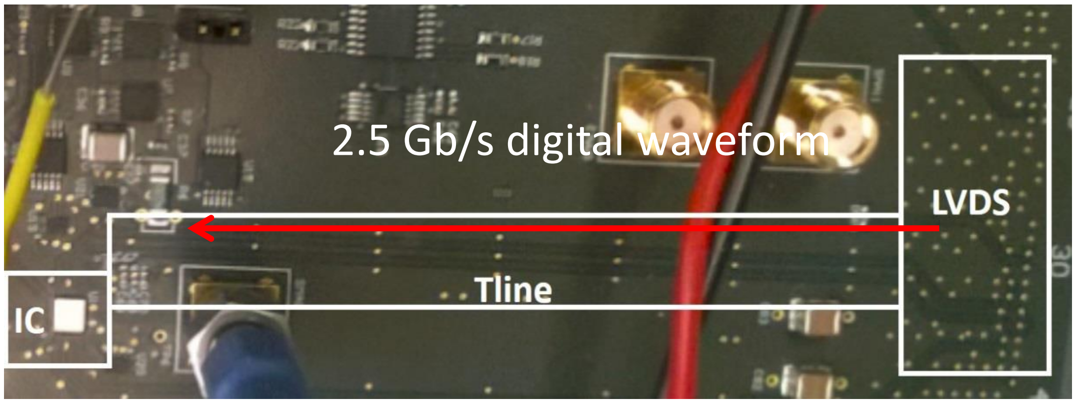
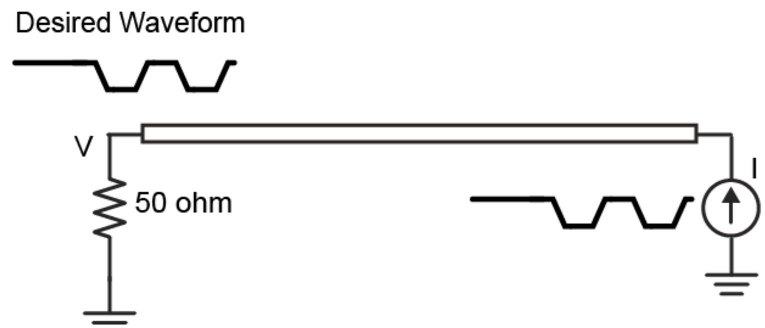
142/242 Discussion (9/6/2017)

- (1) Review transmission line behavior in time-domain
- (2) An example (reflection, energy)
- (3) HW 2.3, 2.4

Transmission Line in Circuits

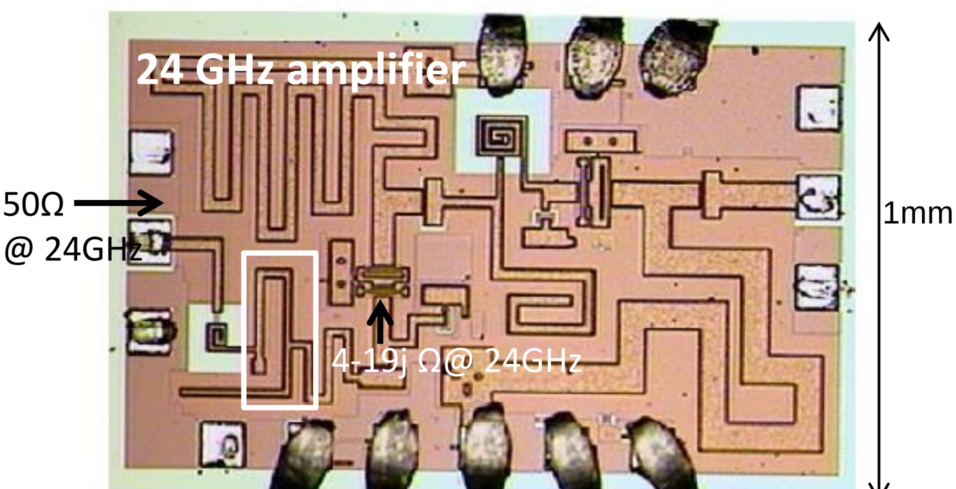
T-line in time domain to connect components



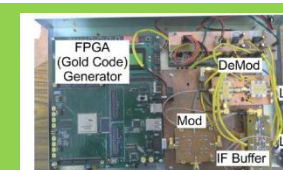


Things get nasty if $Z_0 \neq 50$ ohm

T-line in frequency domain (narrow-band impedance matching to 50 ohm)



Again, why 50Ω ?

