Forensic Analysis of Closed Eyes

Dr. Eric Bogatin, Dean, Teledyne LeCroy Signal Integrity Academy
Stephen Mueller, Applications Engineering Manager, Teledyne LeCroy
Karthik Radhakrishna, Applications Engineer, Teledyne LeCroy

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Dr. Eric Bogatin
Director, Teledyne LeCroy Front Range Signal Integrity Laboratory
Dean, Teledyne LeCroy Signal Integrity Academy
Adjunct Prof, University of Colorado, Boulder, ECEE
www.beTheSignal.com

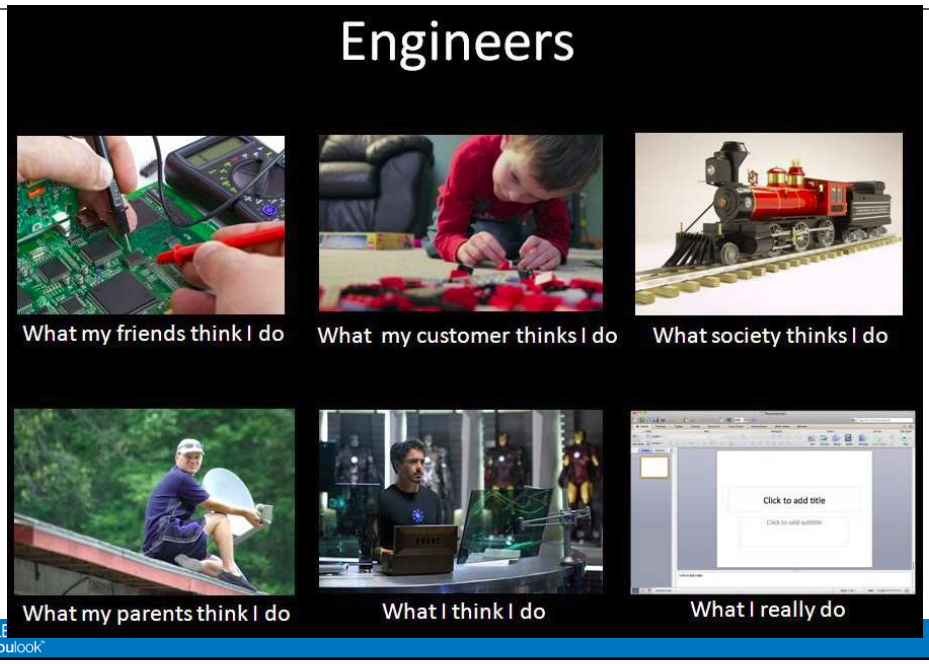
Lesson AGCD-09-51 Forensic Analysis

Course PSMA:
Advanced GigaBit Channel Design
Section 09: Advanced Topics

With Eric Bogatin,
Dean, Teledyne LeCroy Signal Integrity Academy

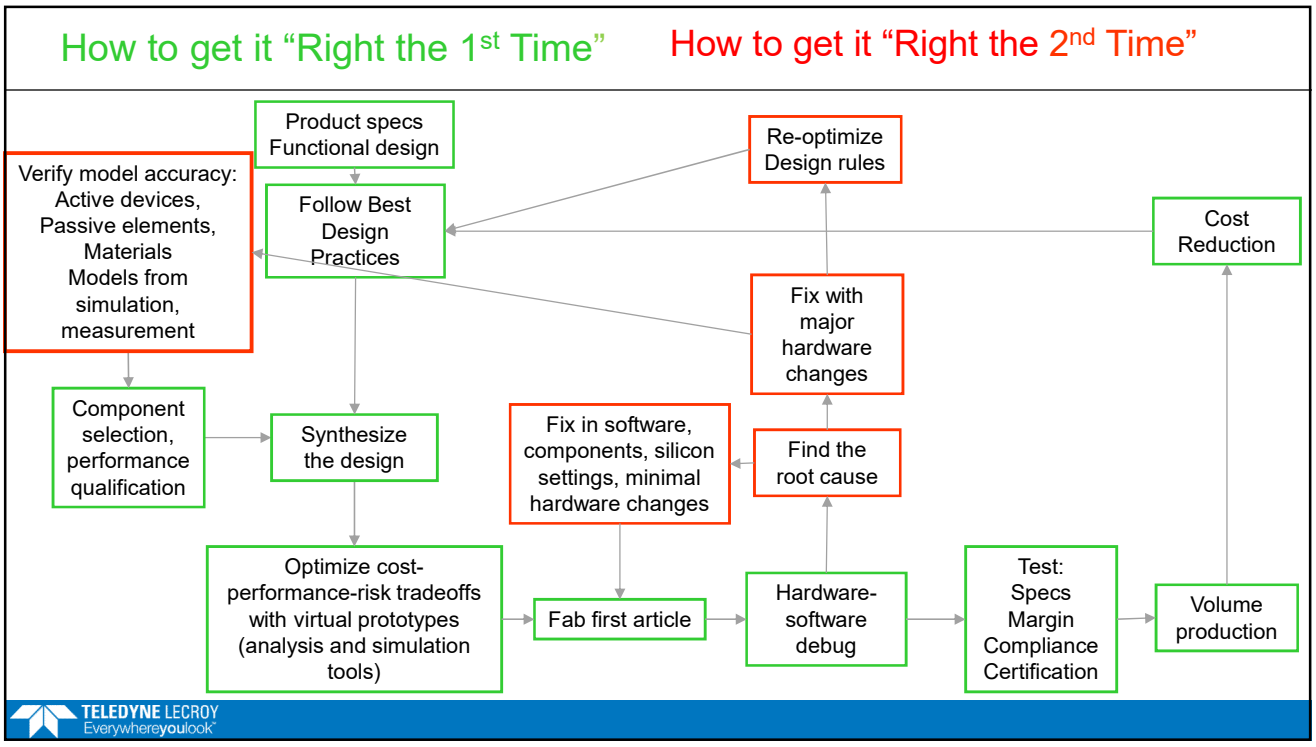
- AGCD-09-51 Forensic Analysis
  - An efficient design methodology
  - Forensic Analysis
  - Scope features and signal features
  - Clock jitter: random and periodic
  - Single bit response
  - Why the S-parameters of the channel tell the real story

