Advanced Antenna Measurement Techniques using Time Domain Gating

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Where do we use TD gating in EMC?

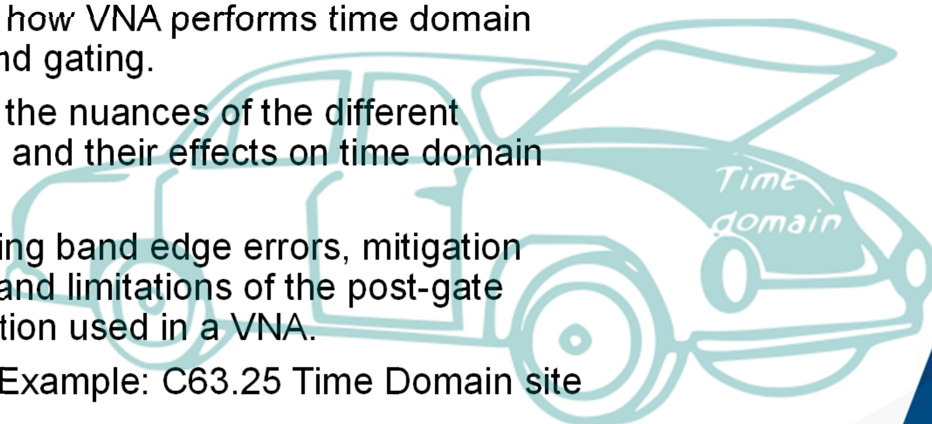
TD Gating is a function provided in VNAs:

- Antenna measurements
- Chamber Qualifications – the new C63.25 TD sVSWR
- Cable/Signal integrity measurement
- General RF/Microwave loss and reflection measurements

- It is a common tool in labs, but rarely fully understood and can be misused.

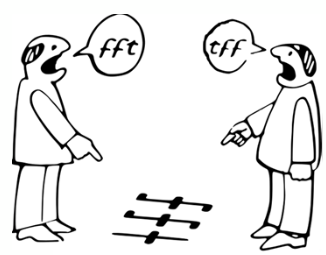
Goals of this Presentation

- Understand how VNA performs time domain transform and gating.
- Understand the nuances of the different parameters, and their effects on time domain gating.
- Discuss gating band edge errors, mitigation techniques and limitations of the post-gate renormalization used in a VNA.
- Application Example: C63.25 Time Domain site VSWR.

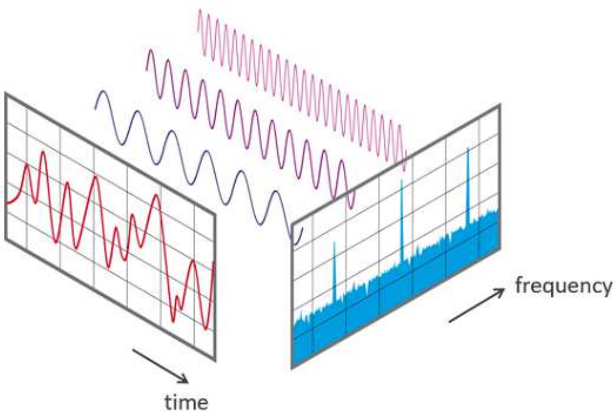


Background on Frequency/Time

- Time domain data is obtained mathematically from frequency domain. Vector antenna responses **in frequency domain** can be transformed to time domain. This is a function in commercial Vector Network Analyzers (VNA).
- Time Domain and frequency domain are in reciprocal space (via Fourier Transform), transformed from one to the other without any loss of information. They are two ways of viewing the same information.
- Bandlimited frequency signals (no DC) is transformed to impulse response in TD. TD step response requires DC, and integration of the impulse response.



Two views of the same function

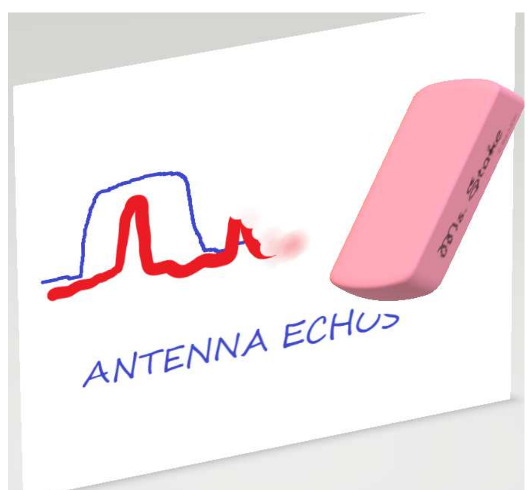


Source: wikipedia

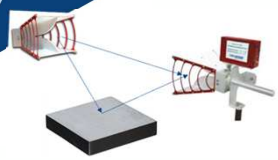
https://tex.stackexchange.com/questions/127375/replicate-the-fourier-transform-time-frequency-domains-correspondence-illustrati?noredirect=1&lq=1

Do more with time domain gating

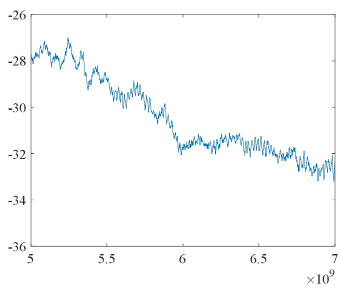
- Time gating can be thought of as a bandpass filter in time. This allows us to look at only a portion of time selectively. We can then transform back to frequency domain, and view the frequency data for the selected signal .



