ISSN No:-2456-2165

Radiation Efficiency of Multiband Antenna for Wireless Communication for Improved Signal Gain Using Friis Transmission Technique

S. I. OBIANIME, EGNR. DR. S. L. BRAIDE, EGNR. DR, T. WIR
Department of Electrical Engineering Rivers State University, Port Harcourt, Nigeria.

Abstract:- Dielectric materials are confronted with conduction and dielectric loses, this has led to low signal gain low radiation efficacy. The purpose of this research work is to improve the signal losses of the existing antenna on the new to analyse different substrates, that is the design frequency was kept constant in order to check the responses of the radiation efficiency and gain performance of the antenna. This steady adopted the application of Friis Transmission Technique with the aim of analysis different substrates with respective gain properties under investigation. The following substrates were used including: foam 1.05, RT Duroid 2.2, Fr4 4.4, Bakelite 4.8 and Taconic 3.2 and after analysing different substrates using HFSS-High Frequency Structure Simulator the best based on least amount of signal losses is foam. The results obtained showed that foam as a substrate had the least amount of losses. The results obtained also showed that foam had the best radiation efficiency and gain. Friis transmission technique was also employed for determination of the signal distance. How much the signal travelled. And also the results showed us that the signal from the foam substrate travelled the longest distance.

Keywords:- *Antenna, Duroid, Friis, Radiation Efficiency, Fr4, Transmission.*

I. INTRODUCTION

Engineering is the application of knowledge for the solving of problems. This knowledge is gained through research, experience or even inspiration. We are dealing with communications engineering here. And communication at the most basic level is interaction between two people, or two devices or two locations via different means. In the area of communications engineering knowledge gained is applied to solve some stubborn problems in the area of communication. A microwave system consists of passive and active microwave components arranged to perform a useful function. Probably the two most important examples are microwave radar systems and microwave communication systems. An important aspect in any radar or communication system is the antenna [9]. An antenna therefore is a very important part of a microwave system. In my own -understanding to break down microwave systems. It is a system made up of high frequency radios beams located at building tops with line of sight to prevent interference for communication between two locations. So therefore in a microwave system what we need an antenna for is to send the signal and receive also the signal this is why an antenna is very important in a microwave system. It acts as transition region between free space and the transmission line to communicate between two or more regions. Antenna provides a simple way to transfer signal where other methods fail. The basic understanding of how an antenna works is that it changes the power signal into an electromagnetic wave. This then now brings us to the understanding of Maxwells equation. Maxwells equation helps us to understand how antennas work. It helps us to breakdown to our own understanding how the current is converted to electromagnetic radiation or waves. And this is the understanding, because of how the current swings through it generates an electric field, and this electric field also changes. Using amperes law which states that the magnetic field created by an electric current is proportional to the size of the electric current with a constant of proportionality equal to the permeability of free space [5].To forge ahead in our understanding let us look at some basic concepts of antenna:

Polarisation: Polarisation in an antenna refers to the directions of the oscillations in the waves produced by an antenna. The direction of the fields determines which the direction in which the energy is moving. We have circular, horizontal, vertical and linear. For maximum transfer of power, the receiving and transmitting antenna should have the same polarisation.

Resonance and Bandwidth: The bandwidth talks about the different range of frequencies that an antenna can operate on. Damage may occur to a radio transmitter not well protected if it is made to operate outside its operating range. An antenna is made up of a circuit that has inductance and conductance, therefore it has resonance frequency. The inductance and capacitance of an antenna is determined by the physical properties of the environment it is located.

Gain and Directivity**:** This talks about the fact that antennas do not radiate equally in all directions except for the isotropic antennas. Gain of antenna combines the directivity and electrical efficiency. To a transmitting antenna, gain is how well it is able to convert electrical power into radio waves in a particular direction. For a receiving signal, gain is how well it is able to convert radio waves into electrical power in a particular direction [6].

Radiation Frequency and Power Gain: The fact that antenna are made from conductive materials makes it possible for them to have ohmic losses. Radiation efficiency is the ratio of radiated power to input power.

