Studying the characteristics impedance of coaxial transmission line using X-band.

Mahdi Hasan Suhail and Fuad malik mutar

***Abstract*— Mat Lab program (Version 7) is used for design and simulation of the microwave circuit using coaxial Transmission line in X- band frequency. An implementation has been done on coaxial transmission line of (53.5Ω) characteristic impedance for dielectric material Polyethylene with permittivity 2.25. The results shows that impedance of the line depend on the coaxial line decreases as the inner radiuses (a) and outer radiuses (b) increases.**

The TEM transmission lines are characterized by some basic parameters such as characteristic impedance (Z_0),reflection coefficient (Γ),wave admittance (Y),voltage standing wave ratio (VSWR) and total attenuation (α) ,in term of physical parameters like properties of the dielectric constant ε_r . The optimal value of the line parameters occur when the line terminated to resistance equal to characteristic impedance of the line. But when the line terminates to load resistance less than characteristic impedance we obtain maximum and minimum value along the line, while the value changed in phase shift when terminated the line to load resistance greater than characteristic impedance of the line. This phase shift depends on the parameters and the effect of (R_L) on them, the phase shift exists on the incident wave because of the additional losses (capacitance & inductance losses).

***Index Terms*— characteristic impedance, losses, coaxial Transmission line, Resonant frequency, Bandwidth.**

I. Introduction

The electromagnetic waves are used to transport energy from place to another. Such as TV or broad casting station .Naturally, a large portion of the energy of such waves is lost. Another and an important application is in the transmission of electromagnetic energy from a source to a single receiver. In such cases, it is desirable to minimize the transmission losses to the practical receiver. Since the electromagnetic waves propagating through free space are not the most suitable type for this purpose, it is necessary to design and drives some system guides of the electromagnetic waves.

Transmission line is a device designed to guide electromagnetic energy from one point to another [1].The transmission line has a single purpose for both the transmitter and the antenna. This purpose is to transfer the energy output of the transmitter to the antenna with the least possible power loss. How well this is done depends on the special physical and electrical characteristics (impedance and resistance) of the transmission line [2]

The main goal of transmission line measurement is to determine the parameters that characterize the line over a frequency range of interest, as well as locate discontinuities that cause unusual loss or standing wave. Although these parameters describe the intrinsic properties of the line, in some cases, particularly with unshielded lines (e.g.microstrip) [3].

The choice of the transmission line is typically based on the following criteria [4]: Frequency operation, Attenuation, Power handling, Characteristic impedance and Tower loading (size & weight).

The coaxial transmission line configuration is simple because there is an exact solution for its impedance and propagation velocity in terms of the physical parameters (conductor sizes). Equations for many transmission line types have been derived by mapping their physical shape into a coaxial shape where the solution is known exactly [5].

There are two types of Coaxial lines, rigid (air) coaxial line and flexible (solid) coaxial line. The physical construction of both types is basically the same; that is, each contains two concentric conductors. Table (1) Transmission line Parameters for Some Common lines.

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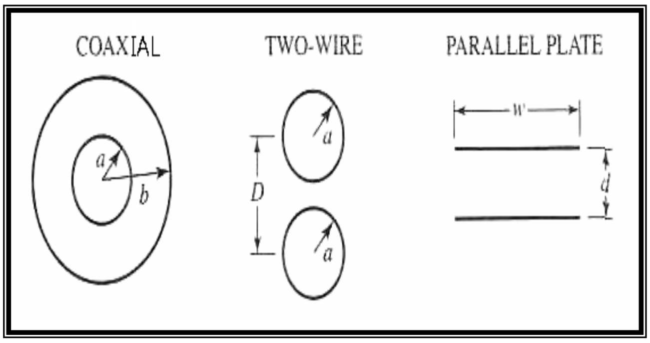

	Coaxial	Two -wire	Parallel Plate
C	$\frac{2\pi\varepsilon}{\ln b/a}$	$\frac{\pi\varepsilon}{\cosh^{-1}(D/2a)}$	$\frac{\varepsilon w}{d}$
L	$\frac{\mu}{2\pi}\ln\frac{b}{a}$	$\frac{\mu}{\pi}\cosh^{-1}\left(\frac{D}{2a}\right)$	$\frac{\mu d}{w}$
R	$\frac{R_s}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$	$\frac{R_s}{\pi a}$	$\frac{2R_s}{w}$
G	$\frac{2\pi\omega\varepsilon''}{\ln a/b}$	$\frac{\pi\omega\varepsilon''}{\cosh^{-1}(D/2a)}$	$\frac{\omega\varepsilon'' w}{d}$

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Mahdi Hasan Suhail, Dept.of Physics, college of science, University of Baghdad

Fuad malik mutar, Expert minister of Education, G.of curricula.

