Introduction:

Rapid progresses are being made in wireless communications to make interactive voice, data and even video services available anytime and anyplace. Nowadays mobile phones are becoming ubiquitous. In order to support all these services, the mobile sets has to work in different frequency band thus paving the way for multi band antennas. Several antennas with different frequency of operation can be designed if we don't have space constraint but unfortunately we have it. Therefore the antenna designed should be as smaller as possible to be fitted in the handsets and should have acceptable performance. Antenna design for mobile handsets can be of two types-internal and external. One of the main disadvantage of external antenna is it is very close to the user's head and the radiation is directly incident on the head making the absorption rate high. Internal antenna can be installed on the side of the PCB i.e. opposite to the human head thus avoiding the human interference. The specification of the internal antenna depends strongly on the design of mobile phones and changes have to be made for each design. Moreover the internal antenna is difficult to design than its counterpart because the designer must consider characteristics such as feed point, ground position, radiator pattern, etc. At present, **P**lanar **I**nverted **F**-**A**ntennas (PIFA) have attracted much interest due to their small size and appreciable electrical characteristics compatible with existing specification, making it a promising candidate for internal antennas. Moreover they can be made to work in double and triple band with slight change in design, without any increase in the volume. **This project concentrates on studying different configurations of PIFA like dual band, triple band, the design parameters, and the factors affecting its operation and to design, simulate.**

Insight on mobile phones and communication system:

Mobile phones can be divided into handheld phones, vehicle-mounted phones and portable phones depending on their construction. In a handheld phone, the microphone, earphone and antenna are all in the same casing. Usually the handheld- phone antenna is located a few centimeters away from the user's head when the phone is used. Sometimes the antenna may even touch the earlobe. In the case of a portable phone the microphone and earphone are located in a separate part that is connected via a cord to the transmitter/receiver. The distance of the user from the transmitter/receiver can be more than 0.5 meters because of the cord. A vehicle-mounted phone is a portable phone that is fixed to the vehicle. It uses a separate antenna that is placed outside the vehicle. Different countries follow different mobile communication system. Countries like USA, Britain follow ***Global system for Mobile communication (GSM)*** and ***Personal communication network (PCN)*** operating at ***900MHz*** and ***1800MHz*** with a bandwidth of ***80MHz*** and ***170MHz*** respectively. A table showing the different frequency bands of operation and minimum bandwidth required is given below.

System	Operating Frequency Bands MHz	Min. BW for Antenna Abs. MHz	Rel. %
GSM 900 MHz Analog	890–915 935–960	70	~8
CT1 (CEPT)	@1MHz 914 @1MHz 959	45	~5
CT2 (UK)	864–868	4	<1
BCT (Sweden)	862–866	4	<1
DECT	@20MHz 1.9 GHz (BW possibly up to 200 MHz)	20 (200)	<2 (~11)

The project is mainly concerned in designing for 900/1800MHZ band. Antennas used can be of external or internal. Two types are discussed in detail.

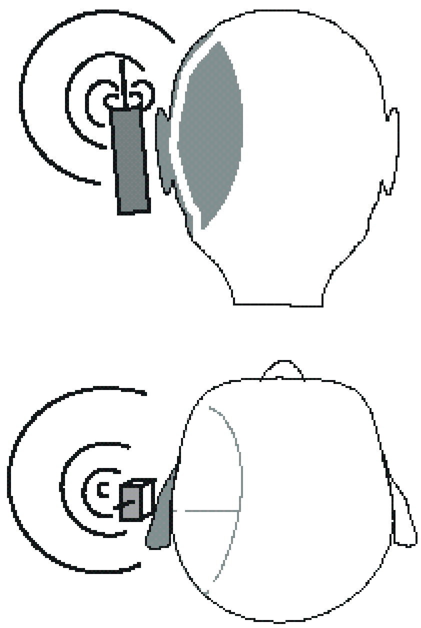
External antenna:

The most common handheld phone antenna is a whip, whose length is typically λ/8 orλ/2 (where is the wavelength). A whip antenna is cheap and easy to manufacture. It has a wide bandwidth and a suitable radiation pattern for mobile- phone use. The current distribution of the antenna changes so that the current maximum moves from the base of the antenna towards the center point of the antenna when the antenna is made longer. The current maximum of a λ/4 antenna is located closest to the user's head. Relatively strong electrical currents may also be induced on the casing of the phone because the casing acts as a ground plane for the antenna. In the case of 3λ/8 and λ/2 antennas the currents are weaker, and the current maximum of the antenna is located farther away from the user's head. In addition to whip antennas helical antennas are also used in handheld phones. A helical antenna consists of a wire that is wound in the shape of a helix. The advantage of the helical design is its small size. The height of a whip antenna for 900 MHz is 100 mm whereas the height of a λ/4 helical antenna is only 26 mm. A dual antenna design including both a whip and a helical antenna is used in more recent phone models. The whip is used only when the antenna is fully extended. Otherwise, the helical antenna, which is located at the base of the whip, is used. However, the whip and helical antennas will break easily if the phone is mishandled by dropping it, for example. Therefore, also integrated planar antennas such as planar inverted F antenna (PIFA), dual L antenna and microstrip antenna have been developed. These antennas are suitable to be used in the 1,800 MHz range, especially, since the high frequency allows them to be made small enough and they can be attached to the phone casing without protruding parts. At the turn of the century, satellite-based networks will accompany ground-based networks. Phones that will be used in the mobile satellite communications may use same or slightly higher output power than the phones of the current ground-based mobile systems. Below is the different type of antennas in practice.

Examples of whip antennas for 900 MHz. a) λ/4 antenna, height
point, height 210 mm, d) Top fed λ/2 antenna, height 200 mm
100 mm, b) 3λ/8 antenna, height 150 mm, c) λ/2 antenna with an elevated feed

Human absorption of radiation:

Radio-frequency electrical currents in the antenna and in the casing of a handheld mobile phone will induce RF electric fields in tissue. As a result of this a part of the radiated energy will be absorbed into tissue causing an increase in the tissue temperature. The absorption is caused by the power loss involved with dielectric polarization. Vibrations of water molecules, movements of free ions and movements of bound charges attached to macro-molecules contribute most to the dielectric polarization in biological material in radio frequencies.



Power loss is defined by SAR (Specific Absorption Rate) which determines the power absorbed per unit mass. Local SAR is given by

$SAR = \sigma E^2/\rho$

Where σ is the electric conductivity and ρ is mass density. The (root mean square) rms value of the electric field strength in the x, y, z point, *E* is defined by

$$E=(Ex^2+Ey^2+Ez^2)^{1/2}$$

where the *Ex*, *Ey* and *Ez* are the rms values of the x, y, and z components of the electric field. In practice SAR is always determined as an average value in the finite tissue volume. The whole body average, SARwba simply gives the power absorbed into the whole human body divided by the mass of the body. In order to avoid the exposure of human to radiation, internal antenna can be used. They are placed on the backside of the phone thus avoiding human interference. This project concentrates on designing internal antennas using PIFA and test it in the specified frequency band.

