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Investigations on the Penetration Properties of Electromagnetic Waves in Biological Media

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Abstract

Interaction of Electromagnetic radiation with the human body is a complex function of numerous parameters. The electromagnetic radiation is characterized by its frequency, intensity of electric and magnetic fields, their direction and polarization characteristics in free space. The fields inside the tissues of biological bodies can interact with them and therefore it is necessary to determine these fields for any meaningful and general quantification of biological data[4] obtained experimentally or theoretically. This data is very useful in the treatment of tissues, usually, EM energy at specified frequencies. As this requires knowledge of the penetration characteristics through a conducting media, variations of depth of penetration for various tissues are obtained.

Keywords: Electromagnetic radiation, intensity, electric and magnetic fields, polarization, free space, biological bodies, tissues, treatment, penetration

Introduction

Interaction of non-ionizing EM waves with biological bodies and tissues results in thermal heating as well as non-thermal effects such as a field - force effect, polarization and depolarization of body cell membranes. The maximum recommended safe power limit for long-term human exposure has been specified as 10 mW.cm-2 in the US [5]. Yet use of power densities up to 590 mW.cm-2 is common in routine diathermy treatments. So it is important to understand the limits of EM power exposure that the human body can sustain without any crucial biological damage.

In the frequency range of 1 MHz to 300 GHz, wavelengths of EM waves are in the range of 300 m to 1 mm and are larger compared to the cell size. Hence there is little scattering of EM waves by a human body in this frequency range. The normal laws of reflection and transmission of waves can be applied in this range. As EM waves propagate through a human body, propagating EM energy can get absorbed by the muscles and tissues producing localized heating[2]. Fields in the EM waves also may cause other non-thermal effects such as electromechanical field force in the cells and polarization and depolarization of cell membranes. The heating of tissues, possible results from both ionic conduction and vibration of the dipole molecules of the water and the protein in tissue cells.

In this paper the propagation of Electromagnetic waves was analyzed and the property of depth of penetration was observed in the analysis.

Derivation of Wave equations in a Homogeneous Medium:

The behavior of electromagnetic fields in the presence of material media is governed by Maxwell's equations [1] of macroscopic electrodynamics.

$$\nabla x H = \dot{D} + J \tag{1}$$

$$\nabla x E = \dot{B} \tag{2}$$

$$\nabla \bullet \overset{*}{D} = \rho \tag{3}$$

$$\nabla \bullet B = 0 \tag{4}$$

Where E = Electric field strength
H = Magnetic field strength
B = Magnetic field strength
D = Electric Displacement
J = Electric Current Density
P = Electric charge density

The propagation constants γ is complex number having real and imaginary part designated by α and β respectively. That is, $\gamma = \alpha + j\beta$, actually the square

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root of γ^2 has two values, but for the sake of convenience, we shall agree that is that the value of the square root which has a positive real part (given by α) [3]. It may be shown easily that if α is positive, β is also positive.

$$\therefore \alpha = \sqrt{x} = w\sqrt{\frac{\mu\epsilon}{2}[\sqrt{1+\frac{\sigma^2}{w^2\epsilon^2}}+1]} \quad (5)$$

$$\beta = \sqrt{y} = w\sqrt{\frac{\mu\epsilon}{2}[\sqrt{1+\frac{\sigma^2}{w^2\epsilon^2}}+1]}$$
(6)

Depth of Penetration

The depth of penetrationδ, is defined as that depth in which the wave has been attenuated to 1/e or approximately 37 percent of its original value. Since the amplitude decreases by the factor $e^{-\alpha x}$ it is apparent that at that distance x, which makes $\alpha x = 1$, the amplitude is only 1/e times its values at x-0. By definition this distance is equal to δ, the depth of penetration; so

