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Antenna Tuning for Mobile Communications

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Abstract— ***The use of mobile phone has increased in the present day with a steady improvement in the technology used. Due to the increase in the functionality of the mobile which makes some components in the phone occupy some space, the need for a compact design of antenna is required which will operate in different frequency bands. The operating environment of a mobile phone varies continuously due to the handling and the proximity of the user's body and hand. The user body in close range with the antenna of the mobile makes the power amplifier of the mobile phone efficiency to suffer from variation in the load impedance, resulting to a variation in the feed-point impedance of the antenna. Thus there is a need for an automatic tuning network which will compensate for the mismatch. A compact multiband Planar Inverted F antenna (PIFA) suitable for mobile phone is designed. Rohde & Schwarz Vector Network analyzer is use to Analyze the modelled antenna. Also, a suitable matching network is designed while the Simulation of the model is been carried out using EZNEC.***

Keywords— ***Mobile Phone, Antenna, Frequency band, Impedance, Planar Inverted F antenna, Network Analyzer, Pi Network, Matching Network, Simulation, Eznec.***

I. INTRODUCTION

Many appliances operating around 1800 MHz needs antennas of 0.25λ or lesser. Instances of antennas which has an electrical size of a quarter wavelength which can be used include monopole, helical, and PIFAs (planar inverted-F antenna).In the past, there has been the development of new design antennas which exhibits a low profile used for wireless devices. The low-profile antennas have some shortcoming in the designs having a narrow bandwidth. Some of the antenna designs can't cover the bandwidth which they are required to cover hence, not suitable due to the margin in the bandwidth for detuning effects which arise from the proximity of the user. The market tendency of wireless devices is migrating in the direction of a global system which has the ability to be used globally. This requires multiple frequency band mode of operation. Dual-band compact antennas have helped in the transformation of new wireless system to operate smoothly. The demand for wireless systems which has the ability of operating in more than two bands is required. In summary, a compact small size antenna that has wide band of frequency, which also has high efficiency are required in mobile phones [2]. Mobile phones are becoming more popular and the rate of utilization has increased nowadays. With the requirement of more functions in the mobile phone, a compact antenna is designed which will take up less space and still have the ability to operate in two or more bands of frequencies [2]. The RF front-ends are put in place when considering the antenna impedance with a nominal value of 50 ohms which guarantees a maximum efficiency. Due to the proximity of the user body with the mobile phone, the narrow band antenna is affected and detuned which reduces its efficiency [1], [2], [3].

A requirement of an increase efficiency of RF front-end is needed consisting of power amplifier. The power amplifier has an overall effect on the power intake of the system. The amplifier is designed in such a way that the output impedance matches with mobile phones antenna impedance having a value of 50 ohms. The hand and body of the user in a close range to the antenna distort the impedance of the antenna [4], which also affects the power amplifier efficiency and also reduces the antenna reception.

The adaptive antenna matching network compensates the mismatch from the proximity of the user body. This give rise to an increase in both the power efficiency of the power amplifier and the mobile phone [5].When there is a mismatch in the system, it leads to an increase in the energy consumption and reduce the transmission quality. Using an automatic matching system will resolve the problem, which extends the mobile range and can serve as an impedance tuner for RF load power transistor [6], [7].

Antennas are important part of a complex system, which allows the use of impedance tuning network with an electromagnetic property which varies constantly. The antenna impedance is a parameter that varies constantly in mobile phone system where there is a constant variation there by leading to a mismatch between the power amplifier and the mobile antenna. This mismatch has effects where the power module performs at a reduced efficiency under load variation and also the power radiated reduces due to reflected power. In other to compensate the power reduction, the system will need to increase the power [23] [7].

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II. WIRELESS AND MOBILE COMMUNICATIONS

Wireless and mobile communications have a high demand nowadays, with the requirement of having the ability to handle different operations and with a compact size. GSM and UMTS technology are often used in mobile communication. Global system for mobile communication can be referred to as second generation of mobile communication operating in the frequency range of 800 MHz & 1800 MHz, while GSM 900 has a frequency between 890 MHz & 960 MHz Also GSM 1800 has a frequency spread between 1.710 GHz to 1.880 GHz.

