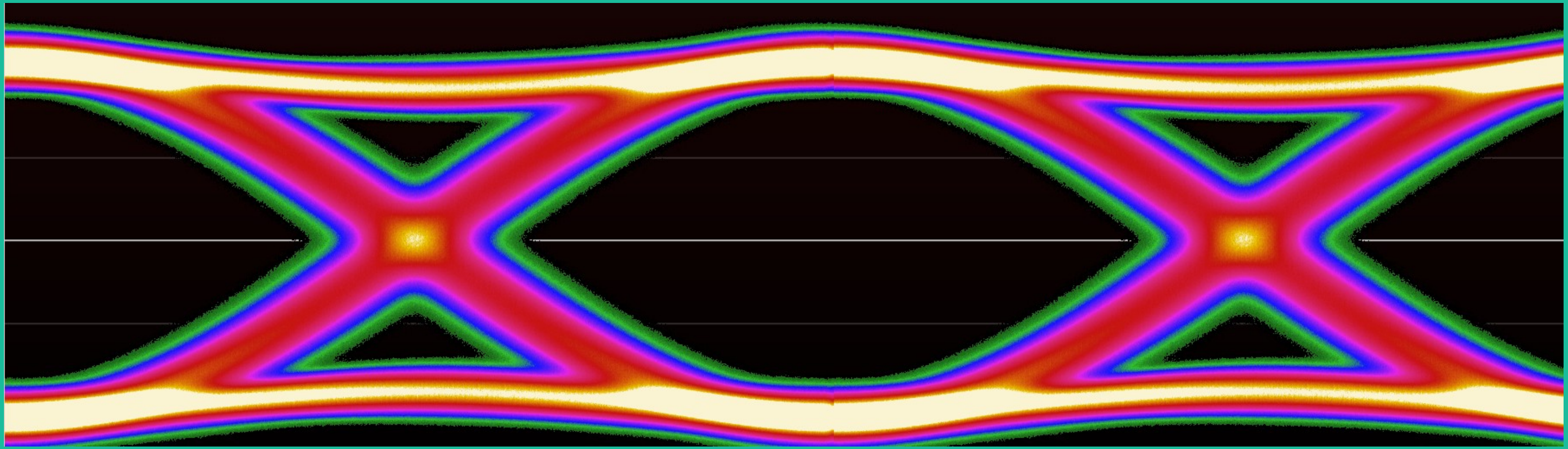


Oscilloscope Probing

Andrew D. Zonenberg, Ph. D

Introduction

Today’s class

- **Lecture followed by hands-on lab**
- **Stop me at any time with questions**
- **Bathroom / emergency procedures**
- **Slides are on my GitHub (CC BY-SA 4.0)**
  - https://github.com/azonenberg/electronics-training/tree/master/oscilloscope-probing

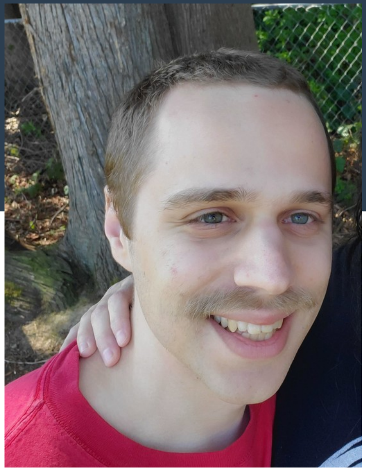
Learning goals

- **Pros and cons of various probe designs**
- **How to select the best probe for a measurement**
- **How to get the most out of each probe**
- **Understand non-idealities of real world probes**

Lecture outline

- **Introduction**
- **What is a probe?**
- **Types of probes**
  - R-C divider probes
  - Resistive probes
  - Active voltage probes
  - Active differential probes
  - Power rail probes
  - Nearfield loop probes
  - Current probes
  - High voltage probes

About Me

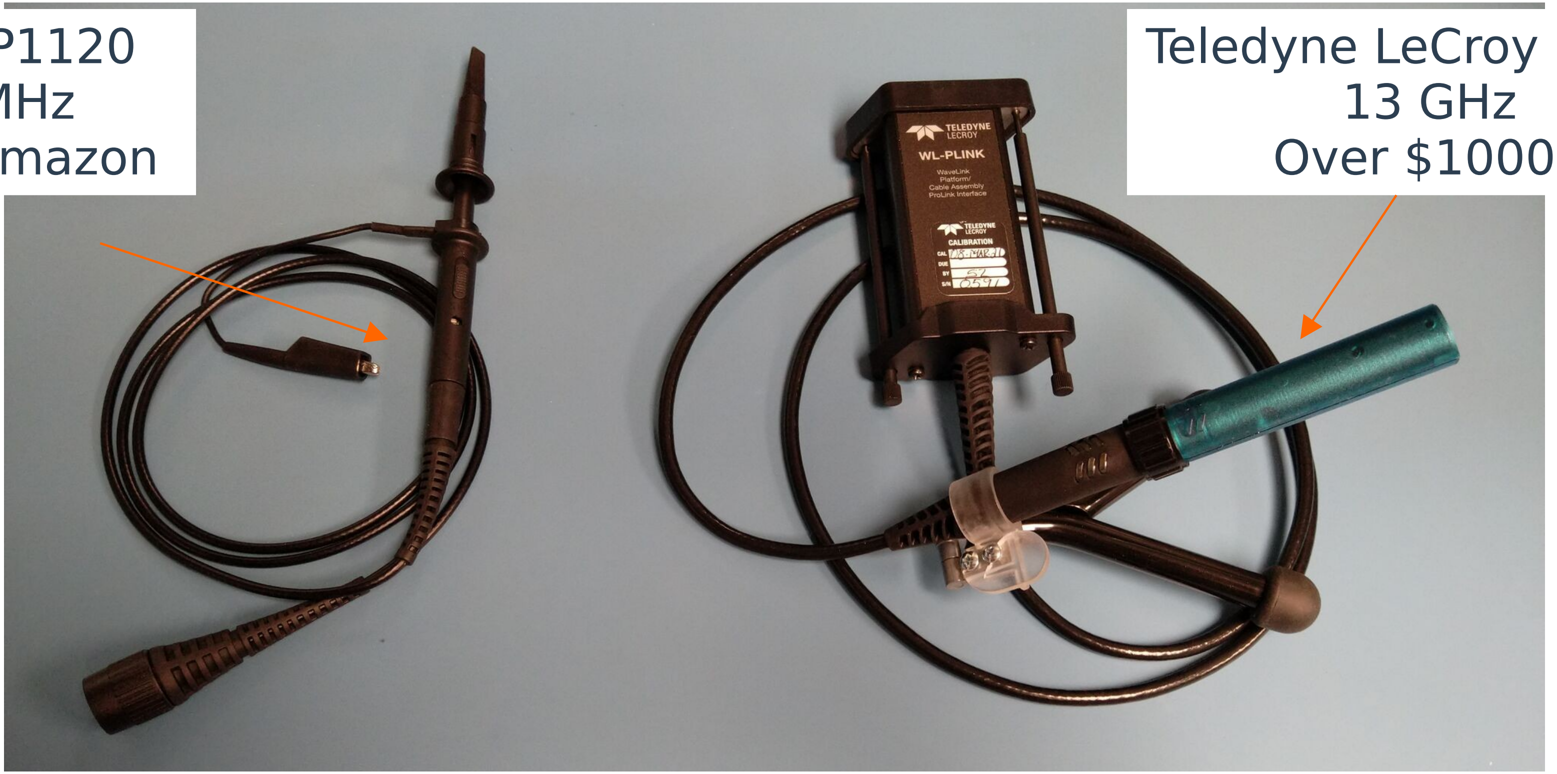


- Ph.D Computer Science (RPI 2015)
- Embedded systems security by day
- High speed digital and test equipment by night
- Author and lead developer of glscopeclient

Why Use One Probe Over Another?

Matrix IP1120
200 MHz
$10 on Amazon

Teledyne LeCroy D1330
13 GHz
Over $10000



What is a Probe?

- Both electrical and mechanical components
- Takes signal from board and puts into instrument

The ideal probe

- **No influence on DUT behavior**
- **No noise**
- **No loss**
- **Low cost**
- **Unlimited frequency / voltage range**
- **Doesn’t exist!**
  - All real probes are compromises

Attributes of a probe

- Bandwidth
- Attenuation
- Noise
- Flatness
- Loading
- Voltage range
- Linearity
- Cost
- Durability
- Ergonomics

Example Hardware

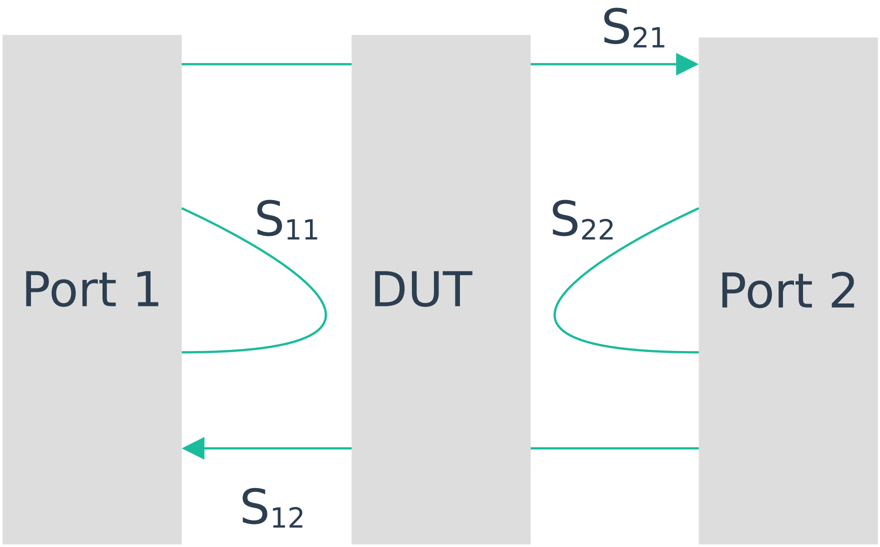
- **I’m primarily a Teledyne LeCroy shop**
  - Most probes we’ll discuss or use are made by LeCroy (or Pico)
- **This does *not* imply they’re the best probes ever**
  - I’m just picking examples from what I have handy

Crash course in S-parameters

- **We have a circuit with N ports**
  - Typical probes are 2-port networks
- **RF energy is applied to one port**
- **Some signal comes out each port**
  - Outputs / reflections have amplitude and phase shift
- **Model this as a NxN "scattering matrix"**

Crash course in S-parameters

- **Notation: S_{xy} is path to X from Y**



Crash course in S-parameters

- **Each S-matrix element is a complex number**
  - Real and imaginary
  - Or (often easier to think about) magnitude and phase angle
- **Value is frequency dependent**
- **Nonlinear effects can create harmonics**
  - S-parameters only model linear behavior
  - Keysight developed X-Parameters for modeling nonlinearities. This is beyond the scope of today’s discussion.

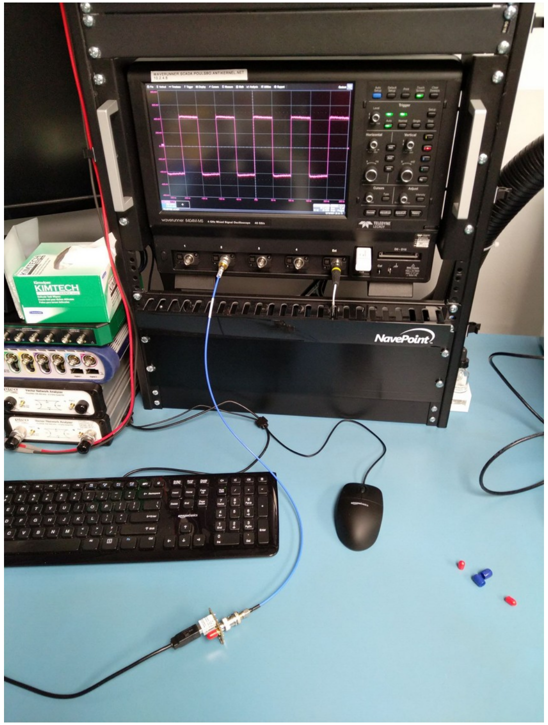
Crash course in S-parameters

- **Typically measured with a VNA**
  - Can also simulate, etc
- **Port numbering is arbitrary**
  - For examples in today's class, 1 = DUT end, 2 = scope end

Direct Coaxial Connection

When Is A Probe Not A Probe?

- **When it's just a cable!**



External 50Ω Termination

- **Lower end scopes lack native 50Ω terminations**
- **Can use in-line or T terminations at lower freqs**

In-Line Terminator vs Native 50Ω Input

Reflection off stub between terminator and scope frontend

Matched input
No reflection

Note rise time difference:
This scope is 4 GHz BW in 50Ω mode, 500 MHz in 1MΩ mode

Direct Coaxial Connection: Advantages

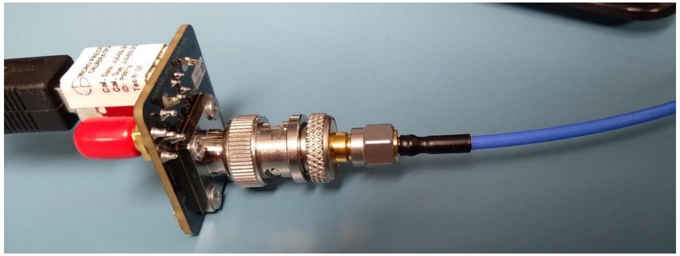
- **Lowest possible noise**
  - No external amplifiers
  - No attenuation so need less frontend gain
- **Low cost – no expensive probe needed**
- **Flattest possible response**
  - Only source of error is cable loss
  - Can de-embed this if cable is characterized

Direct Coaxial Connection: Disadvantages

- **Requires 50Ω scope input**
  - Inline termination works OK at lower freqs
  - Reflection issues at higher speeds
- **High loading on DUT**
  - Probe presents a 50Ω load
- **Limited range**
  - Most 50Ω scope inputs are ±5V max range
  - Many higher BW inputs are even less (±2V is common)

Direct Coaxial Connection: When to Use

- **If your DUT already has coaxial test points**
- **Measuring end of unterminated 50Ω line**
  - Empty DIMM or PCIe socket
  - Card edge connector
  - Unpopulated footprint



- **Ideal reference signal to compare probe against**
  - It’s hard to get flatter response than a short cable

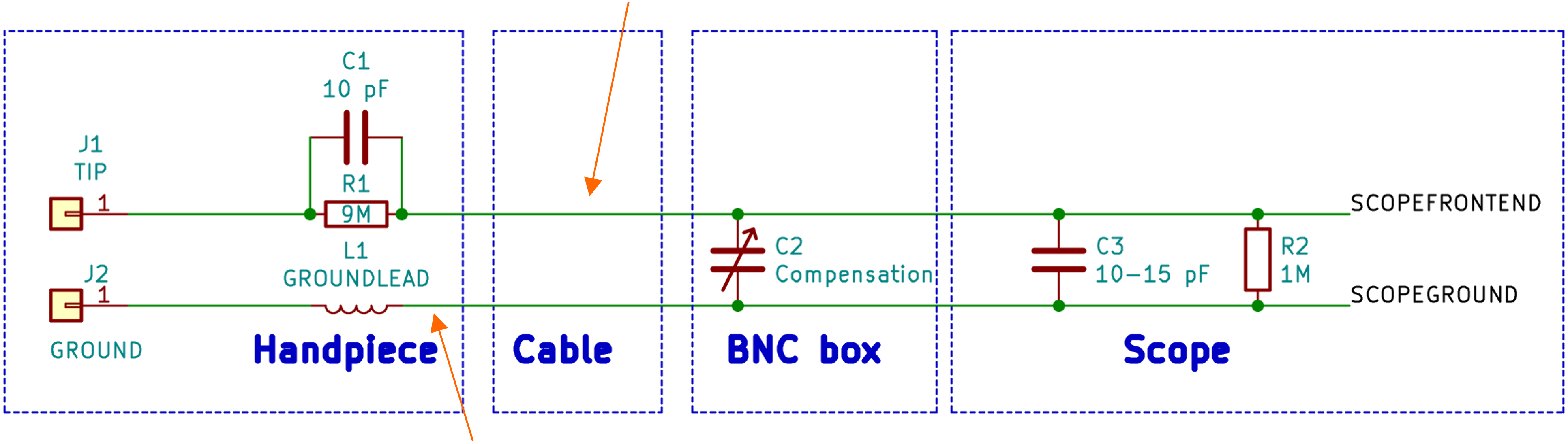
R-C Divider Probe

R-C Divider Probe

- You’ve all used this one
- Dates to the vacuum tube era!

R-C Divider Probe

Lossy cable (often thin Ni-Cr core)
to damp out reflections

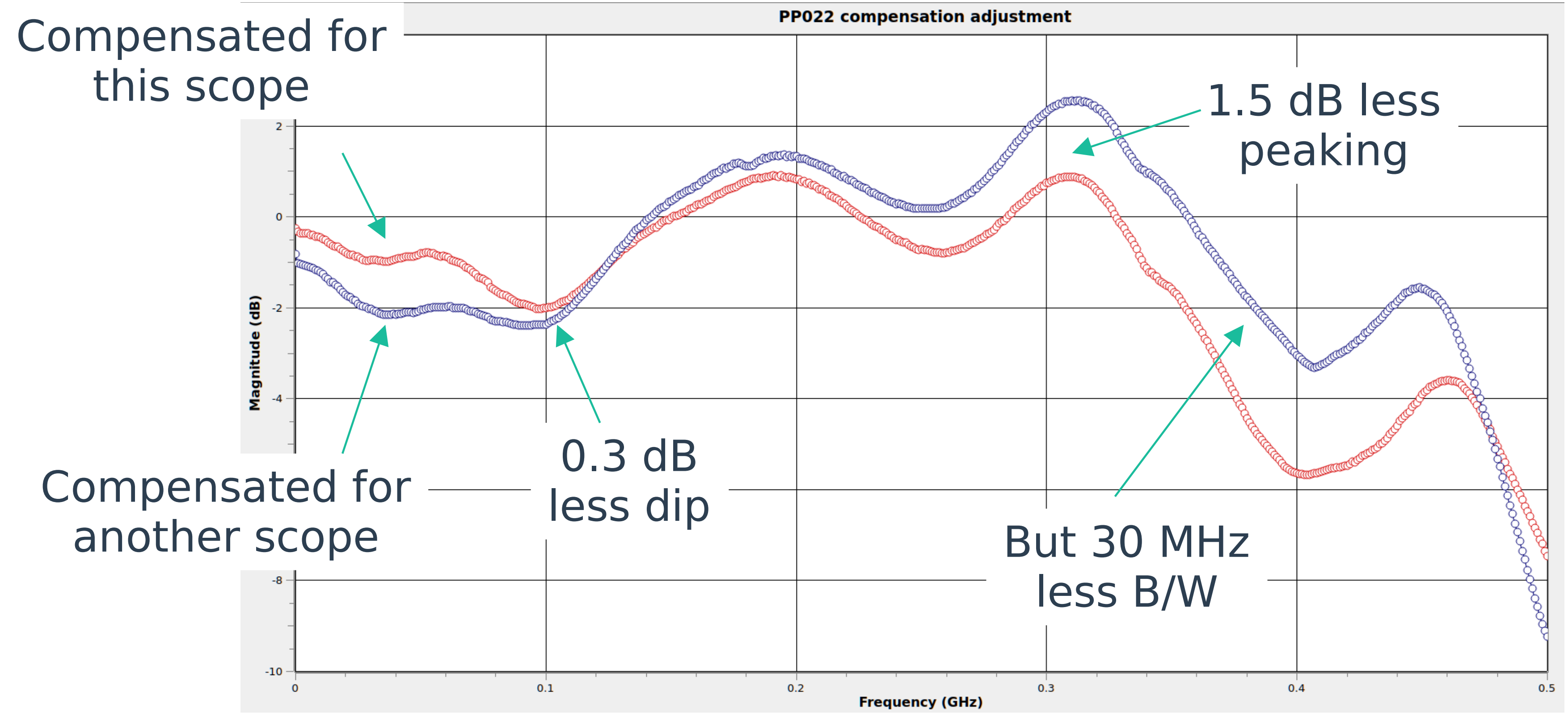


Ground wire has
nontrivial inductance

R-C Divider Probe: Compensation

- **Trimpots / caps near BNC**
  - Simple design is a single C
  - Higher end probes may have multiple trimmers for fine tuning
- **Adjust for desired frequency response**
  - Usually target is broadband flatness
  - For narrowband measurements, optimize for that region
- **Generally not portable across scope models**
  - If moving probe to another instrument, re-compensate

R-C Divider Probe: Compensation



R-C Divider Probe: Loading

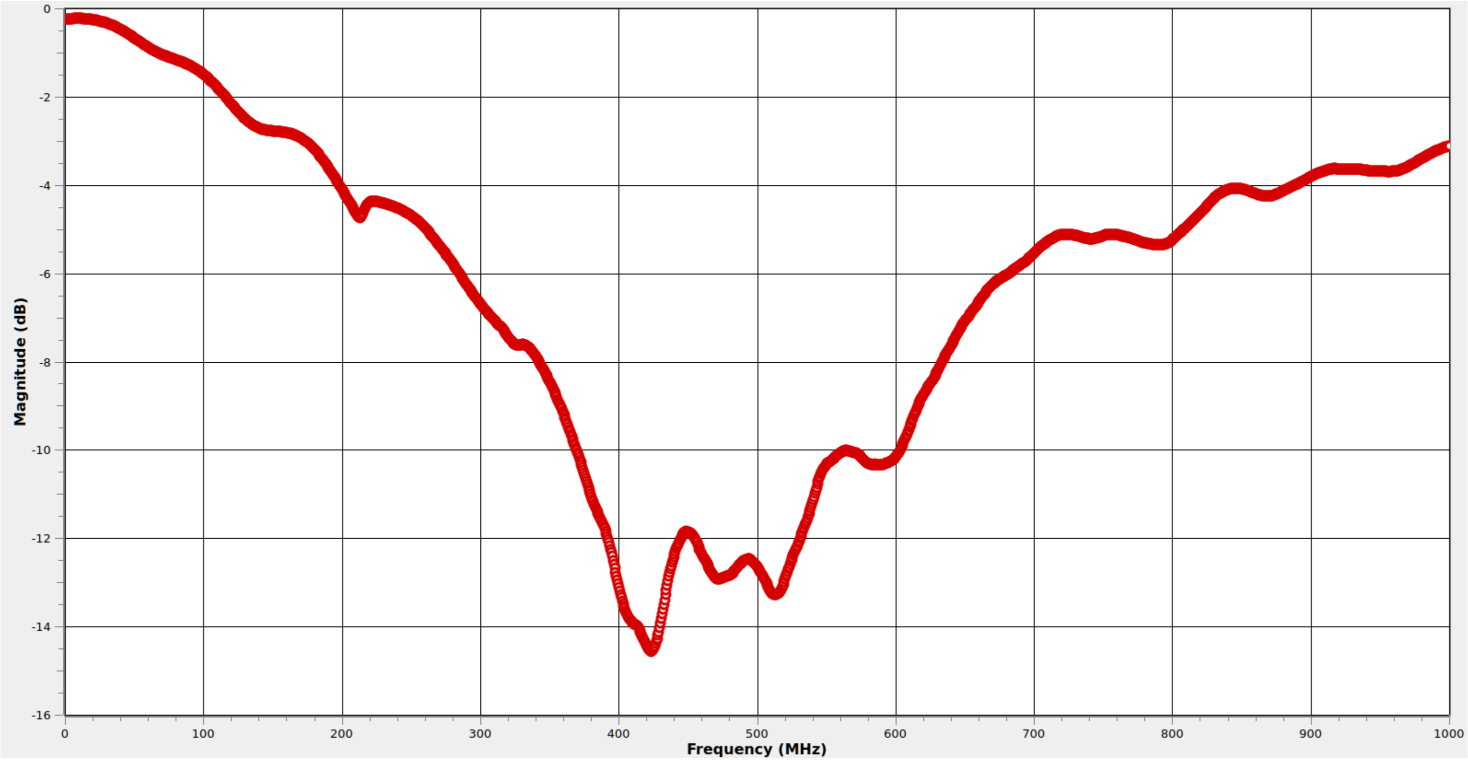
- **10MΩ input impedance is great!**
  - ...right?
- **We might have forgot something :(**