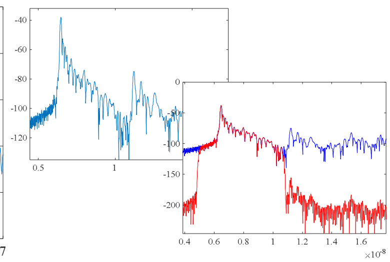
Gating "Conceptually"



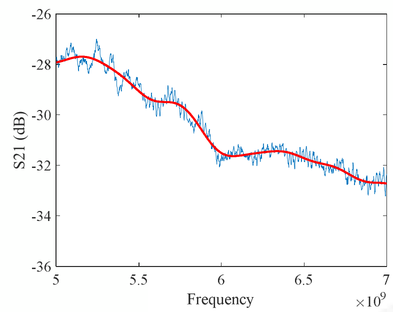
Measure in FD - S21(f) → Transform to TD → Apply Gating → Transform back to FD → Gated S21(f)



Frequency domain



Time domain



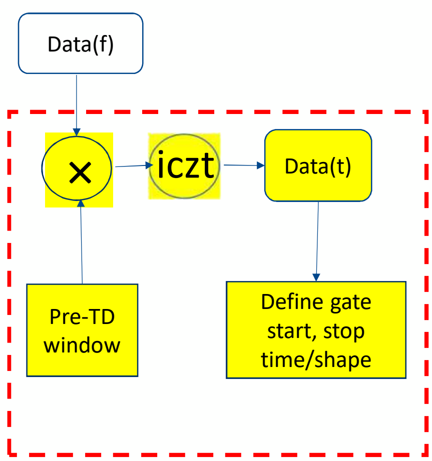
Frequency domain

the devil's in the details

- Actual gating process is more nuanced
  - Windowing
  - Chirp-Z vs. FFT, and aliases
  - Gate design
  - Gating performed in the frequency domain
  - Edge effect mitigation

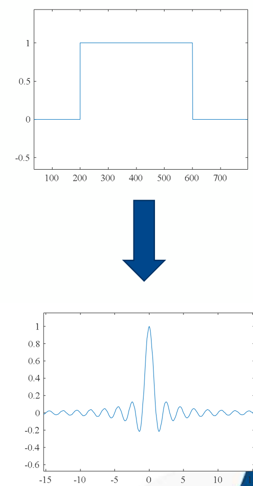
Step 1: View Data in TD

Before we can gate: View Data in TD



Pre-TD Windowing

- Rectangular function transforms to a sinc function.
- $S_{21}(f)$ data typically does not taper to zero at the two frequency ends. If directly transformed, it results in ringing in the time domain. The artifacts can obscure the viewing, thus our ability to identify real responses.
- Windowing is to multiply the frequency domain data (before transformation) with a tapering function.



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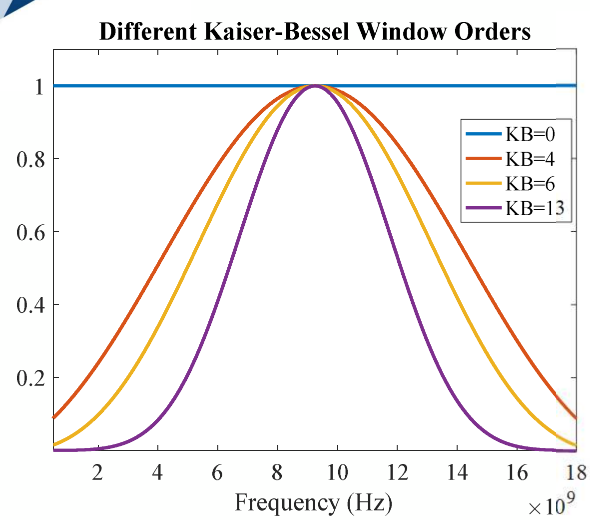

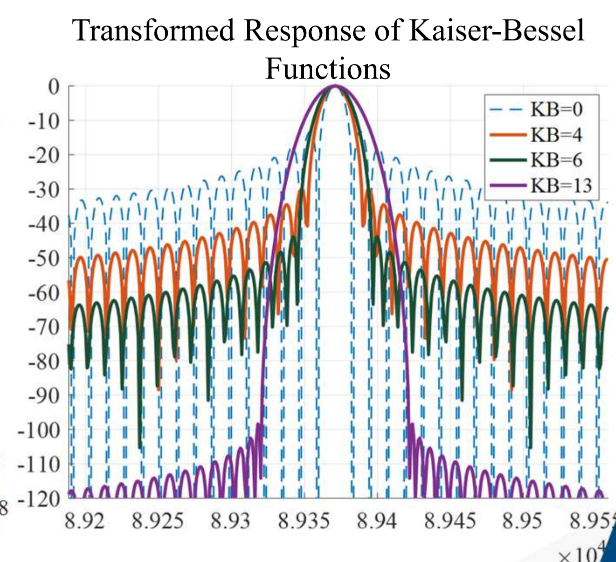

Kaiser-Bessel Windows with varying KB=πα

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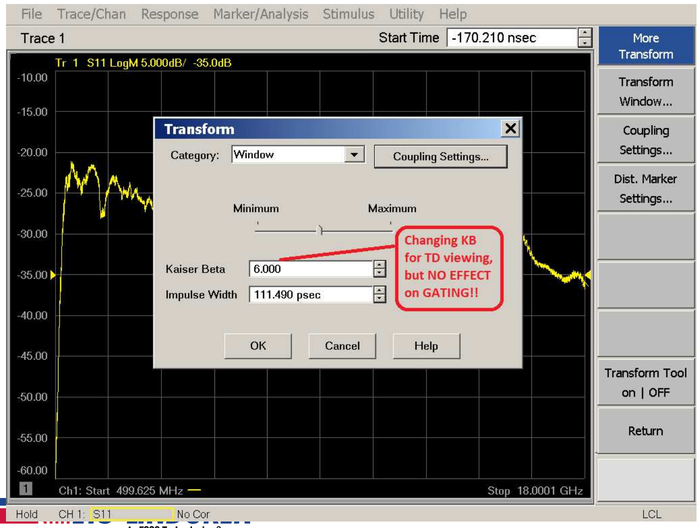
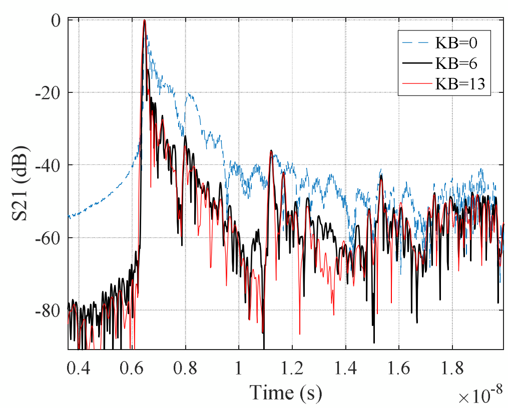
Step 1 is FYVP only (for your viewing pleasure)



