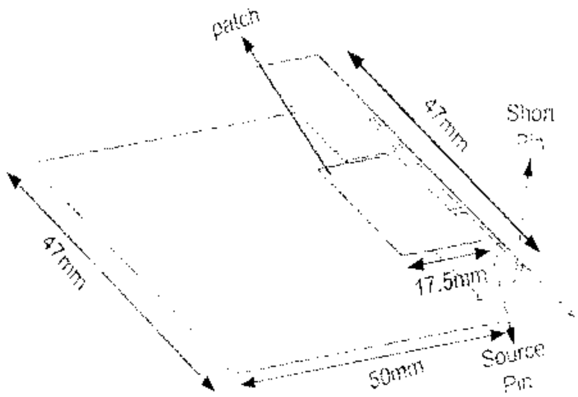

Figure 12: Our first PIFA design

Figure 13: frequency spectrum of our fist PIFA

In Figure 12, the width of patch is 17.5 mm and the length is 47mm which is actually small in size. Using this antenna we do not get the desired frequency spectrum. In this design we only find support for two bands, i.e. 900MHz and 1800 MHz. We get proper uplink and downlink frequency for the 900Mz but do not get full support for 1800 MHz. We see that if we increase the electrical length of the antenna the resonant frequency of the antenna decreases [11]. So we divide the patch into two slots to increase the electrical length. Here we also use dielectric materials to support the patch and also increase the bandwidth, which we explain later. When we modify PIFA design to support our application, our focus is to reduce PIFA's width and length. Our revises PIFA structure is shown in Figure 14, along with its S11 plot in Figure 15.

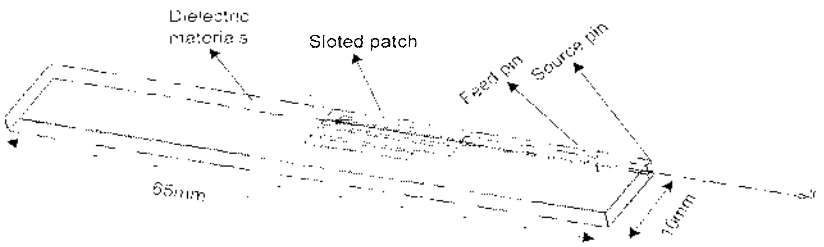

Figure 14: PIFA design only for one band

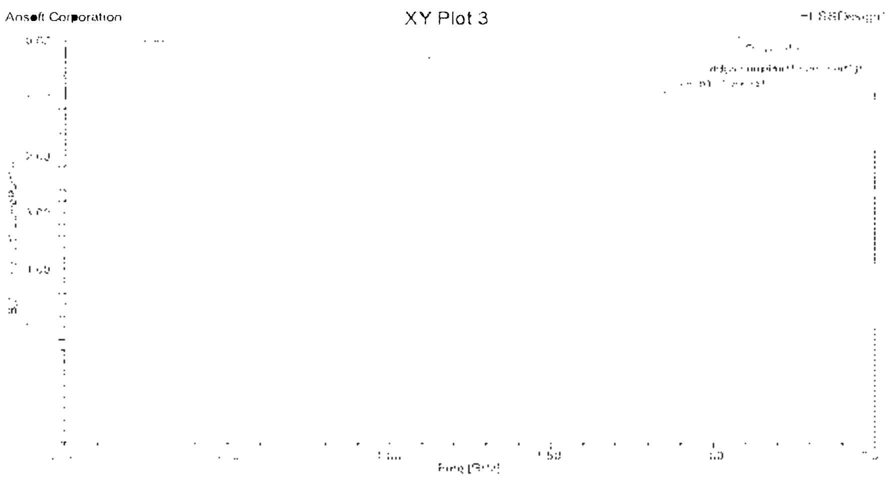

Figure 15 : S parameter for 900MHz

For the antenna showed in Figure 14, the PIFA supports only one desired frequency band. band. We then place serpentine shapes in place of the PIFA patch, shown in Figure 16. We also vary the source pin , short pin and patch width length and position which look like in below patch and get the below Figure 17 S11 plot.

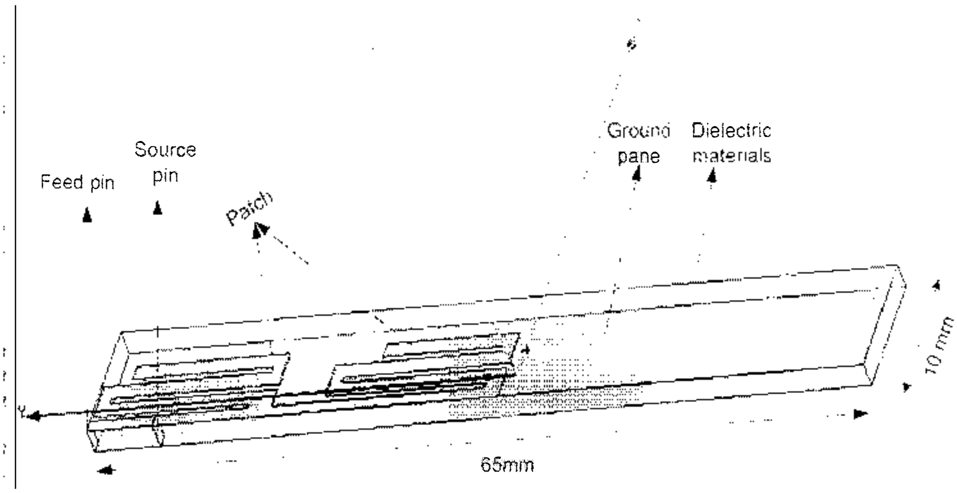

Figure 16: PIFA design for two bands

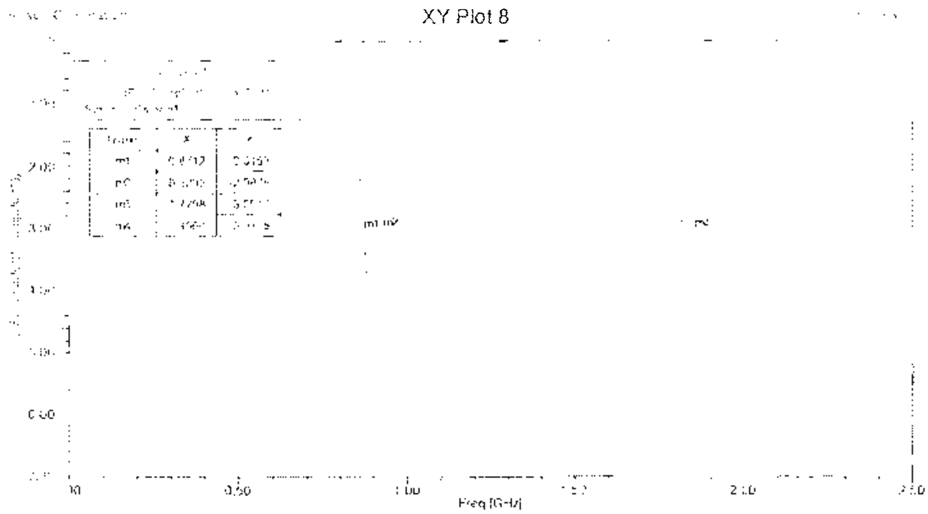

Figure 17: S parameter for 900and 1800MHz

In above PIFA design we don't get the uplink and downlink frequency of 900 MHz and 1800 MHz The bandwidth is very narrow. In this design also exists a very long ground plane which is not as ideal for our propose application. In the next iteration of our design we review all this design considerations on the performance of the antenna. We also introduce a coupling effect to increase the band width of the antenna. We also model the dielectric materials which is generally used in a typical application like ours. The revised final design is shown below

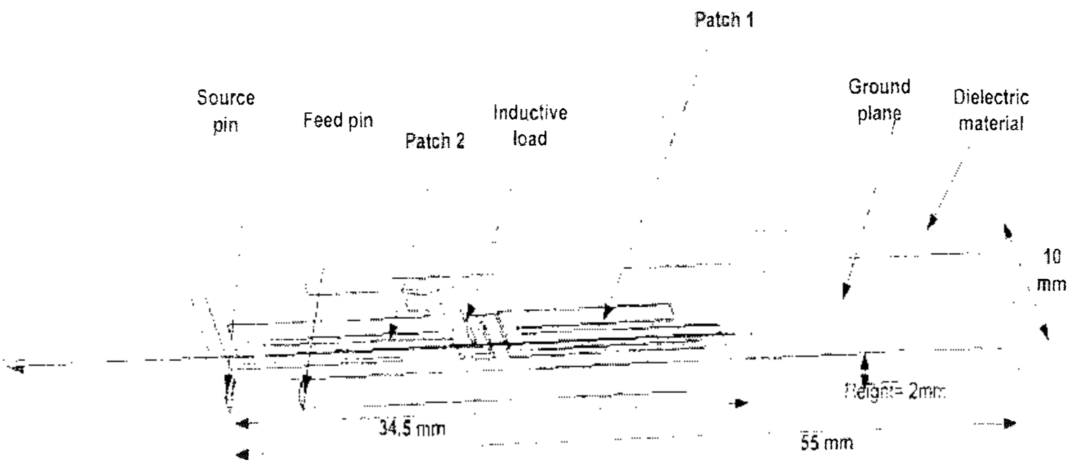

Figure 18: The final PIFA design

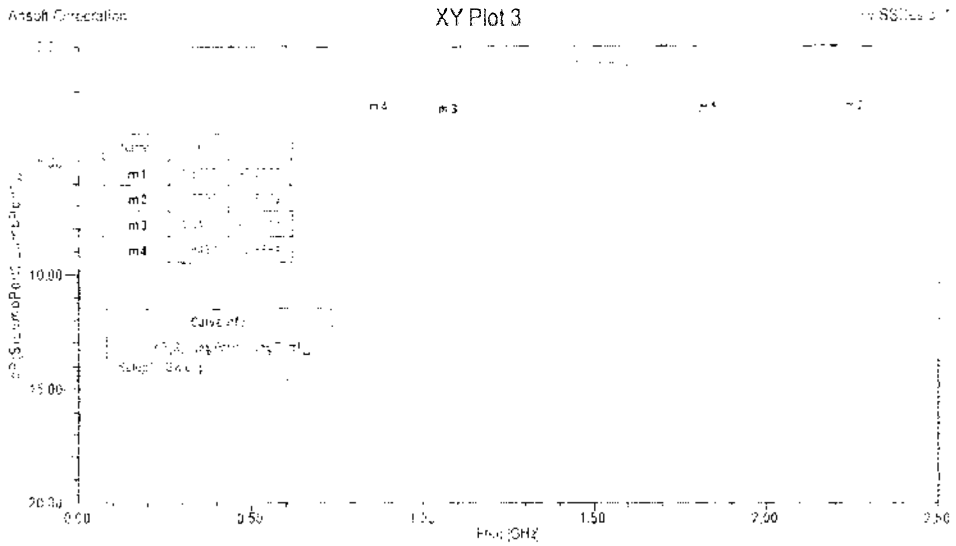

Figure 19: S parameter plot of our final PIFA design

For using the inductive load between two patches we find the wide bandwidth at higher band.