Probe Loading

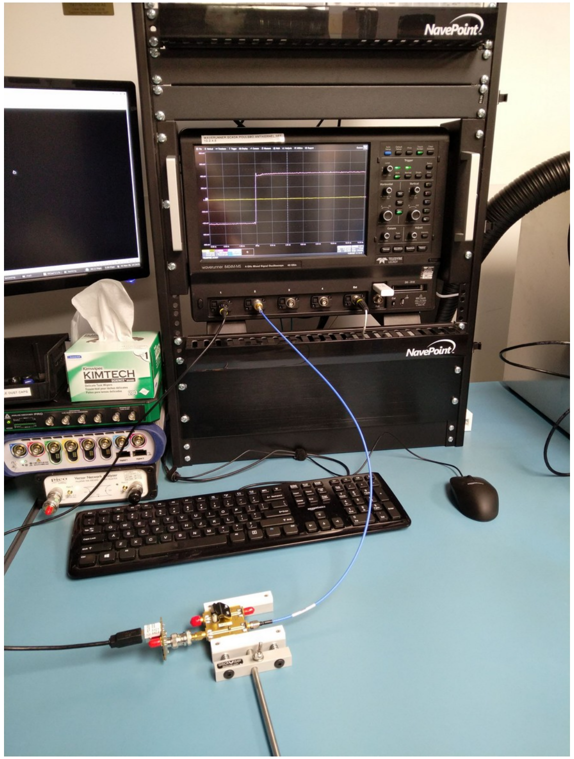
- **Placing probe on a circuit *changes its behavior***
- **This can manifest as a “heisenbug”**
  - DUT stops working when you probe it, or (worse)...
  - DUT only works when you probe it!
  - New, unrelated failure introduced by probing

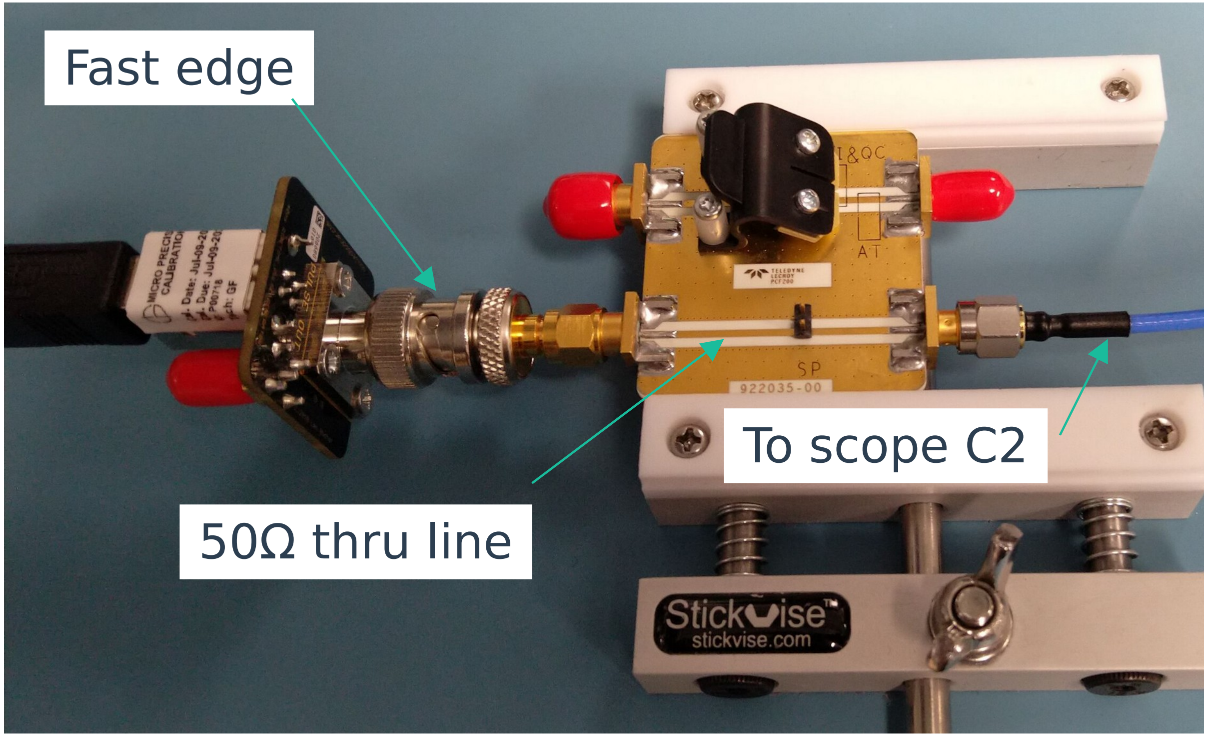
S_{11} Measurement Setup

R-C Divider Probe: S_{11} (across open)



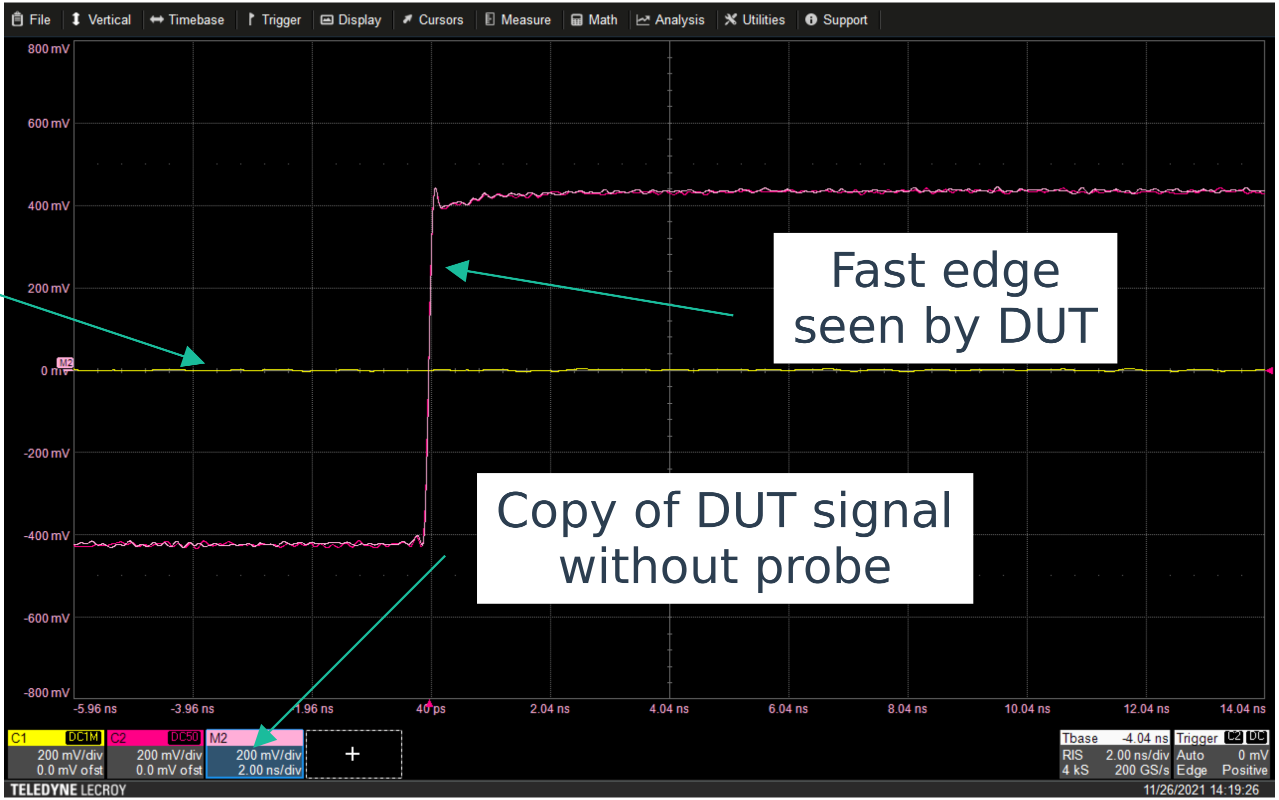
Time Domain Loading Measurement Setup





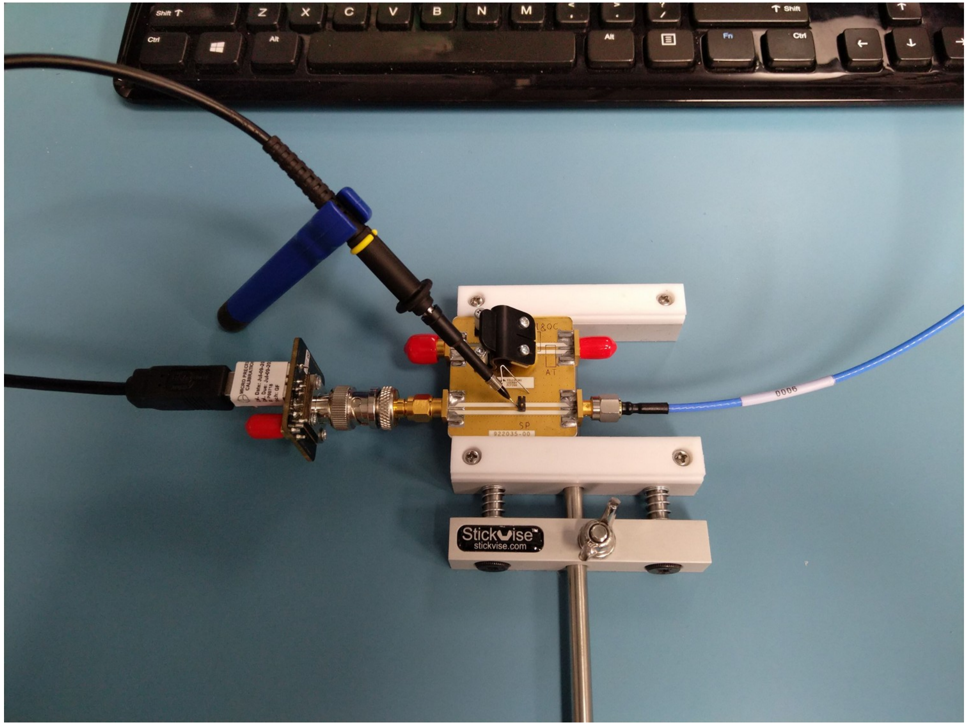
Baseline Measurement

Probe is
off the DUT

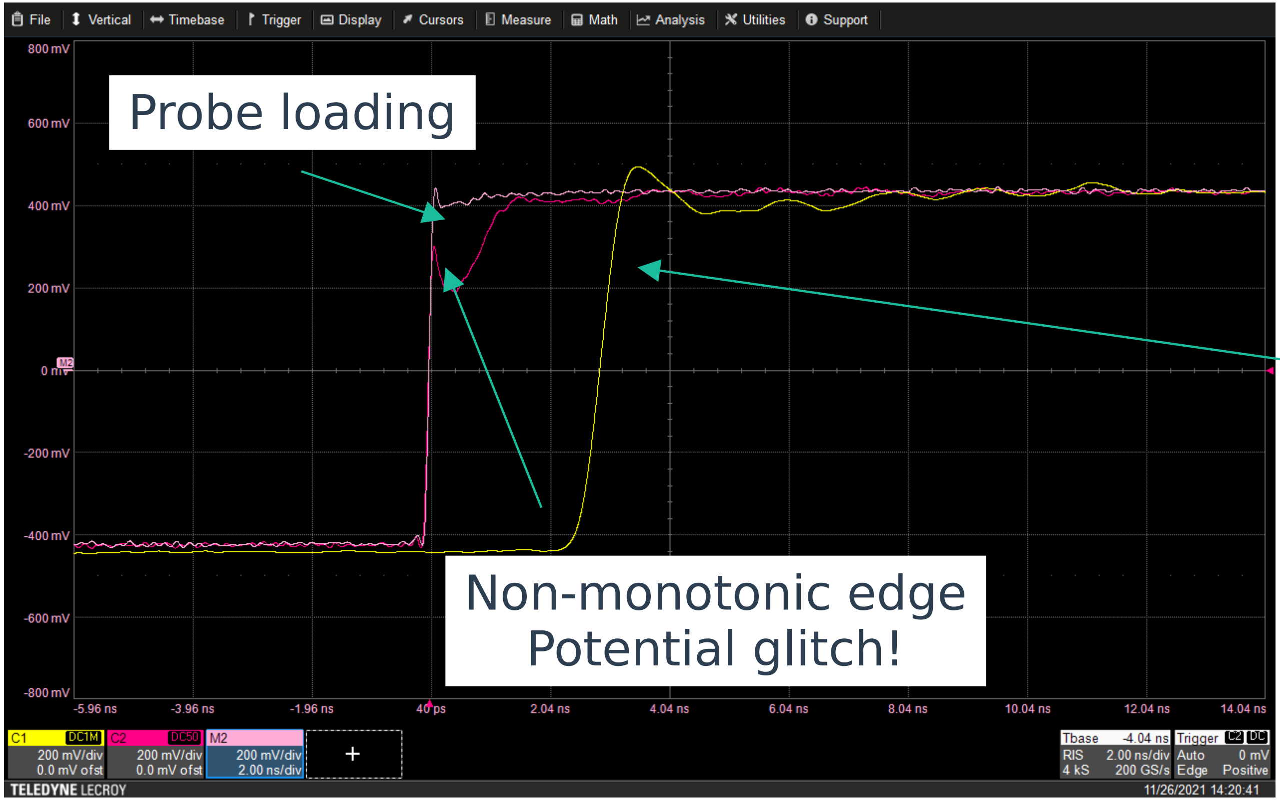


Now let's add the probe...

- **What happens to the signal on the DUT?**

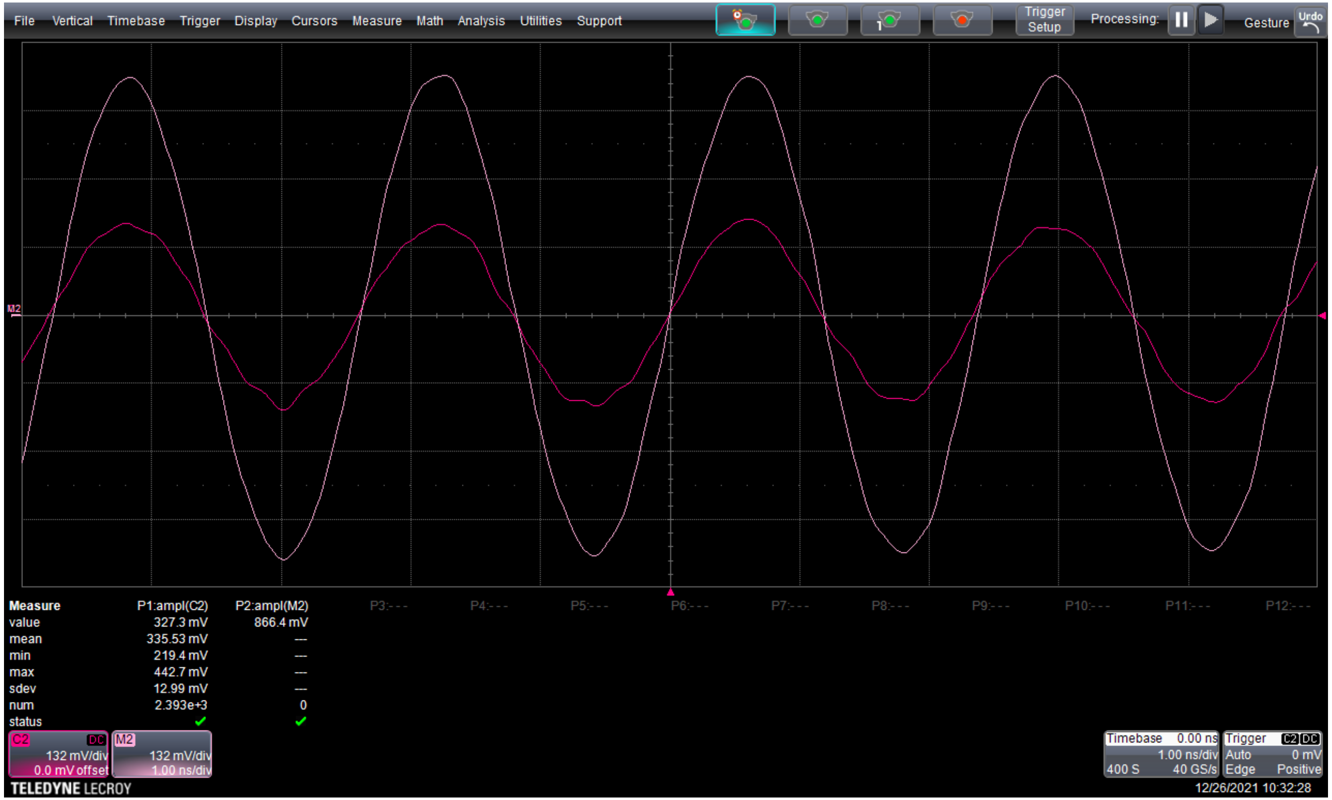


With Probe On DUT



Probe sees this

Pure-Tone Loading Example (High-Z Line)



R-C Divider Probe: Ground Inductance

- **Input is very capacitive**
  - Any extra L will cause ringing
- **Forget that alligator clip ground for anything fast**
  - How fast is “fast”? Let’s find out…
- **Generally, tradeoff of convenience vs performance**
  - Alligator wire: super convenient, huge L
  - Z-ground: trickier to use, moderate L
  - Spring: hard to use, small L

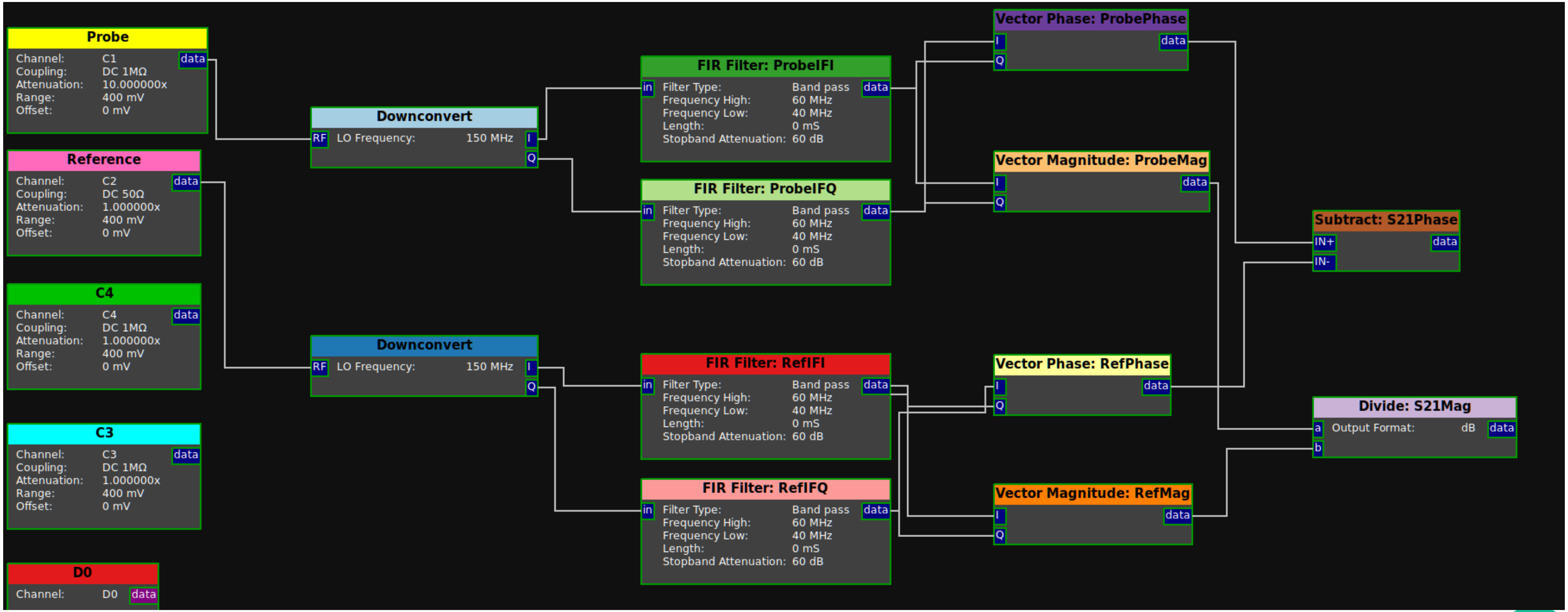
Challenges of measuring probe S_{21}

- **Measuring S_{11} of a probe is straightforward**
  - Same way you'd use a VNA to measure anything else
- **We don't care much about S_{22} or S_{12}**
  - Scope doesn't drive its end of the probe
- **But S_{21} path is tricky!**
  - Active probes – proprietary power/signal interface
  - R-C divider probes: 10MΩ Z0, not 50Ω

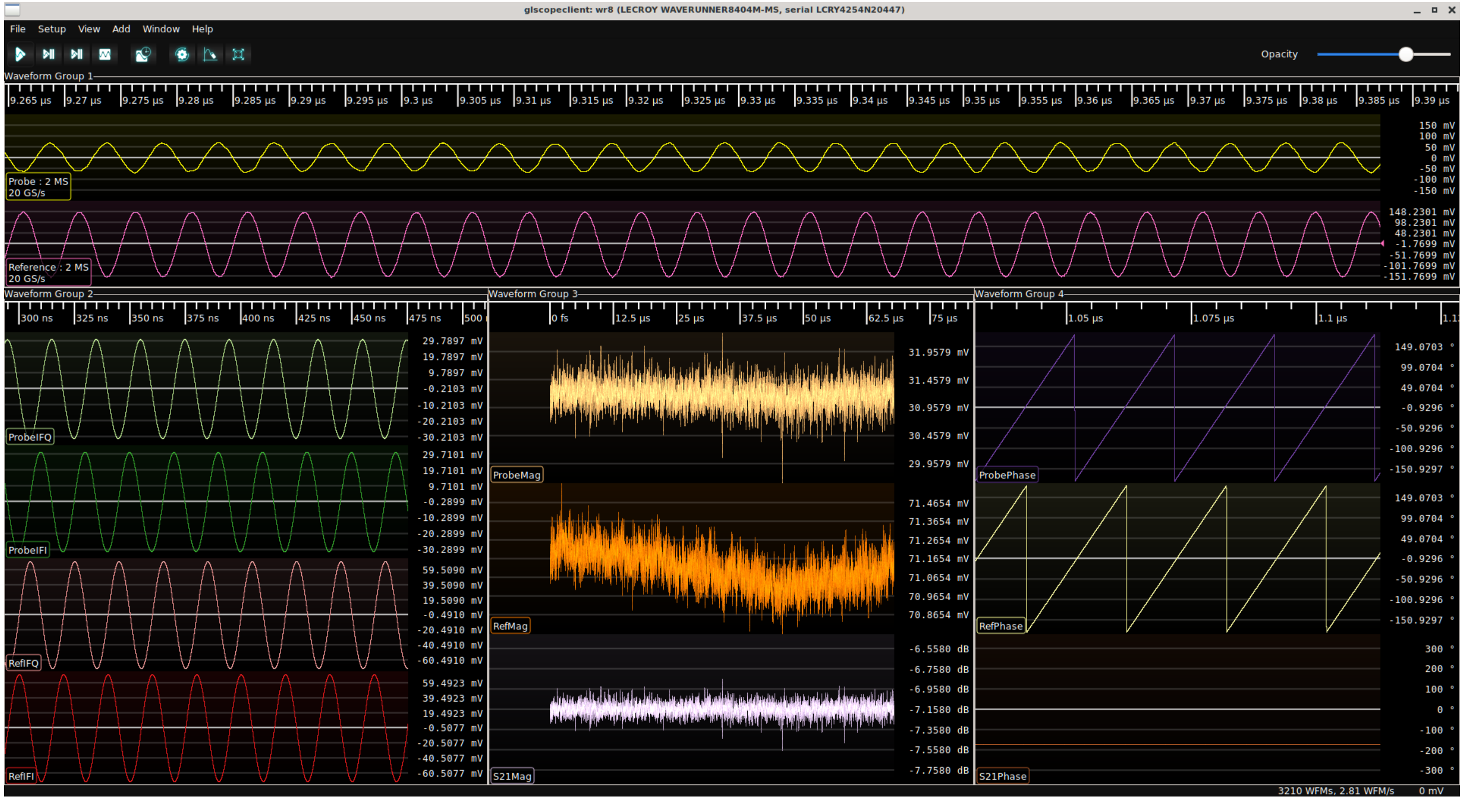
Scope based “mixed signal VNA”