Joke of the day



Outline

- An efficient Design Methodology
- What is Forensic Analysis
- Five important methods:
  - Know your scope and signal
  - Look at the clock
  - Single bit response
  - Look at the common signal
  - Look at the S-parameters of the channel
- Good habits
  - Make rule #9 your friend!
  - Explore all the usual suspects thru simulation
  - Look at ALL the evidence available
  - Know your channel's S-parameters



If it works the first time, there is no problem to fix

okay, we're done

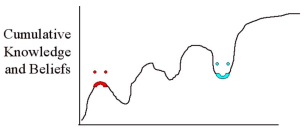
Fastest Way to Solve a Problem is to Identify its Root Cause

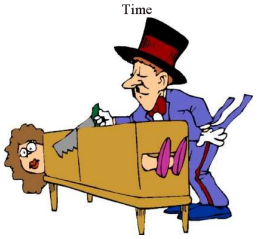
If you have the wrong root cause your chance of fixing the problem is based on pure luck

Finding the root cause: Forensic Analysis- Who Killed the Signal?

How do you find the root cause of any problem?

- Trick #1: Have you seen this problem before? Leverage the learning curve
  - The value of synthesis- seeing many examples and PAYING ATTENTION
  - See the problem through to the end and VERIFY you found the correct root cause
- Trick #2: If you wanted to reproduce this effect, how would you do it?
  - How do magicians do their tricks?
  - If you wanted to re-create this effect, how would you do it?
- Trick #3: "Round up the usual suspects" and interrogate each one
  - What are all the possible root causes?
  - What are the consistency tests to confirm the specific root cause?
- Two really important skills in forensic analysis:
  - Rule #9
  - Studying pathological problems (know your suspects)





Rule #9

Never do a measurement or simulation without first anticipating what you expect to see.

If you are wrong, there is a reason- either the set up is wrong or your intuition is wrong. Either way, by exploring the difference, you will learn something

If you are right, you get a nice warm feeling that you understand what is going on.

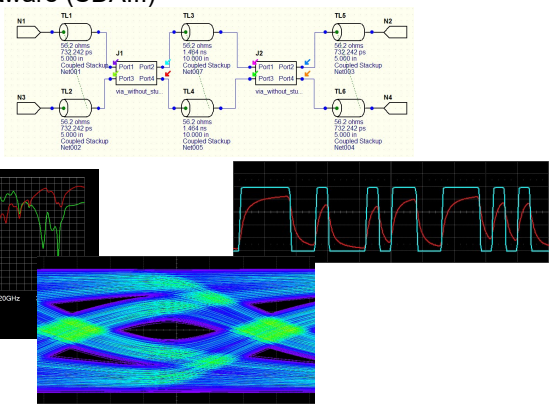
Corollary to rule #9:

There are so many ways of screwing up a measurement or simulation, you can never do too many consistency checks

There is no Substitute to Studying Pathological Problems!

Measure it: Wild River Technology CMP28 board
- re-configurable backplane with a variety of pathological structures
- can be used to generate “stressed eyes”

Simulate it: Mentor Graphics HyperLynx and Teledyne LeCroy (SDAIII)
- Synthesize specific channel
- Simulate the S-parameters
- Analyze impact on real time signals using scope software (SDAIII)



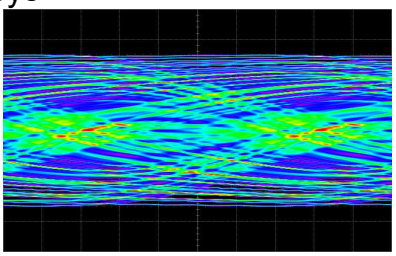
The Usual Suspects List

- Pathological problems (can kill the signal by itself):
  - Insertion loss too high > ~ 0.1 dB/in/GHz
  - Stub resonances
  - Mode conversion
  - Channel to channel cross talk
- Death by a thousand cuts (all of the above and then some)
  - Measurement artifacts
  - Random jitter, Periodic jitter
  - Reflections from discontinuities
  - Cross talk