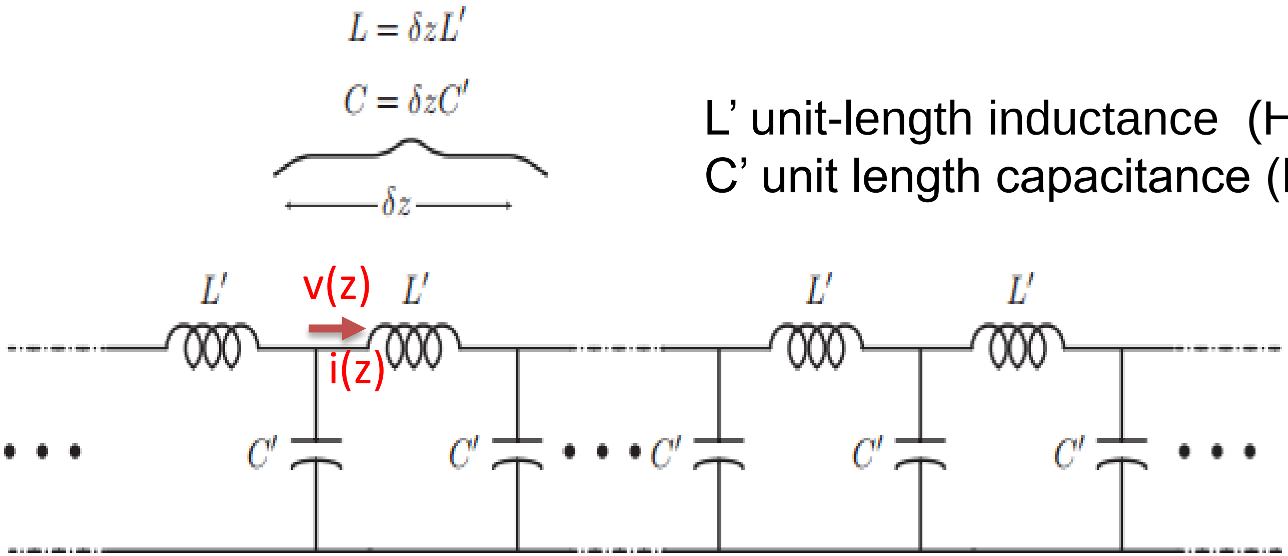


Most systems are less compact and need coaxial cables for the connection. 50-Ω cables are the best

⇒ Components are designed with 50-Ω input impedance

⇒ Now your T-line on PCB has also to be design with $Z_0 = 50$

Transmission Line Theory



L' unit-length inductance (H/m)
C' unit length capacitance (F/m)

Solve KCL and KVL

$$-\frac{\partial i}{\partial z} = C'\frac{\partial v}{\partial t}$$

$$-\frac{\partial v}{\partial z} = L'\frac{\partial i}{\partial t}$$

$$\frac{\partial^2 v}{\partial z^2} = L'C'\frac{\partial^2 v}{\partial t^2}$$

$$\frac{\partial^2 i}{\partial z^2} = L'C'\frac{\partial^2 i}{\partial t^2}$$

First Sol Forward

Second Sol backward

$$V(z,t) = \boxed{\underbrace{f^{+}(z - v\times t)}_{V^{+}}} + \boxed{\underbrace{f^{-}(z + v\times t)}_{V^{-}}}$$

$$I(z,t) = \boxed{\underbrace{f^{+}(z - v\times t)/Z_0}_{i^{+}}}\ \boxed{-\ \underbrace{f^{-}(z + v\times t)/Z_0}_{i^{-}}}$$

$$Z_0 = \sqrt{\frac{L'}{C'}} \qquad v = \sqrt{\frac{1}{L'C'}}$$

- **Characteristic Impedance (Z_0) is the voltage-current ratio for the wave solutions (not node solution)**
- Why a wide transmission line has a lower Z_0 ?