- **Use *scope* as direct sampling RX for S_{21} path!**
  - Port 1: Tone applied to probe tip
  - Port 2: Digitized scope waveform
- **Split tone to provide phase-locked reference**
  - Scope CH2 = RF reference port
  - Scope CH1 = DUT port 2
- **Digital downconversion of both ports**
  - Then calculate ratiometric I/Q phase/amplitude

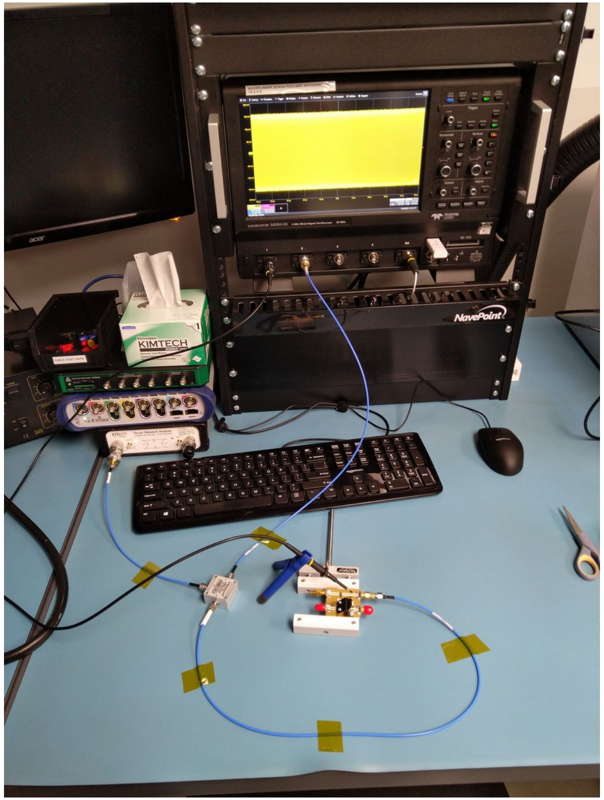
RX Filter Pipeline (example for 200 MHz Fin)

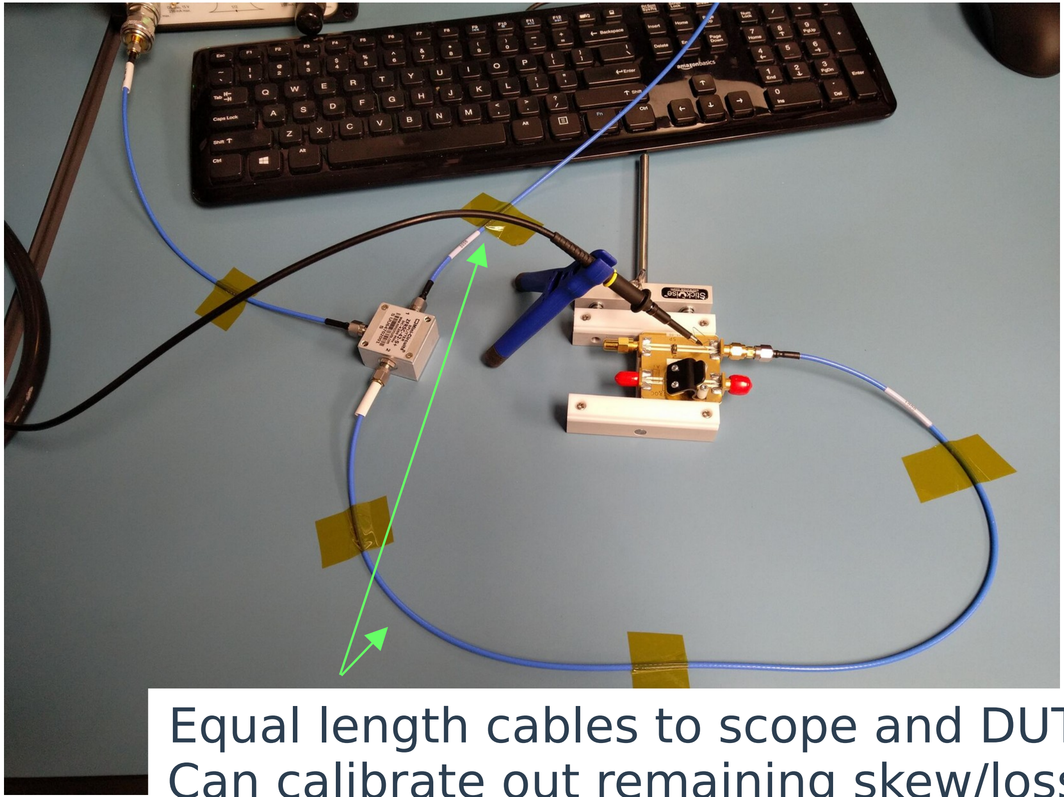


Raw / Processed Data



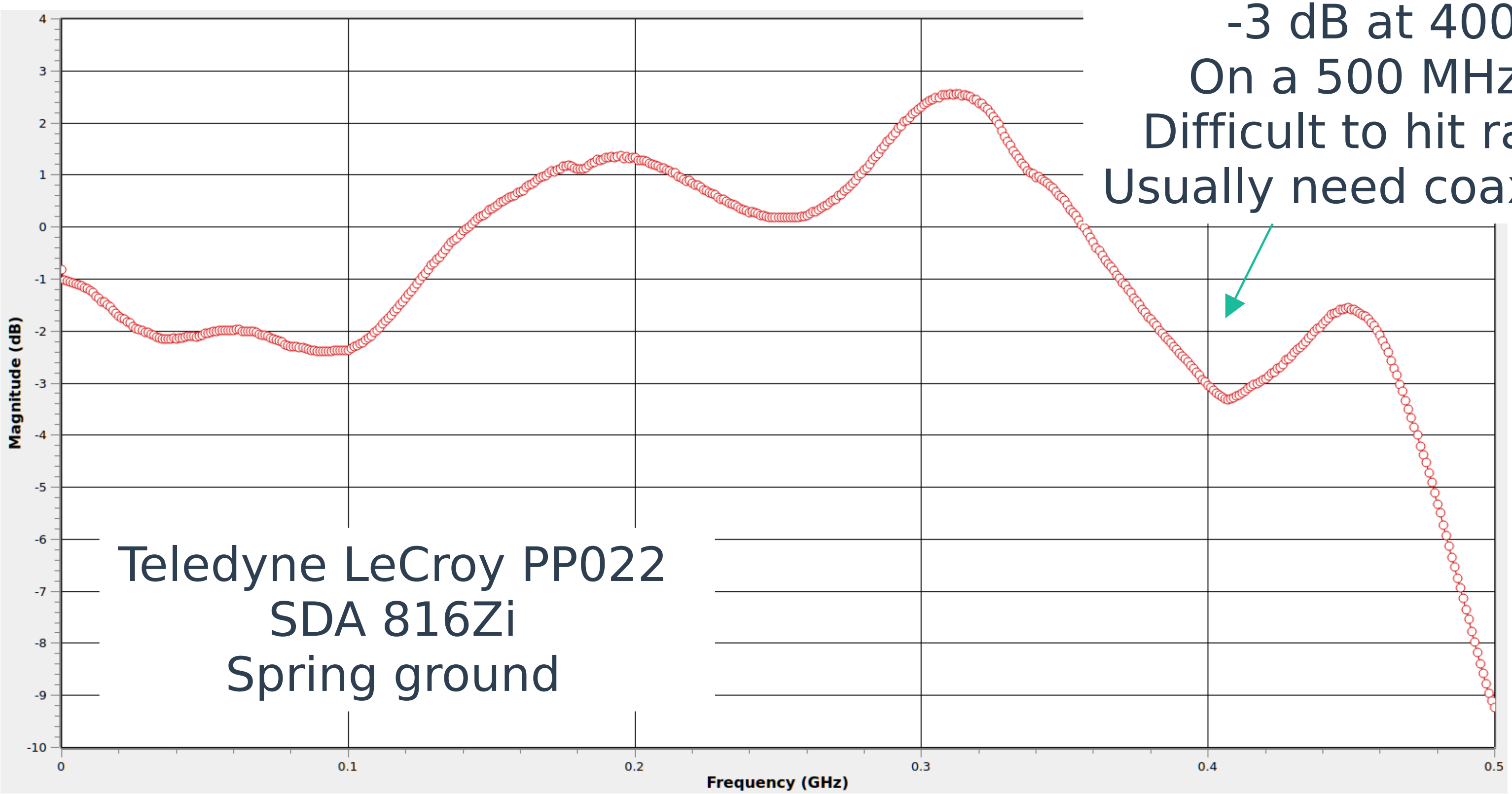
S_{21} Measurement Setup





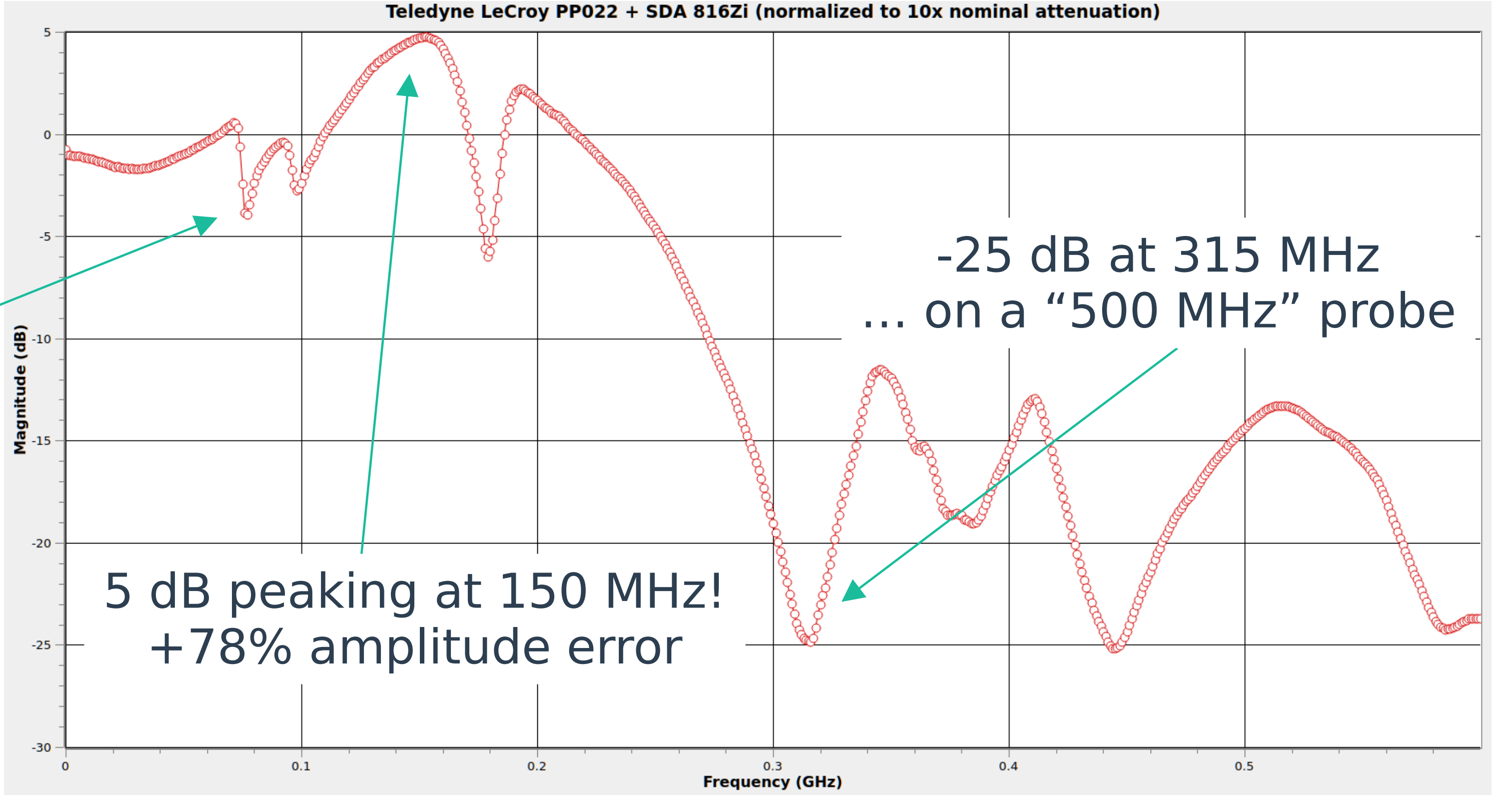
Equal length cables to scope and DUT
Can calibrate out remaining skew/loss

R-C Divider Probe: S_{21} w/ Spring Ground



-3 dB at 400 MHz
On a 500 MHz probe
Difficult to hit rated BW!
Usually need coaxial socket

R-C Divider Probe: S_{21} w/ Alligator Ground

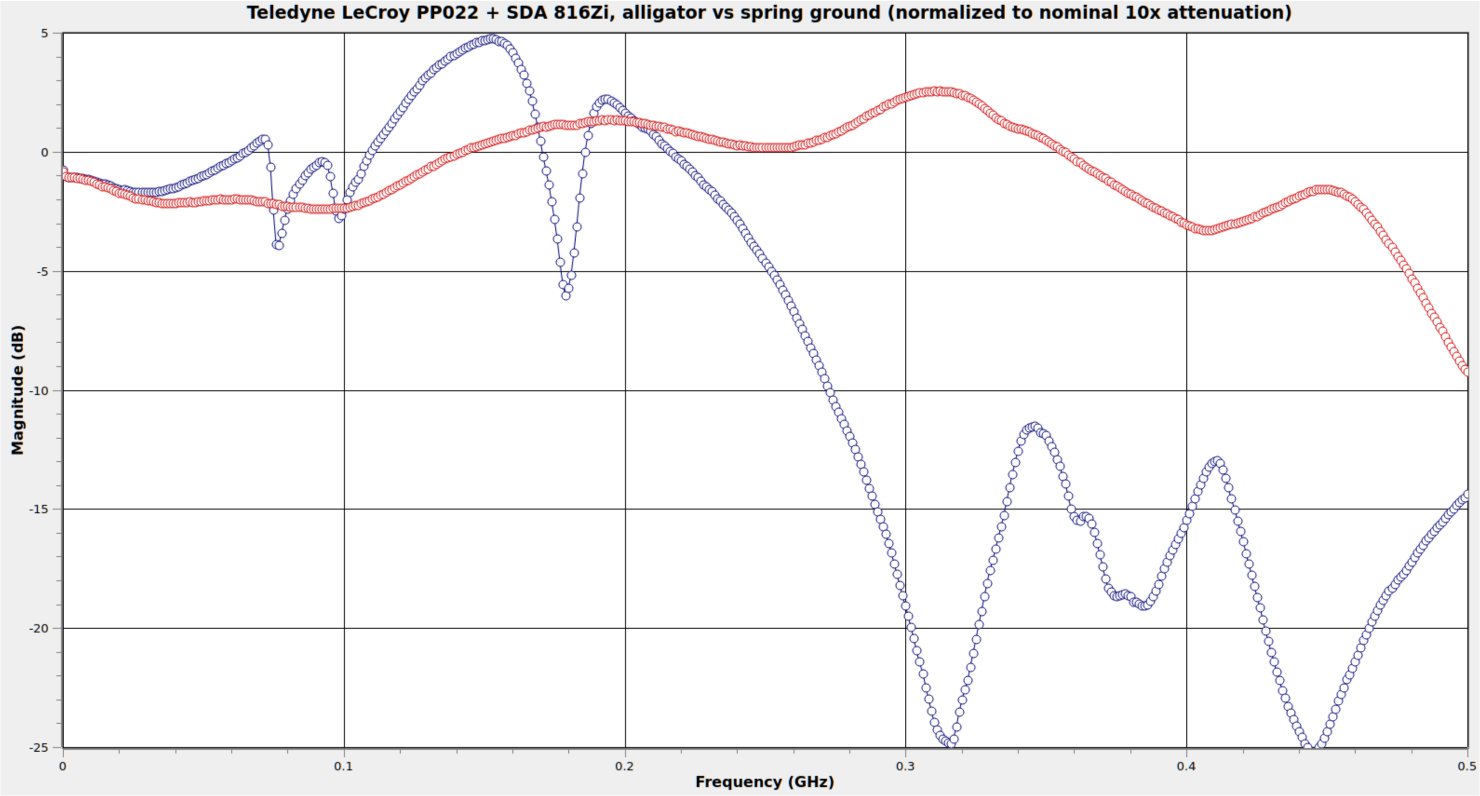


-3 dB at 76 MHz

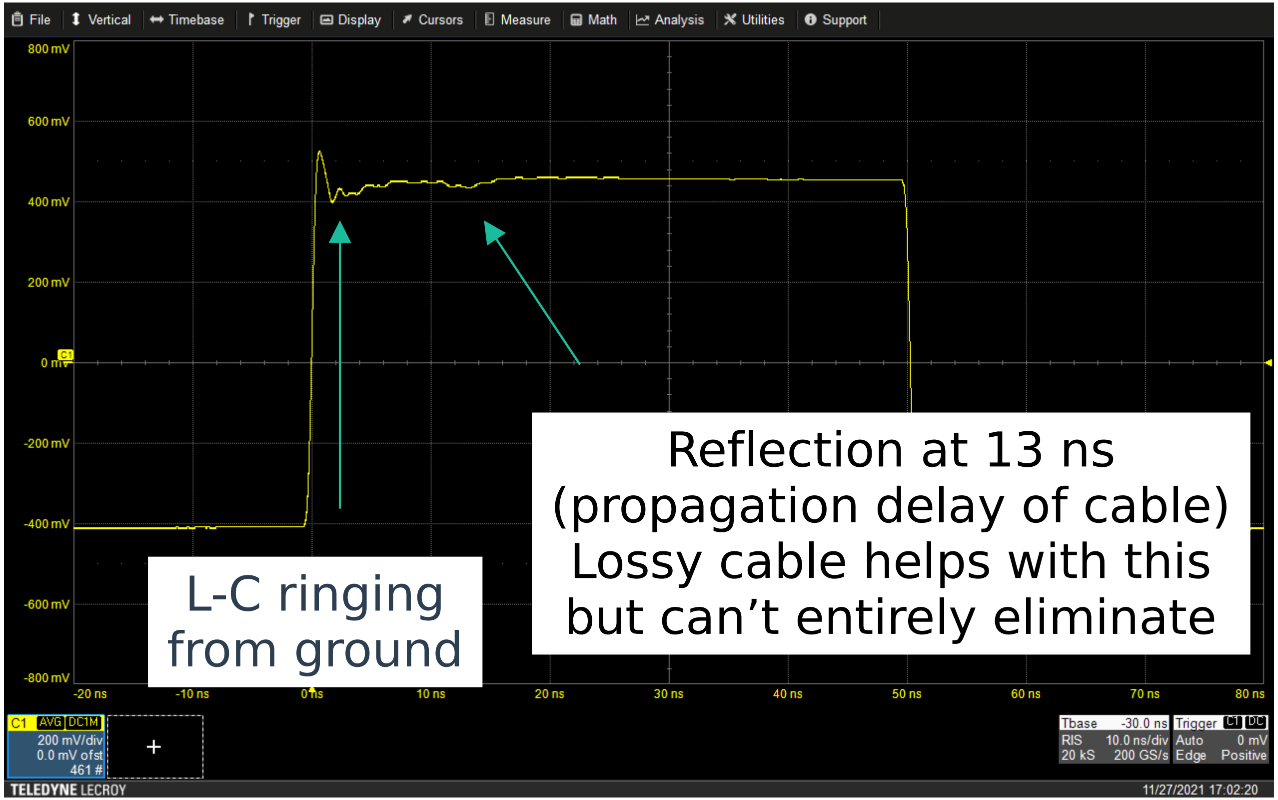
5 dB peaking at 150 MHz!
+78% amplitude error