- Pre-TD window function can be changed by end users,
- It is only used as an aid to select start and stop time
- Feel free to change! No effect on gating

Effects of Kaiser Window on Time Domain View



- KB=0=>no window, equivalent to rectangular window
- KB level: tradeoff between main beam width vs. side lobe levels
- Default (KB=6) provides a good compromise for most applications

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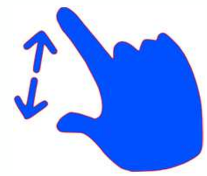
Get a better view: Chirp-Z vs. FFT



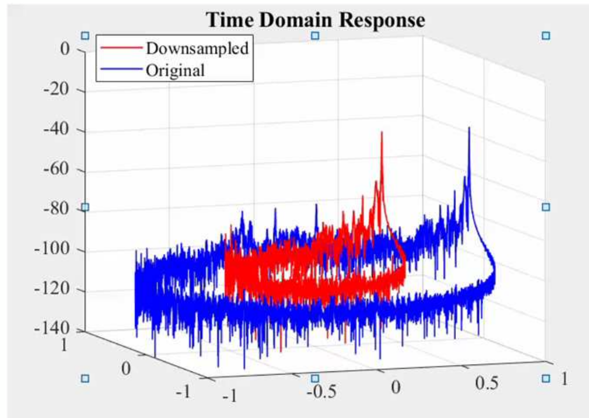
- Resolution is fixed for DFT or FFT.
- Chirp-Z Transform (CZT) is a generalization of the discrete Fourier transform.
- Chirp-Z transform allows re-sampling: arbitrary start/stop points and density in the transform domain
- Often used to zoom into a region, CZT interpolates data (equivalent zero-padding) – it is essentially a sinc interpolation.
- The price for the flexibility of CZT (vs. FFT) is slower speed.

The Cost of Discretization (DFT)

- Taking **discrete** samples makes the transformed domain **periodic**
- The finer the discretization, the longer the period in the other domain

Aliasing

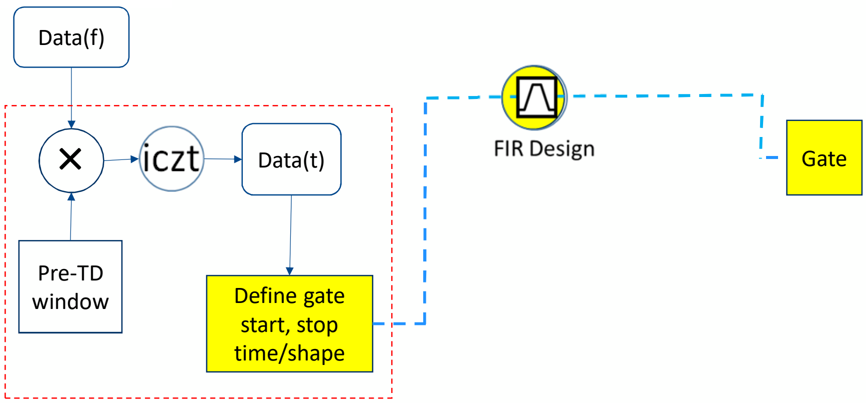
- Transform domain repeats itself (aliasing) because of sampling
- Time Period=1/Δf. This limits how long we can view time.
- To enlarge the alias-free range (bigger cylinder) -> increase the density, e.g., more frequency points



Discrete in one domain = periodic in the other domain

Step 2: Gating

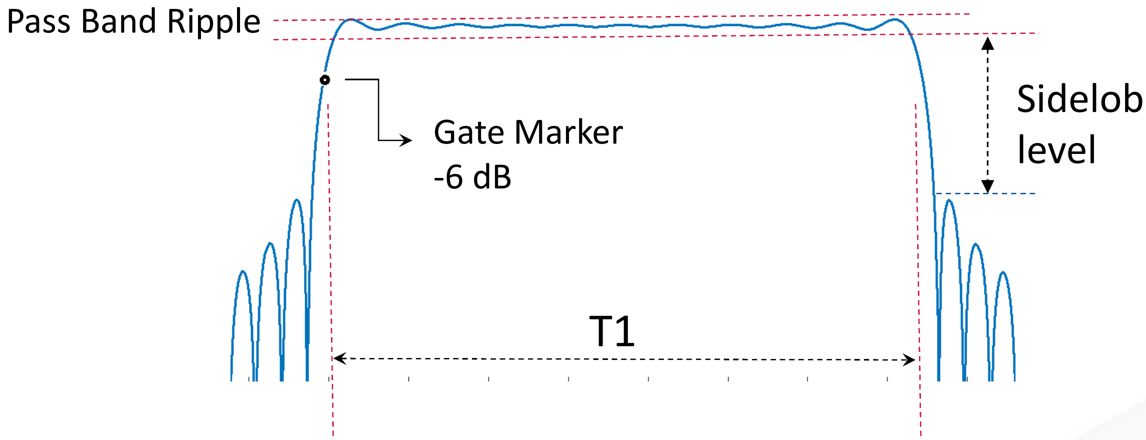
Gate Design



Time Gate is a Filter, done in TD

- Time gate is not a brick wall function, instead is is designed as a filter.
- First things first – Specify the Gate:
  - Start time
  - Stop time
  - Side lobe level / roll off speed
- Based on the specification, a finite impulse response (FIR) filter can be designed.