III. MATCHING NETWORK

The matching network is a very important part in other to be able to achieve the objectives of the project. The variation in the environmental condition and operating frequency results from the proximity of the user body alters the antenna impedance. This prompts the need for impedance matching networks. This will change the impedance present to the antenna (load) so as to realize the conjugate impedance. Several kinds of impedance matching has been used. The most commonly used are [5], the pi, L, and T network. The pi network is used in this paper.

IV. THE PI NETWORK

The π network is made up of three passive components which are 2 capacitors and inductor. The pi network is chosen to be used for the matching network having greater impedance matching flexibility over L and T networks [19].

V. THE TUNING ALGORITHM

Analytical tuning algorithm for pi-network impedance tuner is been used in this paper. The pi-network is made up of tuneable capacitors which have a finite tuning range together with an inductor of a fixed value. The analytical tuning algorithm has the ability of determining all components value for matching any load impedance. This algorithm uses a closed-form formulas & a direct calculation method [24].

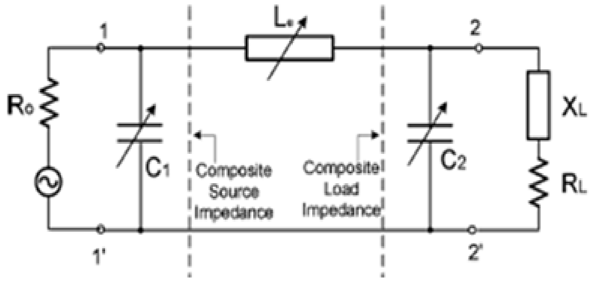

Fig. 1 Circuit of π-network tuner having a source & matching load [21]

VI. ANTENNA

In mobile and wireless communications systems, antenna has been a great part of the signal path which contributes a major impact on the entire system performance. In most wireless systems, a single antenna serves as the transmitter and receiver. This is because of the principle of reciprocity, having an equal significance in a receiving antenna. The most important part of the antenna parameter is the feed point impedance. It is the impedance for both the transmitter power amplifier and the source impedance for the low-noise amplifier receiver [8].

There are a lot of limitations in the design of an antenna with the demand for a small compact size, increase bandwidth and the convergence in a single device. This reduces space available for antennas and the desire to use a single antenna for a wide range of frequencies. Antennas used for wireless applications mostly operate in the UHF range, which are electrically small and compact. The request for an integrated devices which are slimmer, with a compact smaller size, which has a lighter weight than the present one, has created lots of problems for the design of an antenna size, bandwidth, and the efficiency[8].

The recent research into mobile handset antenna has majorly concentrated on compact, multiband antennas. Antennas which possess operating frequency which are reconfigurable with invariant radiating frequency characteristics holds a good technological benefit. This type of antenna doesn't have the ability to capture the entire frequency bands at the same time. Various selectable narrow bands of frequencies where higher efficiency can be realized than with a conventional antenna solution. This method can be used to reduce the size of an antenna while maintaining the operating bandwidth. Antenna tuning compensates for the proximity effect which arises when the user hand and body detune the operating frequencies of mobile phone antennas [8].

A lot of techniques have been put in place to meet the demand for multi band handset antenna for mobile communication system. Such antenna include planar inverted-F antenna [12], [13], printed dipole antenna [14], [15], and planar monopole antenna [16]-[17]. PIFA is made up of a compact size but with a narrow bandwidth not suitable in use for multiband functions. In other to overcome this, a multilayer resonator could be employed. However, this will increase the cost of production.