4.2. Effect of parameter

4.2.1. Source pin effect

Source pin is common in application with similar antennas. In PIFA our PIFA design we use lumped port as a source pin, which is used as the port to receive and transmit signal. Source pin has two effective parameters. One is width & another is the position of source pin, both of which affects the resonance frequency, bandwidth and return loss of antenna. Below we discuss how the width and position of source pin affects the performance of antenna.

4.2.1.1. Source Position Effect on Antenna Performance

The source pin position of PIFA is vital for tuning the resonance frequency of antenna [12]. In our PIFA design we change the position of the source pin and observe the lower and higher band frequency effect with respect to position of source pin. In our below Figure 20 & 21 we provide the return loss plot for both higher and lower band frequency as we vary the position of source pin and observe the change of antenna characteristic.

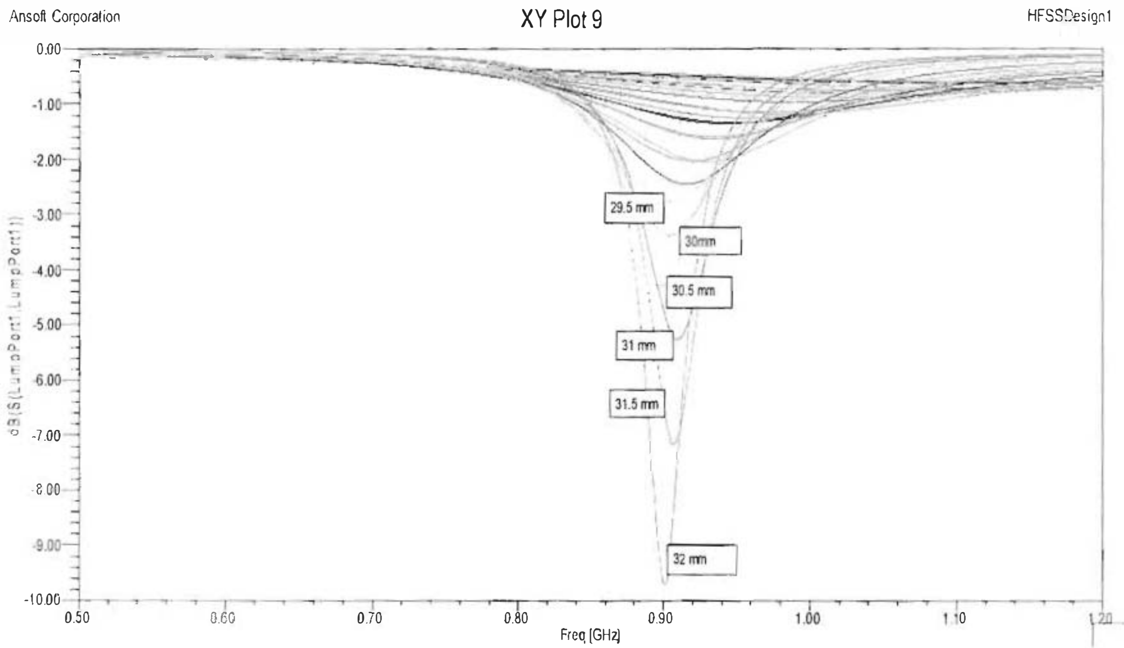

Figure 20: Position based effect for lower band frequency.

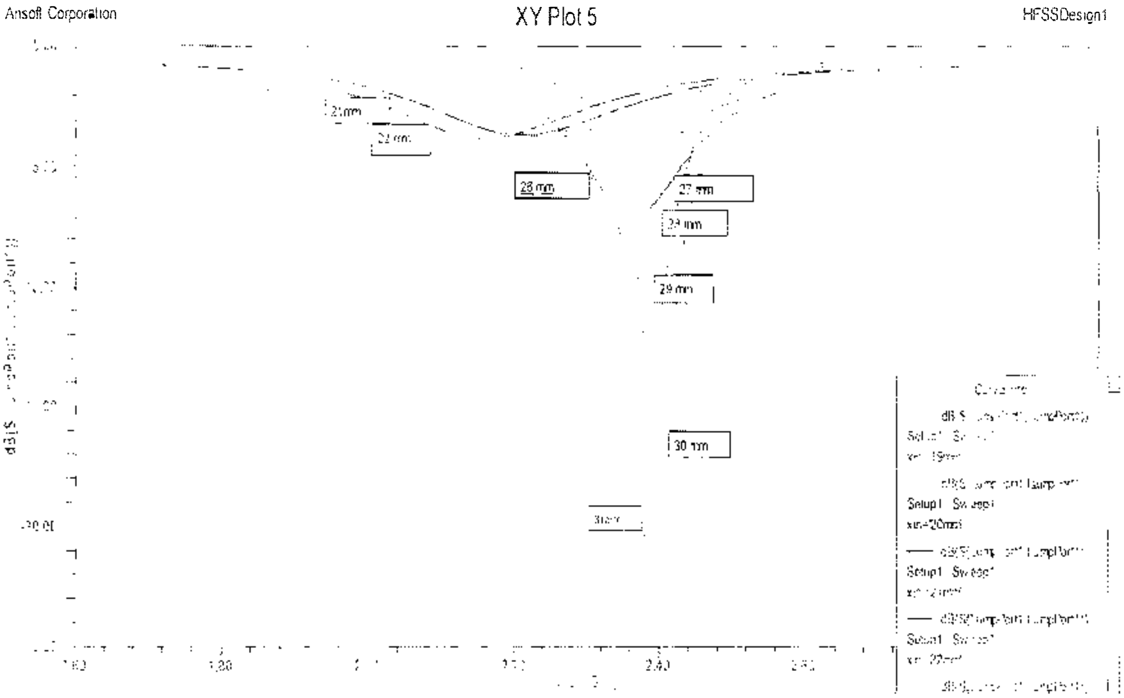

Figure 21: Position based effect for higher band frequency

Figure 20 shows the return loss plot for lower band frequency. We observe that if the source pin is shifted towards the patch 2 means with the source pin situated between the two patches, the return loss increases. This is very useful because large Return loss magnitude means the value of impedance mismatch is very low and the transmission of incident power is high. . We also make another observation that is bandwidth has very little variation with respect to position of the short pin position.

For 1800 & 1900 MHz we observe that the return loss increases2. when the source pin shift away from patch 2. This causes the bandwidth of the resonance frequency to increase. however, the return loss magnitude starts to decrease, which reduces the impedance matching of the antenna. In this case, we also observe that shifting of the source pin does not significantly affect the resonance frequency of antenna.

Our conclusion is that we should always place the source pin in front of patch.

4.2.1.2. Width based effect

The source pin width is also an important parameter necessary for tuning the resonant frequency of antenna. In Figures 22 & 23 we show the plots for both higher & lower band frequency which demonstrates the variation of s parameter with respect to width of the source pin.

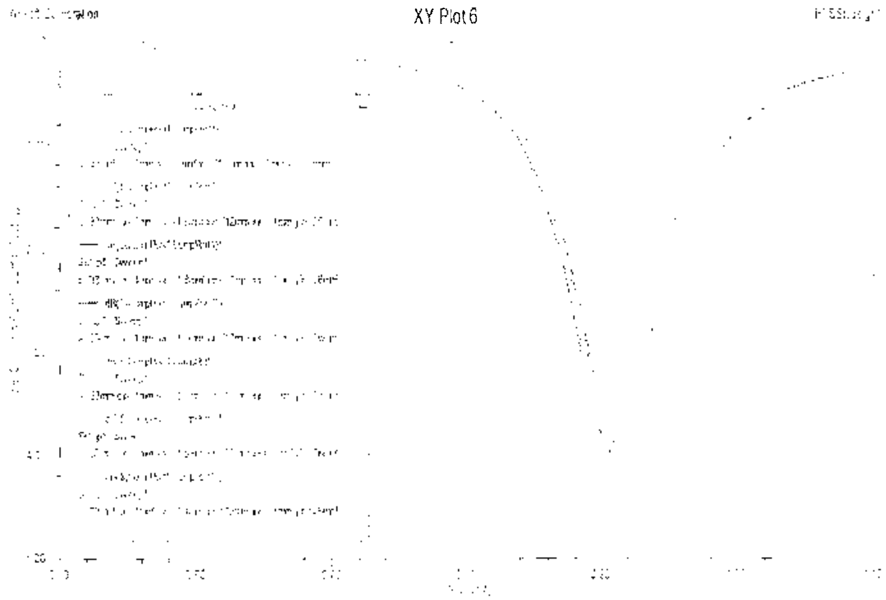

Figure 22: Width based effect for lower band frequency.

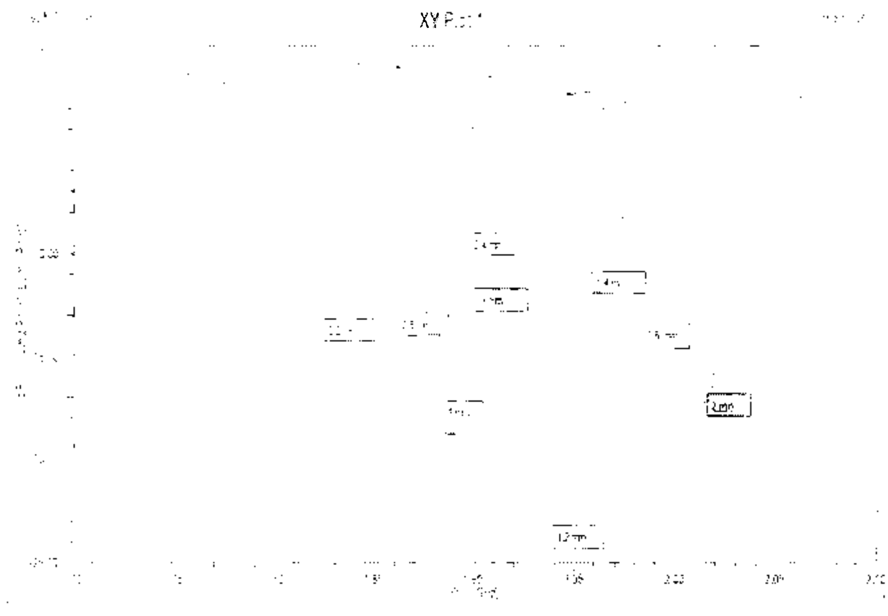

Figure 23: Width based effect for higher band frequency

We see that the source pin width does not significantly affect the lower band. We observe that varying the width of the source pin maintains the resonance frequency, bandwidth and return loss. i.e. very little is changed. However, we observe the change of bandwidth, resonance frequency and the return loss at higher band frequency range. By increasing the source pin width the resonant frequency increases which we observe in Figure 22.

