Design and Optimization of A Mobile Device PCB-PIFL Multiband Antenna for GSM Applications

ARTICLE · OCTOBER 2015

DOI: 10.15680/IJIRSET.2015.0410004

Davies rene Segera
University of Nairobi

ISSN(Online) :2319-8753
ISSN (Print) : 2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

Design and Optimization of A Mobile Device PCB-PIFL Multiband Antenna for GSM Applications

Segera Davies [1], Mwangi Mbuthia [2]

P.G. Student, Department of Electrical Engineering, University of Nairobi, Nairobi, Kenya[1]

Associate Professor, Department of Electrical Engineering, University of Nairobi, Nairobi, Kenya2

ABSTRACT: The latest trend in handset design is slim smart phones that require small, thin, light weight and wideband multiband internal antennas. This trend poses two major challenges in designing a mobile device antenna: how to use a single antenna to cover all the required frequency bands and then how to make the same antenna small enough so that multiple antennas can be deployed within the same device. Although a printed Inverted-F antenna (PIFA) has been a suitable candidate due to its simple modeling and easier fabrication using a printed circuit board (PCB), it has a limitation of a narrow bandwidth characteristic. To address this issue and yet obtain multiband operations for GSM applications, this paper presents the structural optimization of a PIFA antenna which is capacitively loaded with an inverted-L element. The antenna covers GSM-900 and GSM-1800.The results obtained show that the PIFL antenna lower and upper bandwidths determined at -10dB is over 110MHz and 500MHz respectively which covers the above mentioned bands very well with very low return losses of -30dB and -30dB at resonant frequencies 925MHz and 1.795GHz respectively.

KEYWORDS: PCB, Inverted-FL antenna, Bandwidth, GSM

I. INTRODUCTION

There are two major challenges in designing a mobile device antenna: how to use a single antenna to cover all the required frequency bands and then how to make the antenna size small enough so that multiple antennas can be deployed within the same device. For the many antenna types that can be incorporated within mobile devices, a PIFA antenna has proved to be the best candidate because of its low profile, light-weight, easy fabrication [1-6].

Though one of its major limitations is its narrow bandwidth, many researchers have proposed various techniques to improve its bandwidth; **Erik, 2007**[10] suggests that designing an antenna with a relatively longer height (H>= 10mm) is desirable to maximize the radiation resistance and bandwidth of its radiator. **Chung, 2009** [11], also suggested that the bandwidth of a PIFA antenna is directly proportional to the width of the radiating arm. With a width of 1mm and the antenna tuned at 2.4GHz, a 250MHz bandwidth was obtained. And finally **Kim, 2009** [12], suggests an I-slot between two IFAs can enable one attain large bandwidth of 3.5GHz for a wide range of frequency i.e. 4.75-8.25GHz.**Cubedo, 2009** [13] too suggests that creating several radiators for different resonances from a single feed, and inserting slots within the antenna's ground plane creates different resonant currents paths that leads to multi-resonance for multiband operation.

This paper proposes a PIFA antenna capacitively loaded with an inverted-L element to form an inverted-FL antenna for multiband operation. In addition to multiband operation, this approach attains antenna miniaturization in that the size of a single band PIFA antenna is almost the same as that of a multiband inverted-FL antenna. Though loading a PIFA antenna with an inverted-L element increases the antenna height slightly; good operating bandwidth supporting multiple bands (i.e. GSM-900 and GSM-1800) is achieved. For lower frequency operation such as GSM 900 band, the ground plane has to be used as a radiating part. Thus a tight structural optimization of both the antenna and its coplanar ground plane to obtain the minimal size of the antenna and its ground plane for optimal performance is carried out and the results presented.

