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Periodical Discontinuities | Presenter: Gustavo Blando

SCOPE

- Half Wave Resonances
  - Fundamentals
  - How they can be seen in the S-parameter
  - Practical examples
- Periodical Discontinuities
  - What are they?
- Practical Examples
- Mitigation Strategies
- Conclusions

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Half Wave Resonances, time domain (1)

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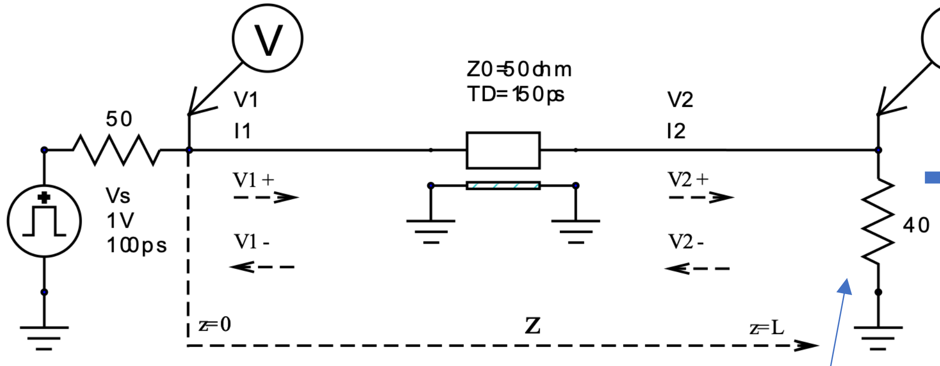
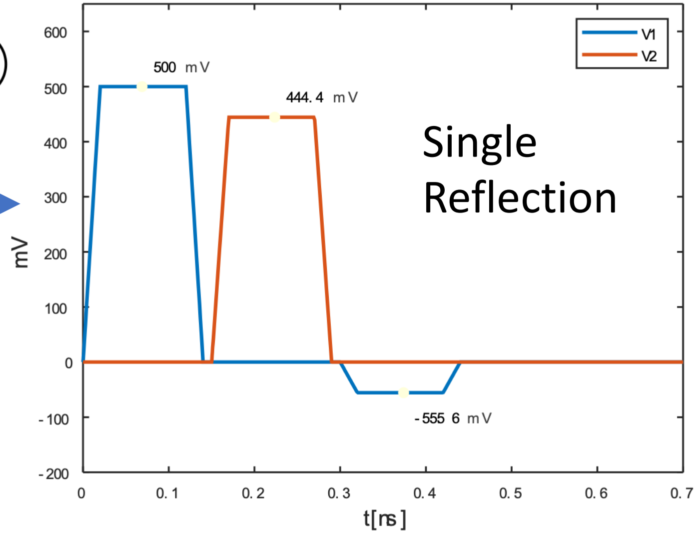
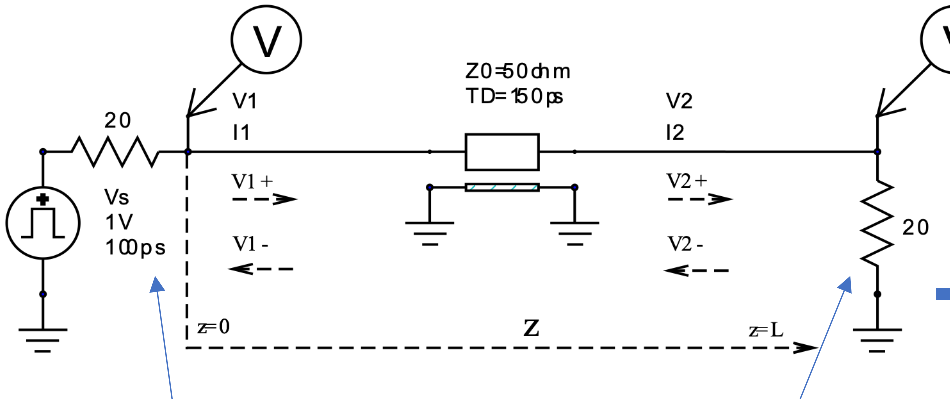


Small reflection only on one side

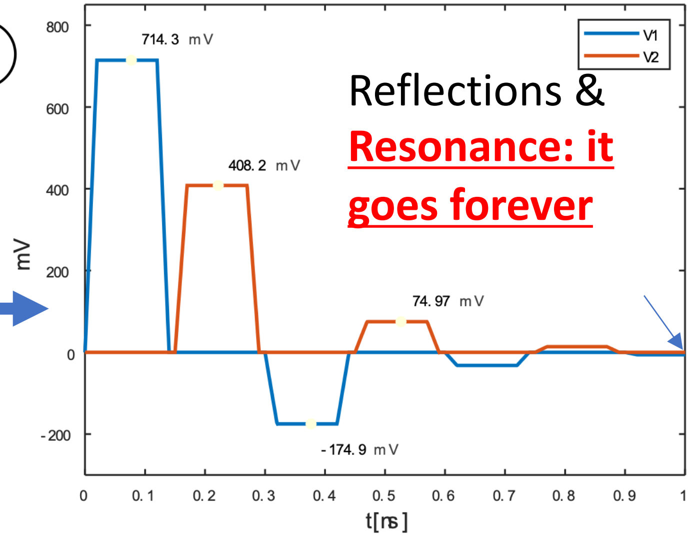


Conditions needed for ½ wave formation:

1. At least two discontinuities
2. Electrical separation between discontinuities
3. Similar reflections at both ends



Stronger reflections on both sides



There is another very important resonance, ¼ wave-length. With dissimilar discontinuities at each end (via stubs). I'll be not looking at those in this presentation

Half Wave Resonances, time domain (2)