$$\alpha\delta = 1 \text{ or } \delta = 1/\alpha \quad (7)$$

The general expression of the depth of penetration is

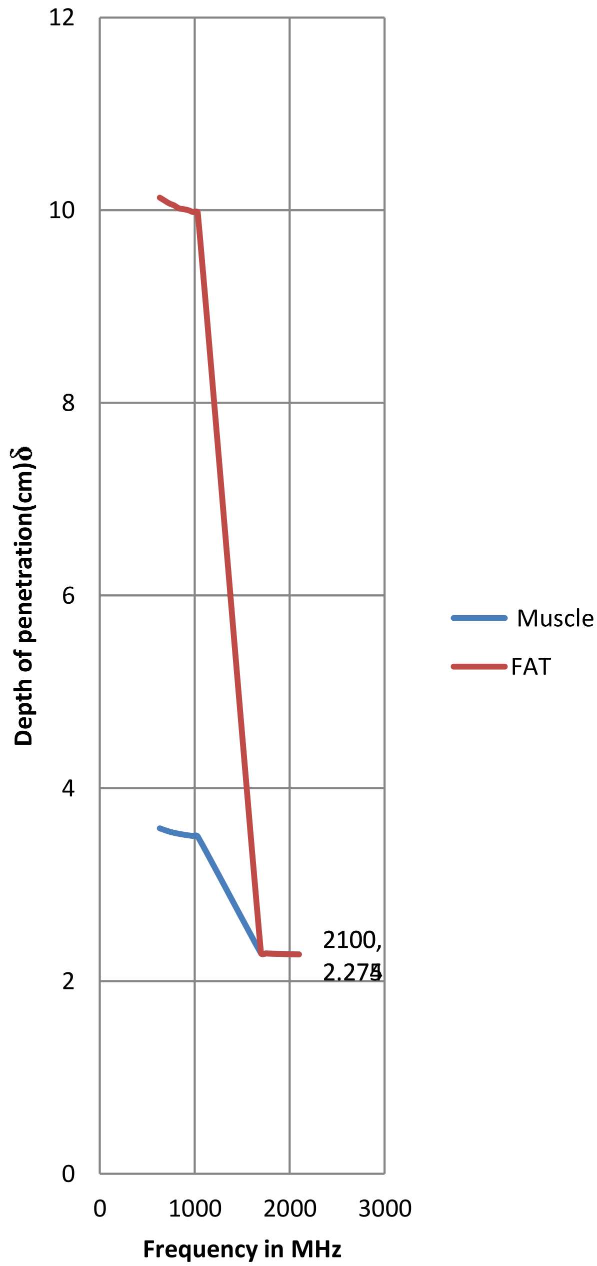
$$\delta = \frac{1}{\alpha} = \frac{1}{w\sqrt{\frac{\mu\epsilon}{2}[\sqrt{1+\frac{\sigma^2}{w^2\epsilon^2}}-1]}} \quad (8)$$

$\therefore$ Depth of penetration = 1/Attenuation

The reciprocal value of attenuation is the depth of penetration.

Results and discussion

Fig. 1: EM-wave penetration characteristics of MUSCLE and FAT



In Fig. 1 the penetration of Electromagnetic wave through the muscle and fat tissues was observed. It was observed that the Electromagnetic waves penetrated deep in fat tissues compared to the muscle tissues.

