Using S-Parameters for Accurate Simulation

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Background

- **S-parameter is becoming more and more popular in high speed simulation**
- **In Howard Johnson’s book, we believe the F_{knee} is the upper limit of T-Line model**

$$F_{knee} = \frac{0.5}{Tr}$$

- **But is it accurate enough for transient analysis in GHz analysis?**

Fourier transform

- **Fourier transform provide mathematical mechanism for transforming frequency data to timing domain**

$$f(t) = \int_{-\infty}^{\infty} S(f)E(f)e^{2\pi jft}df$$

- **There are two approximations in real application**
  - Finite band width
  - Discrete data point

Finite bandwidth

- **Finite bandwidth S parameter like a “window” function** $W(f)$

$$W(f) = \begin{cases} 1 & -b \le f \le b \\ 0 & \text{ot her} \end{cases}$$

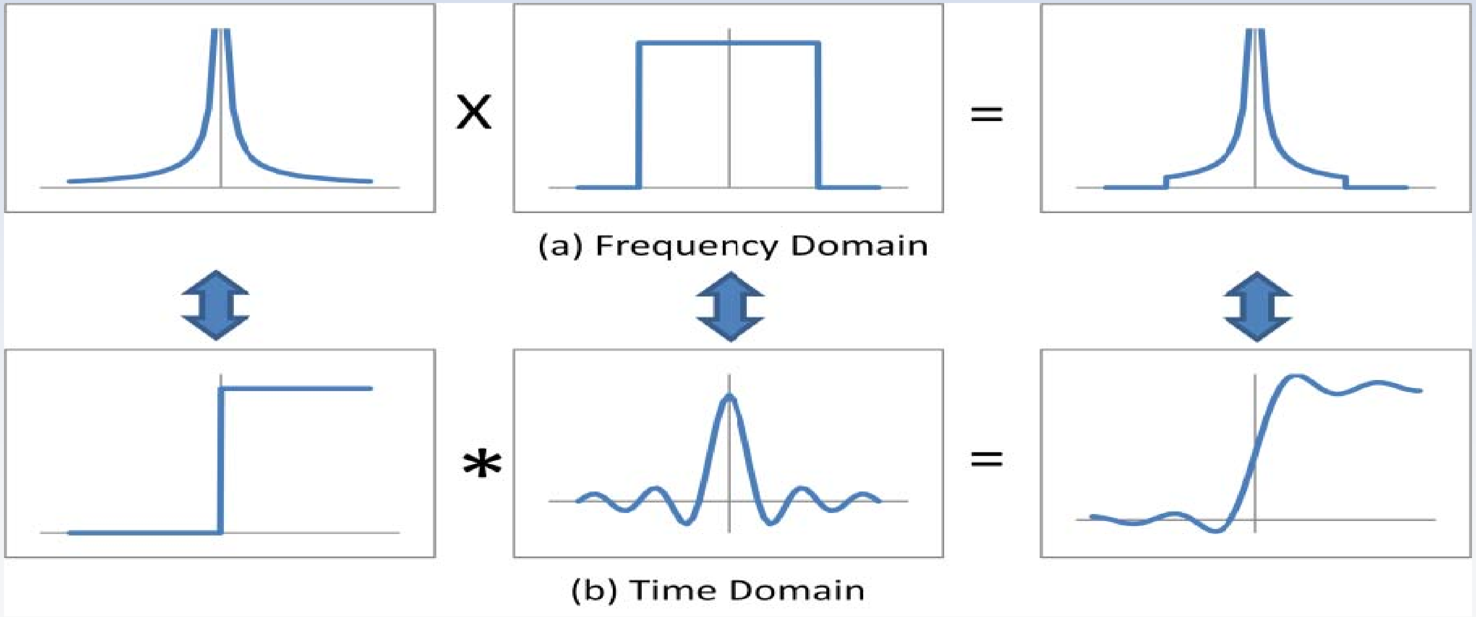
$$f(t) = \int_{-\infty}^{\infty} W(f)S(f)E(f)e^{2\pi jft}df$$