-25 dB at 315 MHz
… on a "500 MHz" probe

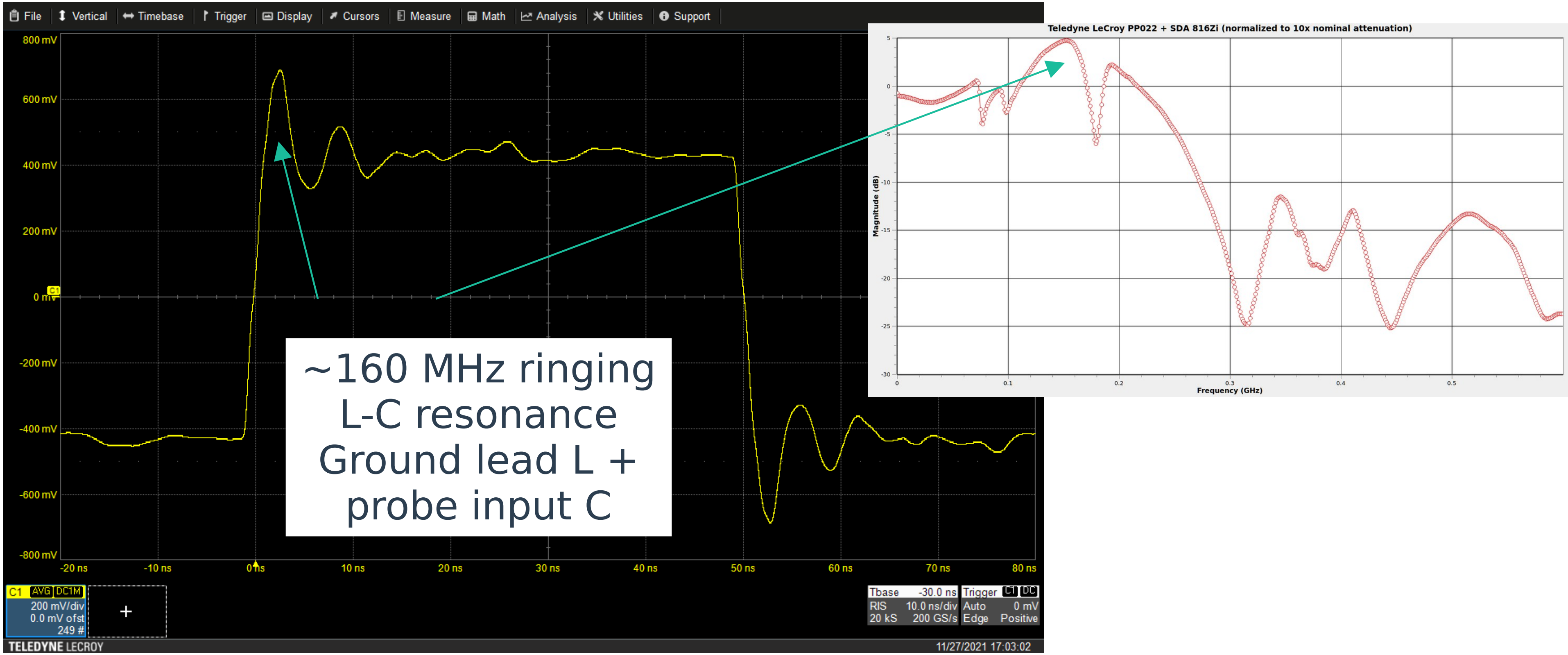
R-C Divider: Spring vs Alligator Ground



Step Response w/ Spring Ground

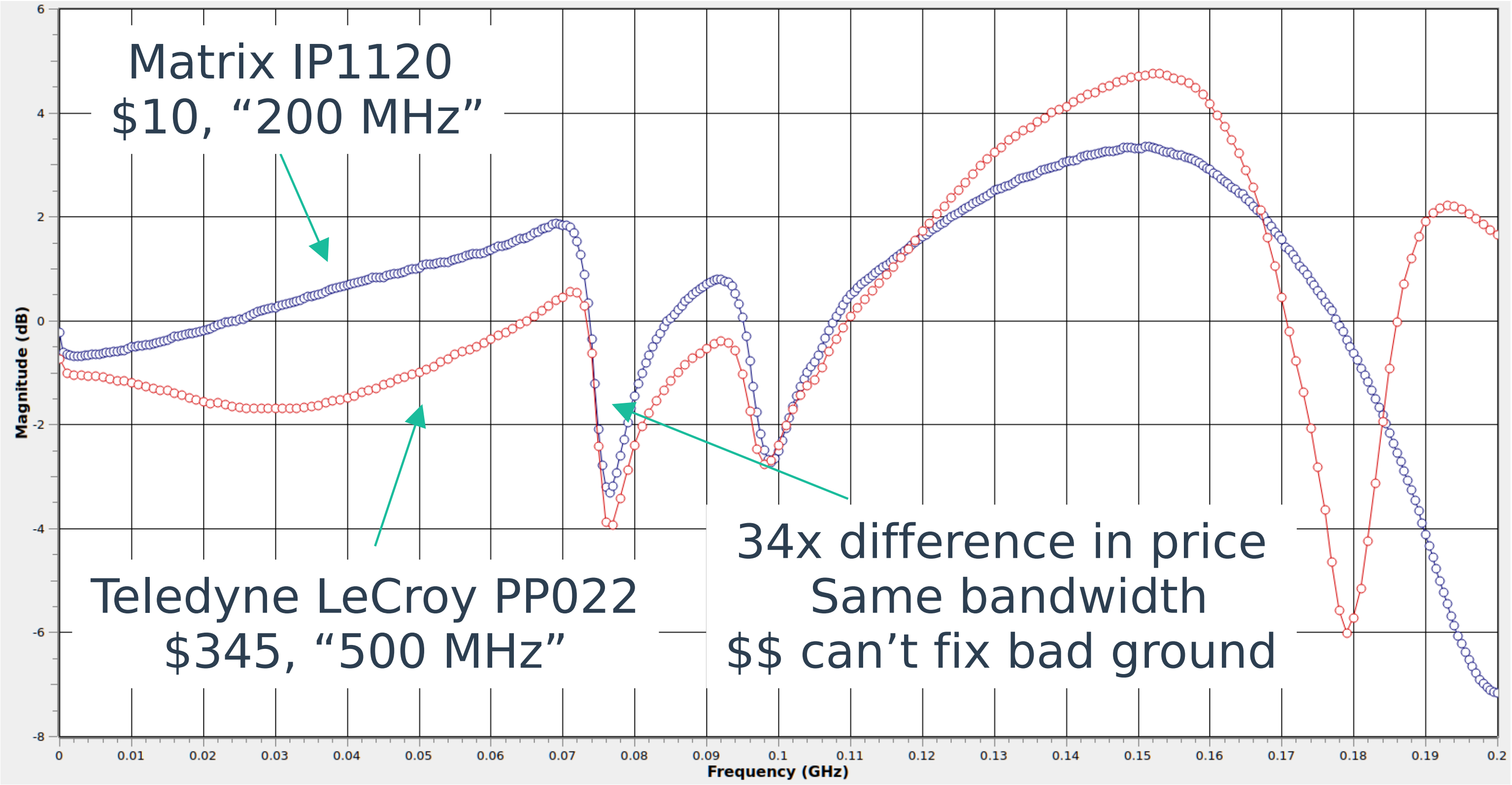


Step Response w/ Alligator Ground

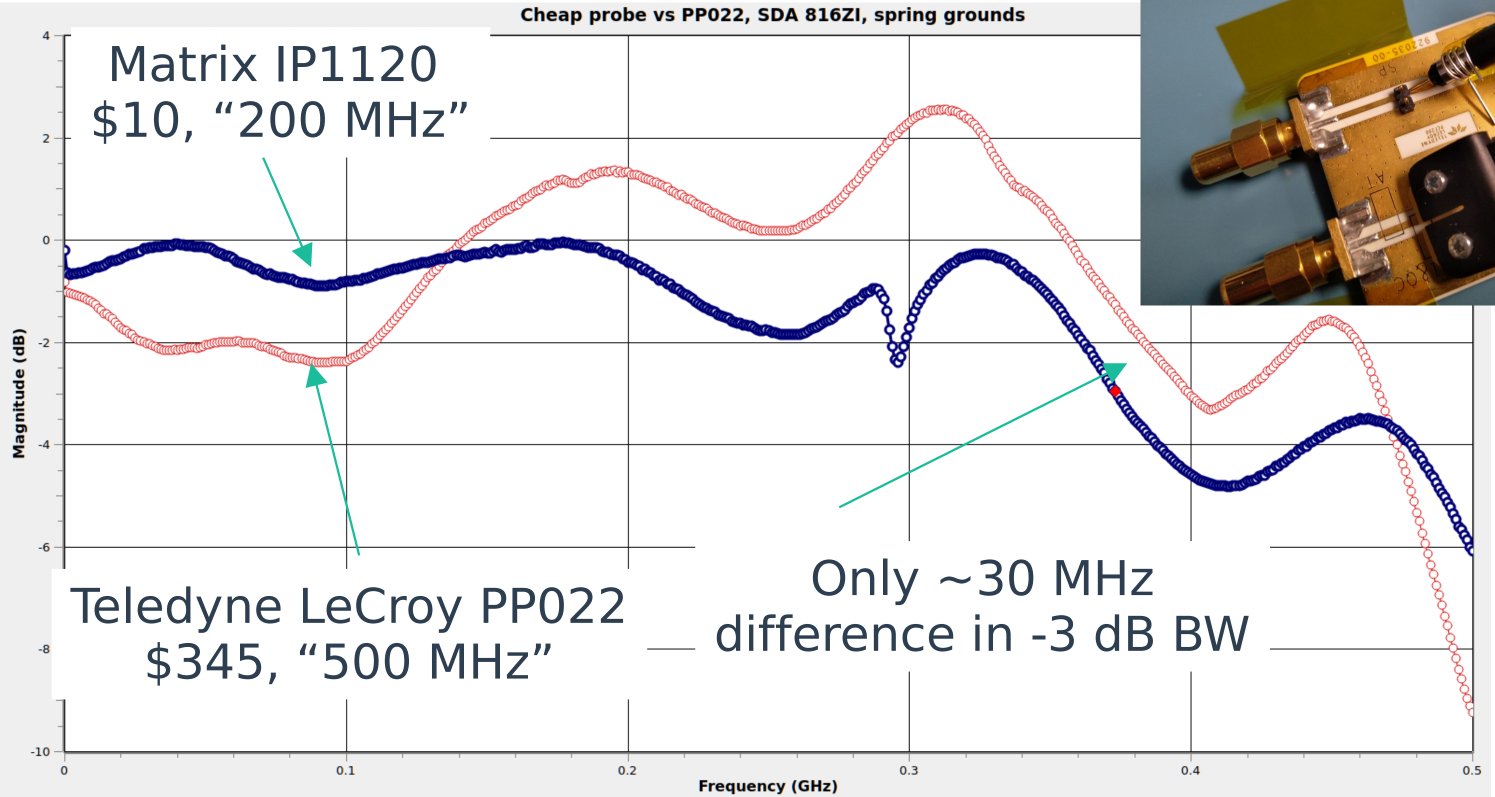


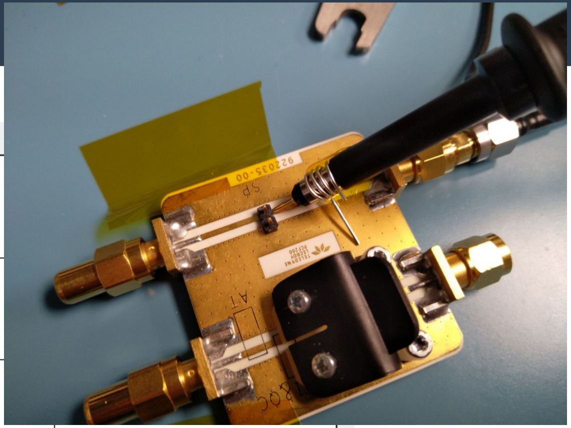
~160 MHz ringing
L-C resonance
Ground lead L +
probe input C

Cheap Vs Expensive Probe, Alligator Ground



Cheap Vs Expensive Probe, (DIY) Spring Ground





So what did that $335 buy you?

- Better ergonomics
- Better accessories
- More compensation adjustments
- Gain autodetection resistor
- No need to DIY a spring ground
- Worth it? Depends on your needs and budget

R-C Divider Probe: Strengths

- **Very low resistive loading *at DC***
- **Low cost**
  - Low 3 digits USD for a nice one
  - Cheap ones down to single digits
- **Hard to damage with overload/ESD**
- **Generic design, no vendor lock-in**

R-C Divider Probe: Weaknesses

- **High input capacitance**
  - Heavy loading on DUT
  - *Extremely* sensitive to L in ground path
  - Running in 1x mode makes this waaaay worse (~95 pF)!
- **Requires compensation adjustment**
- **High attenuation (typically 10:1)**
  - Not great for really weak signals
  - Worse SNR due to higher frontend gain

R-C Divider Probe: When to use

- **Highish voltage, low frequency analog**
  - (As used in vacuum tube systems!)
  - Most active probes don't go past 5-10V
  - Resistive probes have similar limits
- **Beginners you don't trust with $$$ gear**
- **If you have nothing better**

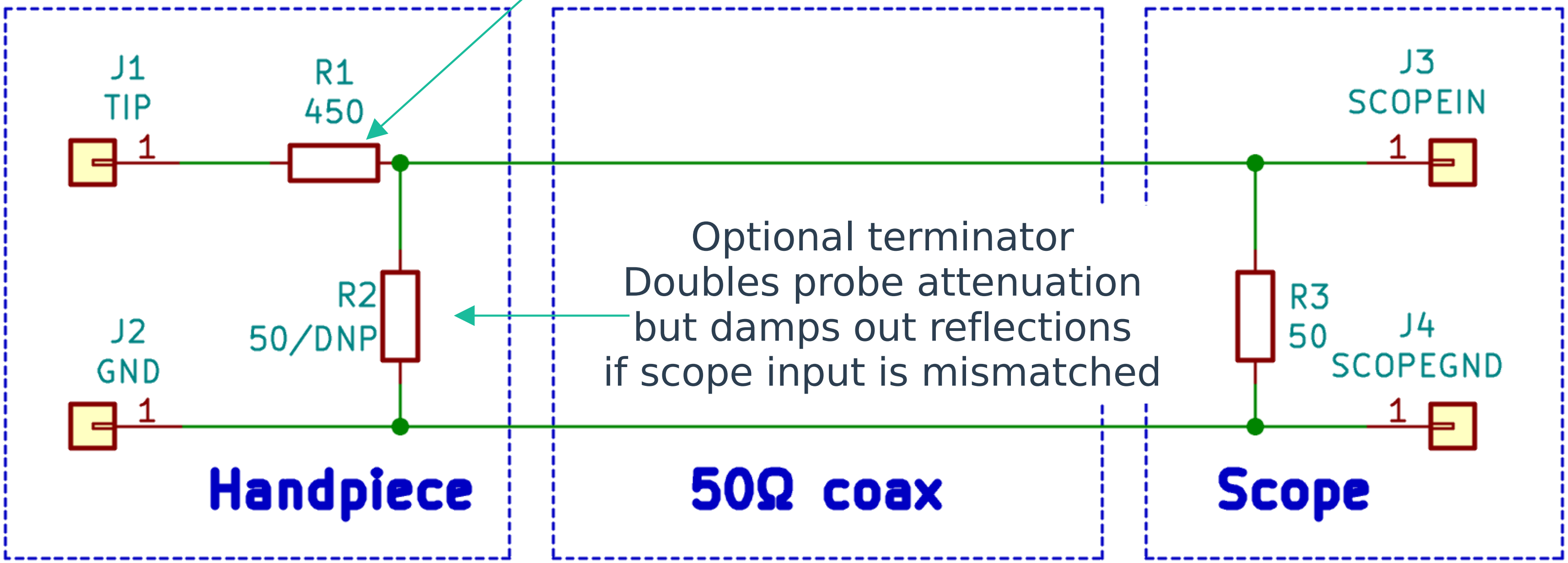
Resistive Probes

Resistive Probe

- **The *other* passive probe design**
  - Aka Transmission line probe, Low-Z probe, Z_0 probe
- **Conceptually super simple**
  - Resistor and a piece of coax
- **Doesn’t get as much love as it deserves**

Resistive Probe

Linear tradeoff between insertion loss and loading on DUT.
450Ω for 10x, 950Ω for 20x



Optional terminator
Doubles probe attenuation
but damps out reflections
if scope input is mismatched

Resistive Probe

- **Much higher DC loading than an R-C divider**
- **But response can be much flatter!**
  - Ideal resistive probe has C=0 and constant S_{21} / S_{11}
  - Of course, parasitics ruin our fun like always...

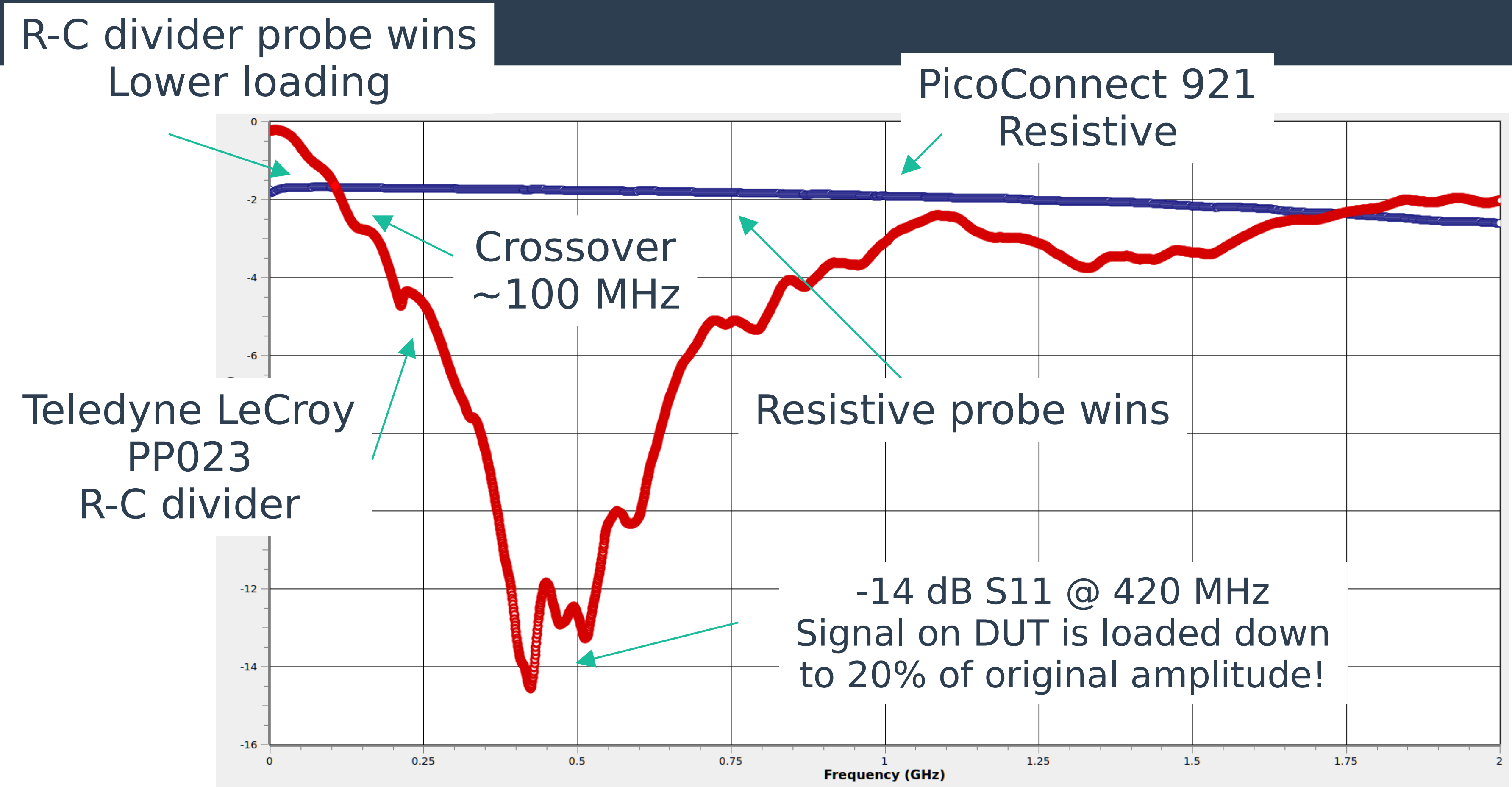
Typical Resistive Probes

Pico TA061
10:1
$419, 1.5 GHz

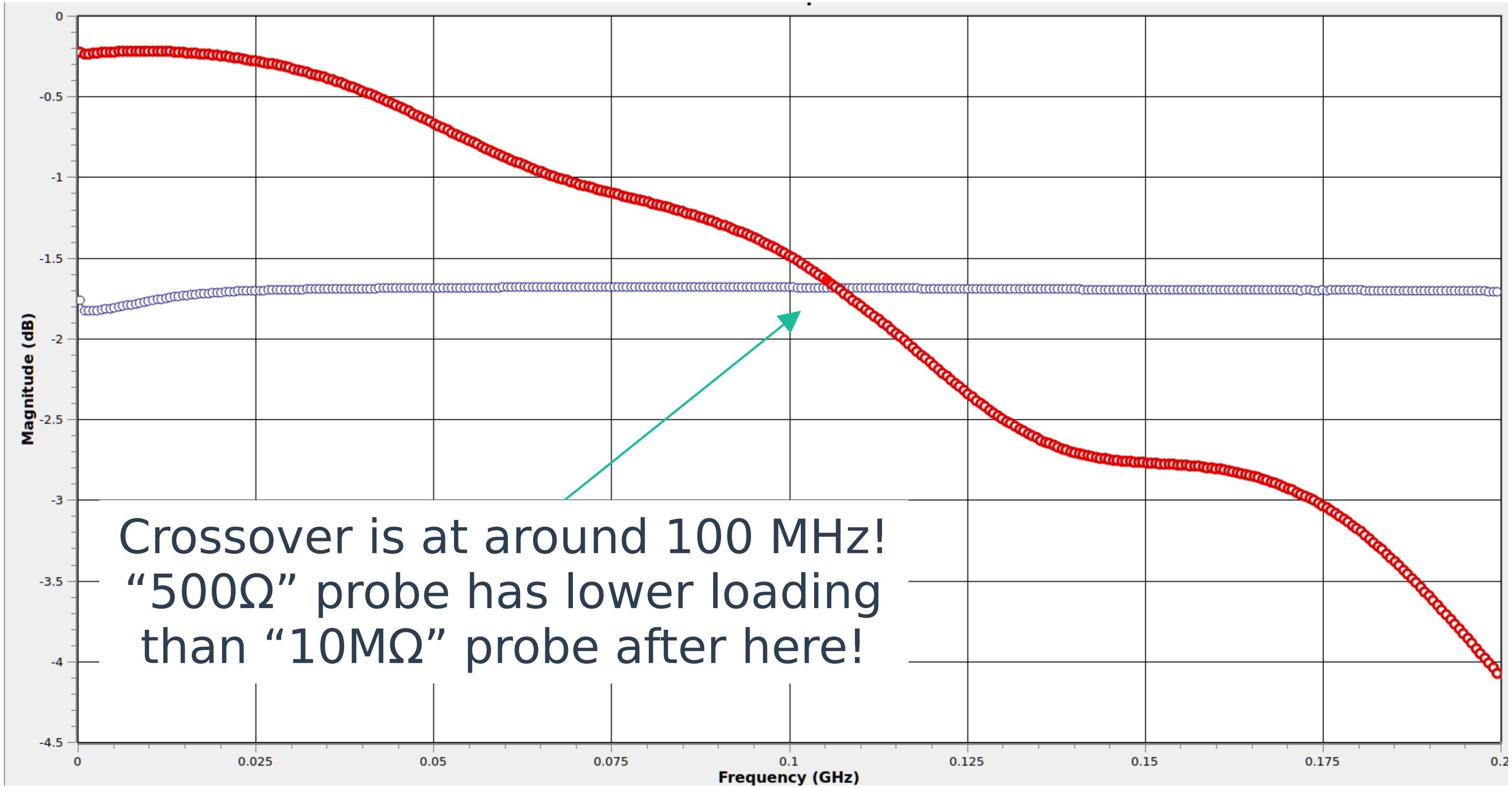
PicoConnect 921
20:1, AC coupled
Source terminated
$1055, 6 GHz

