



Design of a Practical Type Transmission Lines by using COMSOL Multiphysics 5.1

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Abstract: In communications and electronic engineering, a transmission line is a specialized cable or other structure designed to carry alternating current of radio frequency, that is, currents with a frequency high enough that their wave nature must be taken into account.

Transmission lines are used for purposes such as connecting radio transmitters and receivers with their antennas, distributing cable television signals, trunklines routing calls between telephone switching centers, computer network connections, and high speed computer data buses. This paper explains about the practical types of transmission lines i.e Coaxial Line, Twin Lead, Micro Strip and CPW models are designed by using COMSOL Multiphysics software.

Keywords: Transmission Lines; Coaxial Cable; Microstrip; Strip Line; CPW, COMSOL Multiphysics

I. Introduction

Ordinary electrical cables suffice to carry low frequency alternating current (AC), such as mains power, which reverses direction 100 to 120 times per second, and audio signals. However, they cannot be used to carry currents in the radio frequency range or higher,^[1] which reverse direction millions to billions of times per second, because the energy tends to radiate off the cable as radio waves, causing power losses. Radio frequency currents also tend to reflect from discontinuities in the cable such as connectors and joints, and travel back down the cable toward the source.^{[1][2]} These reflections act as bottlenecks, preventing the signal power from reaching the destination. Transmission lines use specialized construction, and impedance matching, to carry electromagnetic signals with minimal reflections and power losses. The distinguishing feature of most transmission lines is that they have uniform cross sectional dimensions along their length, giving them a uniform *impedance*, called the characteristic impedance,^{[2][3][4]} to prevent reflections. Types of transmission line include parallel line (ladder line, twisted pair), coaxial cable, stripline, and microstrip.^{[5][6]} The higher the frequency of electromagnetic waves moving through a given cable or medium, the shorter the wavelength of the waves. Transmission lines become necessary when the length of the cable is longer than a significant fraction of the transmitted frequency's wavelength.

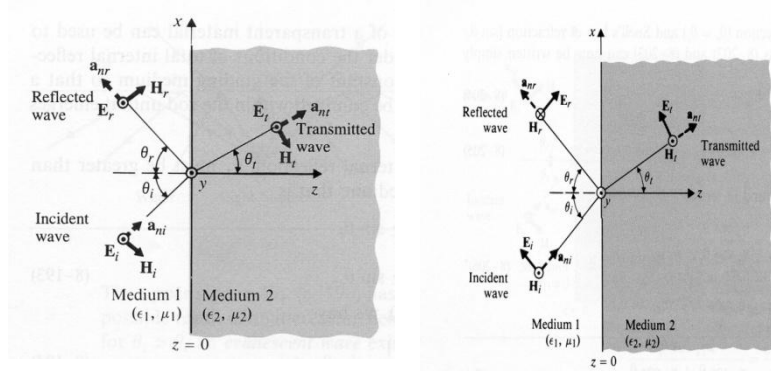
At microwave frequencies and above, power losses in transmission lines become excessive, and waveguides are used instead,^[1] which function as "pipes" to confine and guide the electromagnetic waves.^[6] Some sources define waveguides as a type of transmission line;^[6] however, this article will not include them. At even higher frequencies, in the terahertz, infrared and light range, waveguides in turn become lossy, and optical methods, (such as lenses and mirrors), are used to guide electromagnetic waves.^[6] The theory of sound wave propagation is very similar mathematically to that of electromagnetic waves, so techniques from transmission line theory are also used to build structures to conduct acoustic waves; and these are called acoustic transmission lines. In many electric circuits, the length of the wires connecting the components can for the most part be ignored. That is, the voltage on the wire at a given time can be assumed to be the same at all points.

II. Characteristics of transmission lines

Transmission line: It has **two conductors** carrying current to support an EM wave, which is **TEM** or **quasi-**

TEM mode. For the **TEM** mode, $\vec{E} = -Z_{TEM} \hat{a}_n \times \vec{H}$, $\vec{H} = \frac{1}{Z_{TEM}} \hat{a}_n \times \vec{E}$, and $Z_{TEM} = \eta = \sqrt{\frac{\mu}{\epsilon}}$.

The current and the EM wave have different characteristics. An EM wave propagates into different dielectric media, the partial reflection and the partial transmission will occur. And it obeys the following rules.