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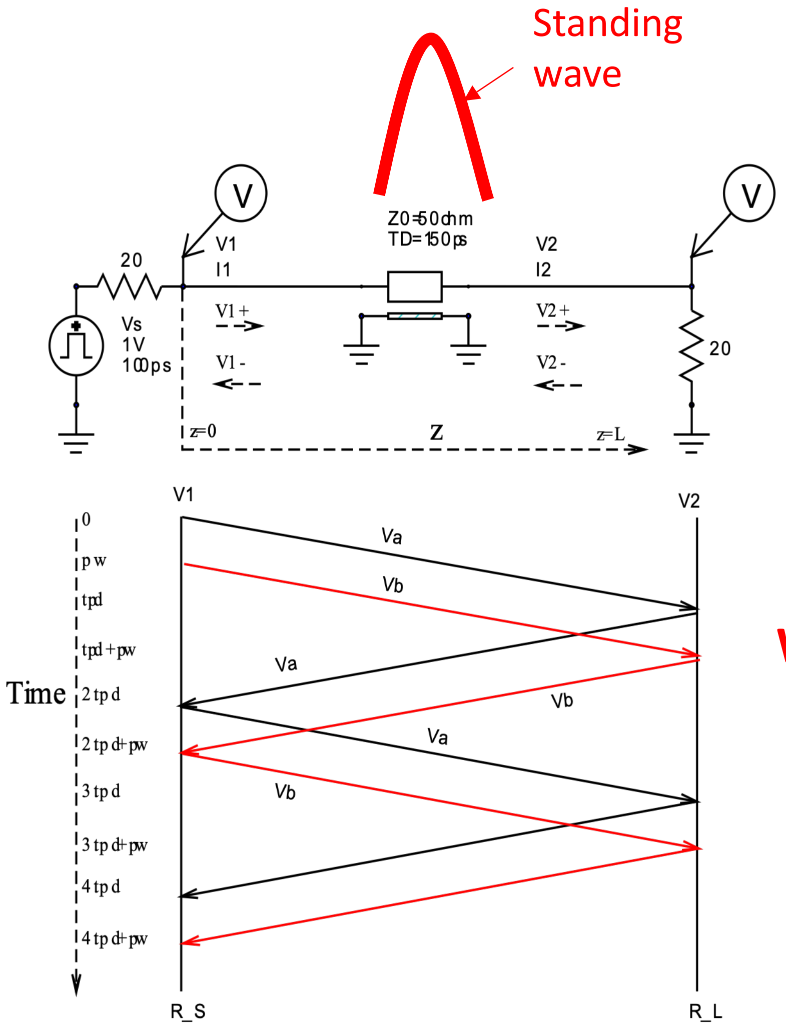
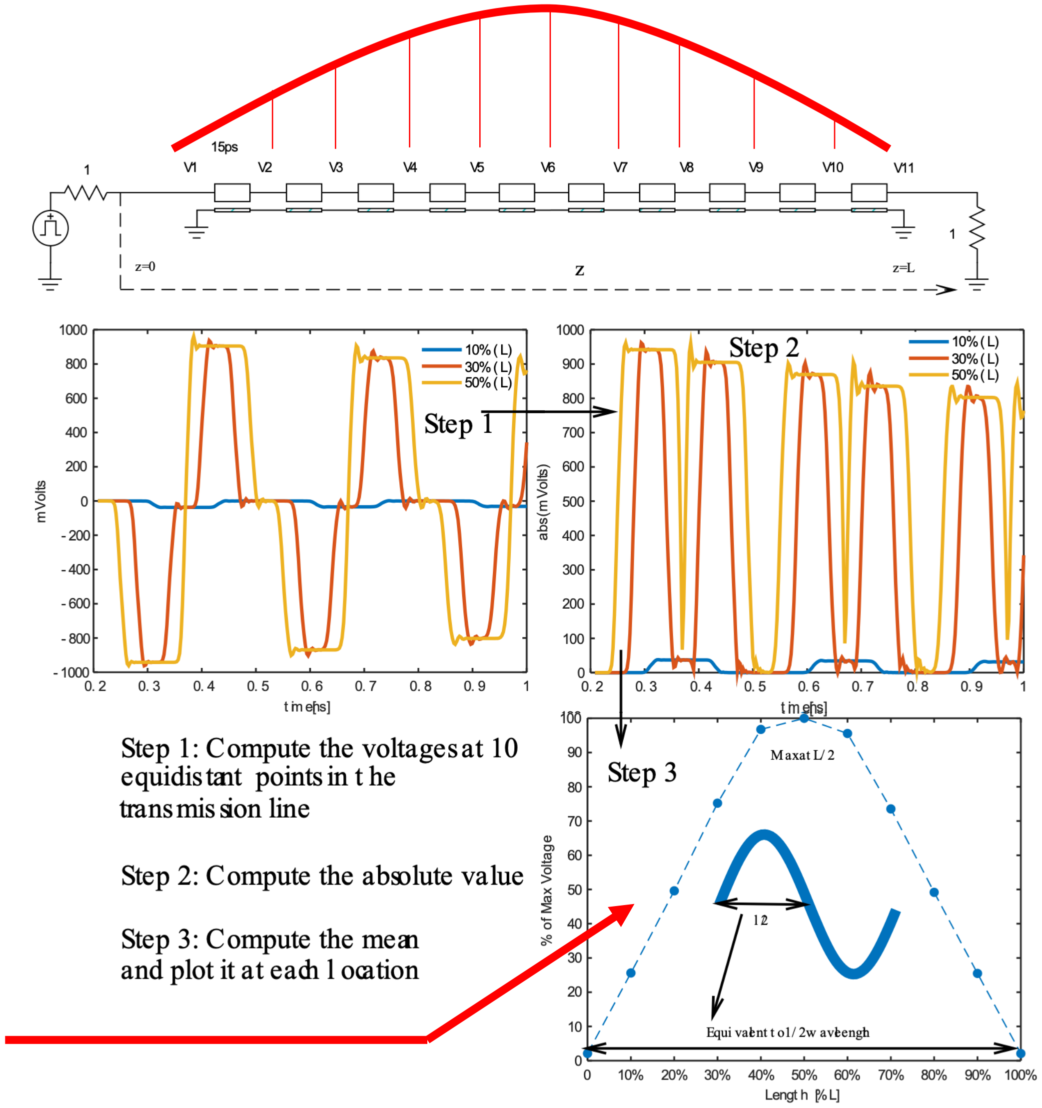
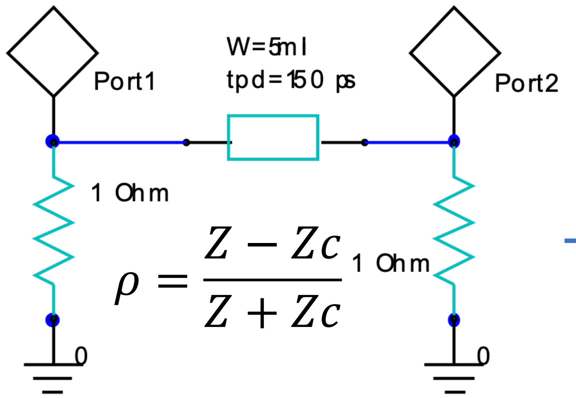


- Normally derived in a steady state sinusoidal wave analysis
- I'll do it by example in the time domain with a constant square wave

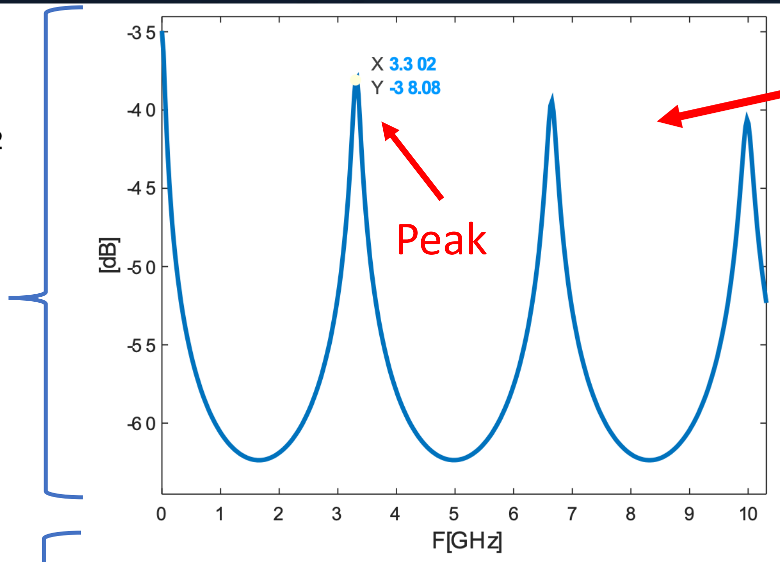
We can clearly see a ½ Wave standing wave shape along the line!!!!!!



