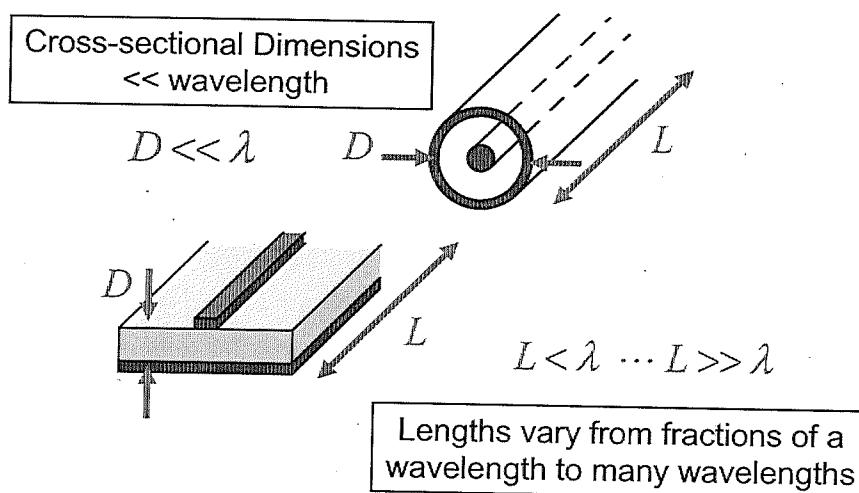


Transmission Line Parameters + Characteristics

- A T-line will be considered to be a two conductor structure of uniform cross sectional dimensions; AKA, "controlled impedance" line. A uniform cross section gives a uniform characteristic impedance.
- The T-lines cross sectional dimensions must be \ll the wavelength of the signals it carries. (contrast w/waveguides)
- The T-line may be of any reasonable length. Its length does not effect its characteristic impedance, (Z_0)

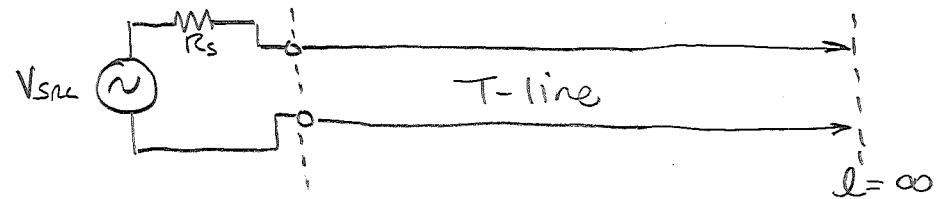


A fixed cross-sectional area yields a controlled impedance

Lengths vary from fractions of a wavelength to many wavelengths

T-line Parameters And Characteristics

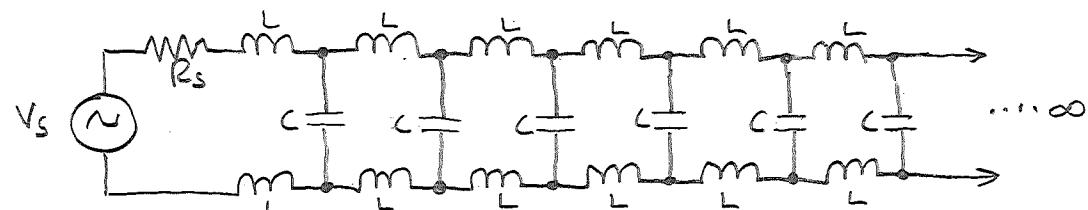
Our T-lines are built from conductor pairs:



We know that any wire carrying current exhibits an inductance.