Feed and Impedance Matching: The input connection to the antenna presents an impedance to the feeder to which it is connected. For optimum power transfer source and load should be matched. Antennas are usually bi-directional in that they can be used for both transmission and reception. Functions. The transmitter can be used as a the venin source consisting of a voltage generator and series impedance, delivering a transmit power to the transmit antenna. The transmit antenna radiates a spherical wave which at large distances approximates a plane wave at least over a localized area. The receive antenna intercepts a portion of the propagating wave and delivers a receive power to the receiver load impedance. A wide variety of antennas have been developed for different applications and are summarised below:

Wire antennas: which include monopoles, dipoles, loops, sleeve dipoles, yadiuda rays. Wire antennas usually have low gains and are usually used at low frequencies (Hf to Uhf) Aperture antennas: include open-ended wave guide, rectangular or circular horns reflector or lenses. Aperture antennas are most commonly used at microwave and millimetre wave frequencies and have moderate to high gains. Printed antennas: include printed time slots, printed dipoles and microstrip patch antennas. Printed antennas are most often used at microwave and millimetre wave frequencies, and can be easily arrayed for high gain. Array antennas: they consist of a regular arrangement of antenna elements with a feed network. Pattern characteristics such as beam pointing angle and side lobe levels can be controlled using by adjusting the amplitude and phase distribution of the array elements[9] [7].

A. *Statement of the Problem*

The microstrip patch antennas are used for their light weight, low cost, low profile, simple structure and omini directional radiation patterns.

The main problem was that there were dielectric losses in the substrates used so we are:

- Low Gain
- Signal Losses
- Low radiation efficiency

Analysing different substrates and we are going to use the one with the least amount of losses in the dielectric one of the problems that a multiband antenna also solves is multi functionality.

For the purpose of this work, the problem we are trying to solve is that of radiation efficiency. We look at how to improve the radiation efficiency of a multiband antenna in relation to the kind of substrate used. Multiband antenna is a really effective antenna because different parts can be working at the same time for different bandwidths but we are trying to work out a way to increase the radiation efficiency so we can get the optimum output i.e. reduce the losses.

B. *Aim of Study*

This research considered the Radiation Efficiency of Multiband Antenna for Wireless Communication for Improve Signal Gain Using Friis Transmission Technique.

The objectives of this research work are presented as:
Study different characteristic of antenna

- Analyze different range of substrates used for antenna design
- Simulate using high frequency structure simulated (HFSS) in order to determine the parameter gain and radiation efficiency.
- Determine the signal loss from the different substrate for the antenna performance under investigation.

II. LITERATURE REVIEW

The problem of radiation of efficiency is not a novel one in the area of antenna construction and implementation. When talking about efficient antenna we look at the gain of the antenna, radiation efficiency, total efficiency etc.

According to [1], Various research has been done for the improvement of radiation efficiency. Efficiency can be improved by using line feed technique in place of coaxial probe. This approach is not the best because it means substrate thickness may increase thereby causing increasing in spurious radiation and limiting the bandwidth which automatically waters down the effect of a multiband antenna [1][8].

According to [2], Research was also done that proposes the use of EBG substrate to improve the radiation efficiency and other parameters of an antenna. This was done to tackle a major drawback of this antenna which is the issue of surface waves. The two techniques applied is that of micromachining and periodic structures called Electromagnetic Band Gap (EBG). However, EBG structures environing the antenna has two resultant effect namely parasitic loading effect and cavity effect. Parasitic loading effect enhances bandwidth while cavity effect diminishes bandwidth [2]. The EBG cells placed close to radiating edges of the antenna components causes parasitic loading. At the same time, the EBG structures also reflect back a portion of energy circulating along the substrate of the antenna, acting as reflecting walls across the antenna causing the cavity effect. With few rows of EBG structures, negative energy is being reflected and parasitic effect prevalent [4]. This causes significant increase in the bandwidth. As the number of rows increases, the energy circulating along the substrate reflects and the cavity effect prevails. This significantly reduces the bandwidth and causes a counter effect [2].

Research was done proposing patch shape constructed by using multiple truncated circular-shaped arcs. A novel method of etching the substrate is implemented to provide a feasible solution for the excitation of the surface waves within the microstrip antenna [6]. The impedance bandwidth and radiation efficiency of the formulated antenna are improved after these portions are removed [3][5].

ISSN No:-2456-2165

III. METHOD

The research adopted the application of friis transmission equation

The following equations are instrumental in the determination of a conventional patch antenna. Following algorithms below: Determine the width of the patch. The width of the patch is calculated using: (Design, 2016)

$Wp = c/2fr\sqrt{2/Er+1}$ (3.1)

Considering c is the speed of light in free space = (3×10^8 m/s)

And $Fo = c/2Le\sqrt{er}$ (3.2)

Taking Le: as the length of the patch as:

$Le = L + 2\Delta L$ (3.3)

Then consider the effective dielectric constant

$E_{reff} = +\frac{er+1}{2}(1+\frac{12h}{Wp})\frac{1}{2}$ (3.4)

We know that L_{eff} is the dielectric constant of the substrate and we know that Ereff is the effective dielectric constant

$L_{eff} = \frac{c}{2Fo\sqrt{\square reff}}$ (3.5)

Next after that we calculate the extended length of the patch due to the fringing field:

$\Delta L = 0.412h\,\frac{\square reff+0.3}{\square reff-0.258}\left(\frac{\frac{w}{h}+0.264}{\frac{w}{h}+0.8}\right)$ (3.6)

The real length of the patch is given as:

$Lp = L_{eff} - 2\Delta L$ (3.7)

For the ground plane dimensions, we have;

$Lg = 6h + Lp$ (3.8)

$Wg = 6h + Wp$ (3.9)

Also to achieve this work the same antenna design was used in simulating for three different substrates namely: FR4, RT Duroid and Foam.