DOI:10.15680/IJIRSET.2015.0410004

II. RELATED WORK

From the many antenna types that can be incorporated within mobile devices the PIFA antenna has proved to be the best candidate and below is a review of past research works on various techniques employed to enhance its bandwidth and support multiband operation:

Bandwidth Enhancement

One of the major limitations of a PIFA antenna is its narrow bandwidth but various techniques to improve it are outlined below:

Erik, 2007[10], suggested that the important design parameters of a PIFA are the height of the PIFA(H),the length of the PIFA(L,) and the position of the feed point relative to the ground connection of the radiator(D).Generally, a large distance, H from the ground plane is desirable to maximize the radiation resistance and bandwidth of the radiator. A height of 0.8mm was used and the measured results were as follows: a return loss of -16dB at 2.4GHz and the -10dB bandwidth was 2GHz, and the measured gain was 0.7dBi that indicated more than 50% efficiency. On the other hand, **Seong, 2007[4]** proposes that the dimensions of a PIFA antenna structure for optimal performance to be:$L = \lambda/_4$,$W = \lambda/_{40}$ and $H = \lambda/_{14}$. Where H is the height of the PIFA, L is the length of the PIFA and W is the width of the radiating arm. All these combined with a ground plane of length $\lambda/_4$ even tuning becomes easier.**Kim,2012[1]**suggested also that the bandwidth of a PIFA antenna is directly proportional to the width of the radiating arm of the antenna (W).With a width (W) of 1mm the antenna tuned at 2.4GHz a bandwidth of 250MHz was obtained. **Abu,2012[3]**suggests a triple inverted PIFA operating between the wide frequency ranges 4.75-8.2GHz,where an I-shaped slot is inserted in between two IFAs. The width of the I-shaped slot is 4mm and the area covered by this antenna is 12x20mm^2 .The proposed antenna provides a small size with a large a large bandwidth of 3.5GHz (4750-8250MHz) and it also ensures a nearly Omni-directional radiation patterns with peak gain 6.27/5.37/4.47 dBi across the operating bandwidth respectively.

Multiband Operation

With the many telecommunication bands introduced, it is of great need for mobile devices to be equipped with antennas that support multiband operation .**Erik, 2007[10]** proposed that there are two main considerations that govern planar antenna designs; *antenna miniaturization techniques and multiband operation.* Multiband operation can be achieved by using three strategies:

Modification of the main radiator; through multi-branching which involves creating several radiators for different resonances from a single feed. These branches are of monopoles strips or arms to create different paths for different resonances. Elongating the main radiator's physical length to achieve multiple resonant modes without diminishing the antenna's compact feature through spiralling, looping, folding into a 3-D geometry and bending.

Modification of the ground plane: Due to the advancement in Radio frequency (RF) transceivers, the space allocated for its radiating element has become smaller because of the increase in the number of new circuitry needed to provide data channelling. Modification of the radiating element in a compact volume has been very challenging. Thus an alternative solution is a better utilization of its ground plane. Even though the geometry of the main radiating element plays a main role in determining the resonant frequency and other performances of the antenna, the importance of the ground plane as a natural complimentary agent to a radiating current must not be neglected. This modification includes size variation, location of the radiating element within the ground plane area or inserting slots in the ground plane. With respect to the PIFA antenna the bandwidth increases with the length of the ground plane. It was demonstrated in [10] that the increased bandwidth especially with respect to the lowest resonant frequency of operation is achieved with a longer ground plane. Secondary radiators are formed by ground slots, which introduce new resonant frequencies or enhance the already existing ones. The feasibility of this approach to enhance an impedance bandwidth has been demonstrated for a PIFA antenna in [13, 14].

Reconfigurable Approach: With multiband capability, reconfigurable antennas can utilize more efficiently the radio frequency spectrum, facilitating better access to wireless services in modern radio receivers. Reconfigurable antennas are generally divided into two main categories; frequency tuneable and pattern diversity antennas. Furthermore, selection of electronic switches is of paramount importance. Depending on the type of antennas, switches such as varactors, Radio Frequency Microelectromechanical Systems (RF MEMs) and PIN diodes can be used. The choice is general by electrical specification, fabrication complexity, bias requirement, switching time and price [12].