The rigid coaxial line consists of a central, insulated wire (inner conductor) mounted inside a tubular outer conductor. However, in a coaxial line no electric or magnetic fields extend outside the outer conductor. The fields are confined to the space between the two conductors, resulting in a perfectly shielded coaxial line. Another advantage is that interference from other lines is reduced.

Flexible coaxial lines are made with an inner conductor that consists of flexible wire insulated from the outer conductor by a solid, continuous insulating material. The outer conductor is made of metal braid, which gives the line flexibility. Early attempts at gaining flexibility involved using rubber insulators between the two conductors. However, the rubber insulators caused excessive losses at high frequencies.

Practically the use of the coaxial line is at higher frequencies ,this is largely because of the convenient construction and practically perfect shielding between fields inside and outside of the line, typical a coaxial line can have characteristic impedance ranging from 30 Ω to 100 Ω but most common impedance value for coaxial cable are 50 & 75 Ω Physical constraints on practical wire diameters and spacing limit Z_0 value to these ranges .The 50 Ω RG-58 cable was developed during world war II to connect antennas which had an impedance of 50 Ω.[6]

Because of the high-frequency losses associated with rubber insulators, polyethylene plastic was developed to replace rubber and eliminate these losses. Polyethylene plastic is a solid substance that remains flexible over a wide range of temperatures. It is unaffected by seawater, gasoline, oil, and most other liquids that may be found aboard ship. The use of polyethylene as an insulator results in greater high-frequency losses than the use of air as an insulator. However, these losses are still lower than the losses associated with most other solid dielectric materials [2] .

The purpose of this study involves the study of the characteristic impedance [53.3 Ω] for polyethylene dielectric materials [at frequency 10 GHz], and the other characteristic of the coaxial transmission line like (Wave impedance, Reflection coefficient, Maximum value of electric field inside the line, Power, Current in the conductor, Capacitance and Inductance per unit length, electric and magnetic field).

II. Coaxial Transmission Lines Equations

For a pure TEM mode propagation on a coaxial transmission line, the electric field has only a redial component and the magnetic field has only an azimuthal component .The coaxial cable, depicted in figure (2-6) is the most widely used TEM transmission line. It consists of two concentric of inner and outer radii of (a) and (b), with the space between them filled with a dielectric ε , such as polyethylene or Teflon. [8],[9]

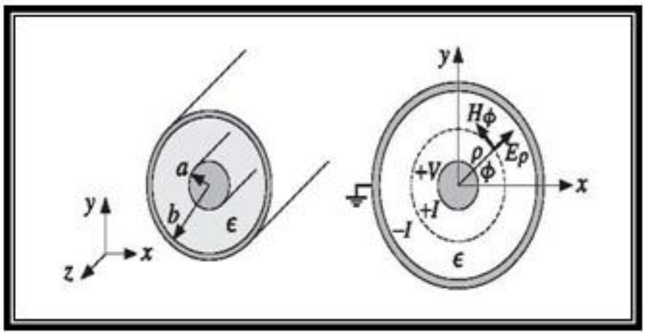

Figure (2-6) Coaxial Transmission line [9].

The equivalent electrostatic problem can be solved conveniently in cylindrical coordinates ρ, ϕ .The potential $\varphi(\rho, \phi)$ satisfies laplace's equation:

$$\nabla_T^2 \varphi = \frac{1}{\rho}\frac{\partial}{\partial \rho}\left(\rho \frac{\partial \varphi}{\partial \rho}\right) + \frac{1}{\rho^2}\frac{\partial^2 \varphi}{\partial^2 \phi} = 0 \qquad (1)$$

