Tensorial Computation of the Intensity of UHF Electromagnetic Radiation within Geometrical Structures.

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ABSTRACT

In this paper, a tensorial method was used in computing the intensity of Ultra High Frequency(UHF) radiation within 2D and 3D geometrical structures. This was done based on the theoretical concepts of classical electromagnetism. Using a software program, "power estimator" the intensities at various distances from the source of radiation were obtained and it was found that shapes which are less geometrically homogenous exhibits high intensity values and that the maximum intensity value was observed within a cylinder to be 1534.70w/m² at 0.02m away from the source of radiation, while the minimum intensity value was observed in a circle at 0.10m away from the source to be 2.49w/m².

Indexing terms/Keywords

Computation, Tensor, Electromagnetic Radiation, UHF, Geometrical Structures

Academic Discipline And Sub-Disciplines

Computer science; Physics; Mathematics

SUBJECT CLASSIFICATION

Physical sciences; Computational sciences; Environmental sciences.

TYPE (METHOD/APPROACH)

Tensorial method; Quasi-computational approach; Theoretical analysis.

[1.0] INTRODUCTION

In the 1800's Scientists were able to unlock the second strongest force that governs the universe, the electromagnetic force, where electricity and magnetism are unified into a single entity, setting into motion the physics of electromagnetism. Because electromagnetic radiation exists naturally in the universe, it is necessary that we investigate the intensity of this radiation and center it on shapes of different kinds.

Numerous Literatures and articles have addressed the computation of intensity, Vibratory power flow through and within various shapes. (Petersson, 1993; Wohlever *et al.*, 1992; Pinnington *et al.*, 1981 and Hamberic, 1990). However much of the investigations and research has been understandably conducted on very simple shapes such as frameworks of two-dimensional rods. (Petersson,1993; Goyder *et al.*, 1980; Wohlever *et al.*, 1992 and Paschetta, 2015). The study of vibratory power flow in more complicated structures and shapes such as those comprised of parabola, ellipse, cylinder as well as plates has given rise to the use of computational and structural methods (Forman, 2003). Since this investigation is more of sstheoretical analysis, we made use of Maxwell's equations which serve as the fundamental model for all such theoretical analysis involving macroscopic electromagnetic phenomena.

So we use as a starting point the time dependent description of Electromagnetic (E.M) wave model to investigate the behavior of waves in various shapes since the physics of electromagnetic phenomena exists in space and time (John, 2006).

It is obvious that the use of theoretical approaches causes large computational problems, since we are to calculate the rate at which energy flows per unit area of the various shapes involved. So as a rule to solve this problem, we employ the use of various fast algorithms, and computer software which significantly reduces computation time.

[2.0]. THEORETICAL BACKGROUND.

The vectorial cross product of two vectors **a** and **b** may be denoted by:

$$c = a \times b = \varepsilon_{ijk} a_i b_j x_k \tag{1.0}$$

We see immediately that the k^{th} component of the vector c can be written as;

$$c_k = a_i b_j - a_j b_i \tag{1.1}$$

(Bo, 2004).

Eq. (1.1) has an immediate implication that eq. (1.0) can be seen as an anti-symmetric tensor of rank two. Having eq. (1.0) on one hand and eq. (1.1) on the other hand, we rewrite Faraday's law

$$\nabla \times \mathrm{E} = -\dot{B}$$

As

$$\frac{\partial E_j}{\partial x^i} - \frac{\partial E_i}{\partial x^j} = -\dot{B}_{ij}, \tag{1.2}$$

The fields in terms of the vector and scalar potentials are such that

$$\mathrm{B} = \nabla \times \mathrm{A} \tag{1.3}$$

$$\mathrm{E} = -\nabla \emptyset - \dot{A} \tag{1.4}$$

In component form, these can be written as:

$$B_{ij} = \frac{\partial A_j}{\partial x_i} - \frac{\partial A_i}{\partial x_j} = \partial_i A_j - \partial_j A_i \tag{1.5}$$

$$E_i = -\frac{\partial \emptyset}{\partial x^i} - \frac{\partial A_i}{\partial t} = \partial_i \emptyset - \partial_t A_i, \tag{1.6}$$

i.e **A** is a vector potential and $\emptyset$ a scalar potential. Using;

$$A^{\mu} = \left({}^{\emptyset}/_{c},\ A \right) \tag{1.7}$$

The four-tensor can be defined as;

$$F^{\mu v} = \frac{\partial A^{v}}{\partial x_{\mu}} - \frac{\partial A^{\mu}}{\partial x_{v}} = \partial^{\mu} A^{v} - \partial^{v} A^{\mu} \tag{1.8}$$

(Bo,2004).