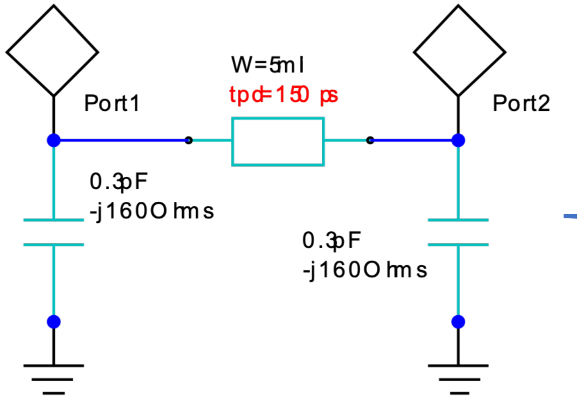
S-Parameters Behavior (1)

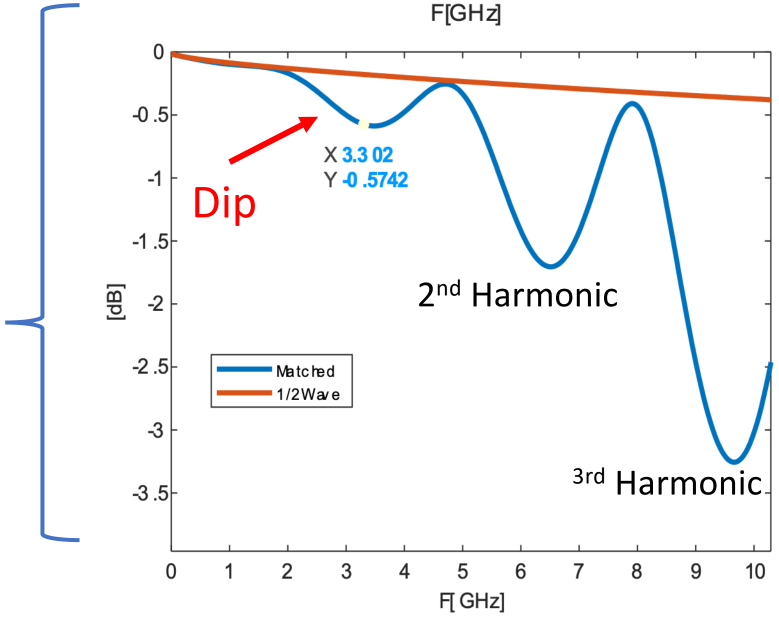


$$\rho = \frac{Z - Zc}{Z + Zc}$$

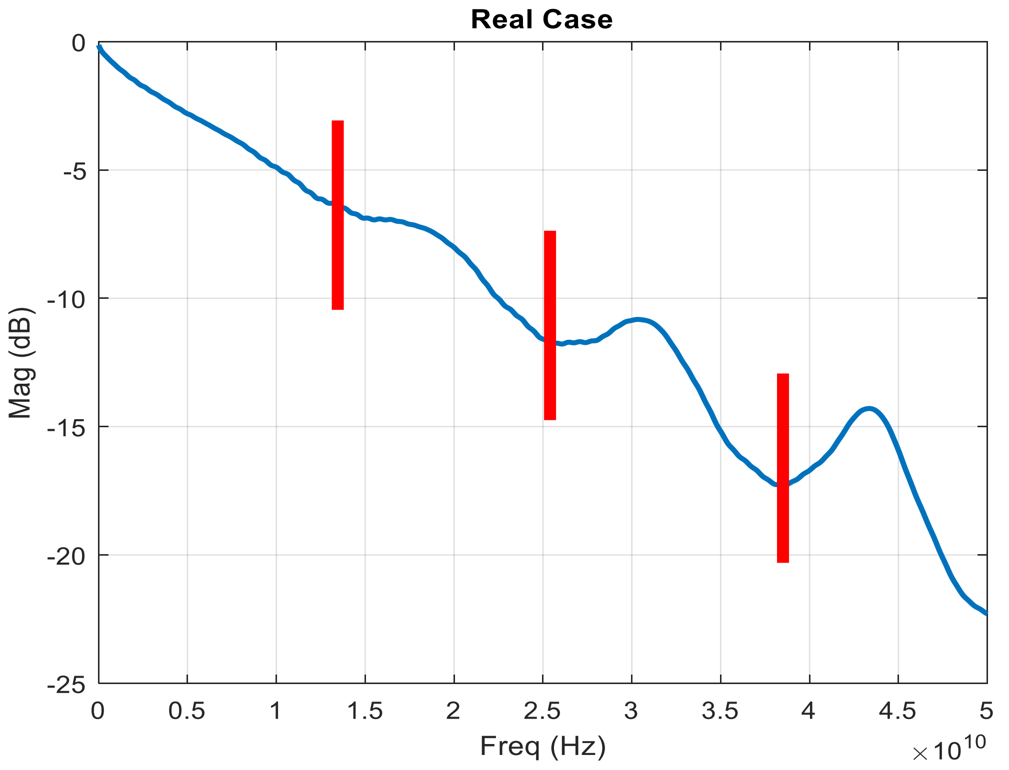


$$f_r = \frac{1}{2.tpd} = \textbf{3.3GHz}$$





But wait, this looks nothing like a typical case in SI topologies!!!!!!



We noticed a PEAK on the resistive case and a DIP on the CAP case?

S-Parameters Behavior (2)

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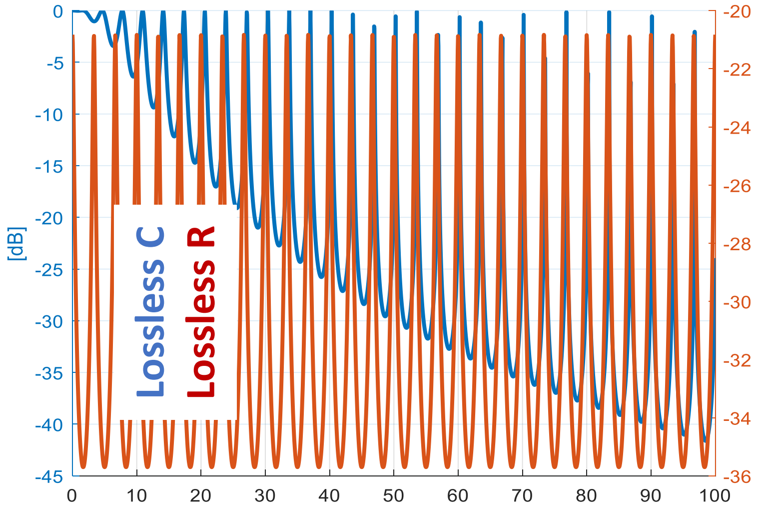
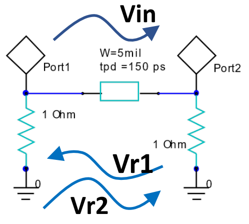


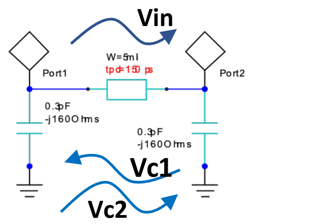
A1: Constructive instead of destructive resonances

A2: Reflection magnitude increases

A3: Losses compress the resonance peaks

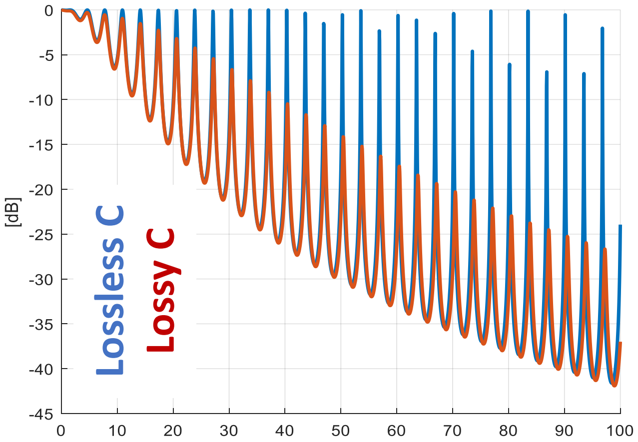
A4: Smaller disc, smaller reflection !!!!