Snell's law: $\frac{\sin \theta_t}{\sin \theta_i} = \frac{\beta_1}{\beta_2} = \frac{n_1}{n_2} = \frac{v_{p2}}{v_{p1}} = \frac{\eta_2}{\eta_1} = \sqrt{\frac{\epsilon_1}{\epsilon_2}} = \sqrt{\frac{\epsilon_{r1}}{\epsilon_{r2}}}$ and $\theta_i = \theta_r$

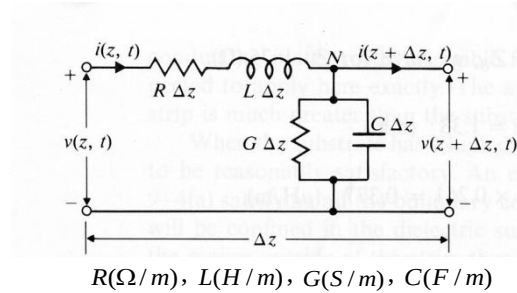
The reflection coefficient: $\Gamma = \frac{E_{r0}}{E_{i0}}$ **and the transmission coefficient:** $\tau = \frac{E_{t0}}{E_{i0}}$

$$\left\{ \begin{array}{l} \Gamma_{\perp} = \frac{\eta_2 / \cos \theta_t - \eta_1 / \cos \theta_i}{\eta_2 / \cos \theta_t + \eta_1 / \cos \theta_i} = \frac{n_1 \cos \theta_i - n_2 \cos \theta_t}{n_1 \cos \theta_i + n_2 \cos \theta_t} = \frac{\sin(\theta_i - \theta_t)}{\sin(\theta_i + \theta_t)} \\ \tau_{\perp} = \frac{2\eta_2 / \cos \theta_t}{\eta_2 / \cos \theta_t + \eta_1 / \cos \theta_i} = \frac{2n_1 \cos \theta_i}{n_1 \cos \theta_i + n_2 \cos \theta_t} = \frac{2 \cos \theta_i \sin \theta_t}{\sin(\theta_i + \theta_t)} \end{array} \right. \quad \text{for perpendicular polarization (TE)}$$

$$\left\{ \begin{array}{l} \Gamma_{\parallel} = \frac{\eta_2 \cos \theta_t - \eta_1 \cos \theta_i}{\eta_2 \cos \theta_t + \eta_1 \cos \theta_i} = \frac{n_1 / \cos \theta_i - n_2 / \cos \theta_t}{n_1 / \cos \theta_i + n_2 / \cos \theta_t} = \frac{\tan(\theta_t - \theta_i)}{\tan(\theta_t + \theta_i)} \\ \tau_{\parallel} = \frac{2\eta_2 \cos \theta_i}{\eta_2 \cos \theta_t + \eta_1 \cos \theta_i} = \frac{2n_1 / \cos \theta_t}{n_1 / \cos \theta_i + n_2 / \cos \theta_t} = \frac{2 \cos \theta_i \sin \theta_t}{\sin(\theta_i + \theta_t) \cos(\theta_i - \theta_t)} \end{array} \right. \quad \text{for parallel polarization (TM)}$$

In case of normal incidence, $\left\{ \begin{array}{l} \Gamma_{\perp} = \Gamma_{\parallel} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}, \text{ where } \eta_1 = \sqrt{\frac{\mu_1}{\epsilon_1}} \text{ and } \eta_2 = \sqrt{\frac{\mu_2}{\epsilon_2}} \\ \tau_{\perp} = \tau_{\parallel} = \frac{2\eta_2}{\eta_2 + \eta_1} \end{array} \right.$

Equivalent-circuit model of transmission line section:



Transmission line equations: In higher-frequency range, the transmission line model is utilized to analyze EM power flow.

$$\left\{ \begin{array}{l} -\frac{v(z + \Delta z, t) - v(z, t)}{\Delta z} = Ri(z, t) + L \frac{\partial i(z, t)}{\partial t} \\ -\frac{i(z + \Delta z, t) - i(z, t)}{\Delta z} = Gv(z, t) + C \frac{\partial v(z, t)}{\partial t} \end{array} \right. \Rightarrow \left\{ \begin{array}{l} -\frac{\partial v}{\partial z} = Ri + L \frac{\partial i}{\partial t} \\ -\frac{\partial i}{\partial z} = Gv + C \frac{\partial v}{\partial t} \end{array} \right.$$