This we do to describe the electromagnetic fields using tensor notation. Eq. (1.8) is an anti-symmetric four-tensor of rank 2. It is the electromagnetic field tensor which in matrix representation is written as,

$$(F^{\mu\nu}) = \begin{pmatrix} 0 & -E_x/_c & -E_y/_c & -E_z/_c \\ E_x/_c & 0 & -B_z & B_y \\ E_y/_c & B_z & 0 & -B_x \\ E_z/_c & -B_y & B_x & 0 \end{pmatrix}$$

(Jim, 2013).

The covariant field tensor is obtained from the contravariant field Tensor by index lowering:

$$(F_{\mu\nu}) = \begin{pmatrix} 0 & E_x/_c & E_y/_c & E_z/_c \\ -E_x/_c & 0 & -B_z & B_y \\ -E_y/_c & B_z & 0 & -B_x \\ -E_z/_c & -B_y & B_x & 0 \end{pmatrix}$$

(Bo, 2004).

Using equation (1.7) and setting μ = 2, 3,..we obtain:

$$\nabla \times B - \varepsilon\mu\dot{E} = \mu J\ (r,t) \qquad (1.9)$$

This is the source equation for magnetic field.

The two Maxwell field equations

$$\nabla \times E = -\dot{B} \quad \text{and} \quad \nabla . B = 0 \qquad (2.0)$$

Corresponds to

$$\partial_k F_{\mu\nu} + \partial_\mu F_{\nu k} + \partial_\nu F_{k\mu} = 0. \qquad (2.1)$$

(Bo, 2004).

This is the Maxwell source equation for electric field.

For $\mu = l.,$

We may write;

$$\frac{\partial F^{01}}{\partial x^0} + \frac{\partial F^{11}}{\partial x^1} + \frac{\partial F^{21}}{\partial x^2} + \frac{\partial F^{31}}{\partial x^3} = \frac{1}{c^2}\frac{\partial E_x}{\partial t} + 0 - \frac{\partial B_z}{\partial y} + \frac{\partial B_y}{\partial z} = \mu J^1 = \mu_0 J^1 \qquad (2.2)$$

Using,

$$\mu_0\varepsilon_0 = {}^1/_{c^2}$$

$$\frac{\partial B_y}{\partial z} - \frac{\partial B_z}{\partial y} - \mu_0\varepsilon_0\dot{E} = \mu_0 J_x$$

In summary, now the two Maxwell source equations can be written as;

$$\partial_\nu F^{\nu\mu} = \mu_0 J^\mu . \qquad (2.3)$$

Setting, $\mu = 0$ in this covariant equation, and using the matrix representation formula for the covariant component form of the E-M field tensor $F_{\mu\nu}$ we obtain;

$$\frac{\partial F^{00}}{\partial x^0} + \frac{\partial F^{10}}{\partial x^1} + \frac{\partial F^{20}}{\partial x^2} + \frac{\partial F^{30}}{\partial x^3} = \mu_0 J^0$$

Or,

$$\nabla.E = \rho/\varepsilon_0. \qquad (2.4)$$

This is the well-known Maxwell source equation for electromagnetic field.

[2.1] Intensity of E.M. Radiation in Selected Shapes.

If a point source is radiating energy in all directions (producing a spherical wave), and no energy is absorbed or scattered by the medium, then the intensity decreases in proportion to distance from the object squared. Applying the law of conservation of energy, if the net power emanating is constant;

$$P = \int I \, dA \qquad (2.5)$$

Where P = net power radiated, I the intensity as a function of position, and dA is a differential element of a closed surface that contains the source. If one integrates over a surface of uniform intensity say sphere, equation (2.5) becomes;

$$P = |I|.A_{surface}$$

$$P = |I|.4\pi r^2$$

Where I is the intensity at the surface of the sphere, and r is the radius of the sphere. ($A_{surface} = 4\pi r^2$, Is the expression for the area of a sphere). So that making $|I|$ the subject of the equation we have that;

$$|I| = \frac{P}{4\pi r^2} \,. \qquad (2.6)$$

It is known that the rate at which power flows per unit area depends on the geometry of the surface that is perpendicular to the direction of propagation of energy. These surfaces differ from shape to shape. In order to analyze quantitatively the intensity of electromagnetic radiation in a closed loop of different shapes, selected plane and 3D shapes were used in this research namely, Circle, Sphere, Cylinder, Ellipse, Parabola.

