ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

Effect of Electromagnetic Energy on Different Biological Tissues

RATNA KUMAR.Y[1], RAJU. G.S.N[2]

Assistant Professor ,Department of Electronics and Communication Engineering, College of Engineering,

Andhra University, Visakhapatnam, Andhra Pradesh, India[1,2]

Abstract: In order to apply electromagnetic energy for the treatment of different tumors. The characteristics of the biological tissues are required to be established. In view of this some studies are made in the present work to estimate the propagation characteristics through different biological tissues. The relative absorption of electromagnetic energy is evaluated. The present work involves the estimation of the above data for different polarization of incident energy. The data presented in this work are extremely useful for the design of sources for the above applications.

Keywords: Different tumors, Frequency, Biological Tissues, electromagnetic energy, polarization

I. INTRODUCTION

Electromagnetic energy is used for the treatment of tumors in different tissues of human body. It is common practice to study the behavior of electromagnetic waves in homogenous media. It is well known that the homogeneous media is characterized by the constant values of permittivity, permeability and conductivity throughout the medium. On the other hand, non homogeneous media are a medium for which the above fundamental parameters are not constants and are different from point to point in the media. The hyperthermia treatments are categorized as a whole body regional or local. In this treatment, specific thermal effects such as structural energy exist when boundaries between different types of tissues or particles can be selectively treated without the substantial effect of the surrounding body. The rational for the whole body hyperthermia is that the cancer is a systemic disease and the cancer cells have metastasized throughout the body in most of the cases.

The interaction of time varying electric fields in EM wave with the human body results in the flow of electric charges, the polarization of bound charge and the reorientation of electric dipoles already present in the tissue. The relative magnitudes of these different effects depend on the fundamental properties of the body that is electrical conductivity (governing the flow of electric current) and permittivity (governing the magnitude of polarization effects). Electrical conductivity and permittivity vary with the type of body tissue and also depend on the frequency of the applied field.

It has been possible to find out relative electromagnetic energy absorption characteristics of the data on fundamental properties of the tissues. In order to apply electromagnetic energy for treatment of tumors, its penetration characteristics are evaluated as a function of frequency. The frequency dependent absorption of electromagnetic energy in biological tissue is illustrated by the use of Debye equations and measured fundamental properties, such as conductivity and permittivity of different tissues [6]. In view of this, the fundamental properties of two adjacent tissues at microwave frequency measured and presented in this chapter.

When electromagnetic waves are propagating within a human body, two adjacent tissues will absorb power per unit volume measured by using Debye equations and is presented for different tissues in this chapter. This data provides useful information for the applications of electromagnetic radiation therapy. Biological tissue is highly scattering medium, in the EM energy. The attenuation constant in the biological tissue is a function of frequency, conductivity, permittivity and permeability of the bio-tissue.

We know that the depth of penetration is its reciprocal. The electrical properties of biological material throughout the total frequency range are due to relaxation phenomenon. Exposure to low frequency electric and magnetic fields results in negligible energy absorption and no measurable temperature rise in the body. Exposure to electromagnetic fields at microwave frequencies can lead to significant absorption of energy and temperature increases. The resultant effect depends on polarization of the radiation fields, ambient temperature, air circulation, body size, resistance and such other factors.

II. RELATIVE ABSORTION OF BIOLOGICAL TISSUES

The microwave radiations interact with biological tissues by the induced changes when they incident. They create force and hence charges in every state. The frequency dependence of conductivity and permittivity is directly related to the polarization of molecules and structural interfaces as a result of the applied electric field within the biological tissue.

A specific polarization effect is important in determining conductivity and permittivity up to a relaxation frequency where the induced polarization can no longer change as fast as the applied field. The biological tissues are of dielectric in nature. The dielectric constant of such tissues is given by,

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

$$\epsilon_r = \frac{I+\frac{P}{\epsilon_0}}{I} \tag{1.1}$$
$$\epsilon = \epsilon_0 + \frac{p}{I} \tag{1.2}$$

Where p is the polarization.
I is Electric field intensity, v/m.
ϵ is dielectric constant.

The dielectric constant of bio-tissues, usually are complex and frequency dependent. Because most types of polarization can be described formally in the same qualitative manner, the Debye equations often apply very well, even though they were derived for the case of molecular rotation.