Illustration of Gate Shape



Data at the Band Edges

$$\boldsymbol{F}\left(\text{data}(t)\cdot\text{gate}(t)\right) = \text{Data}(f) * G(f) = \sum_{j=-M/2}^{M/2} \text{Data}(j)G(f-j)$$

- The convolution theorem provides an intuitive view of the effect of time gating.
- In the frequency domain, this can be viewed as the data being multiplied and summed by a flipped sliding gate kernel

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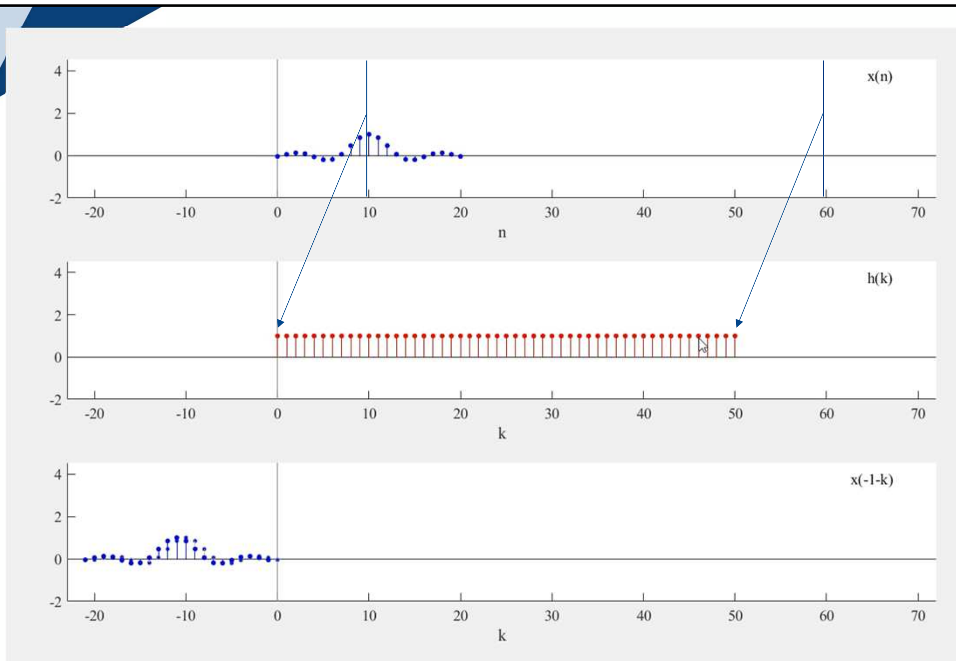
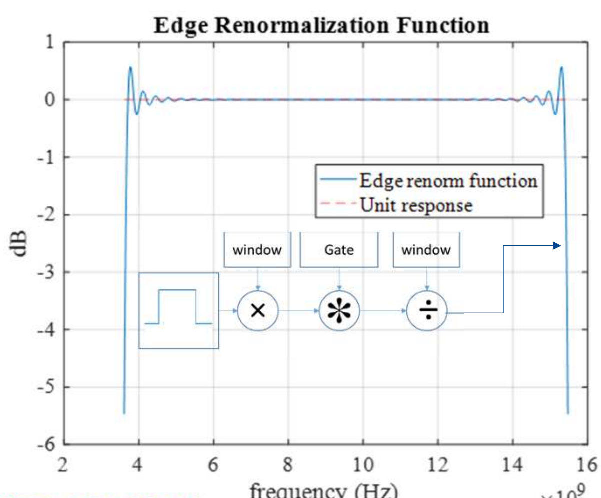


Causal Convolution
Shifts the result

Post-Gate Re-Normalization



- Consider processing a unit function, it will show the edge effect after gating, just like the raw data will
- Gated raw data will be divided by this renormalization function