Set $v(z, t) = \text{Re}[V(z)e^{j\omega t}]$, $i(z, t) = \text{Re}[I(z)e^{j\omega t}]$

$$\Rightarrow \left\{ \begin{array}{l} -\frac{dV}{dz} = (R + j\omega L)I(z) \\ -\frac{dI}{dz} = (G + j\omega C)V(z) \end{array} \right. \Rightarrow \left\{ \begin{array}{l} \frac{d^2 V(z)}{dz^2} = (R + j\omega L)(G + j\omega C)V(z) = \gamma^2 V(z) \\ \frac{d^2 I(z)}{dz^2} = (R + j\omega L)(G + j\omega C)I(z) = \gamma^2 I(z) \end{array} \right.$$

where $\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)} \Rightarrow V(z) = V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z}$, $I(z) = I_0^+ e^{-\gamma z} + I_0^- e^{\gamma z}$

Characteristic impedance: $Z_0 = \frac{V_0^+}{I_0^+} = -\frac{V_0^-}{I_0^-} = \frac{R + j\omega L}{\gamma} = \frac{\gamma}{G + j\omega C} = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$

III. Practical Types

A. Coaxial Cable:

Coaxial lines confine virtually all of the electromagnetic wave to the area inside the cable. Coaxial lines can therefore be bent and twisted (subject to limits) without negative effects, and they can be strapped to conductive supports without inducing unwanted currents in them. In radio-frequency applications up to a few gigahertz, the wave propagates in the transverse electric and magnetic mode (TEM) only, which means that the electric and magnetic fields are both perpendicular to the direction of propagation (the electric field is radial, and the magnetic field is circumferential). However, at frequencies for which the wavelength (in the dielectric) is significantly shorter than the circumference of the cable, transverse electric (TE) and transverse magnetic (TM) waveguide modes can also propagate. When more than one mode can exist, bends and other irregularities in the cable geometry can cause power to be transferred from one mode to another. The most common use for coaxial cables is for television and other signals with bandwidth of multiple megahertz. In the middle 20th century they carried long distance telephone connections.

B. Microstrip:

A microstrip circuit uses a thin flat conductor which is parallel to a ground plane. Microstrip can be made by having a strip of copper on one side of a printed circuit board (PCB) or ceramic substrate while the other side is a continuous ground plane. The width of the strip, the thickness of the insulating layer (PCB or ceramic) and the dielectric constant of the insulating layer determine the characteristic impedance. Microstrip is an open structure whereas coaxial cable is a closed structure.

C. Stripline:

A stripline circuit uses a flat strip of metal which is sandwiched between two parallel ground planes. The insulating material of the substrate forms a dielectric. The width of the strip, the thickness of the substrate and the relative permittivity of the substrate determine the characteristic impedance of the strip which is a transmission line.

D. Balanced lines:

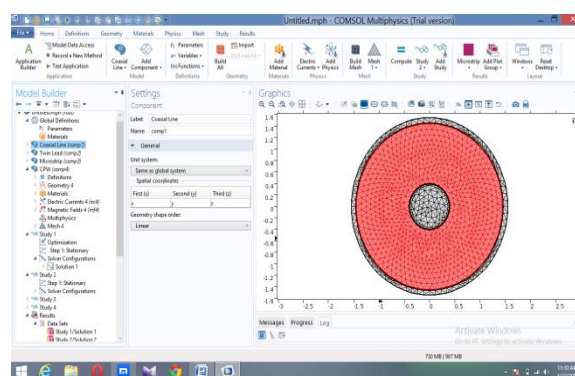
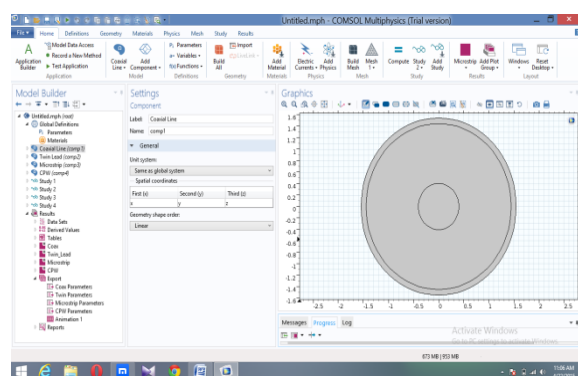
A balanced line is a transmission line consisting of two conductors of the same type, and equal impedance to ground and other circuits. There are many formats of balanced lines, amongst the most common are twisted pair, star quad and twin-lead.