[2.2] Intensity of radiation in a Circle

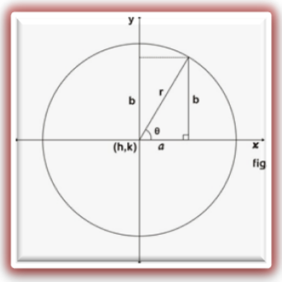

Figure 1a: Segmented circle

Considering fig. 1a, Pythagoras theorem yields the center radius equation of a circle,

$$(x-h)^2 + (y-k)^2 = r^2 \qquad (2.7)$$

If we set;

$$x - h = 0; \quad x = h. \qquad (2.8)$$

$$y - k = 0; \quad y = k. \qquad (2.9)$$

We have

$$x^2 + y^2 = r^2. \tag{3.0}$$

Equation (3.0) is the standard equation of a circle with center (0,0).

[2.3]Area of a Circle

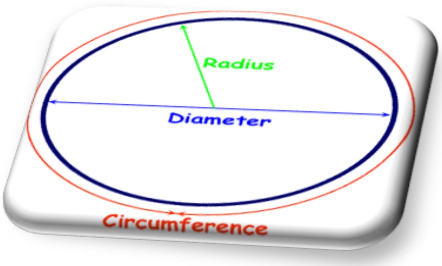

Figure1b: A circle

From Figure 1a. let us construct a circle of radius r in a standard position that is, with center (0,0). This construction is given by the analytic geometry equation representing such a circle. We see that r lies in the first quadrant of the Cartesian plane. Hence, from (2.9),

$$r^2 = x^2 + y^2$$

$$y = \sqrt{r^2 - x^2}$$

Which yields the upper half plane of the circle on the domain interval [-r, r]. Let A represent the area of the circle. Then since the radius sweeps through all the four quadrants, we can write

$$A = 4\int_0^r \sqrt{r^2 - x^2}\, dx. \tag{3.0b}$$

This integral resist solution in this form, but can be solved if converted into polar co-ordinates. Recall that,

$$x = r\cos\theta \;\; (a); \quad y = r\sin\theta \;\; (b) \tag{3.1}$$

where we set

$$f(x) = \sqrt{r^2 \sin^2\theta}$$

Putting (3.1) into (3.0b), we have that

$$A = 4\int_0^r \sqrt{r^2 \sin^2\theta}\;\, dx$$

$$A = 4\int_0^r r\sin\theta\, dx. \tag{3.2}$$

By changing of variable, we have that; from 3.1(a)

$$dx = -r\sin\theta\, d\theta$$

So that (3.2) becomes

$$A = 4\int_{\frac{\pi}{2}}^{0} r\sin\theta(-r\sin\theta)\, d\theta$$

$$A = -4\int_{\frac{\pi}{2}}^{0} r^2 sin^2\theta \, d\theta$$

$$A = 4r^2 \int_0^{\frac{\pi}{2}} \frac{(1-cos2\theta)}{2} \, d\theta$$

$$A = 2r^2 \int_0^{\frac{\pi}{2}} (d\theta - cos2\theta d\theta)$$

$$A = 2r^2 \left[\left(\theta - \frac{sin2\theta}{2}\right)\right]_0^{\frac{\pi}{2}} \qquad (3.3)$$

$$A = 2r^2\left[\left(\frac{\pi}{2} - \frac{sin\pi}{2}\right) - \left(0 - \frac{sin2(0)}{2}\right)\right]$$

$$A = 2r^2\left(\frac{\pi}{2}\right)$$

So that the intensity now becomes;

$$|I| = \frac{P}{\pi r^2}.$$

[2.4] Intensity of radiation in a Sphere

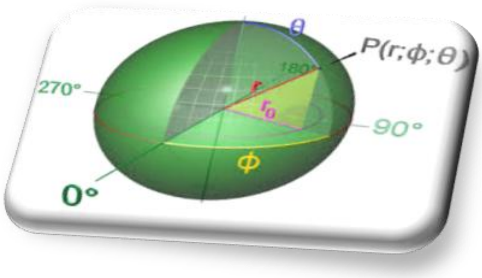

Figure 1c: A sphere.