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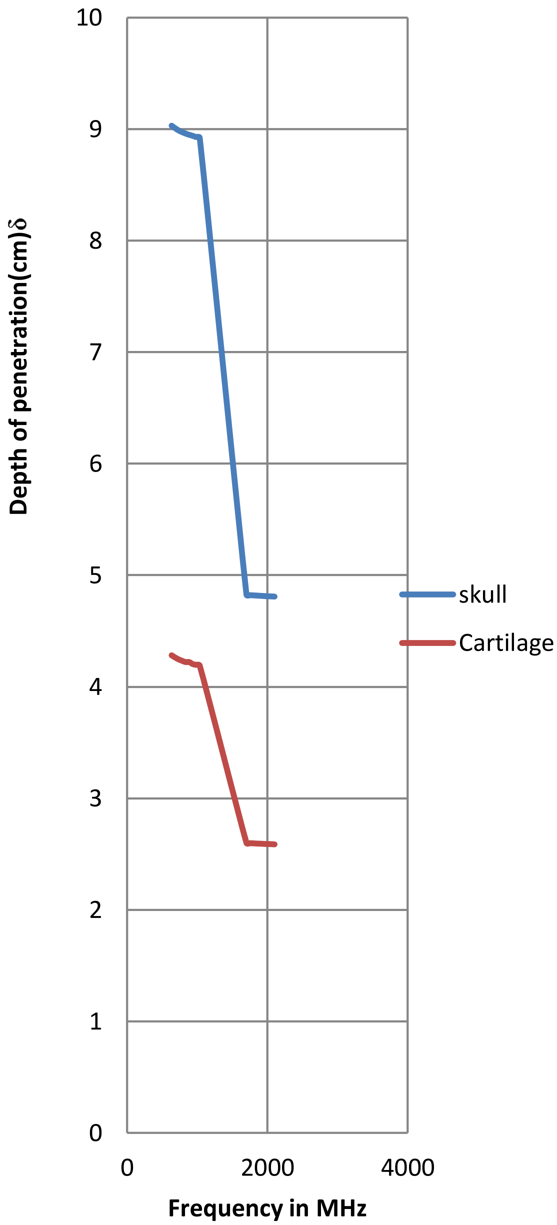
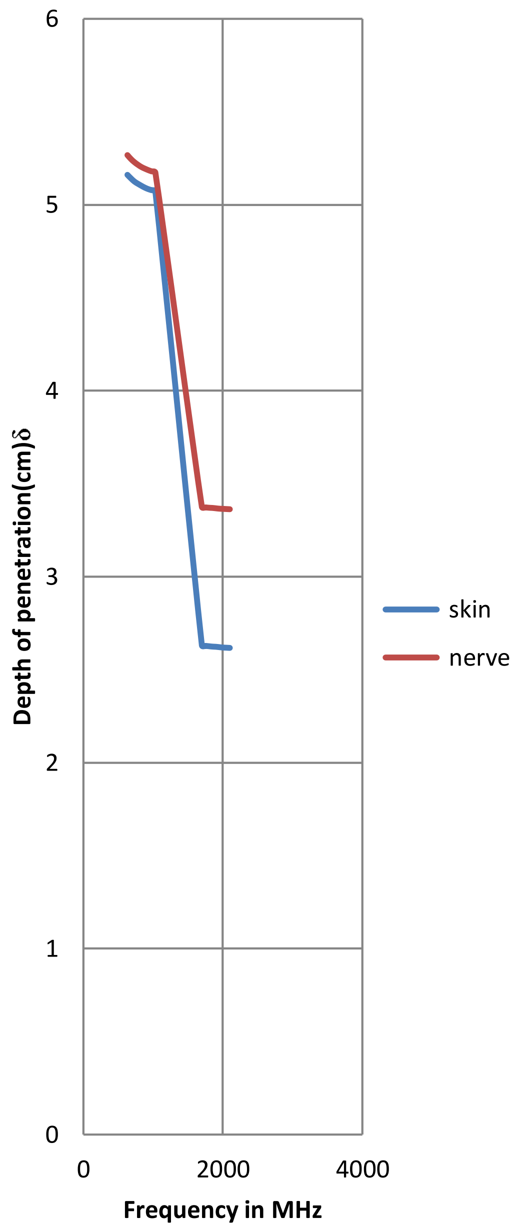
Fig. 2: EM-wave penetration characteristics of BONE(SKULL) and CARTILAGE



In Fig. 2 the penetration of Electromagnetic wave through the bone(skull) and cartilage tissues was observed. It was observed that the Electromagnetic waves penetrated deep in skull tissues compared to the cartilage tissues.

Fig. 3: EM-wave penetration characteristics of SKIN and NERVE



In Fig. 3 the penetration of Electromagnetic wave through the skin and nerve tissues was observed. It was observed that the Electromagnetic waves penetrated similarly through both the skin and nerve tissues.