Because of the cylindrical symmetry, the potential does not depend on the azimuthal angle ϕ , there for,

$$\frac{1}{\rho}\frac{\partial}{\partial \rho}\left(\rho \frac{\partial \varphi}{\partial \rho}\right) = 0 \quad \Rightarrow \rho \frac{\partial \varphi}{\partial \rho} = B \;\Rightarrow \varphi(\rho) = A + B In \rho \qquad (2)$$

Where A, B are constants of integration. Assuming the outer conductor is grounded: $\varphi(\rho) = 0 \; at \; \rho = b,$ and the inner conductor is held at voltage V, $\varphi(a) = V$, the constants A,B are determined to be $B = -V \ln(b/a) and \; A = -B \ln b,$ resulting in the potential:

$$\varphi \;(\rho) = \frac{V}{Ln(b/a)} Ln(b/\rho) \qquad (3)$$

It follows that the electric field will have only a radial component, $E_\rho = -\partial_\rho \varphi$

It follows that the electric field will have only a radial component, $E_\rho = -\partial_\rho \varphi$, and the magnetic field only an azimuthal component $H_\phi = E_\rho / \eta$:

$$E_\rho = \frac{V}{Ln(b/a)}\frac{1}{\rho} \qquad (4)$$

$$H_\phi = \frac{V}{\eta \, Ln(b/a)}\frac{1}{\rho} \qquad (5)$$

Integrating H_ϕ around the inner conductor we obtain the current:

$$I = \int_0^{2\pi} H_\phi \rho \, d\phi = \int_0^{2\pi} \frac{V}{\eta In(b/a)}\frac{1}{\rho}\rho \, d\,\phi = \frac{2\pi V}{\eta \, In\,(b/a)} \qquad (6)$$

It follows that the characteristic impedance of the line $Z = V / I$, and hence the inductance and capacitance per unit length will be:

$$Z = \frac{\eta}{2\pi} Ln(b/a) \qquad (7)$$

$$L' = \frac{\mu}{2\pi} Ln(b/a) \qquad (8)$$

$$C' = \frac{2\pi\varepsilon}{Ln(b/a)} \qquad (9)$$

The transmitted power P_t can be expressed either in terms of the voltage V or in the terms of the maximum value of the electric field inside the line, which occur at $\rho = a$, that is,

$$E_a = |V|/(aIn(b/a)) \qquad (10)$$

$$P_T = \frac{1}{2Z}|V|^2 = \frac{\pi |V|^2}{\eta Ln(b/a)} = \frac{1}{\eta}|E_a|^2(\pi a^2) Ln(b/a) \qquad (11)$$

The smaller the dimensions a & b the larger the attenuation [10].

III. Results & discussions for Coaxial Transmission Line:

A. *Characteristic Impedance:*

Ideal transmission lines with TEM field distributed are characterized by their type (cable or planar) and characteristic impedance [11].To study the characteristic impedance of coaxial line in transmission line, equation (7), which represents the relation between the characteristic impedance (Z_0) and the inner (a) and outer radius of conductor (b) was used.

Dielectric materials of Polyethylene with relative permittivity (ε_r =2.25, was used, It is notice that the value of the characteristic impedance decreases as the value of (a & b) increasing, as shown in the figures (1) and (2) for polyethylene.

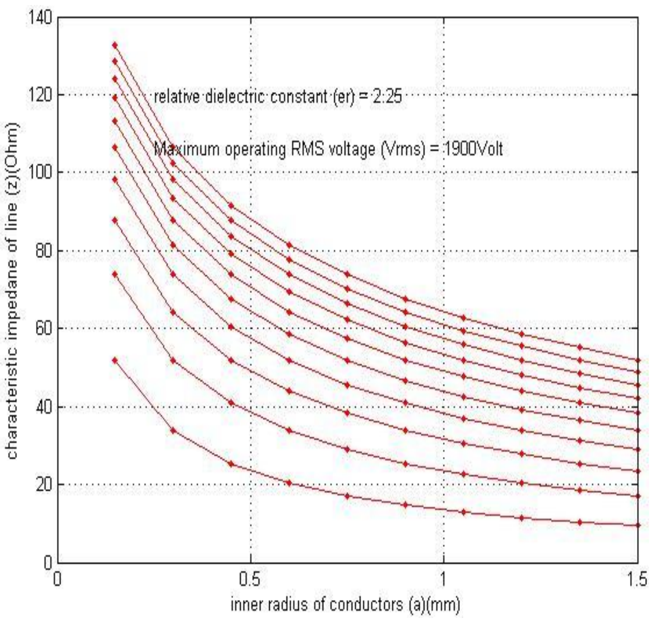

Figure (1) Characteristic impedance as a function of inner radius variation for Polyethylene