Internal antenna:

Figure 1 is a sketch of a mobile phone with an internal antenna. The user holds the lower part of the mobile phone. The internal antenna is installed in the upper part of the phone on the backside thus avoiding human interference.

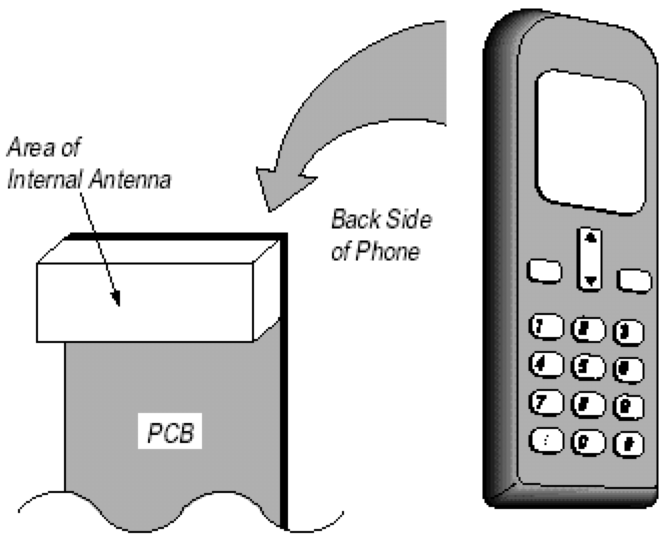


Fig. 1—External view of mobile phone with internal antenna The internal antenna is installed on the top of the back side of mobile phone.

PCB (Printed circuit board) act as a ground plane for the antenna and is fed through a coax from the mobile handsets As seen, the area occupied by the internal antenna is very small and should be capable of performing well in the desired frequency. An internal antenna should have the following features:

- Adequate bandwidth covering the frequency range used by the system, including a safety margin for production tolerances.
- Minimum occupied volume with regard to portability and overall size minimization of the mobile terminal
- Isotropic radiation characteristic
- Polarization independence
- Negligible human body effect.
- Simple and robust mechanical connection.
- Simple and low loss impedance matching to receive/transmit trains

- High radiation efficiency.

PIFA, satisfying most of the above requirements for an internal antenna, makes it a promising candidate.

Why PIFA?

- Simple concept
- Low losses
- Occupies less volume
- Good electrical characteristics.
- Easy to match (position of the feed)
- Easy to tune (adjusting the length of the arm)

BASIC PIFA GEOMETRY:

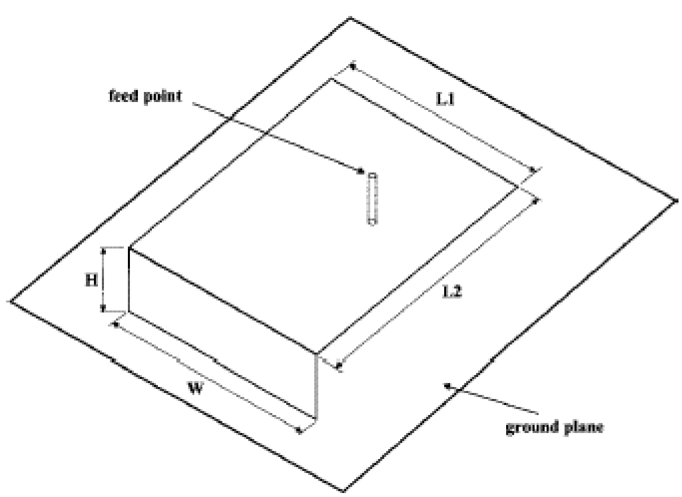
A planar inverted F-antenna is generally a λ/4 resonant structure achieved by short-circuiting its radiating patch to the antenna's ground plane using a shorting wall, shorting plate of shorting post. Their structure is similar to a ***shorted rectangular microstrip patch antenna*** with air as dielectric. They can resonate at a much smaller patch size for fixed operating frequency compared to the conventional patch antenna. The resonant frequency can be calculated by using the closed form equation as

f (resonant)=C/4(l_2+l_1).

where C=velocity of light(3*10^8 m/sec)

l_1=width of the conducting element

l_2=length of the conducting element



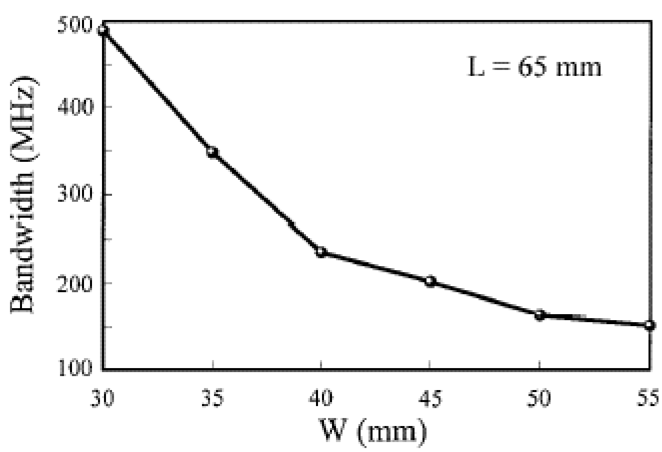
The parameters of PIFA can be adjusted by varying the dimensions with respect to other.

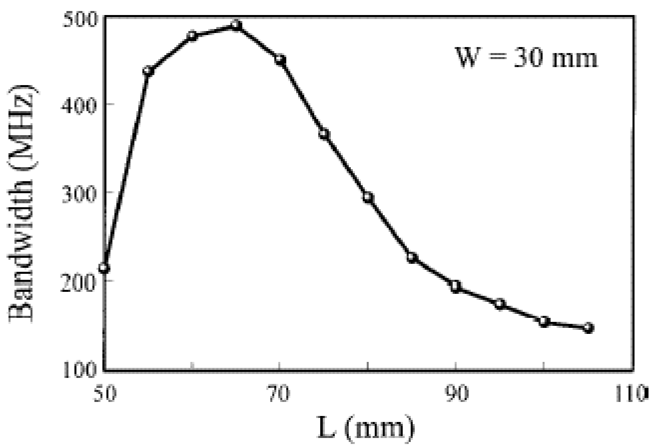
- An increase in H widens the bandwidth
- Reducing W (W< L1) reduces the overall dimension and also the bandwidth
- L_2 allows frequency tuning
- Every modification changes the position of the feed point for given impedance.

PIFA can be made to operate in multiband with etched slot on the radiating element. The slot in the radiating element gives a more compact design for the antenna and thus reduces the volume occupancy.

Effects of ground plane on impedance bandwidth:

The impedance bandwidth of PIFA is greatly affected by the length and width of the ground plane. The bandwidth variations are larger for the design frequency of 900MHz and 1800MHz. The variation of bandwidth for various lengths and widths for fixed widths and lengths respectively are shown below.





Hence the dimensions of the ground plane have to be optimized to obtain good return loss and bandwidth. The optimized length and width of the ground plane was around 45% and 25% of the design wavelength respectively. The ground plane size for our design frequency came around 112mm and 67mm.