Therefore, we need to place the source pin in such a position where we find our interested band. The effect of both position and width of the source is not significant at lower band but significant of higher band. And we generally place the source pin in front of such patch which is design for higher band to get the high return loss and also if we want to increase the resonance frequency at higher band we should increase the width of the source pin.

4.2.2. Short pin effect

Short pin is a uniqe charateristic of PIFA. In a typical microstrip anteena short pin are not used. Short pin connect ground to the patch, effectively short-circuiting the two. It is very important parameter of PIFA. The S11 plot of our designed PIFA without any short pin is shown in Figure 24.

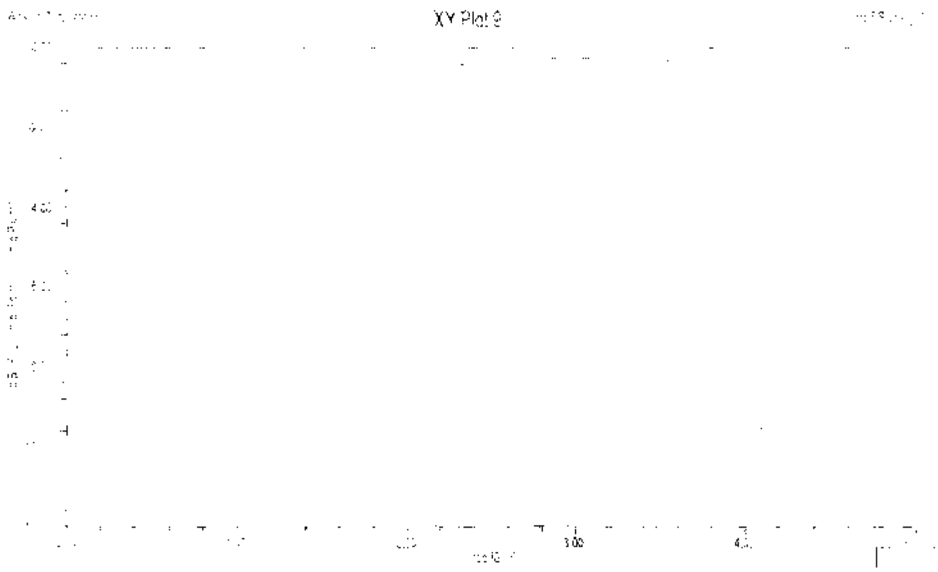

Figure 24: S-parameter without short pin effect.

Here we observe that we don't get any resonance frequency in 900 and 1800 MHz, which existed when we had the short pin in our antenna. We however see a resonance at 1900 MHz.. Short pin adds capacitive load in the anteena but the capatitive load is removed without the pin and this shifts the resonace frequency shifted. So the removal of the short pin causes the our 900 MHz resonance frequency shifed to 2000 MHzWe also know that if we reduce the capacitance, the quality factor increse and the bandwidth decreses that is

$$Q = \frac{[illegible]}{B.W} = {}^{1}/_{Bandwidth}$$

We see in Figure 24 that as we remove the short pin the bandwidth decrease which is prove in above equation.

Now we analyze the effect of varying the short pin position & width. We also observe the effect of multiple short pin.

4.2.2.1. Source pin position effect

In PIFA we know that if we vary the position, the resonance frequency shiftsvary. Here we try to find a relation between the resonance frequenency and the variation of short pin position. Two patches exists in our design PIFA. So we add a short pin in common position of two PIFA.Here we first change the position in y direction in our proposed PIFA design. We also change the short pin position and observe the effect on the resonances at 900 , 1800 and 1900MHz. The result of this analysis is shown in Figures 25 & 26.

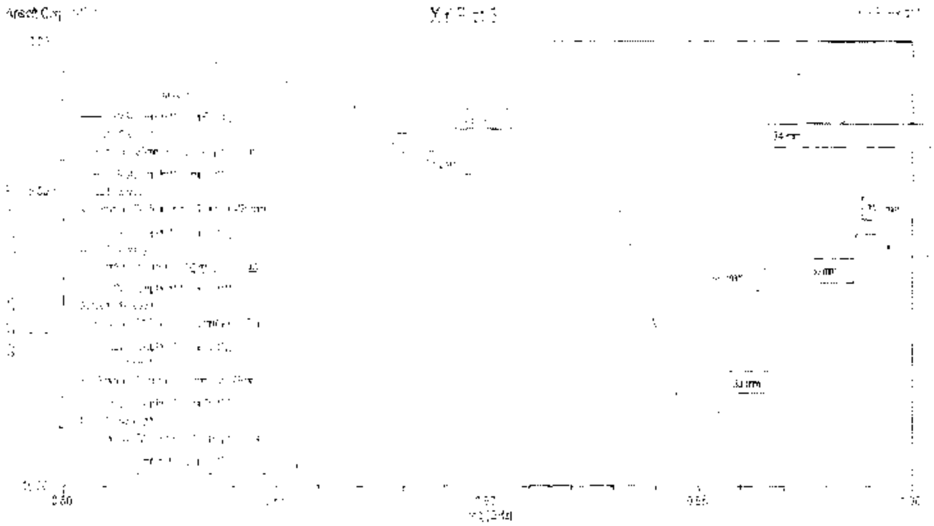

Figure 25: Position based short pin effect for lower band frequency.

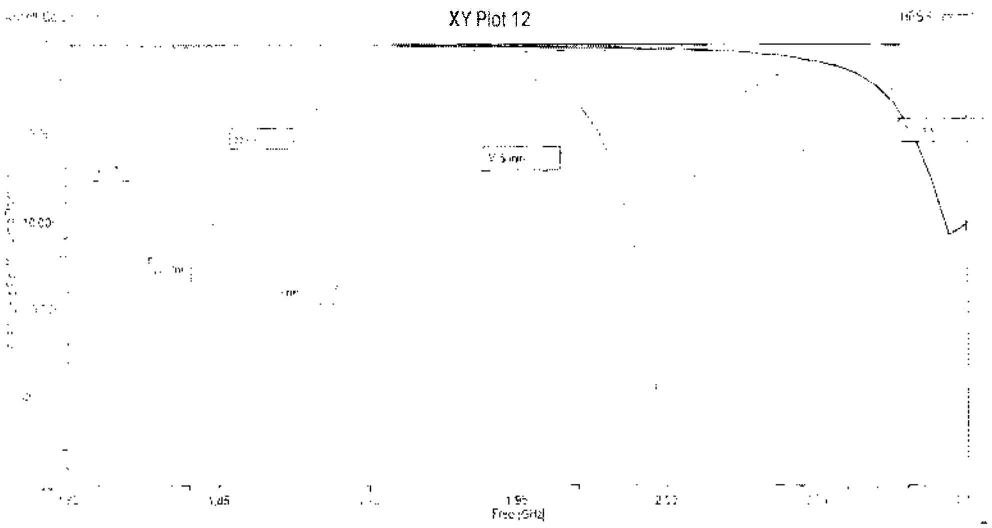

Figure 26: Position based short pin effect for higher band frequency.

Figure 25 shows the S11 around 900 MHz. We observe that the resonant frequency reduces when the short pin is moved closer to patch 2 and higher when shifted towards patch 1. But the variation of resonance frequency for 900 MHz is very little when the position of the short pin is between 35.5mm to 31mm. We first design a PIFA for 900 MHz which is patch 1 and then add another patch which is designed for 1800 MHz which is patch 2. For the short pin position between 35.5 mm to 31mm, there is patch 2 which is designed for 1800 MHz. This might be responsible for low variation of resonance frequency. We also observe that the variation of short pin does not have any effect on, as shown in Figure 25. If we calculate each patch inductance, capacitance and consider the coupling effect, then we may find some correlation between bandwidth and the short pin position.

For 1800 & 1900 MHz, we observe that the gap between two resonance frequency decreases when the short pin is moved towards the patch 2. We very much interest to decrease the gap between two resonance frequencies because in GSM they need very high band width for both 1800 & 1900 MHz and 1800 MHz uplink and 1900 MHz downlink frequency.. We stated before that we design patch 2 for 1800 MHz and in front of that patch there exists a small patch which has high resonance frequency, we know the value for resonance frequency is inversely proportional to patch effective length. So the above two reasons are responsible for the merging of two band.

4.2.2.2. Short pin width effect

Short Pin width is very vital parameter for tuning the resonance frequency. By varying the short pin width we can find the optimum solution of GSM band. In below in Figure 27 & 28 we state the plot for 900, 1800 & 1900 MHz by varying the short pin width in the range of 0.5mm to 1.5 mm of our design PIFA.