- Verification
  - Think of all the consistency tests you can to confirm the root cause
  - THE BEST way of verifying an interconnect problem is to look at the channel S-parameters
  - Sometimes verification may require "hacking" a model for the interconnect and removing the feature in the model to verify this was the root cause

A Special Case: Your eye is closed

- If eye is closed at RX:
  - May be difficult to find equalization settings to open eye
  - (usually only successful for a loss mechanism)



- Need to use other techniques to find root cause
  - Measurement artifacts
  - Clock jitter analysis (periodic and random)
  - Single bit response (reflections)
  - Common signal response (mode conversion)
- THE BEST way of identifying interconnect related root causes is
  - Look at the S-parameters!

If You Know What To Expect, You Will Be Dismayed, Shocked And Surprised at what is in Some Channel Models!

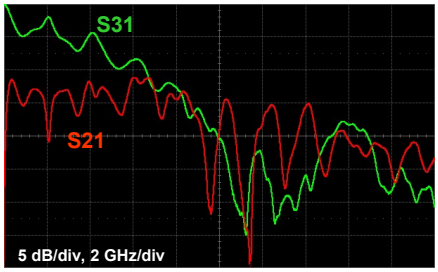
Strategy for Evaluating an S-parameter Channel Model

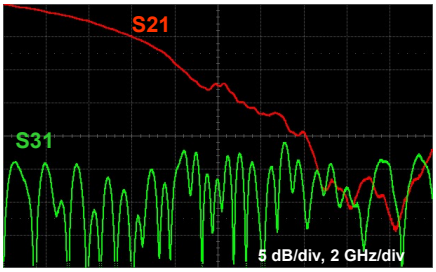
- Rule #9 is your best friend
- Look at ALL the data:
  - SE in the freq domain
  - SE in the time domain
  - Diff in the freq domain
  - Diff in the time domain
- Are the measurements reasonable?
  - Perform the obvious consistency tests of the data
- Is the interconnect reasonable?
  - Look at the important figures of merit of the channel
- Look for the usual suspects

"The spec is -13 dB at 4 GHz. We simulated -12 dB for the channel. We measured -17 dB. What's wrong with our channel?"

Are the measurements reasonable?

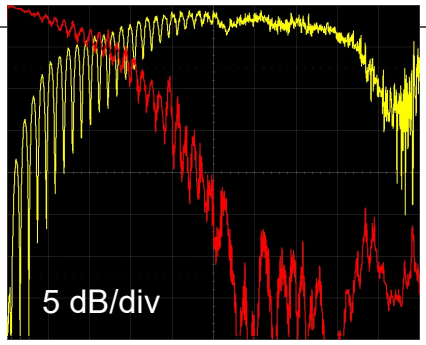
- What are the port assignments:
  - 1 → 2 or 1 → 3? (look for the insertion loss!)

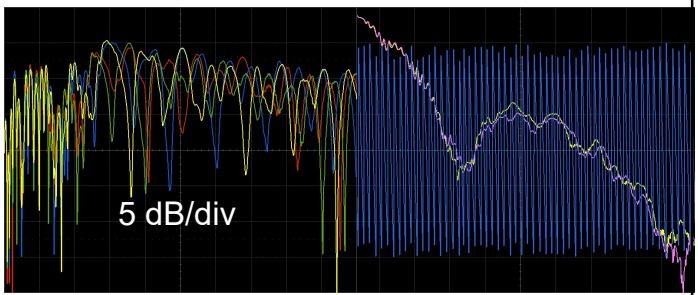




Are the measurements reasonable?

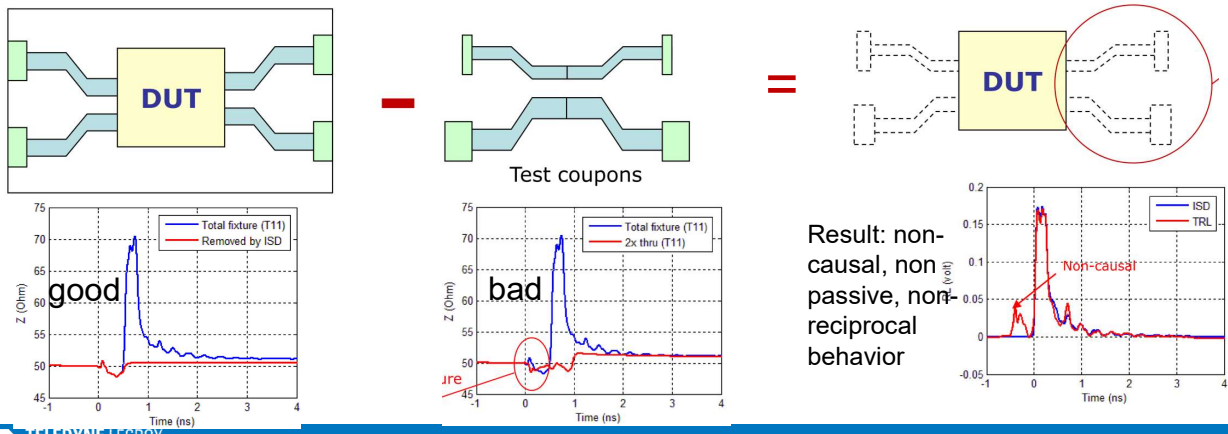
- Are the SE terms reasonable?
  - Is S11 larger negative dB and S21 0 dB at low freq?
  - Peaks in S11, > -13 dB, related to dips in S21?
  - Are S11, S22, S33, S44 similar to each other, passive
  - Are S21 and S43 similar to each other?, passive
  - Phase of S21 starts at 0 deg, increases negative direction