EFFECTS OF SHORTING POSTS:

The shorting posts can be analyzed by modeling them as short pieces of a transmission line of length 't' where t is the height from the ground plane to the conducting patch. Therefore the shorting posts will add inductance and capacitance to antenna structure. The series inductance is the total self-inductances of all shorting posts whereas capacitance is due to the close proximity of the shorting posts. There is also a series resistance R that represents the resistance due to the finite conductivity of the shorting posts and a shunt conductance G due to the dielectric loss between the shorting posts. However the values of R and 1/G are too small and hence can be neglected. The values of L and C depend on the number of the shorting posts, their radius 'a', the separation between the centers 'd', the permitivitty ε and permiability μ of the substrate. If two shorting posts are used, then

$L=(t\mu/\pi)\cosh^{-1}(d/2a)$

$C=(t\pi\varepsilon)/\cosh^{-1}(d/2a)$

- Increasing the separation between the shorting posts increases L
- Increasing the separation between the shorting posts decreases C
- Increasing height (t) increases both L and C.

- Depending on the value of L and C, the resulting reactance will be either inductive or capacitive.
- The resonance frequency of the antenna will be decreased if the resulting reactance of the short-circuiting posts is inductive and increases when capacitive.

DUAL BAND PIFA GEOMETRY:

PIFA can be made to work in dual band by two methods.

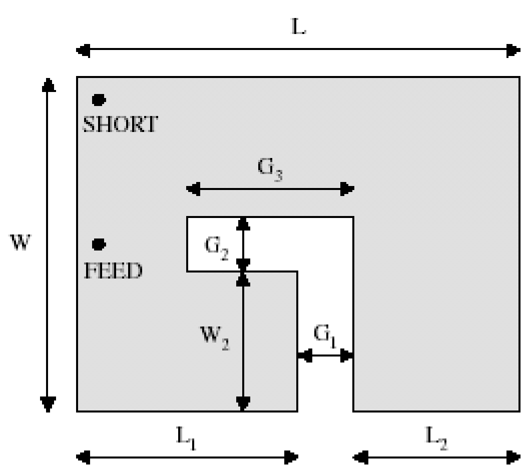
- Dual feed
- Meandered slit or slot formation.

Dual feed technique:

PIFA is fed through two ports

Meandered slit or slot technique:

Simple configurations of dual band PIFA are possible having either L-shaped or the U-shaped slots on the radiating patch. The geometry of dual band PIFA with L-shaped slots are shown in fig 2.



The lower resonant frequency of the above geometry is given as

F(lo)=C/4(w+l)

The upper resonant frequency cannot be approximated using closed form since there are too many parameters controlling it. The most critical parameters controlling the resonant frequencies, input impedance and impedance bandwidth of the above configuration are

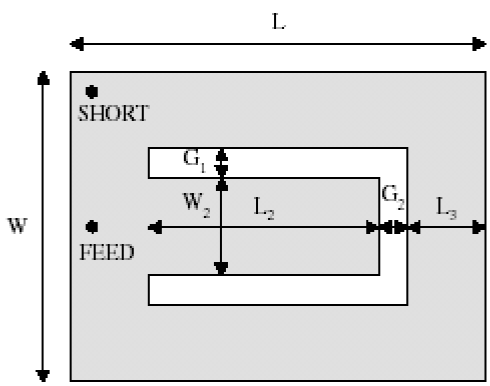
- G1, width of gap between L1 and L2
- G2, width of gap in the middle of the radiating element
- G3, length of gap in the middle of the radiating element
- L2, length of edge at the open end.

Table1 provides the dependence of SWR and bandwidth on the above parameters at two frequencies.

TABLE 1 Trends of Resonant Frequency, Input Impedance, and Bandwidth as a Function of the Geometrical Parameters of the L-Shaped Slot Dual-Band PIFA

	F_1	F_2	$SWR1$	$SWR2$	$BW1$	$BW2$
$G_1 \uparrow$		$\uparrow$				
$G_2 \uparrow$		$\downarrow$	$\uparrow$			
$G_3 \uparrow$		$\downarrow$		$\downarrow$	$\downarrow$	$\uparrow$
$L_2 \uparrow$	$\downarrow$	$\downarrow$				

The geometry of U-shaped slots radiating patch PIFA is shown in fig 3



The lower resonant frequency of the U-shaped slot PIFA is the same as the L-shaped. In this case upper resonant frequency can be approximated using the closed form equation as

$$f(up)=C/4(w_2+l_2).$$

The most critical parameters controlling the resonant frequencies and impedance bandwidth are

- W, width of radiating element
- L, length of radiating element
- W2, width of inner radiating element
- L2, length of inner radiating element

Table 2 shows the dependence of SWR and bandwidth on the above parameters.

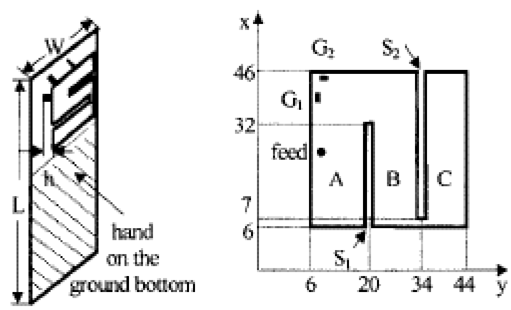
TABLE 2 Trends of Resonant Frequency, Input Impedance, and Bandwidth as a Function of the Geometrical Parameters of the U-Shaped Slot Dual-Band PIFA

	F_1	F_2	$SWR1$	$SWR2$	$BW1$	$BW2$
$W, L \uparrow$	$\downarrow$					
$L_2 \uparrow$		$\downarrow$				
$W_2 \uparrow$		$\downarrow$				
$G \uparrow$		$\downarrow$	$\downarrow$	$\downarrow$		

These dual band antennas are same size as that of single band. The radiating element was grounded by a shorting strip at its corner and is fed near the shorting strip using coaxial cable. The antenna impedance can be matched to the coax by playing with the distance of the feed from the shorting strip.

Triple band PIFA geometry:

A possible geometry for the triple band operation is shown below.



There are two shorting strips G1 and G2 for matching the feed. Two linear slots S1 and S2 are cut in the patch for triple frequency operation. The dimensions of S1 determine the highest resonant frequency and the next resonance is mainly dependent on the dimension of S2. The highest resonant frequency decreases with narrower width or a longer length of S1. The patch size determines the lowest resonant frequency.

PIFA can be made to work in multiband by following the meandering technique. Additional slots or slits can be built to work in the specified frequency without any increase in the volume.