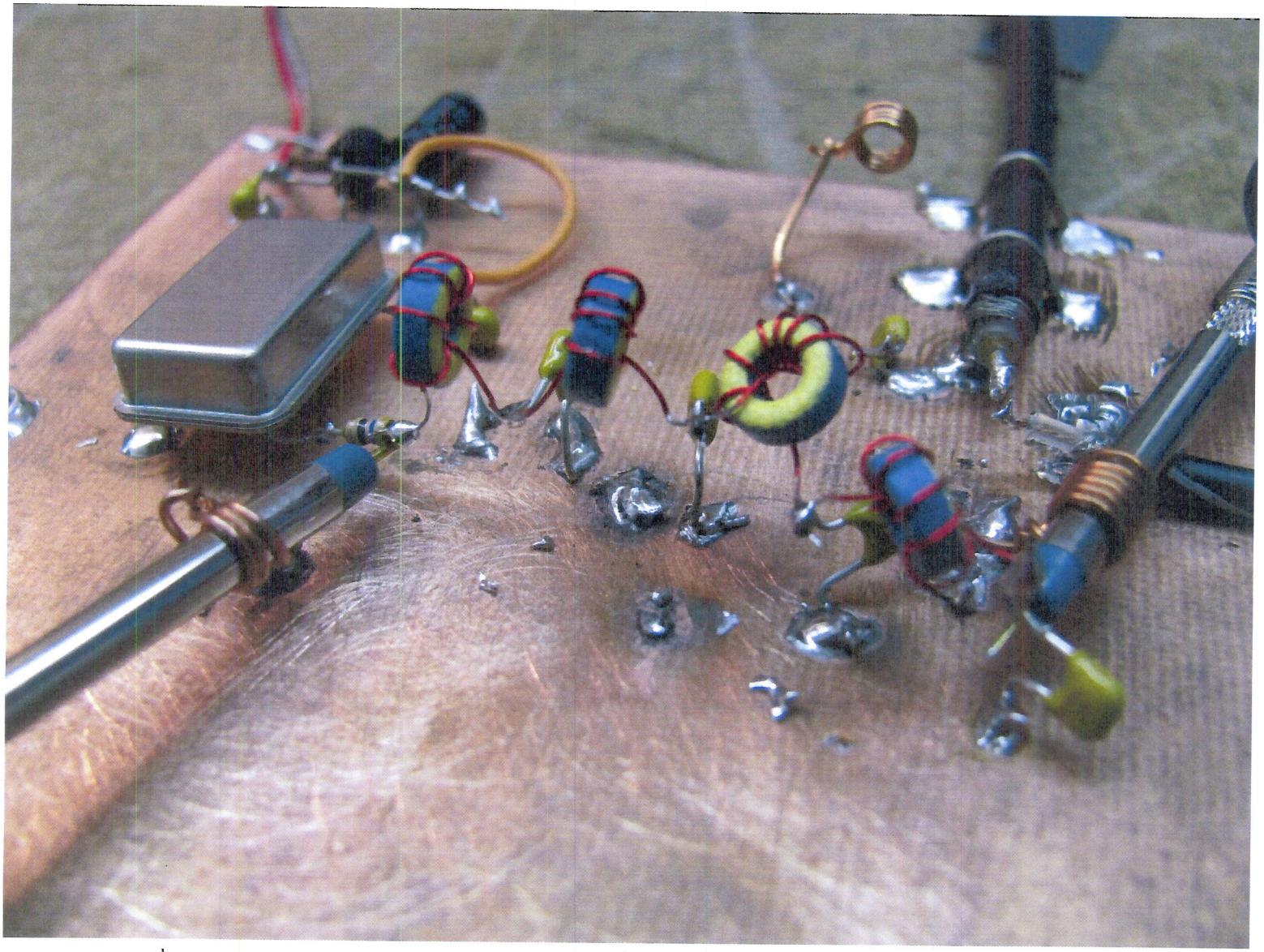
Also, two conductors separated by an insulator & charged by an electric field exhibit a capacitance.