Since a circle is two dimensional, and a sphere is three dimensional, we can as well obtain a standard equation of a sphere from that of a circle by introducing some components in the Z-axis. Hence, for a circle, we had that;

$$x^2 + y^2 = r^2$$

So now for a sphere, we can write that:

$$x^2 + y^2 + z^2 = r^2 \qquad (3.4)$$

Equation (3.4) is the standard equation of a sphere with center (0,0,0).

[2.5] Area of a Sphere.

From equation (3.3),

$$A = 2r^2\left[\left(\theta - \frac{sin2\theta}{2}\right)\right]_0^{\frac{\pi}{2}}$$

If we change the limit of integration from $0 \leq \theta \leq \frac{\pi}{2}$ to $0 \leq \theta \leq 2\pi$ for a unit sphere, we have:

$$A_{sphere} = 2r^2\left[\left(\theta - \frac{sin2\theta}{2}\right)\right]_0^{2\pi}$$

$$A_{sphere} = 2r^2\left[\left(2\pi - \frac{\sin 4\pi}{2}\right) - \left(0 - \frac{\sin 0}{2}\right)\right]$$

$$A_{sphere} = 2r^2[(2\pi)]$$

$$A_{sphere} = 4\pi r^2 \tag{3.5}$$

Now the intensity becomes;

$$|I| = \frac{P}{4\pi r^2}. \tag{3.6}$$

[1.5] Intensity of radiation in a Cylinder.

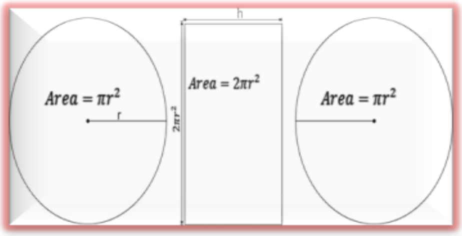

Figure 2: Segmented Cylinder

[2.6] Area of a Cylinder.

$$A_{cylinder} = 2\pi r^2 + 2\pi rh$$

From the diagram,

$$A_{cylinder} = 2\pi r(r + h) \tag{3.7}$$

Now the intensity becomes;

$$|I| = \frac{P}{2\pi r(r+h)}.$$

[2.7] Intensity of radiation in an Ellipse.

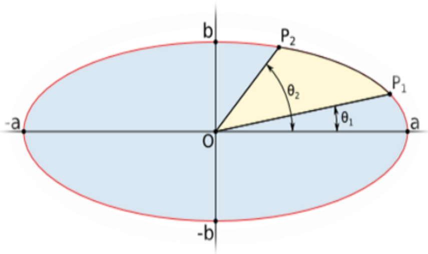

Figure 3a: An ellipse.

An ellipse is a locus of a point that moves in a plane. Surrounding two focal points such that the sum of the distances to each focal points is constant for every point on the curve.

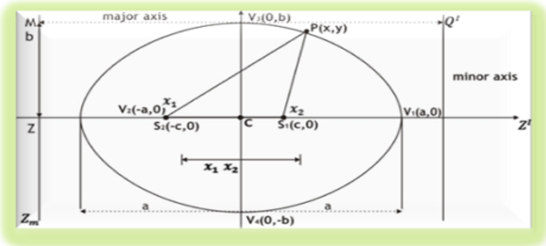

Figure 3b: A segmented Ellipse.

Let x_1 and x_2 be two fixed points in a plane and let P be a number greater than the distance between x_1 and x_2 i.e their product ($x_1 x_2$) and Z_m is the direction. The locus of all points P in the plane such that;

$$|S_1P| + |S_2P| = K \tag{3.8}$$

An ellipse is in standard position if its center is at the origin. If the foci are at the same point, an ellipse becomes a circle. Note that $x_1 x_2$ are called the foci of the ellipse.