III. DUAL BAND GSM INVERTED-FL ANTENNA DESIGN

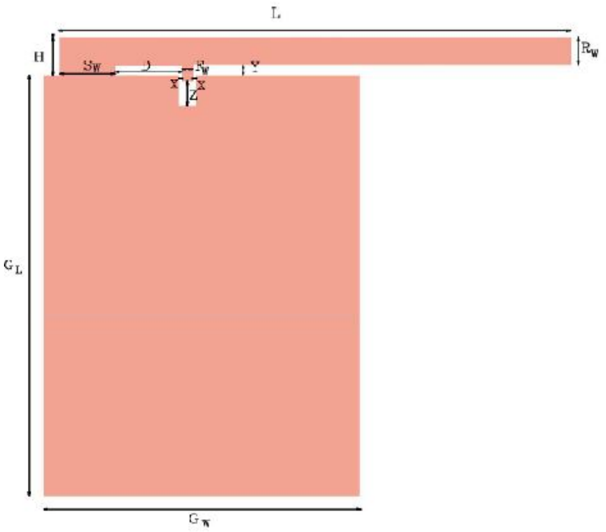

Fig 1: Printed inverted-F antenna (PIFA) element

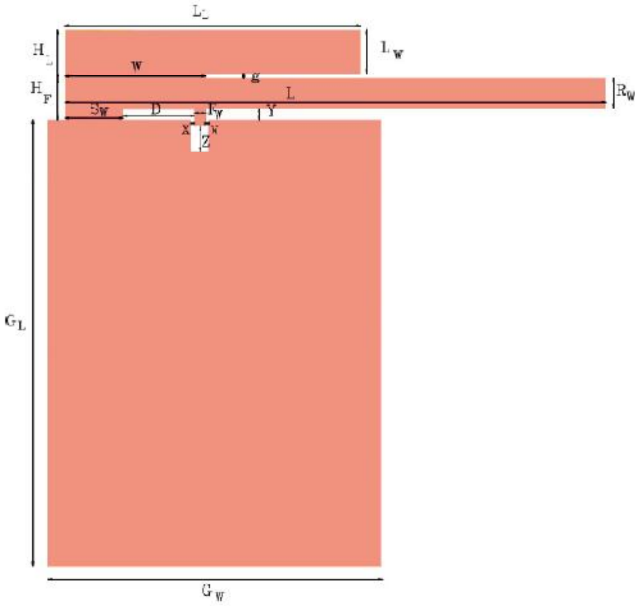

Fig 2: Printed inverted-FL antenna element

Fig. 1 above demonstrates the steps involved in obtaining the inverted-FL antenna. First the inverted-F antenna element covering GSM-900 band alone (figure 1) is designed, after which it is capacitively loaded with an inverted-L element covering GSM-1800 band to form the dual band inverted-FL antenna covering both bands(figure 2).

Both antennas, figure 1 and figure 2 reside on the same plane with their respective ground planes. That is, both antennas have co-planar ground planes.

The final structural parameters for the dual band inverted-FL antenna in figure 2 are obtained through a step-by-step investigation of the following structures:

i) GSM-900 PIFA antenna element design
ii) GSM-1800 Inverted-L element design
iii) Dual band Inverted-FL antenna(a compound of elements i and ii above)
iv) Modification of the inverted-FL antenna and its coplanar ground plane to obtain the two resonant frequencies i.e. 925MHz(center frequency for GSM-900) and 1795MHz(center frequency for GSM-1800)

GSM-900 PIFA antenna element design

From figure 1, the effective length of the current on the PIFA antenna structure is L+H+R_W.Thus the resonant condition can be expressed as follows [9]:

$$L + H + R_W \sim \lambda/4 \qquad (1)$$

The PIFA's resonant frequency is then expressed as follows:

$$f_r \sim \frac{c}{4(L+H+R_W)} \qquad (2)$$

Equation 2 above reflects the similarity that a PIFA has with a monopole antenna. Like a monopole, a PIFA forms a radiating structure through the interaction of the main radiating arm with its image on the ground plane (resembling a dipole).For this reason, the ground plane plays an important role in the radiation characteristics of a PIFA. Empirical data from simulations carried out in research works as [7,8] suggests that the optimal performance can be achieved when the ground plane is at least ${}^{\lambda}/_{4}$ in length in the direction of the dominant current distribution on the ground plane i.e.