$$= \int_{-b}^{b} S(f)E(f)e^{2\pi jft}df$$

Finite bandwidth Problems

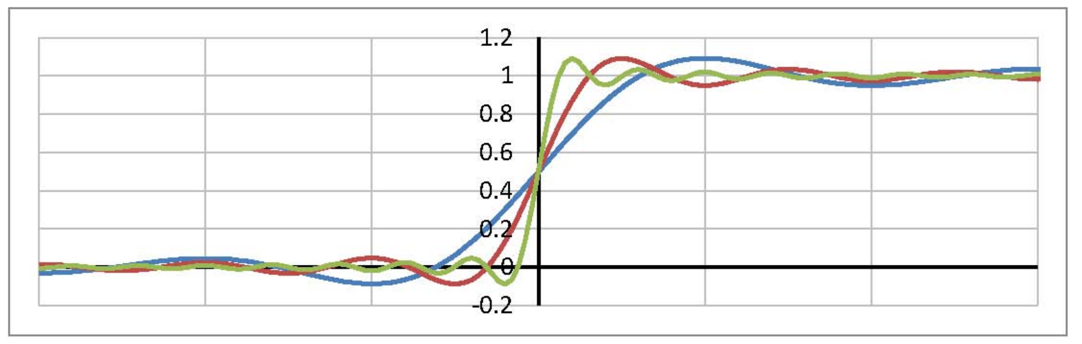
- **“Window” function will cause Oscillation**

$$W(f) \leftrightarrow 2bSa(\pi bt) = \frac{\sin \pi bt}{\pi t}$$



Finite bandwidth Problems

- **Increase bandwidth cause sharper oscillation, but never disappear**

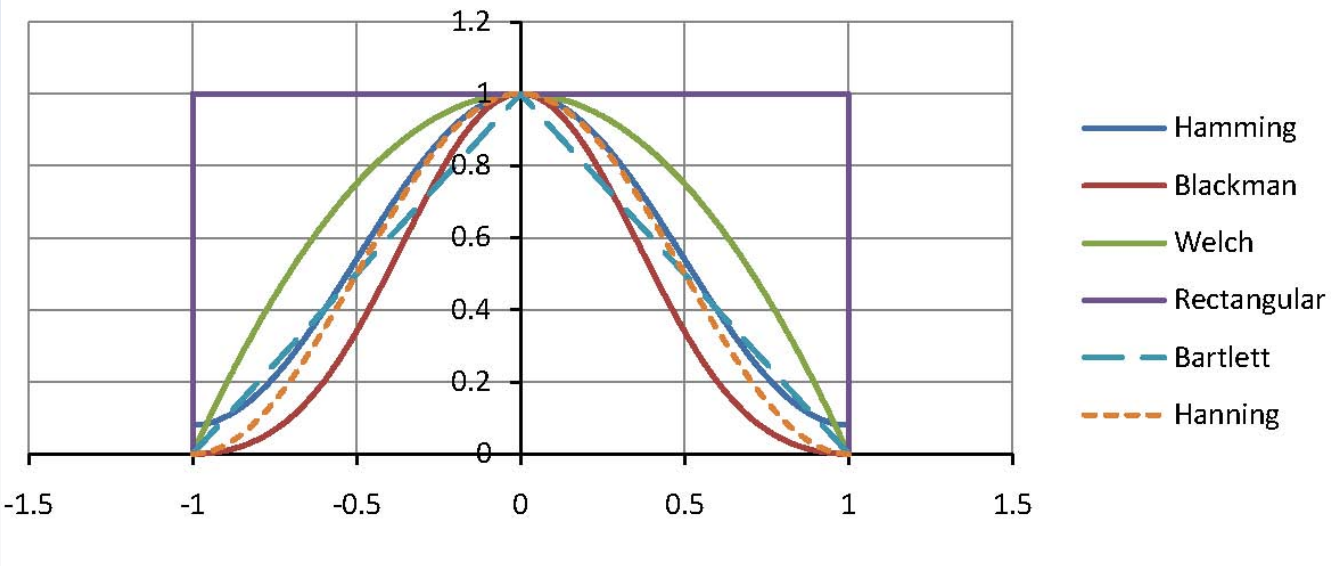


- **If expand bandwidth to infinite**

$$\lim_{b \to \infty} \frac{\sin(bt)}{\pi t} = \delta(t)$$

Using other “windows”