It is required to find out the absorption characteristics of the biological tissues. The absorption characteristics of biological tissue can be measured from the relative characteristics of adjacent tissues and the frequency dependent absorption of electromagnetic energy is calculated by Debye equations, model calculations for different irradiation conditions also.

The power absorbed by each tissue is proportional to the square of the incident electric field of the electromagnetic wave. It has been possible to find out the ratio of power absorption from the knowledge of conductivity, dielectric constant and polarization.

The two adjacent tissues in the human body will absorb power per unit volume in the ratio is given by,

$$\frac{A_{p2}}{A_{p1}} = \frac{\sigma_2}{\sigma_1}\left|\frac{I_2}{I_1}\right|^2 \tag{1.3}$$

Where
σ_1 = conductivity of tissue1, (mho/m)
σ_2 = conductivity of tissue 2, (mho/m)
I_2= Electric field intensity within tissue1, V/m
I_1 = Electric field intensity within tissue2, V/m
A_{P_2} = Absorb power per unit volume of tissue 2, W/m^3
A_{P_1} = Absorb power per unit volume of tissue 1, W/m^3

When an electromagnetic wave is allowed to incident on the tissue 2 in such a way that electric field is parallel to the interface between the tissues, two adjacent tissues absorb power. Under these conditions the electric fields are tangent to the interface between the pair of tissues and they are equal.

When the electric fields are perpendicular to the interface, the conduction and displacement currents become continuous across the interface.

III. RESULT ANALYSIS

The relative absorption of electromagnetic energy is found out by considering the cases below.

CASE 1: The electric field vector of EM energy parallel to the interface between tissues1 and 2.
The boundary condition is E_1=E_2
The relative absorption power ratio in equation (4.3) becomes,

$$\frac{A_{p2}}{A_{p1}} = \frac{\sigma_2}{\sigma_1} \tag{1.4}$$

CASE 2: The electric field vector of EM energy perpendicular to the interface between tissues. The conduction and displacement currents must be continuous across the interface as [113].

$$(\sigma_2 + j\omega\sigma_2)E_2\,(\sigma_1 + j\omega\epsilon_1)E_1 \tag{1.5}$$
$$\left|\frac{E_2}{E_1}\right| 2 = \frac{\sigma_1^2+\omega^2\epsilon_1^2}{\sigma_2^2+\omega^2\epsilon_2^2} \tag{1.6}$$

Where Є is the electrical permittivity of the respective tissue and ω is the radian frequency

Now,

$$\frac{A_{p2}}{A_{p1}} = \frac{\sigma_2}{\sigma_1}\left(\frac{\epsilon_1}{\epsilon_2}\right)^2 \frac{1+(\sigma_1/\omega\epsilon_1)^2}{1+(\sigma_2/\omega\epsilon_2)^2} \tag{1.7}$$

CASE 3: EM energy incident upon tissue 2 from tissue 1, the tissue2 is a sphere and its radius □, small compared to the wavelength in tissue 1 [114] is,

$$\frac{E_2}{E_1} = \frac{3}{2+\frac{\epsilon_2^*}{\epsilon_1^*}} \tag{1.8}$$

Here,

$$\frac{\epsilon_2^*}{\epsilon_1^*} = \frac{\epsilon_2 - j\sigma_2/\omega}{\epsilon_1 - j\sigma_1/\omega} = \frac{\epsilon_2\left(1-j\frac{\sigma_2}{\omega\epsilon_2}\right)}{\epsilon_1\left(1-j\frac{\sigma_1}{\omega\epsilon_1}\right)} \tag{1.9}$$

And,

$$\frac{E_2}{E_1} = \frac{3(1-j\sigma_1/\omega\epsilon_1)}{2+\frac{\epsilon_2}{\epsilon_1}-j\left(\frac{2\sigma_1}{\omega\epsilon_1}+\frac{\sigma_2}{\omega\epsilon_1}\right)} \tag{1.10}$$
$$\frac{A_{p2}}{A_{p1}} = \frac{\sigma_2}{\sigma_1}\frac{9[1+(\sigma_1/\omega\epsilon_1)2]}{\left(2+\frac{\epsilon_2}{\epsilon_1}\right)2\left(\frac{2\sigma_1}{\omega\epsilon_1}+\frac{\sigma_2}{\omega\epsilon_1}\right)} \tag{1.11}$$