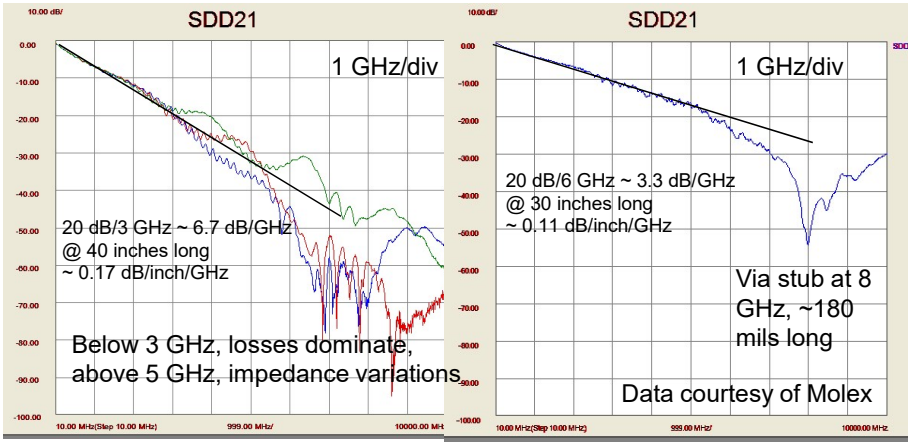
If you de-embedded…

- Is the TDR of fixture model the same as the TDR of the fixture attached to the DUT?
- Adapted from Ching-Chao Huang, www.ataitec.com



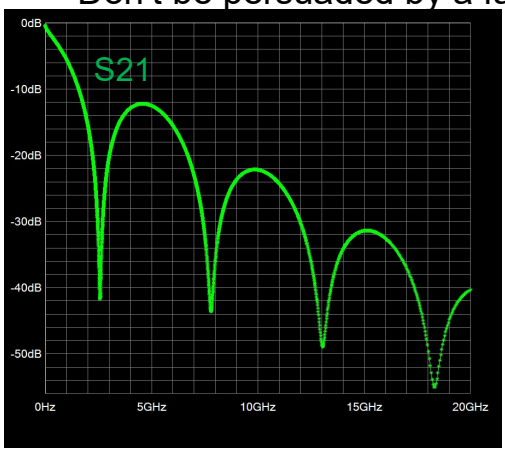
Interconnect Figures of Merit

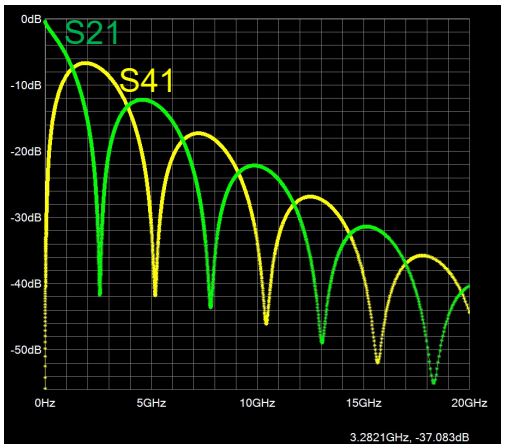
- Frequency domain:
  - Magnitude of S21, SDD21 ~ 0.1- 0.2 dB/inch/GHz



An Innocent Suspect: MS

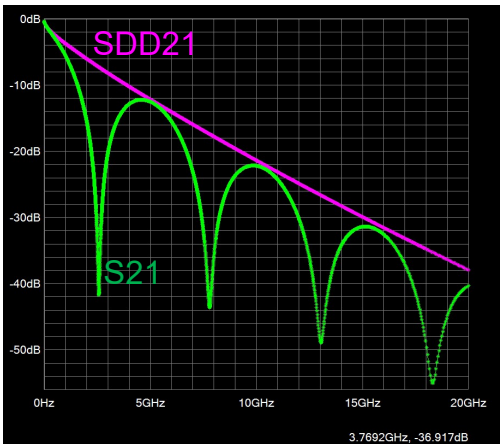
- What is the expected insertion loss for microstrip?
- A stub, mode conversion? How to confirm?
- Don't be persuaded by a false positive