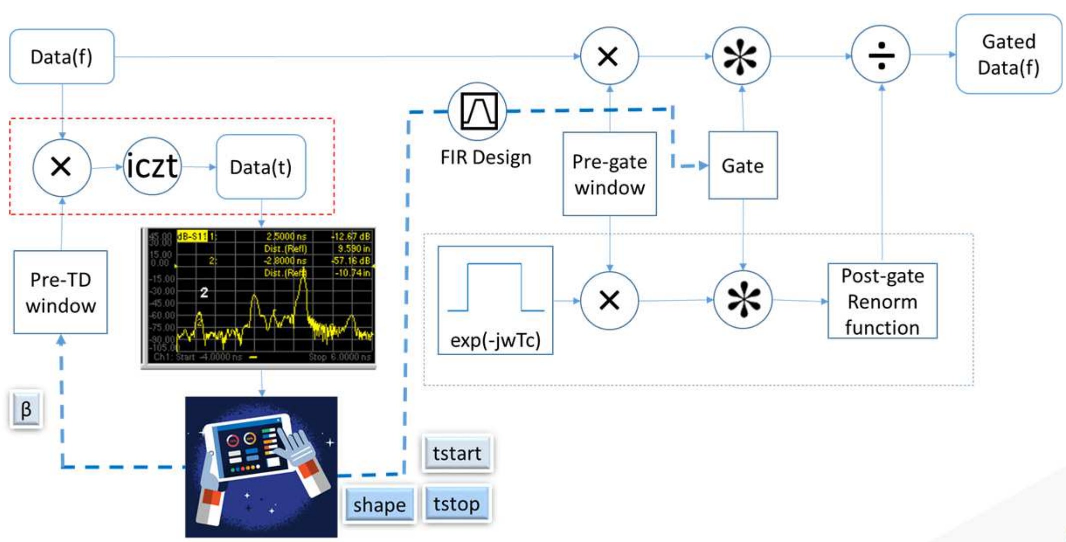
Post Gate Renormalization

- Post Gate Renormalization makes two important assumptions

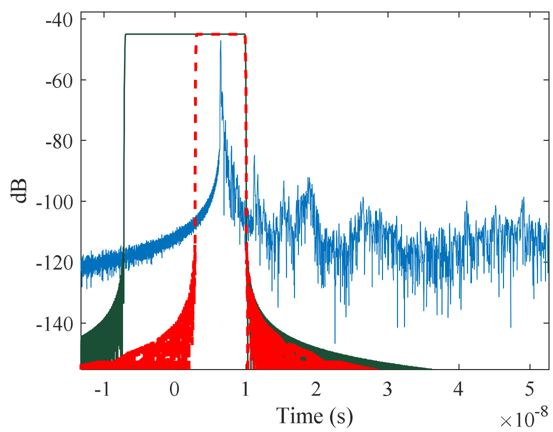
  - Edge effect on the unit (**flat**) function is similar to that on the raw data
  - Post gate renormalization assumes the time domain pulse is centered around the gate

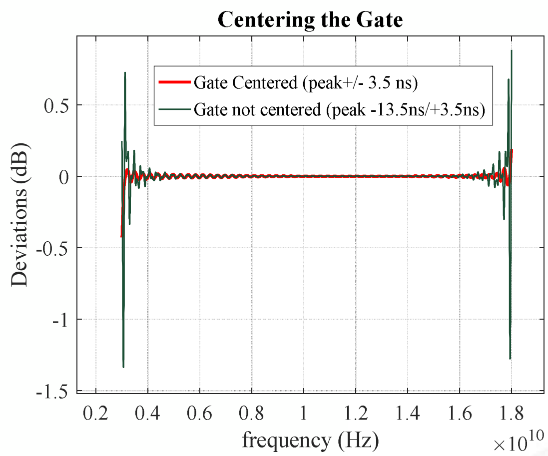
- Violating either condition will result in edge errors.

Putting it all together

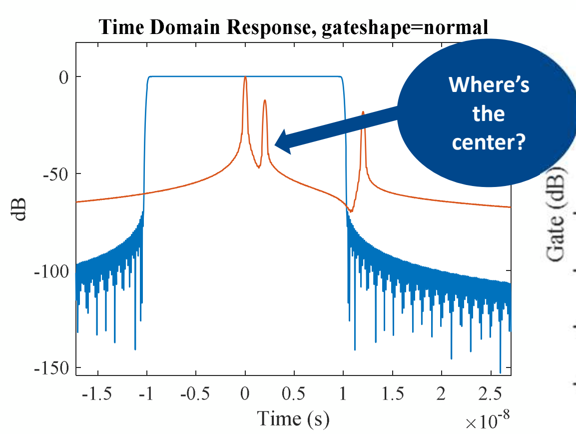


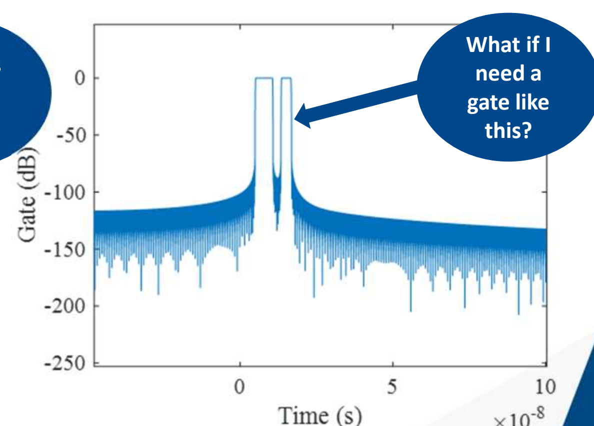
Gate Centering = smaller edge errors





Practical Issues with Gating

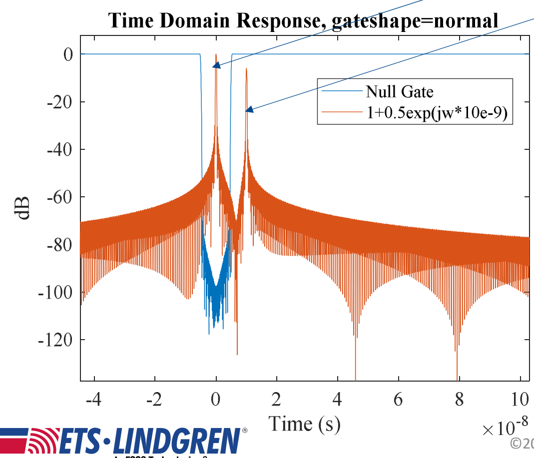


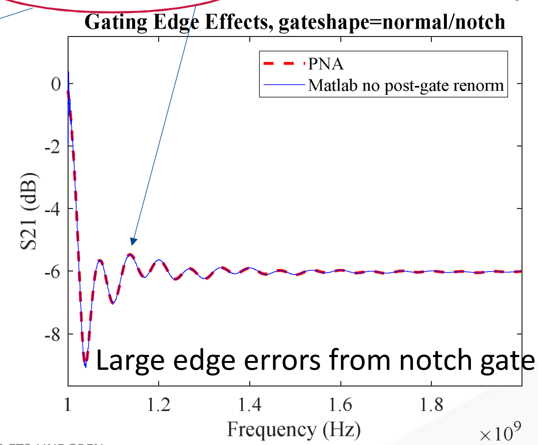


Practical Issues with Gating – Notch Gate

- Notch gate can't apply post-gate renormalization

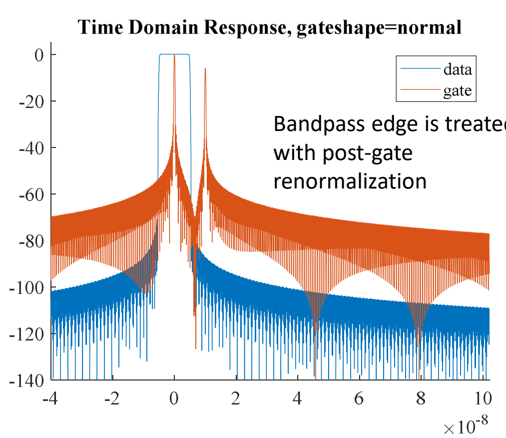
$$data = 1 + 0.5e^{-j\omega \cdot 10e-9}$$, 1-6 GHz, 16001 points