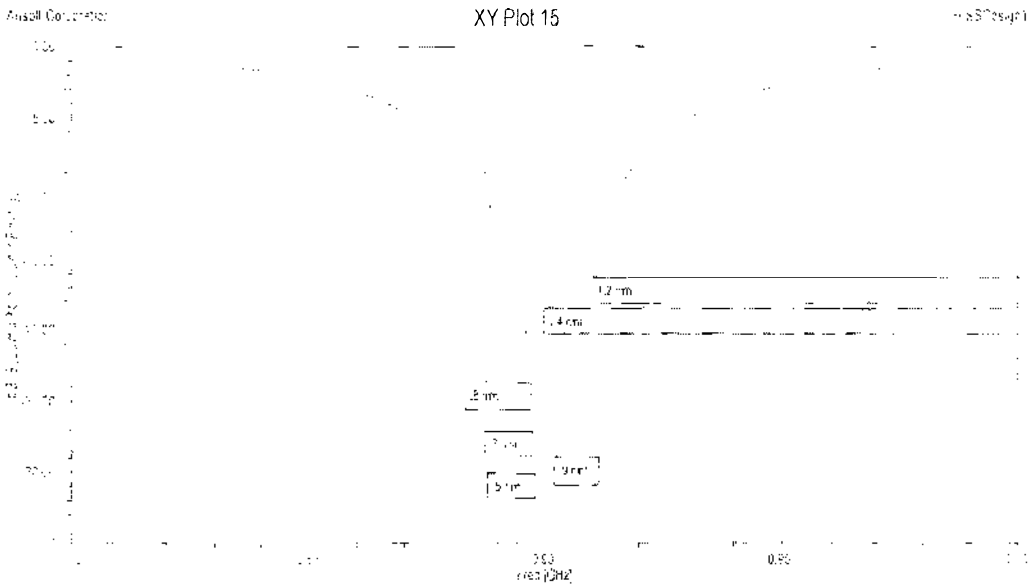

Figure 27: Snort pin width effect in lower frequency band

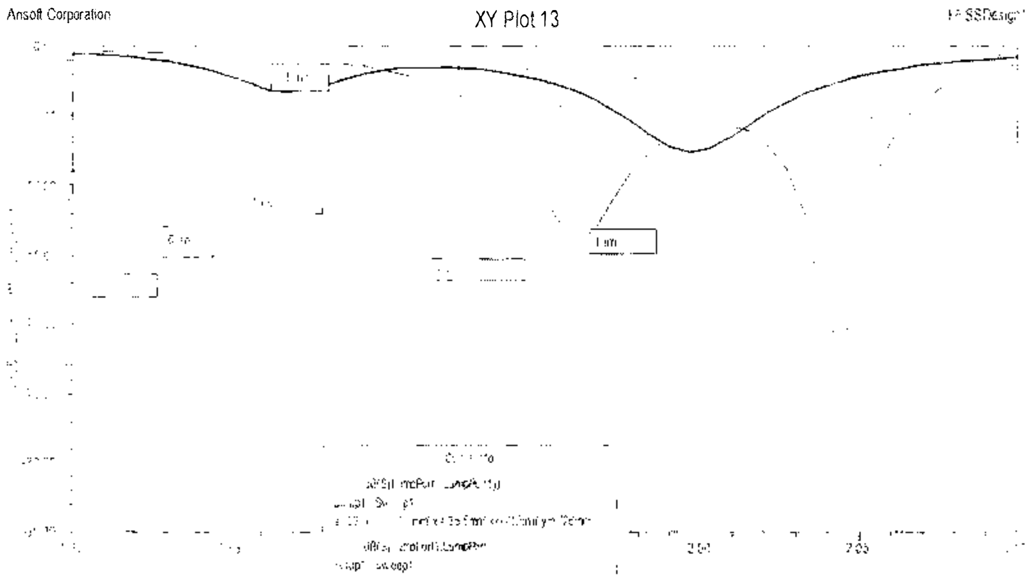

Figure 28: Short pin width effect in higher frequency band

In above plot we observe that the increasing the width of the short pin we can increase the resonant frequency of lower band. But we observe the above figure that the change of resonance frequency is very small for lower band frequency. So ultimately the main observing point is that the short pin width is not affected in lower band. But above statement is not true for higher band. Figure 28 shows that for higher bands, the variation of short pin width has significant effects. We observe that at small width short pin the gap between two high band resonance frequencies is high. The gap is reduced proportionately as we increase the width of the short pin until 1mm and then increase the gap between two higher bands. Here we also observe that the return loss and the bandwidth varies with width but that occurrence does not have a stable pattern. .

4.2.2.3. Multiple short pin effect

We state before that adding the short pin means adding capacitive load. If we add multiple short pin the resonance frequency shift more compared to when we had one capacitive load. If we add shorter pin the resonance frequency shifts more [13]. In below Figure 29 & 30 we state two plots where we add two & three short pin.

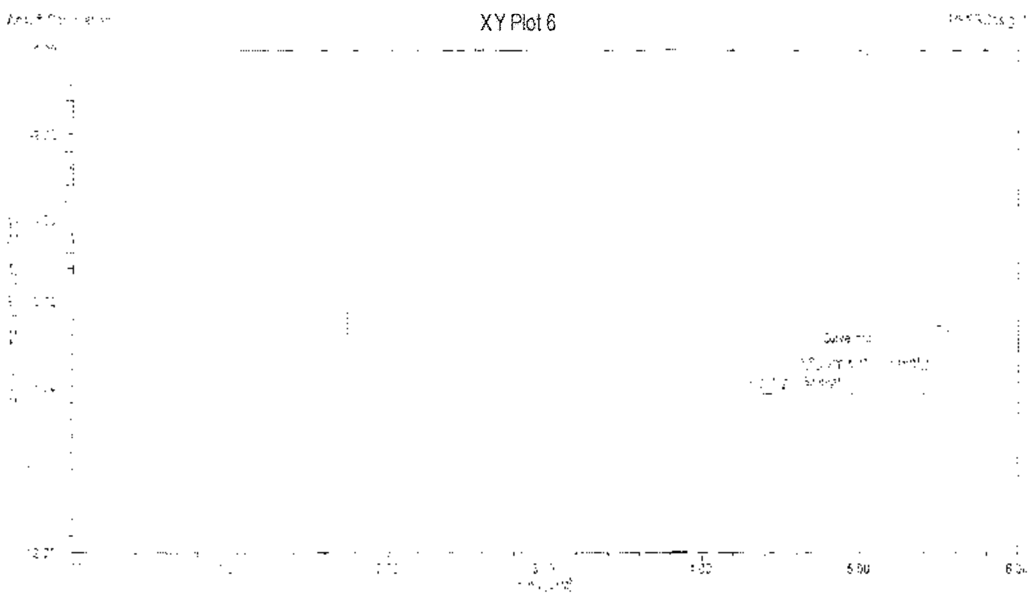

Figure 29: Effect after using 2 short pin .

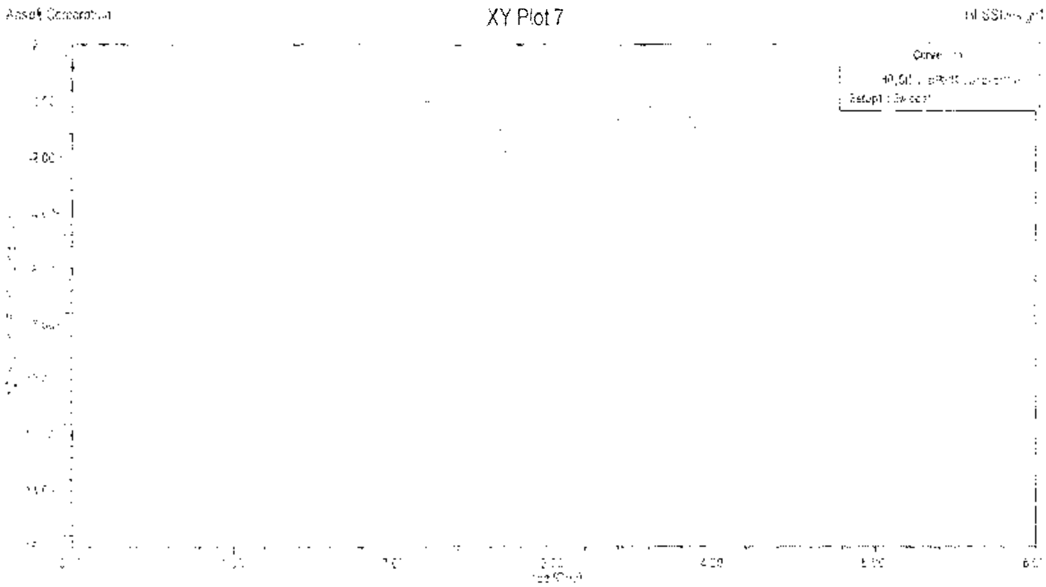

Figure 30: Effect after using 3 short pin

Here if we compare that the plot of our original PIFA design with results showed in Figures 29& 30.We observes that the resonance frequency has shifted. In lower frequency band we find resonance frequency band at 900 MHz and after adding one extra short pin the resonant frequency changes to 1.5 GHz. An extra short pin shifts the resonant frequency further to 1.6 GHz. After adding the 2nd short pin the frequency shifted significantly but after add 3rd short pin frequency shifted is smaller.

4.2.3. Ground plane effect

Ground plane play a significant role in antenna operation. It is use as a perfect energy reflector in PIFA. The ground plane is generally one quarter wavelength of the operating wavelength which is $\frac{\lambda}{4}$ [14]. In our design, the operating wavelength should be around 84mm. We have used a 55mm long ground plane which is the length of the base in our application. In figures 31 & 32 we change the ground plane length and observe its effect of antenna characteristic.