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Fig. 4: EM-wave penetration characteristics of BLOOD and PAROTID GLAND

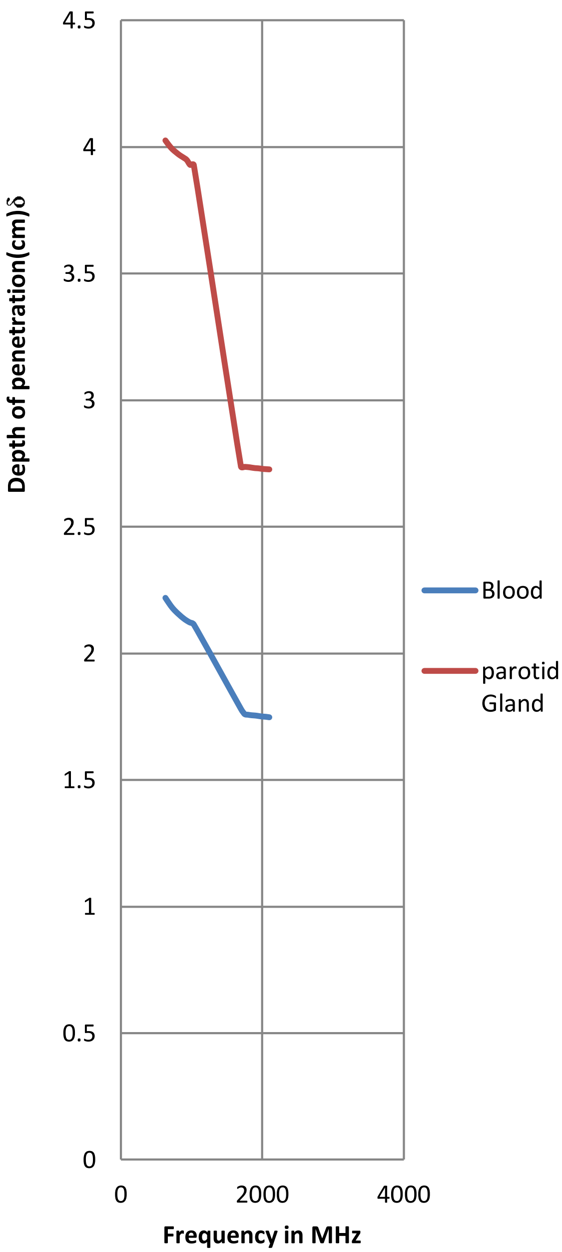
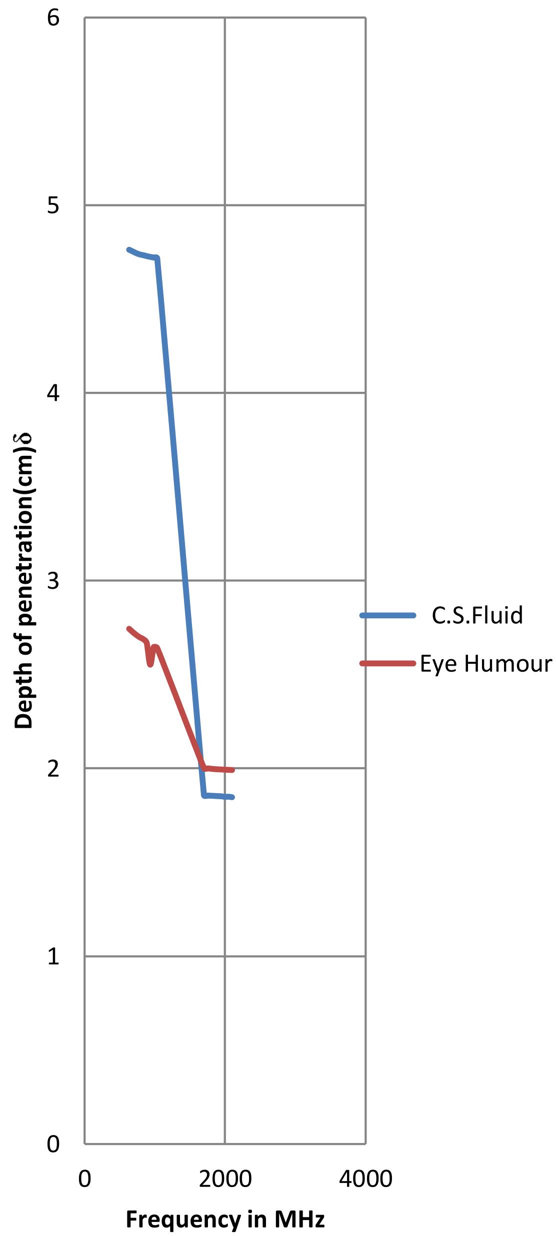