- **Hamming** $0.54 + 0.46\cos\left(\frac{2\pi f}{w}\right)$
- **Hanning** $0.5\left[1 + \cos\left(\frac{2\pi f}{w}\right)\right]$
- **Blackman** $0.42 + 0.5\cos\left(\frac{2\pi f}{w}\right) + 0.08\cos\left(\frac{4\pi f}{w}\right)$
- **Welch** $1 - \left(\frac{2\ f}{w}\right)^2$
- **Bartlett** $1 - \left(\frac{2\ f}{w}\right)$



3. Window functions with a width of w=2

Results of other “windows”

- **Attenuate the spectrum near upper limit**
- **Trade-off between edge and oscillation**

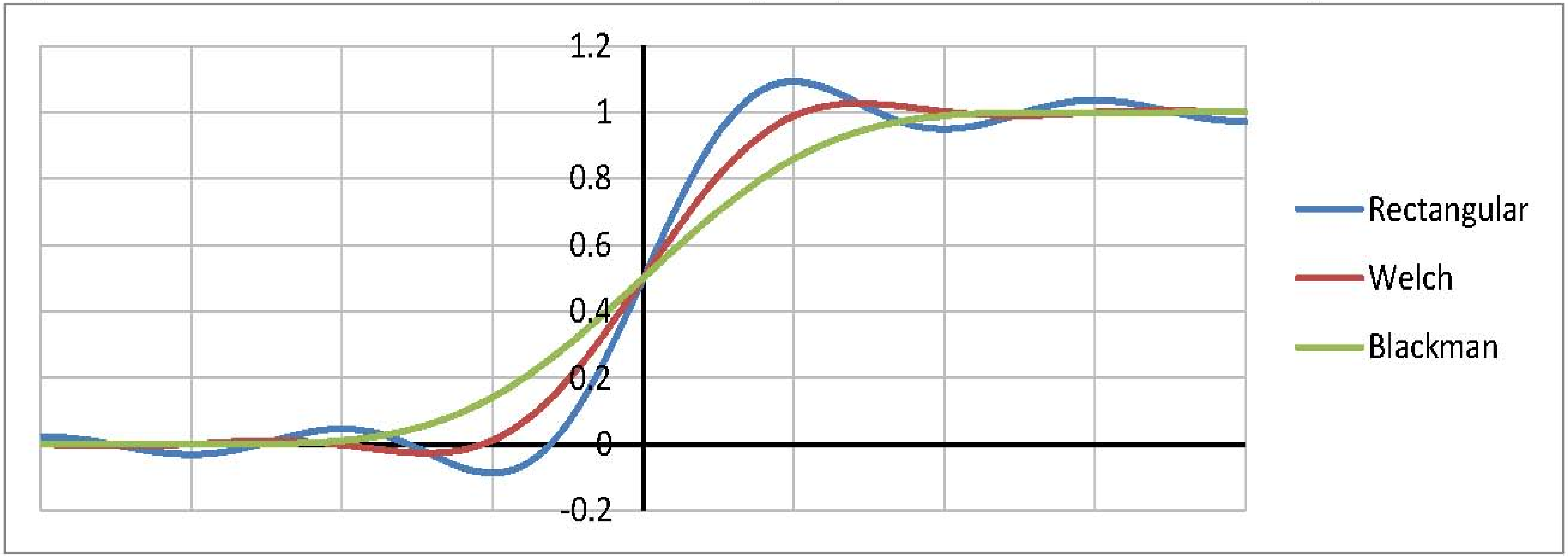


Figure 7. Step response for three different windows, each with the same bandwidth.