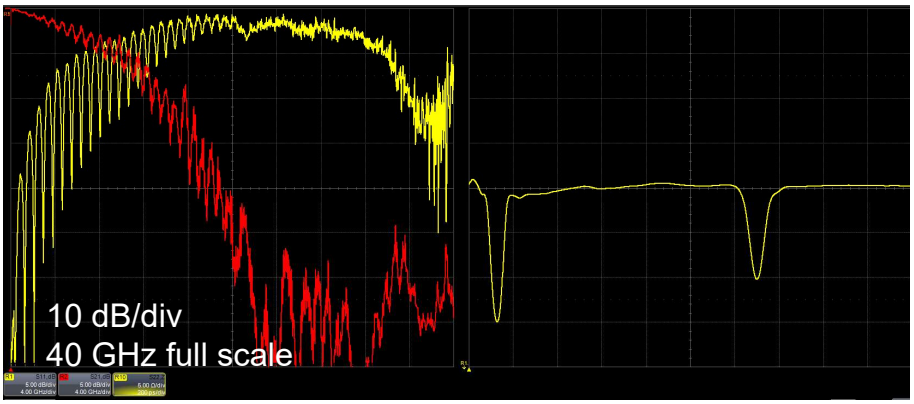
MS must make terrible differential pairs

- Of course not! Don't confuse differential behavior with SE behavior when there is tight coupling



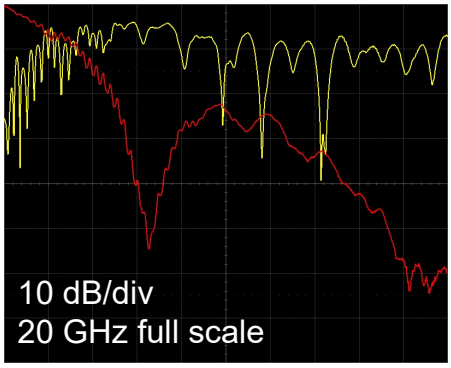
The usual suspects

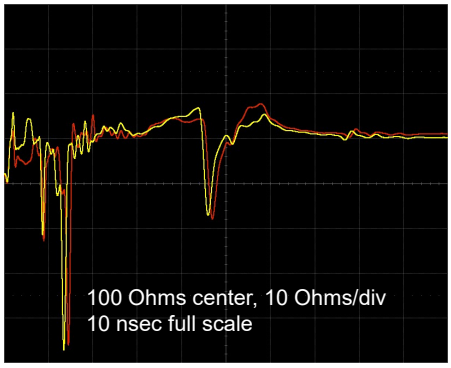
- Reflections
  - Large dips in S21 and corresponding peaks in S11
  - Increasing S11 peaks with freq (bad launch)
  - S11 in time domain shows location of discontinuities



The usual suspects

- Stubs:
  - large dips in SDD21
  - Confirm with peaks in SDD11
  - Confirm with SDD11 in time domain for location (which via has the stub?)

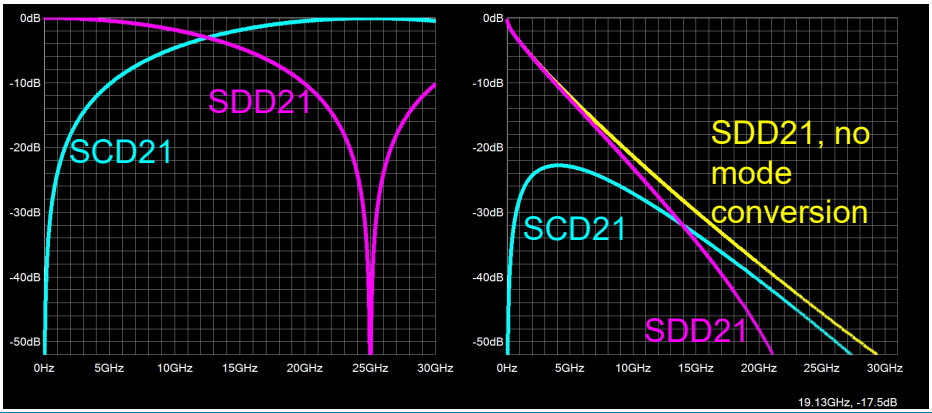




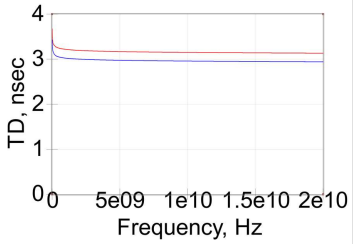
The usual suspects

- Mode conversion:
  - Dips in SDD21, confirmation of peaks in SCD21
  - Much less obvious with losses (SCC21 is attenuated!)
  - Mode conversion can impact SDD21 at ½ dip freq