There are many ways a microstrip patch antenna that can be fed respectively: probe feed, microstrip line feed and coaxial feed.

Microstrip was used for this design using a driven lumped port, and the line parameters were designed using a standard input impedance of 50Ω.

Feed point specific point where our input impedance given as 50Ω which can be checked using the following equations;

$Wf = \frac{2h}{\Pi}(B-1-In(2B-1) + \frac{\square r-1}{2ER} + 0.39-(0.61\varepsilon_r)$ (3.10)

Where;

$B = \frac{377\Pi}{2Zo\sqrt{\square r}}$

LF= 3.96WF

$Y_o = \frac{cos^{-1}\sqrt{\frac{z}{Rin}}}{\frac{\Pi}{L}}$ (3.11)

And

ISSN No:-2456-2165

$$X_o = \frac{c}{\sqrt{2\square reff}} \frac{4.65\times10^{-9}}{f} \quad (3.12)$$

Feed point location where input impedance is approximately 50Ω is given as:
Wf=w/2
Lf= L/2 Ɛr (3.13)
With these antenna dimensions fr4, duroid and Foam were used as substrate for four different antenna designs.

$$B = \frac{377\Pi}{2Zo\sqrt{\square r}} \quad (3.14)$$

And
LF= 3.96WF (3.15)
Also,

$$Y_o = \frac{cos^{-1}\sqrt{\frac{Z}{Rin}}}{\frac{\Pi}{L}} \quad (3.16)$$

$$X_o = \frac{c}{\sqrt{2\square reff}} \frac{4.65\times10^{-9}}{f} \quad (3.17)$$

Feed point location where input impedance is approximately 50Ω is given as:
Wf=w/2
Lf= L/2 Ɛr (3.18)

Following to the analysis, the antenna dimensions Fr4, Duroid and Foam are used as substrate for the study is the antenna designs.

Foam	Received Power	10 MW
	Received Power	10MW
	Radiated Power	7.2685 MW
	Gain Transmitted	2.0931
	Gain Received	1.4952
	Frequency	4.6 GHz
Bakelite	Received Power	10 MW
	Radiated Power	5.8324 MW
	Gain Received	1.4857
	Gain Transmitted	1.4857
	Frequency	4.6GHz
FR4	Received Power	10 MW
	Radiated Power	5.834 MW
	Gain Received	1.4857
	Gain Transmitted	1.4857
	Frequency	4.6Ghz
RT Duroid	Received Power	10 MW
	Radiated Power	1.9938
	Received Gain	0.54169
	Radiated Gain (Gain Transmitted)	2.6927
	Frequency	4.6GHz
Taconic	Frequency	4.6GHz
	Radiated Gain	2.8435
	Received Gain	0.60927
	Received Power	10 MW
	Radiated Power	1.9908

Table 1: Substrates Value for Received power, Radiated power, Gain Transmitted, Gain Received and Frequency

$$P_r = \frac{Pt\ Gt\ Gr\ \lambda^2}{(4\pi R)^2} \quad (3.19)$$

Source: (HFSS ENVIRONMENT)

Where P_r: Power of the receiving Antenna

ISSN No:-2456-2165

P_t: Output Power of transmitting antenna

G_t: Gain of the transmitting Antenna

G_r: Gain of the receiving Antenna

Λ: Wavelength

R: Distance between the antennas

Since, from the data in Table 3.1, the evaluated are imputed as looking for the Range of the Antenna,

Making R subject of the formula.