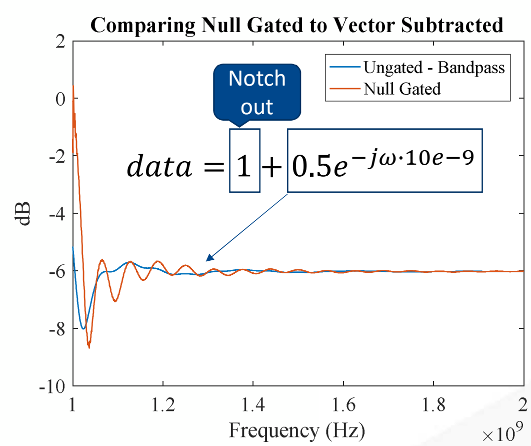




Alternative to Notch (Null) Gate

- Use a bandpass gate instead:
  - Notch gated (f) = Ungated – Bandpass Gated (in vector)





Time Domain Application Example

- Time Domain Site VSWR for EMC site (chamber) validation > 1 GHz

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Site VSWR

- Site VSWR (sVSWR) is specified in CISPR 16-1-4, used for qualifying an anechoic chamber used above 1 GHz for EMC measurements
- The goal is to probe the QZ to measure ripples in response due to chamber reflections.
- 6 points are measured along the 40 cm. The ripples in responses are the standing waves.
- The test is repeated at several locations in the quiet zone to obtain the sVSWR of the chamber.

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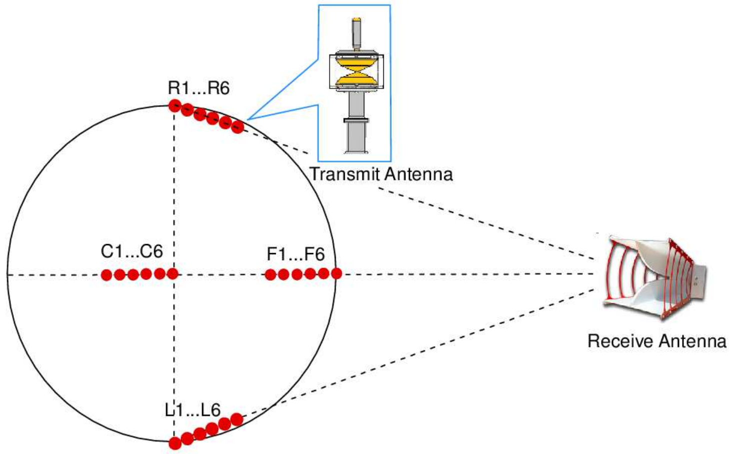
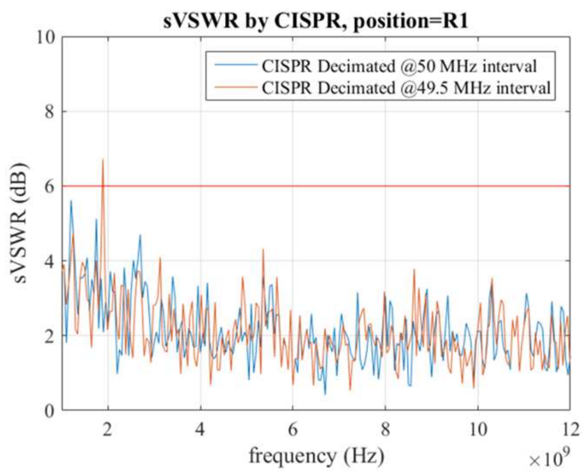
TD sVSWR only requires one (vs. 6) test point @ each location



Compromises in the CISPR SVSWR

- In order to reduce test complexity and time, several simplifications are made
  - The travel length is limited to 40 cm
  - Only 6 (irregularly positioned in order to break harmonic relations) measurement points along the line are sampled
  - VSWR measurements is typically done at every 50 MHz
- These compromises made SVSWR less accurate, and repeatability is a major concern

Example of Repeatability



- Even changing frequency steps can have a major impact on SVSWR results
- Positioning accuracy – A change in mm can change the peak!

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C63.25.1 TD SVSWR

- Instead of moving the receive antenna to plot the standing wave pattern. A vector response is measured between two antennas.
- Time domain transformation is used on the frequency domain data
- Gating is used to measure the VSWR of the chamber

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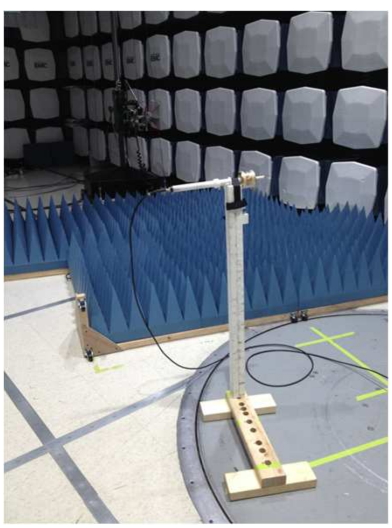
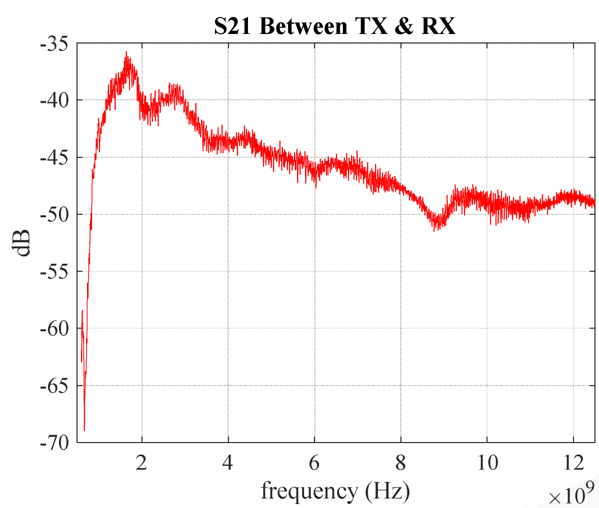
TD sVSWR ⇔ CISPR sVSWR