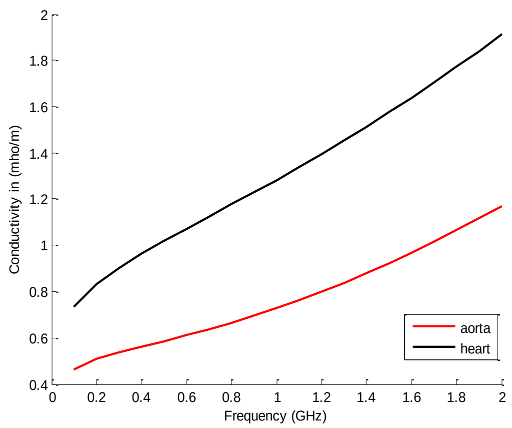
CASE 4: EM energy incident upon tissue 2 from tissue 1, the tissue2 is a long Cylinder of radius.

$$\frac{E_2}{E_1} = \frac{2}{1+\frac{\epsilon_2^*}{\epsilon_1^*}} \tag{1.12}$$
$$\frac{E_2}{E_1} = \frac{2(1-j\sigma_1/\omega\epsilon_1)}{\left(1+\frac{\epsilon_2}{\epsilon_1}\right)-j\left(\frac{\sigma_1}{\omega\epsilon_1}+\frac{\sigma_2}{\omega\epsilon_1}\right)} \tag{1.13}$$

And,

$$\frac{A_{p2}}{A_{p1}} = \frac{\sigma_2}{\sigma_1}\frac{4\left[1+\left(\frac{\sigma_1}{\omega\epsilon_1}\right)^2\right]}{\left(1+\frac{\epsilon_2}{\epsilon_1}\right)^2+\left(\frac{\sigma_1}{\omega\epsilon_1}+\frac{\sigma_2}{\omega\epsilon_1}\right)^2} \tag{1.14}$$

The frequency dependence of energy absorption directly related to the polarization of molecules and structural interfaces as a result of the applied electric field with in the biological tissue.



ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

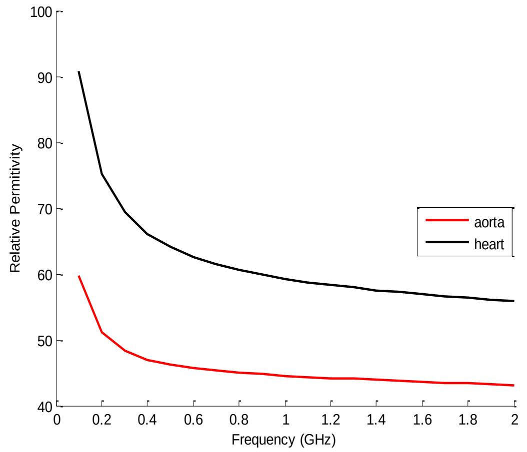


Fig 1.1: The fundamental properties of Conductivity (σ) of adjacent tissues Aorta and Heart variation with Frequency.
Fig 1.2: The fundamental properties of Relative ermittivity (ε_r) of adjacent tissues Aorta and Heart variation with Frequency.

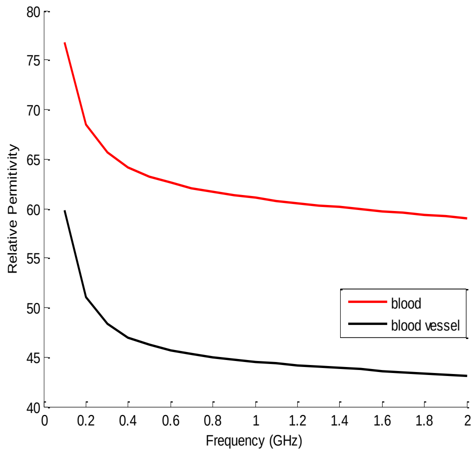


Fig 1.4: The fundamental properties of Conductivity (σ) of adjacent tissues Blood and Blood vessel variation with Frequency.
Fig 1.5: The fundamental properties of Relative Permittivity (ε_r) of adjacent tissues Blood and Blood vessel variation with Frequency.