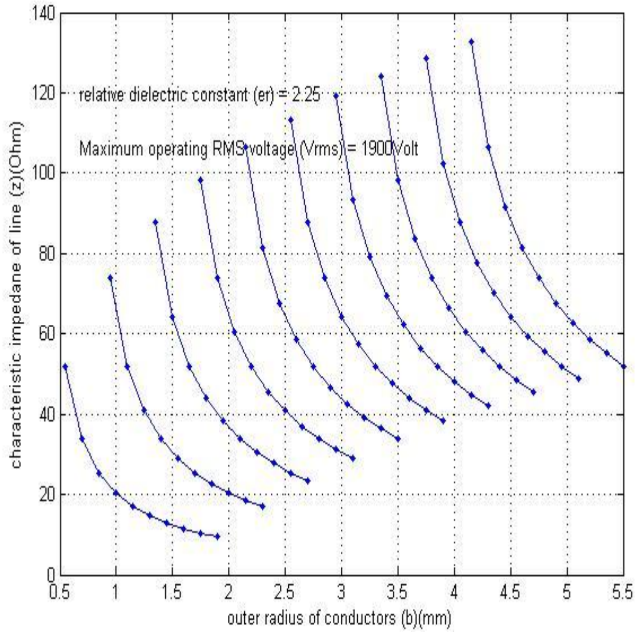

Figure (2) Characteristic impedance as a function of outer radius variation for Polyethylene

B. *Transmitted power:*

Equation (11) estimate the transmitted power thought the line (P_t) due to the inner & outer radiuses for the polyethylene material as in figures (3) & (4) .It is noticed that the value of the transmitted power increase due to inner & outer radiuses increase. That is mean the smaller the dimension a & b the larger the attenuation. We can see that the variation in transmitted power value during the increases of the inner radius (a) at the small value of (b) is so obvious while at large value of (b) the variation is so small & close.

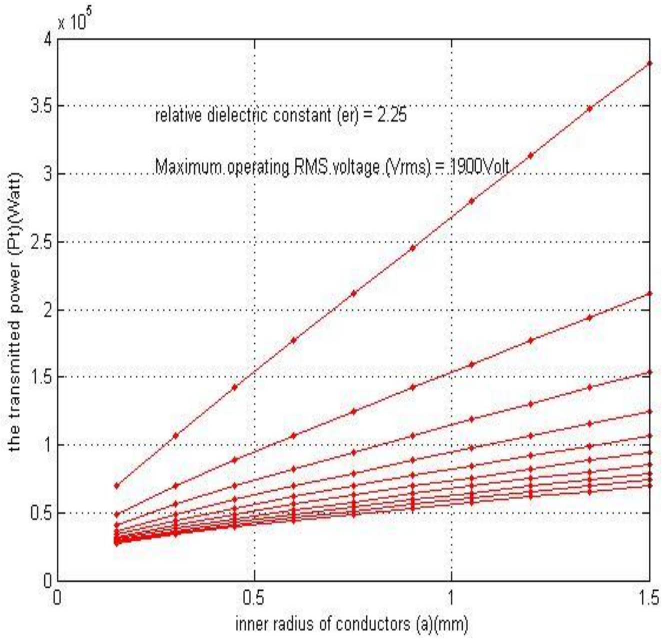

Figure (3) Transmitted power as a function of inner radius variation for Polyethylene