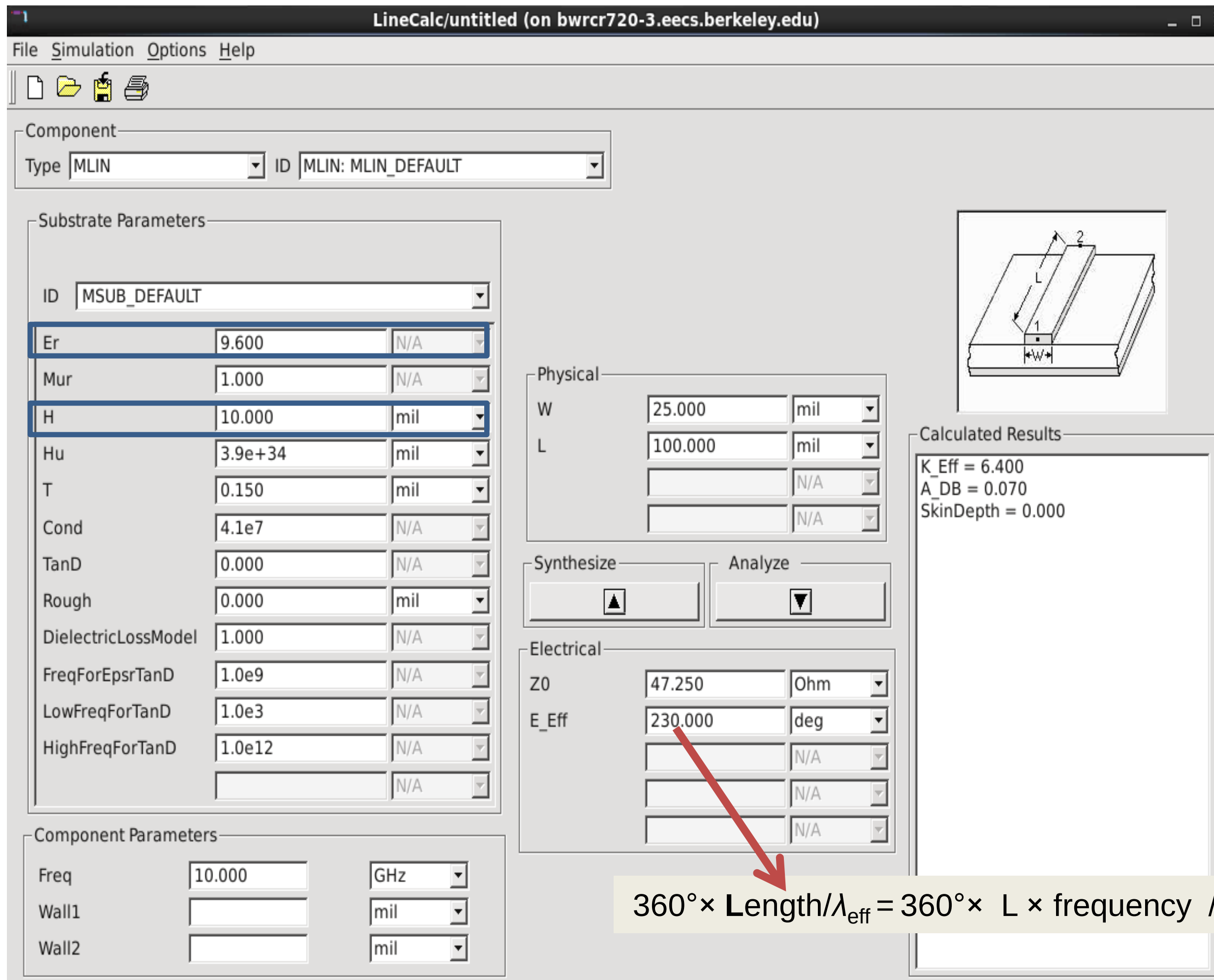
ADS Transmission Line Calculator

Tools => LineCal: A useful tool in ADS to calculate T-line Z_0

Dielectric Constant: E_r $\uparrow$ Z_0 $\downarrow$ λ_{eff} $\downarrow$

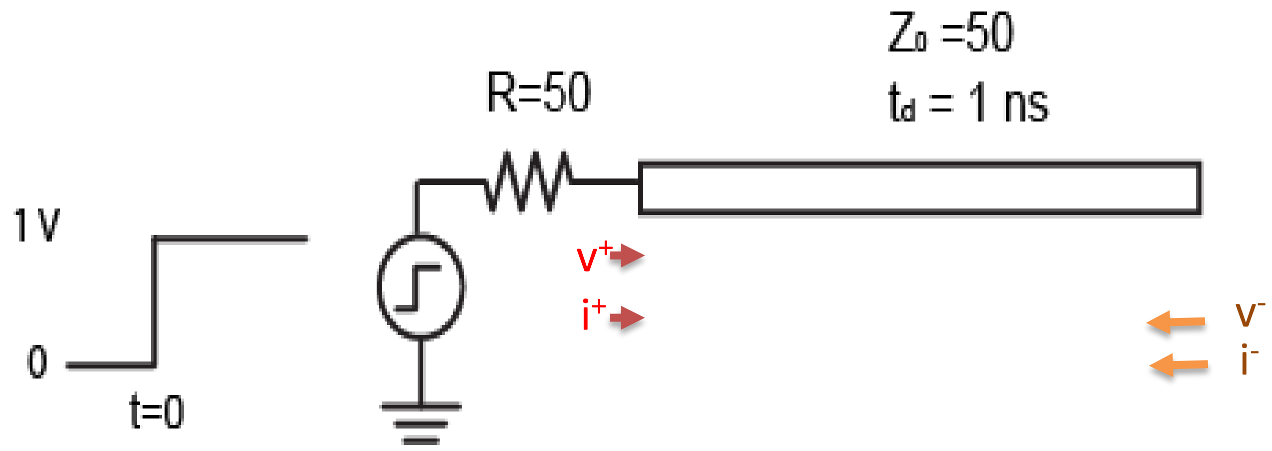
Substrate Thickness: H $\uparrow$ Z_0 $\uparrow$ λ_{eff} ?

Trace Width: W $\uparrow$ Z_0 $\downarrow$ λ_{eff} $-$



$360° \times \text{Length}/\lambda_{eff} = 360° \times L \times \text{frequency} / v$