$$G_L \sim {}^{\lambda}/_{4} \qquad (3)$$

An attractive feature of a PIFA is the ability to control the imaginary component of its input impedance by changing its layout parameters. Specifically, the distance **D**, between the shorting arm and the vertical portion of the radiating arm (feeder arm) can be used to control the reactive impedance of the antenna. The value of the reactive impedance is inversely proportional to the value of D [7].By varying the distance D, the reactive impedance may be cancelled, resulting in real input impedance.

$$X_A \alpha \, {}^{1}/_{D} \qquad (4)$$

The width, R_W **,** of the main radiating arm of the PIFA controls different characteristics of the antenna. First it controls the reactive impedance (X_A). Increasing R_W of the antenna arm brings it closer to the ground plane (for fixed H) thereby creating a higher capacitance. Another characteristic is the bandwidth (B_W), which is directly proportional to the value of R_W. Increasing the width of the radiating arm extends the operating bandwidth i.e.

$$X_A \alpha \; R_W \qquad (5)$$

$$B_W \alpha \; R_W \qquad (6)$$

Finally, the final characteristic affected by the R_W is the resonance frequency. Alternatively, if the resonance frequency of the antenna must be kept constant, then R_W allows for the length L, to be changed. This fact can be utilized to miniaturize the antenna length. For example, if the width is increased, the length of the antenna can be reduced.

Thus PIFA's effective length at GSM-900 band is approximated to be (L+H+R_W) =81mm=0.25λ_{925MHz} (925MHz being the center frequency for GSM-900 band).

The dimensions of coplanar ground plane as suggested in [12] were set as follows: G_L=0.25λ_{925MHz}=81mm and G_W=0.2λ_{925MHz}=65mm.Once the PIFA dimensions are determined mathematically and the intended board constraints applied, an iterative simulation process in Agilent Advanced Design System (AADS) momentum was conducted to obtain the correct dimensions combination. The simulation results obtained are presented in the next section.

GSM- 1800 Inverted-L element design

To set the resonant frequency of the inverted-L element to 1795MHz (the centre frequency for GSM-1800 band), its structural dimensions are set as follows:

L_L+H_L+H_F= 42mm= 0.25$\lambda_{1795MHz}$.

Dual band Inverted-FL antenna

Compounding a single band PIFA element with an inverted-L element, a dual band inverted-FL structure for dual band operation is formed. For this design, the inverted-L element decides the higher frequency band resonance(i.e. 1795MHz) while the PIFA element controls the impedance matching at the lower frequency band(925MHz).

Although creating multiple resonant paths (branches) of the inverted–FL antenna generates multiple resonances, the coupling between each resonant path makes it difficult to match the dual band antenna at each resonant frequency .However, a modification of the size of the gap between the two arms, **g**, the individual lengths and widths of the arms did help to reduce the coupling and match the antenna at each resonant frequency as depicted in the results given below.

IV. SIMULATION RESULTS

The surface current distribution for the optimized dual band inverted-FL antenna resonant at 925MHz and 1795MHz are shown in figures 3 and 4 respectively. It is evident that there is a stronger current distribution on the longer arm when the antenna is resonant at 925MHz and a stronger current distribution on the shorter arm when the antenna resonates at 1795MHz. Using markers m3 and m4, it can be deduced that the antenna is almost perfectly matched to the transmission line impedance. From figure 5, the antenna has the lowest return loss of -30.319dB at 925MHz and -30.187dB at 1795MHz as depicted by markers m1 and m2 respectively.