Therefore, it is reasonable to model our T-lines as follows:

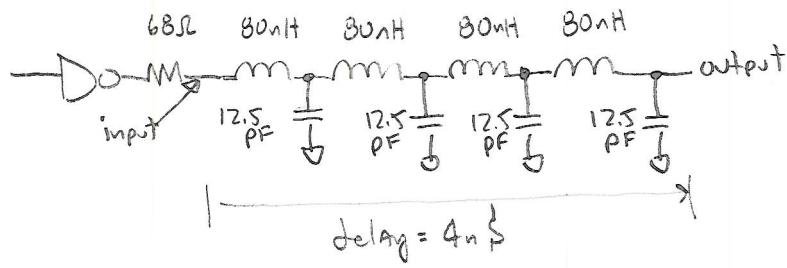


The basic T-line model is an infinite series of simple networks

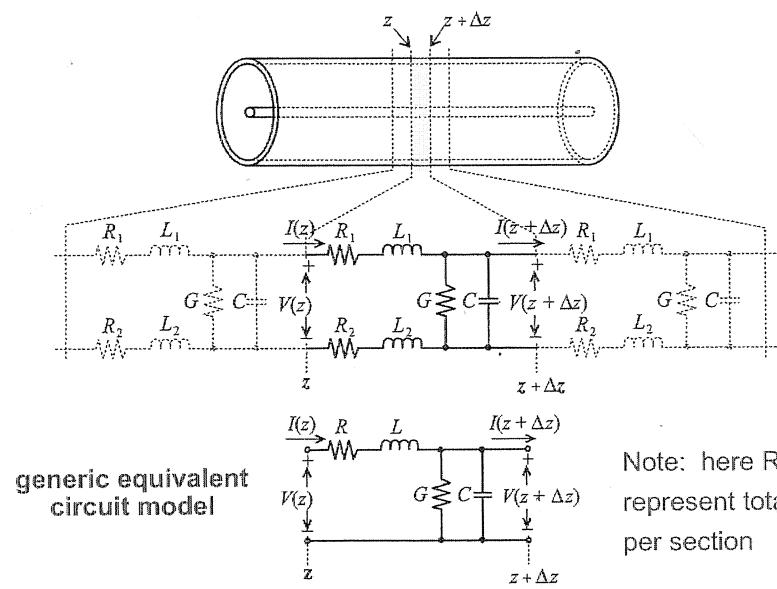
But for a finite length line we can build the same model by specifying each network to represent an infinitesimally short section of the T-line. Actually, as long as each section is short enough to act as a lumped model at the frequency of interest, model accuracy will be maintained.



A $4n\frac{1}{2}$, $80\Omega Z_0$, lumped element transmission line



T-line Parameters And Characteristics



NGSPICE "Y" model
for lossy line

R : represents the resistance* of the unit length conductor

G : represents the leakage conductance of the dielectric (insulator) per unit length

L, C are the per unit length inductance and capacitance

Δz is the incremental length of our model

* eventually includes DC resistance and skin effect resistance

6.4.1 Single Lossy Transmission Line (TXL)

General form:

YXXXXXXX N1 0 N2 0 mname <LEN=LENGTH>

Example:

Y1 1 0 2 0 ymod LEN=2
.MODEL ymod txl R=12.45 L=8.972e-9 G=0 C=0.468e-12 length=16

n1 and n2 are the nodes of the two ports. The optional instance parameter len is the length of the line and may be expressed in multiples of [unit]. Typically unit is given in meters. len will override the model parameter length for the specific instance only.

The TXL model takes a number of parameters:

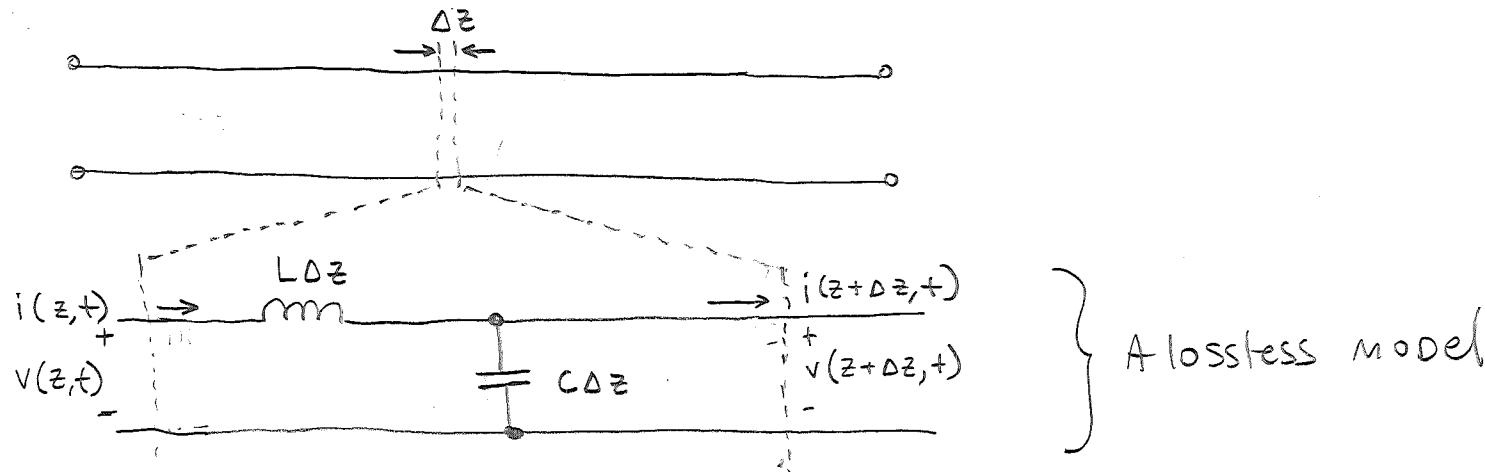
Name	Parameter	Units/Type	Default	Example
R	resistance/length	Ω/unit	0.0	0.2
L	inductance/length	H/unit	0.0	9.13e-9
G	conductance/length	$mhos/\text{unit}$	0.0	0.0
C	capacitance/length	F/unit	0.0	3.65e-12
LENGTH	length of line	unit	no default	1.0

Model parameter length must be specified as a multiple of unit. Typically unit is given in [m]. For transient simulation only.

T-line Parameters And Characteristics

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For many applications we can assume a lossless T-line model:



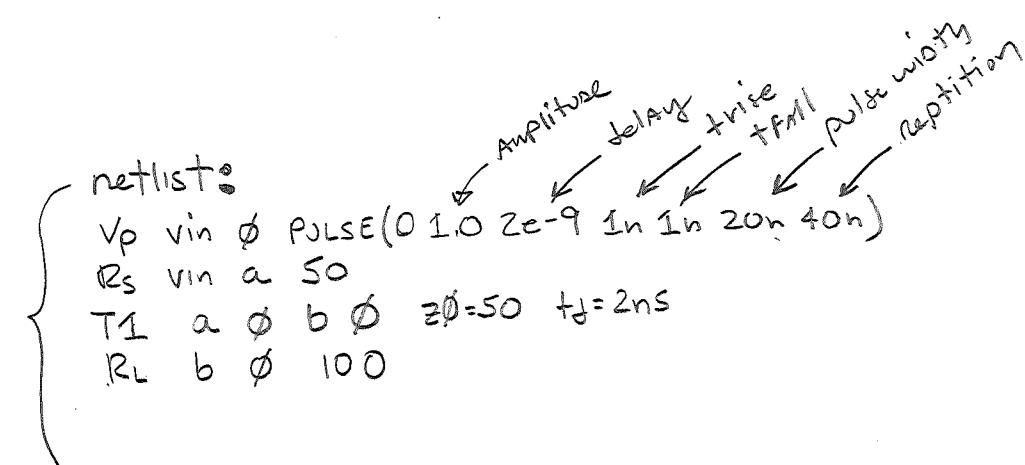
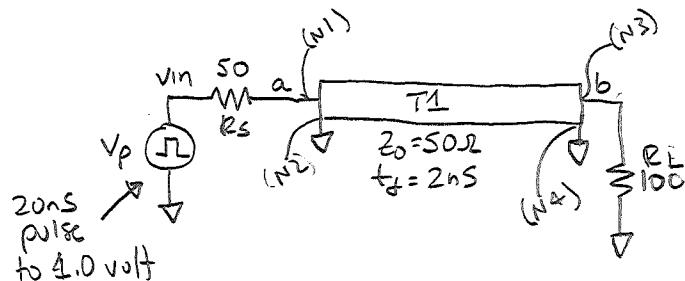
6.1 Lossless Transmission Lines