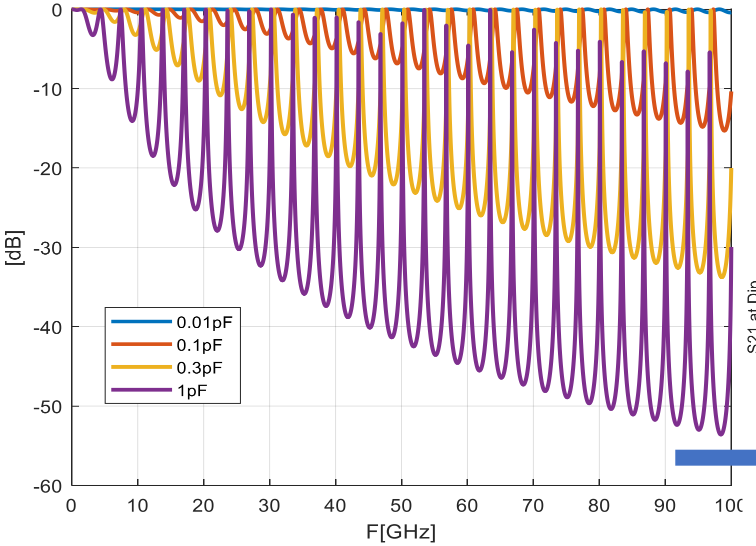


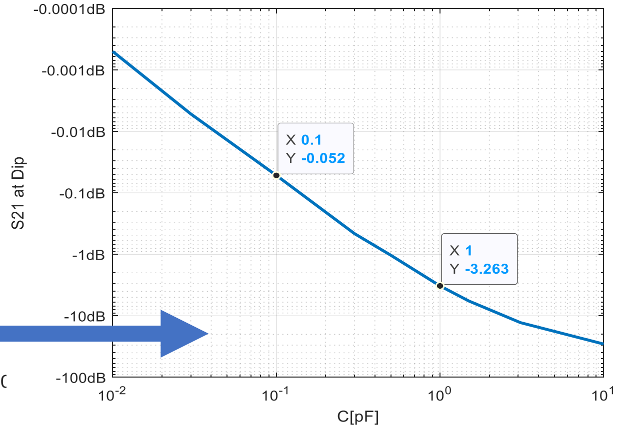


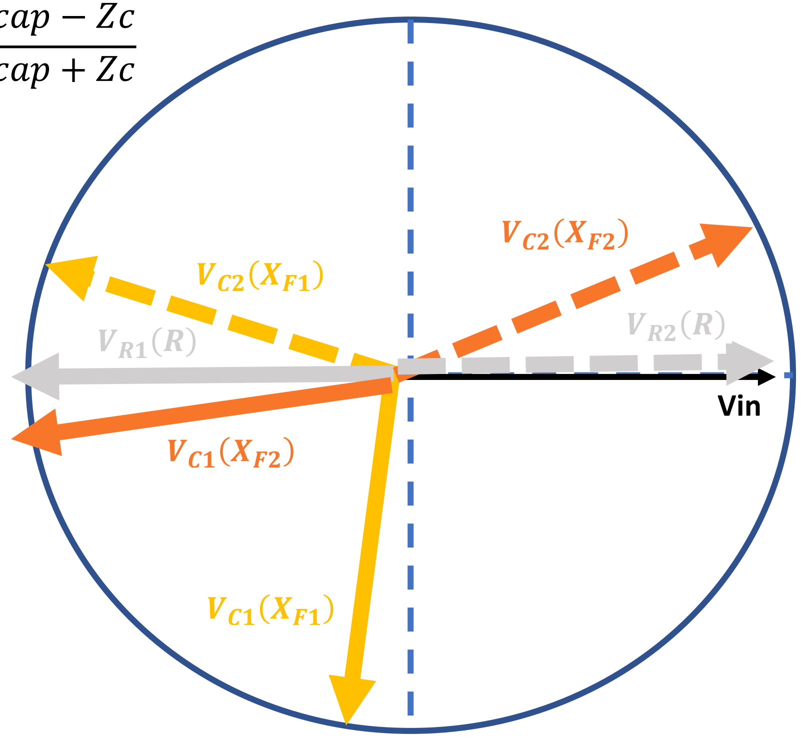
$$Zres = 1||50 \qquad Zcap = \frac{1}{j2\pi.3.3GHz.N.0.3pF}||50$$

$$\rho = \frac{Zres/cap - Zc}{Zres/cap + Zc}$$

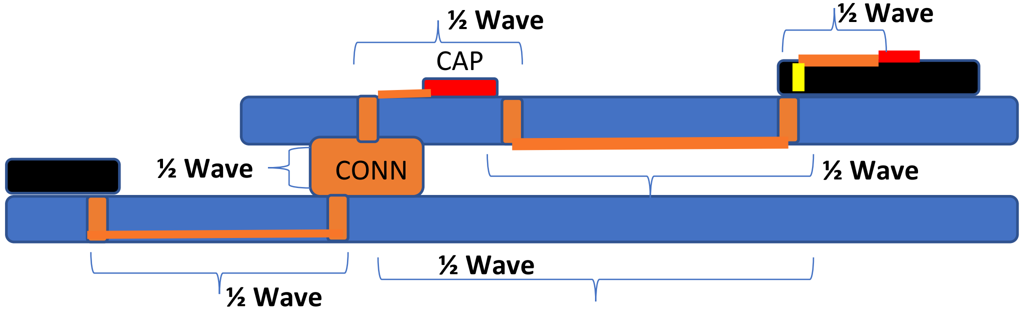


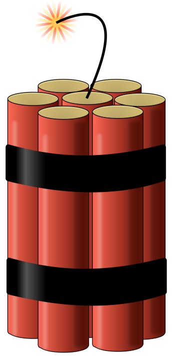






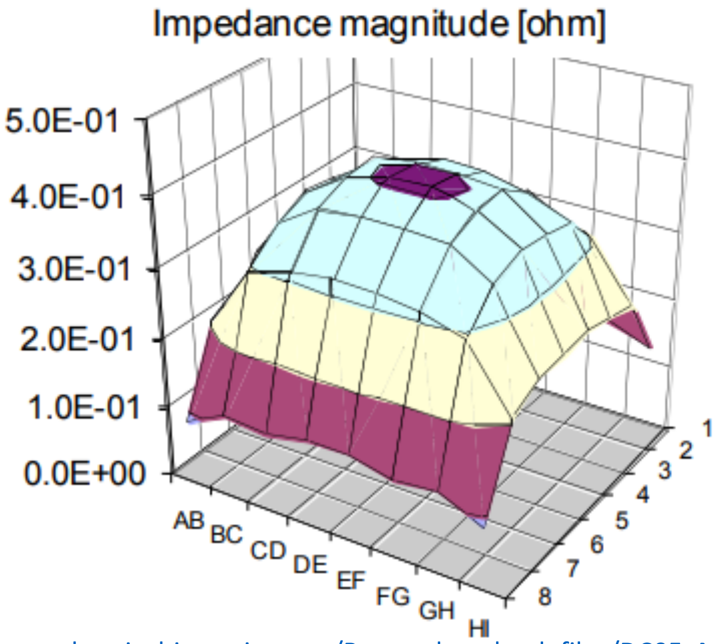
Where are they? (½ Wave Resonances)





There could be many ½ wave resonances (and others) formed in the topology. They'll depend of the magnitude and separation of discontinuities