Example

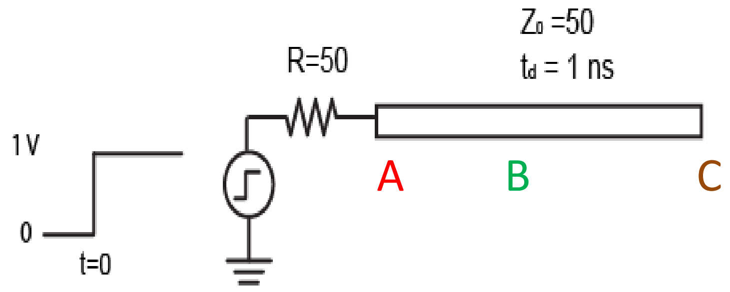


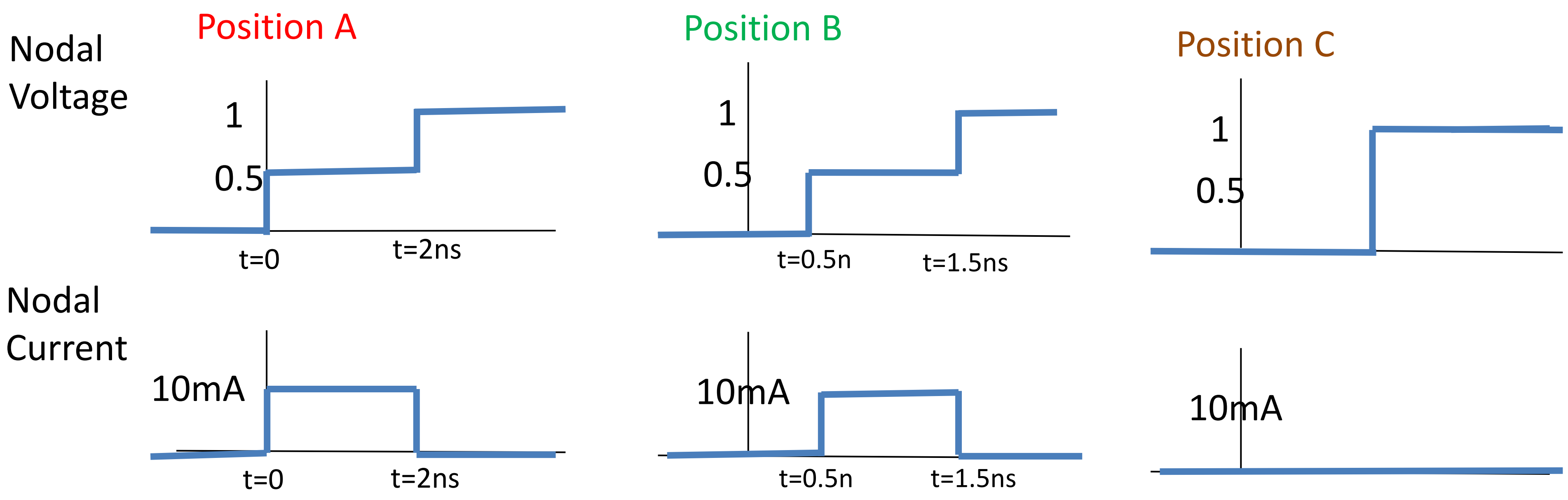
At t=0, a forward traveling voltage/current wave is excited

- What are the values of v^+ and i^+ ?
  $V^+ = 0.5$, $I^+ = 0.01$
- What will happen at t =1 ns ?
  backward wave is excited to satisfy boundary condition
- What are the value of v^- and i^- ?
  $0.01 - I^- = 0$ => $I^- = 10\text{mA}$ => $V^- = 0.5$
- Will a new forward traveling wave be generated by v^- and i^- ?
  No! no new wave has to be generated to satisfy the boundary condition, so the bounce stops

Now, You might understand why the T-line (cable) should have a load impedance of Z_0

Example: Time-Domain Diagram



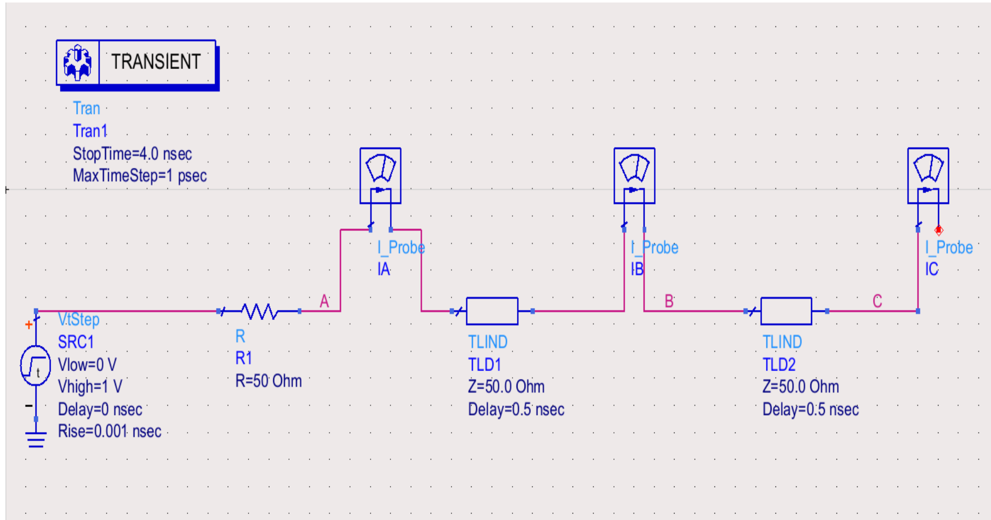


What is the energy stored on the transmission line?