[2.8] Equation of an Ellipse

If Z_m is the directrix then;

$$k = 2a \tag{3.9}$$

By symmetry, putting (3.9) into (3.8) we have.

$$|S_1P| + |S_2P| = 2a$$

$$\sqrt{(x-c)^2 + (y-0)^2} + \sqrt{(x+c)^2 + (y-0)^2} \qquad = 2a \ \sqrt{(x+c)^2 + (y-0)^2}$$
$$= 2a - \sqrt{(x-c)^2 + (y-0)^2}$$

Squaring both sides,

$$(x+c)^2 + y^2 = \left(-\sqrt{(x-c)^2 + y^2}\right)\left(-\sqrt{(x-c)^2 + y^2}\right)x^2 + 2xc + c^2 + y^2$$
$$= 4a^2 - (2a)\sqrt{(x-c)^2 - y^2} - (2a)\sqrt{(x-c)^2 + y^2} + \{(x-c)^2 + y^2\}x^2 + 2xc + c^2 + y^2$$
$$= 4a^2 - (4a)\sqrt{(x-c)^2 + y^2} + \{x^2 - 2cx + c^2 + y^2\}$$

Collecting like terms, we obtain

$$x^2 + 2cx + c^2 + y^2 - x^2 + 2cx - c^2 - y^2 = 4a^2 - (4a)\sqrt{(x-c)^2 + y^2}$$

$$4cx = 4a^2 - (4a)\sqrt{(x-c)^2 + y^2}$$

$$4cx = 4\left[\{a^2\} - \{a\}\sqrt{(x-c)^2 + y^2}\right]$$

$$cx = a^2 - (a)\sqrt{(x-c)^2 + y^2} \ \ (a)\sqrt{(x-c)^2 + y^2} = a^2 - cx \tag{4.0}$$

Squaring (4.0) on both sides,

$$\left\{(a)\sqrt{(x-c)^2 + y^2}\right\}^2 = (a^2 - cx)^2$$

$$a^2[(x-c)^2 + y^2] = a^4 + c^2x^2 - 2a^2cx$$

$$a^2[(x^2 - 2cx + c^2) + y^2] = a^4 + c^2x^2 - 2a^2cx$$

$$a^2x^2 - 2a^2cx + a^2c^2 + a^2y^2 = a^4 + c^2x^2 - 2a^2cx.$$

Collecting like term;

$$a^2x^2 - c^2x^2 + a^2y^2 - 2a^2cx + 2a^2cx = a^4 - a^2c^2.$$

$$a^2x^2 - c^2x^2 + a^2y^2 = a^4 - a^2c^2 .$$

$$x^2(a^2 - c^2) + a^2y^2 = a^2(a^2 - c^2) \tag{4.1}$$

From Pythagoras;

$$a^2 = b^2 + c^2.$$

$$b^2 = a^2 - c^2 . \tag{4.2}$$

So that putting (4.2) into (4.1) we have,

$$x^2b^2 + a^2y^2 = a^2b^2$$

Dividing through by a^2b^2, we have;

$$\frac{x^2b^2}{a^2b^2} + \frac{a^2y^2}{a^2b^2} = \frac{a^2b^2}{a^2b^2}$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \quad \forall \quad a \geq b > 0. \tag{4.3}$$

(4.3) is the equation of an ellipse.

Area enclosed by an ellipse

From equation (4.3),

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1.$$

The curve is symmetrical about the x and y axis, we need the area in the first quadrant and multiply the result by 4,

$$Area = 4\int_0^a y\, dx. \tag{4.4}$$

But,

$$\frac{y^2}{b^2} = 1 - \frac{x^2}{a^2}$$

$$y^2 = b^2\left(1 - \frac{x^2}{a^2}\right)$$

$$y = \sqrt{b^2\left(1 - \frac{x^2}{a^2}\right)}$$

$$y = \sqrt{b^2\left(\frac{a^2 - x^2}{a^2}\right)}$$

$$y = \sqrt{\frac{b^2}{a^2}(a^2 - x^2)}$$

$$y = \left(\frac{b}{a}\right)\sqrt{(a^2 - x^2)}\ . \qquad (4.5)$$

And,

$$Area = 4\int_0^a \left(\frac{b}{a}\right)(a^2 - x^2)^{1/2}\ dx$$

Put $x = asin\theta, dx = acos\theta d\theta, when\ (x = 0, \theta = 0)\ and\ \left(x = a, \theta = {}^{\pi}/_{2}\right)$.

$$Area = \frac{4b}{a}\int_0^{\pi/2} (a^2 - a^2sin^2\theta)^{1/2}. acos\theta d\theta$$

$$Area = \frac{4b}{a}\int_0^{\pi/2} [a^2(1 - sin^2\theta)]^{1/2}. acos\theta d\theta$$