BGA via pin-field



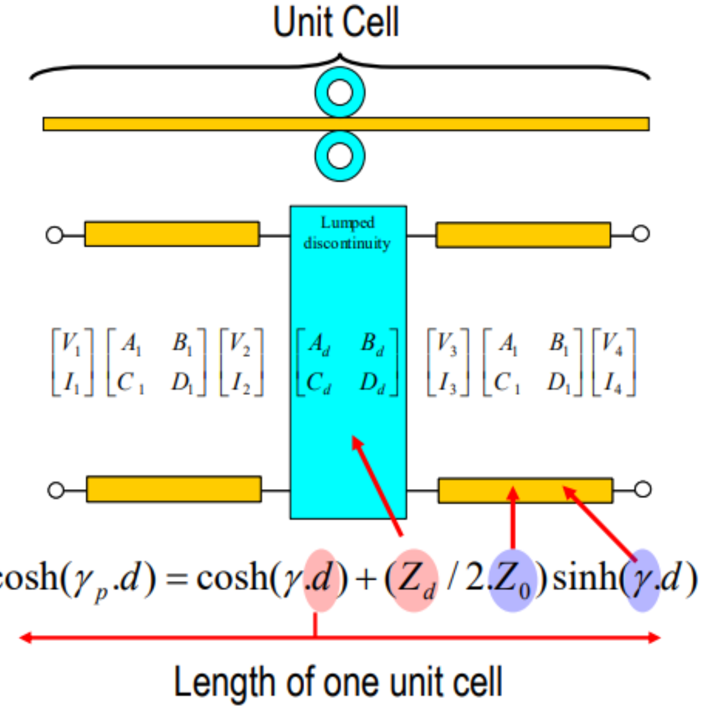
Very common in power structures, (planes and plane shapes)

What happens when we put many similar ½ wave resonances one after the other?

http://www.electrical-integrity.com/Paper_download_files/DC05_Miller_Novak_Delap_slides.pdf

Periodical Discontinuities

- If we put many of these ½ wave resonant cells one after the other, the discontinuity constructively adds and the reflections amplifies

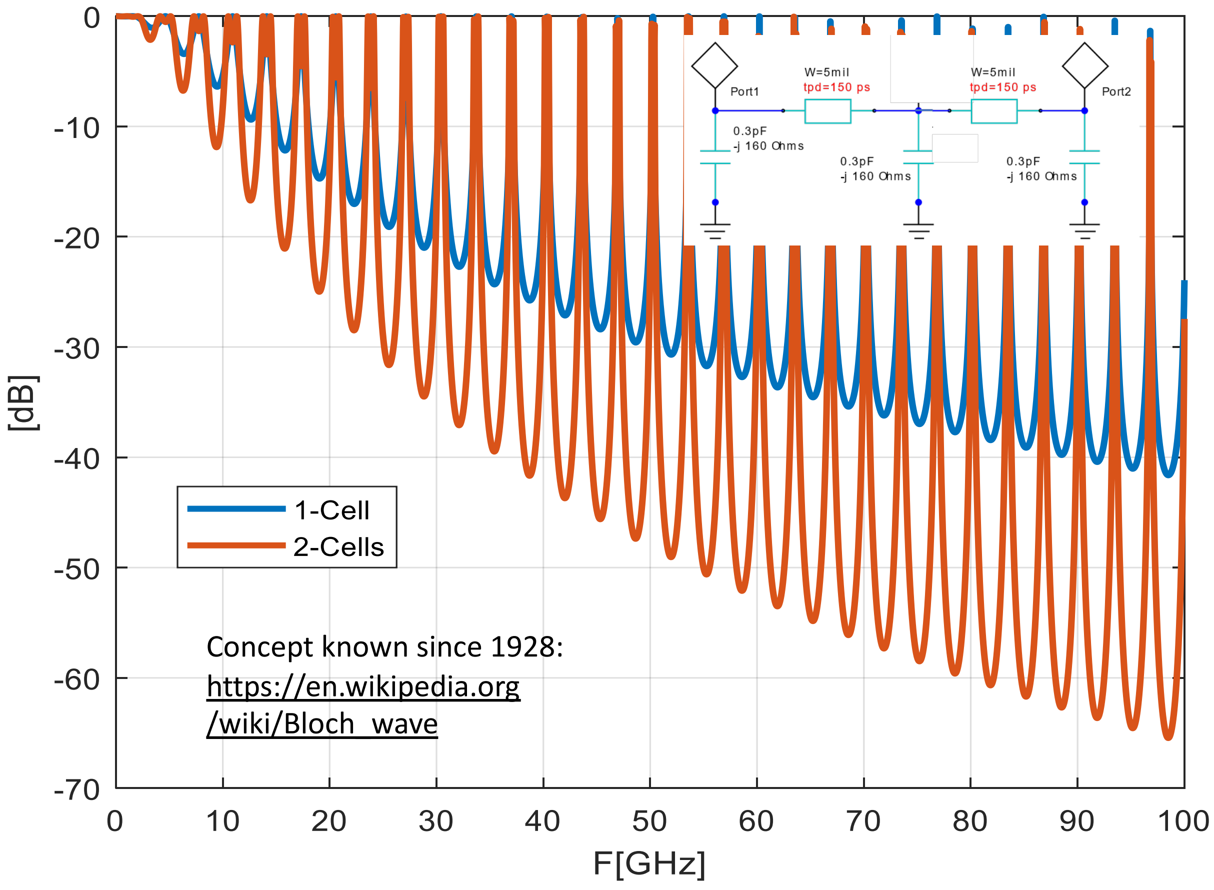


$$\cosh(\gamma_p.d) = \cosh(\gamma.d) + (Z_d/2.Z_0)\sinh(\gamma.d)$$

$$A = D = \cosh(\gamma d) + (Z_d/2Z_0)\sinh(\gamma d)$$

$$B = Z_0[\sinh(\gamma d) + (Z_d/2Z_0)\{\cosh(\gamma d)+1\}]$$

$$C = [\sinh(\gamma d) + (Z_d/2Z_0)\{\cosh(\gamma d)-1\}]/Z_0$$



Concept known since 1928: https://en.wikipedia.org/wiki/Bloch_wave

http://www.electrical-integrity.com/Paper_download_files/DC06_SUN_AttenuationPeriodicalSiscontinuities_slides.pdf