General form:

TXXXXXXX N1 N2 N3 N4 Z0=VALUE <TD=VALUE> <F=FREQ <NL=NRMLEN>
+ <IC=V1, I1, V2, I2>

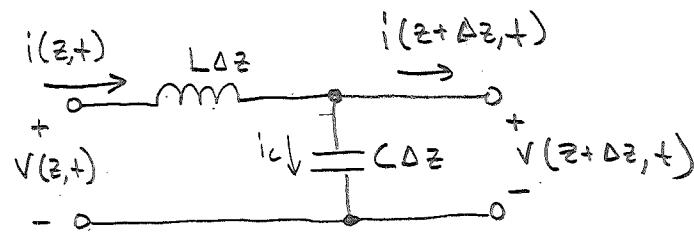
Examples:

T1 1 0 2 0 Z0=50 TD=10NS



T-Line Parameters + Characteristics

Applying KVL + KCL to our lossless model:



$$\text{KVL: } -V(z, t) + L\Delta z \frac{di(z, t)}{dt} + V(z + \Delta z, t) = 0$$

$$V(z + \Delta z, t) - V(z, t) = -L\Delta z \frac{di(z, t)}{dt}$$

; divide thru by Δz +
mult by -1

$$-\left[\frac{V(z + \Delta z, t) - V(z, t)}{\Delta z} \right] = L \frac{di(z, t)}{dt}$$

$$\boxed{-\frac{\partial V(z, t)}{\partial z}} = L \frac{\partial i(z, t)}{\partial t}$$

{ remember: $\frac{V(z + \Delta z, t) - V(z, t)}{\Delta z}$; let $\Delta z \rightarrow 0$ = $\frac{\partial V(z, t)}{\partial z}$ }

the voltage on the line
is related to the time rate
of change through the inductor
of current

The "Transmission Line Equations" or
"Telegrapher's Equations"
(lossless case)

RCL at center node:

$$i(z, t) - C\Delta z \frac{\partial v(z + \Delta z, t)}{\partial t} - i(z + \Delta z, t) = 0$$

$$-i(z + \Delta z, t) + i(z, t) = C\Delta z \frac{\partial v(z + \Delta z, t)}{\partial t}$$

divide thru by Δz +
mult by -1

$$-\left[\frac{i(z + \Delta z, t) - i(z, t)}{\Delta z} \right] = C \frac{\partial v(z, t)}{\partial t}$$

the current drawn by the line
is related to the time rate of
change of voltage across the capacitor

$$\boxed{-\frac{\partial i(z, t)}{\partial z}} = C \frac{\partial v(z, t)}{\partial t}$$

T-Line Parameters and Characteristics

$$\text{The telegrapher's equations: } \begin{aligned} (1) \quad -\frac{\partial v(z,t)}{\partial z} &= L \frac{\partial i(z,t)}{\partial t} \\ (2) \quad -\frac{\partial i(z,t)}{\partial z} &= C \frac{\partial v(z,t)}{\partial t} \end{aligned}$$

Can be combined to yield an equation entirely in terms of only v or i .