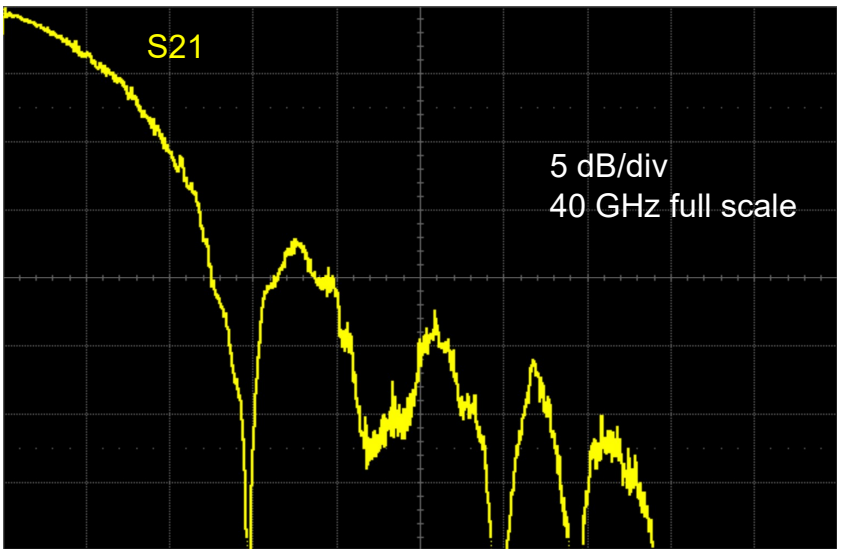
$$f_{dip} = \frac{1}{2 \times TD_{skew}} = \frac{1}{2 \times 20 \text{ psec}} = 25\ GHz$$



Most effective confirmation test: plot the time delay of each SE line



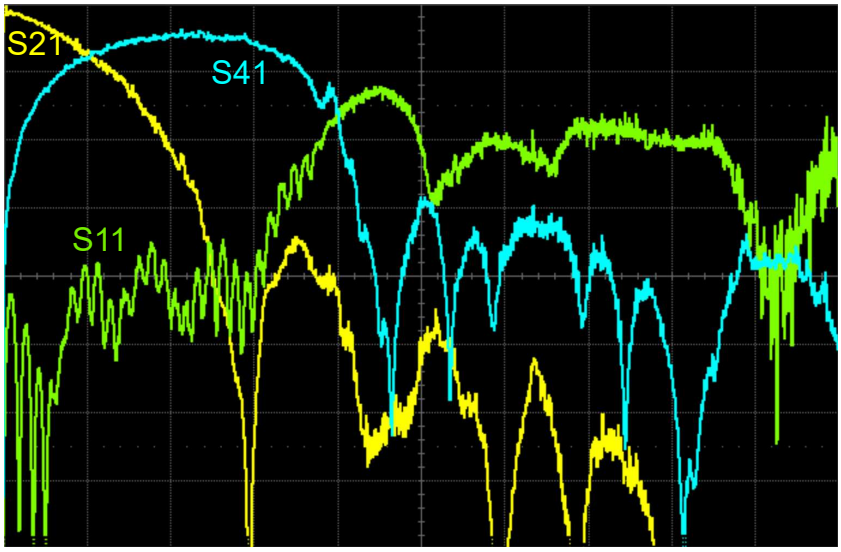
Final Exam: What is going on in this channel?



Suspects?

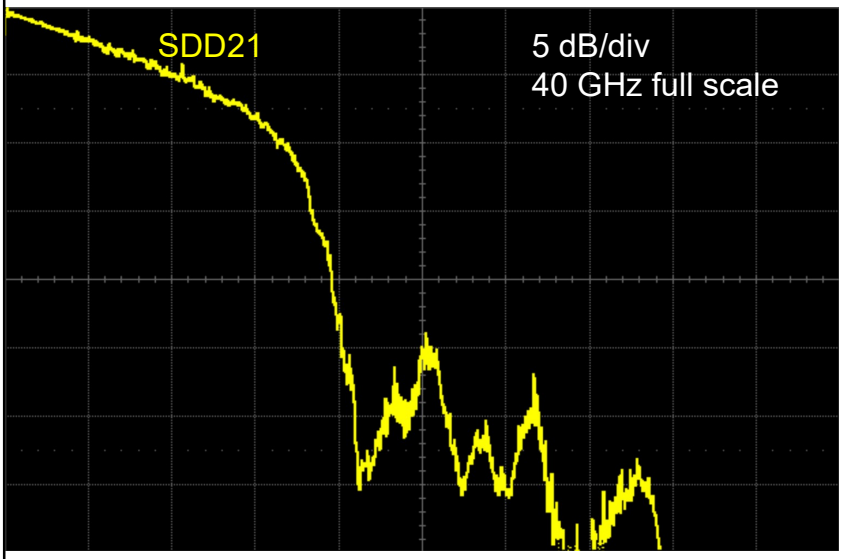
- Microstrip- confirm looking at S41
- Stub - confirm looking at S11
- Mode conversion-
  - (it's single ended!!)