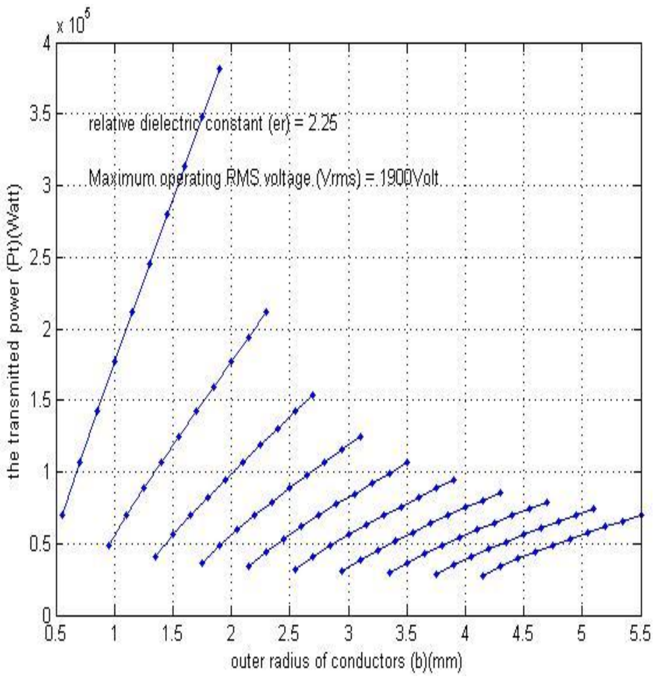

Figure (4) Transmitted power as a function of outer radius variation for Polyethylene

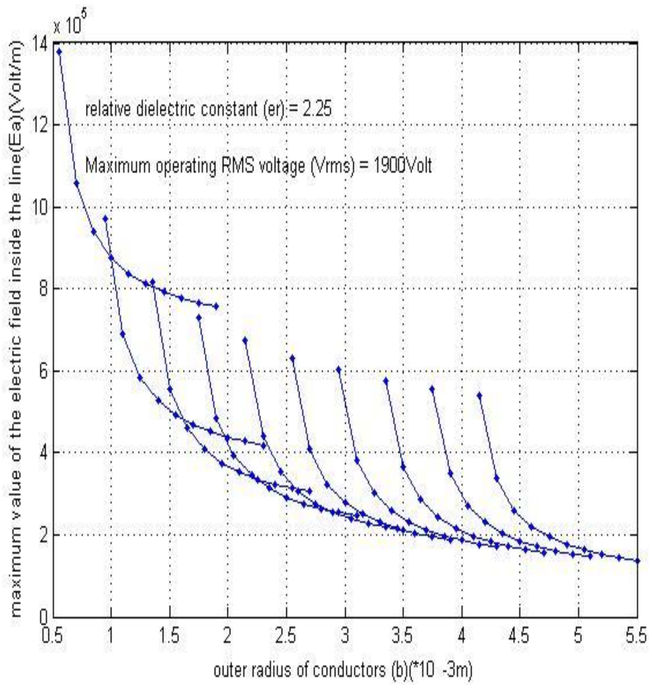

Figure (6) Maximum value of the electric field as a function of outer radius variation for polyethylene.

C. Maximum value of the electric field:

The value of the maximum electric field inside the line **(** E_a **)** is calculated by equation (10).we observed that the value of (E_a) decrease when (a) and (b) value increasing as in figures (5) & (6) for polyethylene, similarly for Teflon & Nylon. We also noticed that the variation in the maximum value of the electric field during the increases of the inner radius (a) at the small value of (b) is so obvious & large compared with the variation in the maximum value of electric field when (b) is large.

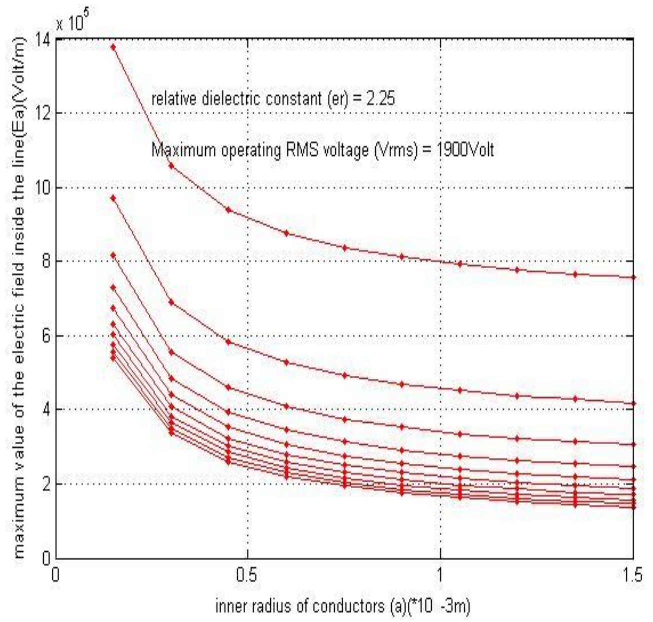

Figure (5) Maximum value of the electric field as a function of inner radius variation for polyethylene.