Frequency and Time Domain Response

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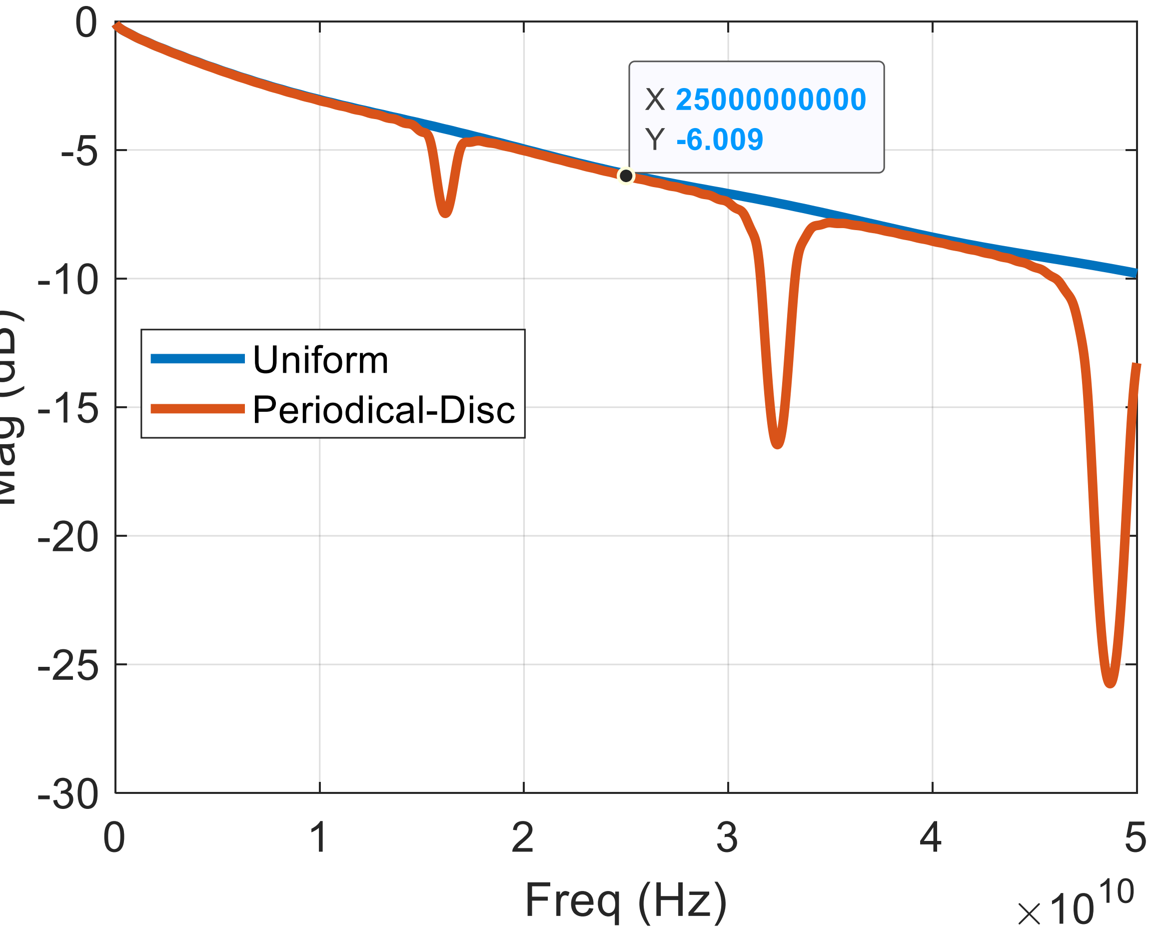
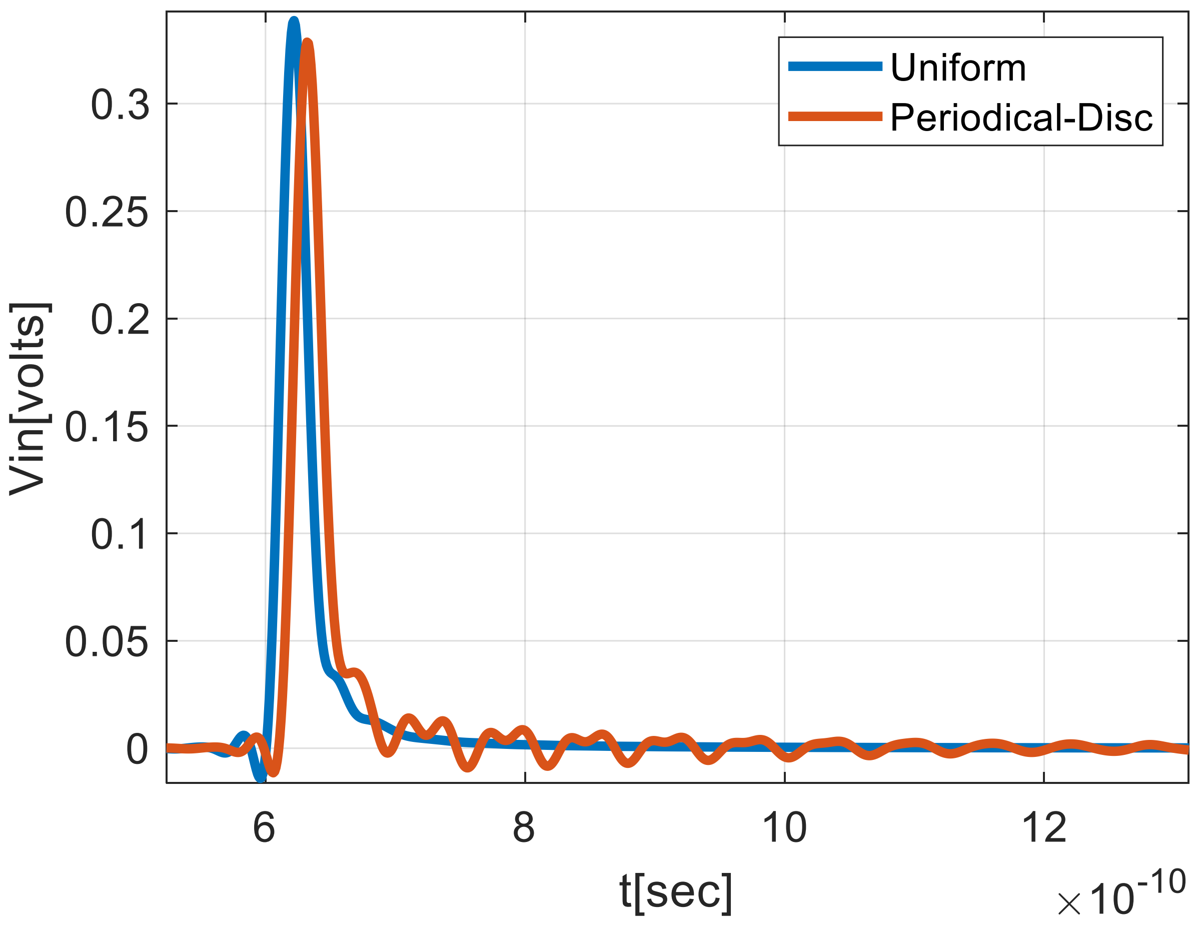
- Just a 4in line with 20 small capacitive discontinuities 0.05pF

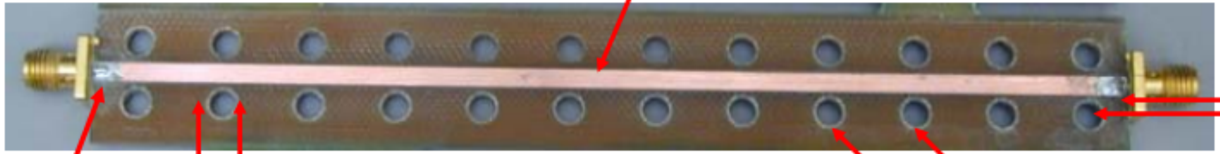




Periodical Discontinuity Test Board

Test board

2.5 mm wide, 6in long microstrip on top of a 800 mil wide, 63 mil thick FR4 dielectric