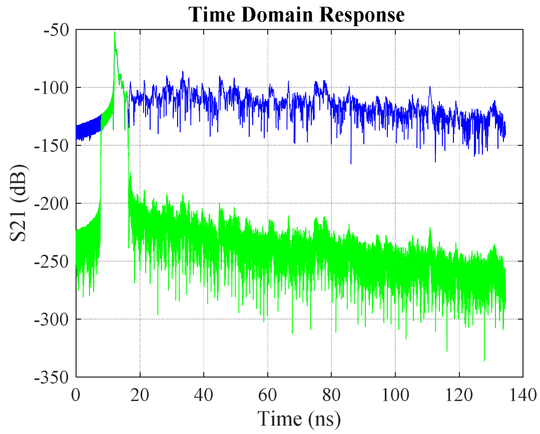
- TD sVSWR is developed so
  - It can be closely correlated to the CISPR sVSWR results
  - It overcomes the repeatability and under-sampling difficulties of the CISPR sVSWR
- Additional benefits of the TD sVSWR method:
  - Real-time/Fast results
  - More accurate in detecting defects
  - Results with defined uncertainties and sound mathematical principles

Illustration of the Test Method

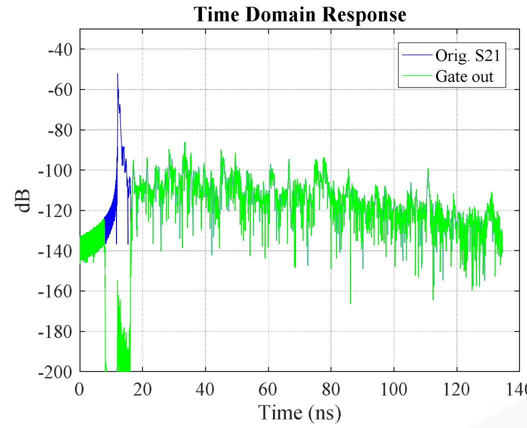




Frequency ->Time Domain (Inverse Fourier Transform)



Gate In – Keeping main response only



Gate out – Nulling out main response

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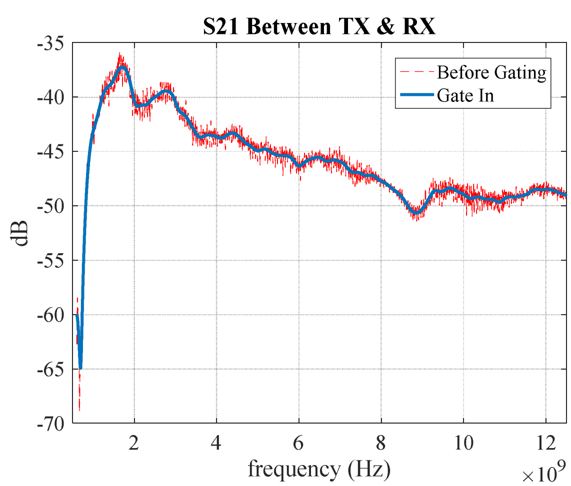
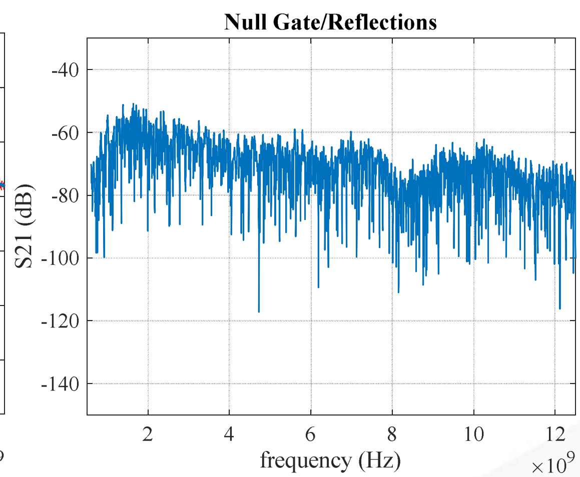
Back to Frequency Domain





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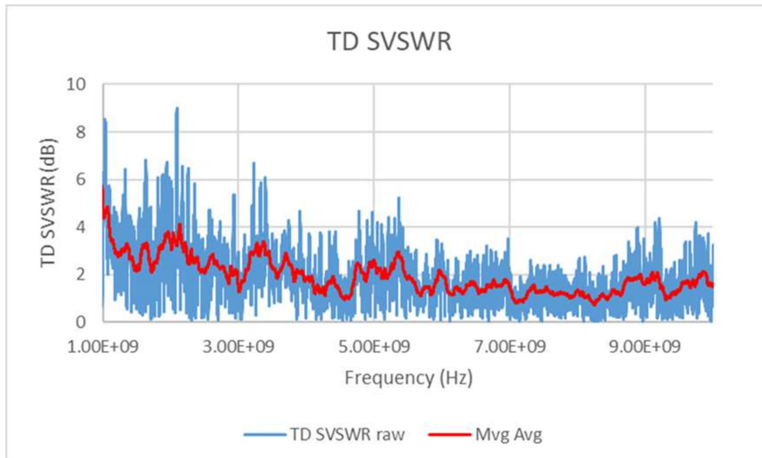
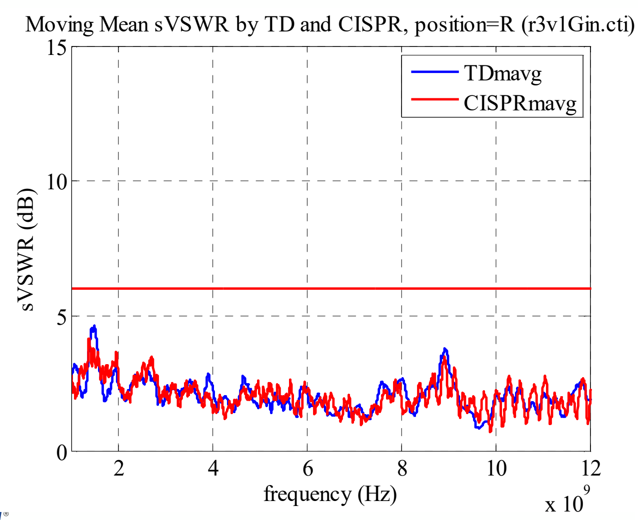
Calculate SVSWR