From Trig. Identity, $cos^2\theta + sin^2\theta = 1$, we see that $cos^2\theta = 1 - sin^2\theta$

$$Area = \frac{4b}{a}\int_0^{\pi/2}[a^2(cos^2\theta)]^{1/2}. acos\theta d\theta \quad Area = \frac{4b}{a}\int_0^{\pi/2}(acos\theta)(acos\theta)\ d\theta$$

$$Area = \frac{4b}{a}\int_0^{\pi/2} a^2cos^2\theta\ \ d\theta$$

$$Area = \frac{4a^2b}{a}\int_0^{\pi/2} cos^2\theta\ \ d\theta$$

But, $cos^2\theta\ = \frac{1+cos2\theta}{2}$

$$Area = \frac{4ab}{2}\int_0^{\pi/2}(1 + cos2\theta)\ \ d\theta$$

$$Area = 2ab\left[\theta + \frac{sin2\theta}{2}\right]_0^{\pi/2}$$

$$Area = 2ab\left[\left(\frac{\pi}{2} + \frac{sin\pi}{2}\right) - \left(0 + \frac{sin0}{2}\right)\right]$$

We know that $sin\pi = 0\ \forall\ n \in Z^+$, hence

$$Area = 2ab\left(\frac{\pi}{2}\right)$$

$$Area = \pi ab. \qquad (4.6)$$

So that the intensity becomes;

$$|I| = \frac{P}{\pi ab}\ .$$

[2.9] Intensity in a Parabola.

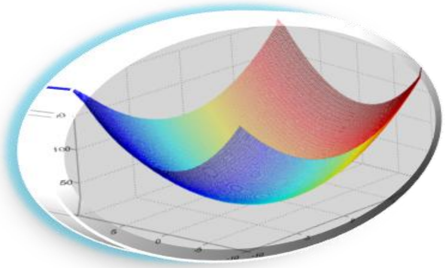

Figure 4a: A parabola.

Consider the diagram,

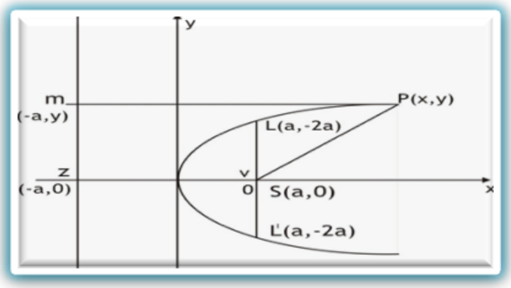

Figure 4b: segmented Parabola

Equation of a Parabola can be written such that,

$$|Pm| = |Ps|$$

$$\sqrt{[(x-a)^2 + (y-0)^2]} = \sqrt{[(x+a)^2 + (y-y)^2]}$$

$$\sqrt{[(x-a)^2 + y^2} = \sqrt{[(x+a)^2]}$$

$$(x^2 - 2ax + a^2 + y^2)^{1/2} = (x^2 + 2ax + a^2)^{1/2}$$

$$x^2 - 2ax + a^2 + y^2 = x^2 + 2ax + a^2$$

Collecting like terms,

$$x^2 - x^2 - 2ax - 2ax + a^2 - a^2 + y^2 = 0$$

$$-4ax + y^2 = 0$$

$$y^2 = 4ax \tag{4.7}$$

(Blessed,2013).

Equation (4.7) is an equation describing a parabola facing the positive x -axis. If;

$$y^2 = -4ax \tag{4.8}$$

The equation faces the negative x -axis. If;

$$x^2 = 4ay$$

The equation faces the positive side of y-axis. If;

$$x^2 = -4ay$$

Then, the equation faces the negative y-axis (wolfram, 2017).

[1.91] Area of a Parabola

The Area of the parabola is therefore represented in terms of its base and height and can be written as

$$\frac{2}{3}ab\,. \tag{4.9}$$

(eFunda, 2017).

So that the intensity becomes;

$$|I| = \frac{P}{(\frac{2}{3}bxh)}$$

Hence with the intensity relationships obtained for the various shapes, computations were made using a software program "program field strength and power estimator", which assumes conditions that are close to the best theoretical values(Rhode-swartz, 2013). The program was basically used to obtain values for the received power p_{rx} (w), electric field strength E (v/m), magnetic field strength H(A/m) and power flux density S(W/m^2), with UHF being maintained at 1.8GHz, and setting the distances from the source from 0.02m to 0.10m.