D. Current in the conductor:

From equation (6),current inside the conductor (I_c) due to inner & outer radius of the coaxial line are calculated .It is noticed that the current increases with the increasing of inner (a) &outer (b) radiuses as in figures(7) & (8) for polyethylene . From all that it is obvious that the increases in the dielectric constant (ε_r) of the insulated material means the increasing of the current in the conductors.

We can also notice that the variation in value of current inside the line during the increases of the inner radius (a) at large value of radius (b) is so small & close ,while at small value of (b) the variation in current inside the line is so large & obvious.

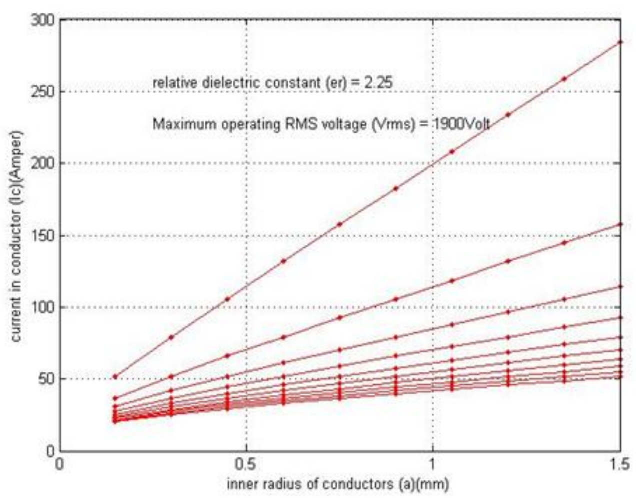

Figure (7) Current in the conductor as a function of inner radius variation for Polyethylene

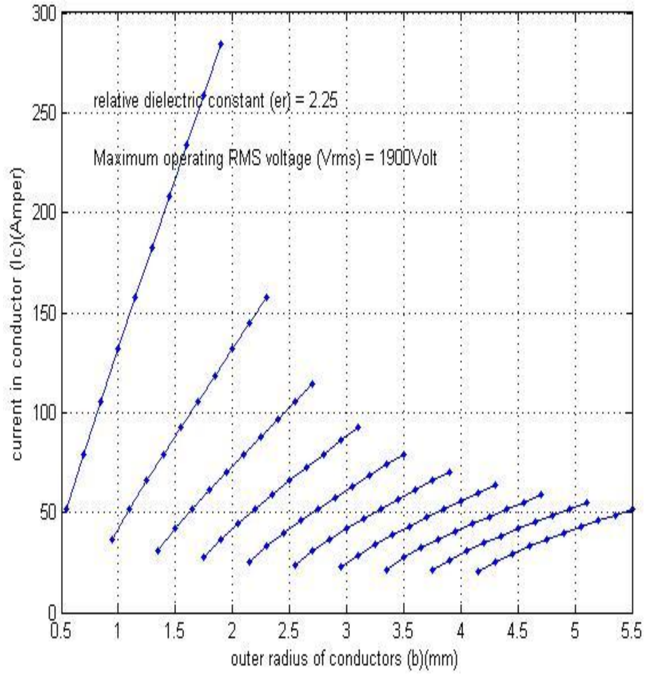

Figure (8) Current in the conductor as a function of outer radius variation for Polyethylene