VII. AUTOMATIC NETWORK TUNING

An automatic antenna tuning is said to be a system which is capable of transforming the impedance mismatch of a mobile phone automatically. Fig 2 shows an antenna tuner which is made up of matching network, control network, and impedance sensor. The high speed programmable ATU is designed for a wide range of antenna operating in different frequencies and environmental conditions. The sensor is used to indicate the antenna impedance. Automatic antenna tuner can be used which can be categorized either by their adapting property or by how impedance matching is measured [9]. The monitoring unit may contain the impedance, SWR, reflection coefficient etc. The impedance matching network is very important in the ATU.

The circuit structure and the value of components of the network are determined by the antenna impedance and working frequencies. Due to the relatively slow changing environment of a mobile device, the performance of this control unit is enough to keep the antenna properly tuned [10]. In order to get higher front- end efficiency, the use of some antenna tuning is required. The fluctuation of the antenna due to the body contact happens in milliseconds, this is slow when compared with gigahertz RF signal range. When there is a mismatch, antenna tuner system should match and correct heavily detuned antenna impedance. Also the insertion loss of the antenna tuner should be very minute in other to get a high efficiency. To obtain an efficient power transfer from transmitter output to the antenna, impedance matching must be provided. In mobile phones, automatic antenna tuner is usually located close to the antenna feed point which makes it easier to minimize feeder loss [11].

The AATU is usually positioned close to the antenna feed point in order to minimize feeder loss; here it is exposed to the environment, and is difficult to access, and so must be rugged and operate with high reliability. In order to achieve a high frequency, and also make the best use of the available bandwidth, and be compatible with frequency hopping techniques, the time it takes the tuning process for each change of frequency should be as short as possible [16].

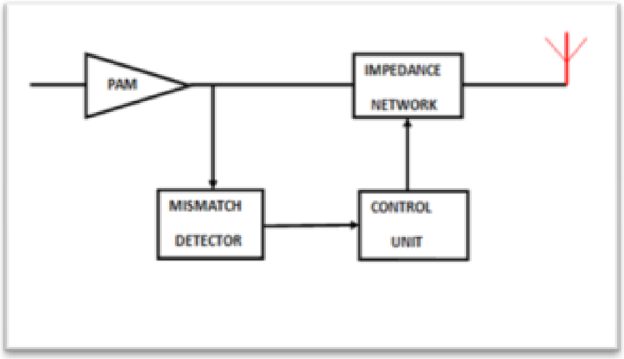

Fig. 1. Automatic antenna tuning network [20]

VIII. INPUT IMPEDANCE

The antenna input impedance is said to be the proportion of voltage and current at the terminal of the antenna. Maximum power is disseminated at the antenna within frequency in which the input impedance is near the real value. The antenna is usually fed by transmission line such as coaxial cable, micro strip line, etc. The aim is to match the antenna impedance with the impedance of the connecting transmission line. However, a standing wave is caused by the mismatch between the antenna impedance and the transmission line. Voltage Standing Wave Ratio is measured as the ratio of the voltage max and voltage min of standing wave. Input impedance comprises real and imaginary parts, expressed as: $Z_{in} = R_{in} + j X_{in}$.

Where Z_{in} is the impedance at the terminal of the antenna, while R_{in} is resistance at the terminal and X_{in} is the reactance at the terminal. X_{in} which is the imaginary part of the input impedance corresponds to the power stored in the near field of the antenna. R in consists of the radiation resistance R_r and the loss resistance R. The power dissipated in is lost as heat energy in the antenna which results from the dielectric loss [21].

IX. IMPEDANCE MATCHING NETWORK

In other to achieve a maximum power transfer, a complex conjugate matching between the source and the load impedance is vital. Due to the nearness of the user head and hand, there is an impedance mismatch which results to a low power gain, reduction in the transmission power, and reduced reliability of the antenna.

The impedance matching network is designed and sandwiched between load impedance source impedance. The network is lossless which obviate redundant power loss and its designed in such a way that the observable impedance in the matching network is Z0. The reflections are taken off from the source on the transmission line, but there are still several reflections between the load and the matching network. This is known as tuning [20]

The reason why it is important to use Impedance matching is:

1. There will be a reduced power loss in the feed line taking an assumption that the generator is matched, thereby resulting in a maximum delivered power when the load is matched to the line.
2. The signal to noise ratio is improved with the help of the matching components (antenna).