Teledyne LeCroy
PP066
1:1 / 10:1 / 20:1
$1860, 7.5 GHz

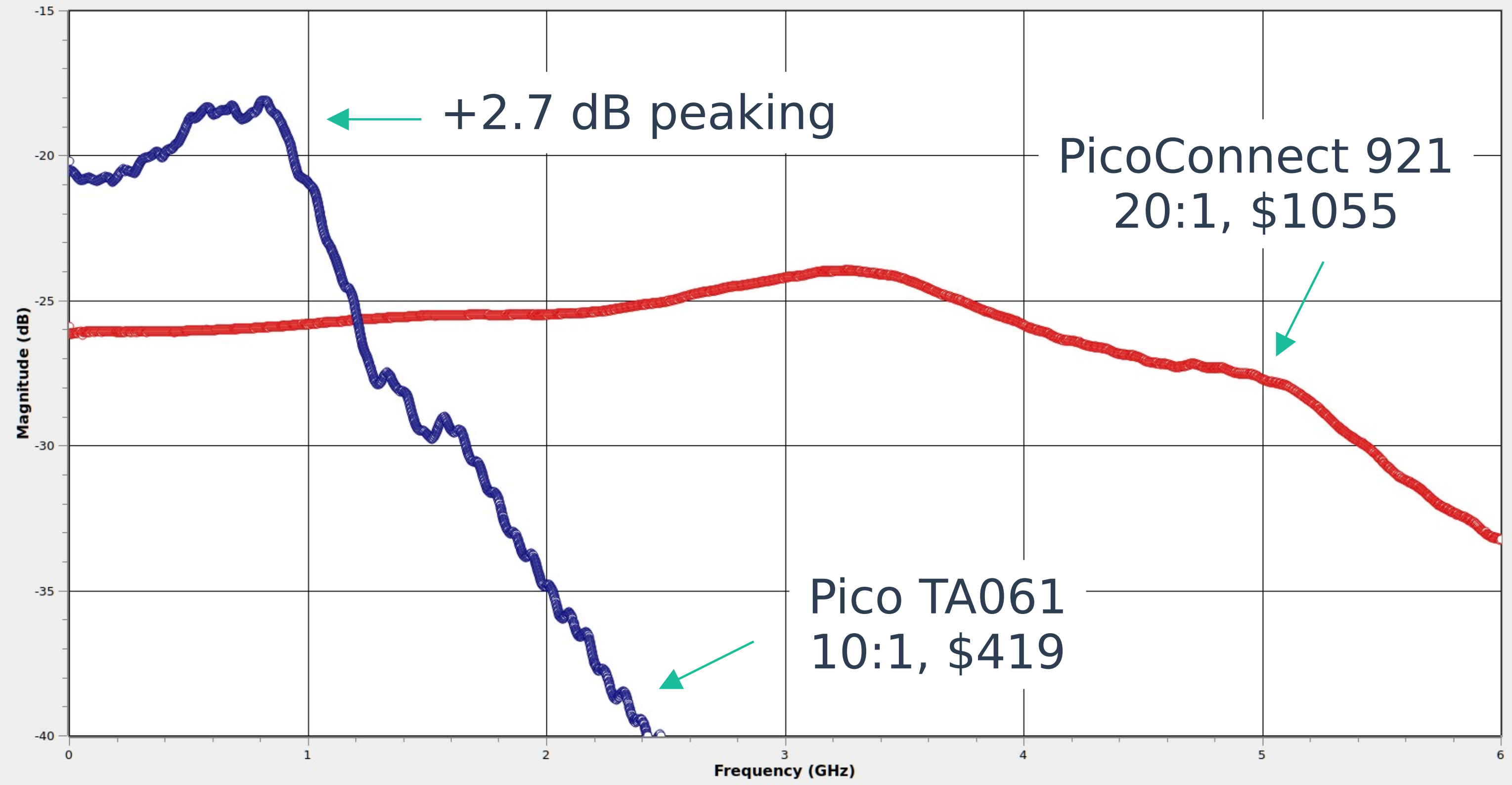
Resistive Probe: S_{11} vs R-C Divider



Resistive Probe: S_{11} Crossover



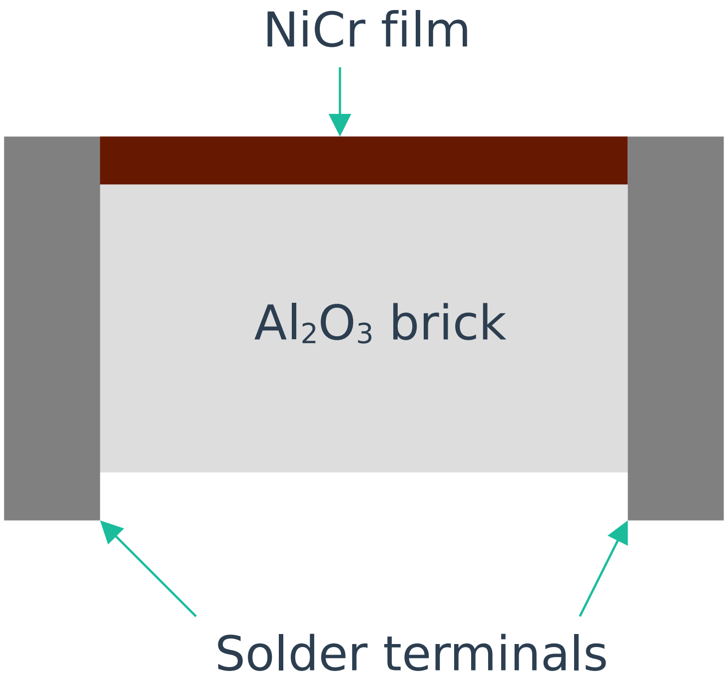
Resistive Probe: S_{21} Flatness Across Models



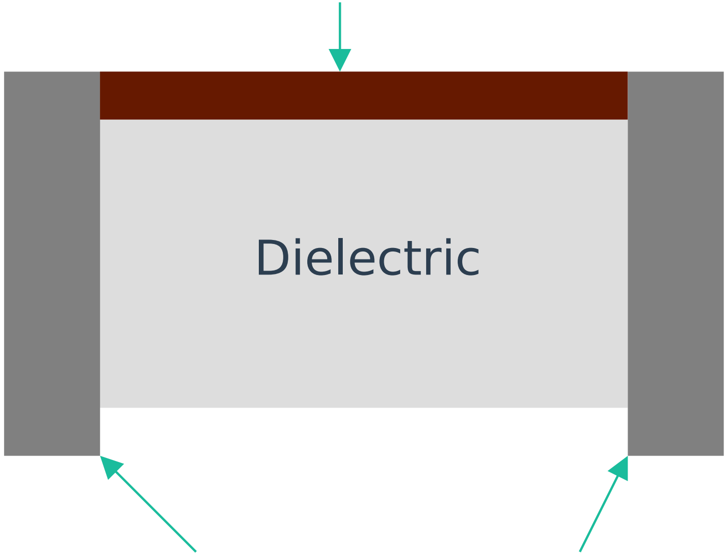
Resistive Probe: S_{21} Flatness Across Models

- Lower cost probe has much worse flatness
- But why?
- Let’s look at some of the effects in play

Chip Resistor Cross Section

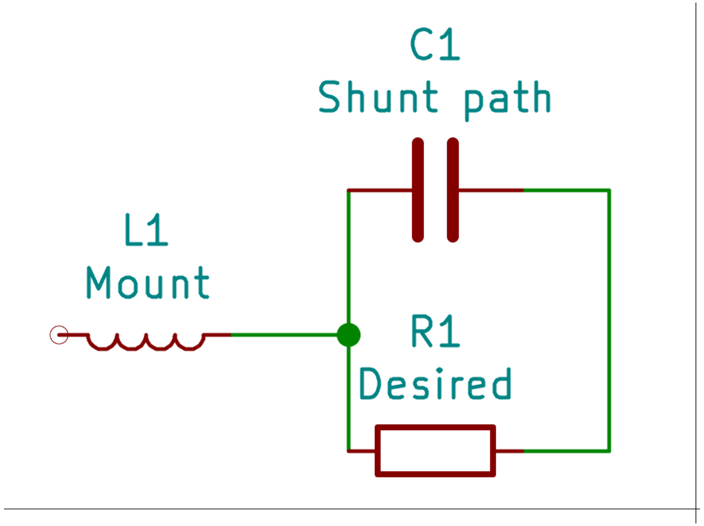


But from a different perspective...

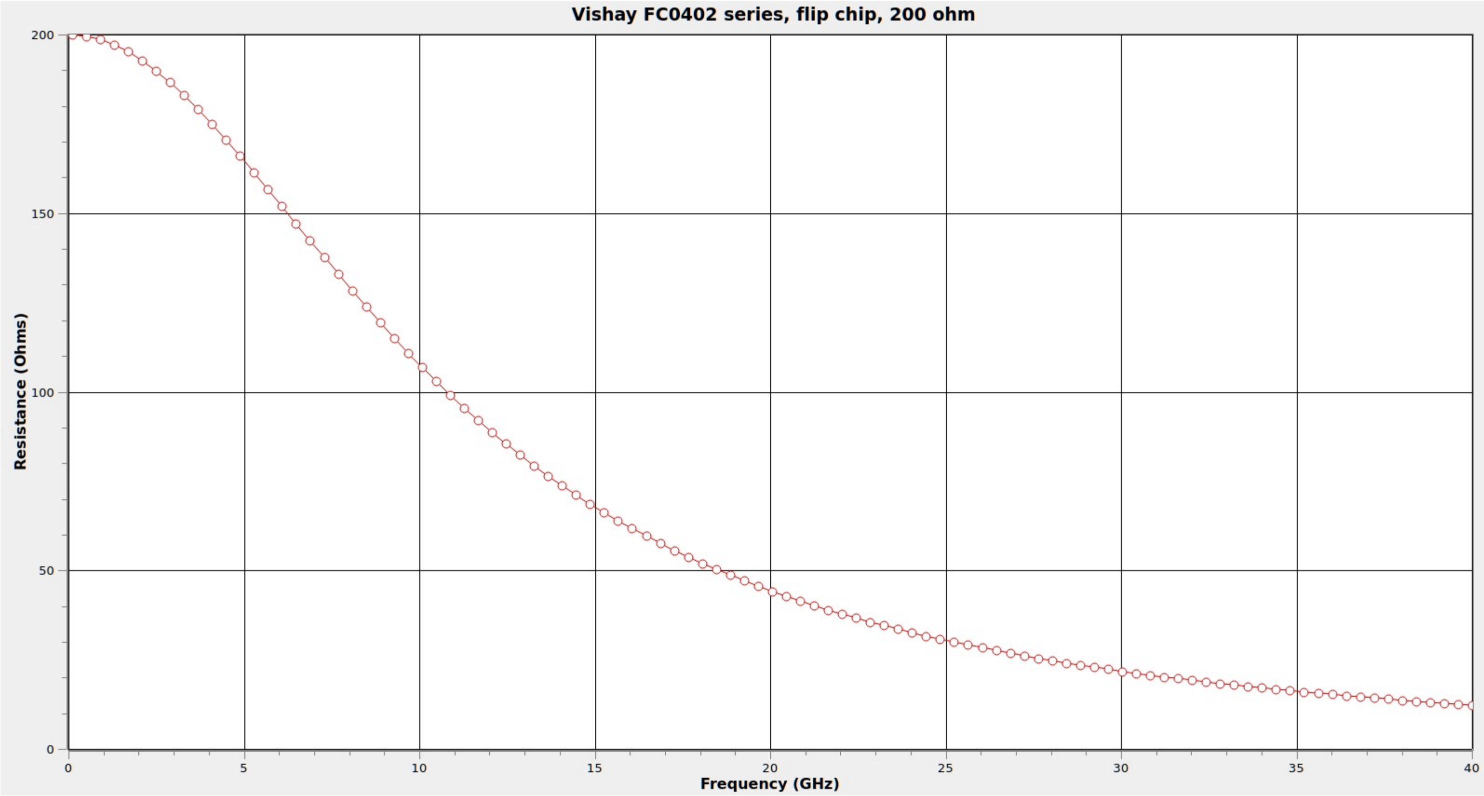


Yep, it's a capacitor!

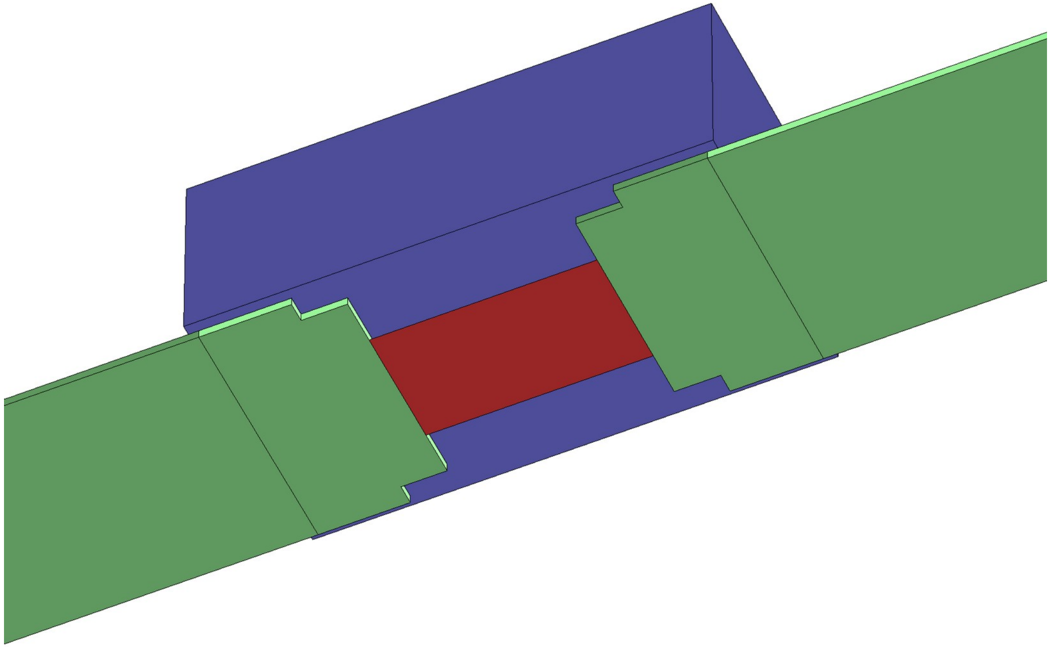
- **Here's a better model of a real resistor**



Real Resistor Behavior



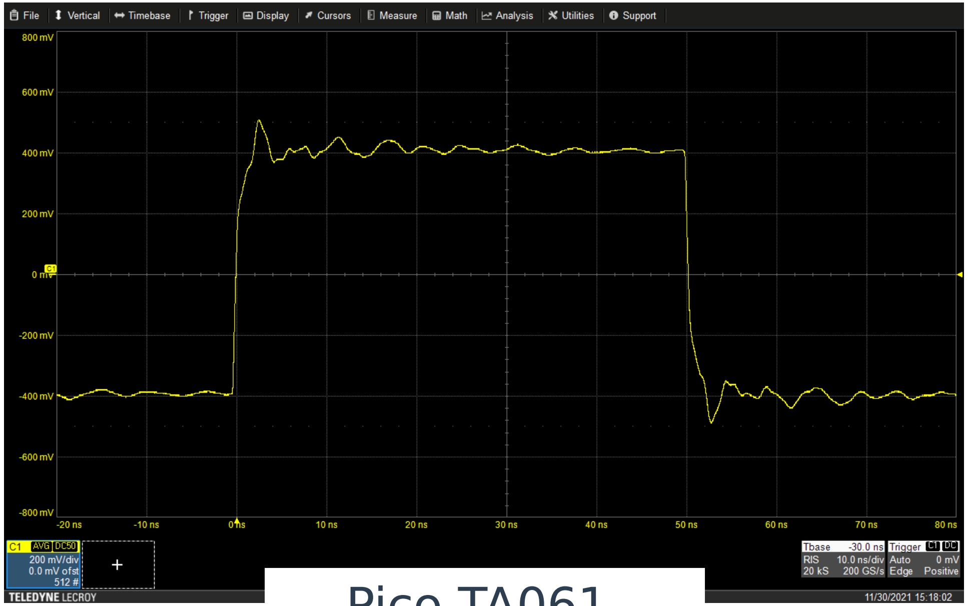
Flip-Chip Resistors



Resistive Probe: Ground L Sensitivity

- **Much less input C than an R-C divider**
  - Low end ones (Pico TA061) can be as *high* as 2 pF
  - Better ones (PicoConnect) are hundreds of fF
- **Less C means less ringing for same L**
  - You can often get away with worse grounding vs R-C divider

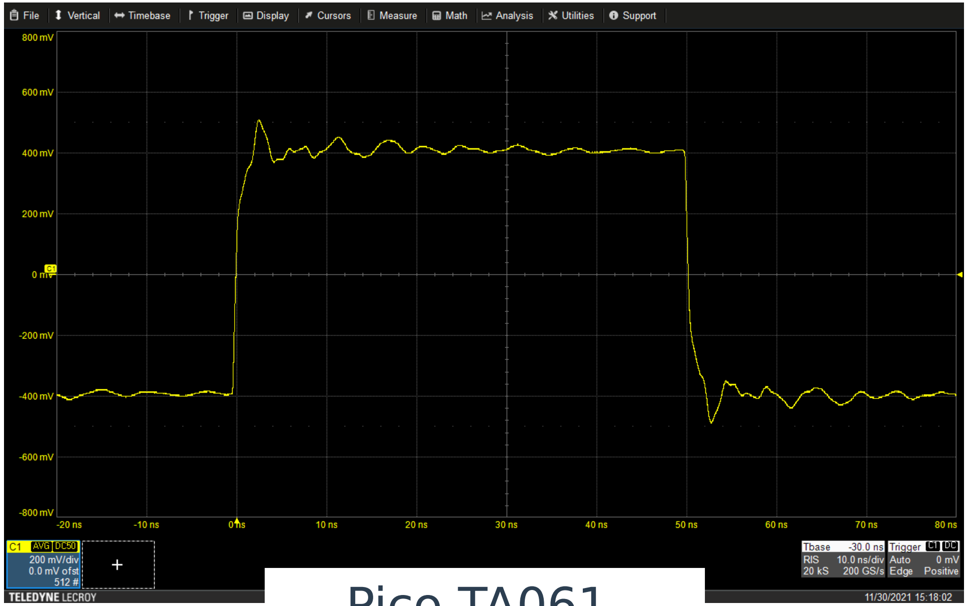
Resistive Probe: Ground L Sensitivity



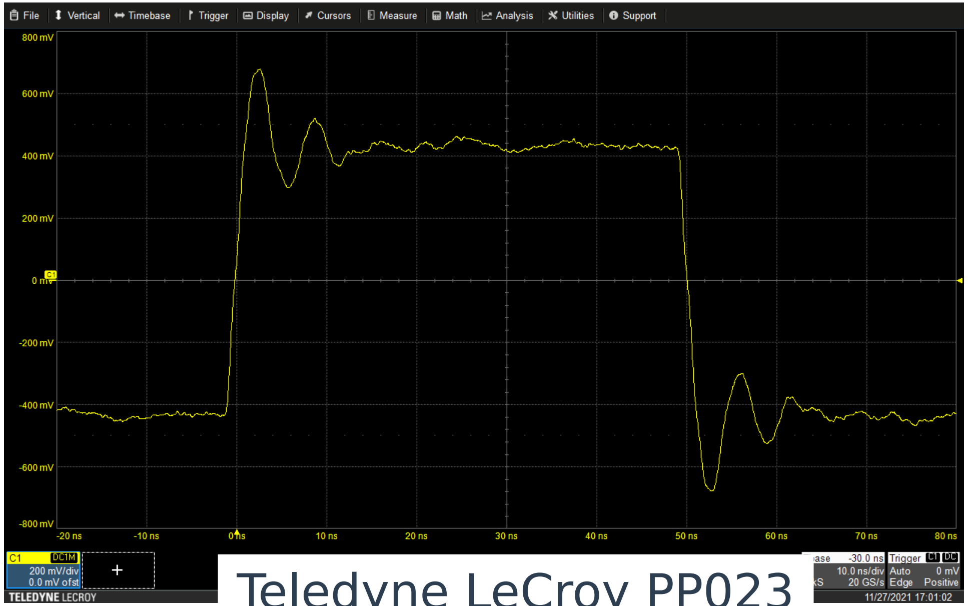
Pico TA061
Alligator ground

Pico TA061
Spring ground

Resistive Probe: Ground L Sensitivity vs R-C



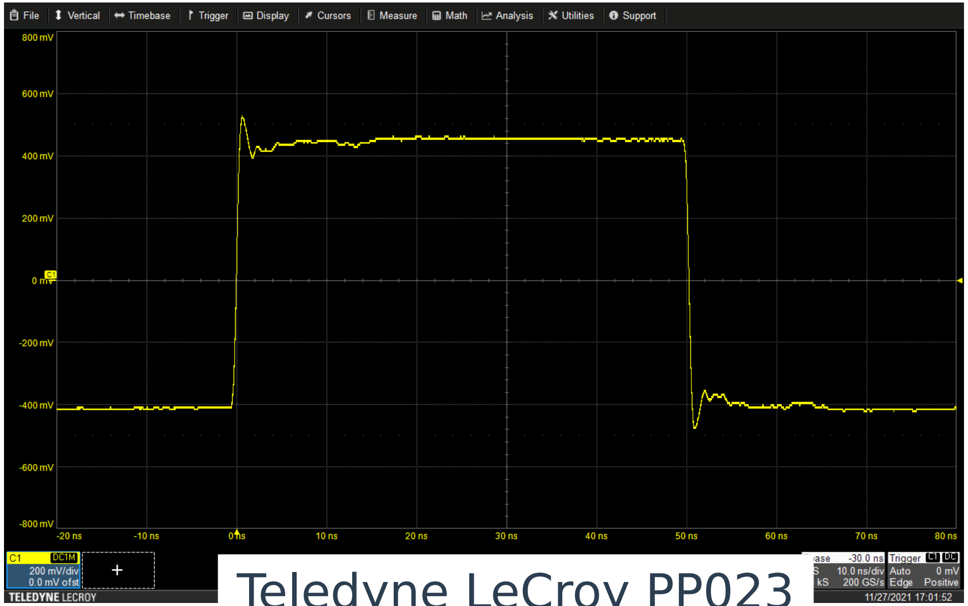
Pico TA061
Alligator ground



Teledyne LeCroy PP023
Alligator ground

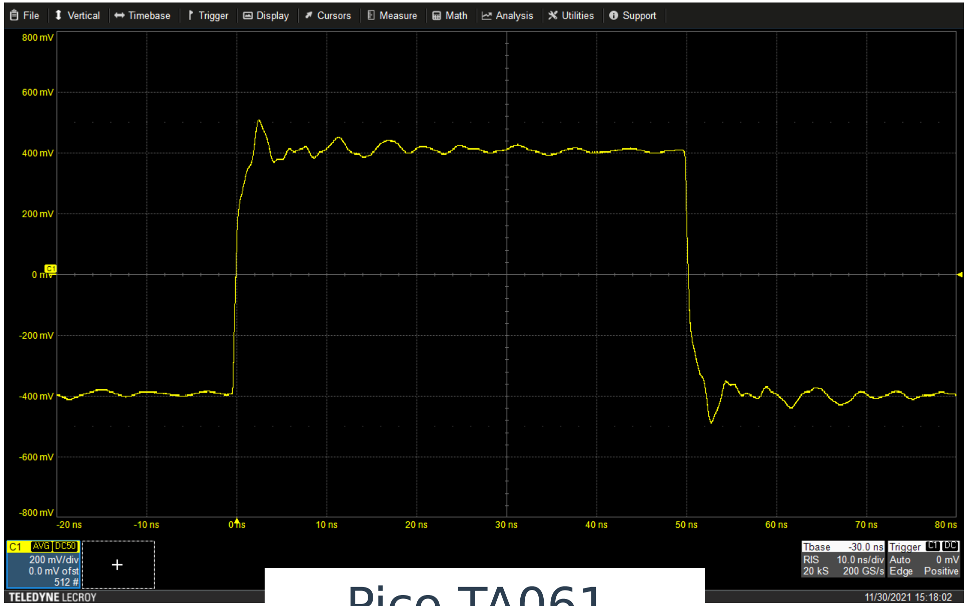
Resistive Probe: Ground L Sensitivity vs R-C

