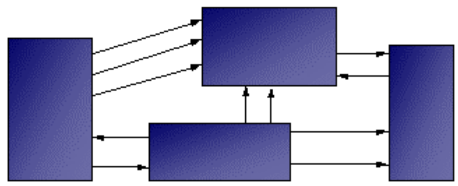
TRANSIENT SIGNALS IN COMPUTERS

Dream World:

Only 1's and 0's
Instantaneous links



Reality:

- Voltages, not 1's and 0's
- Levels and impedances matter
- Delays and transients matter
- Spurious transient waveforms generated at mismatches, can superimpose to flip bits erroneously
- RFI generated and picked up by wires can flip bits
- Ground loops matter

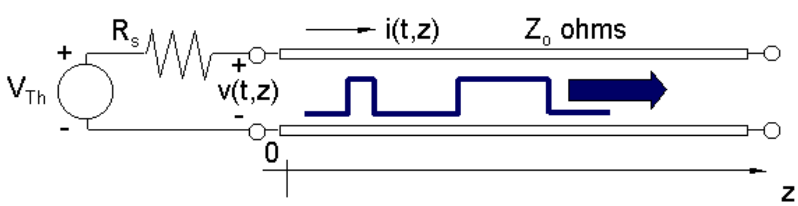
Paradigm:

Use Thevenin equivalent circuits for transmission lines, etc.

L13-1

TEM LINE THEVENIN EQUIVALENT (1)

Basic Equations for Lossless TEM Wires:



$$v(z,t) = v_+(t - z/c) + v_-(t + z/c)$$

$$i(z,t) = Y_o[v_+(t - z/c) - v_-(t + z/c)]$$

Where:

$$Y_o = 1/Z_o = (C/L)^{0.5}$$

This is a "boundary value problem"
The boundary is at z = 0

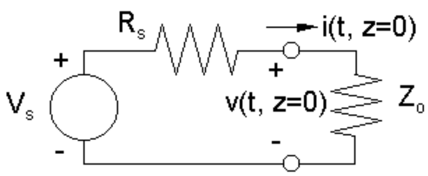
L13-2

TEM LINE THEVENIN EQUIVALENT (2)

Boundary Value Problems, Solution Method:

1) Characterize waves in each medium, with unknown coefficients
2) Impose boundary condition equations
3) Solve equations for unknowns

Example: Given $V_s(t)$:



$v(z,t) = v_+(t - z/c) + v_-(t + z/c)$
$i(z,t) = Y_o[v_+(t - z/c) - v_-(t + z/c)]$

Assume $v_- = 0$ (no other sources)
Then $v(t,z = 0) = Z_o i(t,z = 0)$
Yields equivalent circuit; solve it

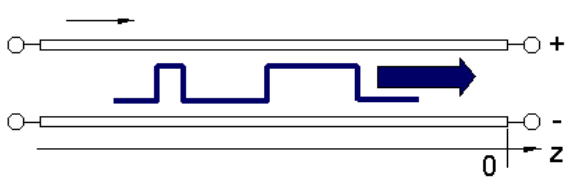
$v_+(t, z=0) = (Z_o/[Z_o + R_s])V_s(t)$
$v_+(t, z) = (Z_o/[Z_o + R_s])V_s(t - z/c)$

L13-3

TEM LINE THEVENIN EQUIVALENT (3)

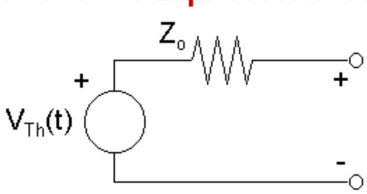
Voltages at an Open Circuit:

$v(z,t) = v_+(t - z/c) + v_-(t + z/c)$



Since: $i(z,t) = Y_o[v_+(t - z/c) - v_-(t + z/c)] = 0$ at $z = 0$
Therefore: $v_+(t) = v_-(t)$ at $z = 0$, and $v(t) = 2v_+(t)$

Thevenin Equivalent for TEM Source:



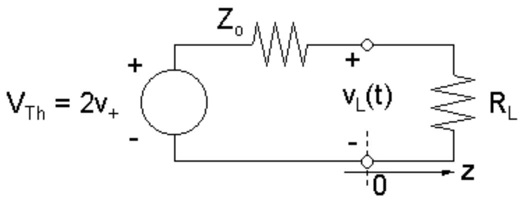
$v_{open\ circuit}(t) = 2v_+(t,z = 0)$

Therefore: $V_{Th}(t) = 2v_+(t, z=0)$

L13-4

TEM LINE THEVENIN EQUIVALENT (4)