Design and simulation:

Single frequency (900MHz):

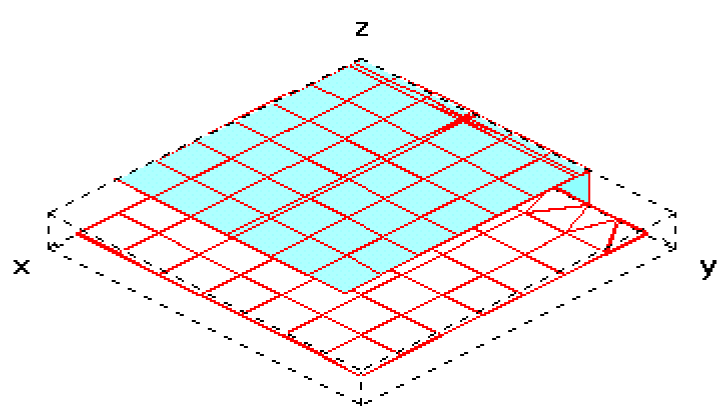
Design:

IE3D(Zeland software) was used for designing and simulation. First, a single frequency PIFA was constructed and tested. The design parameters are

- Length & width (affects the resonant frequency)
- Height from the ground plane (affects the bandwidth)

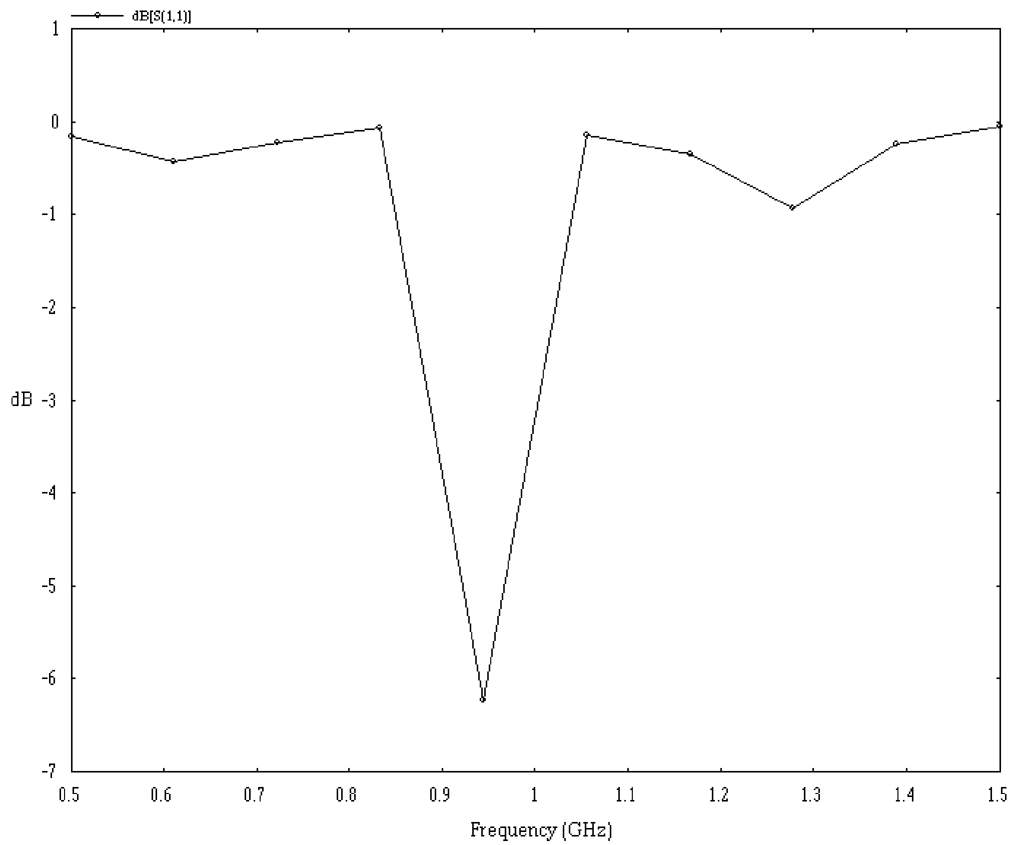
A finite ground plane was used since it was noticed that the size of the ground plane influences the bandwidth of the antenna. In order to avoid losses dielectric substrate is neglected and the antenna consists only conduction plate of thickness 2mm. A ground plane of size 112*60mm was used. The design frequency was 900MHz. According to the closed form equation, the ***length and width calculated was 43.3mm and 40mm*** respectively. Thus the conducting patch is λ/4 of the wavelength. A dielectric layer of 0.8mm F4 substrate with permitivitty of 4.4 is used. Coax feed of input impedance 50ohms was used.

Schematic:



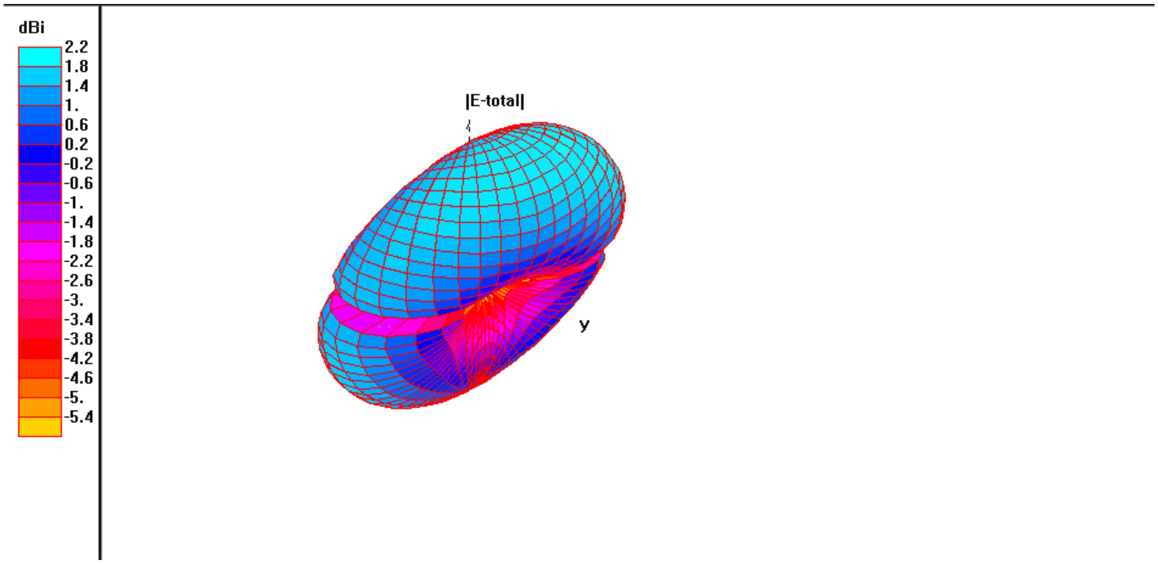
Simulation:

Full matrix solver was used for solving the impedance matrix. The frequency points ranged from ***0.5GHz to 1.5 GHz***. The return loss graph is shown below.