Pico TA061
Spring ground

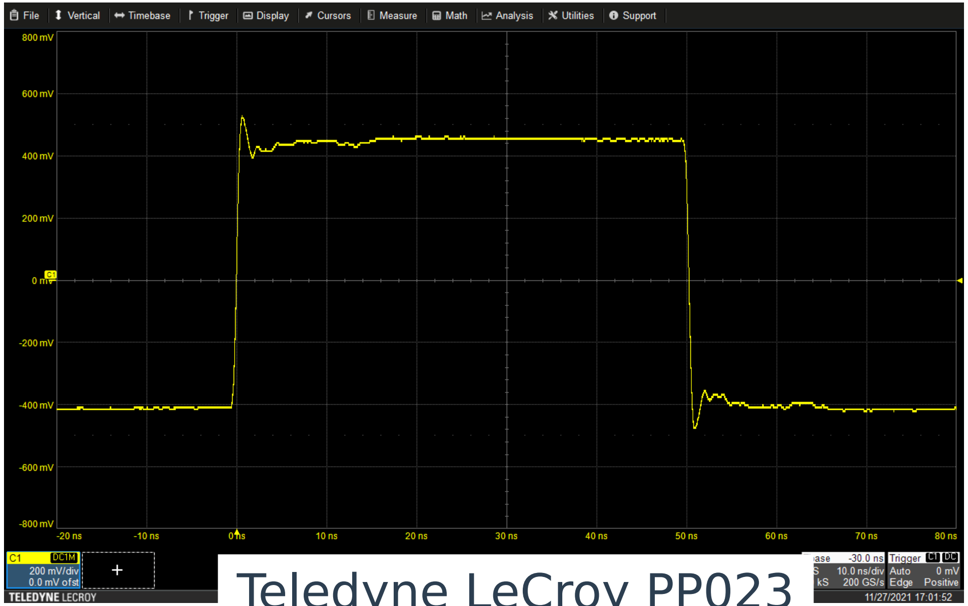


Teledyne LeCroy PP023
Spring ground

Resistive Probe: Ground L Sensitivity vs R-C



Pico TA061
Alligator ground

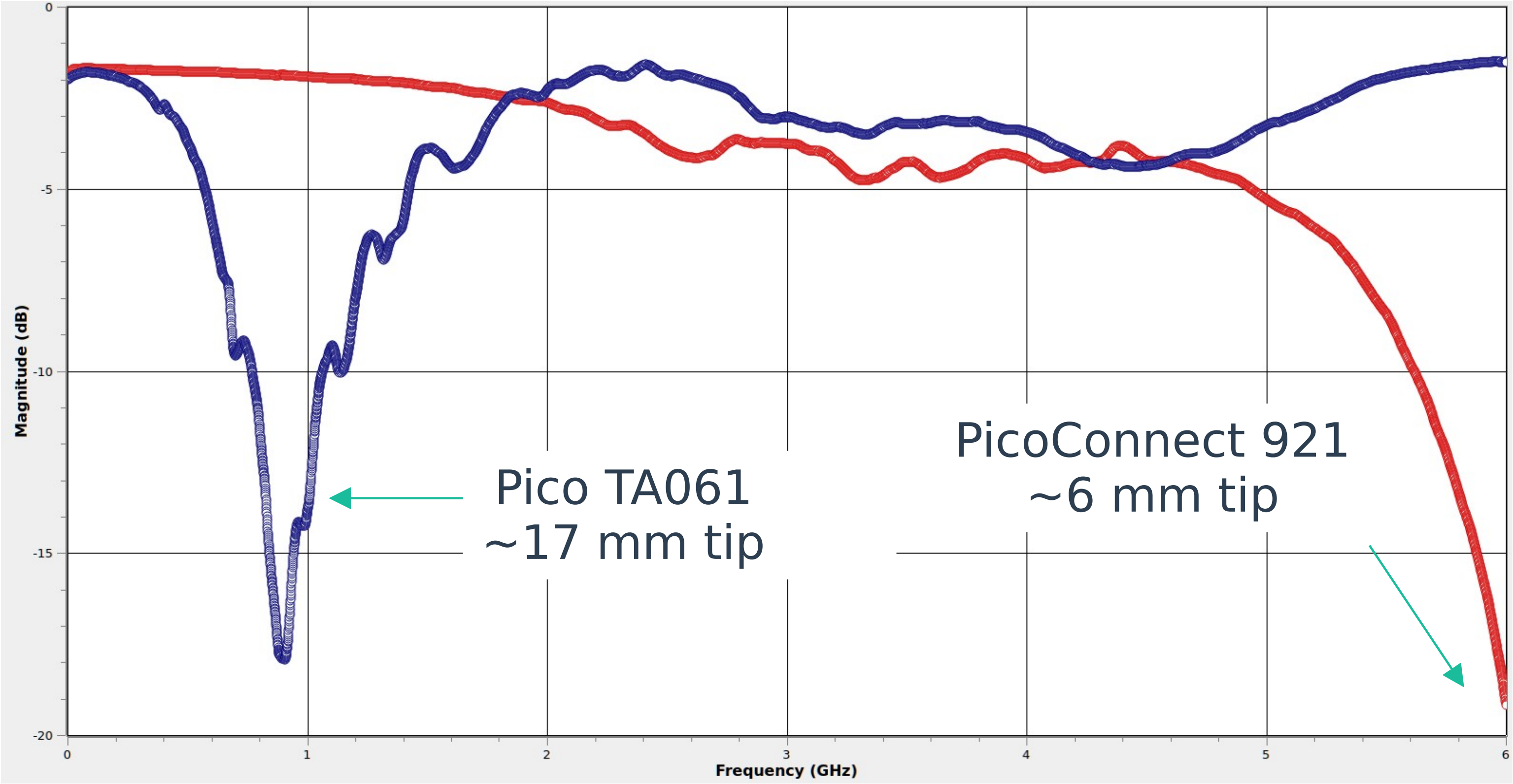


Teledyne LeCroy PP023
Spring ground

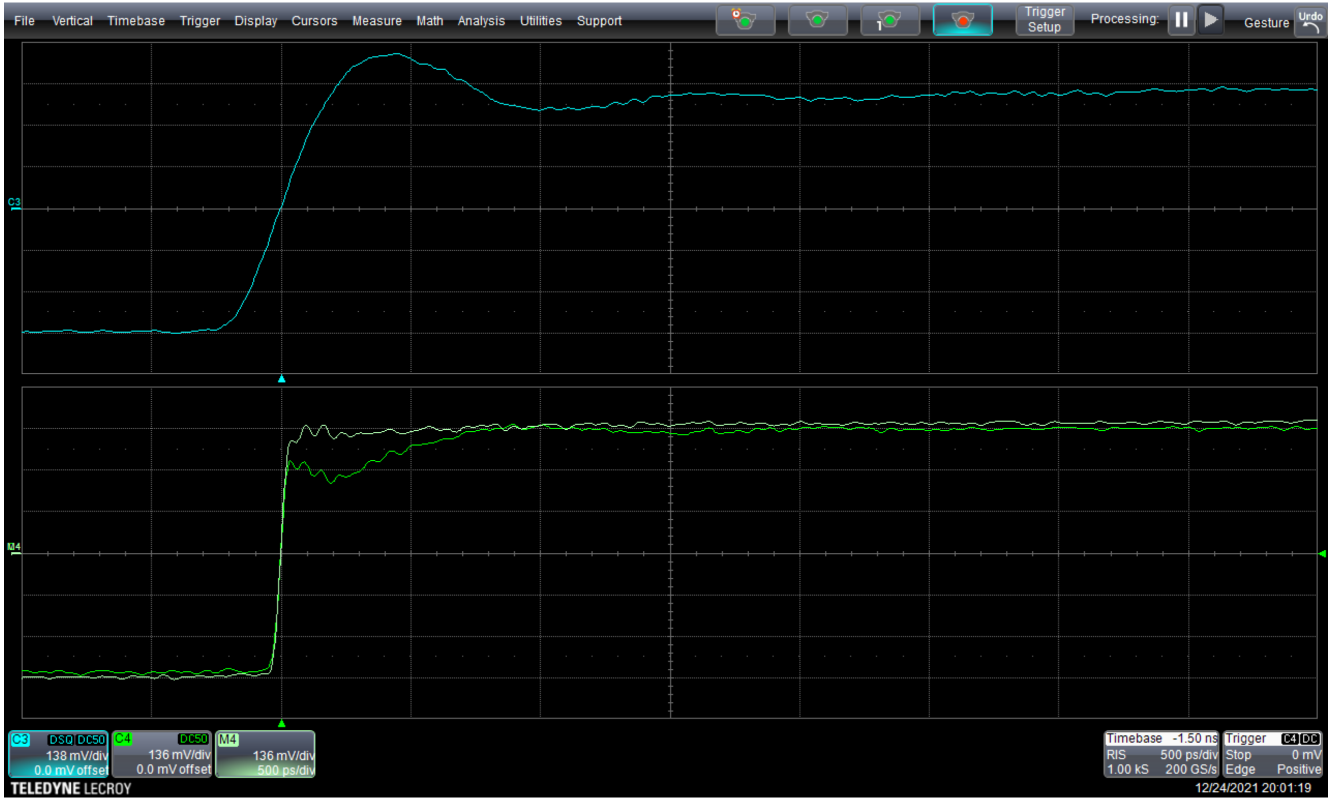
Resistive Probe: Input Stub

- **Distance from probe tip to resistor is critical**
  - This is an unterminated low-Z stub!
  - Reflection off resistor causes ¼ wave null in response
- **Longer tip needle makes this effect worse**

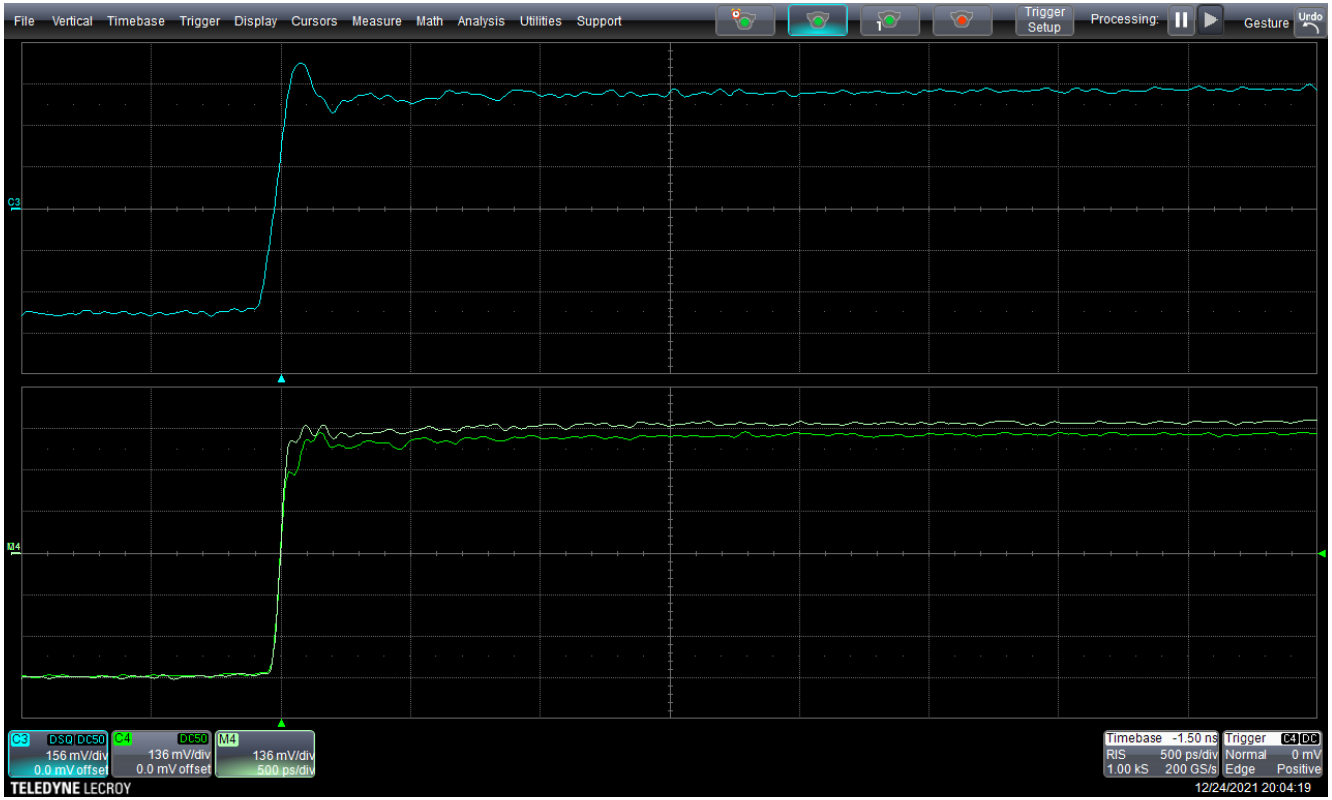
Resistive Probe: Input S_{11} vs Needle Length



Resistive Probe – Time Domain Loading (TA061)



Resistive Probe – Time Domain Loading (921)



Resistive Probe – Input Stub

- **Ideally we want no reflection at all!**
  - But how can we get that?
  - Need to eliminate the mismatched stub somehow...

Resistive Probe – Reducing Reflections

- **What if we match tip Z_0 to probe resistance?**
  - For example, 500Ω Z_0 for a 500Ω 10:1 probe
- **This eliminates mismatch at tip-to-R junction**
  - All power we don't sample is instantly reflected back to DUT

Resistive Probe – Reducing Reflections

- **There's just one problem…**
  - The impedance of free space is ~377Ω
  - Matched tip is impossible with a 10:1 or 20:1 probe
  - Doable (maybe) with a 5:1, but mechanically tricky

Resistive Probe – Reducing Reflections

- **Alternative: Make the stub really short**
  - Move the null past the band of interest
- **Lots of fun ways to do this**
  - Castellated probe tips
  - Solder-in damping resistors
  - Carbon fiber tip needles
- **Any of these sound familiar?**
  - We’ll return to this in a later section…

Resistive Probe: Strengths

- **Excellent price / performance ratio**
  - Nothing else gives you GHz of BW for $1K!
  - Prices typically mid 3 to low 4 digits USD
- **No active components – fairly ESD resistant**
- **Generic design – no vendor lock-in**

Resistive Probe: Weaknesses

- **Relatively high DC loading**
  - Not suitable for use on lines with pullups
- **May disturb DC bias on DUT**
  - Can mitigate this w/ coaxial DC block
  - Some probes include AC coupling cap
- **High attenuation (typically 10:1 or 20:1)**
  - Can reduce attenuation at the cost of worse DC loading

Resistive Probe: When to Use

- **Fast digital signals with push-pull drivers**
  - Excellent general purpose embedded debug probe
  - Easily usable out to several Gbps
- **Low impedance analog**
  - Great for 50Ω RF

High Impedance Active Probes

High-Z Active Probe

- **FET amplifier in probe head**
- **Typically fixed HW gain**
  - Some (not all) provide offset capability
- **High DC input resistance (MΩ range)**
- **Relatively low input C (usually sub-pF)**

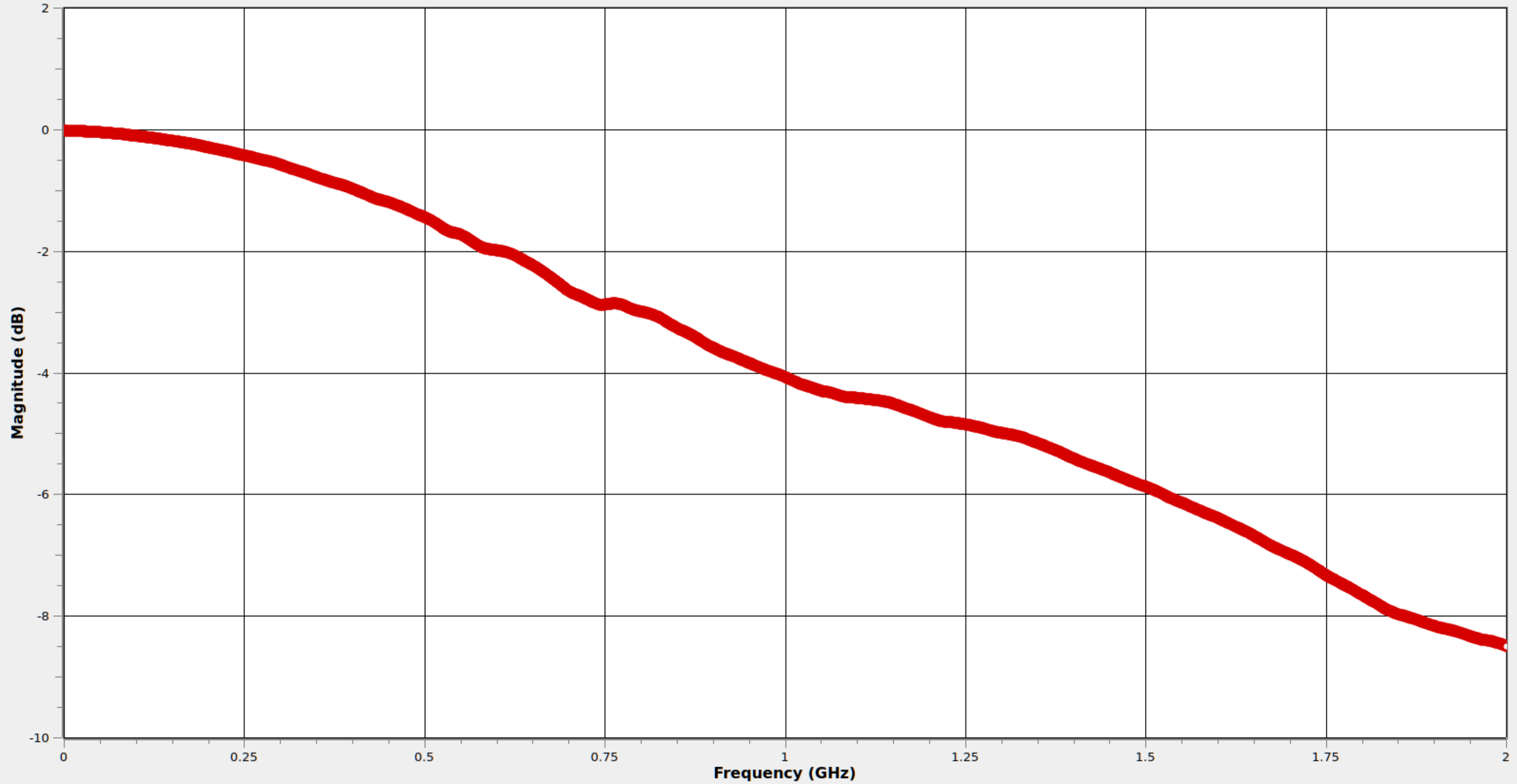
High-Z Active Probe

- **Most are made by scope vendors**
  - Proprietary interface, not portable across makes
- **Some third party ones exist**
  - Tetris by PMK (1 to 4 GHz models)
  - External power supply, 50Ω BNC to scope

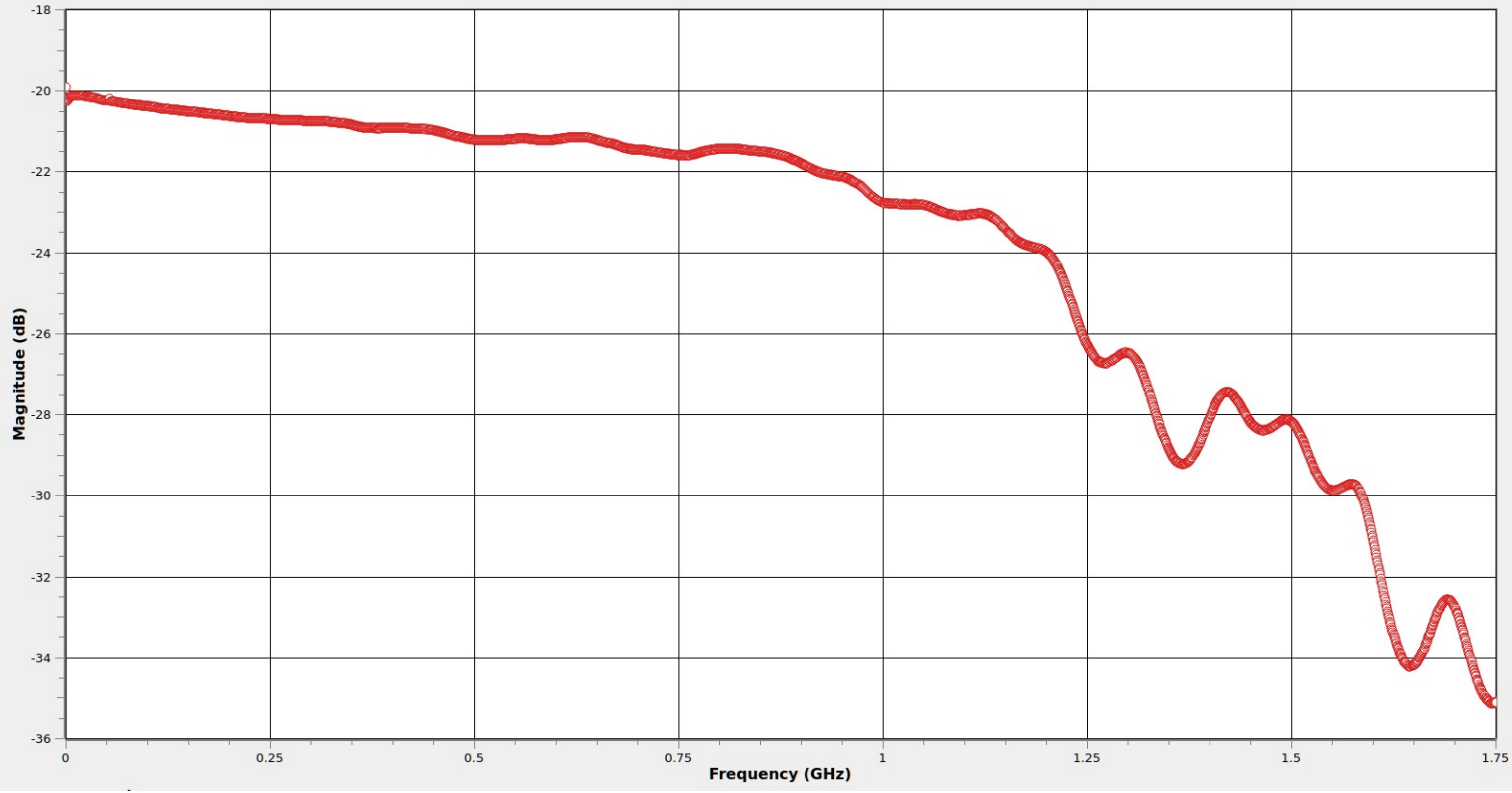
Teledyne LeCroy ZS1500

- **Probe head based on PMK Tetris 1500**
  - 1.5 GHz, 1MΩ || 900 fF
- **ProBus control pod**
  - Adds ± 12V offset capability
  - (PMK version has no offset DAC)