The amplitude and the phase error are minimised using impedance matching like the array feed network.

X. STRUCTURE OF THE ANTENNA

The use of tuneable planar inverted F antenna (PIFA) is been proposed for mobile communication antenna. The antenna can cover a wide range of frequency bands like GSM850, GSM900, GSM1800, & UMTS frequencies ranges with 40% efficiency. Figure 4 consist of the picture of the front layout the dual band PIFA. The antenna view shows the switch diode, the inductor, and the capacitors [8]. The rectangular patch is split to form two separate parts to be able to provide resonant currents, which results to dual band operation of the antenna. The detailed dimension of the proposed antenna used can be found in table1.

The antenna is built on a 1.6mm thick PCB with a 35μm thick copper. The PCB is made from a photo resist copper clad single sided board. The element of the antenna has air substrate of about 9.2mm thick located on top of a 45mm x 110mm reverse side grounded PCB. The short pin is separated from the other part of the antenna with the help of an L shape slit. In other to generate a dc PD across the diode, an inductor and 2 capacitors are connected in parallel. The low impedance capacitor at the RF behaves like a dc block thereby allowing easy flow of current in the antenna [8]. The inductor has a high RF impedance acts as a block which blocks the RF signal thereby passing DC down to diode switch. The PD generated is found between the feed and the short pin. By changing the polarity of the DC voltage, biased in the forward (ON) or reverse bias (OFF), this is used to control the impedance of the switch. The diode acts as switch with high or low impedance. When the diode is biased in the forward state, it acts as a pure ohmic resistance modelled with a resistor. But when reverse bias, it acts as a small capacitance modelled as an open circuit [8].

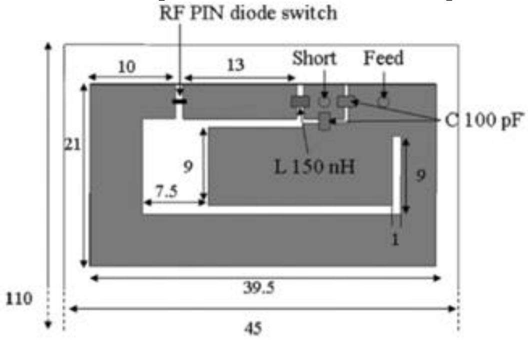

Fig. 3. Dual Band PIFA [9]