Fig. 5: EM-wave penetration characteristics of C.S.FLUID and EYE HUMOUR



In Fig. 4 the penetration of Electromagnetic wave through the blood and parotid gland tissues was observed. It was observed that the Electromagnetic waves penetrated deep in parotid gland tissues compared to the blood.

\In Fig. 5 the penetration of Electromagnetic wave through the cerebro spinal(C.S) fluid and eye humour was observed. It was observed that the Electromagnetic waves penetrated deep in cerebro spinal(C.S) fluid compared to the eye humour at around 1GHz, but at higher frequencies around 3GHz both have a similar depth of penetration.

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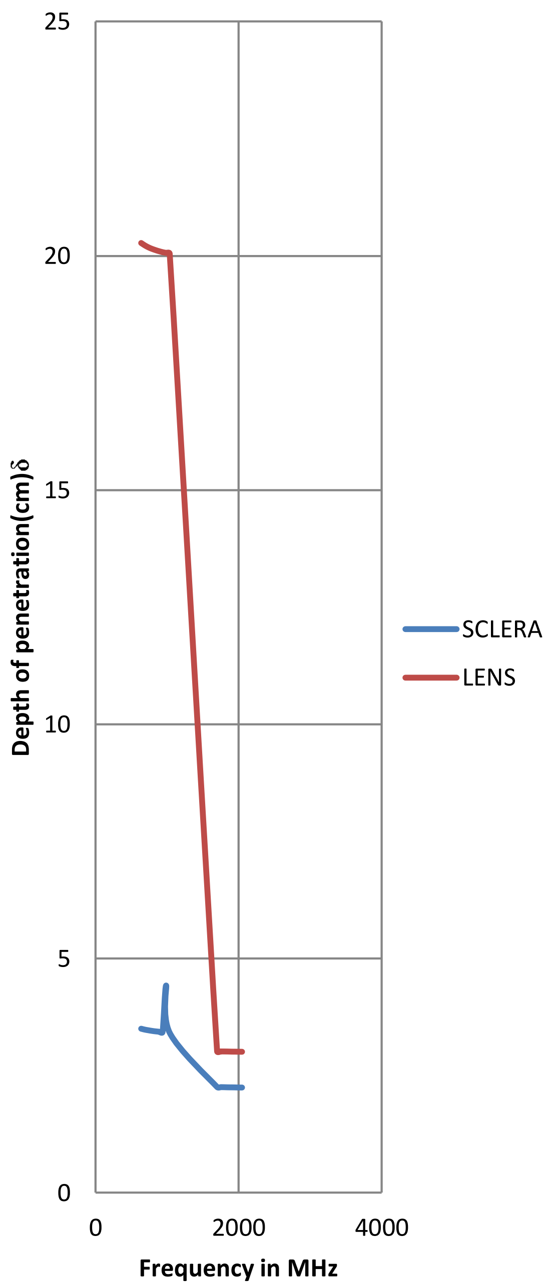
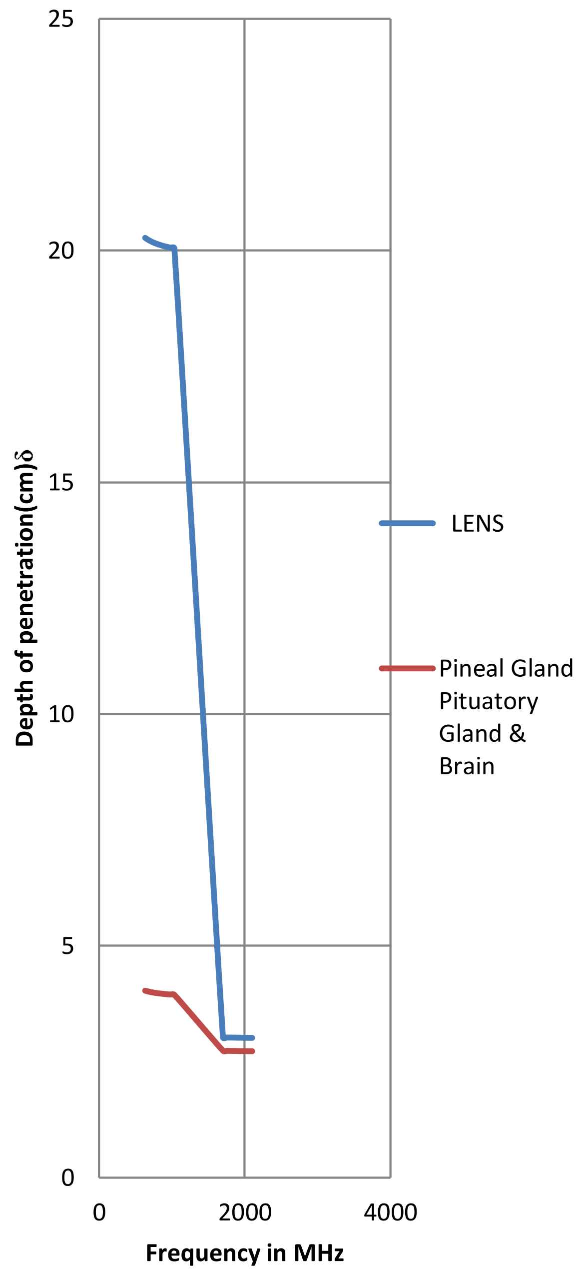
Fig. 6: EM-wave penetration characteristics of SCLERA and LENS