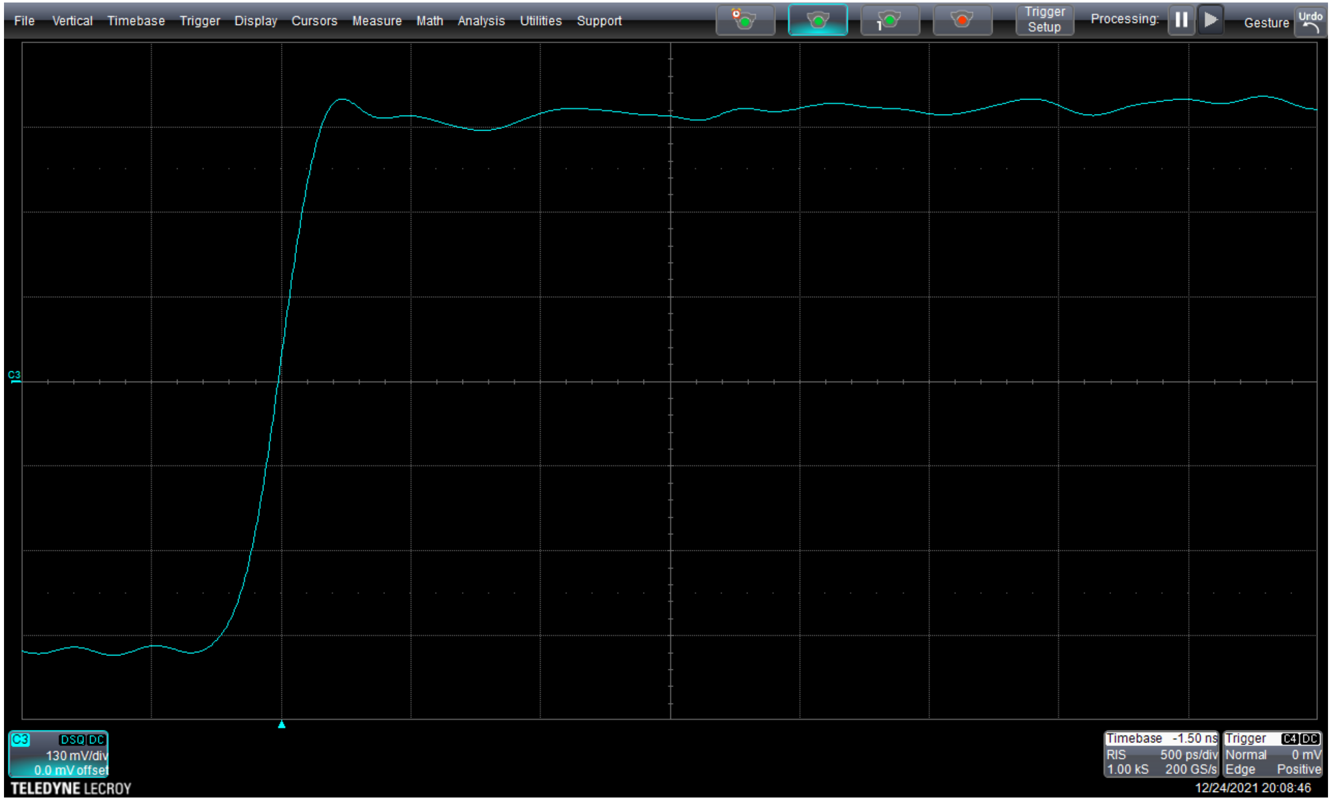
ZS1500 – S_{11} w/ Leaf Ground



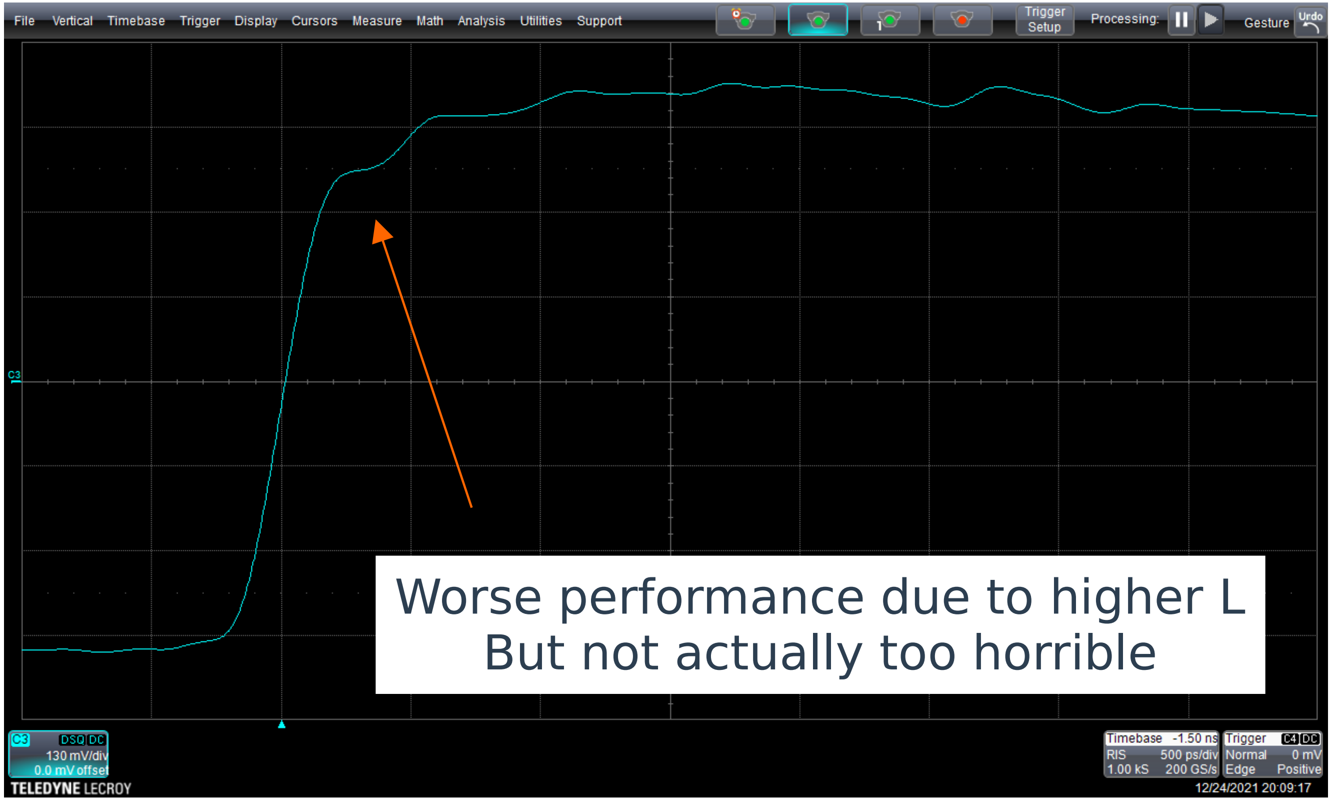
ZS1500 – S_{21} w/ Leaf Ground



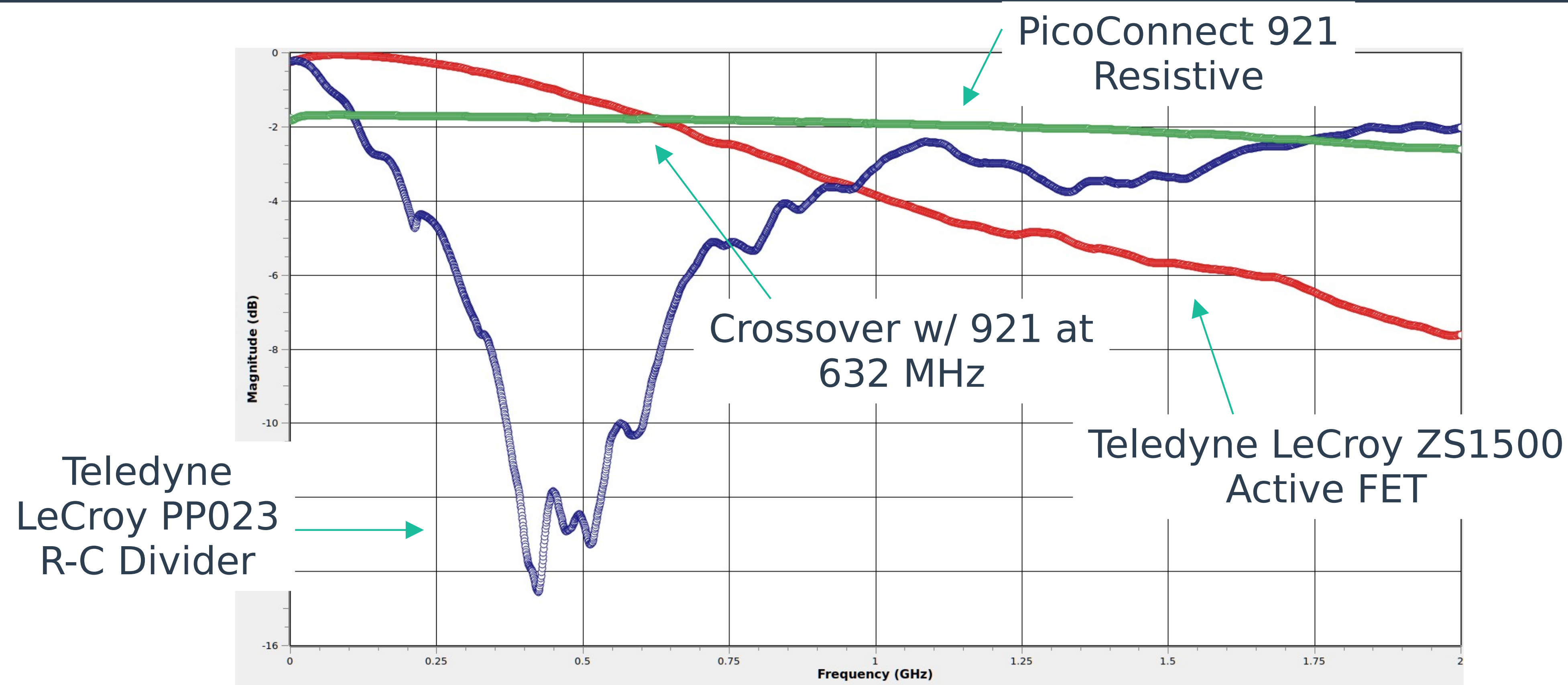
ZS1500 – Step Response w/ Leaf Ground



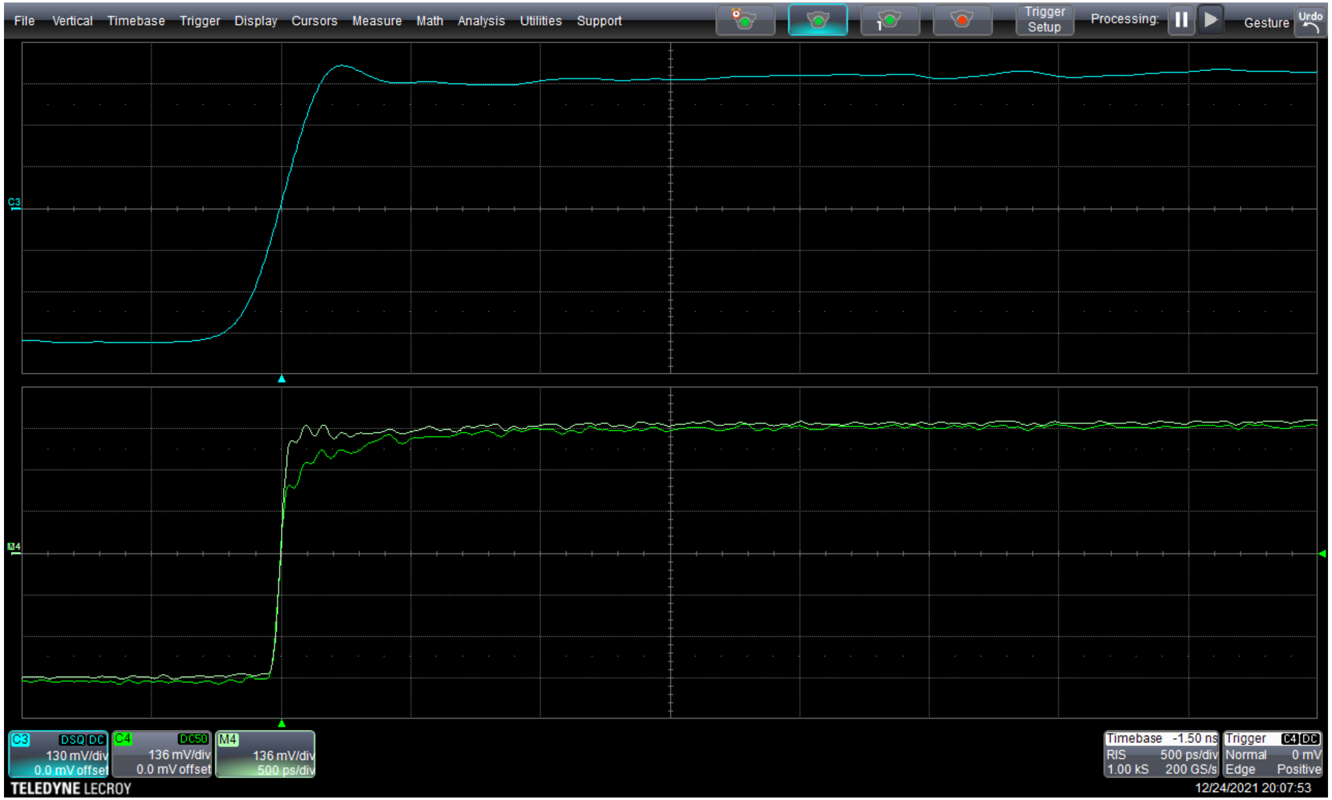
ZS1500: Step Response w/ 7cm Wire Ground



ZS1500 – S_{11} Across Open



ZS1500: Time Domain Loading w/ Leaf Ground



High-Z Active Probe: Strengths

- **Lowest DC loading of any common probe**
  - Maintains high input Z much longer than R-C divider
- **Relatively low capacitance**
- **Somewhat tolerant of poor grounding**
  - Resistive probes are usually better at this, though

High-Z Active Probe: Weaknesses

- ESD sensitive
- Expensive (low-mid 4 digits USD)
- High attenuation (typically 10:1)
- Small but non-negligible input capacitance

High-Z Active Probe: When to use

- **Loading-sensitive low to mid speed signals**
  - The ZS1500 is my probe of choice for crystal oscillators
- **Excellent general purpose embedded debug probe**
  - But you can buy 4+ resistive probes for cost of one FET probe!
  - Don’t go out and buy a case of them unless you really need to

Active Differential Probes

Differential Probe

- **Differential amplifier fed by probe tip**
- **Typically used for low swing, high BW signals**
  - HV diff probes exist, will be covered separately

Differential Probe: Input Considerations

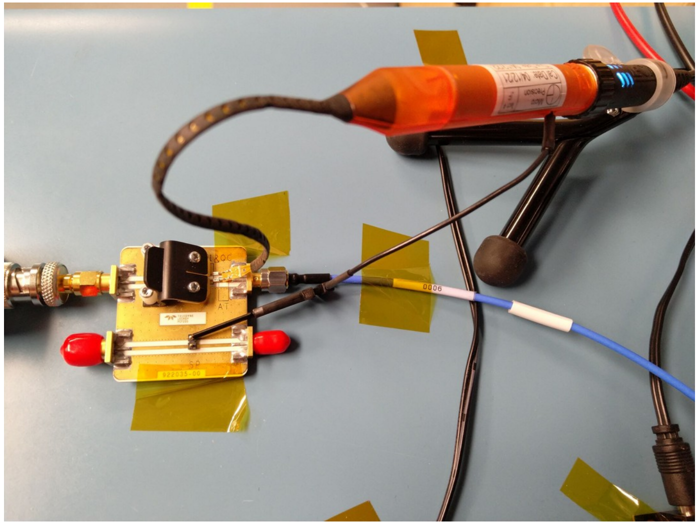
- Loading
- Common mode range
- Differential dynamic range
- Damage levels
- Overload recovery

Differential Probe: Grounding

- **Input signal isn't measured WRT ground, but…**
- **Very limited common mode range**
  - ± 5V for Teledyne LeCroy DH series
  - ± 2.4V for Teledyne LeCroy D400A-AT
- **Board needs to share same DC ground as probe**
  - No need for a low-L RF ground path!

Differential Probe: Grounding Methods

- **Ground from another probe**
- **Grounded power supply**
- **Ground input on amplifier**
  - Only need to use one per DUT
- **USB / UART / JTAG cable**
- **Coax shield**



Differential Probe: Simplified Schematic

Loading (Teledyne LeCroy D420-A, SI tip)

Shift is almost invisible!
Good diff probes have
extremely low loading

Differential Probe: Tips/Accessories (D1330)

Mounting jigs, tape, tip clips, etc.
Yes, they're Legos!

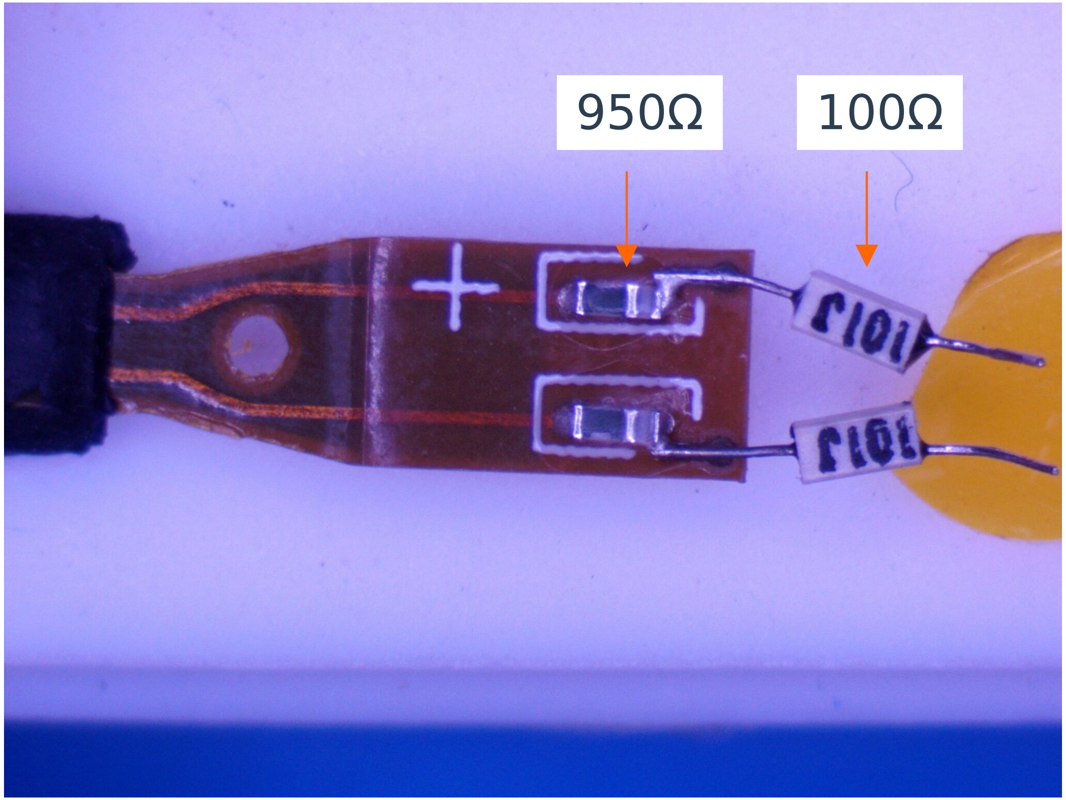
Handheld browser

Solder-in

Pin header

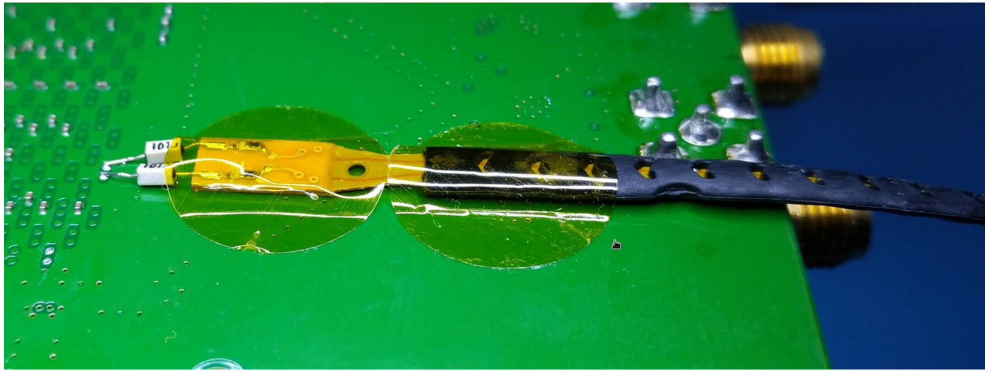
Solder-In Tip (D1330-SI)

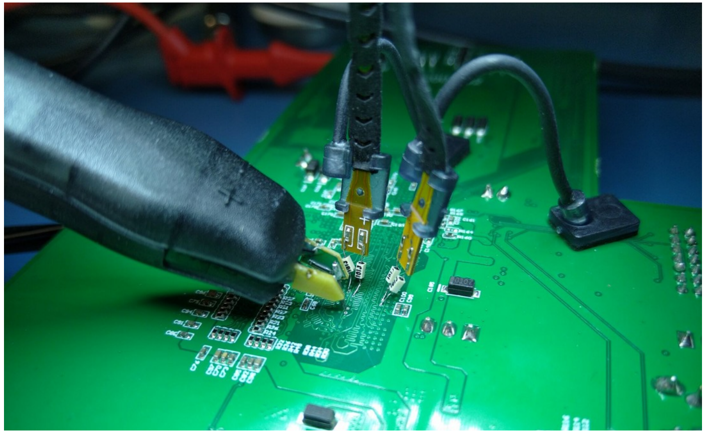
Tip is just two resistive probes!



