Transient Analysis - Applications, Switches, and SPICE

Voltage-Controlled Switches, and Designing Responses
Recall Example

Determine the pulse response for $i_o(t)$ the circuit below with input $v_s(t) = 40v(t)$, where pulse duration $T$ is 2 ms:

Show:

$$i_{0\text{pulse}}(t) = [(0.8 - 0.8 \exp(-1250t))u(t) - (0.8 - 0.8 \exp(-1250(t-2m)))u(t-2m)] \text{amps}$$

$$i_{opulse}(t) = 0.8[u(t) - u(t-2m)] - 0.8 \exp(-1250t)[u(t) - 12.1825u(t-2m)] \text{amps}$$
Recall SPICE Simulation

Do a SPICE Simulation to determine the pulse response for \( i_o(t) \) the previous circuit with input \( v_s(t) = 40v(t) \), where pulse duration \( T \) is 2 ms:

- To solve you must do a transient analysis, define the voltage source as piece-wise linear, and describe its transient properties.

<table>
<thead>
<tr>
<th>TIME (s)</th>
<th>I(VAM) (Amp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.000e+000</td>
<td>+0.000e+000</td>
</tr>
<tr>
<td>+10.000n</td>
<td>+99.999n</td>
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<tr>
<td>+10.840n</td>
<td>+109.104n</td>
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<tr>
<td>+7.285m</td>
<td>+972.534u</td>
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<td>+7.445m</td>
<td>+795.710u</td>
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<tr>
<td>+7.605m</td>
<td>+651.035u</td>
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<tr>
<td>+7.765m</td>
<td>+532.665u</td>
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<tr>
<td>+7.925m</td>
<td>+435.817u</td>
</tr>
<tr>
<td>+8.000m</td>
<td>+396.630u</td>
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</tbody>
</table>
SPICE Simulation With Switches

Use voltage controlled switches in SPICE to determine the pulse response for $i_o(t)$ in the previous circuit with input $v_s(t) = 40v(t)$, where pulse duration $T$ is 2 ms:

- To solve you must set up separate circuits for the controlling voltages defined as piece-wise linear voltage to achieve switching action.

For switch settings, you should give each a unique name and indicate the controlling source (V1 or V0) or a voltmeter name. You can also modify the closed and open resistances of the switch, which are default 1 ohm and 1G ohm, respectively. When control voltage is less than 0, switch is closed. When control voltage is greater than 0, switch is open.
SPICE Plots

Compare the results from response using a pulsed voltage source to that of the result using switches (Closed resistance = 1 Ohm, Open resistance = 1G Ohm:

706mA  
Switch  
Example

735mA  
Pulse Source  
Example
Design Transmitting Terminal for Digital Communications Link

The circuit below represents a channel for sending digital data in the form of unit pulses transmitted from $v_p$. A pulse with amplitude -1 V is a binary 0 and a 1 V pulse is a binary 1. The receiver has an infinite input impedance and is connected at $v_r$. Find $R_0$ to make the system critically damped. For the critically damped case using a detector that requires the voltage to be greater than 0.95 volts for a binary 1 (below -0.95 volts for binary 0) for at least 50% of the pulse duration, what is the smallest pulse duration that should be transmitted over this channel?

$$R_0 = 2 \Omega, \quad L = 10 \mu\text{H}, \quad C = 0.1 \mu\text{F}$$
Obtain Design Equations:

Characteristic Equation for System:

\[ s^2 + \left( \frac{R + R_0}{L} \right)s + \frac{1}{LC} = 0 \]

Roots:

\[ s_{1,2} = \frac{-\left( \frac{R + R_0}{L} \right) \pm \sqrt{\left( \frac{R + R_0}{L} \right)^2 - \frac{4}{LC}}}{2} \]

\[ \therefore R_0 = 18\Omega, -22\Omega \]

While a negative resistance can be achieved with electronics and a power supply, it will be more expensive than a simple positive resistance so choose \( R_0 = 18\Omega \).
Analysis to Determine Bit Rate

For \( R_0 = 18\Omega \), solution becomes:

\[
v_r = \begin{cases} 
1 + A_1 \exp(-10^6 t) + A_2 t \exp(-10^6 t) & \text{For Binary 1 Interval} \\
-1 + B_1 \exp(-10^6 t) + B_2 t \exp(-10^6 t) & \text{For Binary 0 Interval}
\end{cases}
\]

Assume a worse case transition of -1 V to 1 V, where steady-state had effectively been reached before the transition. Therefore initial conditions become \( v_c(0^+) = -1 \) and \( i_L(0^+) = 0 \):

\[
v_r = 1 - 2 \exp(-10^6 t) - 2(10^6) t \exp(-10^6 t)
\]
Find Result Numerically

Can write a Matlab program to plot result and numerically find pulse width:

Since waveform must be above .95 volts for 50% of the pulse duration, the smallest pulse that should be used is 11.14 µs. This would correspond to a bit rate of 8.97 kbits/sec. This could carry 0.064 channels of stereo CD quality audio, or 1.4 telephone quality voice signals.
A Matlab program is referred to as a script (type “help script” at the Matlab prompt for more information). This is a text file that ends with a *.m extension (also called an mfile). Program comments are preceded by the percent symbol %.

% This program will find the time point where the waveform \( vr = 0.95 \)

% Since time constant is \( 1/1e6 = 1 \) microsecond, create a time axis for about 10 time constants:

\[
t = 10*(1/1e6)*[0:9999]/10000; \quad \% \text{Create 10000 points over 10 time constants}
\]

\[
vr = 1 - 2*\exp(-1e6*t) - 2e6*t.*\exp(-1e6*t); \quad \% \text{Create function points}
\]
% Plot waveform, divide axis by 1e-6 to put units in microseconds
plot(t/1e-6,vr)
xlabel('microseconds')  % Label x-axis
ylabel('volts')  % Label y-axis
% Plot and plot a dashed line at .95 volts
hold on  % Keep current plot in figure box and plot over it with ...
plot(t/1e-6,.95*ones(size(t)), 'k--')
    % in above, k means black, and -- means broken line (see help plot)

% Loop to find points where vr exceed .95:

k = 1;  % Initialize array index
kend = length(t);  % Find total number of points in array

% While loop, increment k until vr equals or exceeds .95
while (vr(k)<.95)
    k=k+1;
end
tint = t(k)  \textit{\% Find time point from index}
plot([tint, tint]/1e-6, [-1 1], 'k--')  \textit{\% Plot vertical line}
hold off