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The Effects of a Human Hand on a Wireless Mouse Antenna

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Abstract
In this paper, Finite Difference Time Domain (FDTD) method is used to analyze the effect of a human hand on a wireless mouse antenna. The need for this analysis is based on the fact that human tissues are dielectric in nature and they can, therefore, be treated as electromagnetic absorbers. In the first part, hand effect on reflection coefficient, input resistance, bandwidth and radiation efficiency are studied. In the second part, the variation of radiation efficiency with the position of the hand from the antenna feed point is estimated. The Method of Moments is used to validate the results.
Keywords: Wireless mouse, Antenna dipole, Electromagnetic Field, FDTD, Efficiency.

1. Introduction

One of the accessories that come with a computer is the mouse. It has become an extremely popular technology because it is more convenient for a user to point at an object on the display instead of typing a command [1]. Mouse technology has changed in very significant ways in the last fifteen years. Focus now is, not only on functionalities, but also on design and aesthetics of the devices.

At the same time, users' appetite for better performance and more services has increased. Users are now expecting more attractive and better performing devices [2]. Therefore, wireless mice designers have the challenge of meeting these demands. However, it is hoped that this design challenge can be helped by the many computer-assisted techniques that can simulate different situations.

The Finite Difference Time Domain (FDTD) method, based on the Yee's algorithm introduced in 1966 has proved more accurate and hence reliable over the years for simulating new antenna designs for optimum performance.

Former antenna design studies, including human interactions [3, 4] have particularly focused on mobile phones handsets especially the effect of the head on the antenna. However, recent studies [5], [6], stated that the hand effects were way larger than the head ones

This study sets out to analyze these effects, particularly on wireless mouse antenna, in order to facilitate its design process in the future.

This paper is divided into five sections. The first part provides ample background on the topic. The second section focuses on the method of calculation (FDTD). Section (3) discusses the modelling of a dipole in free space. Section (4) explores the interaction between the wireless mouse and the human hand. Section (5) illustrates the effect of the hand position on the mouse radiation efficiency. Finally, we present our conclusion in section (6).

2. FDTD formulation

In the FDTD approach, both the space and time are divided into discrete segments. Space is segmented into box-shaped cells, which are small in comparison to the wavelength. The electric fields $E_x(i,j,k)$, $E_y(i,j,k)$ and $E_z(i,j,k)$) are located on the edges of the box, and the magnetic fields $H_x(i,j,k)$, $H_y(i,j,k)$ and $H_z(i,j,k)$) are located on the faces as shown in Figure 1. This orientation of the fields is known as the Yee cell [7] and is the basis for FDTD. Time is partitioned into small steps. Each time step is the period a field takes to travel from one cell to the next. The magnetic and electric fields are offset both in space and time. A leapfrog scheme is used to update these fields. For example, updates for the electric fields come first. This is then followed by the updates of the magnetic ones. A combination of many FDTD cells results in a three-dimensional volume called an FDTD grid or mesh. The edges and faces of each cell overlap with their neighbours. Therefore, each cell has three electric fields that begin at a common node associated with it. The electric fields at the other nine edges of the FDTD cell belong to other adjacent cells. Each cell also has three magnetic fields originating on the faces of the cell adjacent to the common node of the electric fields as shown in Figure 1.

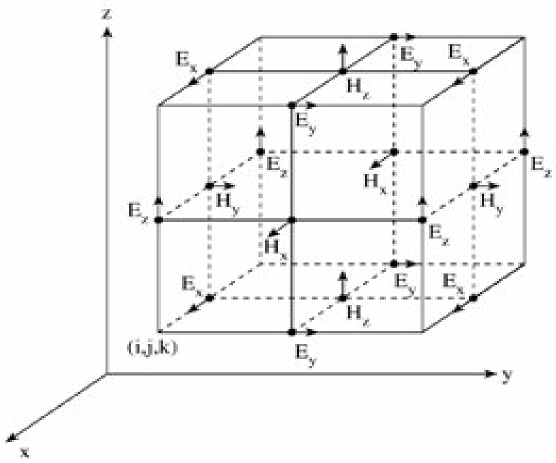

Figure1. Positions of the electric and magnetic field components in a Yee cell [10].