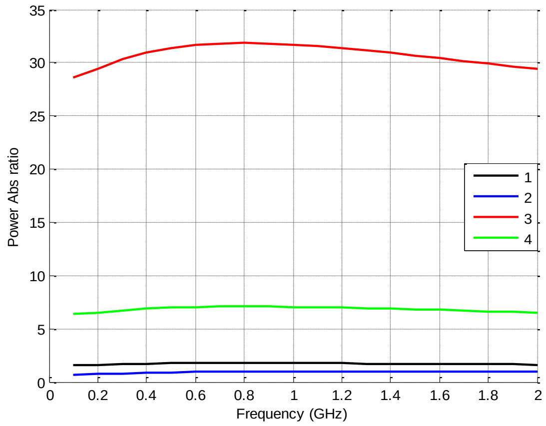


Fig 1.3: plot of Power absorption ratio P_{a2}/P_{a1} vs. Frequency with Aorta and Heart for the irradiation conditions:

1) E parallel to interface 2) E Perpendicular to interface 3) Heart sphere within Aorta, and 4) Heart cylinder within Aorta

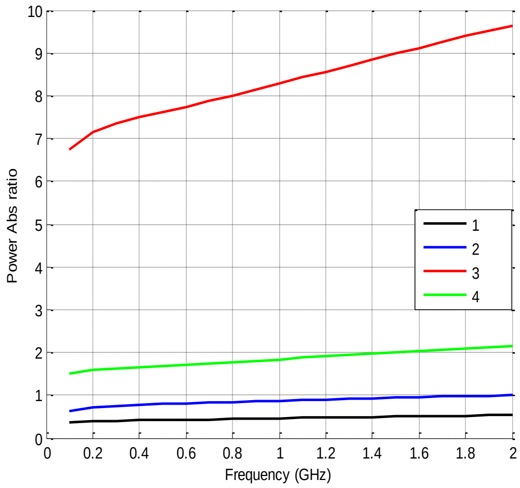
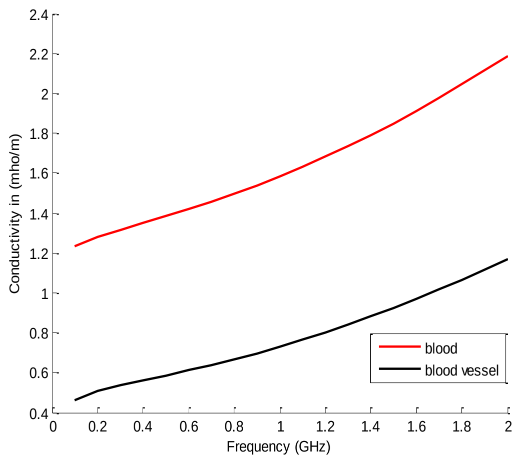
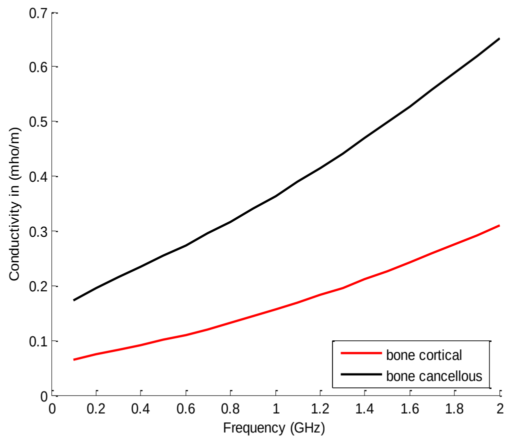


Fig1.6: plot of Power absorption ratio P_{a2}/P_{a1} vs. Frequency with blood and blood vessel for the irradiation conditions:
1) E parallel to interface 2) E Perpendicular to interface 3) Blood vessel sphere within blood, and 4) Blood vessel cylinder within blood





ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

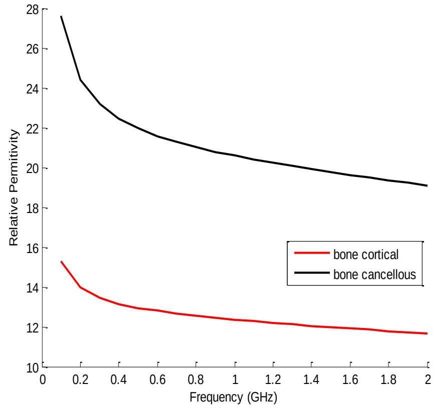


Fig 1.7: The fundamental properties of Conductivity (σ) of adjacent tissues Bone cortical and Bone cancellous variation with Frequency.