(1) Source energy – Energy dissipated on resistor = 10mA*1V*2ns – 10mA*10mA*50*2ns = 20pJ – 10 pJ =10pJ

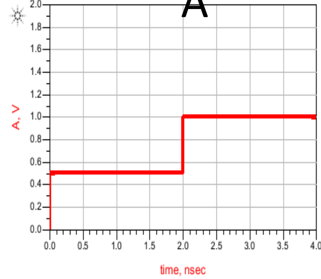
(2) $(1/2)CV^2 = (1/2) \times C \times 1^2 = 10$ pJ $C = C'*L = (1/Z_0v)*(v*td) = t_d/Z_0 =$ 20e-12

Example: Simulation in ADS

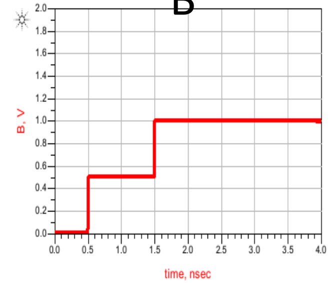


Nodal Voltage

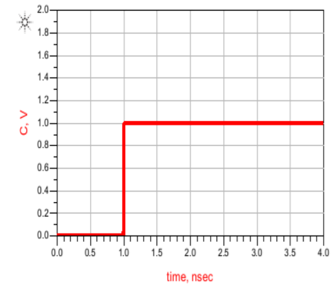
A



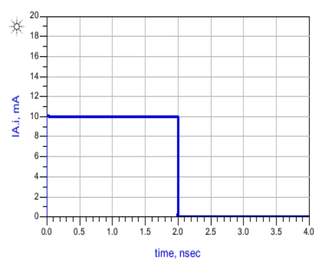
B

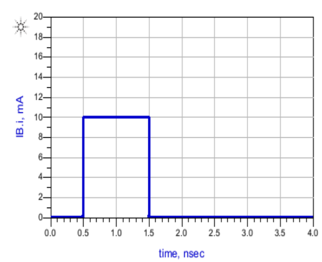


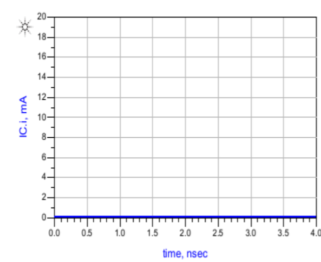
C



Nodal Current







HW2.4

4. A step voltage source is connected to a transmission line, as shown above.

   (a) Draw the time-domain response of the current flowing through the voltage source.

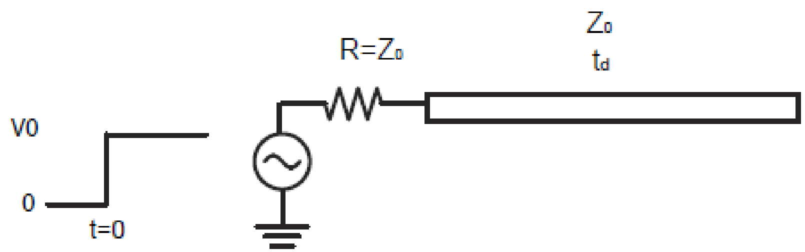
   (b) Using the time-domain response to calculate the total energy delivered by the voltage source and the total energy consumed on the resistor. What is the energy stored on the transmission line at $t = \infty$s?

   (c) Express the total capacitance of the transmission line by the line parameters Z_0 and t_d.

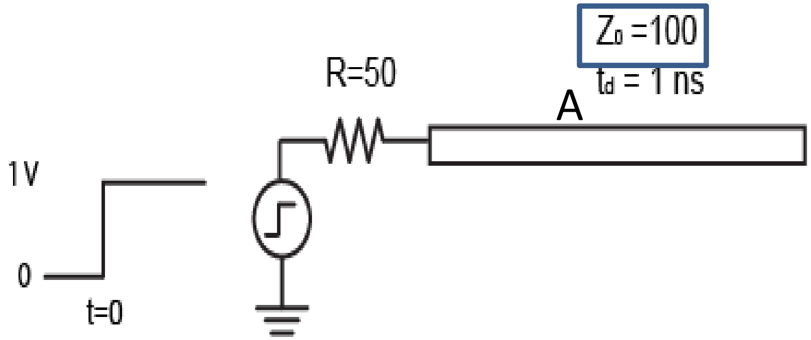
   example

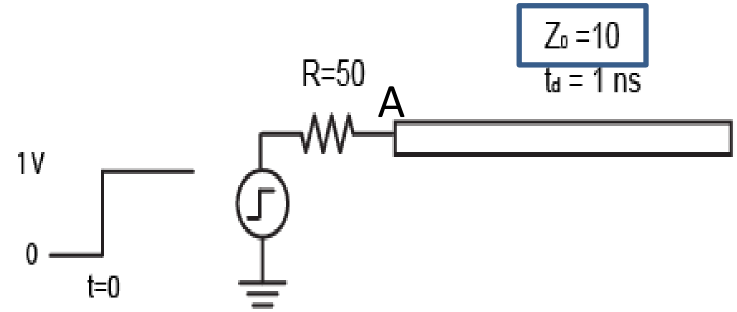
   (d) Repeat parts (a)-(b) but with the source resistance changed to $2Z_0$.