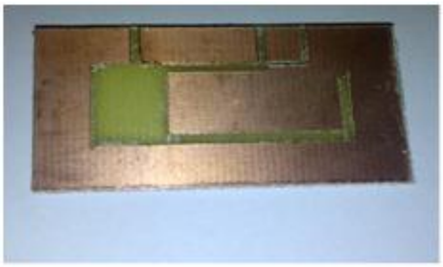

Fig .4. Constructed PIFA antenna without tuning circuit

Fig .4. Constructed PIFA antenna with tuning circuit on ground plane

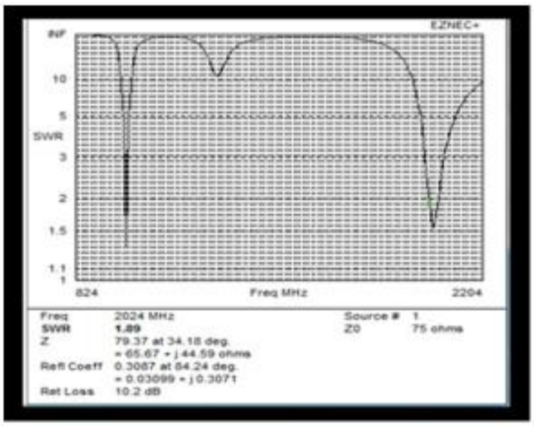

Fig. 5. Antenna with tuning circuit on the ground plane with SMA connector

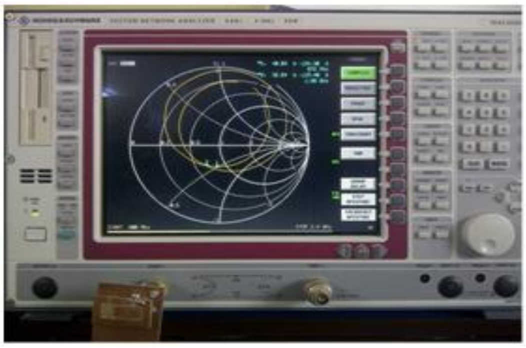

Fig. 6. Antenna connected to the ROHDE network analyzer showing smith chart.

XI. SIMULATION

The components and elements that are used in the design of the antenna are of great importance in the antenna of the mobile communication system. There are some useful parameters which are critically considered when the matching network is constructed. This consists of the input impedance, transmission impedance, return loss and the reflective coefficient. The impedance Z0 is given as 50 ohms operating at a frequency band ranging from 824MHz - 2170MHz. The input impedance is described as the capability of the antenna to receive power from the source. In other to generate a maximum transfer of power, there should be a match between the input and the output impedance [22].

XII. EZNEC ANTENNA MODELING SOFTWARE

The result of the simulation and the measured result are then demonstrated after the test has been done on the antenna element. The results of the tested simulation are presented. PIFA antenna is modelled using NEC4 engine in EZNEC pro, this is done using wires. A wire grid is a good way whereby flat solid conducting surfaces such as metal roof, car top and flat antennas can be simulated. The performance properties of the flat solid antenna configuration are essentially the same as those of the wire configuration. In modelling of the proposed PIFA antenna, the spacing between the wires is taken to be 0.1wavelength with the diameter taking to be wire spacing/pi [18]. When modelling a flat antenna like the planar inverted F antennae, the use of segment is also taken into consideration because when the wire is segmented using a reduced amount of segments on each wire, it will give a better and accurate reading of the standing wave ratio. The antenna is simulated on a perfect ground type using four wires with 11 segments. The wavelength is taken to be 1000mm having a single source.EZNEC is a very useful antenna modelling program for modelling and analyzing almost all types of antenna. It has the ability of plotting azimuth, it gives the gain, impedance, voltage standing wave ratio, current in the simulated antenna, beam width, smith chart etc. In the simulation result of the design, the VSWR, the Return Loss and the gain are to be considered. Then vector network analyzer is used to test the antenna model and the SWR plot and the complex plots are gotten.

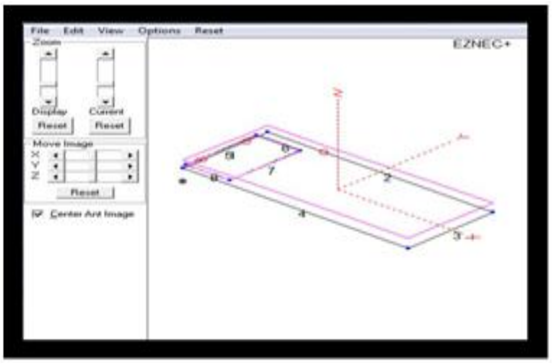

Fig.7 Diagram of the simulated antenna using Eznec

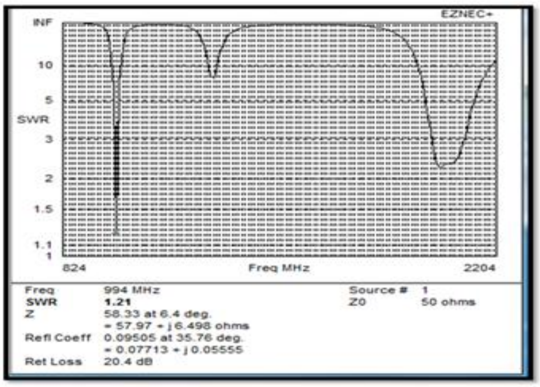

Fig. 8. SWR plot at 50ohms impedance

Figure 8 is the simulation result of the antenna using Eznec. The start frequency is 824MHz and the stop frequency is 2.2GHz. It can be deduced that the resonance at the narrow band 994MHz, has 1:1.21 VSWR which is used in mobile phone antenna. It also has an impedance of 58.33 at 6.4deg with a reflective coefficient of 0.07713 +j0.05555.