Fig 1.8: The fundamental properties of Relative Permittivity (□$_r$) of adjacent tissues Bone cortical and Bone cancellous variation with Frequency.

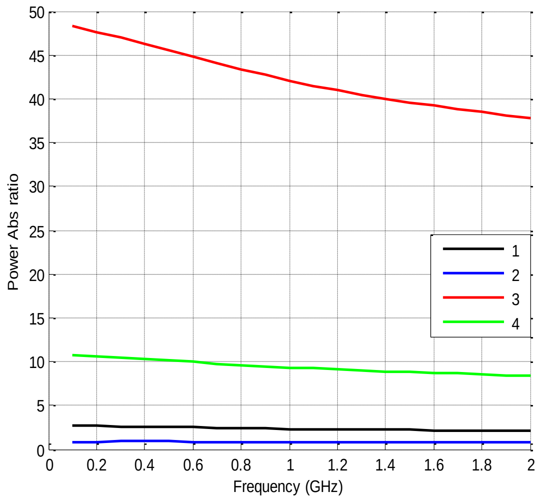
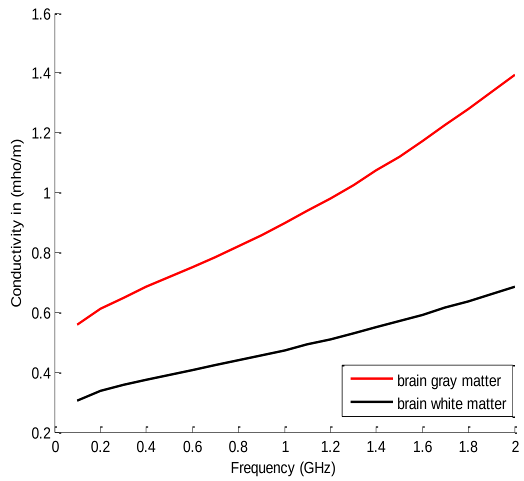


Fig1.9: plot of Power absorption ratio P_{a2}/P_{a1} vs. Frequency with Bone cortical and Bone cancellous for the irradiation conditions:

1) E parallel to interface 2) E Perpendicular to interface 3) Bone cancellous sphere within Bone cortical and 4) Bone cancellous cylinder within Bone cortical



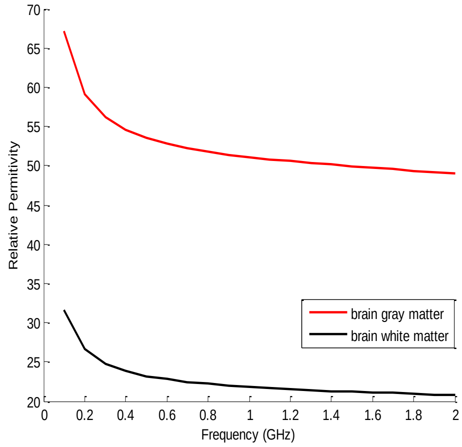


Fig 1.10: The fundamental properties of Conductivity (σ) of adjacent tissues Brain gray matter and Brain white matter variation with Frequency.