Fixed 125 mils from the edge of the trace to center of the hole

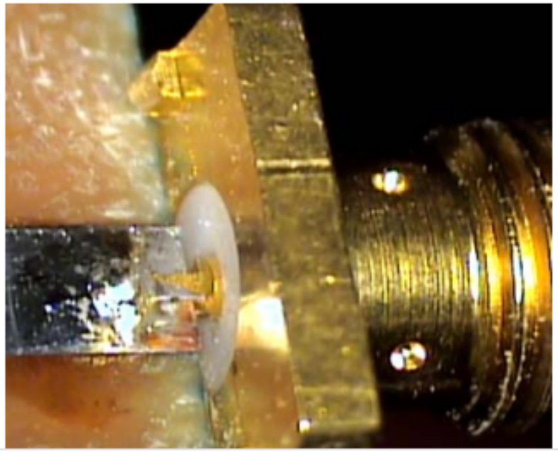
500mils pitch

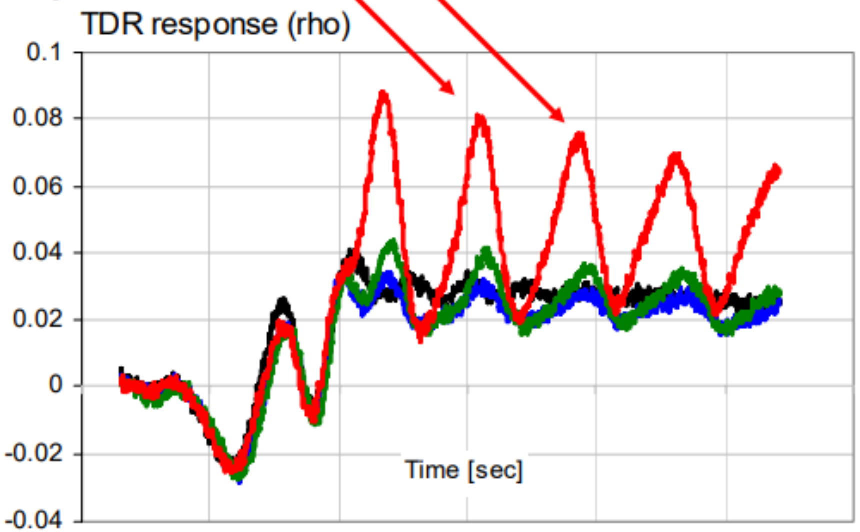
Hole diameter increased from:
125,164,194,250mils

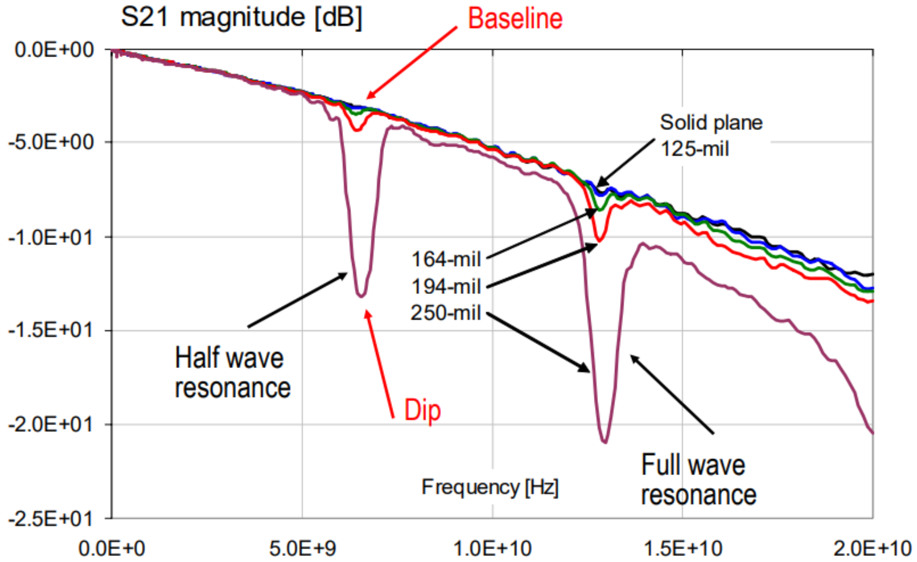
Half wave resonance
1/ 2*500mils*150ps/in=6.6GHz

Resonance clearly seen in the time and frequency domain

Edge launch SMA







http://www.electrical-integrity.com/Paper_download_files/DC06_SUN_AttenuationPeriodicalSiscontinuities_slides.pdf

Practical Examples of Periodical Discontinuities

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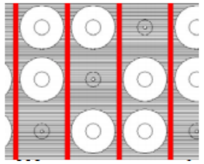
- Originally studied in cable wrap.
  - Small differences between each turn adds up when there are 1000's of them!!!! (High frequency, depending of wrap pitch)

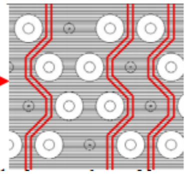
- When you are routing full-mesh backplanes
  - Low frequency periodical discontinuities can be created as traces passes under backplane connector

- As you are crossing a BGA pin-field, or going around a connector.

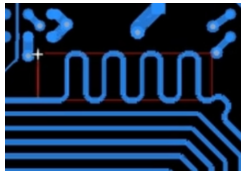
BGA pin-field



Conn pin-field



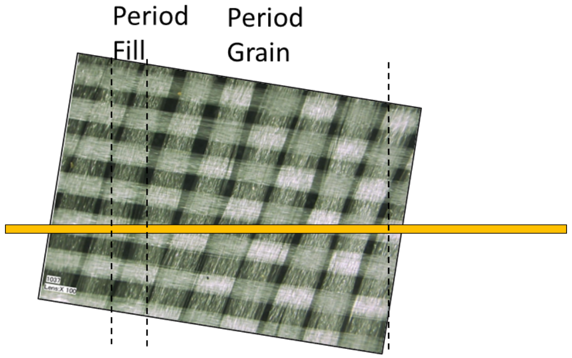
Serpentine in general

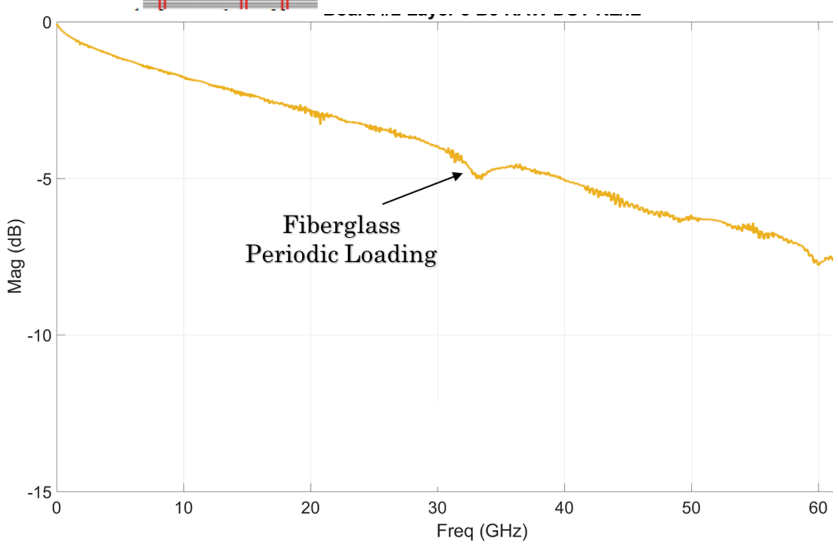


- Traces crossing the weave at an angle:

$$Period = \frac{Pitch_{GRAIN}}{\sin(rotation)}$$

$$f_{res} = \frac{c}{2 \times Period \times \sqrt{\varepsilon_r}}$$





Mitigation

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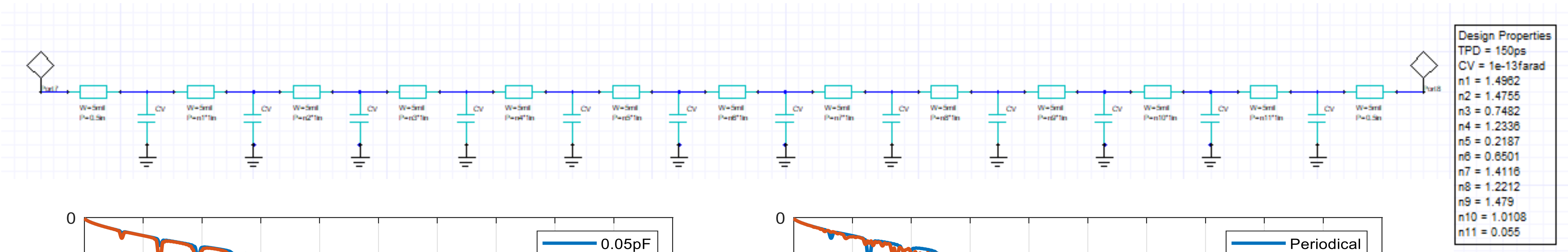

