Transmission Line Simulator
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file: shortlin.mcd

Investigation of untermiated lines showing effects of rise time and line length.
Order of operations: Establish indices for FFT operations, generate frequency response of unterminated line, convert to time domain waveform and display.

Establish indices for FFT operations

Sampling resolution, in seconds $\Delta T := 10^{-10}$

$fsample := \frac{1}{\Delta T}$

Desired trace length, in seconds $Tlen := 100 \cdot 10^{-9}$

$logN := ceil\left(\frac{\log\left(\frac{Tlen}{\Delta T}\right)}{\log(2)}\right)$

Pick next biggest power of two trace length $N := floor\left(2^{logN} + 0.5\right)$

Index to time points $j := 0, 1 .. N - 1$

Index to frequency points $k := 0, 1 .. \frac{N}{2}$

List of frequency points $f_k := fsample \cdot \frac{k}{N}$

$s := 2j \cdot \pi \cdot f$

Dummy vector used to vectorize some scaler functions $Vdummy_k := 1$

Vector operations $mpy(A,B) := \overrightarrow{(A \cdot B)}$ $div(A,B) := \overrightarrow{\frac{A}{B}}$

Source impedance $ZS := 30$ $RL := 10000$

Load impedance $ZL(cl) := div(RL, 1 + s \cdot RL \cdot cl)$ cl = load capacitance

Transmission line impedance $ZC := 65$

Delay function, argument t is delay in seconds $D(t) := \overrightarrow{\exp(-s \cdot t)}$

Generate frequency response of unterminated line

Transmission line response (delay only, assume no distortion) $H(t) := D(t)$

Acceptance function $A := \text{div}(ZC, ZS + ZC)$

Near-end reflection $R1 := 1 - 2 \cdot A$

Transmission function at far end $T(cl) := \text{div}(2 \cdot ZL(cl), ZL(cl) + ZC)$

Far-end reflection $R2(cl) := T(cl) - 1$

System response

$$S3(t, cl) := \text{div}(\text{mpy}(A, \text{mpy}(H(t), T(cl))), 1 - \text{mpy}(\text{mpy}(R2(cl), H(t)), \text{mpy}(R1, H(t))))$$

Driving waveform (a rectangular waveform, N/2 points in length)

$$S1_k := \text{if}\left(k = 0, \frac{N}{2}, \frac{1 - e^{-s_k \cdot \frac{N}{2} \cdot \Delta T}}{1 - e^{-s_k \cdot \Delta T}}\right) \cdot \frac{1}{\text{fsample}}$$

Linear rise/fall slopes; 0-100% risetime = r

$$\text{linear}(\mu, r) := \text{if}\left(\mu = 0, 1, \frac{1 - e^{-\mu \cdot r}}{1 - e^{-\mu \cdot \Delta T}} \cdot \frac{\Delta T}{r}\right)$$

Gaussian rise/fall slopes, 10-90% risetime = r

$$\text{gaussian}(\mu, r) := \text{if}\left[|\mu \cdot r| < 10, e^{\frac{\mu^2 \cdot \left(\frac{r}{2.56}\right)^2}{2}}, 0\right] \cdot e^{-\mu \cdot \frac{r}{2}}$$

Use linear or gaussian slope $S2(r) := \overrightarrow{\text{gaussian}(s, r)}$

Convert to time domain and display

Ideal driving waveform $SYS1 := \text{IFFT}(S1) \cdot \frac{\text{fsample}}{N}$

Driving waveform with rise/fall slopes $SYS2(r) := \text{IFFT}(\text{mpy}(S1, S2(r))) \cdot \frac{\text{fsample}}{N}$

Response of driven trace $SYS3(d, r, cl) := \text{IFFT}(\text{mpy}(\text{mpy}(S1, S2(r)), S3(d, cl))) \cdot \frac{\text{fsample}}{N}$

Set nominal transmission line delay and risetime $\text{delay} := 10^{-9}$ $ZS = 30$ $RL = 1 \times 10^4$

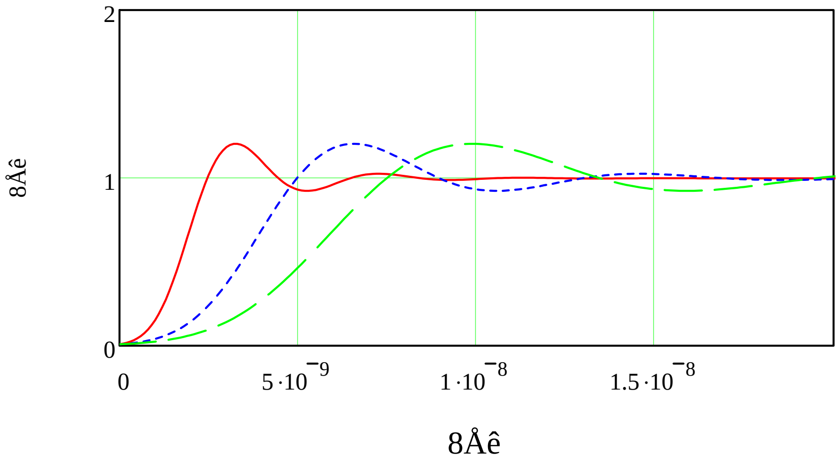
risetime := 2·delay ZC = 65 CL := 0

Scale both delay and risetime to see what happens

X1 := SYS3(delay, risetime, CL)

