Subject: Transmission line L and C

From: G8MNY@GB7CIP.#32.GBR.EU
To : TECH@WW

From: Ralph VK2ZRG@VK2AAB.SYD.NSW.AUS.OC (+comments Oct 04)

Hello all techies,
Here are two simple formulas to calculate inductance and capacitance in a transmission line.

pF per metre = Square Root(Er) / (3 * Zo) * 10000
nH per metre = Square Root(Er) * Zo / 0.3

Er is the dielectric constant.

So what use is that you say? Well you could measure the capacitance of a coax cable plus its length, and determine it's Zo. Useful if you have some coax cable of an unknown brand, or no brand at all.

For 50ohm PE cables of Er=2.3	For 75ohm PE cables of Er=2.3
Capacitance = 101 pF/m	Capacitance = 67 pF/m
Inductance = 253 nH/m	Inductance = 379 nH/m
For 50ohm PTFE cables of Er=2.1	For 75ohm PTFE cables of Er=2.1
Capacitance = 97 pF/m	Capacitance = 64 pF/m
Inductance = 241 nH/m	Inductance = 362 nH/m
For 50ohm Foam cables of Er=1.4	For 75ohm Foam cables of Er=1.4
Capacitance = 79 pF/m	Capacitance = 53 pF/m
Inductance = 197 nH/m	Inductance = 296 nH/m
For 50ohm Air spaced Er=1.0	For 75ohm Air spaced Er=1.0
Capacitance = 67 pF/m	Capacitance = 44.5 pF/m
Inductance = 167 nH/m	Inductance = 250 nH/m

Most amateurs know that the Zo of a transmission line is determined by the ratio of it's dimensions. So if you double the diameter of a coax cable of given Zo, the area of the inner and outer conductors will double as well as the spacing, resulting in the same capacitance per unit length. And the inductance per unit length must also stay the same!

Now here is something to ponder upon. The inductance per unit length of RG58 50 ohm coax with a 0.8mm dia inner, is the same as a RG19A 50ohm coax with 6.3mm dia inner. Most amateurs will know that thin wires have more inductance than thick wires, so how can both cables have the same distributed inductance?

I know the answer, see if you can work it out.

The characteristic impedance (Zo) of a transmission line is set by the ratio of inductance and capacitance per unit length. The formula is...

Zo = Square Root(L/C)

L and C are in same relative units per unit length.
Eg Farads and Henries or picrofarads and picohenries.

This means that the Zo will be half if Er is increased by a factor of four (providing that the conductor diameters remain the same). Because the capacitance is proportional to the Er. Well that's what I was taught.

Here is a little gem from an amateur radio publication by someone writing on transmission lines. The name of the gentleman who wrote this and the organisation that published it, will remain nameless but you can probably guess if you have read my recent bulletins. On page 5-14.

Quote -

> Similarly, capacitance varies inversely with the outer conductor diameter B, because the greater the diameter of the outer conductor, the greater distance between the "plates" of our "capacitor". And distributed capacitance should vary directly with the square root of the permittivity of the dielectric, just as any capacitor increases by a factor of four if the dielectric constant is doubled.

End quote.

What I learnt is, that the definition of dielectric constant of a material is the capacitance ratio when the dielectric of a capacitor changes from air to the material in question. Even the ARRL Handbook says so. So don't believe everything you see in print (or on a computer screen).

Transmission line losses.

Losses are mainly due to conductor (copper) loss. At 30MHz this accounts for greater than 97% of the loss in a 50 ohm coax cable and nearly 100% for a balanced cable. At 1200MHz, conductor loss is over 85% of the total in hard line coax and even more for braided cables. So most of the reduced loss in foam PE cables is due to a larger centre conductor.
For a constant outer diameter the minimum loss per unit length in air spaced coax lines occurs when Zo=77 ohms. When Er=2.3, the minimum loss occurs at 50ohms. Balanced lines have lower losses than coax lines simply because the impedance is generally 5 to 10 times that of coax. High Zo means less current for the same power and power lost is proportional to the square of the current. So the current in a 500ohm balanced line will be 31.6% of that in a 50ohm coax and given equal copper loss, the loss will be 10% of the loss in the 50ohm coax.

73s from Ralph VK2ZRG@VK2W1.#SYD.NSW.AUS.OC

Comments From Dick VK3ABK @ VK3KAY.#WEV.VIC.AUS.OC

Not exactly, Ralph...

For coax, $Z_o = \frac{138}{E_r} * \log \frac{b}{a}$

Where Zo is the 'Characteristic Impedance'
b and a are diameters. (log base 10)
Er is the dielectric constant of the insulation.

Another way....

$$Z_o = \sqrt{\frac{R + jwL}{G + jwC}}$$

Where R is the resistance of conductors
G is the conductance
L is the distributed inductance
C is the distributed capacitance

(Note these complex impedances)

So instead of the "square root (L/C)" (quoted) you must invoke the other parameters, but the first equation is sufficient for normal use. In fact, the L and C that Ralph quotes, above, is not used to calculate 'Characteristic Impedance'. We only deal with the 'diameters' and the 'dielectric' in the cable.

Look at the definition of Impedance. It is....

$$L = \frac{v}{dv/dt}$$

Where L is Impedance
and di/dt is the rate of current change
in Amps per Sec.
and v is applied voltage

Note, this involves 'rate of change' not 'frequency'. (Incidentally, this is reminiscent of 'Baud' as distinct from 'Bit Rate')

A similar situation exists with Capacitance...

A Capacitor is defined by the dimensions of the electrodes, and Capacity is defined by the volume of dielectric.

$$C = k * \frac{A}{d} * 8.85 * 10^{-12} \text{ Farad}$$

Where k is the dielectric constant
A is the plate area in metre
and d is the plate separation in metre
The rest of this equation involves
the 'Absolute Permittivity of air.

(OK, you can use other
specific equations to
work in PF and micro H)

So, the Characteristic Impedance is not the Impedance you would 'measure' at the end of a cable, using an inductance meter and a capacitance meter.

In addition to the above we have 'Distributed' inductance in a capacitor and 'Distributed' capacity in an inductor, giving 'Distributed Impedance'. But these are not the same as 'Characteristic'Impedance.

Coax cable losses are Resistive (Ohmic) and Dielectric and Power Factor loss. This contributes to heating loss and high SWR 'losses' (frequency dependant), generally called transmission line losses as Ralph explained.

Why don't U send an interesting bul?

73 De John G8MNY @ GB7CIP
/EX