In Fig. 6 the penetration of Electromagnetic wave through the Sclera and Lens tissues was observed. It was observed that the Electromagnetic waves penetrated deep in Lens tissues compared to the Sclera tissues.

Fig. 7: EM-wave penetration characteristics of LENS and PINEAL GLAND PITUATORY&BRAIN



In Fig. 7 the penetration of Electromagnetic wave through the Lens and Pineal Gland Pituatory&Brain tissues was observed. It was observed that the Electromagnetic waves penetrated deep in Lens compared to the Pineal Gland at around 1GHz, but at higher frequencies around 3GHz both have a similar depth of penetration.

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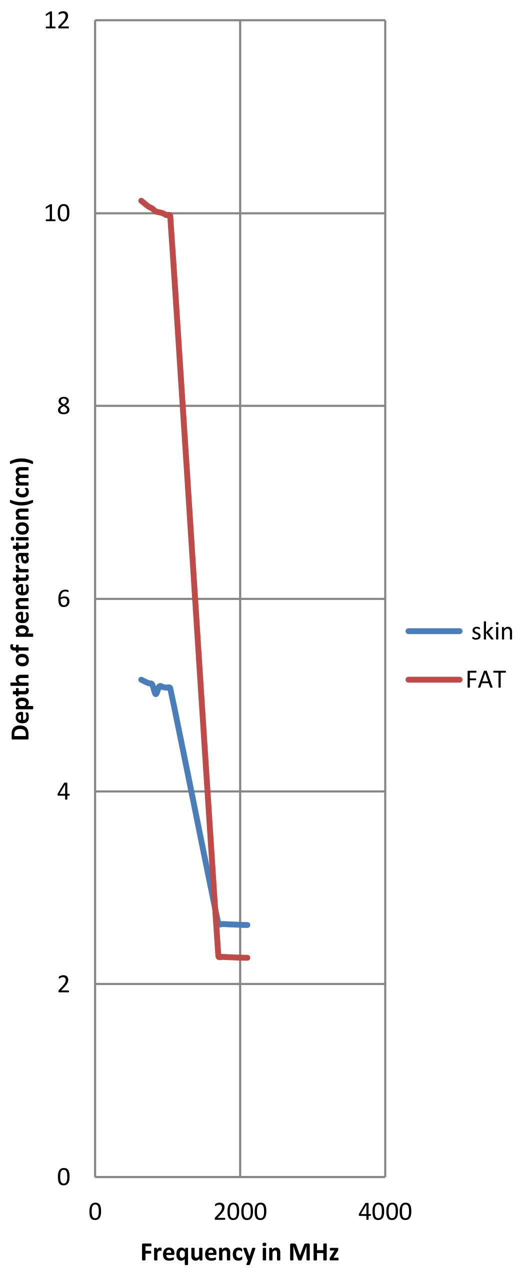
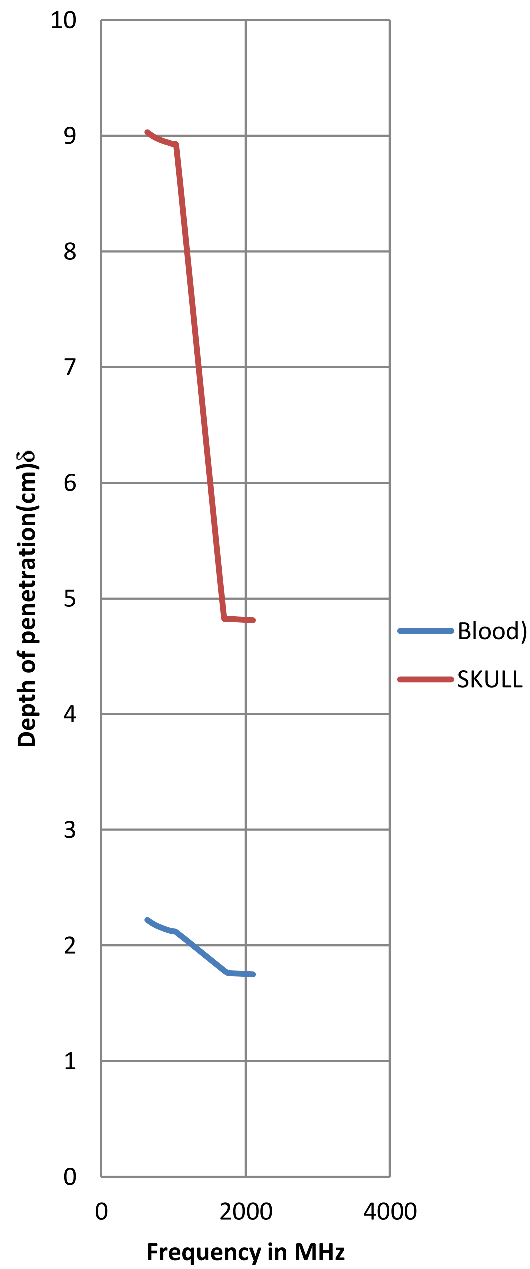
Fig. 8: EM-wave penetration characteristics of SKIN and FAT



In Fig. 8 the penetration of Electromagnetic wave through the skin and fat tissues was observed. It was observed that the Electromagnetic waves penetrated deep in fat compared to the skin at around 1GHz, but at higher frequencies around 3GHz the Electromagnetic waves penetrated deep in skin compared to the fat tissues.

Fig. 9: EM-wave penetration characteristics of BLOOD and SKULL



In Fig. 9 the penetration of Electromagnetic wave through the blood and skull tissues was observed. It was observed that the Electromagnetic waves penetrated deep in skull tissues compared to the blood.

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Conclusion

Thus the penetration characteristics of Electromagnetic waves on various human tissues in a frequency range of 100 MHz to 10 GHz. The depth of penetration of the Electromagnetic waves was observed in case of various tissues and compared with each other. The depth of penetration of Electromagnetic waves was observed high in the case of the tissues of the lens. The lowest depth of penetration was observed in case of blood than any other tissues.

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