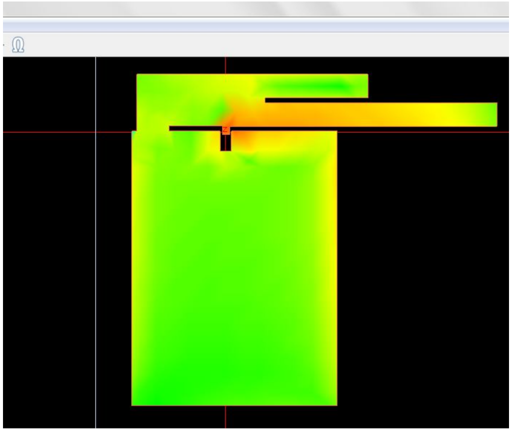

Figure 3: surface current magnitudes at 925MHz

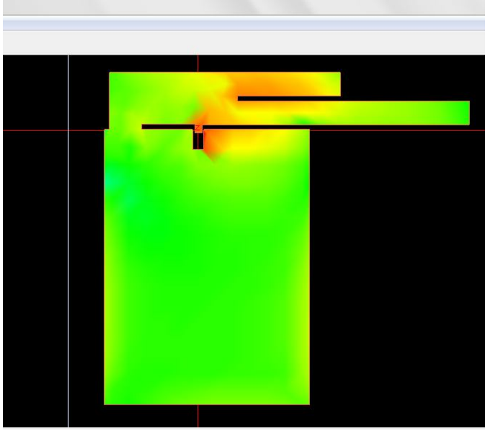

Figure 4: surface current magnitudes at 1725MHz

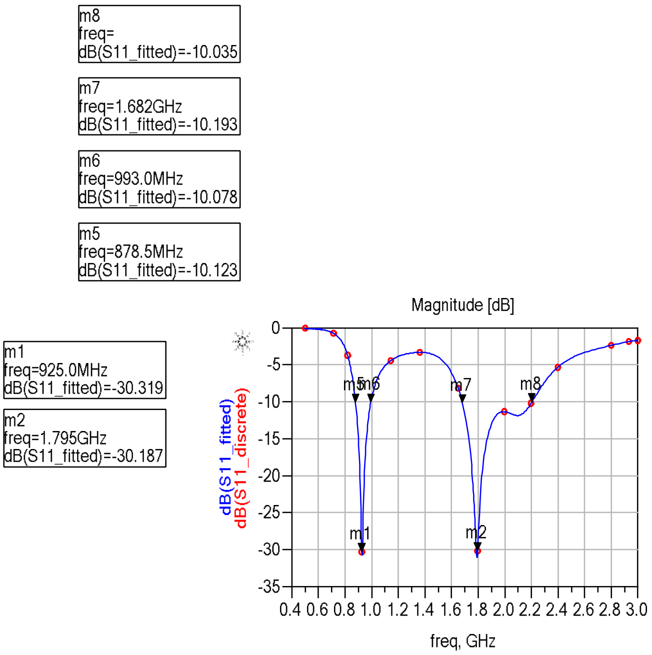

Figure 5: simulated return loss

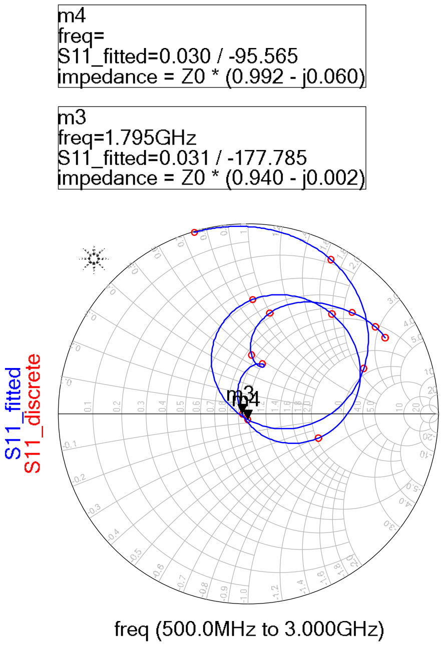

Figure 6: simulated input impedance

V. DISCUSSION

From figure 5, the designed dual band inverted-FL antenna operates efficiently at both GSM-900 and GSM-1800 bands. This is primarily because at both 925MHz (centre frequency for GSM-900) and 1795MHz (centre frequency for GSM-1800), its coplanar ground plane is $0.19\lambda_{925MHz}$x$0.15\lambda_{925MHz}$ and $0.36\lambda_{1795MHz}$x$0.27\lambda_{1795MHz}$ respectively which is therefore relatively large enough to supply a full resonant current distribution at both bands. The antenna can also be viewed to be having two radiating arms. The longer arm covers the GSM-900 band while the shorter arm covers the GSM-1800 band. A further proof that these two arms resonate at the centres of the two frequency bands is depicted in the strength of the excited surface current distributions of figures 3 and 4 respectively. For the 925MHz excitation (see figure 3), a stronger surface current distribution is observed along the longer arm element of the antenna thus suggesting it is the major radiating element at the GSM-900 band. At 1795MHz (see figure 4), the surface current distribution on the shorter arm of the antenna becomes stronger, indicating too that it is the major radiating element at the GSM-1800 band. From figure 5, the antenna's lower bandwidth determined at -10dB reaches 114.5MHz and covers the entire GSM-900 band (i.e. 890-960MHz) while its-10dB upper bandwidth is 512MHz and covers the DCS (1710-1880MHz) and PCS (1850-1990MHz). These sufficient bandwidths were attainable due the widths of the antenna's arms i.e. R_W=5.33mm and L_W.