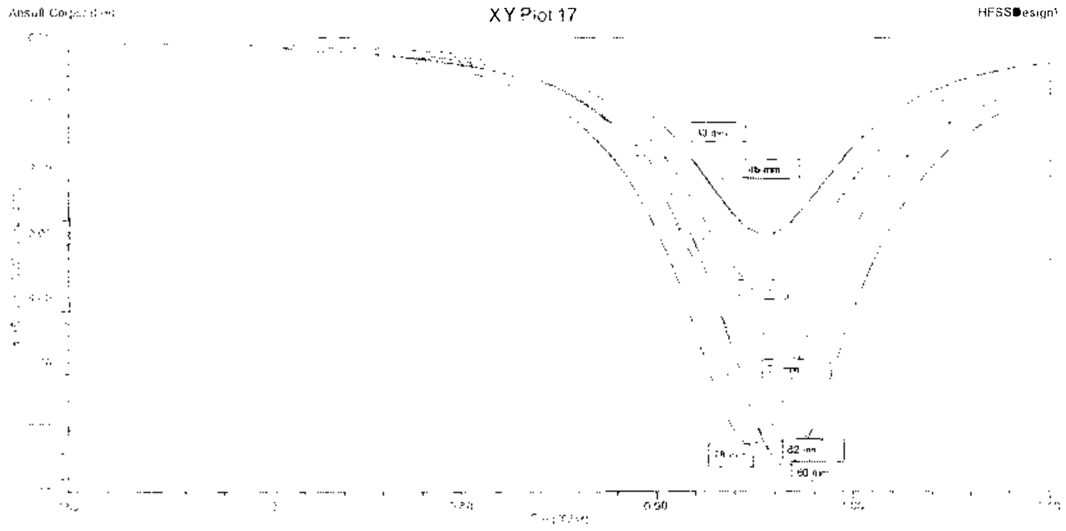

Figure 31: Ground plane effect of PIFA for lower band

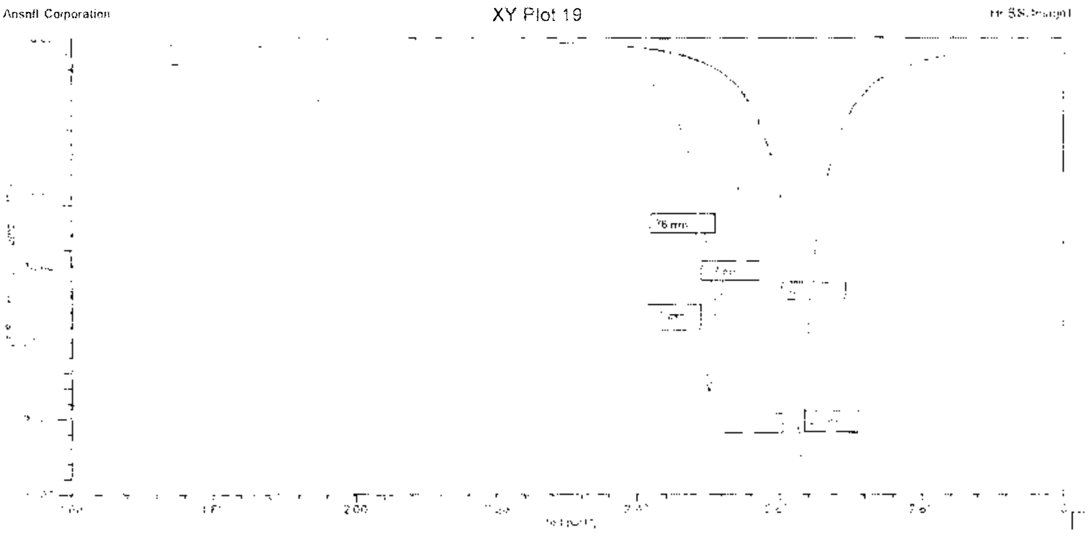

Figure 32: Ground plane effect of PIFA for Higher band

In the figure for lower band we observe that the bandwidth increases with the increase in the size of the ground plane. We also observe an increase in the resonance frequency though the change is not significant. Here we also see that the return loss increases with increase of the ground plane length, so that is also very important information, because high return loss means high incident power transmission. But in higher band frequency the bandwidth doesn't increase with the increase of length of ground plane. Here increase the resonance frequency with increase the ground plane. Thus a trade off must be made. If we increase the bandwidth of signal the resonance frequency shift. For this reason it is rather difficult to attain the target frequency bands.

4.2.4. Dielectric material effect

Dielectric material is a very essential element for the antenna. In one light it is used to support the patch mechanically and from another perspective, the variation of the materials, its width and other physical parameters, we can tune the resonance frequency. Next we discuss the dielectric materials and size effect of antenna.

4.2.4.1. Size based effect

In our PIFA design we use a 10×55 mm dielectric substrate which is used as the base of our application. In Figures -33 & 34 we shown S parameter plot to observe the effect of dielectric material on resonant frequency for both higher and lower band frequency.

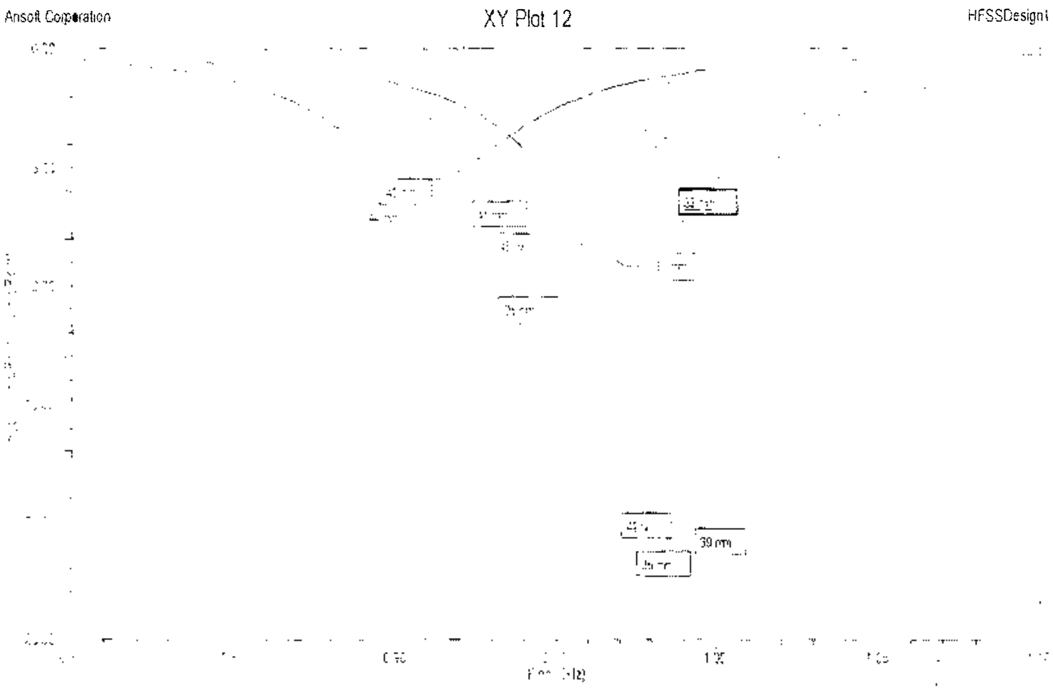

Figure 33: Dielectric size effect of PIFA for lower band

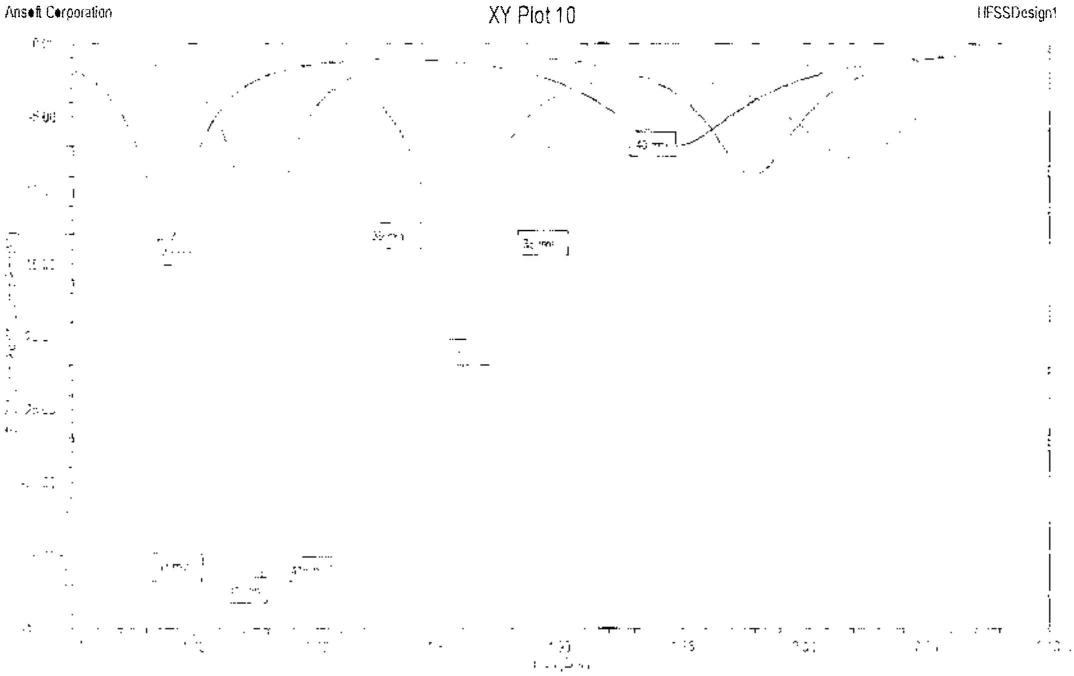

Figure 34: Dielectric size effect of PIFA for higher band

In Figure 34, for higher band frequency, return loss plot shows that the resonant frequency decreases with the increase in the size of dielectric. We also observe changes in the bandwidth but not in a predictable way.

In lower band (Figure -33) the resonant frequency also decreases with the increase of the length of dielectric materials. However, in some cases (dielectric material of length 35 and 36 mm), we did see an anomaly.

4.2.4.2. Effect of using different materials

We know if the dielectric has high dielectric constant value its store energy more than radiate it and we also know that the quality factor proportional to energy stored that is [15]

$$Q = \frac{\text{Energy stored}}{\text{power lost}}$$

But the quality factor is inversely proportional to the bandwidth, so ultimately if we increase the dielectric constant of materials the bandwidth will decrease, which is not desirable. As shown in Figures 35& 36 we observe the plot of return loss for different dielectric materials.