Table 1. Parameters of the PIFA antenna

Antenna Parameter	Value	Groundplane	Value
Length	39.5mm	Length	110mm
Breadth	21mm	Breadth	45mm
Thickness	1.6mm	Thickness	1.6mm
Copper Thickness	35 μm	Copperthick Ness	35 μm
Capacitor C	100pF	Diode	BAR50-02V
Inductor L	150nh		

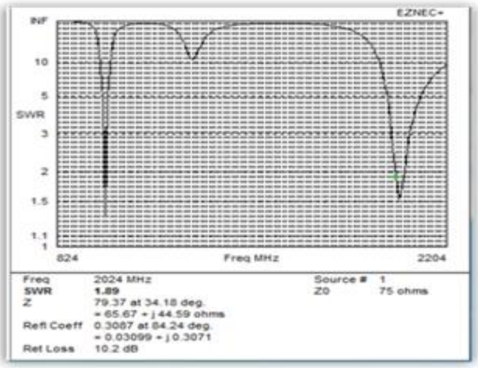

Fig. 9. SWR plot at 75ohms impedance

From figure 9, the start frequency is 824MHz while the stop frequency is put on 2.2GHz. The alternate SWR impedance is 75 ohms. The measured VSWR is 1:1.89 while the reflective coefficient is 0.3099 + j0.3071 with a return loss of 10.2dB.

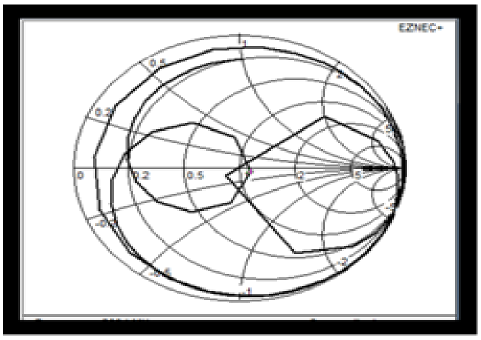

Fig. 10.Complex plot of the simulation (smith chart)

XIII. TEST RESULT AND DISCUSSION

The performance parameters of the matched antenna are measured with the help of rohde &Schwarz vector network analyzer. The plots of complex smith chart and that of the SWR are taken. The frequency response curves for VSWR are given. The network analyzer used for the measurement is been calibrated. The analyser when there is no load connected, the offset was moved to the feed point of the antenna so as not to allow the return flow of the dc voltage. Calibrating the analyser is important in other to get the best and accurate results.

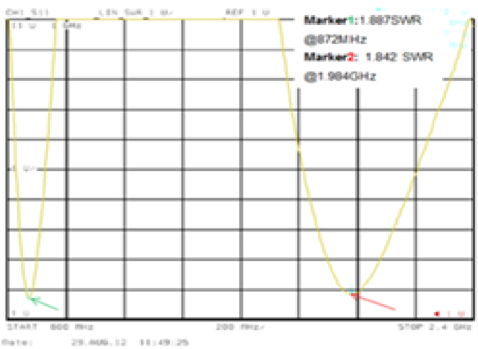

Fig.11. SWR (narrow band) plot of antenna modeled with PIN diode\

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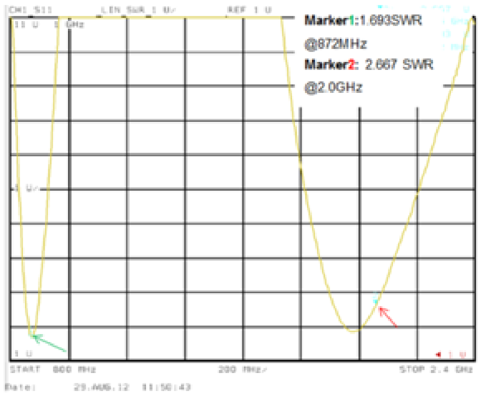