Analysis



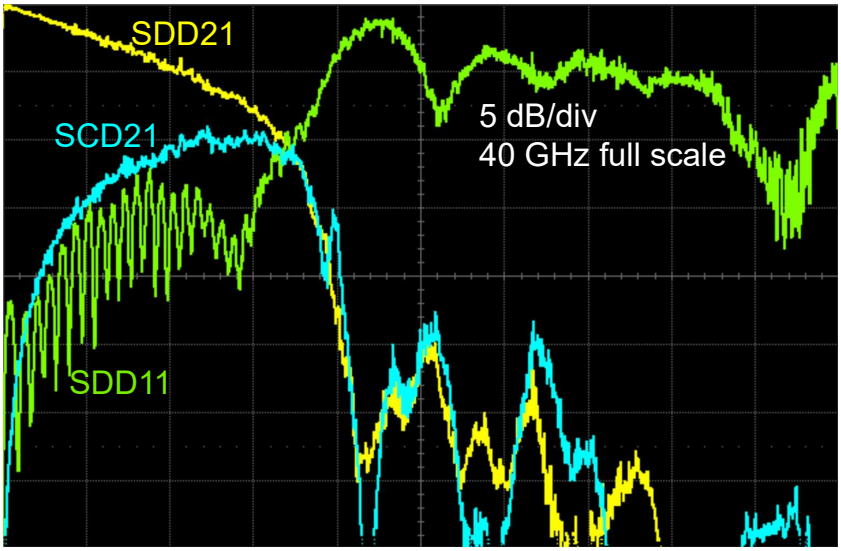
- What's the answer?
  - MS, and far end cross talk is a possible explanation

Final exam Part 2- the differential response



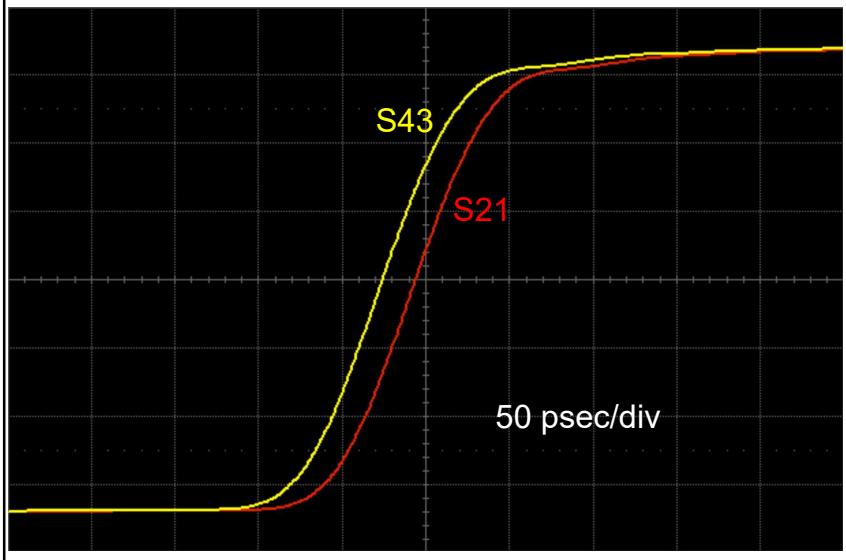
- Differential response of this channel looks better, but still falls of cliff at about 14 GHz
- Suspects:
  - Stub, resonance, look at SDD11
  - Mode conversion, look at SCD21
  - Confirm with time domain: SDD11, S21, S43

Final Exam- resolution



- SDD11 turns on at ~ 14 GHz, consistent with resonance dip
- But… SDC21 is high, suggests mode conversion as well- confirm with S21 and S43 delays

Final Exam confirmation: S21, S43 in the time domain

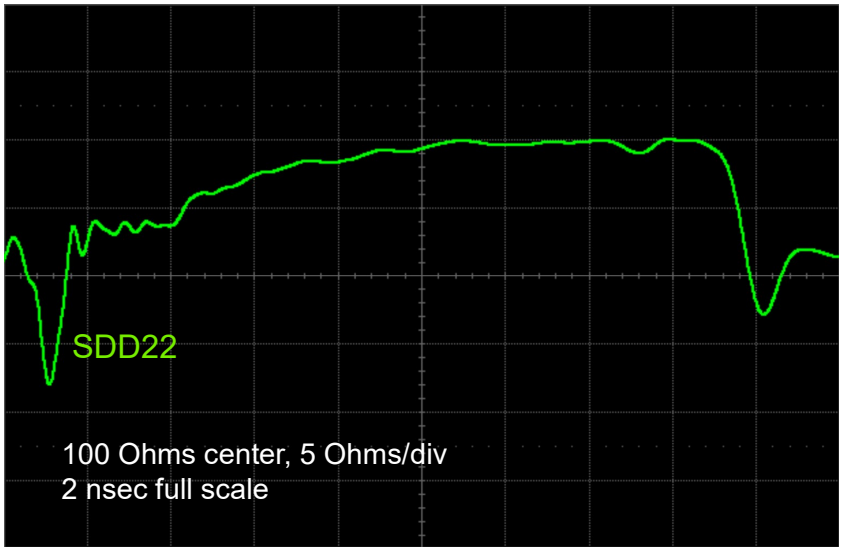


- There is a skew of about 25 psec
- Expect insertion loss dip at about:

$$f_{dip} = \frac{1}{2 \times TD_{skew}} = \frac{1}{2 \times 25\ \text{psec}} = 20\ GHz$$