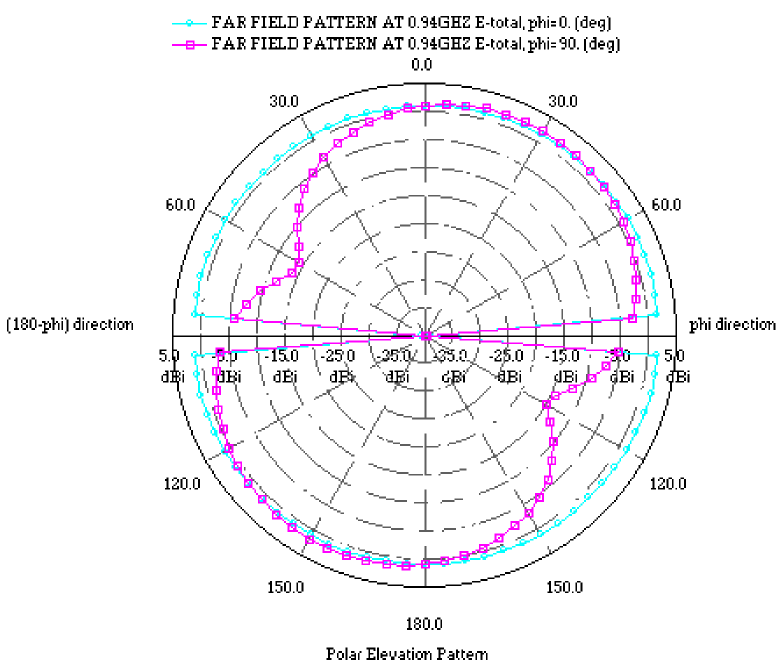


The resonance was around 0.94GHz, which is close to the design frequency. The voltage standing wave ratio was 2.9 at the resonant frequency, which is an acceptable limit. The matching of PIFA is a very tricky task. The feed should not be too close nor too far from the shorting end. The smaller the spacing between them, the lower the resonant frequency will be.

The 3-D far field radiation pattern at design frequency is shown below.



2-D pattern is given below.



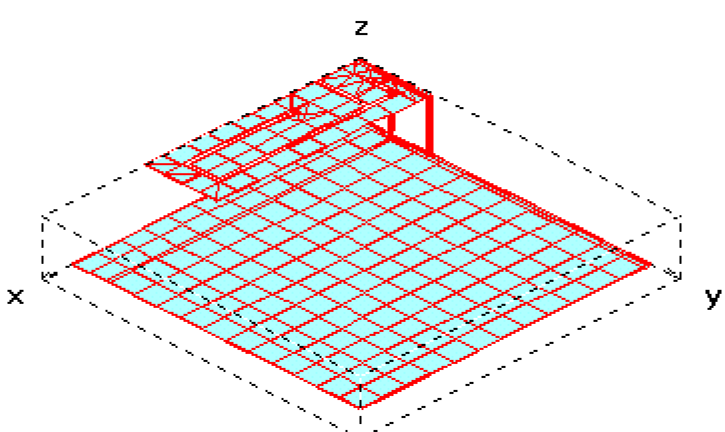
Antennas used of mobile phone sets are required to be omni directional i.e. they should have uniform pattern on one plane and non-uniform pattern in the other. As we see above, the pattern is uniform in xy plane and non-uniform in the yz plane thus making it omni directional. The ground plane is a conductor with conductivity of 4.9e +7.

Radiation parameters at 944MHZ:

- Maximum at (95, 220) degrees
- The Directivity: 4.3528 (dB)
- Mismatch Loss: -1.18142 (dB)
- Circular Polarization Loss: -1.96586 (dB)
- Total Radiated Power: 0.000744203 (W)
- Average Radiated Power: 5.92218e-005 (W/s)
- Input Power at Ports: 0.00761831 (W)

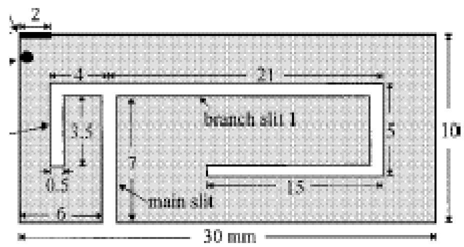
Dual frequency PIFA:

The dual frequency PIFA was designed by cutting slits in the conducting patch. A shorting plate is used to short the conducting patch with the ground plane. The slits meanders the excited patch currents in the shorted patch. The meandering in the patch leads to a large reduction in the required dimensions of the shorted patch for 900/1800MHz band operations. The schematic is shown below.

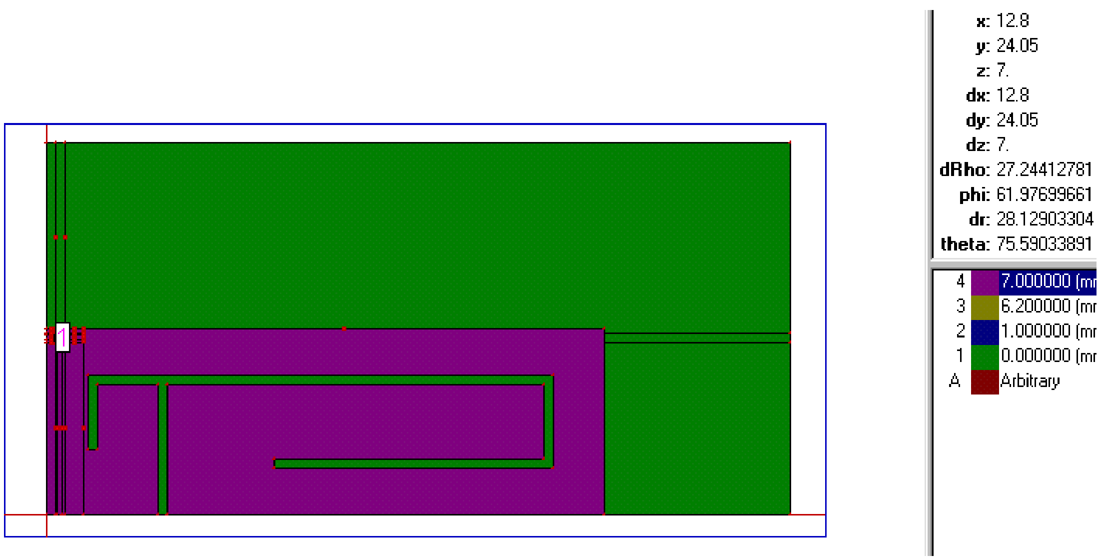


Design and working:

The conducting patch is 7mm above the ground plane printed on a 0.8mm FR4 substrate. A branch line slit consists of a main slit, a long folded branch slit and a short bent branch slit embedded in the shorted patch. The layout of he main slit, which has an open end at the patch boundary, and the long folded branch slit in the shorted patch are mainly for effectively meandering the excited patch surface currents, while the short bent branch slit is mainly for achieving enhanced impedance matching of the first two excited resonant frequencies to obtain wider operating bandwidths. The length of short bent branch slit is much smaller than that of the long folded branch slit. The conducting patch is shorted to the ground by a conducting wall. The short should be placed close to the feed to get a perfect matching impedance. The dimensions of the slit are given below:



Schematic:



Effects of shorting plates:

As discussed for shorting posts, shorting plate can be also modeled as a transmission line with series inductance L and shunt capacitance C with R and G neglected. The inductance is given by:

$L=\mu d/w$

d-width of the plate

w-length of the plate

Capacitance is given by

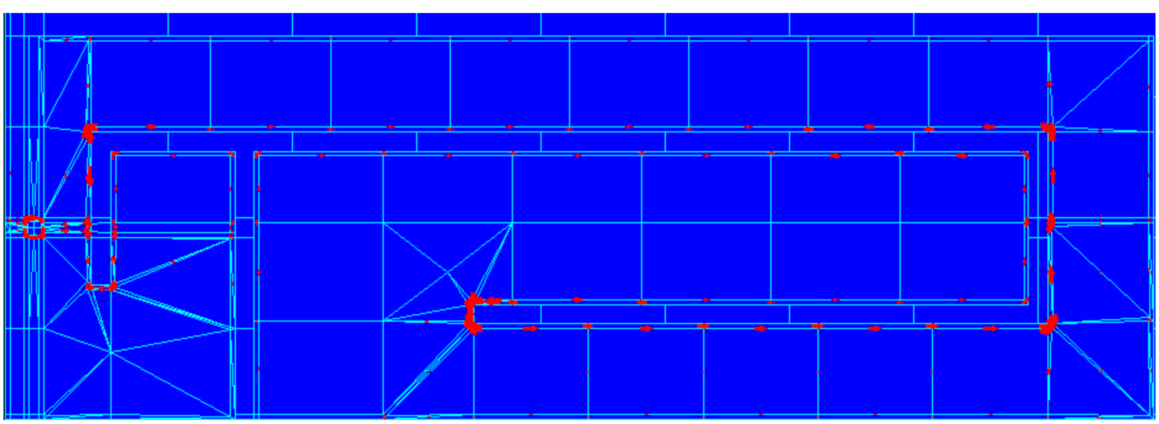
$C=\varepsilon w/d.$

- When distance of the plate 'w' increases, inductance decreases and capacitance increases thereby making total reactance capacitive and hence increasing the resonant frequency.
- When distance of the plate 'w' decreases, inductance increases and capacitance decreases, hence resonant frequency decreases.

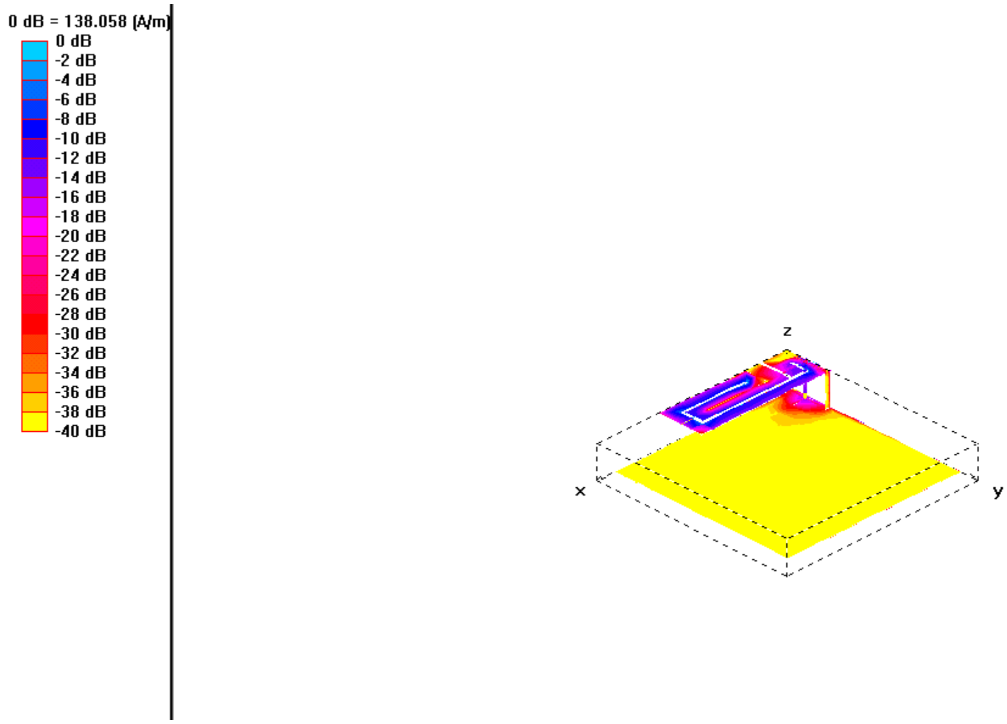
900MHz:

The antenna designed was first tested at 900MHZ frequency band. It can be seen that there is no perfect match and hence the return loss is very high. A match can be obtained using a matching network with lumped components or playing with the feed position. The feed should be close to the short in order to obtain exact match. The current density pattern and average current density shown below shows that the current is distributed over the conducting patch thereby making the antenna to resonate.

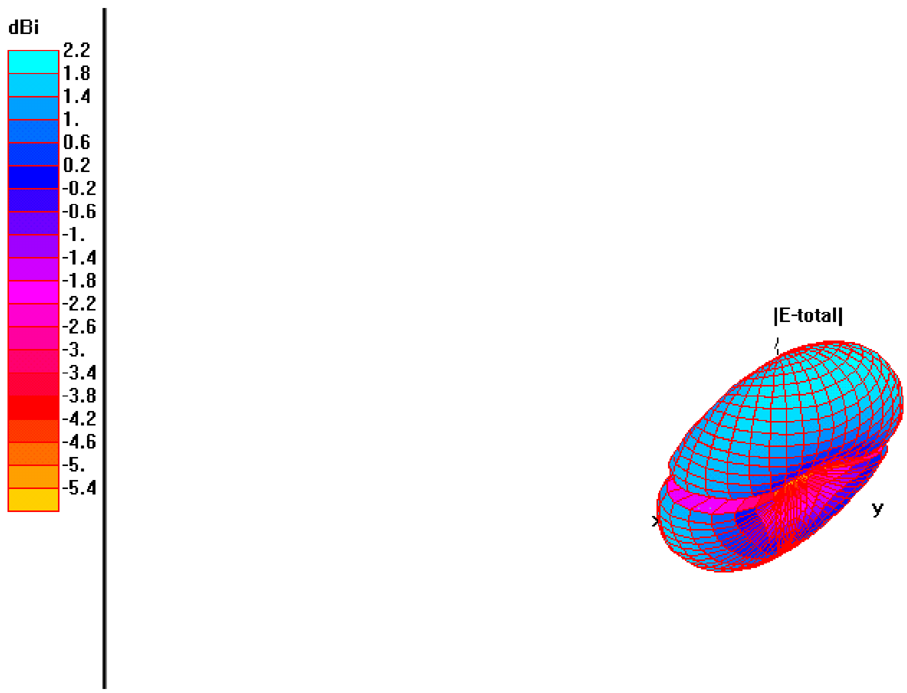
The current flow in the conducting patch is shown below.