X2 := SYS3(delay·2, risetime·2, CL)

X3 := SYS3(delay·3, risetime·3, CL)



Sample some test functions

X0 := SYS3(delay, 0, CL)

X01 := SYS3(delay, delay, CL)

X02 := SYS3(delay, delay·2, CL)

X03 := SYS3(delay, delay·3, CL)

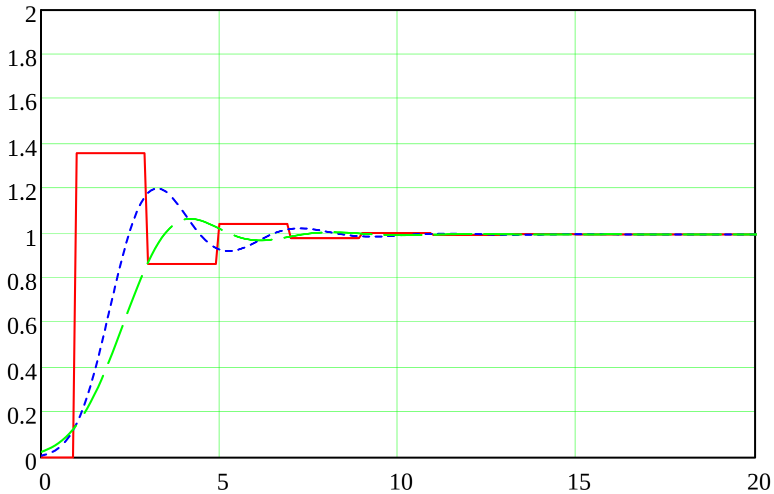
X04 := SYS3(delay, delay·4, CL)

X05 := SYS3(delay, delay·5, CL)

X06 := SYS3(delay, delay·6, CL)

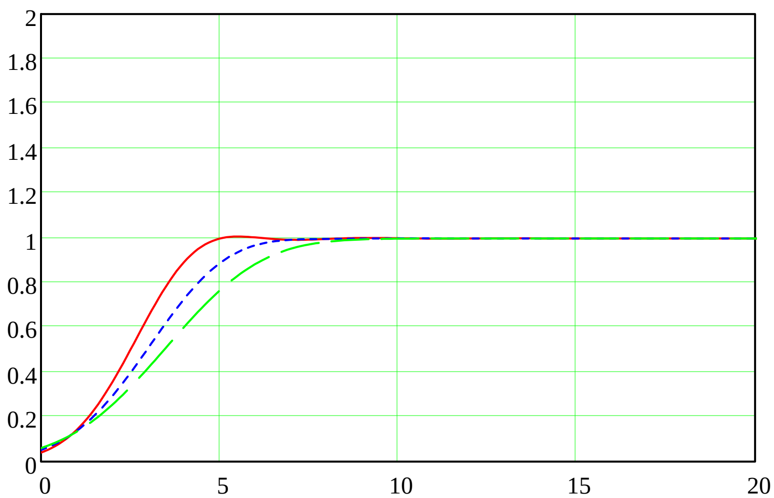
Unterminated line response
Risetime set to 0, 2 and 3 times transmission line delay

$ZS = 30$ $RL = 1 \times 10^4$
$ZC = 65$ $CL = 0$



Unterminated line response
Risetime set to 4, 5 and 6 times transmission line delay

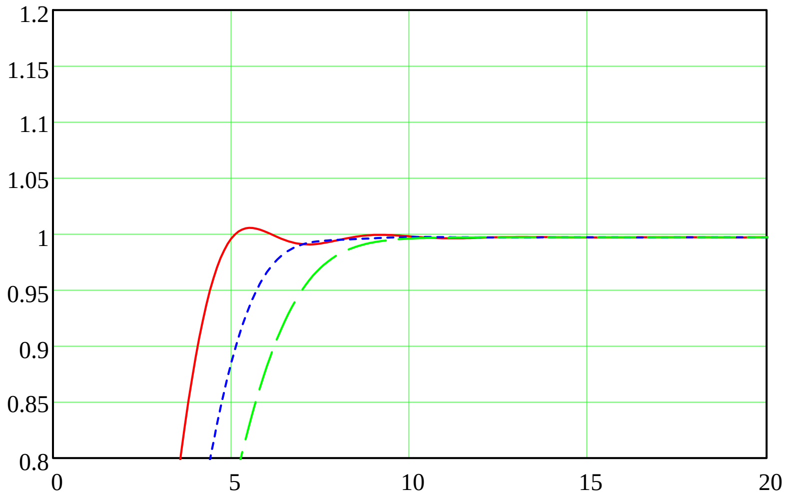
$ZS = 30$ $RL = 1 \times 10^4$
$ZC = 65$ $CL = 0$