VI. CONCLUSION

A printed inverted-FL antenna, where the radiating element is a compound of a PIFA antenna and inverted-L elements, adjacent to a coplanar ground plane is presented. The design procedure for dual-band operation at frequencies 900MHz and 1800MHz is described in four steps. In the first step, a PIFA antenna is designed to operate at 900MHz.In the second step, an inverted-L element operating at 1800MHz is designed. Thirdly, the PIFA antenna element is capacitively loaded with the inverted-L element for dual band operation. And lastly, structural adjustments are carried out on the compounded inverted-FL antenna and its co-planar ground to obtain optimal dual frequency operation at the desired frequencies. It is found out that the antenna's lower and upper bandwidths determined at -10dB reach 114.5MHz and 512MHz respectively which covers the above mentioned bands very well with very low return losses of -30.319dB and -30.189dB at resonant frequencies 925MHz and 1.795GHz respectively.

REFERENCES

[1]D.-O. Kim, and C.-Y. Kim D.-G. Yang, "Design of Internal Multi-band Mobile Antenna for LTE700/WCDMA/UMTS/WiMAX/WLAN Operation," PIERS Proceedings, Kuala Lumpur, MALAYSIA, March 27-30, 2012.

[2]Mikko Karkkainen, "Meandered multiband PIFA with coplanar parasitic patches," IEEE Microwave and Wireless Components Letters, vol. 15, pp. 630-632, 2005.

[3]Debabrata Kumar Karmokar and Ashif Raihan Himel Abu Naim Rakib Ahmed, "Broadband Tiny Triple Inverted-F Antenna for 5 GHz WLAN and Bluetooth Applications," ACEEE Int. J. on Communications, vol. 3, pp. 25-29, 2012.

[4]Seong-Ook Park, Young-Sang Yoon, Jeong-Kun Oh, Kyung-Joon Lee, and Gwan-Young Koo Byoung-Nam Kim, "Hexaband Planar Inverted-F Antenna With Novel Feed Structure for Wireless Terminals," IEEE Antennas and Wireless Propagation Letters, vol. 6, pp. 66-69, 2007.