To eliminate $i(z,t)$ from the equations, differentiate (1) with respect to z , and (2) with respect to t .

$$-\frac{\partial^2 v(z,t)}{\partial z^2} = L \frac{\partial^2 i(z,t)}{\partial z \partial t} \quad \text{And} \quad \boxed{-\frac{\partial^2 i(z,t)}{\partial z \partial t}} = C \frac{\partial^2 v(z,t)}{\partial t^2}$$

Now, substituting for $\frac{\partial^2 i(z,t)}{\partial z \partial t}$:

$$\frac{\partial^2 v(z,t)}{\partial z^2} = L C \left[\frac{\partial^2 v(z,t)}{\partial t^2} \right] ; \text{ this is a one-dimensional wave equation}$$

A general solution for this equation is:

$$\begin{aligned} v(z,t) &= V^+(z - V_p t) + V^-(z + V_p t) \\ &= \underbrace{V^+}_{\substack{\text{wave going} \\ +z \longrightarrow}} (t - \underbrace{z/V_p}_{}) + \underbrace{V^-}_{\substack{\text{wave going} \\ -z \longleftarrow}} (t + \underbrace{z/V_p}_{}) \end{aligned}$$

the notation V^+ refers to a voltage waveform propagating towards the right.

V^- refers to a voltage waveform propagating from right to left.

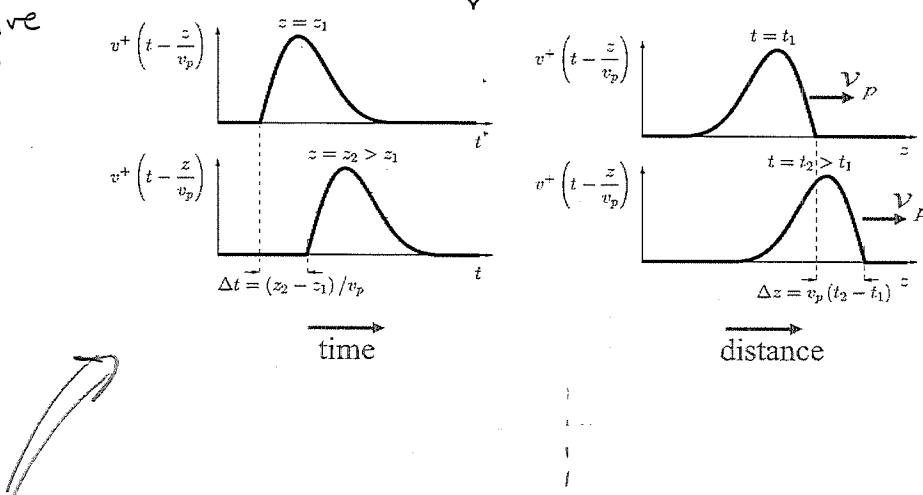
T-Line Parameters and Characteristics

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$$v(z, t) = v^+(z - v_p t) + v^-(z + v_p t)$$

$$= v^+(t - z/v_p) + v^-(t + z/v_p)$$

imagine riding a wave
on a surfboard and
observing its shape



Looking at the wave at two different times, we see it is moving in the z^+ direction, and is maintaining its shape as time increases.

Looking at the wave from two different positions we see that the shape at $z + \Delta z$ is the same as at z , but simply appears later.

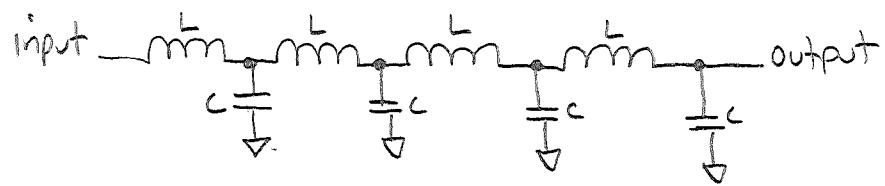
There is no change in the waveform shape over time or distance with an ideal or lossless T-line. Constant shape indicates that all frequency components are delayed identically. \therefore This T-Line has ∞ bandwidth.

imagine two observers, one 200yd from shore, one 50yd from shore observing the wave's shape,

T-Line Parameters & Characteristics

There is an "apparent contradiction" between our T-line model and the idea of infinite bandwidth.

Question: What type of filter is this?



Question: Isn't this our model for an infinite bandwidth T-line?

How can both be true?