A. Case 1: Analaysis of Foam

Foam → $R = (GR)\frac{(GT)}{4\pi}\frac{C}{F}\frac{P_T}{P_R}$

$$R = 1.4952 \times \frac{2.0931}{4 \times {}^{22}/_{7}} \times \frac{3 \times 10^8}{4.6\text{GHz}} \times \frac{7.2685}{10}$$

R = 11 800 838.09 m

B. Case 2: Analysis of Bakelite

Bakelite → $R = GR \times \frac{GT}{4\pi} \times \frac{C}{F} \times \frac{P_T}{P_R}$

$$R= 1.4857 \times \frac{21.4857}{4 \times {}^{22}/_{7}} \times \frac{3 \times 10^8}{4.6\text{GHz}} \times \frac{5.8324}{10}$$

R = 6 678 644.685m

C. Case 3: Analysis of FR4

FR4 → $R = GR \times \frac{GT}{4\pi} \times \frac{C}{F} \times \frac{P_T}{P_R}$

$$R = \frac{1.4857 \times 1.4857 \times 3 \times 10^8 \times 5.8324}{4 \times {}^{22}/_{7} \times 4.6 \text{ GHz} \times 10}$$

R = 6678644.685m

D. Case 4: Analysis of Duroid

Duroid → $0.54169 \times \frac{2.6927}{4 \times {}^{22}/_{7}} \times \frac{3 \times 10^8}{4.6\text{GHz}} \times \frac{1.9938}{10}$

R = 1 508 436. 417 m.

E. Case 5: Analysis of Taconic

Taconic → $R = GR \times \frac{GT}{4\pi} \times \frac{C}{F} \times \frac{P_T}{P_R}$

$$R = \frac{1.9908 \times 2.8435 \times 3 \times 10^8 \times 0.60927}{4 \times {}^{22}/_{7} \times 4.6 \text{ GHz} \times 10}$$

R = 1 789 243. 507

$P.e = (G.R)\ (GT) \left(\frac{\lambda}{4\pi R}\right)\text{Ptrans}$

$R = \frac{(G.R)(GT)}{4\pi}\frac{C}{F}\frac{PT}{Pr}$

$\lambda = {}^{c}/_{f} = \frac{3 \times 10^8}{4.6\text{GHz}} = 6.5 \times 10^7$

IV. RESULTS OBTAINED FOR DIELECTRIC CONSTANT PLOTTED AGAINST DIELECTRIC LOSS TANGENT

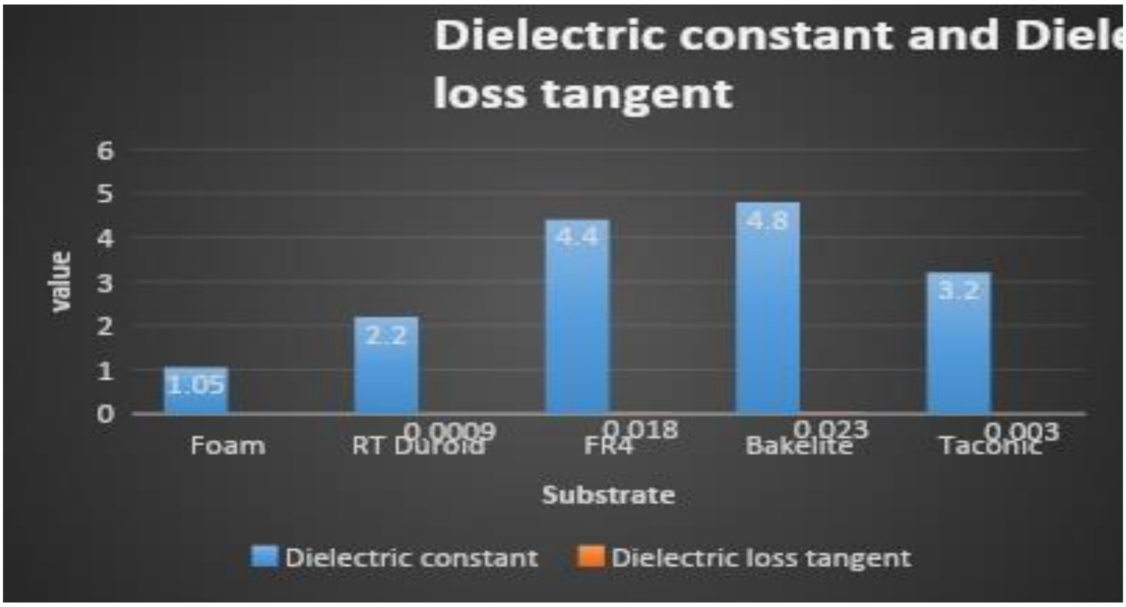

Fig. 1: Dielectric Constant Plotted against Dielectric Loss Tangent

The dielectric constants of the different substrates and we observe the least of them which is foam and the greatest of them which is Bakelite.