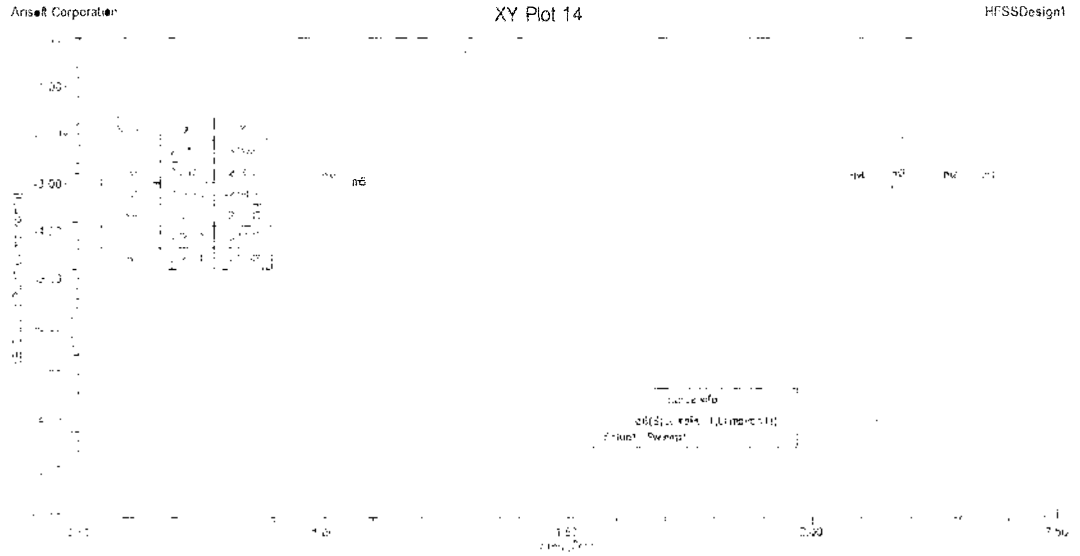

Figure 35: S parameter plot for Dielectric constant - 2.2

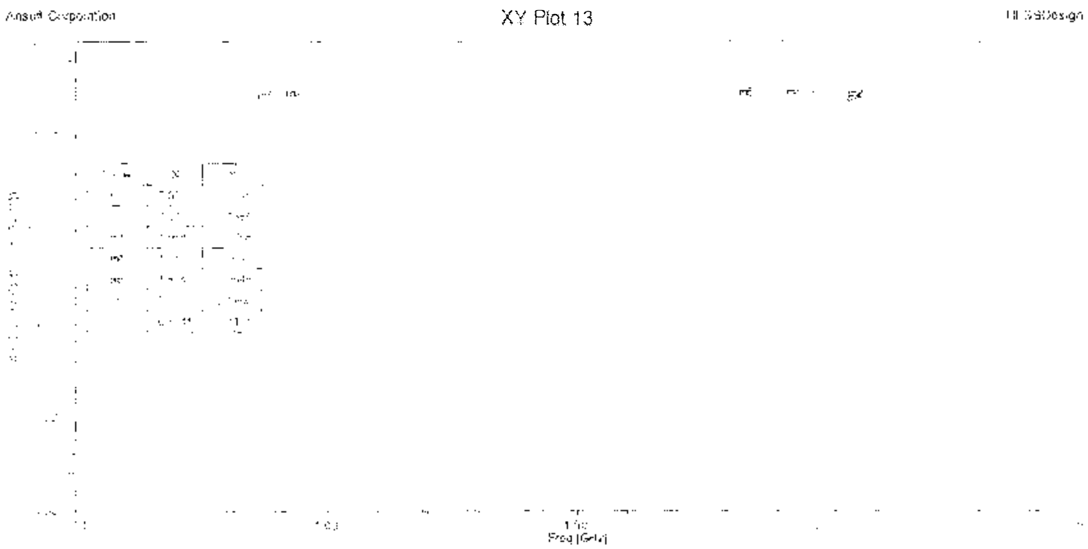

Figure 36: S parameter plot for dielectric constant 3.2

In Figure 35 & 36 we observe that the resonance frequency decreases with the increase of the dielectric constant of materials. We have however seen that increasing the dielectric constant will decrease the bandwidth. Here we observe similar characteristic but that change is very small.

4.2.5. Coupling effect

Coupling is a critical physical phenomenon for the PIFA antenna. By coupling we can increase the bandwidth of the antenna. Coupling effect can be introduced by adding capacitive or inductive load to the patch or ground plane. We increase coupling by placing the capacitive or inductive load very close to patch or ground. We can also place the two patches very close to each other. Here in our design we add an inductive load between two patches to introduce the coupling effect. It is very important because by adding coupling effect, varies its position and vary its width and length we can vary the bandwidth and tuning the resonance frequency. In our design before adding the inductive load, we observe in our return loss plot that bandwidth resonant frequency is low. After adding the inductive load we find improved bandwidth which can be seen in Figure 17 & 19.

4.3. Current field distribution on PIFA

PIFA surface current distribution varies for different width of short circuit plate and also position. The current distribution is also different for different frequencies. In our design PIFA the 3D plot of current distribution for different frequency is shown in Figures 37 & 38.

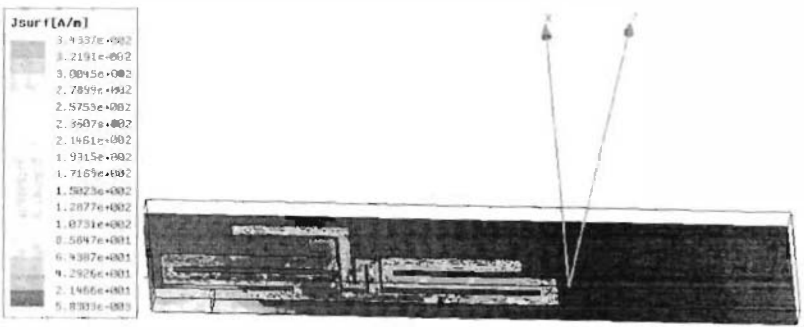

Figure 37: Current distribution for 0.9GHz

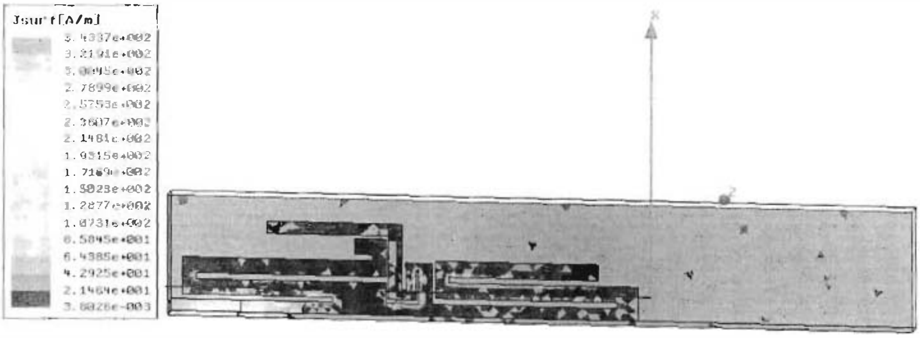

Figure 38: Current distribution for 1.8GHz

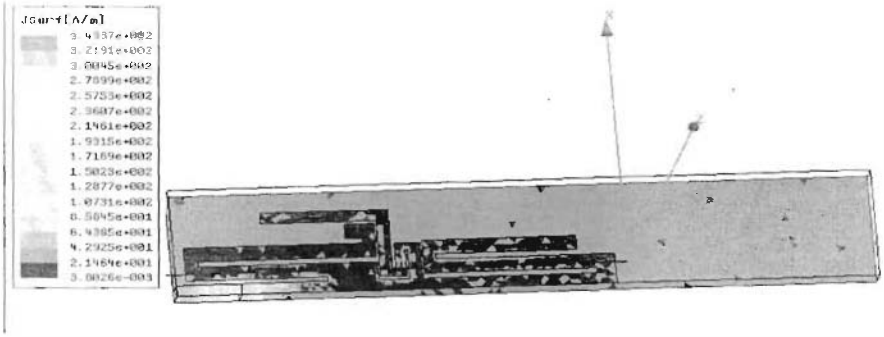

Figure 39: Current distribution for 1.9GHz

Here we observe that the source pin effect on the current distribution is high. At 0.9 GHz the current distribution is significant at patch 1 which was a targeted patch design for 0.9 GHz. The coupling effect is significant for the lower leg at 0.9 GHz. At 1.9 and 1.8 GHz the current distributions significant near the source pin, their also exists the coupling effect but not as significant as at 0.9 GHz.

4.4. 3D Radiation pattern

Three dimensional radiation patterns show how much power is radiated in a particular direction or in what direction the power is highest. This radiation pattern is measured in the far field region. Basically we can see from this plot that how much power is radiated in different direction measuring its directivity. Here we show the three different radiation pattern for 900, 1800 and 1900 MHz

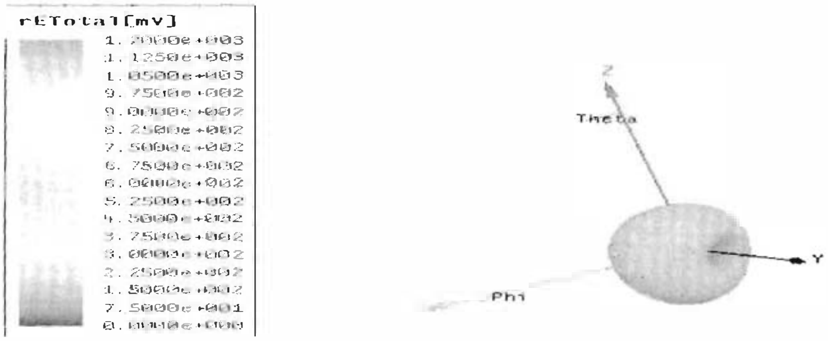

Figure 40: Radiation Pattern at 900 MHz

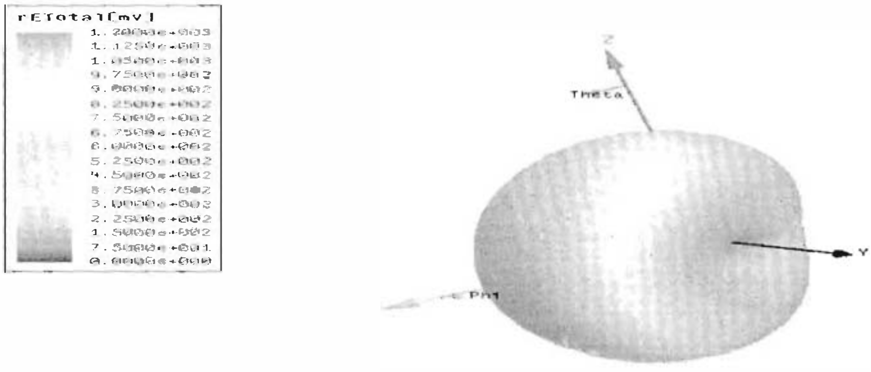

Figure 41: Radiation Pattern at 1.8GHz

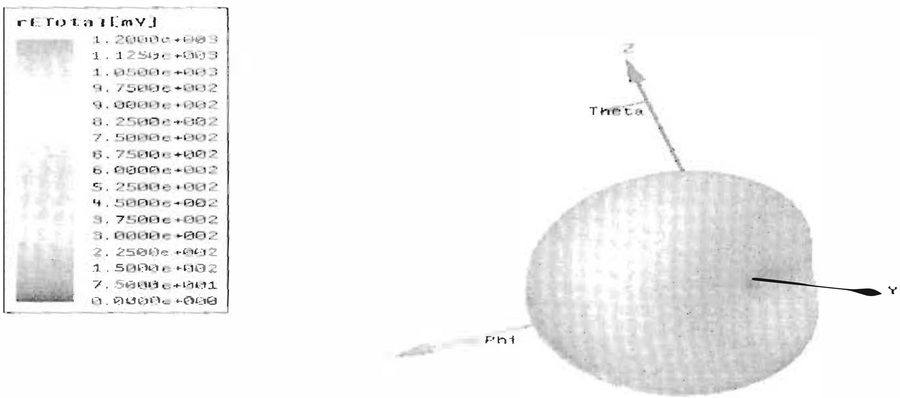

Figure 42: Radiation Pattern at 1.9 GHz

From Figures 41 and 42 we see that the power radiation is high in direction normal to the antenna plane. From the figures we also see that the radiation directivity is changed with frequency. The directivity of the radiation pattern for 0.9GHz is less comparatively 1.8 and 1.9 GHz which is shown in Figures 40, 41 & 42. From these figures we can also calculate the directivity.