Fig 1.11: The fundamental properties of Relative Permittivity (□$_r$) of adjacent tissues Brain gray matter and Brain white matter variation with Frequency

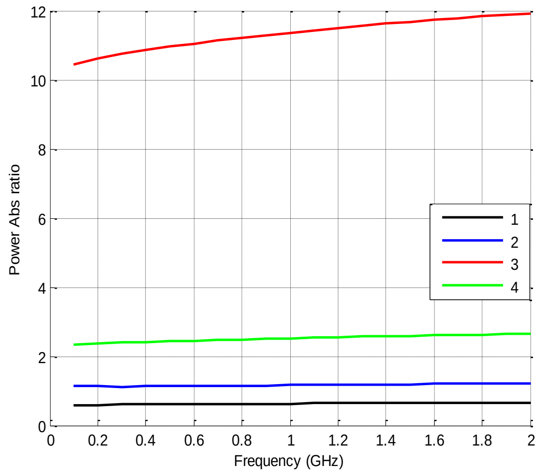


Fig 1.12: plot of Power absorption ratio P_{a2}/P_{a1} vs. Frequency with Brain gray matter and Brain white matter for the irradiation conditions:

1) E parallel to interface 2) E Perpendicular to interface 3) Brain white matter sphere within Brain gray matter, and 4) Brain white matter cylinder within Brain gray matter

IV. CONCLUSIONS

The relative absorption of Electromagnetic energy in the tissues of Aorta/heart, Blood/blood vessel, Bone Corticle/bone cancellous and Brain Gray Matter/brain white matter has been evaluated for different polarization of incident energy at different frequencies. From the results, it is found that the largest power absorption observed in a Bone Cancellous Sphere within bone corticle is 48.25 at 0.1 GHz frequency. Similarly, power absorption at other tissues is also evaluated as a graphical representation. The data evaluated here is very much useful for the application of Electromagnetic energy for the treatment of different tissues.

V. REFERENCES

[1] John W Strohtech, “Hyperthermia and cancer therapy,” IEEE, BME – 31, No. 12, December 1984.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 8, August 2014

[2] H.C. Nants, "Pyrogen therapy of cancer," Proc. Int Symp. Cancer therapy by hyperthermia and radiation, 1976, pp 239-250.
[3] G.M. Hahn, "Hyperthermia and cancer," New York, Planum, 1982.
[4] N.B. Hornbeck, Hypertherma and cancer : Human Clinical trial experience, Vol. I and II, FL CRC Press, 1984.
[5] G.S.N. Raju, "Electromagnetic Field Theory and Transmission Lines," Pearson Education (Singapore) Pte. Ltd., New Delhi, 2005.
[6] William T. Joines, "Frequency dependent absorption of electromagnetic energy in biological tissue," IEEE Trans. on biomedical engineering, Vol. BME-31, No. 1, January 1984.

BIOGRAPHIES

Dr. Y. Ratna Kumar did his B. Pharmacy in JNTUH and M. Tech (Biomedical Engg.) in Andhra University. At present, he is Assistant Professor (C) in the Centre for Biomedical Engineering, Dept. of Electronics and Communication Engineering, AU College of Engineering (A), Visakhapatnam, under the guidance of Prof. G.S.N. Raju. He is a life member of MPCI, SEMCE (I), BMSI, and ISB.

Dr. G.S.N. Raju received his B.E., M.E. With distinction and first rank from Andhra University, Visakhapatnam and Ph.D. from IIT, Kharagpur. He is Professor of Electronics and Communication Engineering in Andhra University College of Engineering, Visakhapatnam, India. He is in teaching and research for the last 30 years , Andhra University, Visakhapatnam. He guided 16 Ph.D.s in the fields of Antennas, Electromagnetics, EMI/EMC and Microwave, Radar Communications, Electronic circuits. Prof. Raju has published about 260 technical papers in National/ International Journals/Conference Journals and transactions. He is the recipient of "The State Best Teacher Award" from the Government of Andhra Pradesh in 1999, "The Best Researcher Award" in 1994, Prof.Aiya Memorial "National IETE Award" for his best Research guidance in 2008 and "Dr. Sarvepalli Radha krishnan Award for the Best Academician of the year 2007". He was a visiting Professor in the University of Paderborn and also in the University Karlsruhe, Germany in 1994. At present he holds the positions of Principal, Andhra University College of Engineering (A), Visakhapatnam, Chief Editor of National Journal of Electromagnetic Compatibility, India. Prof. Raju has published five textbooks "Antennas and Wave Propagation", "Electromagnetic Field Theory and Transmission Lines", "Electronics Devices and Circuits", "Microwave Engineering", Radar Engineering and Navigational Aids".Prof. Raju has been the best faculty performer in Andhra University with the performance index of 99.37%.