- In frequency domain, reflection coefficient
- $\rho = \frac{\text{Gate Out}}{\text{Gate In}}$
- $\text{SVSWR} = \frac{1+|\rho|}{1-|\rho|}$



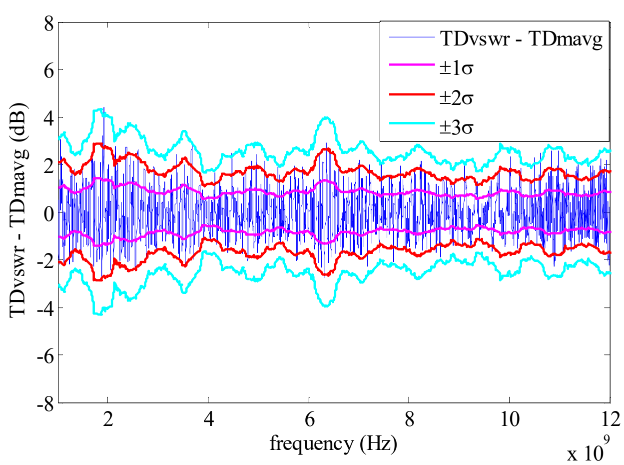
TD SVSWR correlates to CISPR SVSWR

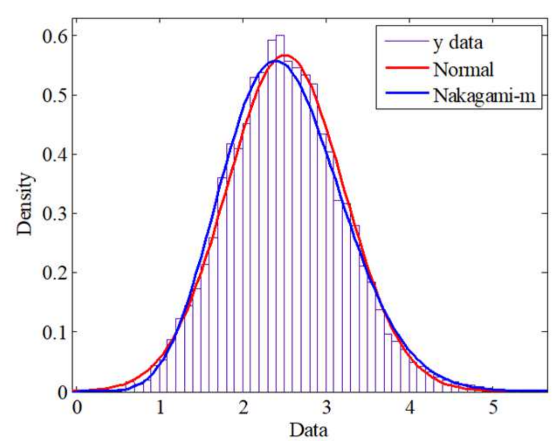


Processing the data

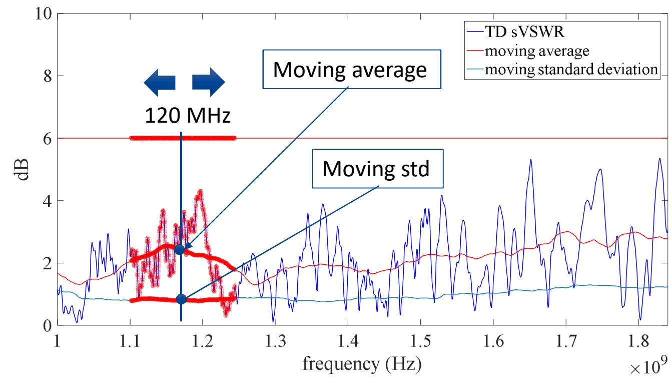
- The TD SVSWR data looks rather “erratic”
- Experienced user will notice the TD SVSWR maybe more “pessimistic” than the CISPR VSWR data
- The reason is because of the undersampling in the CISPR SVSWR method
- A post processing of TD SVSWR is needed to correlate to the CISPR VSWR

TD SVSWR has a “random” normal distribution





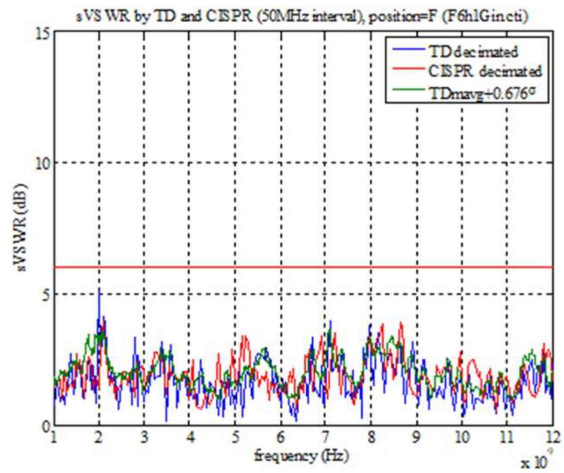
Sliding Window



The final reported TD SVSWR

- $Final\ TD\ SVSWR = moving\ average + 0.676\,\sigma$
- Moving average is determined from 120 MHz moving window
- σ is the standard deviation of the (TD-moving average) in the same 120MHz window
- Essentially the post processing includes 75% of the SVSWR. This is needed so the severity of TD method matches the severity of the CISPR SVSWR.

Final TD SVSWR compared to CISPR SVSWR



Time Domain Summary

- We have looked in to the time domain gating function “black box” in a network analyzer to gain a better understanding.
- Discussed edge effects due to time domain gating, and post-gate renormalization.
- We provided a real world application using time domain gating for EMC site validation measurements