5. APPLICATION:

In this part of the project we use our proposed antenna to design a cell phone in an eye frame. . We introduce the product using a small form factor PIFA in the handle of the eye frame which we have not yet seen in the market. We want to design the whole mobile system in a single eye frame. There are many issues that must be considered when we design such an interesting product. The issues we have to address are: how do we place the mobile IC chips in a small area, how do we reduce the battery size and place it in the small area, what should be eye frame size and eye frame materials. Here setting up of a display is impossible, hence what is the alternative to the display. In the next section we try to answer these questions and provide an architecture view of the circuit and give a design proposal for the eye frame mobile phone.

5.1. Design a mobile system in eye frame

Here we discuss the basic block diagram of mobile system. A mobile phone generally consists of a

- A Network Unit that provides connection to various networks, e.g. Bluetooth and WLAN, broadcasting functionalities and location-based services (GPS).
- A RF unit that consists of antenna, RF switch and transceiver system
- A power control unit which consists of a battery and battery controller,
- Application unit which consists of microphone. speaker, keyboard ,display, camera, USB device and so on
- An external memory unit

Our proposed eye frame mobile will consist of only call receive and dial related features. No display is proposed here for this small form factor structure so the question arises on how an individual dials a call. So we introduce here a voice sensor part. This part consists of a voice sensor and activation switch for the voice sensor. When anyone wants to call he/she will first activate the voice sensor device by pushing the ON/OFF at switch and then say out the number, which will be recognized by the voice recognition software in the cell phone. Then push another switch which will be used to call the dialed number. In here we also propose to provide some external port for use external keyboard, external battery and display. We propose to use here SOC (system on chip) technology ause without this it is impossible to place all the ICs in a small form factor. Here we do not pose to use any external memory network. Such application which uses high power will not be d in this application to help reduce the battery size. The Architecture view of our propose eye ne mobile is given Figure 43.

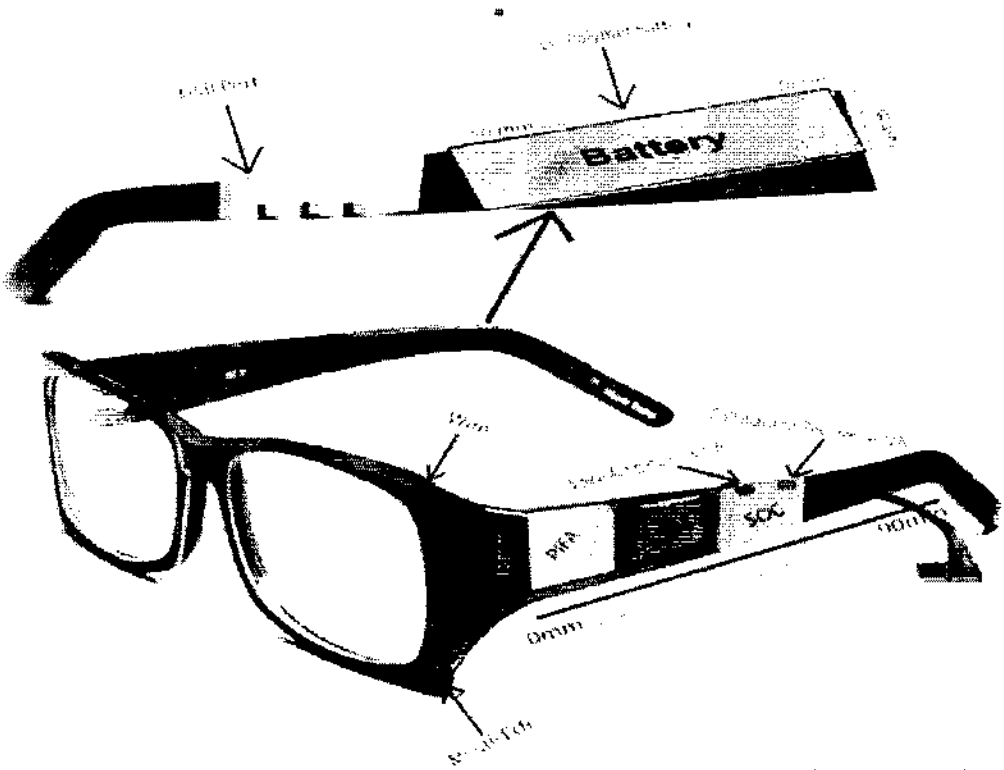

Figure 43: Architecture view of our propose Eye Frame mobile

t section we give a brief description about SOC, battery, frame size, material standard and to construct the propose design.

5.2. Frame size and material

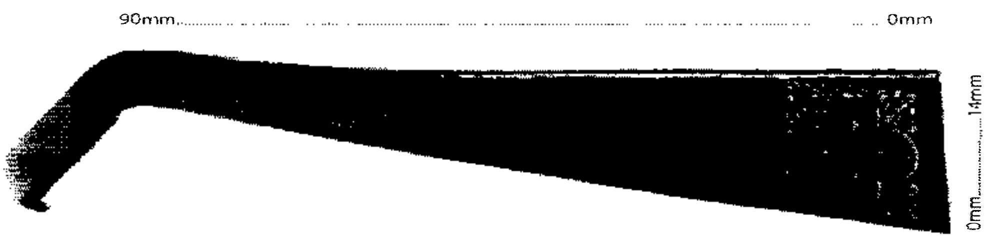

Figure 44: Width and length of Frame Leg

length of frame hands should be about at least 90 mm or 9cm. In our proposal the height of the ne hands in the first half near the glass should be at least14mm, as shown in Figure 44.. In our

\ antenna we use a plastic material with dielectric constant 3. Most of the eyeglass frame rials are poly carbon which dielectric constant is 2.9 to 3.0.

5.3. Base band

band is the Heart of any Mobile Phone. In normal mobile cell phones, base band of the phone Power energy management system, Audio management system, Memory, RF processor and lication Processor. We need ICs to control the activities of all the different parts and manage coexistence. Now a day the cellular mobile uses the technology which called system on board re separate processors exist for separate Unit. Because of this requirement our mobile can ome very large which is not possible in our design as the available real estate in the eye frame is ll. Here we use system on chip technology where all the IC for different units are embedded in a le IC. So this save area and that is suitable for our proposed mobile system. In Figure 45, we see xample of System on board and comparison with system on Chip technology. Here we see that em on chip requires very little area as compared to System on board.

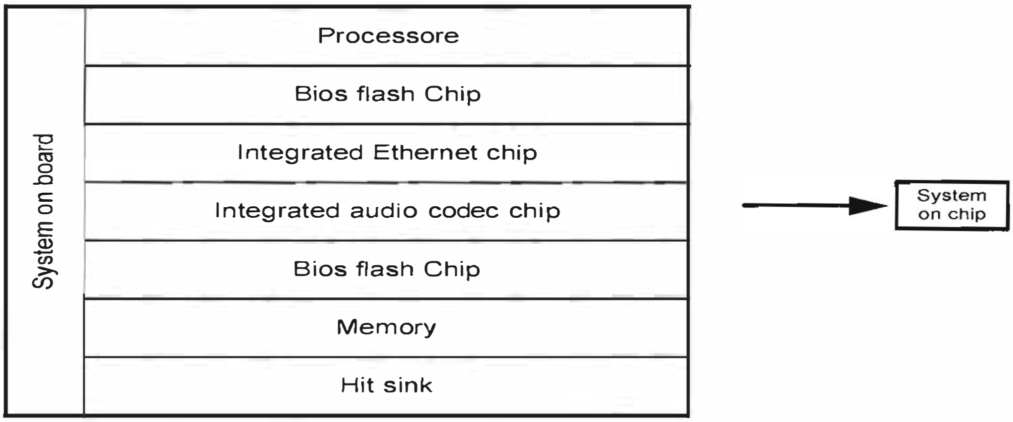

Figure 45: Difference between system on board and system on Chip

(System on Chip) technology is a very novel technology which is yet to be mature. A typical em on chip is not only a chip but it is very much like a system. The SOC has hardware and ware element [16]s, hence, SOC = Chip + Software + Integration

SOC chip includes:

- Embedded processor
- ASIC Logics and analog circuitry
- Embedded memory

.e SOC Software includes:

- OS, compiler, simulator, firmware, driver, protocol stack Integrated development
- Environment (debugger, linker, ICE) Application interface (C/C++, assembly)
- The SOC Integration includes:
- The whole system solution
- Manufacture consultant
- Technical Supporting

o the advantages offered by SOC technology include:

1) Higher performance, since all the circuits will be on a single chip;

2) Smaller space requirements;

3) lower memory requirements;

4) Higher system reliability; and

5) Lower consumer costs.

In our proposed design we have not provided any application units like camera or video player. We also have not provided any LCD display. Here in application processor we don't need any graphic/video accelerator and also in memory area we need very Low memory because we don't provide any option which need high memory like camera , audio & video player and LCD display. Here we just propose an ASIC with SOC technology. ASIC means Application Specific Integrated Circuit which is an IC for customize application. Here we don't need the all parts which are available in normal mobile system.

An IC is a very sensitive device which must be packaged for protection. A typical die is typically very small. Its packaging is 4 or 5 times the chip. Hence packaging needs a large area. In our propose application the available area is small so optimizing on the package size is critical. Here we propose to use CSP (Chip scale package) technology which requires a very small package. The package area is around 1.2 times that of the chip. Another criterion to qualify these packages as CSPs is that their ball pitch should be no more than 1 mm.

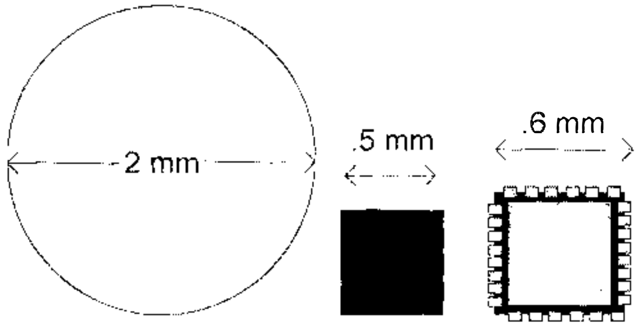

Figure 46: Typical Chip size before & after package compared with a coin

re 46 shows the comparison between the chip after package and before package of a CSP iguration IC.

5.4. SIM

I means subscriber identity module, which we can simply say is a communication identity lule for a user. A SIM card contains a unique serial number, internationally unique number of the bile user (IMSI), security authentication and ciphering information, temporary information ted to the local network, a list of the services the user has access to and two passwords (PIN for al use and PUK for unlocking) [17]. There exist a small memory chip which contains all the vant information which we share above. The structure picture of SIM chip is shown figure - 47.