A. Results Obtained for Radiation Efficiency of all the Substrates

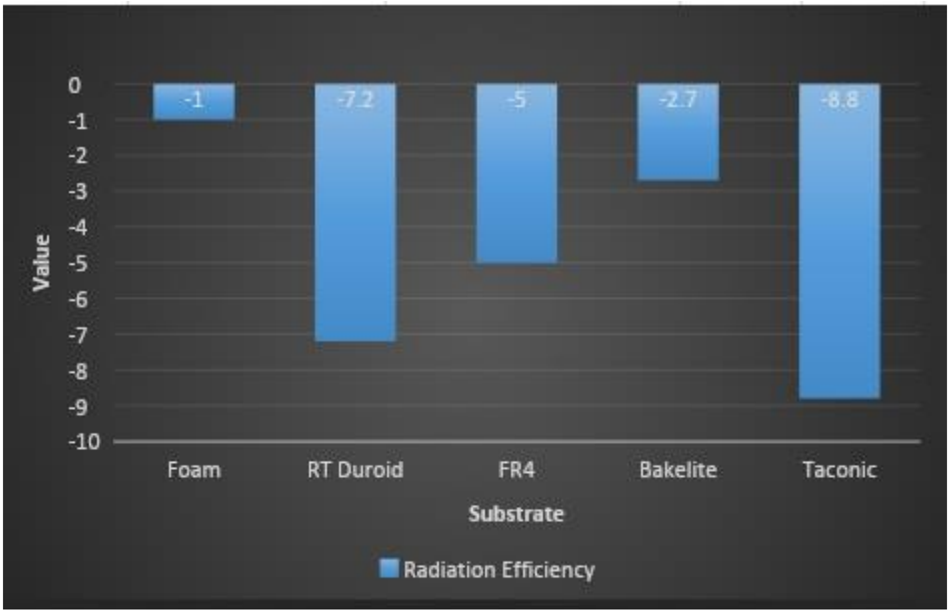

Fig. 2: Radiation Efficiency of all the Substrates

From the graph above it is observed that foam has the best radiation efficiency this is due to its high dielectric loss tangent of 1.72% and dielectric constant 1.05, minimal losses to the environment. And it is followed by Bakelite; apart from its dielectric constant of 4.8. Bakelite has a loss tangent of 2.3%which gives it good gain and good radiation efficiency. This is followed by FR4 it has a good dielectric loss tangent of 1.8% and a dielectric constant of 4.4. It is followed by RT Duroid which has a dielectric loss tangent of 0.09% and a dielectric constant of 2.2. And then Taconic which has a dielectric constant of 3.2 and a dielectric loss tangent 0.3%.

B. Results Obtained for Gain for all the Antennas

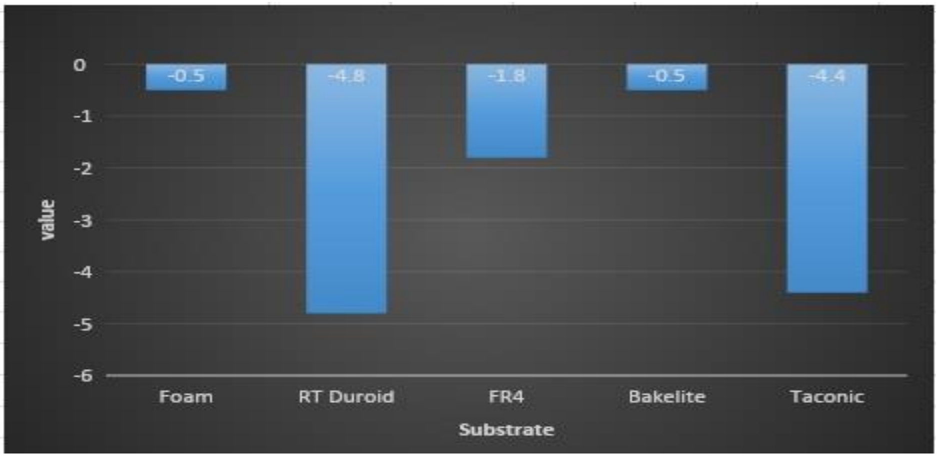

Fig. 3: Gain for all the Antennas

The same principles stated above for the radiation efficiency also affect the gain as well. This is become any antenna that has a good gain will also have a good radiation efficiency.