[5]M. Krishna Kumar2 R. Shantha Selva Kumari1, "A Modern Approach for Planar Inverted F Antenna Miniaturization," International Journal of Emerging Technology and Advanced Engineering, vol. 2, pp. 343-351, 2012.

[6]Zhijun Zhang, antenna design for mobile devices, 1st ed. Asia: John Wiley & Sons Pte Ltd, 2011.

[7]A. M. Abbosh ,M. A. Antoniades,A. R. Razali,"Compact Planar Multiband Antennas for Mobile Applications",Ch4, Intech OpenScience,2013.

[8]Agilent, Advanced Design System inbuilt manual.

[9]2, Hosaeng Kim2, Maifuz Ali1, and Seong-Ook Park1 Sangjin Eom1, "Embedded Antenna for Metallic Handheld Communication Devices," Progress In Electromagnetics Research B, vol. 57, pp. 127-138, 2014.

[10]Ngoc-Anh Nguyen, Viet-Anh Nguyen and Seong ook Park Rashid Ahmad Bhatti, "Design of a Compact Internal Antenna for multi-Band Personal Communication Handsets," IEEE Proceedings of Asia-Pacific Microwave Conference, pp. 1-4, 2007.

[11]Ya-Chung Yu and Jenn-Hwan Tarng, "A Novel Modified Multiband Planar Inverted-F Antenna," IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 189 – 192, 2009.

[12]C.W. Jung and K. Kim J. Cho, "Frequency-reconfigurable two-port antenna for mobile phone operating over multiple service bands," IEEE Electronics Letters, vol. 45, pp. 1009 – 1011, 2009.

[13]J. Anguera, C. Picher, M. Ribo, C. Puente A. Cabedo, "Multiband Handset Antenna Combining a PIFA Slots, and Ground Plane Modes," IEEE Transactions On Antennas And Propagation, vol. 57, pp. 2526 – 2533, 2009.

[14]Hyengcheul Choi, and Hyeongdong Kim Sinhyung Jeon, "Hybrid Planar Inverted-F Antenna with a T-shaped slot on the ground plane," ETRI Journal, vol. 31, pp. 616-618, 2009.

[15]Andre' Vander Vorst Houda Halheit, "A Simple Wideband Antenna for Mobile Handset," 3rd IEEE European Conference on Antennas and Propagation,vol.10, pp. 553-555, 2009.

BIOGRAPHY

Eng. Prof. Mwangi Mbuthia was born in Nyeri, Kenya in 1952. He is an Associate Professor in the School of Engineering at the University of Nairobi. He received a B.Sc.(First Class Honours) in Electrical and Electronic Engineering in 1976 from the University Nairobi, An M.Sc. and DIC in 1978 from Imperial College of Science Technology and Medicine in London, and a Ph.D in 1985 from the University of Manchester in England.In 1976 to 1977, he was a graduate engineer trainee with Kenya Power and Lighting Company. In 1978, he joined the University of Nairobi as a lecturer in the Electrical and Electronic Engineering department, rising to Senior Lecturer in 1988. In 1994 he left the University and founded Elcom Systems Ltd. a company providing specialized hardware and software solutions for the telecommunication sector. As the CEO of Elcom Systems Ltd. he has developed and deployed several specialized telecommunication hardware and software solutions for many private and public sector companies and institutions.In 2000, he rejoined the University of Nairobi and he is currently the Dean, School of Engineering. He is a Professional Engineer, a chartered Engineer in United Kingdom and a Member of IEEE.He is the author of more than 30 articles and has created over 15 inventions under Elcom Systems Ltd. His research interests include broadband last mile connectivity devices, special materials and devices for solar power applications, internet of things devices, energy delivery automation and smart grids.

Davies Rene Segera was born in Nyamira, Kenya in October 30, 1988. He received his BSc. Degree in electrical and Information Engineering from the University of Nairobi, Kenya in 2013, where he is currently working towards the MSc. degree in Electrical and Information Engineering. His research interests include embedded systems design, Embedded antenna design, Robotics and compiling Linux images for embedded devices.