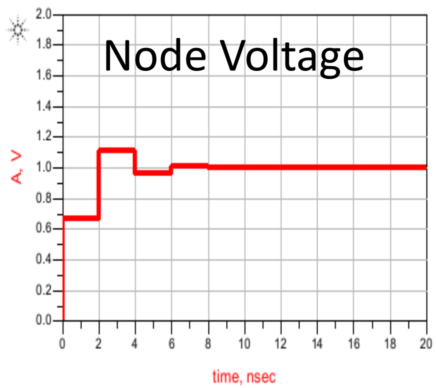
   (e) Calculate the energy stored on the transmission line at $t = \infty$s. Is there a way to bypass the tedious sum of infinite geometric series?



- 1. Calculate the total energy from the source then take away the total energy consumed on the resistor
- 2. Directly use the steady-state voltage and the total capacitor ($C_{total} = t_d/Z_0$)







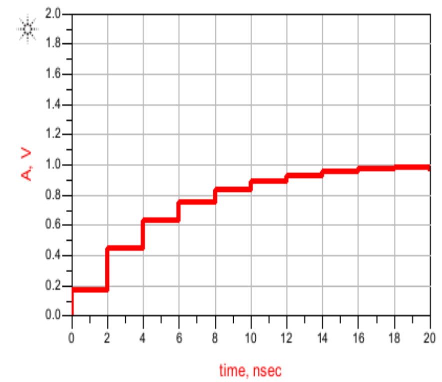
$V^+_1 = 0.66 \quad I^+_1 = 6.6\text{mA}$

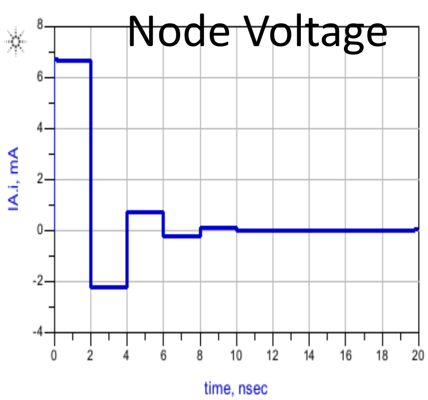
$V^-_1 = 0.66 \quad I^-_1 = 6.6\text{mA}$

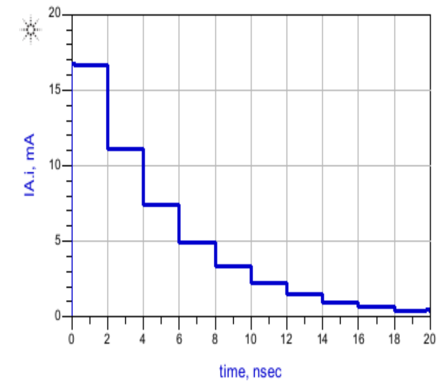
$V^+_2 = -0.22 \quad I^+_2 = -2.2\text{mA}$

$V^-_2 = -0.22 \quad I^-_2 = -2.2\text{mA}$

$V^+_3 = 0.07 \quad I^+_2 = 0.07\text{ mA}$



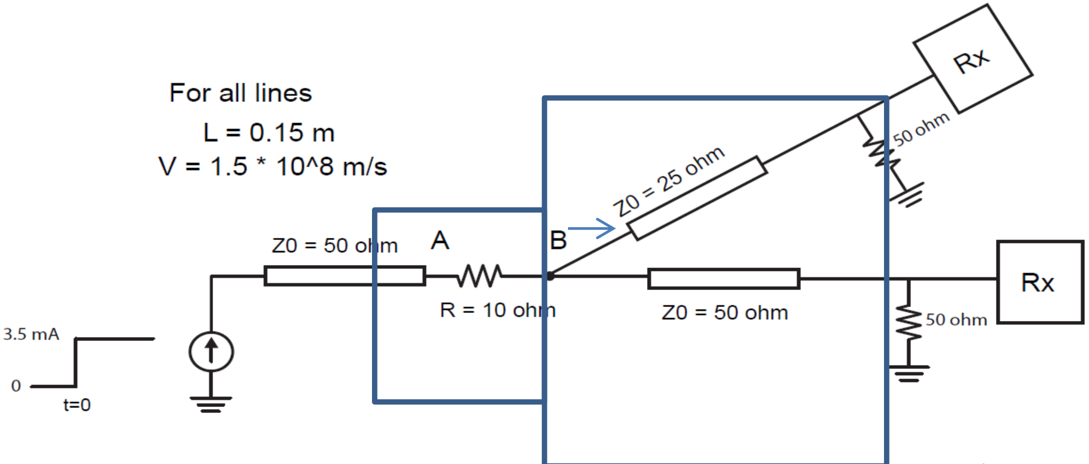




Resemble RC charging curves

Use ADS to verify your calculation!!!