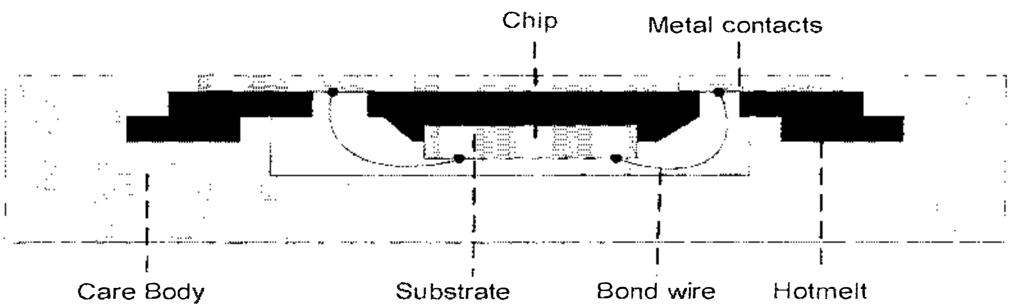

Figure 47: Internal diagram of SIM

Table 2: SIM card standards

SIM card	Standard reference	Length (mm)	Width (mm)	Thickness (mm)
ull size	ISO/IEC 7810:2003, ID-1	85.60	53.98	.76
Aini size	ISO/IEC 7810:2003, ID-000	25	15	.76
Aicro	ETSI TS 102 221 V9.0.0, Mini-UICC	15	12	.76

re is three standard of SIM card. These standards are shown in Table 3. Our propose design can use the micro SIM card which is very small form factor and suitable for our proposed eye mobile. In Table 2 there are some information on the standards of SIM cards. The table ırovides information on various SIM card dimensions.

5.5. Battery

5.5.1. Power consumption area

ry and its size is the one of the main concern of our proposed design. We have earlier ssed a typical multimedia handsets block diagram. A breakdown of the power consumption fferent components in a typical multimedia mobile phone is given in Table 3 [18].

Table 3: Power consumption in Cell Phones [18]

Subsystem application	Application energy distribution
A/V Transport	4.4 %
Video Encode	9.9 %
Audio	15.5 %
Modem processing	9.8 %
Multimedia	39.5%
Modem processing	8.3 %
Receive	5.0 %
Transport	8.2 %
Memory	19.4 %
LCD Control	3.7 %
LCD driver	13.9 %
Other Peripherals / units	2 %

ırding to Table 3 we see that the major power consumption is in the application units, which ist of Modem processing Multimedia, A/V transport, Video & Audio encode. The total ɛr consumption by the application units is 39.5 %. In our propose eye frame mobile system id not include any application part, hence most of the power dedicated for such areas will be ɪ. However, there exists audio part for calls receive and dial. So if we here take out the cation part, excepting the audio circuitry, we can save 24 % of the application power. We observe that the power consumption of LCD is 17.6 %. But in our proposed eye frame le there is no display, therefore we can save 17.6 % power consumption. Another high ɛr consume area is memory, which in a typical phone can consume up to 19.4 % of the ry power. In our propose design there is no external memory. Also, there is no display, nor player, nor video device, all of which require huge memory. But some internal memory such as cache), will be required, such as in the CPU and voice sensor cash & register memory That internal memory consumes very little power. Therefore, by removing any external memory requirements, we can save approximately 14% Energy. In our proposed design we use system on chip technology. The SOC saves significant amount of power including power saved due to absence of interconnect bus. If we sum all the power saved, we can reduce power requirement by approximately 58%, which means power need for our propose design will be 42% of normal mobile system. We know that the power consumption in standard CMOS circuit is dependent on speed, which is given by

$$P = a \times C_{eff} \times V^2 \times f$$

Therefore one way to reduce power is to reduce the operating frequency of the circuit. In our proposed design we don't need high speed for faster processing, as we do not have any advanced feature such as MP3 or video processing requirements.. So by lowering speed we can save power to consumption.

5.5.2. Battery type

There are various types of mobile rechargeable battery that are available in the market. In table-4 we mention several commonly used rechargeable battery with their important characteristics. From the data we can say the LI- ion polymer specifically the Li –ion Phosphate has the desired characteristic which best suits our proposed design. Ni based Ni-Cd battery was the first to be available in the market. It has several disadvantages for which we have not selected this battery. Some of the disadvantages are [19],

- Low power density
- Highly toxic material, very bad for environment.
- Relatively high self-discharge - needs frequent recharging.
- Relatively heavier
- High maintenance need
- High from factor

For above reasons, the demand for Ni based rechargeable battery is dropping day by day. Li-ion polymer battery is the fastest growing battery system; it offers high-energy density, low weight; low from factor it no need to maintenance and it has low toxicity. For these reasons Li-ion based battery is gaining popularity very quickly. The Li-ion battery is best suited for our proposed eye frame mobile, which meets our need low toxicity, high energy density and low weight. Another important ır is battery life time. To increase the life time of a battery we need to use a battery efficiently. efore, good and efficient energy management is needed.

Table 4: Characteristic of Commonly used Mobile rechargeable battery [19]

	Nickel cadmium	Nickel Metal hybrid	Li –ion cobalt	Li –ion manganese	Li –ion Phosphate
imetric energy ity (Wh/kg)	45-80	60-120	150-190	100-135	90-120
nal resistance)	100-200[1] 6V pack	200 – 300[1] 6V pack	150-300[1] Pack 100-130 per cell	25- 75[2] per cell	25-50[2] per cell
e life	1500[2]	300-500[3]	300-500[3]	Better than 300-500[4]	>1000
charge time	1h typical	2 – 4 h	1.5- 3h	1h or less	1h or less
voltage minal Average)	1.25[5]	1.25 7	3.6-3.7 V [5]	Nominal 3.6v Average 3.8V	3.3V
l current peak result	20C 1C	5C .5C or lower	< 3C 1C or lower	>30C 10C or lower	>30C 10C or low
rating Temperature charge only)	-40 -60 °C	-20- 60 °C			
ntenance require	30 to 60 days	60 to 90 days	Not required		
ty	Thermally stable, fuse recommended	Thermally stable, fuse recommended	Protection circuit mandatory	Protection circuit recommend	
nmercial used e	1950	1990	1991	1996	2006
icity	Highly toxic, Harmful to environment	Relatively low toxicity, should be recycle.	Low toxicity, can be disposed in small quantity		

ternal resistance of a battery pack varies with mAh rating, wiring and number of cells. Protection circuit of lithium-adds about 100mW.
ased on 18650 cell size. Cell size and design determines internal resistance. Larger cells can have an impedance of mOhms,
cle life is based on battery receiving regular maintenance. Failing to apply periodic full discharge cycles may ce the cycle life by a factor of three.
cle life is based on the depth of discharge. Shallow discharges provide more cycles than deep discharges.
e traditional nominal voltage is 1.25V; 1.2V is more commonly used to harmonize with lithium-ion (3 in series =). [19]

5.5.3. Battery size

ize of battery also is critical given our small form factor for our proposed application. The al Li-ion battery size is generally 40X 40 mm [20]. Therefore, this battery is impossible for use r propose eye frame mobile. However, there is also available Li- polymer battery which has a small form factor, which can be quite comfortably used in our proposed eye frame mobile. Here ssume need of 42% power of a normal cell phone battery. The power required for a normal ry is

3.7 * 650mAh = 2.405wh

he power need for our propose mobile is 42% of normal battery that is

2.405* 42% = 1.01wh

don't change the voltage, the current for our proposed design is

1.01wh/ 3.7V = 273 mAh

efore, for our proposed eye frame mobile, we basically need a battery which needs to support er of 1.01wh or 3.7 V and current of 273mAh.. According to EEMB Company (address), such a ry will look like the one in Figure 48.

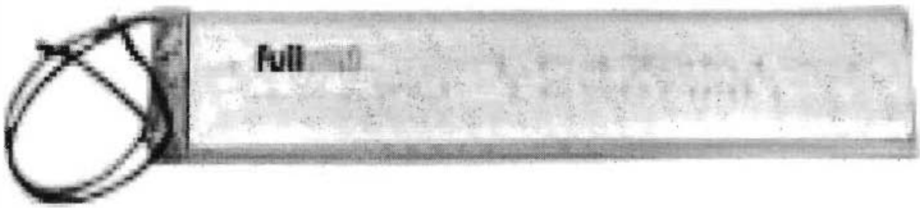

Figure 48: A typical Li - polymer Battery from www.XXXXXX

company is one of the largest battery manufacture company the battery in Figure 48 has the ID 01250 (www.XXXXDX0).

battery thickness is 7mm, while the width = 12mm, length =50mm and weight 7gm. Battery ent rating is 350 mAh and voltage is 3.7 V. So this is the battery which we can adjust easily in propose eye frame mobile

6. DISCUSSION AND CONCLUSION:

n this thesis we design a small form factor tri band PIFA for mobile applications. Our designed PIFA bandwidth supports T-GSM900, GSM 1900 and GSM 1800. However, it does not support the uplink frequency of GSM 1800. We particularly designed this PIFA to support our proposed application, which is an eye frame with mobile cellular phone application. In this mechanical design we have limited length and width within which the complete set of features of the phone must be accommodated. We know from our analysis that if we were to increase the length of ground planes the bandwidth of the antenna increases. Hence, we could have succeeded in supporting the uplink 1800 if we could have designed a very long ground plane. Also we have used high dielectric constant materials which we think also responsible for the bandwidth problem. Here in analysis part we did not analyze the effect of dielectric materials height, nor the short and source pin position, as it is virtually fixed for any particular application. The periodicity of the antenna resonant frequency with changes in its dimensions meant too large a variation in antenna parameter would result in an unpredictable shift in the antenna performance. We had to therefore study the effect of different parameters by using small incremental variations. We also wanted to implement our antenna design and test it in a lab, however, due to lack of materials and laboratory support we did not manufacture the proposed PIFA design.

7. FUTURE WORK

Our designed PIFA antenna was not able to support the tri band feature. The simulated result of the antenna showed that the antenna does not support the uplink frequency of GSM-1800. The next step for this thesis is to modify the antenna to support the uplink frequency of 1800. Based on our experience, we believe this can be achieved in a short time. New generation devices will always seek designs which will allow will be very easy to carry and also be stylish. Therefore, we propose this eye frame with mobile feature. We have not been able to locate similar designs in the industry, we believe this will be a very promising product. In our proposed design, all parts are available except the SOC chip, which has to be custom designed.

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