Now we present the Maxwell's equations in three dimensions. We suppose the absence of magnetic or electric current sources and the existence of absorbing materials in the space under study.

$$\nabla \times E + \mu \frac{\partial H}{\partial t} = 0 \qquad (1)$$

$$\nabla \times H - \varepsilon \frac{\partial D}{\partial t} = \sigma E \qquad (2)$$

Where the displacement vector D is related to the electric field through the complex permittivity

$$\overset{*}{\varepsilon_r}(\omega) = \varepsilon_r - j\frac{\sigma}{\omega \varepsilon_0} \quad \text{by} \quad D(\omega) = \overset{*}{\varepsilon_r}.E(\omega) \qquad (3)$$

Where ω is the angular frequency, this gives expressions of the form:

$$E_z\Big|_{i,j,k}^{n+1} = \left(\frac{1-\dfrac{\sigma_{i,j,k}\Delta t}{2\varepsilon_{i,j,k}}}{1+\dfrac{\sigma_{i,j,k}\Delta t}{2\varepsilon_{i,j,k}}}\right) E_z\Big|_{i,j,k}^{n} + \left(\frac{\dfrac{\Delta t}{\varepsilon_{i,j,k}}}{1+\dfrac{\sigma_{i,j,k}\Delta t}{2\varepsilon_{i,j,k}}}\right) \cdot \left(\frac{H_y\big|_{i+1/2,j,k}^{n+1/2} - H_y\big|_{i-1/2,j,k}^{n+1/2}}{\Delta x} - \frac{H_x\big|_{i,j+1/2,k}^{n+1/2} - H_x\big|_{i,j-1/2,k}^{n+1/2}}{\Delta y}\right)$$

$$H_z\Big|_{i,j,k}^{n+1/2} = \left(\frac{1-\dfrac{\rho_{i,j,k}\Delta t}{2\mu_{i,j,k}}}{1+\dfrac{\rho_{i,j,k}\Delta t}{2\mu_{i,j,k}}}\right) H_z\Big|_{i,j,k}^{n-1/2} + \left(\frac{\dfrac{\Delta t}{\mu_{i,j,k}}}{1+\dfrac{\rho_{i,j,k}\Delta t}{2\mu_{i,j,k}}}\right) \cdot \left(\frac{E_x\big|_{i,j+1/2,k}^{n} - E_y\big|_{i,j-1/2,k}^{n}}{\Delta y} - \frac{E_y\big|_{i+1/2,j,k}^{n} - E_y\big|_{i-1/2,j,k}^{n}}{\Delta x}\right) \qquad (4)$$

3. Modeling the wireless mouse and the human hand

3.1 Modeling the wireless mouse

The wireless mouse was designed as a half wave dipole antenna. A simple dipole antenna that consists of two metal arms is illustrated in Figure 3.1.

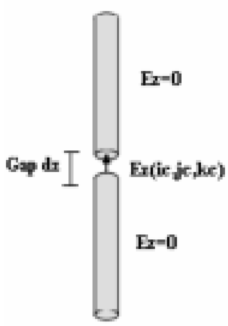

Figure 3.1 Geometry of the dipole antenna model [10]

Current flowing through the arms results in radiation. FDTD simulates a dipole in the following way: The metal of the arms is specified by setting the Ez parameters to zero in the cells corresponding to the metal; except in the place where the source is placed. This ensures that the corresponding Ez field at this point remains zero as well as it would if that point were inside the metal. The dipole is fed at the center (x =xc Δx, y=yc Δy, z=zc Δz). This is a gap of length Δz where a sinusoidal wave called source [8] is applied. The antenna length was held constant at each simulation.

3.2 Electric current

The current in the antenna at the feed point is obtained by applying Ampere's law [8] to the surface S with the bounding contour C on the wire at (ic, jc, kc +3/2):

$$\oint_c \vec{H}.d\vec{l} = \iint_s \vec{J}.d\vec{s} + \varepsilon_0 \iint_s \frac{\partial \vec{E}}{\partial t}.d\vec{s} \quad (5)$$

3.3 Modeling the human hand

The human hand model was designed as a homogeneous hand using the average dielectric properties of the skin, muscle and bones. These values were determined by C. Gabriel and are available in the literature [9]. A simplified homogeneous rectangular hand model was used. These tissue equivalent dielectric parameters were chosen according to [9] to simulate the hand tissue at 2.4125GHz. Since the pointing finger was the part of the hand that affected the wireless antenna most, the hand model was truncated resulting in greatly reduced slab dimensions. Thus, the hand model shape was designed as a dielectric slab. The dimensions of the cubical slab were 1.48 x 1.48 cm x 1.48 cm and the tissue it contained had relative permittivity of $\varepsilon_r = 35.4$ and conductivity of σ=1.81 S/m.