C. Results Obtained for Dielectric Constant Plotted against Loss Tangent

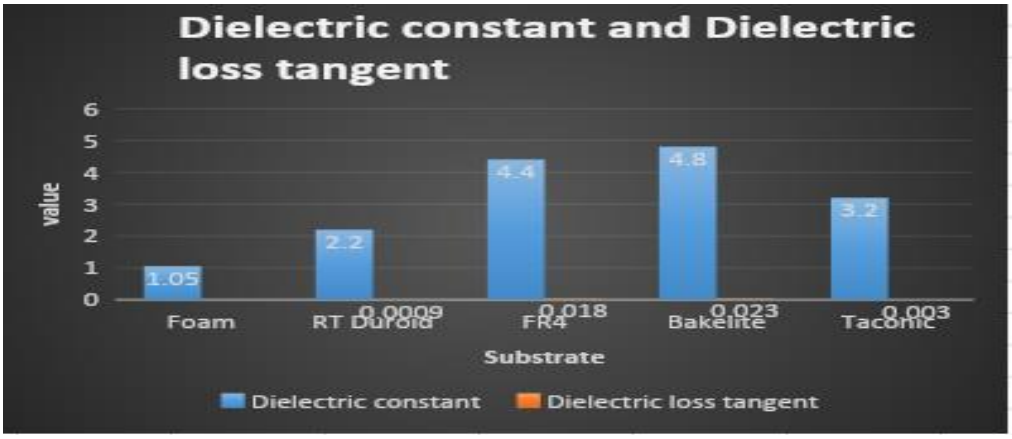

Fig. 4: Dielectric Constant Plotted against Loss Tangent

It is observed that the dielectric constants plotted against Dielectric loss tangent.

D. Results Obtained for Line Graph for Gain of Substrate

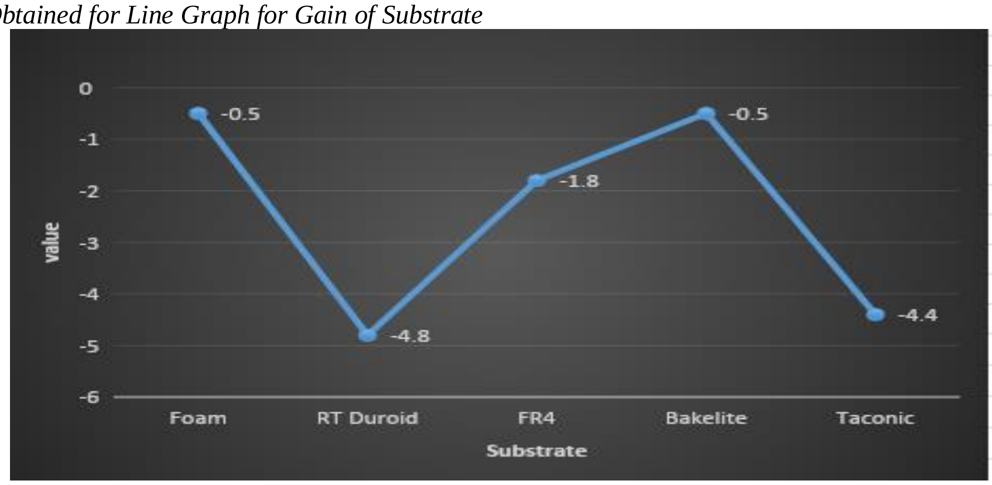

Fig. 5: Line Graph for Gain of Substrate

The gain of all the substrates are plotted on a line graph for clarity. The substrates with the highest gains are above while substrates with the lowest gain are below.

ISSN No:-2456-2165

E. Results Obtained for Dielectric Constant of Substrates

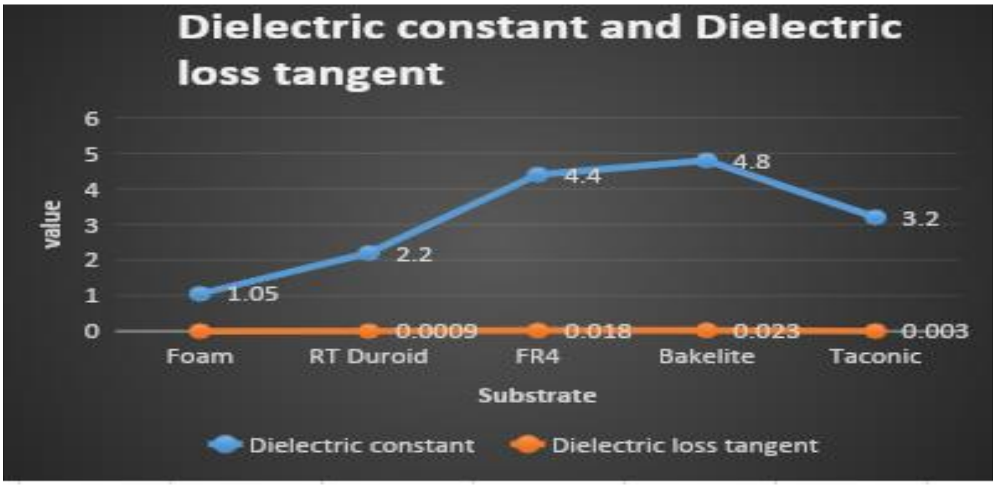

Fig. 6: Dielectric Constant of Substrates

The dielectric constants plotted against Dielectric loss tangent. We see the values clearer on a line graph.