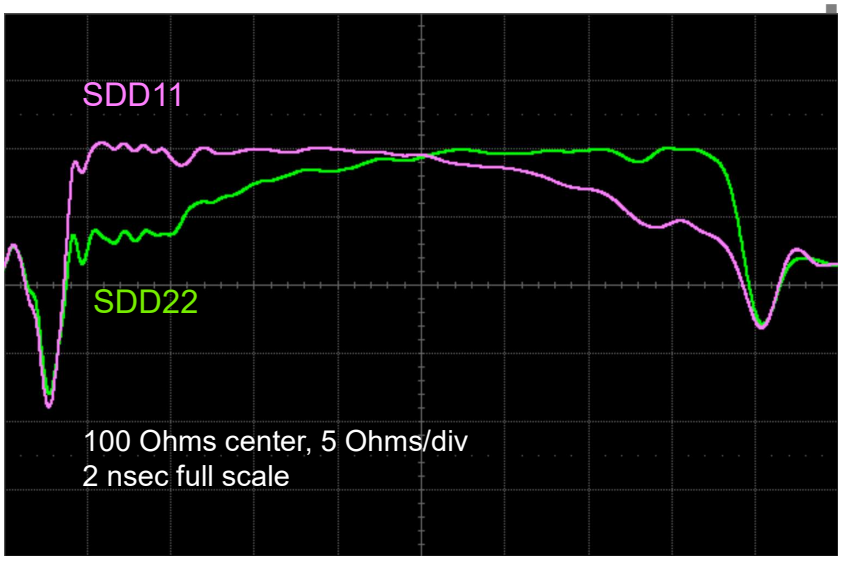
- Cliff is at 14 GHz, may have some impact from mode conversion at 10 GHz

Main impact is from reflection loss- resonance somewhere



- Confirm with SDD22
- Looks like is discontinuity at launch
  - Via or connector
- Why does impedance creep up? Is there a large series resistance?
  - Confirm with SDD11

Is there high series resistance?



Analysis

- Line is not uniform
- Little evidence of high series resistance
- Confirms discontinuity at each end of the line
  - (turns out to be low cost SMA)

The 21 point S-parameter check list for 4-ports

1. Open in notepad++: what is the freq start, freq step, max freq
2. What is the reference port impedance
3. What is the port assignment? Is S21 and S43 an insertion loss?
4. Frequency domain: is S11 large negative dB and S21 0 dB at low freq?
5. Frequency domain: estimate the magnitude of S21- is it close to 0.1 dB/in/GHz?
6. Is the phase of S21 decreasing with frequency?
7. Is the peak in S11 correlated with the dip in S21?
8. How much coupling is there in S31, S41? Is this expected?
9. How much asymmetry is there in the magnitude and phase of S21 and S43?
10. In the time domain, look at S11, S22, S33, S44- are the magnitudes expected? End to end, line to line symmetry?
11. In the time domain, is NEXT from end to end symmetric? S31 and S42
12. Where does coupling occur: In time domain, S31 and S11, and S42 and S22
13. Measure the TDT of S21 and S43. Is the TD what is expected? How much time delay skew is there?
14. In the time domain, how does SDD21, SDD11, compared with S21 and S11? Is this consistent with the coupling?
15. In the time domain, how symmetric are SDD11 and SDD22 and SCC11 and SCC22?
16. How much SCD11 and SCD21 is there?
17. Where is the source of the SCD11, viewed in the time domain, compared with SDD11?
18. The three amigos: Passivity: S11, S22, S21,
19. The three amigos: Reciprocity: S21 = S12
20. The three amigos: Causality: TDT: S21, S43, and S11, S21 in polar plot- clockwise rotation
21. Compare the TDR of the fixture file you are de-embedding with the actual fixture attached to the DUT

Summary

- Make Rule #9 your best friend
- Before you start a measurement, consider the limitations of the measurement instrument
- When de-bugging a channel, use all available information
- Never look at one frequency value of one S-parameter and expect to know anything about the channel
- Look at each S-parameter term, as SE and differential, in the frequency domain and the time domain: read the S-parameters like a book
- Use every opportunity to move up the learning curve, with a solid foundation along the way.

The Signal Integrity Academy: www.SignalIntegrityAcademy.com

- A web portal with > 80 hours of recorded signal integrity training videos

All the analysis in this presentation used SI Studio and measured S-parameter channels