4. Hand effect on dipole antenna

4.1 Validation of the code

Before embarking on simulations, we developed a 3D FDTD program implemented in Matlab code. We used the code to analyze the variation of input resistance with frequency of a half wave dipole antenna radiating in free space at a frequency of 2.4 GHz. We compared our results with the results for the same analysis which was done using the method of moments (MoM) [11]. As Figure 4.1 shows, we obtained a very good agreement.

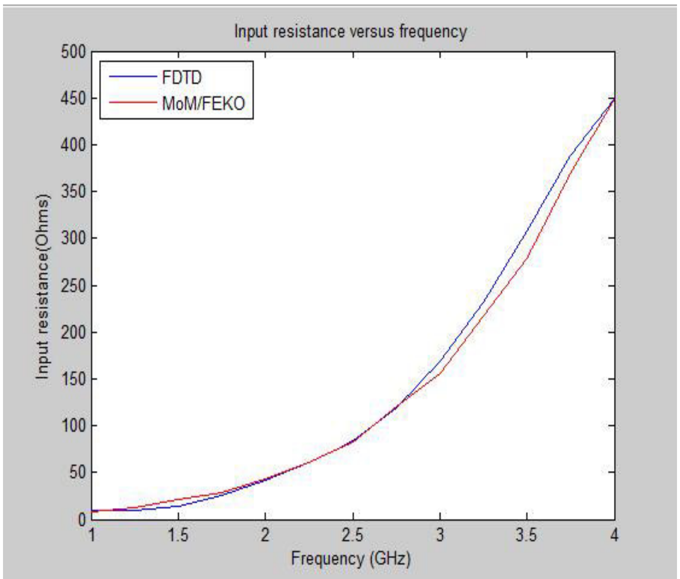

Figure 4.1 Plot of variation of input resistance with frequency.

4.2 Hand effect on near fields

The following results were obtained using the 3D FDTD program implemented in the Matlab software. Figure 4.2 shows the interaction between a plane wave and free space at time step 123. It can be seen that free space does not absorb power from an electromagnetic plane wave. Furthermore, free space does not distort the wave.

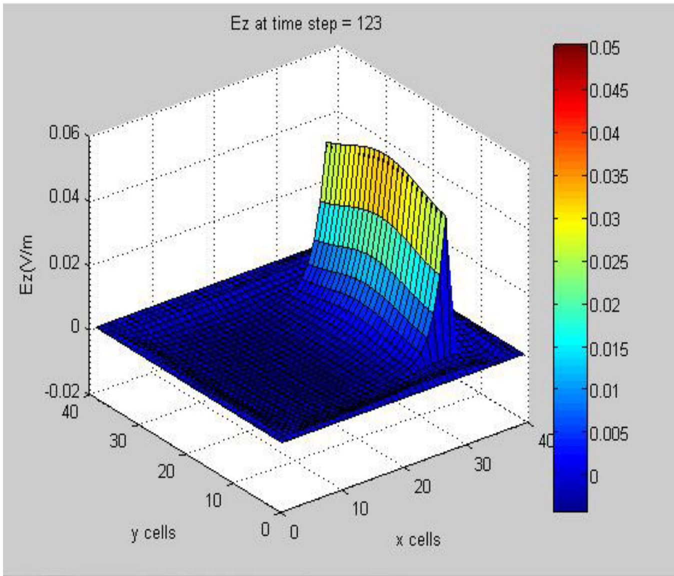

Figure 4.2 Interaction between a plane wave and free space at time step 123.

Figure 4.3 shows the interaction between a plane wave and a human hand at time step 123. It can be seen that hand tissues act as a dielectric and therefore absorb power from an electromagnetic plane wave. Furthermore, the hand distorts the wave.