F. Results Obtained for Radiation Efficiency of all the Substrates

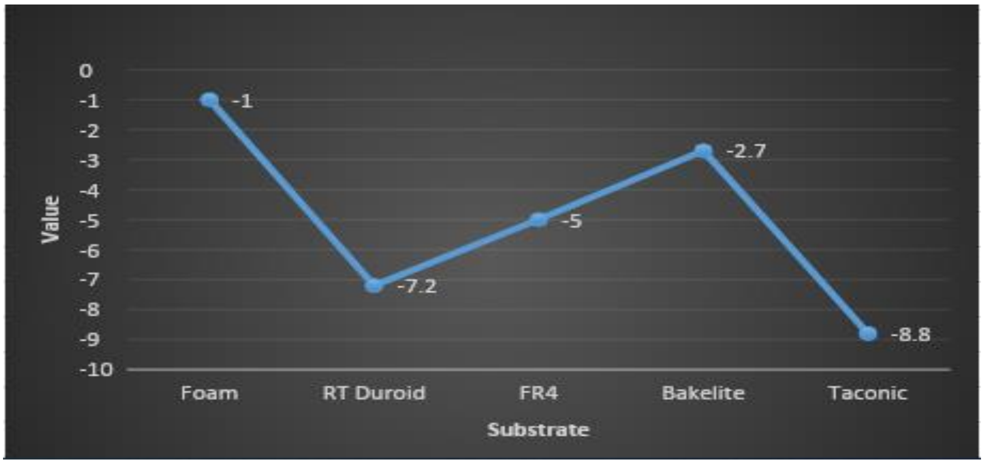

Fig. 7: Radiation Efficiency of all the Substrates

The radiation efficiencies of all the substrates showing that the highest are up and the lowest are all down.

G. Results Obtained for Mass Versus Dielectric Loss Tangent Vs Dielectric Constant

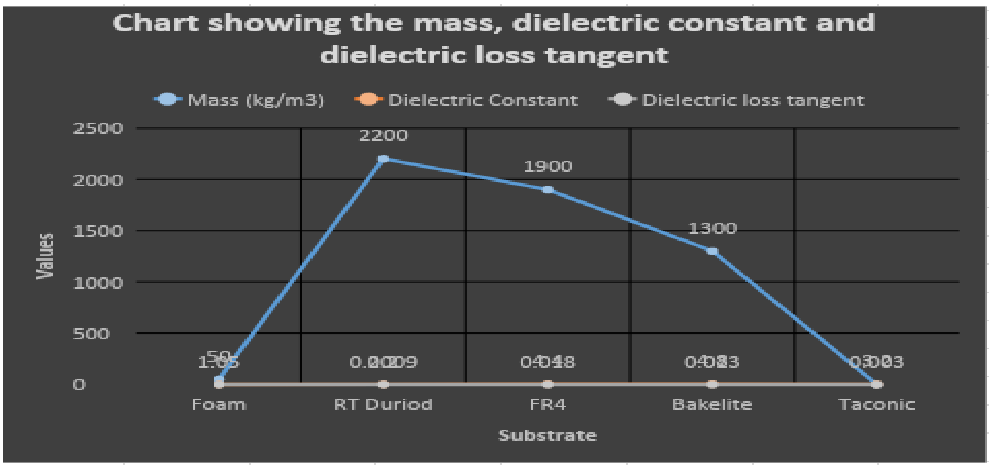

Fig. 8: Mass versus Dielectric Loss Tangent Vs Dielectric Constant

The figure 4.8 shows the relationship between dielectric constant, dielectric loss tangent and also the mass of the substrate.

