**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.

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**TEM LINE THEVENIN EQUIVALENT (1)**

**Basic Equations for Lossless TEM Wires:**

\[ v(z,t) = v_0(t - z/c) + v_0(t + z/c) \]

\[ i(z,t) = Y_o [v_0(t - z/c) - v_0(t + z/c)] \]

Where:
\[ Y_o = 1/Z_o = (C/L)^{0.5} \]

**This is a “boundary value problem”**
- The boundary is at \( z = 0 \)
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 $V_{s}(t)$:

$\begin{align*}
 v(z,t) &= v_{s}(t - z/c) + v(t + z/c) \\
i(z,t) &= Y_{0}[v_{s}(t - z/c) - v(t + z/c)]
\end{align*}$

Assume $v = 0$ (no other sources)
Then $v(t, z = 0) = Z_{0}i(t, z = 0)$
Yields equivalent circuit; solve it

$v_{s}(t, z = 0) = (Z_{0}/[Z_{0} + R_{s}])V_{s}(t)$
$v_{s}(t, z) = (Z_{0}/[Z_{0} + R_{s}])V_{s}(t - z/c)$

TEM LINE THEVENIN EQUIVALENT (3)

Voltages at an Open Circuit: $v(z,t) = v_{s}(t - z/c) + v_{s}(t + z/c)$

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

Thevenin Equivalent for TEM Source:

$V_{TH}(t)$

Therefore: $V_{TH}(t) = 2v_{s}(t, z = 0)$
TEM LINE THEVENIN EQUIVALENT (4)

Example—Resistive Load:

\[ V_{th} = 2v_+ \]

\[ v_L(t) = v_{th}R_i/(R_i + Z_o) = v_i(t; z=0) + v_i(t; z=0) \]

Therefore: \[ v_i(t; z=0) = v_-(t) - v_i(t; z=0) = -2v_i(t; z=0)[R_i/(R_i + Z_o) - 0.5] \] and 
\[ \Gamma = \left| v_-/v_+ \right|_{z=0} \] “Reflection Coefficient” 
\[ \Gamma = 2R_i/(R_i + Z_o) - 1 \]

\[ \Gamma = \left| v_-/v_+ \right|_{z=0} = \left( R_i - Z_o \right)/(R_i + Z_o) \]

\[ \begin{cases} 1 & \text{for } R_i = \infty \\ 0 & \text{for } R_i = Z_o \\ -1 & \text{for } R_i = 0 \end{cases} \]

TEM LINE THEVENIN EQUIVALENT (5)

Example, Time-Domain Solution:

\[ v(z,t) = v_i(t - z/c) + v_i(t + z/c) = 0.5[u_i(t - z/c) + u_i(t + z/c - 2W/c)] \]

\[ i(z,t) = Y_o[v_i(t - z/c) - v_i(t + z/c) = 0.5Y_o[u_i(t - z/c) - u_i(t + z/c - 2W/c)] \]
CAPACITIVELY TERMINATED TEM LINE

Example—Capacitive Load:

\[ V_{Th} = 2v_c(t, z=0) \]
\[ = 2[0.5 u_i(t - W/c)] \]
\[ v_i(t) = v(t; z=0) + v_i(t; z=0) \]

Therefore:
\[ v(t; z=0) = v_i(t) - v_i(t; z=0) \]

\[ 0.5 \]
\[ z = -W \]
\[ 1/2Z_0 \]
\[ -W \]
\[ 0 \]
\[ z \]

\[ i(z,t) = Y_i[v_i(t - z/c) - v(t + z/c)] \]

\[ t = 0^+, \text{ short-circuit response} \]
\[ t \to \infty, \text{ open-circuit response} \]

DIODE-TERMINATED TEM LINE

Example—Computer Circuit:

\[ 2u_i(t) \]
\[ Z_0c \]
\[ Z_0c \]
\[ 0.5v \]
\[ v_i(t) = v(t; z=0) + v_i(t; z=0) \]

\[ 0.5 \text{ V} \]
\[ v_i(t-z/c) \]
\[ v_i(t+z/c) \]

\[ v_i(t; z=0) = v_i(t) - v_i(t; z=0) \]

\[ v_i(t) = v_i(t - z/c) + v(t + z/c) \]
\[ i(z,t) = Y_i[v_i(t - z/c) - v(t + z/c)] \]

Do we violate KVL, KCL?
**MISMATCHED SOURCES**

**Current Source:**

\[ \Gamma = \frac{(R_i - Z_0)(R_i + Z_0)}{(3 - 1)(3+1)} = \frac{1}{2} \]

Note:
Current source and \( v_+ \) superimpose as sources