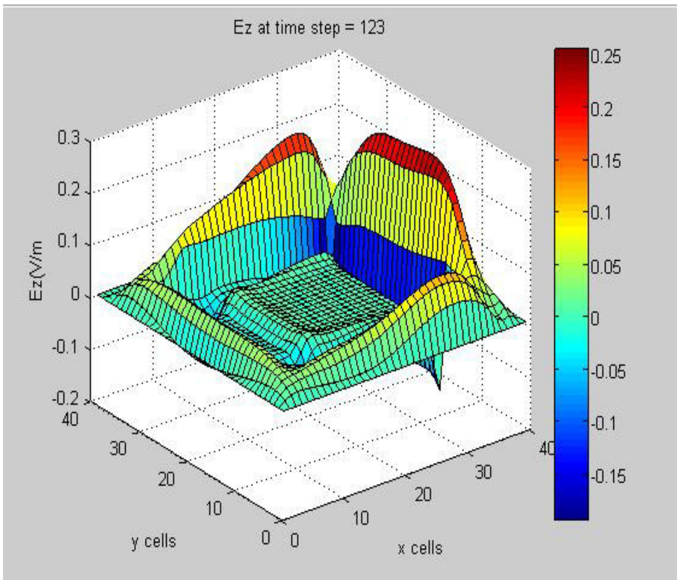

Figure 4.3 Interaction between a plane wave and a human hand at time step 123

4.3 Hand effect on bandwidth

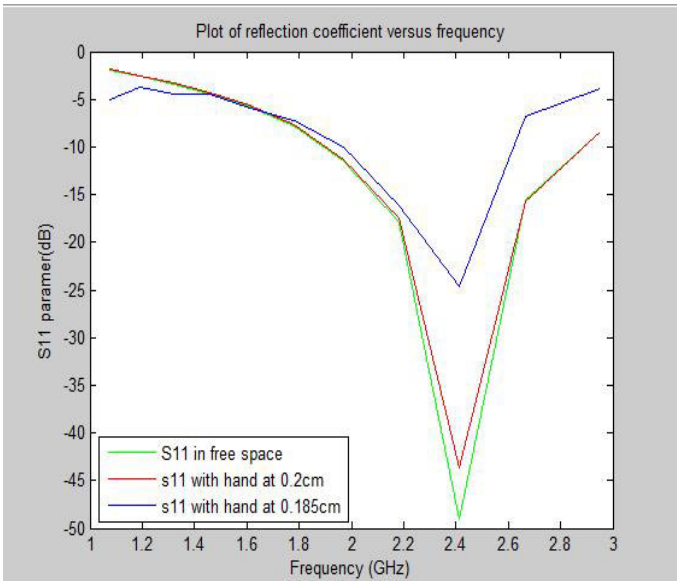

Figure 4.4 Reflection coefficients (s11) versus frequency

The bandwidth of the antenna, which was determined by the impedance data, is the frequency range of the antenna (less than or equal to 1/3) that corresponds to s11 of -6 dB. It can be seen in Figure 4.4 that when the antenna was operating in free space, its bandwidth was about 1GHz (1.9 GHz to 2.9 GHz). However, when the hand was in close proximity, the bandwidth changed to about 0.5 GHZ (2 GHZ to 2.5 GHz at 0.185 cm). This was a reduction of about 500 MHz. The amount of detuning depends on the antenna shape, the near-fields, as well as on the antenna-hand-separation distance