ISSN No:-2456-2165

H. Results Obtained for Dielectric Constant Vs Dielectric Loss Tangent vs Mass

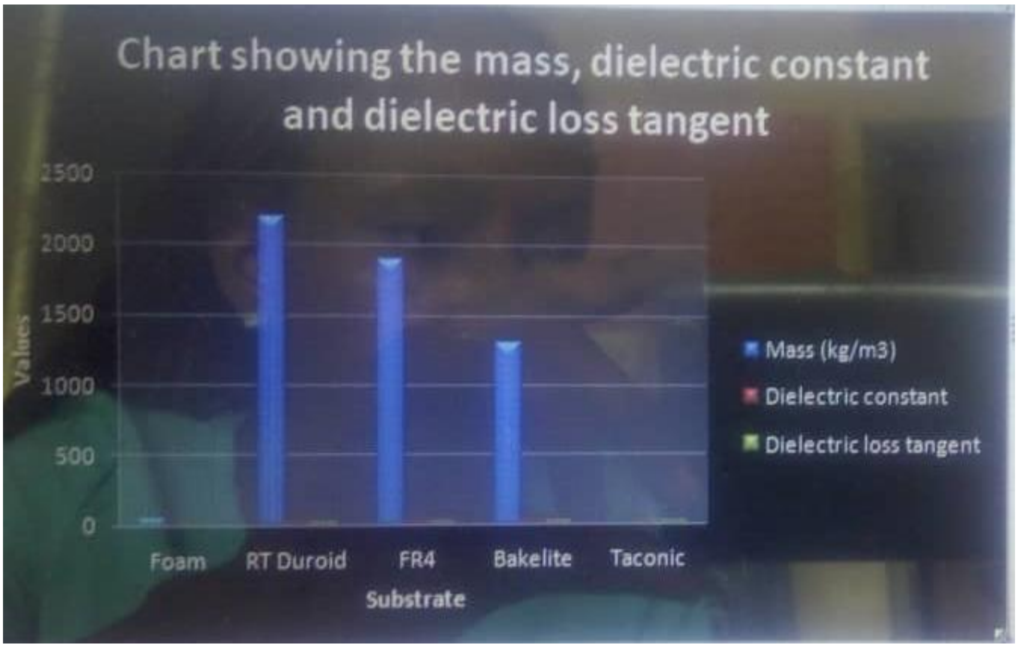

Fig. 9: Dielectric Constant Vs Dielectric Loss Tangent vs Mass

The dielectric constant plotted against the dielectric loss tangent also in respect to the mass.

S/No	Substrate	Distance of the signal (m)	Dielectric constant	Loss Tangent
1	Foam (FR – 3703)	11 800 838.09m	1.05	0.0172
2	Rt Duroid	6 678 644. 685m	2.2	0.0009
3	Fr4	6678644.685m	4.4	0.018
4	Bakelite	1 508 436. 417m	4.8	0.023
5	Tanaconic	1 789 243. 507m	3.2	0.003

Table 2: Result Obtained in the Calculations using Friis Transmission Technique

This table shows the result for the distanced travelled for each signal under each of the substrates being analysed namely: Foam, RT Duroid, FR4, Bakelite and Taconic.

Material	Radiation Efficiency	Dielectric Constant	Dielectric Loss Tangent	Gain	Mass Kg/m3
Foam (FR – 3703)	-1	1.05	0.0172	-0.5	50
RT Duroid	-7.2	2.2	0.0009	-4.8	2200
FR4	-5	4.4	0.018	-1.8	1900
Bakelite	-2.70	4.8	0.023	-0.5	1300
Taconic	-8.80	3.2	0.003	-4.4	2500

Table 3: HFSS Simulation Results

Simulation results for all the substrates used from HFSS Environment.

Material	Dielectric Constant	Percentage	Dielectric Loss Tangent	Percentage
Foam (FR – 3703)	1.01	6.7%	0.0172	1.72%
Rt duroid	2.2	14.50%	0.0009	0.09%
Fr4	4.4	28.11%	0.018	1.8%
Bakelite	4.8	30.67%	0.023	2.3%
Tanaconic	3.2	20.44%	0.003	0.3%

Table 4: Percentage Retention of Energy and Percentage Dissipation of Energy

This shows the percentage losses of all the substrates used during the simulations as obtained during the simulations.

V. CONCLUSION

After a comparative analysis on the effect of different substrate used in antenna, the research carried out gave further insight into antenna characteristics and behavior of different antennas.The research further revealed performance characteristics of different substrates and gave insight into the advantages and limitations of different substrates. The research also showed that foam had the least amount of losses and also better gain and radiation efficiency. The research was simulated using HFSS and different results were obtained for all the substrates. The results obtained showed that foam as a substrate had the best gain and efficiency. Finally friis transmission technique was used to determine the distance travelled by the signal for all the substrates and it was observed that foam travelled the longest with a distance of 11800838.09m.

A. Recommendation

After a comparative analysis, five different substrate materials are used, consideration of their respective ranking order of performance foam as a substrate is declared, best for signal stability in that order. Following the trend of study under investigation with the integration of friis transmission technique foam as a substrate is identified as the materials that has the lowest amount of signal losses as a dielectric material for long distance signal communication as compared to other dielectric material under study.

Therefore it is strongly proposed to:

- Consider material selection for dielectric properties before design considerations to avoid excusive losses.
- Design scenarios for wireless multiband and antenna must always match the consideration of declared material selection for purposes of better performance.
- Design Technique must also conform to other methods used for purpose of valued antenna implied performance.

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