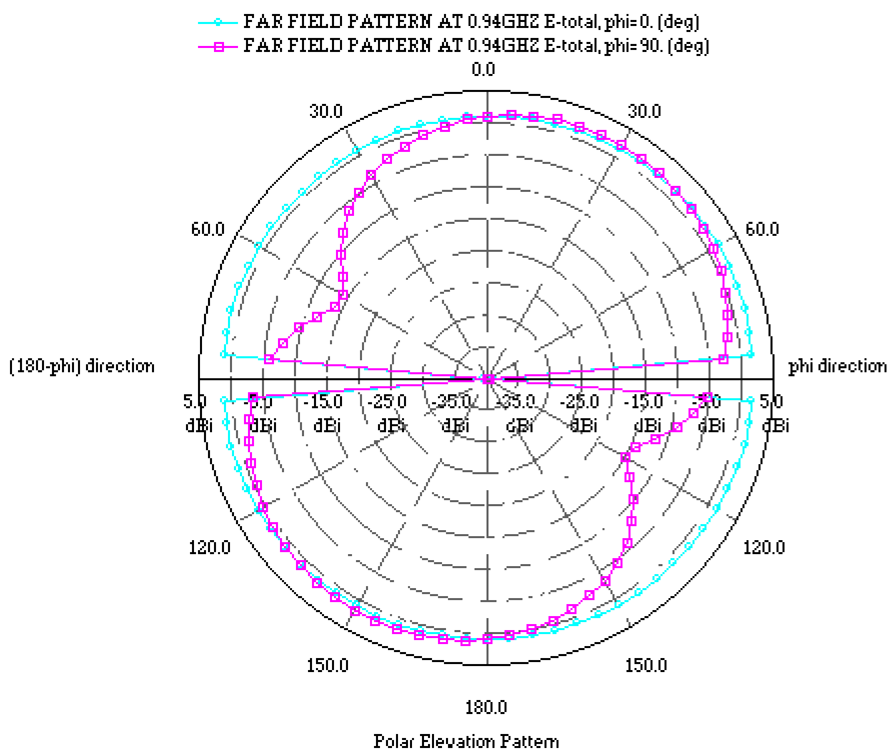
Average current density:



3-D far field pattern:



2-D far field pattern

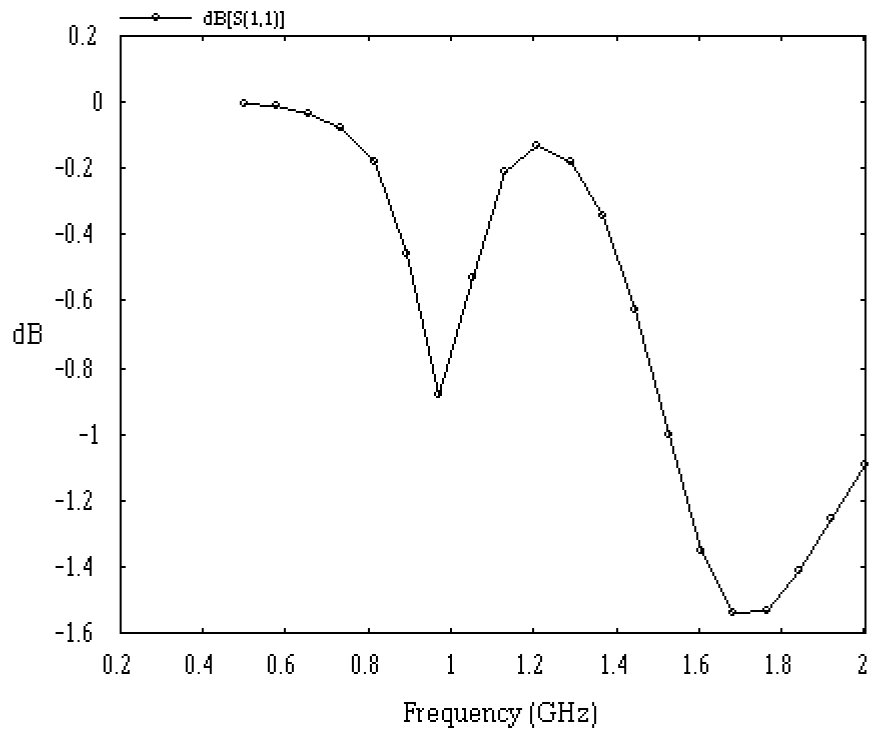


Thus the pattern is omni directional at the design frequency. A perfect match cannot be obtained due to various reasons. The antenna was tried with different feed in different positions, changed the height from the ground plane. The minimum voltage standing wave ratio was 19. This can be reduced using a matching network to match the antenna impedance with the coax feed.

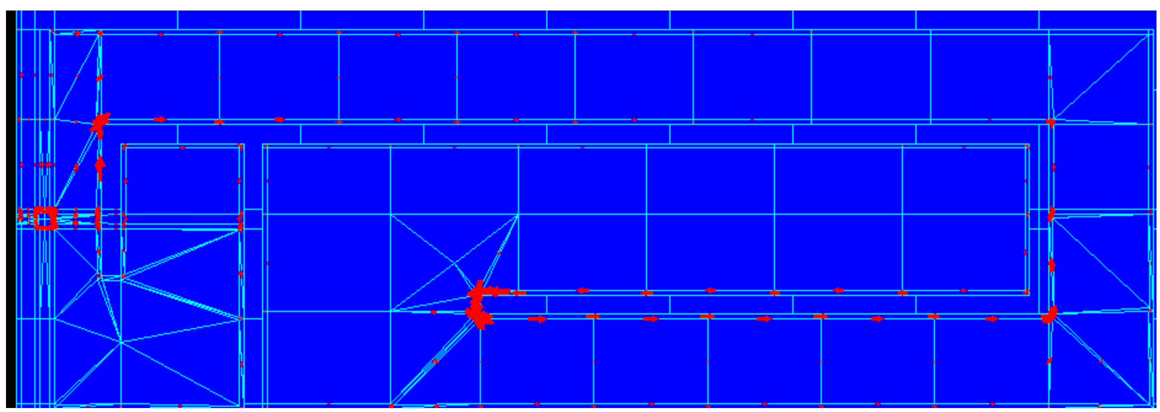
1800MHz:

The antenna was tested at the upper resonant frequency (1800MHz) and its behavior was noted to be the same as the lower resonant frequency. The return loss, average current density and current flow in the radiating patch are shown below.