4.4 Hand effect on radiation efficiency

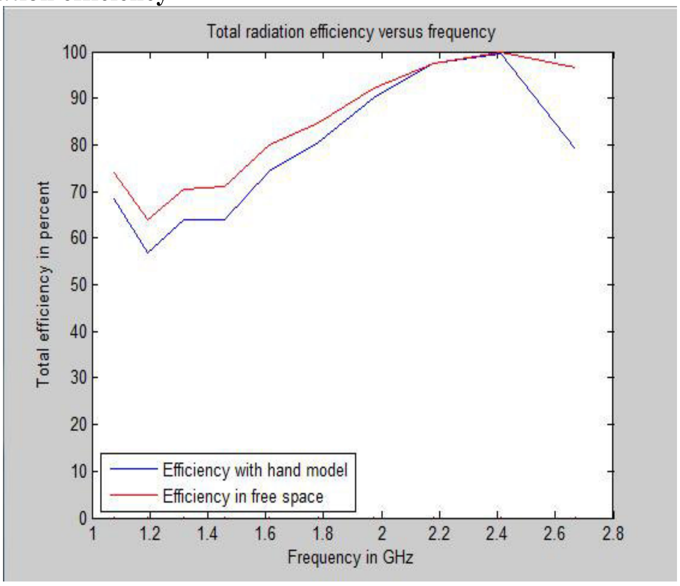

Figure 4.5 Efficiency versus frequency

Figure 4.5 shows the efficiency of the dipole antenna when radiating into free space and when radiating in the presence of a hand. As can be seen, the efficiency of the antenna is decreased by the hand.
The pointing finger can alter the electromagnetic field distribution and absorb power when it enters the reactive near-field of the antenna. In this region, the electric field is strong and since power loss is comparable to the square of the electric field, absorption is large. As the finger moves away from the near field region, the absorbed power decreases.

5. The effect of hand position from the antenna feed point on wireless mouse radiation

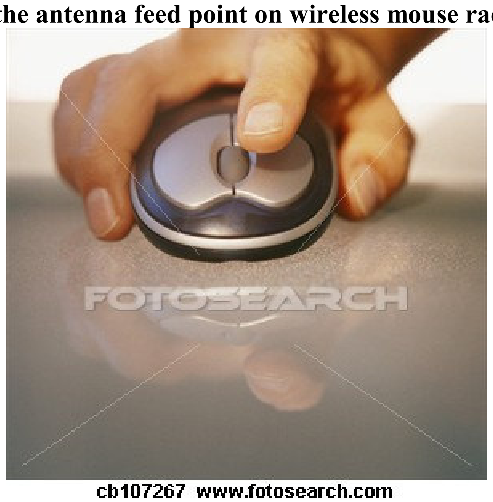

Figure 5.1 Hand Holding Wireless Computer Mouse
(CB107267 Corbis Royalty Free Photograph)

Figure 5.1 was used as a reference in terms of specifying the position of the pointing finger. When the finger is said to be at the middle of the wireless mouse the finger is just above the scroll wheel at the middle. In the above figure, the finger is to the left of the middle.

5.1 Hand position effect on input resistance

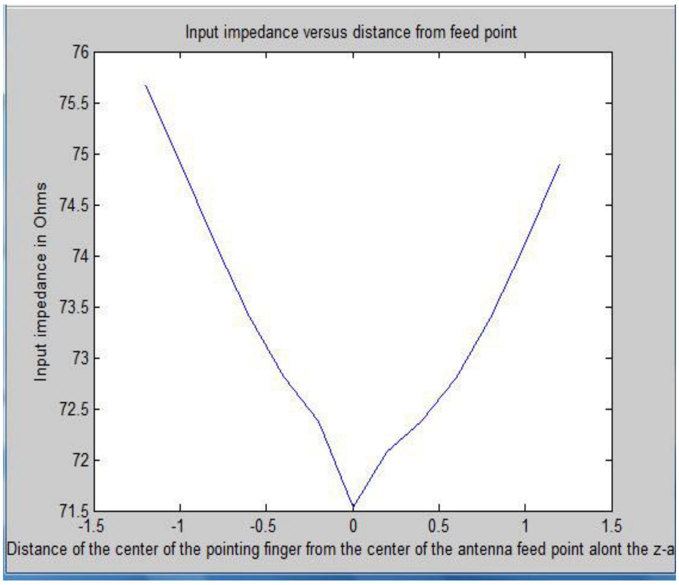

Figure 5.2 Input resistance versus distance from the feed point (middle).

Figure 5.2 shows that when the pointing finger is at the middle of the wireless mouse the amount of input resistance is small. As the finger is moved about 0.3cm to the left the resistance increases. The same case applies when the finger is moved to the right. However, it can be seen that there is no balance in the two arms of the antenna.

5.3 Hand position effect on radiation efficiency

In order to determine the effect o a human hand on the wireless mouse efficiency, it was necessary to ignore the reduction of efficiency due to other dielectrics such as the PCB and mouse plastic cover. In this way, we were able to isolate the effect of the hand tissues.