Fig.12 SWR (wide band) plot of antenna modelled with PIN diode

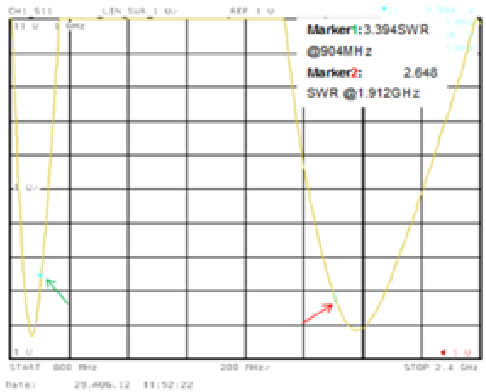

Fig. 13 SWR (narrow- band) plot of antenna modelled with PIN diode at 900MHz.

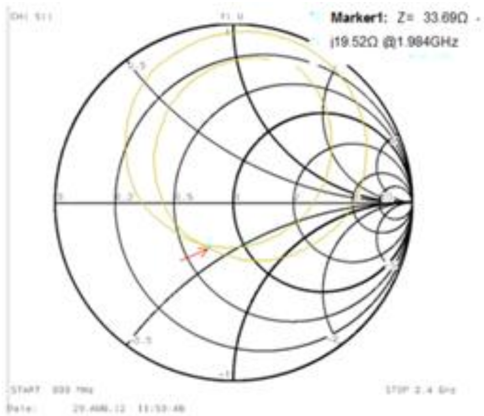

Fig. 14 Smith chart plot of antenna modelled with PIN diode

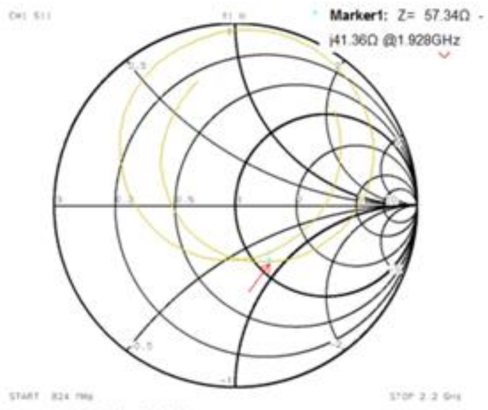

Fig. 15. Smith chart of antenna modelled with PIN diode as a resistor

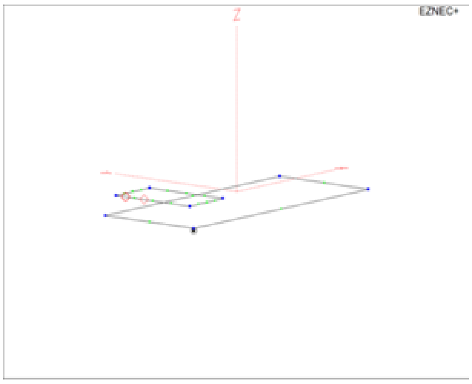

Fig. 16 Plot of the simulated antenna showing the feed point and short pin

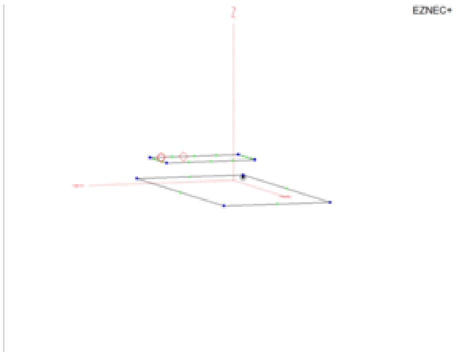

Fig. 17 Plot of the simulated antenna showing the 9.2mm air substrate

From figure 11, when the antenna modelled with a PIN diode which acts as a switch is connected to the analyzer, the resonance at frequency 872MHz has a SWR of 1:1.687 which is the lowest standing wave ratio at the narrow band. On the wide band frequency of 1.984GHz, there is a minimum SWR of 1:1.842. This range of frequency corresponds to the UMTS band.
From figure 12, on the wideband frequency, there is a good and ideal SWR on the frequency of 2.0GHz with an SWR of 1:2.6 which is acceptable in mobile phone antenna.it also has an SWR of 1:2.6 at a frequency of 1.9GHz according to the plot on figure22. Figure 16 shows the standing wave ratio at frequency 904MHz at 1:3 SWR. This is not a good SWR at the narrow band but can still be matched around that area. This corresponds to the GSM900 frequency band. When the PIN diode was modelled with a wire (resistor) as a PIN diode conducting, it generates three resonant frequencies compared to the one modelled with PIN diode. The minimum SWR were on the frequencies of 976MHz with SWR of 1:1.66, 1.66GHz having an SWR of 1:1.82, and the third resonant frequency is 2.19GHz with SWR of 1.87. the bands on the third resonance is at 2.1GHz having SWR of 1:2.7, while the second resonant frequency has a frequency band on 1.7GHZ with SWR of 1:2.3, as shown on figure 17. The narrow bandwidth has a frequency band of 968MHz with SWR of 1:2.4. Figure 15 shows the corresponding smith chat, the chat has 2 markers and when a circle is plot around the unity value from 2 to 0.5, having 1 at the centre of the blue circle. It is seen that the markers falls within the circle which shows they can be matched. So also the smith chat on figure 14, this shows the marker point at which there can be a match having an impedance of 57.34ohm –j19.52ohms at a frequency band of 1.9GHz

XIV. CONCLUSION