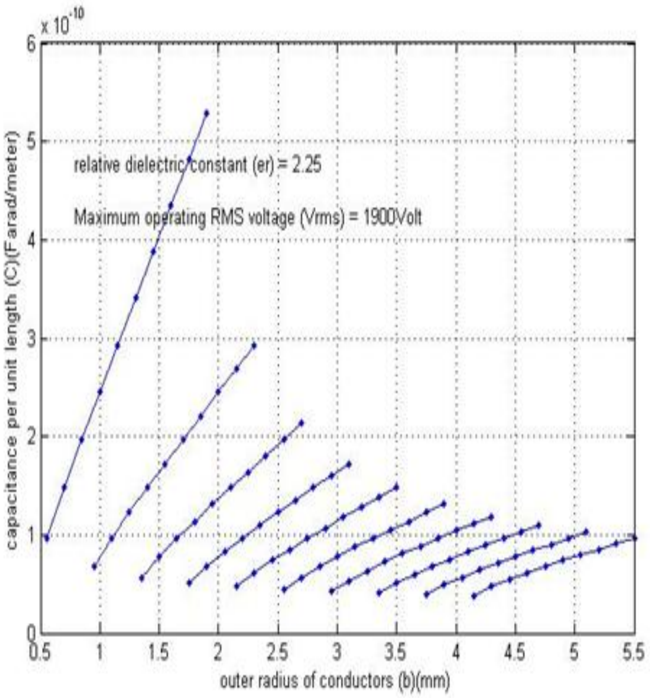

Figure (10) Capacitance per unit length as a function of outer radius variation for Polyethylene

E. Capacitance & Inductance per unit length:

The capacitance per unit length (C) due to inner radius (a) & outer radius (b) was calculated using equation (9). It is noted that the capacitance value increases as the inner & outer radiuses increasing as shown in figures (9) & (10) for polyethylene. As in the previous cases it is noticed that at large value of (b) during the increases of the inner radius (a) the variation in capacitance value is so small while at small value of (b) the variation is large and observe.

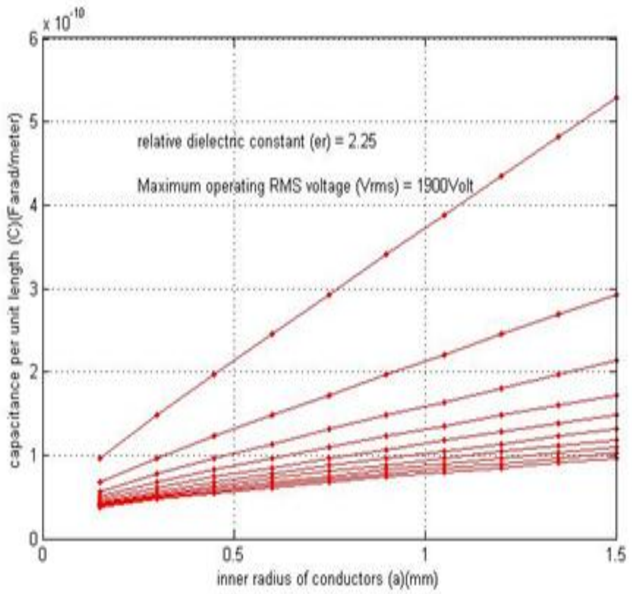

Figure (9) Capacitance per unit length as a function of inner radius variation for Polyethylene

The inductance per unit length (I) due to inner & outer radius of the conductor was also calculated using equation (8). We can notice that the inductance decrease due to inner (a) & outer (b) radius increasing, as in figure (11)& (12) for Polyethylene, Teflon & Nylon, It is noticed that the value of inductance per unit length didn't depend on the insulated material inside the line.

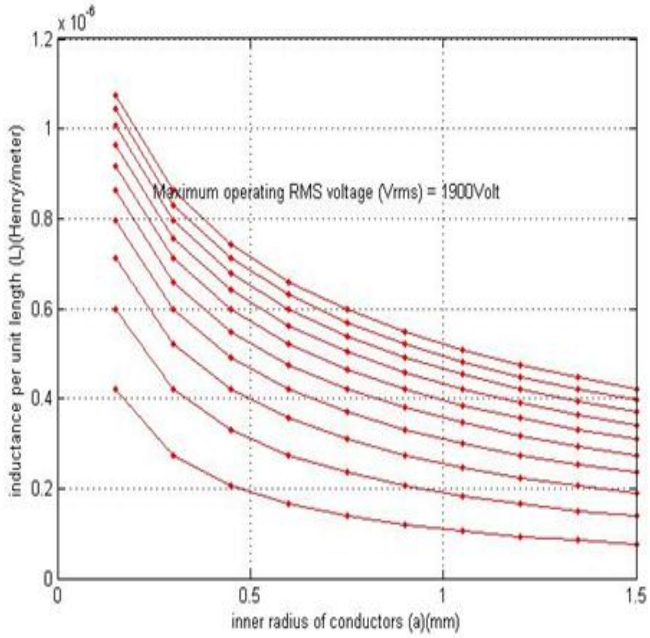

Figure (11) Inductance per unit length as a function of inner radius variation for Polyethylene