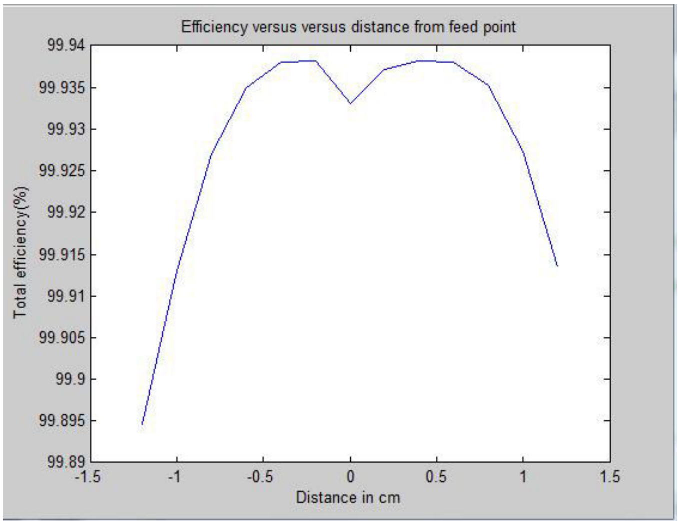

Figure 5.3 Total radiation efficiency variation with distance from feed point.

Figure 5.3 shows that when the pointing finger is at a distance within the range 0.25 cm to 0.75 cm from the middle of the wireless mouse, we have the largest antenna efficiency. At the middle of the mouse, there is a dip in efficiency because the pointing finger is very near the antenna feed point.

6. Conclusion

Our computer code based on FDTD technique used in the analysis of the problem under discussion has been validated using MoM and existing data in the public domain. The important parameters of the wireless mouse that are affected by a human hand such as input resistance, reflection coefficient, bandwidth (resonance frequency) and efficiency, have been evaluated. Our study has established that the hand decreases the input resistance of the mouse. Generally, bandwidth decreases with decrease in impedance and vice-versa, however, in our case there are other factors, as well, which affect the bandwidth. The effect on bandwidth, for example, depends on the distance of the hand from the mouse antenna: Bandwidth decreases with the decrease in the separation of the hand from the wireless mouse and vice versa. We established that the hand also reduces the efficiency of the mouse antenna. This can be explained by the fact that the human hand absorbs energy and hence mouse efficiency is affected. It was further established that the wireless mouse antenna's efficiency depends on the position of the pointing finger. When the finger is at a distance within the range 0.25 cm to 0.75 cm from the middle of the wireless mouse, antenna's efficiency is relatively high. However, antenna's efficiency deteriorates when the finger is located at distances greater than 0.75cm from the middle of the mouse. At the middle of the mouse, there is a dip in efficiency because the pointing finger is very near the antenna feed point.

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Biographies

Prof. Dominic B. Onyango Konditi was born in Kochia, Homa Bay County on 22 July, 1950. Dr. Konditi is a full Professor of Electrical & Electronic Engineering at Technical University of Kenya, Nairobi. He earned PhD in Electronics and Communication Engineering from Indian Institute of Technology Roorkee in 2000 and Masters of Engineering, M.Eng., in Electrical Engineering from Tottori University, Japan, in 1991, a Higher Diploma in Electrical Engineering (Communication Engineering option) from Technical University of Mombasa, Post-Graduate Certificate in Electromagnetic Compatibility and Electromagnetic Interference (EMC/EMI) from Dresden University of Technology (DUT), Republic Germany, in 2005. Professor is the recipient of SAHA Gold Medal Award for their Best Application - Oriented paper published in the Institution of Electronics & Telecommunications Engineers (IETE) journal in 2001. Dr. Konditi has supervised successfully two (2) PhD students and fourteen (14) MSc. Degree students. He has authored and coauthored over twenty five (25) papers in refereed journals and over fifteen (15) in reviewed conference papers and a couple of invited talks. His interests are in integral equation methods, numerical analysis, and electromagnetic theory, development of hybrid surface/volume integral equation method for scattering problems, application of Fourier series expansion technique and hybrid finite element/Moment method for the analysis of High frequency fields, treatment of nonlinear problems.

Prof. Stephen Musyoki is an Associate Professor of Electrical & Electronic Engineering at Technical University of Kenya, Nairobi. He holds a D.Eng degree in electronics from Tohoku University, Japan. His research interests are in computational electromagnetics, mobile telephony and computer networks. He has published widely in areas of his interest.

Mr. Rainsford Karanja Njoroge is an assistant lecturer of Electrical and Communication Engineering at Multimedia University of Kenya. He obtained a B.Tech degree at Moi University, Kenya and is currently a post graduate student at Jomo Kenyatta University of Agriculture and Technology at Juja, Kenya. He conducts researches in Telecommunication.