HW2.3



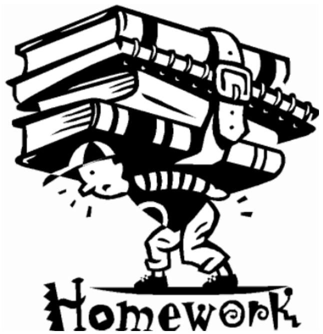
(a) What are the magnitudes of the forward traveling voltage wave (V^+) and the backward traveling wave (V^-) at A and B, at $t = 1.5$ns.

(b) Repeat part (a) but at time $t = 3.5$ns.

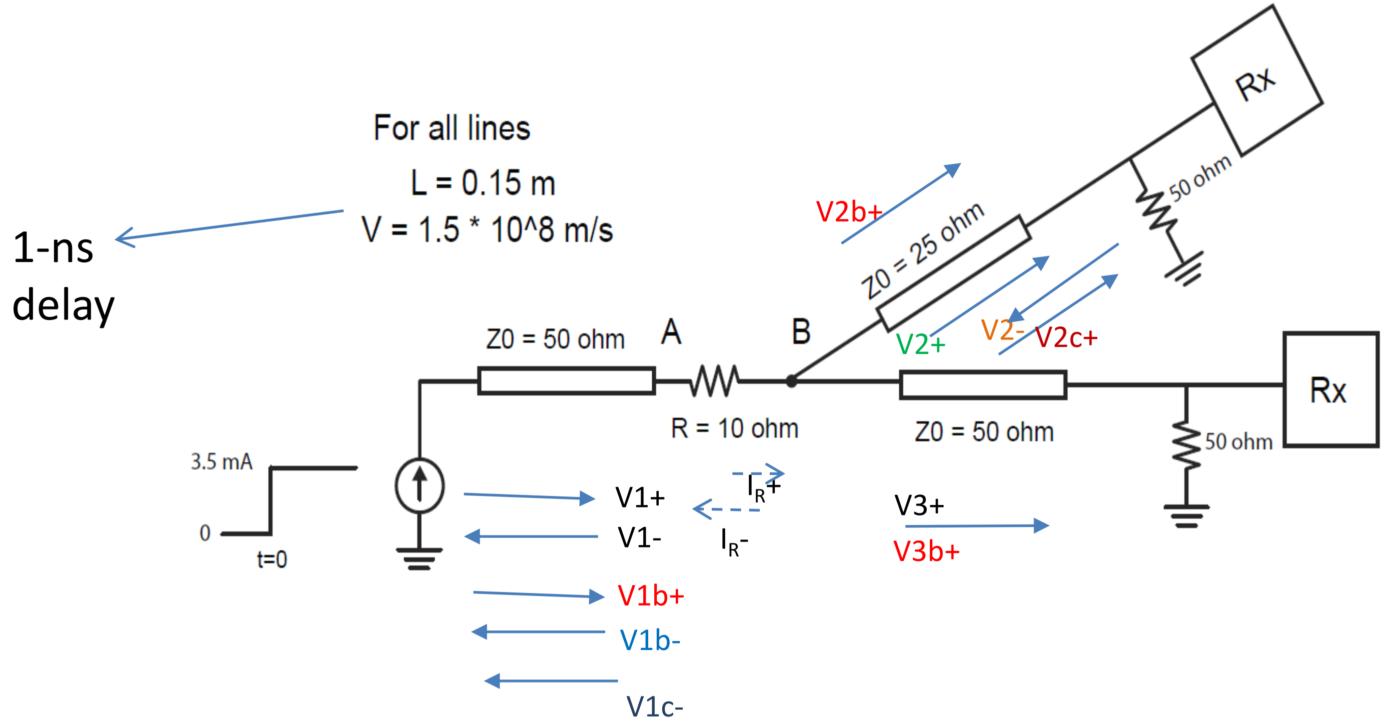
(c) Repeat part (a) but at time $t = \infty$s (steady state). Is there a way to bypass the tedious sum of infinite geometric series?

New Stuffs

A resistor in series !!!
Parallel T-lines !!!



HW2.3



At 1 ns:

$V1^+ = 175\text{mV}$, $V1^- = 175*(26.7-50)/(26.7+50) = 175*-0.30 = -53\text{ mV}$

$I_R+ = 175/50+53/50 = 4.56\text{ mA}$

$V2^+ = V3^+ = V1^+ + V1^- - 10*I_R^+ = 77.4\text{ mV}$

At 3.5 ns:

$V1^-$ has created a new forward traveling wave : $V1b^+ = V1^- = -53$ mV

$V1b^+$ has created $V2b^+$ and $V3b^+$ (as $V1^+$ creating $V2^+$ and $V3^+$)

=> $V2b^+ = V3b^+ = -23.4$

$V1b^- = 16$ mV

$V2^+$ has created a new backward wave: $V2^- = 25.8$ mV

$V2^-$ has created $V2c^+$: $V2c^+ = 25.8*(60//50 - 25)/(60//50 + 25) = 1$ mV

$IR- = (25.8 - 1)/25 \ *(50/110) = 0.48$mA

$V1c^- = V2^- + V2c^+ - 10*IR^- = 22$ mV

At Point A:

$V^+ = 175\ (V1^+) + -53\ (V1b^+) = 122$ mV

$V^- = -53\ (V1^-) + 16\ (V1b^-) + 22\ (V1c-) = -15$ mV

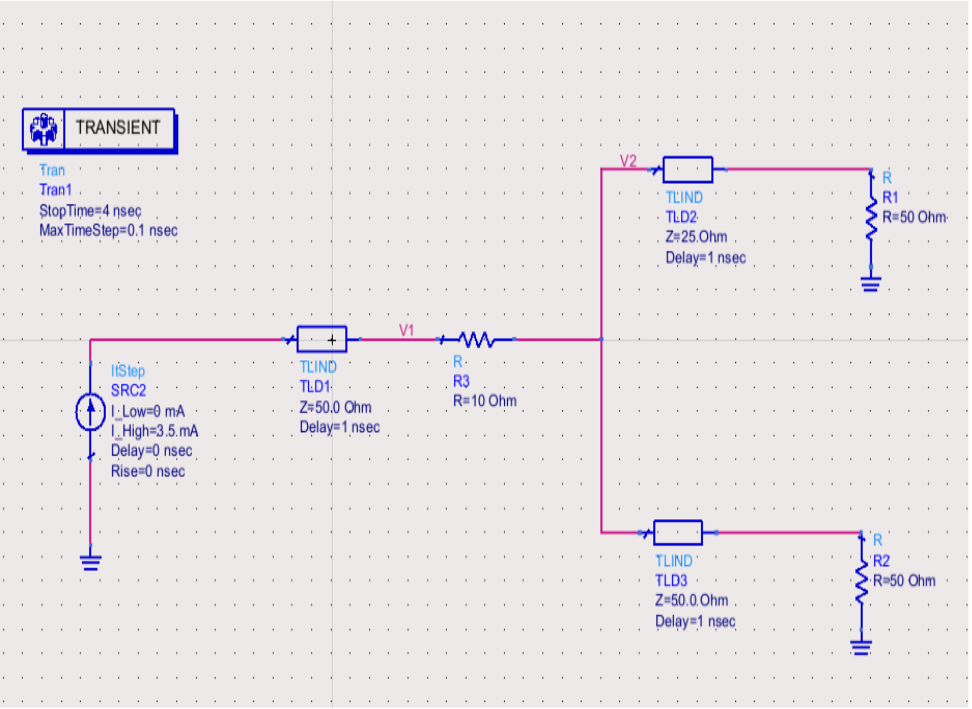
At Point B:

$V^+ = 77.4\ (V2^+) + -23.4\ (V2b^+) + -1(V2c^+) = 53$ mV

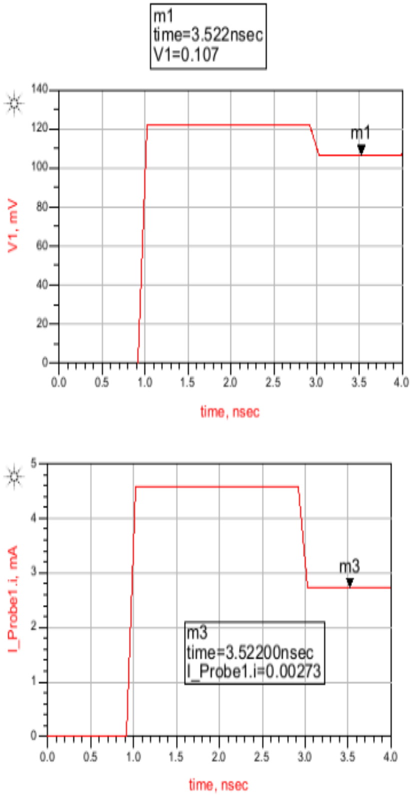
$V^- = 25.8$ mV $(V2^-)$

HW2.3

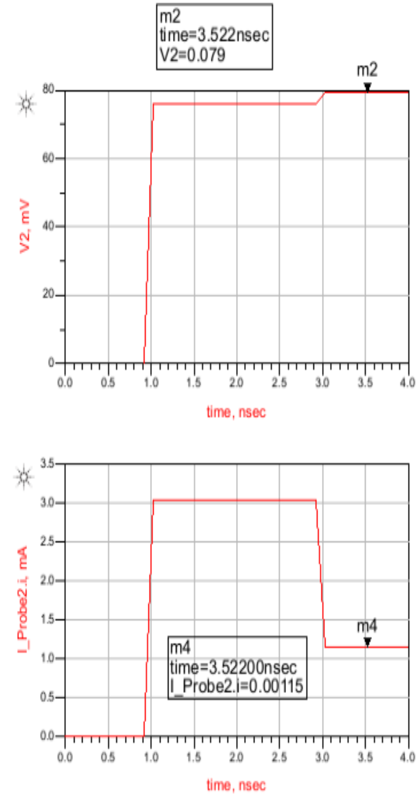
Check it in simulation



V1 Node



V2 Node



Only Nodal **V** and **I** can be measured(or Simulated)

$V^+ + V^- = \mathbf{V}$

$V^+/Z_0 - V^-/Z_0 = \mathbf{I}$

$V^+,\ V^-$