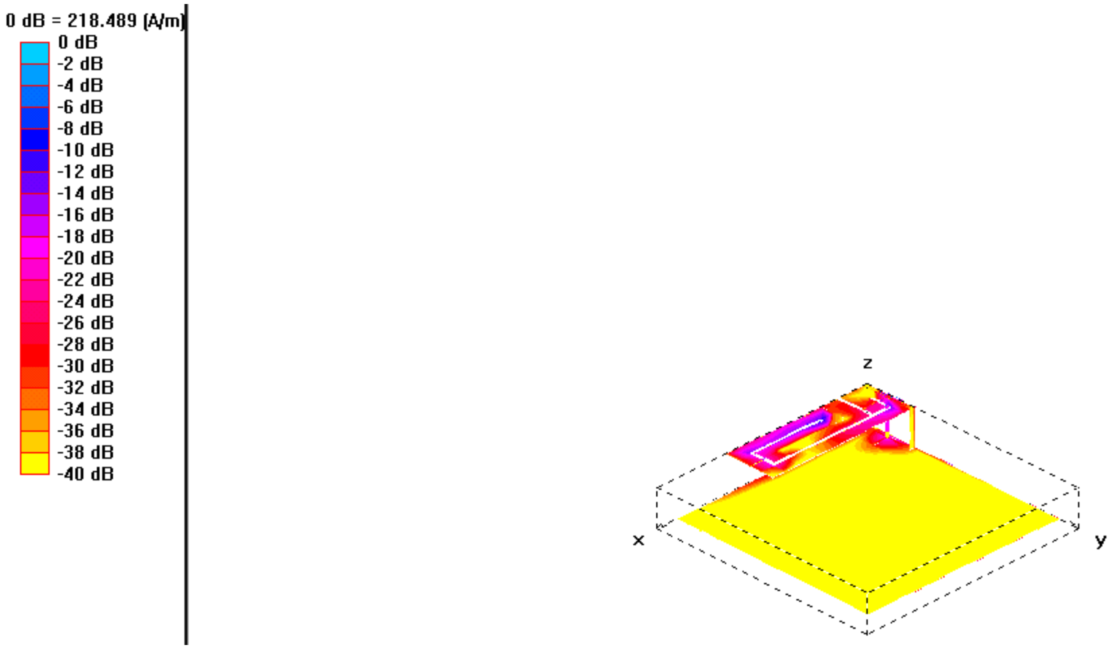
Return loss (dB):



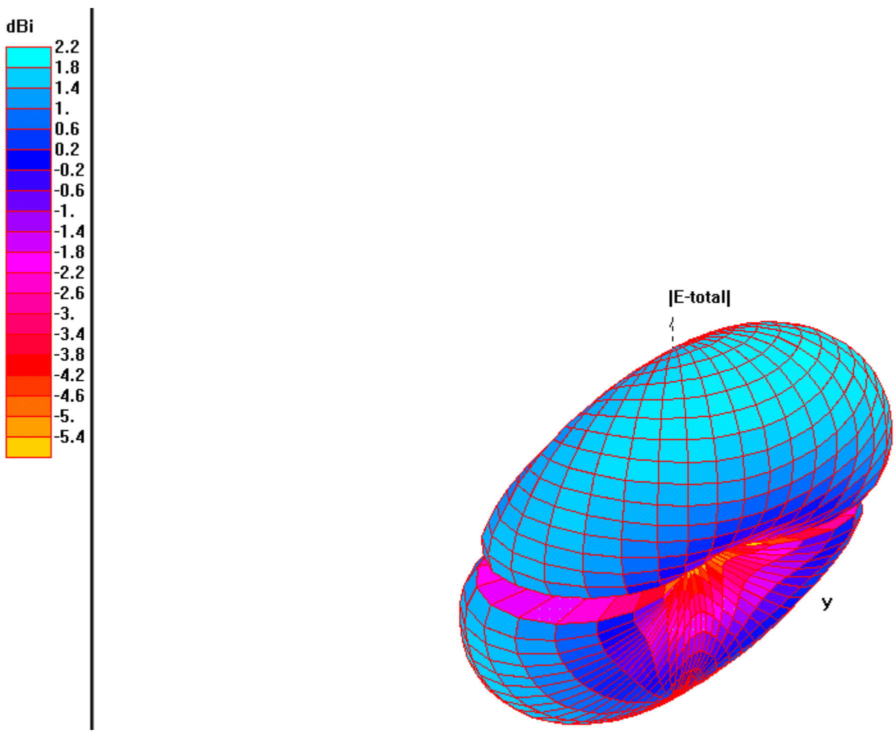
Surface current in the conducting patch:



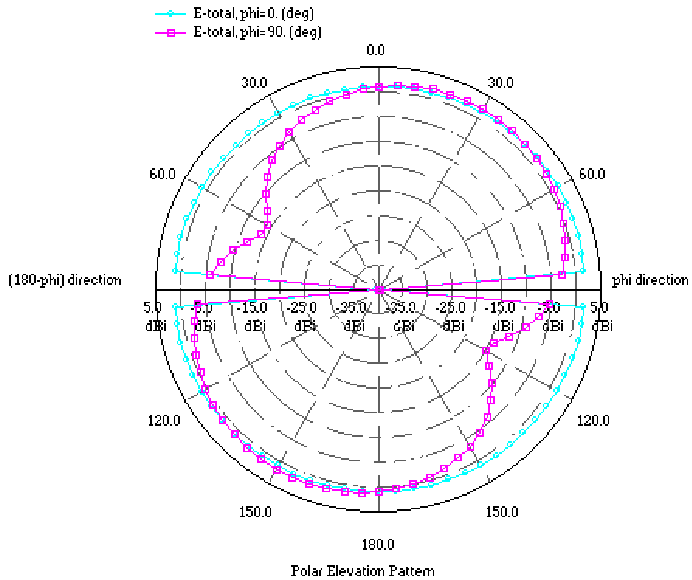
Average current density (1800MHz):



3-D far field pattern:



2-D far field pattern:



Radiation parameters at 900MHZ

- Maximum at (30, 110) degrees
- 3dB Beam Width (99.3889, 110.664) degrees
- The Directivity: 2.16333 (dB)
- Mismatch Loss: -9.96109 (dB)
- Circular Polarization Loss: -1.42515 (dB)
- Efficiency: 43.8838% (-3.57695 dB)
- Total Radiated Power: 0.000442787 (W)
- Average Radiated Power: 3.52359e-005 (W/s)
- Input Power at Ports: 0.001009 (W)

Radiation parameters at 1800MHZ

- Maximum at (15, 10) degrees
- 3dB Beam Width = 135.848 degrees
- The Directivity: 2.84092 (dB)
- Mismatch Loss: -5.54977 (dB)
- Circular Polarization Loss: -1.41886 (dB)
- Efficiency: 78.4566% (-1.05371 dB)
- Total Radiated Power: 0.00218601 (W)
- Average Radiated Power: 0.000173957 (W/s)
- Input Power at Ports: 0.00278627 (W)

Conclusion:

Small volume, good electrical characteristics make PIFA a promising candidate for the mobile phone applications. Main considerations for the design are

- *Dimensions of conducting patch:* They depend on the design frequency. The conducting patch should be of $\lambda/4$ dimension.
- *Size of the ground plane: G*round plane affects the bandwidth to a greater extent; it should be optimized for the design frequency. The optimized value is 45% for the length and 25% for the width respectively.
- *Position of the feed:* They play a major role in the impedance matching. The position of the feed should be as close to the short in order to get good impedance matching.
- *Height of PIFA from ground plane:* They determine the bandwidth of PIFA. More the height, more the bandwidth will be.

PIFA can be made to operate in different frequencies without altering the space volume. No antenna is devoid of disadvantage. PIFA has disadvantages like device dependence, design difficulty etc. But clearly, it's advantages outweigh the disadvantages. The design seems to work perfectly avoiding the matching, which can be attained by playing little more with the feed position. The far field radiation pattern was observed to be ***omni directional*** for all the design frequency with good gain. The future work will be to built the simulated antenna and test it in real time environment and to check the credibility of simulation.

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