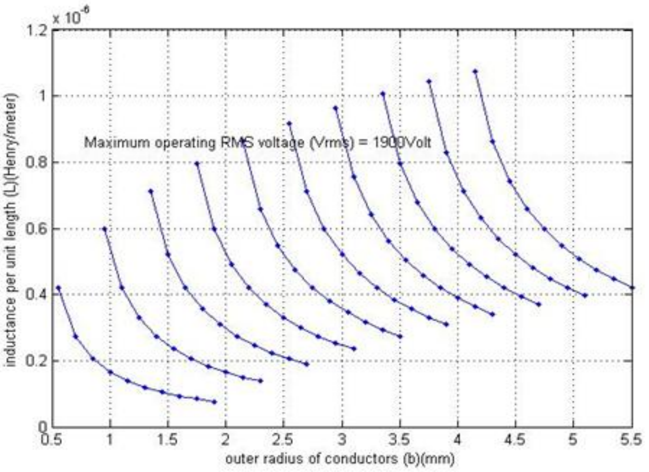

Figure (12) Inductance per unit length as a function of outer radius variation for Polyethylene

The three quantities [the electric field (E_a) inside the guide, the power transfer (P_T) & the conductor attenuation (α_c)], can be though as a function of the ratio $x = b/a$ and take the following forms:

$$a)\ E_a = \frac{V}{b}\frac{x}{\ln x}$$

$$b)\ P_T = \frac{1}{\eta}|E_a|^2 \pi b^2 \frac{\ln x}{x}$$

$$c)\ \alpha_c = \frac{R_s}{2\eta b}\frac{x+1}{\ln x}$$

By setting the derivation of the three function of (x) to zero, we obtain the following three conditions:

a) ln x=1

b) ln x= $\frac{1}{2}$

c) ln x= $1+\frac{1}{x}$

with solutions:

$$a)\ \frac{b}{a} = e^1 = 2.7183$$

$$b)\ \frac{b}{a} = e^{1/2} = 1.6487$$

$$c)\ \frac{b}{a} = 3.5911$$

The three optimization problem at fixed outer conductor radius (b), we can find the optimum value of (a) that minimizes (E_a), maximizes of (P_T) & minimizes (α_c). We have three different answers & it may possible to satisfy them simultaneously at any algorithm genetic. The corresponding impedance (Z) for the three values of ($\frac{b}{a}$) are 60 Ω, 30Ω & 76.7Ω for an air filled line and 40 Ω ,20Ω & 51Ω for polyethylene filled line ,so the value of 50Ω is considered to be a compromise between 30Ω & 76Ω corresponding to maximum power & minimum attenuation .

The minimum of (α_c) is very broad & any neighbor value to $\frac{b}{a} = 3.591$ will result in (α_c) very near its minimum.

(TE) and (TM) modes with higher cutoff frequencies exist in coaxial line [69], with the lowest being a TE_{11} mode with cutoff frequency

$f_c = \frac{c}{\lambda_c} = \frac{c_0}{n\lambda_c}$, where (λ_c) is the cutoff wave length & approximated by π (a + b) .The operation of the TEM mode is restricted to frequency that are less than (f_c). For example the RG-58 cables we may use (a=0.406) mm & (b=1.548) mm resulting in $\lambda_c = 5.749$ mm & f_c =34.79GHz. Another example RG8/U&RG213/V cables we may use (a=1.03) mm & (b=3.60) mm resulting in $\lambda_c = 13.622$mm & f_c =14.68GHz. The above cutoff frequencies are far above the useful operating range over which the attenuation of the line is acceptable.

IV. CONCLUSIONS:

The variation in transmission line parameter (transmitted power, maximum value of electric field, current in the conductor & capacitance per unit length) during the increasing of the inner radius (a) at the small value of (b) is observable while at large value of (b) the variation is so small & close. The maximum value of electric field and the value of inductance per unit length are independent on (ε_r), while the value of current in the conductor and the value of capacitance per unit length are increased as the value of (ε_r) increasing. In the case of matching line ($R_L = Z_0$) the total power absorbed by the load is at the maximum, while at $R_L < Z_0$, the best power value is at (0& $\lambda/2$), and at $R_L > Z_0$, the best power value is at ($\lambda/4$).

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