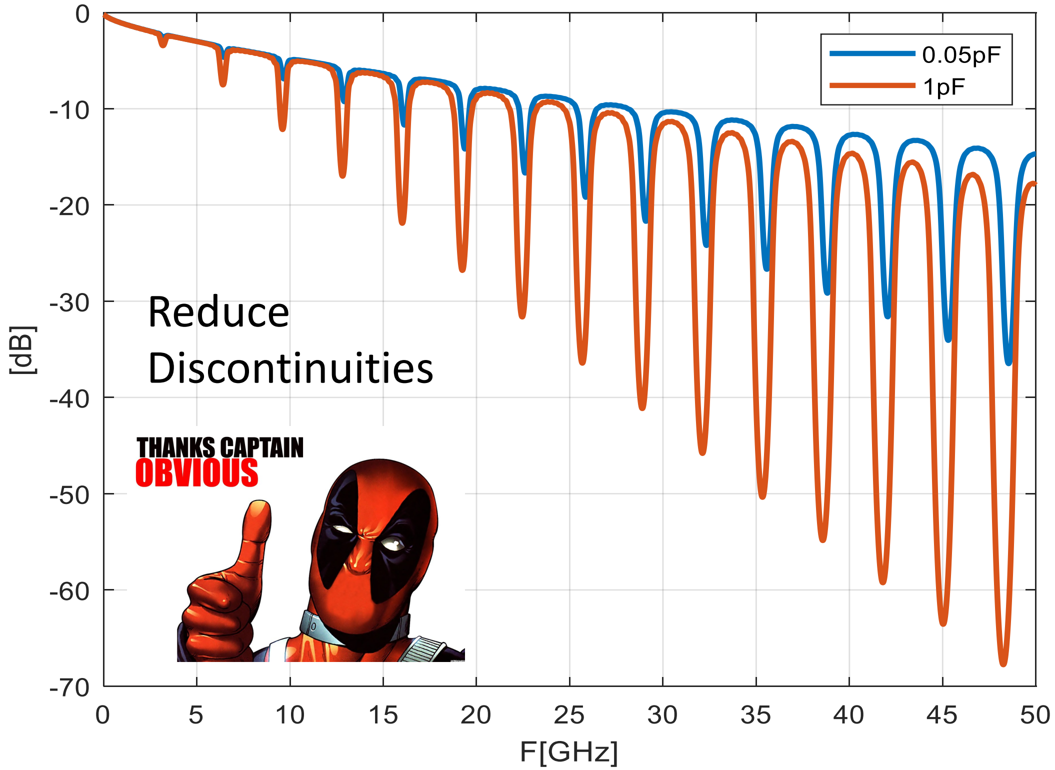

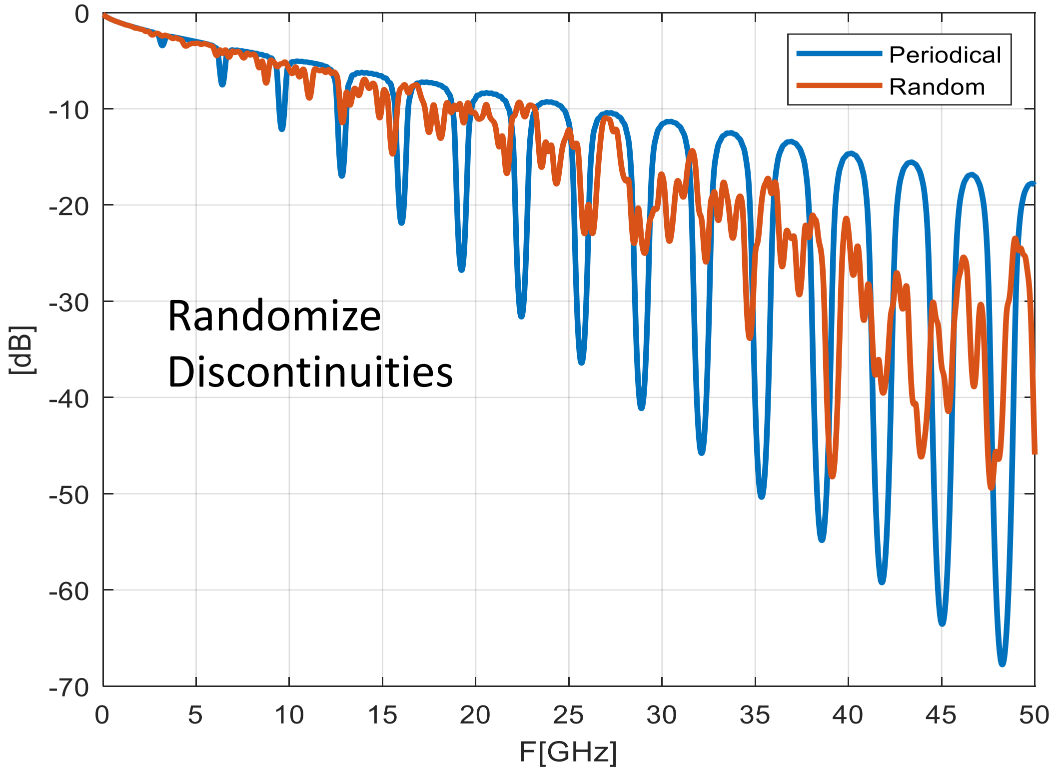

Conclusion

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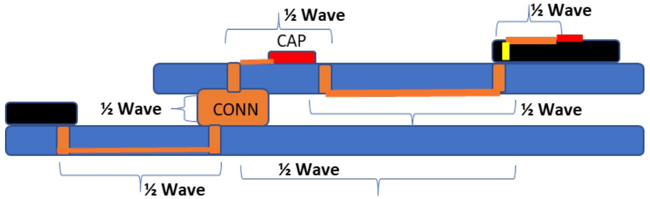
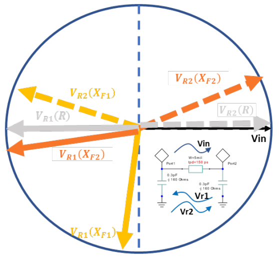
- Half wave resonances are the building block of periodical discontinuities and are everywhere



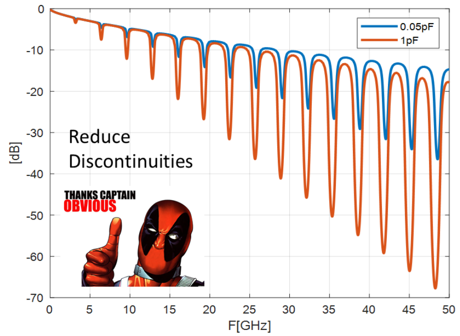
- Reactive discontinuities modify the phase, such the resonance dips, changes with frequency



- For the fundamental frequency using this approximation will likely get very close to the dip frequency

$$f_r = \frac{1}{2.tpd}, or\ tpd = \frac{1}{2.f_r}$$

- Small discontinuities add up when you align the resonances in periodical discontinuities



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- G.J. Blando, J.R. Miller and I. Novak, “Attenuation in PCB Traces due to periodic discontinuities”, DesignCon, 2006
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For Signal Integrity questions, contact: **SIG@samtec.com**