E. Single-wire line:

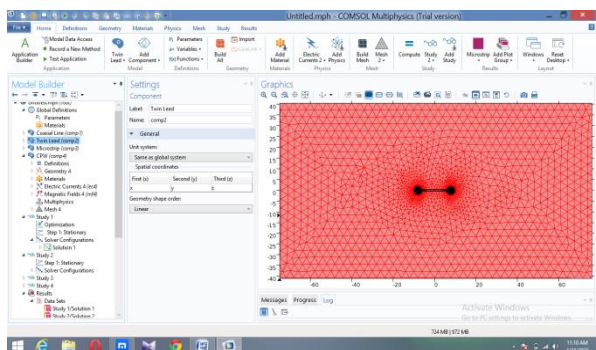
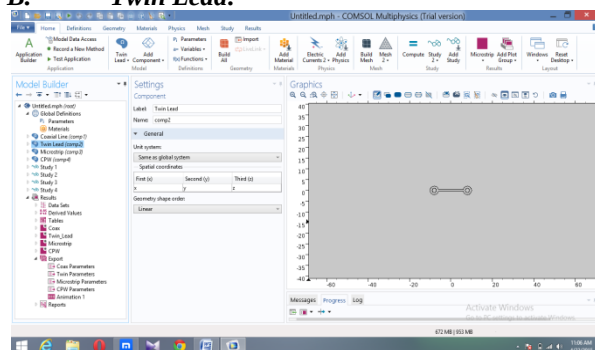
Unbalanced lines were formerly much used for telegraph transmission, but this form of communication has now fallen into disuse. Cables are similar to twisted pair in that many cores are bundled into the same cable but only one conductor is provided per circuit and there is no twisting. All the circuits on the same route use a common path for the return current (earth return). There is a power transmission version of single-wire earth return in use in many locations.

IV. Design & Simulation Results by COMSOL

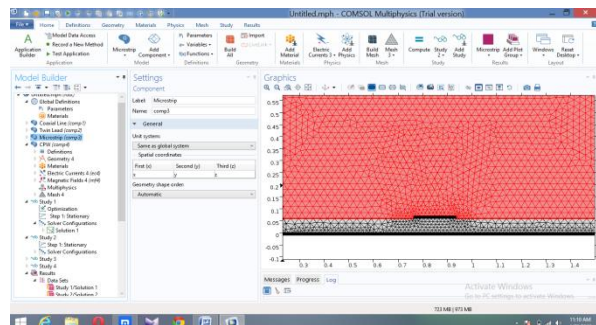
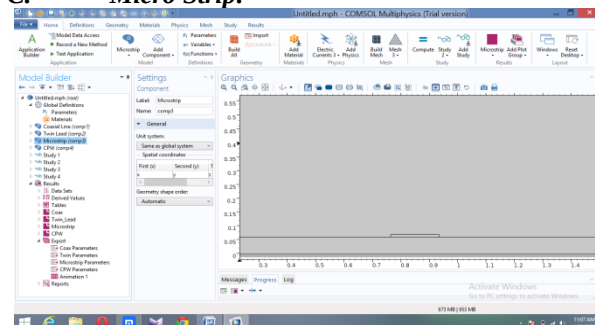
A. Coaxial Line:



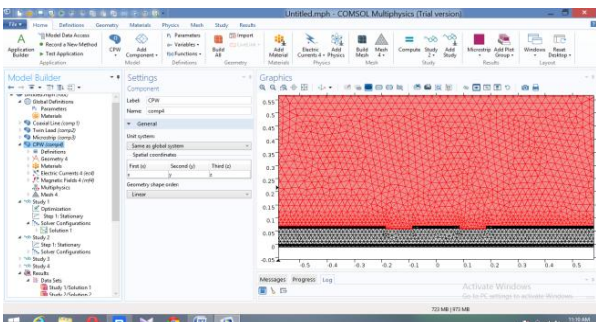
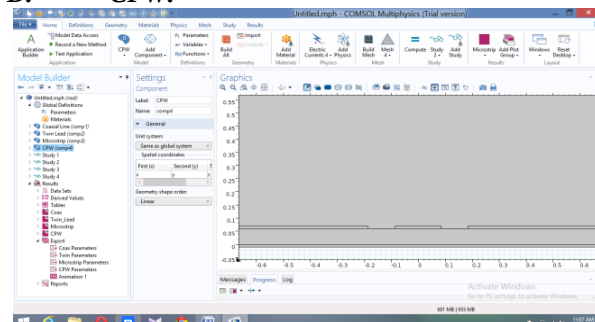
B. Twin Lead:



C. Micro Strip:



D. CPW:



Specifications:

Coaxial Line

Expression	Unit	Description
frq_coax	Hz	frequency
Ri_coax	m	inner radius
dR_coax	m	outer radius-inner radius
d_s_coax	m	screen thickness
epsr_coax		relative permittivity of dielectric
mur_coax		relative permeability of dielectric
sigma_d_coax	S/m	conductivity of dielectric
sigma_c_coax	S/m	conductivity of conductors
R_coax	Ω/m	distributed resistance
L_coax	H/m	distributed inductance
G_coax	S/m	shunt conductance
C_coax	F/m	capacitance
Zc_coax	Ω	characteristic impedance
gamma_coax	1/m	propagation constant

Twin Lead

Expression	Unit	Description
frq_twin	Hz	frequency
R1_twin	m	
t_ins_twin	m	wire insulation thickness
d_twin	m	insulation surface-to-surface distance
epsr_twin		relative permittivity of dielectric
sigma_d_twin	S/m	conductivity of dielectric
sigma_c_twin	S/m	conductivity of conductors
R_twin	Ω/m	distributed resistance
L_twin	H/m	distributed inductance
G_twin	S/m	shunt conductance
C_twin	F/m	capacitance
Zc_twin	Ω	characteristic impedance
gamma_twin	1/m	propagation constant

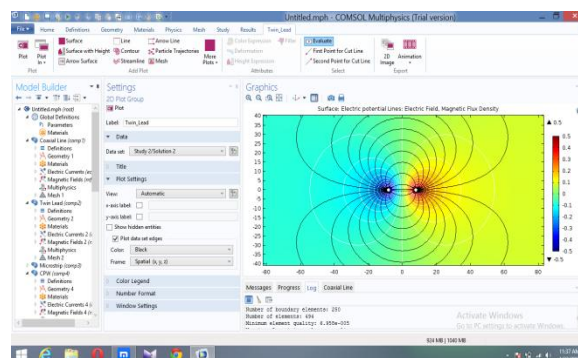
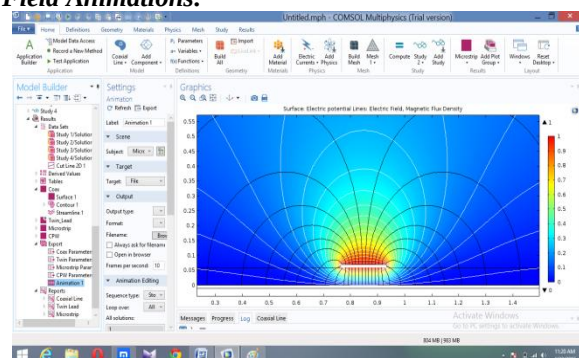
Micro Strip:

Expression	Unit	Description
frq_ms	Hz	frequency
W_ms	m	strip width
t_ms	m	strip thickness
h_ms	m	height of dielectric
t_gp_ms	m	thickness of ground plane
epsr_ms		relative permittivity of diel...
sigma_d_ms	S/m	conductivity of dielectric
sigma_c_ms	S/m	conductivity of conductors
R_ms	Ω /m	distributed resistance
L_ms	H/m	distributed inductance
G_ms	S/m	shunt conductance
C_ms	F/m	capacitance
Zc_ms	Ω	characteristic impedance
gamma_ms	1/m	propagation constant

CPW:

Expression	Unit	Description
frq_cpw	Hz	frequency
bp_cpw		conductive back plane sw...
W_cpw	m	central track width
g_cpw	m	gap to ground width
t_cpw	m	track thickness
h_cpw	m	height of dielectric
t_bp_cpw	m	thickness of metallic back...
epsr_cpw		relative permittivity of diel...
sigma_d_cpw	S/m	conductivity of dielectric
sigma_c_cpw	S/m	conductivity of conductors
R_cpw	Ω /m	distributed resistance
L_cpw	H/m	distributed inductance
G_cpw	S/m	shunt conductance
C_cpw	F/m	capacitance
Zc_cpw	Ω	characteristic impedance
gamma_cpw	1/m	propagation constant

Field Animations:



The above figures can represent the design models of Practical type transmission lines. Here the paper gives the technical specifications of individuals.

V. Conclusion

This paper concludes about the practical types of transmission lines i.e Coaxial Line, Twin Lead, Micro Strip and CPW models are designed by using COMSOL Multiphysics software. A transmission line is a specialized cable or other structure designed to carry alternating current of radio frequency.

VI. References

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