Idea step response of different "windows"

Table 1. Characteristics of selected window functions for continuous time

Window	*Step Response* $f_s(t)$	*10-90 Edge Rate*	*Max Overshoot*
Rectangular	$\frac{1}{2}+\frac{\mathrm{Si}(2\pi bt)}{\pi}$	$\frac{0.45}{b}$	8.95%
Welch	$\frac{1}{2}+\frac{\cos(2\pi bt)}{2\pi^2 bt}-\frac{\sin(2\pi bt)}{4\pi^3 b^2 t^2}+\frac{\mathrm{Si}(2\pi bt)}{\pi}$	$\frac{0.70}{b}$	2.70%
Hanning	$\frac{2\pi+2\mathrm{Si}(2\pi bt)-\mathrm{Si}(\pi-2\pi bt)+\mathrm{Si}(\pi+2\pi bt)}{4\pi}$	$\frac{0.97}{b}$	0.64%
Blackman	--	$\frac{1.19}{b}$	0.02%

$$Si(x)=\int_0^x \frac{\sin(a)}{a}da$$

Finite edge response of Rectangular "window"

- **Finite edge response of Rectangular "window"**

$$f(t) = \frac{1}{2} + \frac{Si(2\pi b(r-t))}{\pi} + \frac{\cos(2\pi bt) - \cos(2\pi b(t-r)) + 2\pi bt(Si(2\pi b(r-t)) + Si(2\pi bt))}{2\pi^2 br}$$

$$f(0) = \frac{1}{2} + \frac{1 - \cos(2\pi br)}{2\pi^2 br} - \frac{Si(2\pi br)}{\pi}$$

- **Rectangular "window" is Non-Causal system**

Finite edge response of Rectangular "window"

- **If increase** br **,** $f(0)$ **will closer to 0**

Table 2. Finite edge response for rectangular windows for continuous time

*Bandwidth*Risetime (**br**)*	*Edge Response at t = 0*	*Max Overshoot*
0.5	0.113	5.34%
0.75	0.056	2.41%
1	0.049	1.19%
2	0.025	0.72%
3	0.017	0.51%
5	0.010	0.32%
10	0.005	0.17%

Discrete data point

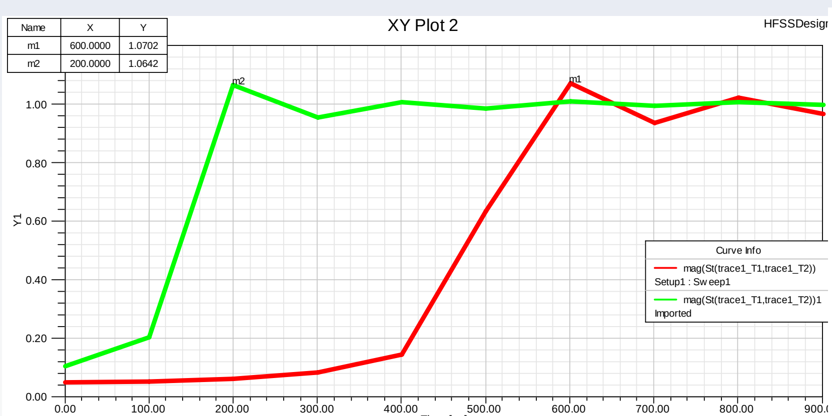
- **Simulation is discrete point data both in Timing domain and Frequency domain:**
- **Relationships of step**