Received power = $\frac{G\lambda^2 S}{4\pi}$

Electric field strength (E)$= Z.H$

Power flux density (S) $= \frac{E^2}{Z_\circ}$ Hence, through these parameters, the various intensities wereobtained.

Figure 5: power estimator.

[3.0]. RESULTS AND DISCUSSION.

Table 1: The Intensities and Distances of the Various Shapes.

Intensities in Watts per square meters					
Distance (m)	**I(Cylinder)**	**I(Parabola)**	**I(Ellipse)**	**I(Sphere)**	I(circle)
0.02	1534.70	117.30	253.32	153.47	62.18
0.04	383.68	273.07	62.18	38.37	15.55
0.06	170.52	130.25	27.64	17.05	6.91
0.08	95.92	73.27	15.55	9.59	3.89
0.10	61.39	46.89	9.95	6.14	2.49

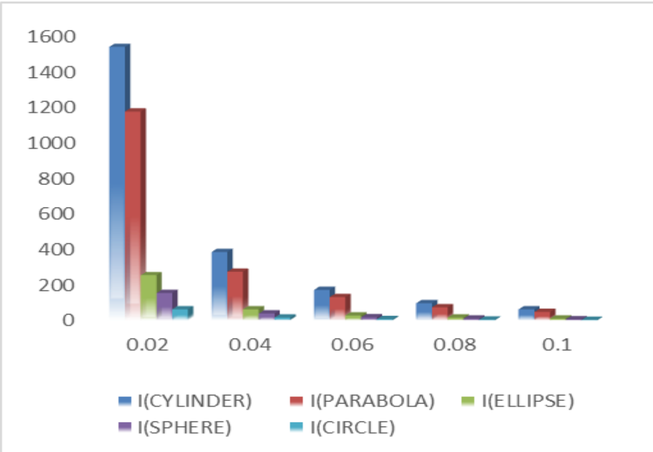

Figure 5: Chart showing the variation of intensity.

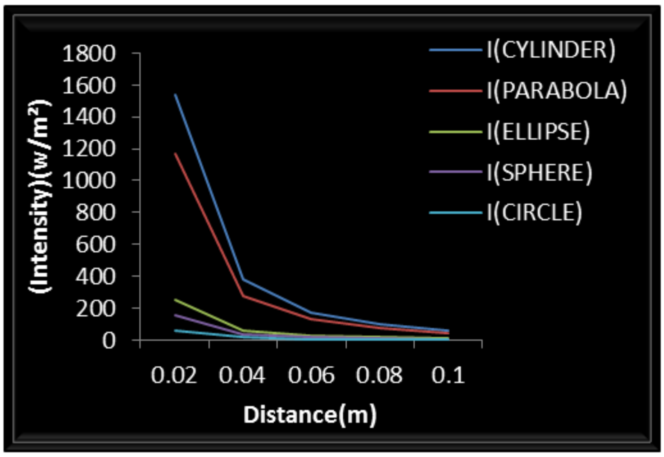

Figure 6: Decay in intensity with distance for the various shapes.

From the data, chat and graph obtained so far, the result of the investigation shows that the body of cylindrical nature experiences the maximum intensity, followed by a parabola then an ellipse, sphere and circle in that order. The nature of the chart in Figure 5. conforms to the inverse square law, which also agrees with the works of (Joshua, 2003 and Radiopedia, 2017) showing the decay of intensity per unit increase in distance.

At the various distance from the source of UHF radiation, the intensity experienced by a body of cylindrical nature increase by 2367.998% of that absorbed by a circular body, 1785.211% for a parabola, 307.3716% for an ellipse and 146.7998% for that of a sphere respectively as this is clearly seen on bar chart Figure 5

[4.0] CONCLUSION.

From the computational and theoretical investigation carried out at the course of the research, shapes of cylindrical nature were found to exhibit higher intensity of UHF radiation than the other shapes involved in the study. This is because of the geometrical in-homogeneity the cylinder possess, hence shapes which are geometrically homogenous will experience lesser exposure level since the intensity is found to depend on the geometry of the surface in question.

[5.0] RECOMMENDATION.

Since the intensity is greater within a body of cylindrical nature, and in turn increases the level of radiation beyond the natural background, the internal design of buildings, lifts and airplanes should not be made into a cylindrical form.

[6.0] ACKNOWLEDGEMENTS

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