In other to compensate for the mismatch between the load and the source impedance due to the proximity of the users hand and body, an automatic antenna tuner for planar inverted-F antenna has been used. For the realization of a maximum power transfer, there should be a match between (load) & the source impedance. Pi-network is sandwiched between the load and the source in other to match the impedance.
From the result, when the antenna is modelled with the switch diode and the passive tuning circuit, it is seen from the SWR plot on figure 11 that there are two resonances one at the narrow band frequency of 872MHz with SWR of 1:1.687 and also at the wideband of 1.984GHz, there is SWR of 1:1.84. These values of SWR gotten are acceptable in mobile antenna. Simulation result is gotten from EZNEC shown on figures 7 to figure 10, while the test result is gotten from the plots from the vector network analyser. When the results (plots of the SWR) from the simulation are compared with the plots from the test results from the vector analyser, it is seen that they have a close value of voltage standing wave ratio. This SWR plot falls in the middle of the smith chart centred at 1 +j0 as shown in figure 15. This indicates that there is a match for the antenna.
The design of a small compact antenna operating in different frequency band is achieved, an automatic tuning algorithm has been used which compensates for the mismatch in the source and load impedance of the antenna. Since there is an

acceptable plot of standing wave ratio of 1:2 which is acceptable in mobile antenna, it can be concluded from the results and analysis that the objectives have been achieved.

XV. FUTURE WORK

Future work can be done on this paper by increasing the ease of the antenna tunability to obtain a minimum VWSR. This is because the higher value of voltage standing wave ratio, the greater the mismatch of the impedance is.

The tuning concept that is used can further be applied to more antenna structures. The use of RF MEM components and varactors can be used in place of the switch diode in other to improve the electrical efficiency of the antenna.

Also the analytical tuning algorithm concept can be employed in the determination of components setting of pi- network for the impedance. The development of software for the algorithm can also be developed which can be implemented in mobile network at any frequency range.

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