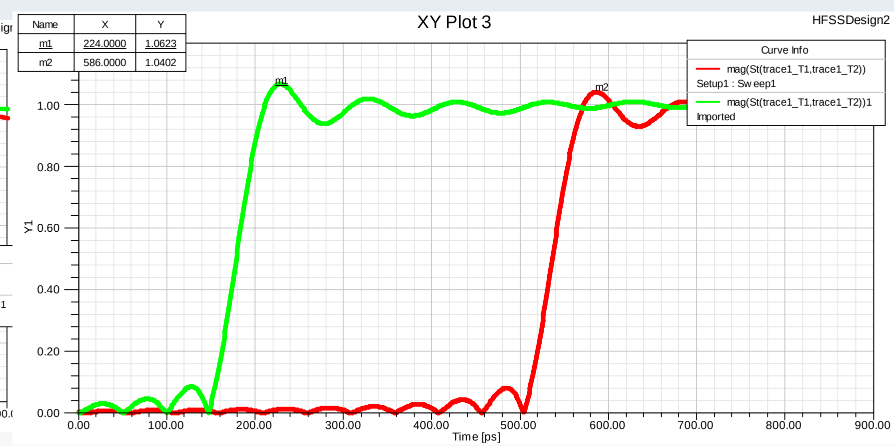
$$T_{step} = \frac{1}{2F_{\max}} \qquad T_{\max} = \frac{1}{2F_{step}}$$

- **Minimum timing step is decided by the bandwidth which has been discussed**

Timing step influence

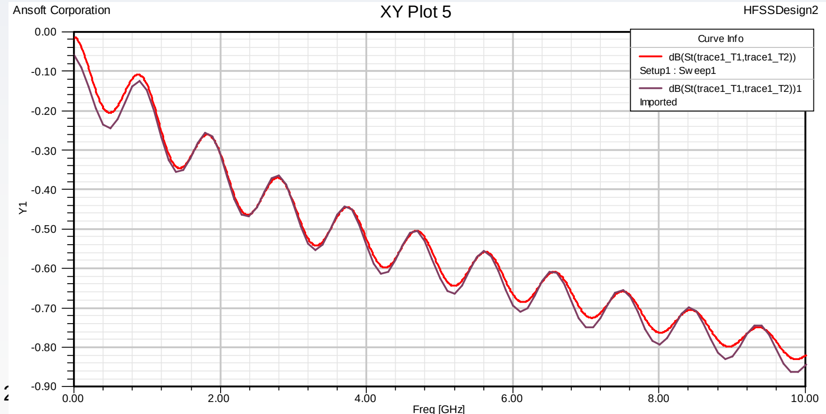
- **1 inch and 3 inch matched T_line's step response using different timing step:**
- **Only different delay are expected, but different oscillation when bigger timing step**
- **Reduce timing step get correct results**

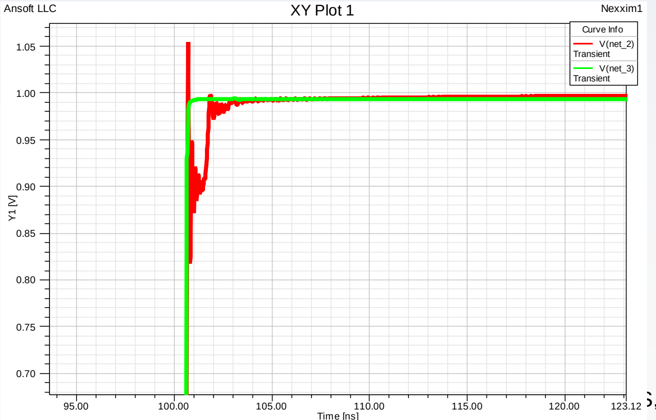




Frequency step influence

- **Discrete frequency point data convert to timing domain look like repeating series of long pulse.(Discrete Fourier transform)**
- **If frequency step is bigger, the repeating series pulse will interrupt each other**
  - Same T_line S21 using different frequency step and corresponding transient results





Different requirements of parallel and Serial signal simulation

- **Parallel signal is repeating of one bit.**
  - One rising and falling edge
  - Frequency step should be denser than 1/T
- **Serial signal is series of bit.**
  - Random bits for testing ISI
  - Frequency step should be denser than 1/n*UI

conclusion

- **Mathematical based simulation or testing have native limitation**
- **Serdes GHz simulation need broadband channel characteristic**
  - F_{knee} is limited, 5/Tr or 10/Tr
- **Discrete frequency point data is also critical for analysis**

$$T_{step} = \frac{1}{2F_{\max}} \qquad T_{\max} = \frac{1}{2F_{step}}$$

Thank you

谢谢