## Technical Note: Rise Time and frequency response

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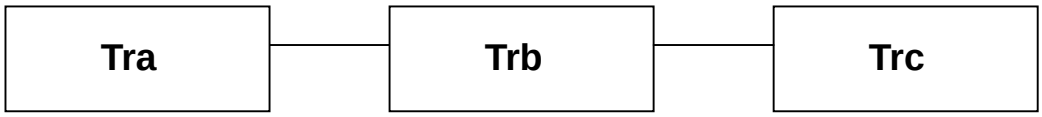
### *General:*

When translating specifications from the analog world to the digital world, one often must convert from frequency response to rise time. Understanding the relationship between frequency domain and time domain responses will lead to accurate estimation of impulse response of the transmission line circuit.

### *System timing chain*

Overall system rise time of a transmission line can be calculated as a root mean square of each subcomponent's rise time.




$$Tr\ (total)=(Tra^2 + Trb^2 + Trc^2)^{1/2}$$

### *Rise Time and Bandwidth*

Oscilloscope manufacturers quote a maximum operating bandwidth for each vertical amplifier and corresponding bandwidth for each probe by either a 3-dB bandwidth or an RMS (noise equivalent) bandwidth. The 3-dB bandwidth is rather straight forward of the two as a sine wave feeds into the vertical amplifier at 3-dB frequency will appear on scope screen at only 70.7% of its actual value. 3-dB bandwidth can be calculated as follows.

F3dB = K / Tr

Where F3dB = frequency at which impulse response rolls off by 3 dB

K = constant of proportionality depending on exact pulse shape

K = 0.338 for gaussian pulses

Tr = pulse rise time (10-90%)

If waveforms with 1nS rise time is observed by oscilloscope with 400MHz bandwidth and probe with 200pS rise time, expected rise time at scope screen can be calculated as follows.

Tr (scope) = 0.338 / 0.4 E9 = 0.845 E-9, Tr (probe) = 0.2 E-9, Tr (input) = 1 E-9

$Tr\ (composite) = (1^2 + 0.2^2 + 0.845^2)^{1/2} \times 1\ E\text{-}9 = 1.324\ (nS)$

If a waveform with rise time of 500 pS (10-90%) needs to be delivered to destination with less than 5% of rise time degradation, the bandwidth required can be calculated as follows.

$Tr\ (interconnect) = ((500 \times 1.05)^2 - 500^2)^{1/2} \times 1\ E\text{-}9 = 160\ (pS)$

Following is a calculation of effect by transmission line with 100(pS) rise time to various incident waveform rise time. If the rise time of transmission line is less than one third of rise time of the incident waveform, there will be no significant degradation of rise time.

| Incident Waveform Rise Time | Output Rise Time | Delta (%) |
|---|---|---|
| 3.00 nS => | 3.00375 nS | 0.12 |
| 1.00 nS => | 1.01119 nS | 1.12 |
| 0.50 nS => | 0.52201 nS | 4.40 |
| 0.20 nS => | 0.25000 nS | 25.0 |

The F3dB of transmission line with 150 pS rise time can be calculated as follows.

F3dB = 0.338 / 0.15 E-12 = 2.25 E12 = 2.25 (GHz)

The relationship between the rise time and frequency bandwidth depends on the shape of the waveform. The equation presented here is an approximation but should be adequate for a design guideline.