Unterminated line response
Risetime set to 4, 5 and 6 times transmission line delay
BLOWUP of vertical axis

$ZS = 30 \qquad RL = 1 \times 10^4$

$ZC = 65 \qquad CL = 0$



Investigate effect of termination capacitance

Set nominal transmission line delay and risetime

$delay := .5 \cdot 10^{-9}$ $ZS = 30$ $RL = 1 \times 10^{4}$

$risetime := 6 \cdot delay$ $ZC = 65$

$NOLOAD := 0$

$TEN\_PF := 10 \cdot 10^{-12}$

$TWENTY\_PF := 20 \cdot 10^{-12}$

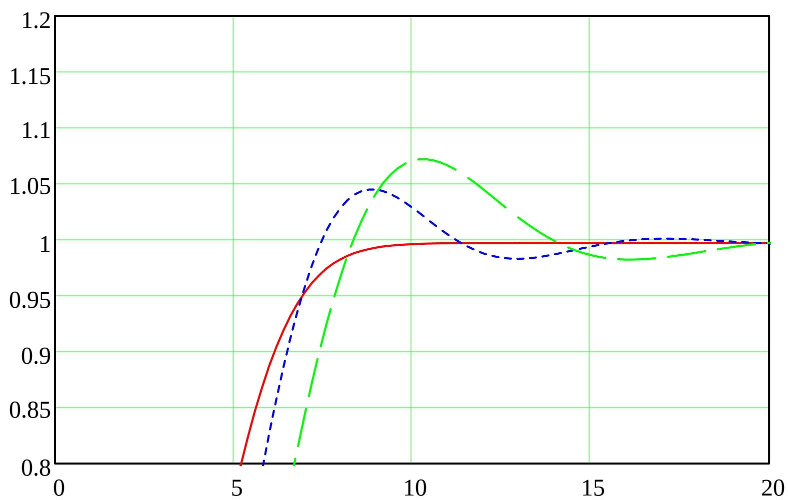
Adjust load capacitance and produce step response for each c ase

$X1 := SYS3(delay, risetime, NOLOAD)$

$X2 := SYS3(delay, risetime, TEN\_PF)$

$X3 := SYS3(delay, risetime, TWENTY\_PF)$

Step response of 1/2 ns line with 0, 10 and 20 pF load
BLOWUP of vertical axis



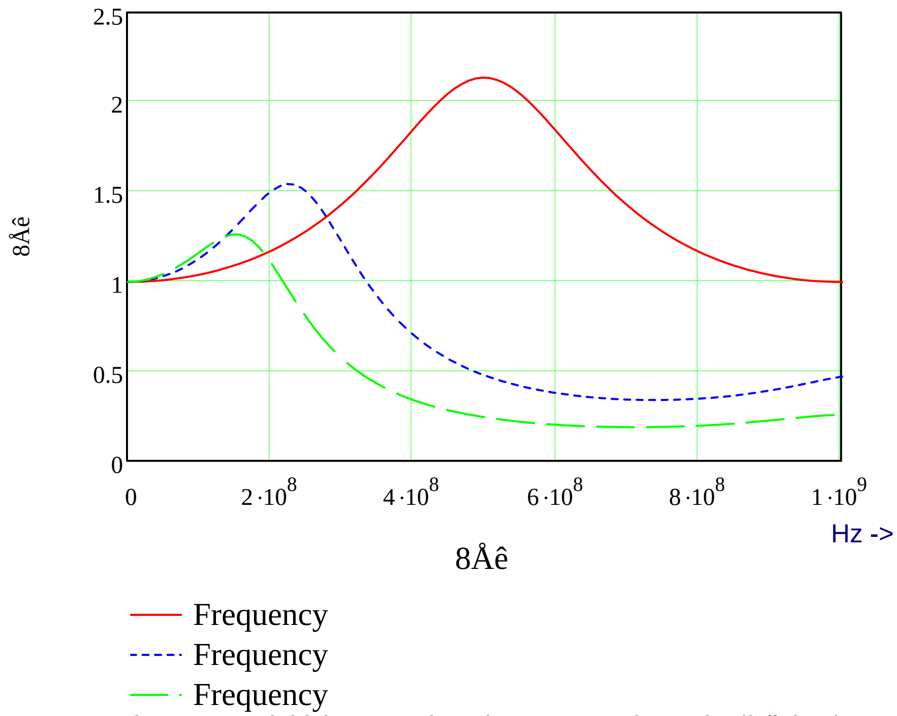
Record frequency response for each value of load capacitance

$Y1 := S3(delay, NOLOAD)$

$Y2 := S3(delay, TEN\_PF)$

$Y3 := S3(delay, TWENTY\_PF)$

Frequency response of 1/2 ns line with 0, 10 and 20 pF load



Knee frequency of driving waveform is 160 MHz (3-ns rise/fall time)