Example—Resistive Load:



$v_L(t) = V_{Th}R_L/(R_L + Z_0)$
$= v_-(t;\ z=0) + v_+(t;\ z=0)$

Therefore: $v_-(t;\ z=0) = v_L(t) - v_+(t,\ z=0) =$

$2v_+(t;\ z = 0)[R_L/(R_L + Z_0) - 0.5]$ and

$\Gamma = v_-/v_+|_{z=0}$ "Reflection Coefficient"

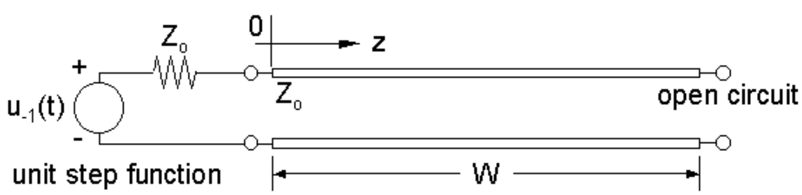
$\Gamma = 2R_L/(R_L + Z_0) - 1$

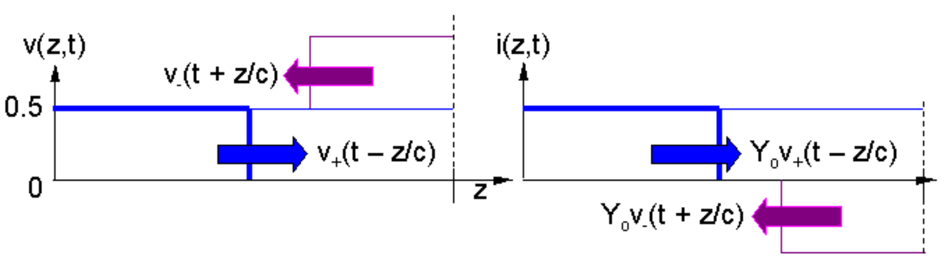
$$\Gamma = v_-/v_+|_{z=0} = (R_L - Z_0)/(R_L + Z_0) \quad \begin{cases} = 1 & \text{for } R_L = \infty \\ = 0 & \text{for } R_L = Z_0 \\ = -1 & \text{for } R_L = 0 \end{cases}$$

L13-5

TEM LINE THEVENIN EQUIVALENT (5)

Example, Time-Domain Solution:





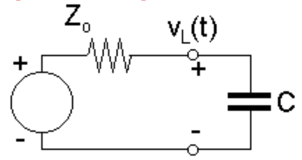
$v(z,t) = v_+(t - z/c) + v_-(t + z/c) \quad = 0.5[u_{-1}(t - z/c) + u_{-1}(t + z/c - 2W/c)]$

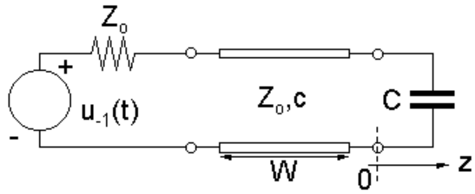
$i(z,t) = Y_0[v_+(t - z/c) - v_-(t + z/c) = 0.5Y_0[u_{-1}(t - z/c) - u_{-1}(t + z/c - 2W/c)]$

L13-6

CAPACITIVELY TERMINATED TEM LINE

Example—Capacitive Load:



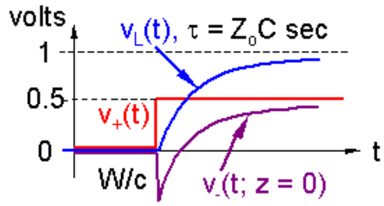


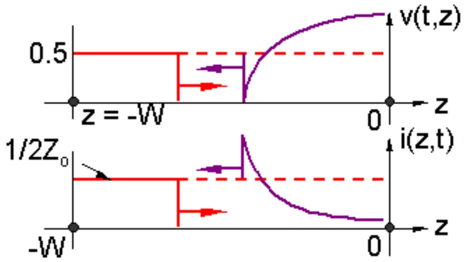
$V_{Th} = 2v_+(t, z=0)$

$= 2[0.5\ u_{-1}(t - W/c)]$

$v_L(t) = v_-(t; z=0) + v_+(t; z=0)$

Therefore: $v_-(t; z = 0) = v_L(t) - v_+(t; z = 0)$





$i(z,t) = Y_o[v_+(t - z/c) - v_-(t + z/c)]$

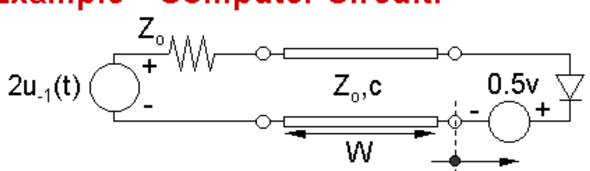
t = 0+, short-circuit response

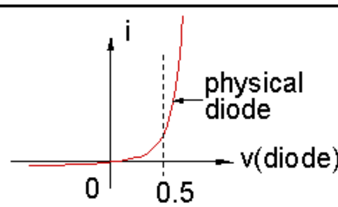
$t \rightarrow \infty$, open-circuit response

L13-7

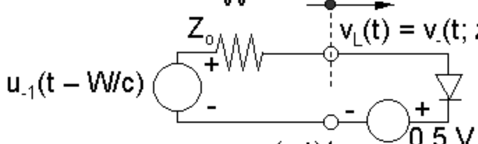
DIODE-TERMINATED TEM LINE

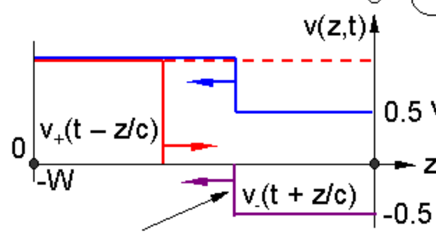
Example—Computer Circuit:

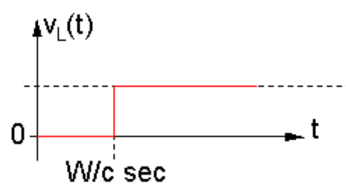




$v_L(t) = v_-(t; z=0) + v_+(t; z=0)$







$v_-(t; z=0) = v_L(t) - v_+(t; z=0)$

$v(z,t) = v_+(t - z/c) + v_-(t + z/c)$

$i(z,t) = Y_o[v_+(t - z/c) - v_-(t + z/c)]$

Do we violate KVL, KCL?

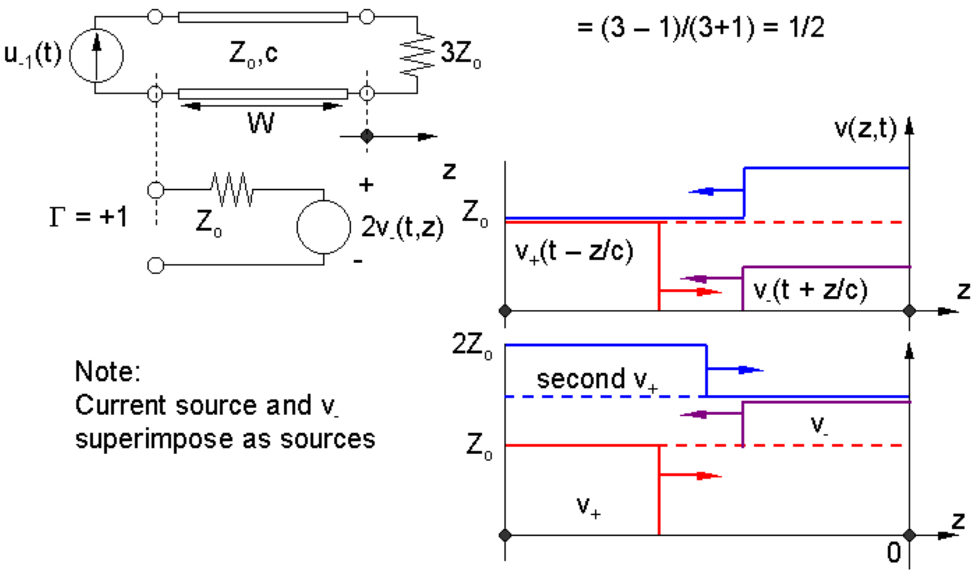
L13-8

MISMATCHED SOURCES

Current Source:

$\Gamma = (R_L - Z_0)/(R_L + Z_0)$

$= (3 - 1)/(3+1) = 1/2$



Note:
Current source and v_- superimpose as sources

L13-9