Differential Probe: Securing Tips

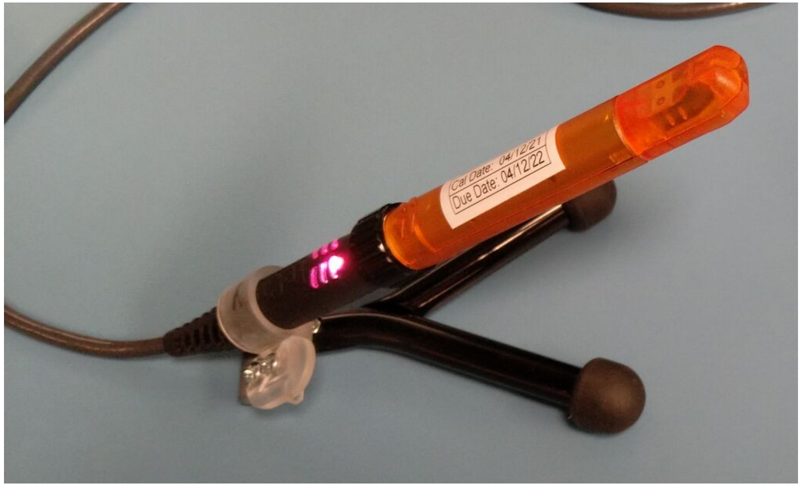
- **Solder-in probe tips are fragile!**
  - Cannot handle significant shear forces
- **Secure them with tape or dedicated probe clips**



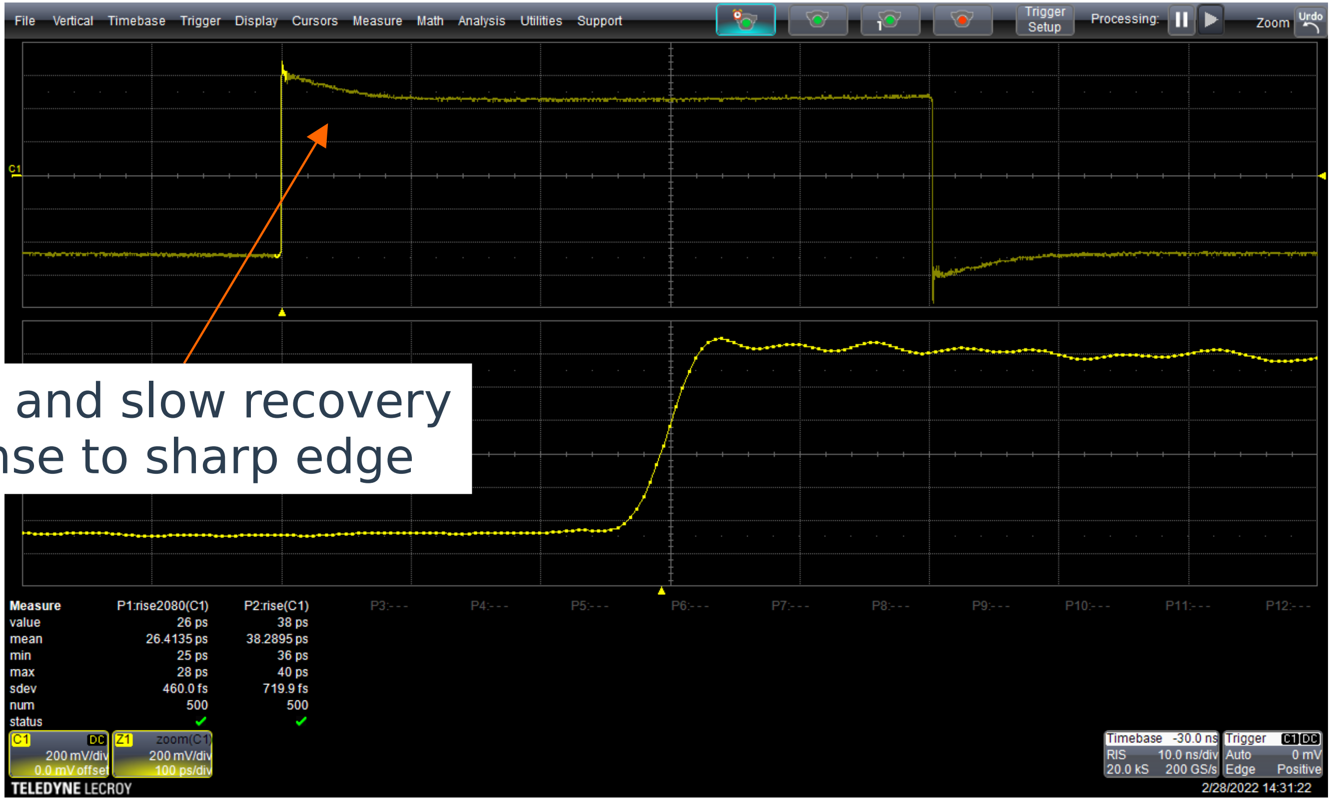


Differential Probe: Securing Probe Body

- Amplifier is large and heavy compared to tip
- If it moves, it will damage the tip
- Use provided holders
- Taping wires down helps too

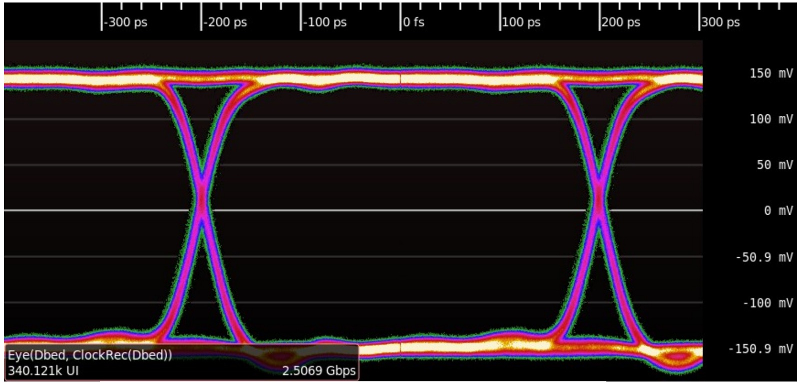


Overload Recovery (LeCroy D1605)

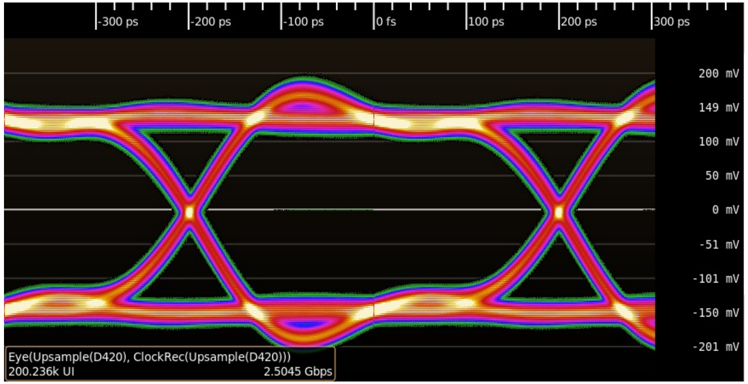


Overshoot and slow recovery in response to sharp edge

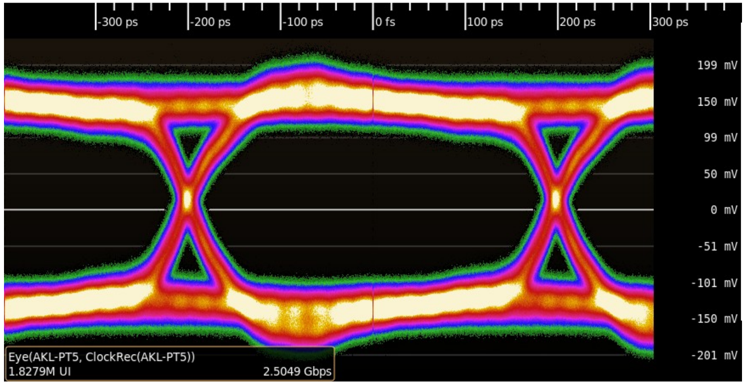
Eye Pattern Comparison: 2.5 Gbps PRBS-9



Direct coaxial input
Best performance
High loading



LeCroy D420-A
(Active differential)
Strong overshoot
Low noise



Antikernel Labs
AKL-PT5
(Resistive)
Slight overshoot
Worse noise

Differential Probe: Strengths

- **Relatively low DC loading**
  - Often not as low as high-Z active probe
- **Very low capacitance**
- **Very tolerant of poor grounding**
  - Ground is only used to keep common mode in range

Differential Probe: Strengths

- **Rejection of common mode noise**
- **Saves scope channels when probing a diff pair**
  - Psuedo-differential input uses 2 channels + math function
- **Low net attenuation (typ range /1 to /5)**
  - Probe head has significant attenuation = low loading
  - Amplifier means scope sees strong signal anyway

Differential Probe: Weaknesses

- Very ESD sensitive
- Extremely expensive (4-5 digits USD)
- Limited range
- Overload recovery issues

Differential Probe: When to use

- **High speed low-swing differential signals**
- **High speed low-swing single-ended signals (DDRx)**
  - Need to make it differential somehow
  - Most common is to measure WRT ground
  - Can also measure WRT SSTL Vref etc

Active Power Rail Probes

Challenges of Power Rail Measurement

- **Looking for weak ripple on large offset**
- **DC coupled measurements are hard**
  - Most active probes can’t work with 5 / 12 / 24V rails
  - Even at lower voltages, often limited offset at low V/div
- **AC coupled measurements lose LF content**

Challenges of Power Rail Measurement

- **We want low attenuation to see weak signal**
- **But also need low loading**
  - Heavy DC load will alter DUT PSU behavior

Power Rail Probe: Architecture

- **Split the signal into two paths**
- **High(ish) impedance DC path**
  - Around 50KΩ is common
  - Active amplifier with large offset range (± 24-60V)
- **Capacitively coupled 50Ω AC path**
  - Minimal attenuation, close to 1:1
  - Entirely passive, no additive noise

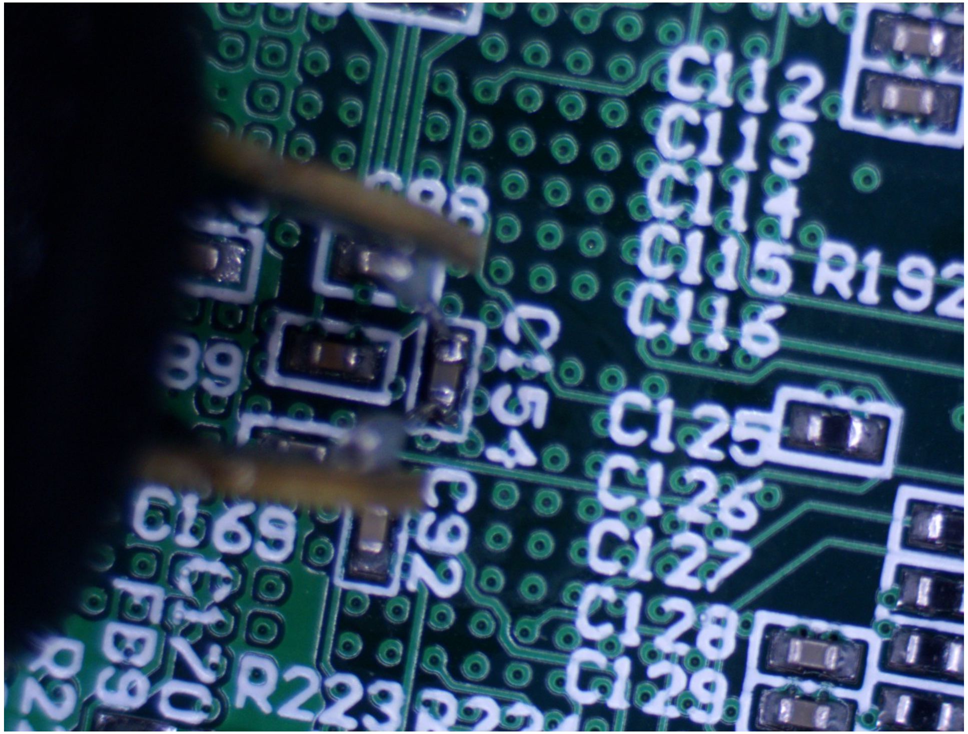
Power Rail Probe: Simplified Schematic

Power Measurement Scenario

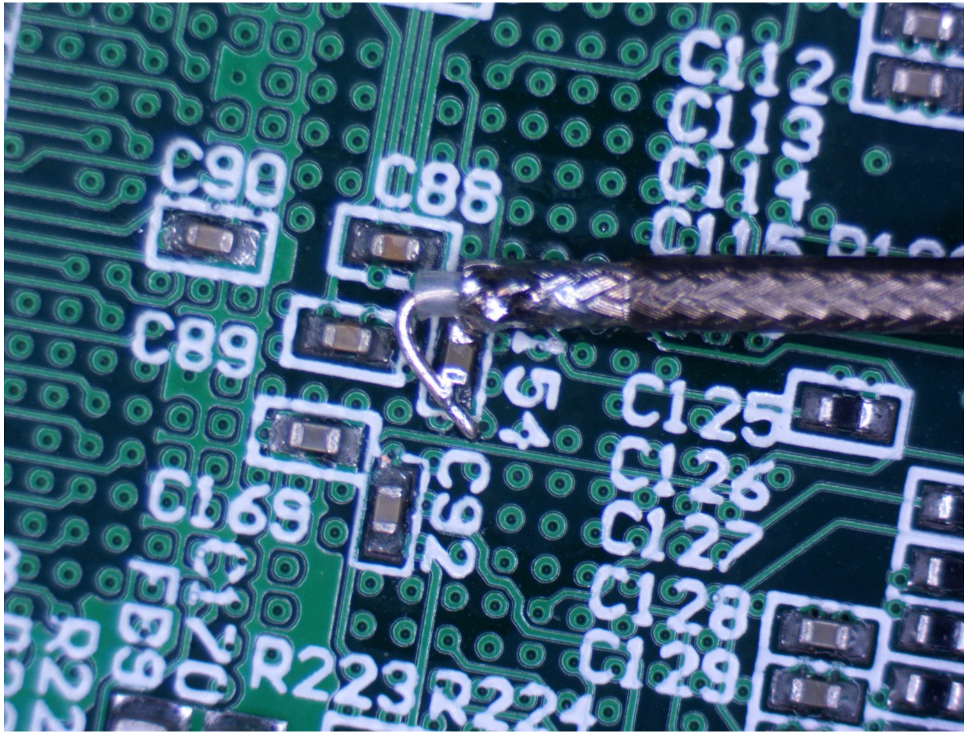
- **Zynq-7000 series SoC (Digilent Zybo)**
- **Looking at 1.0V core power rail**
- **Time domain and spectral analysis in glscopeclient**
- **Compare two 4 GHz probes on same 4 GHz scope**
- **Teledyne LeCroy WaveRunner 8404M-MS**
  - D400-AT: 4 GHz /2.5 differential
  - RP4030: 4 GHz /1.2 power rail

Power Measurement Scenario

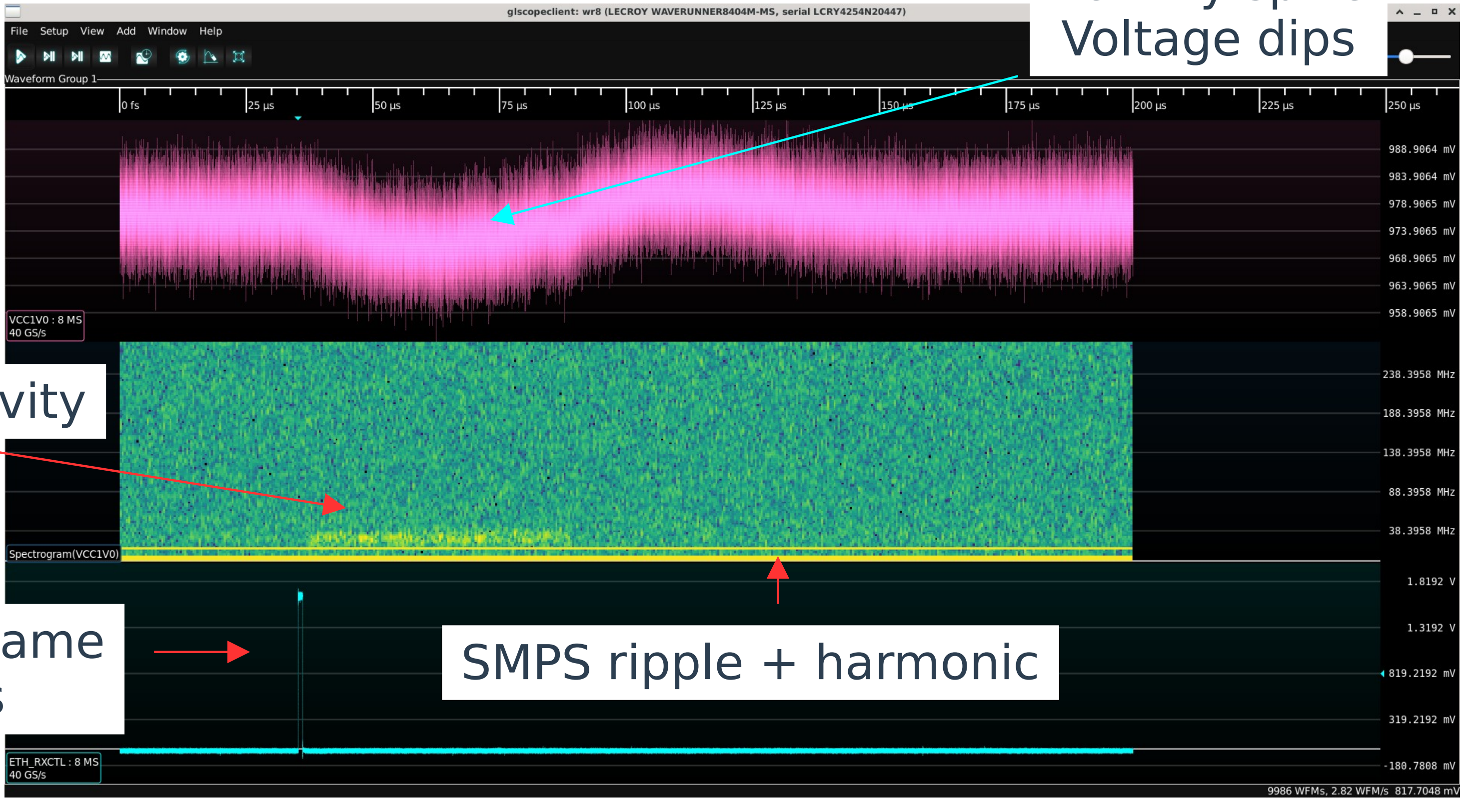
D400A-AT



RP4030



Results using D400A-AT



Activity spike
Voltage dips

On-die activity

Ethernet frame
arrives

SMPS ripple + harmonic

Results using RP4030

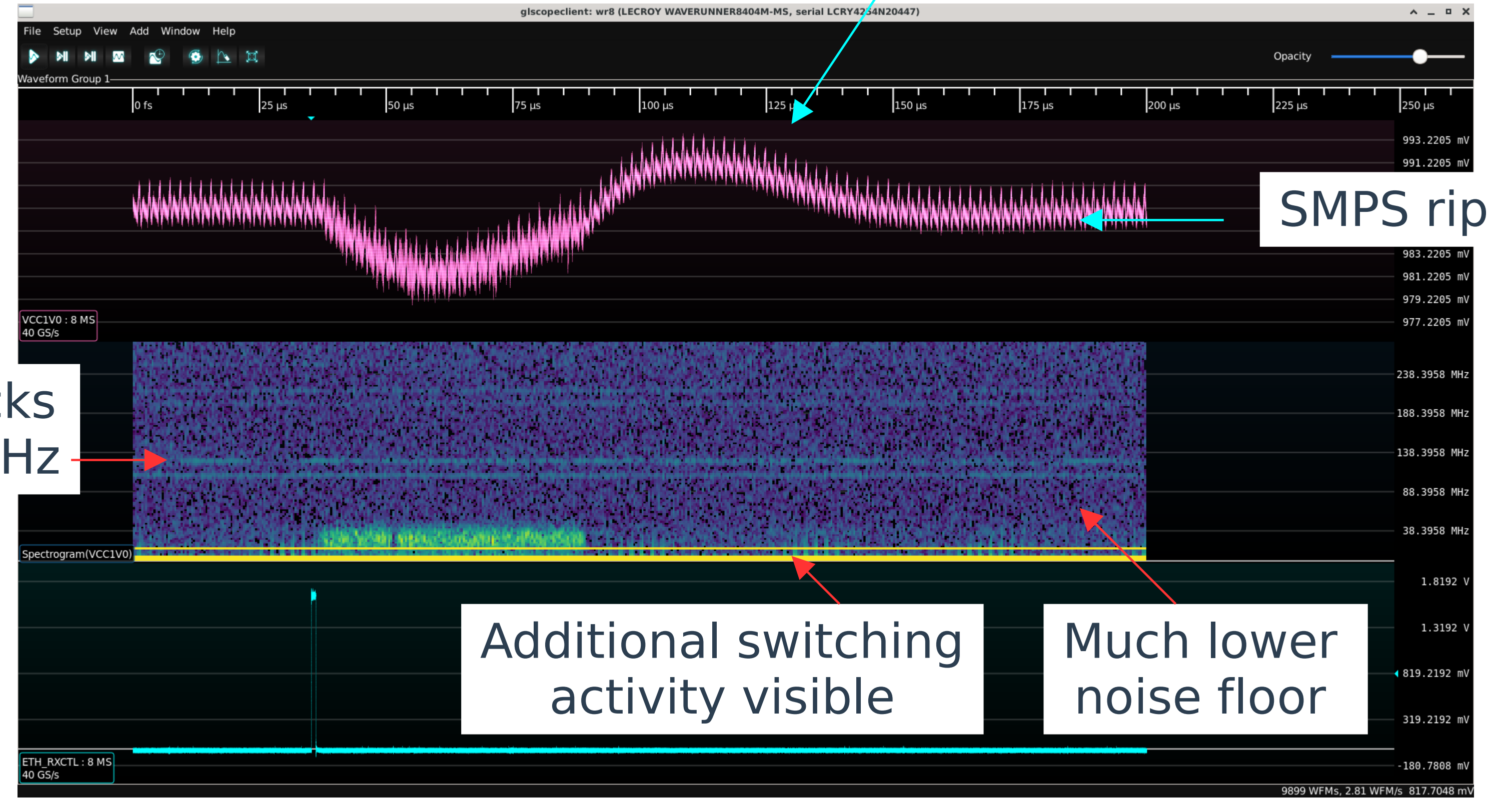
Overshoot as control loop recovers from transient

SMPS ripple

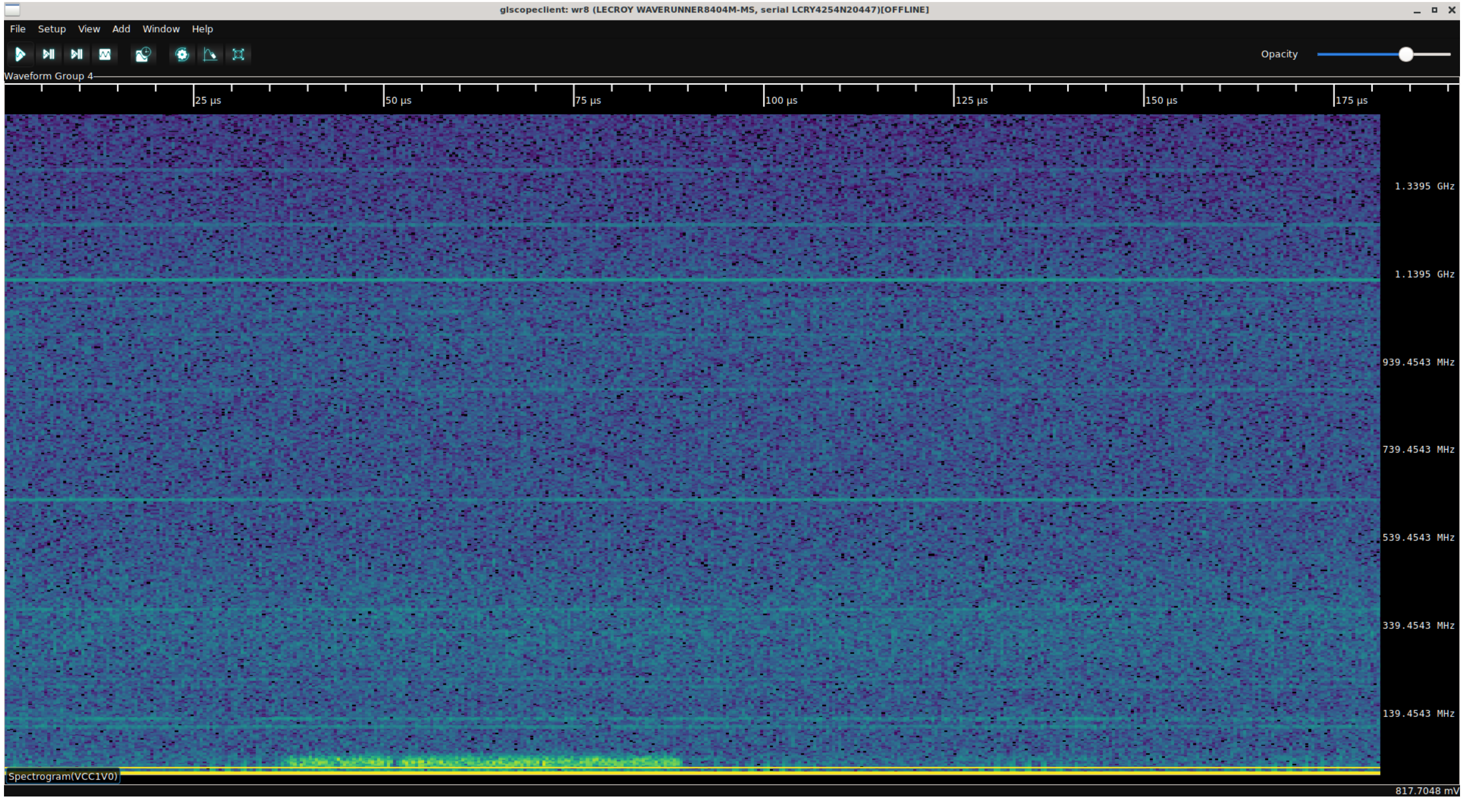
On-die clocks 108, 125 MHz

Additional switching activity visible

Much lower noise floor



Better view of spectrogram



Power Rail Probe: Strengths

- **Extremely low noise**
- **Very low attenuation (close to 1:1)**
  - Can detect extremely weak signals

Power Rail Probe: Weaknesses

- Expensive (RP4030 $3016, TPR4000 $7380)
- Limited dynamic range (± 1V or less)
- Not much good for anything but power rails

Power Rail Probe: When to use

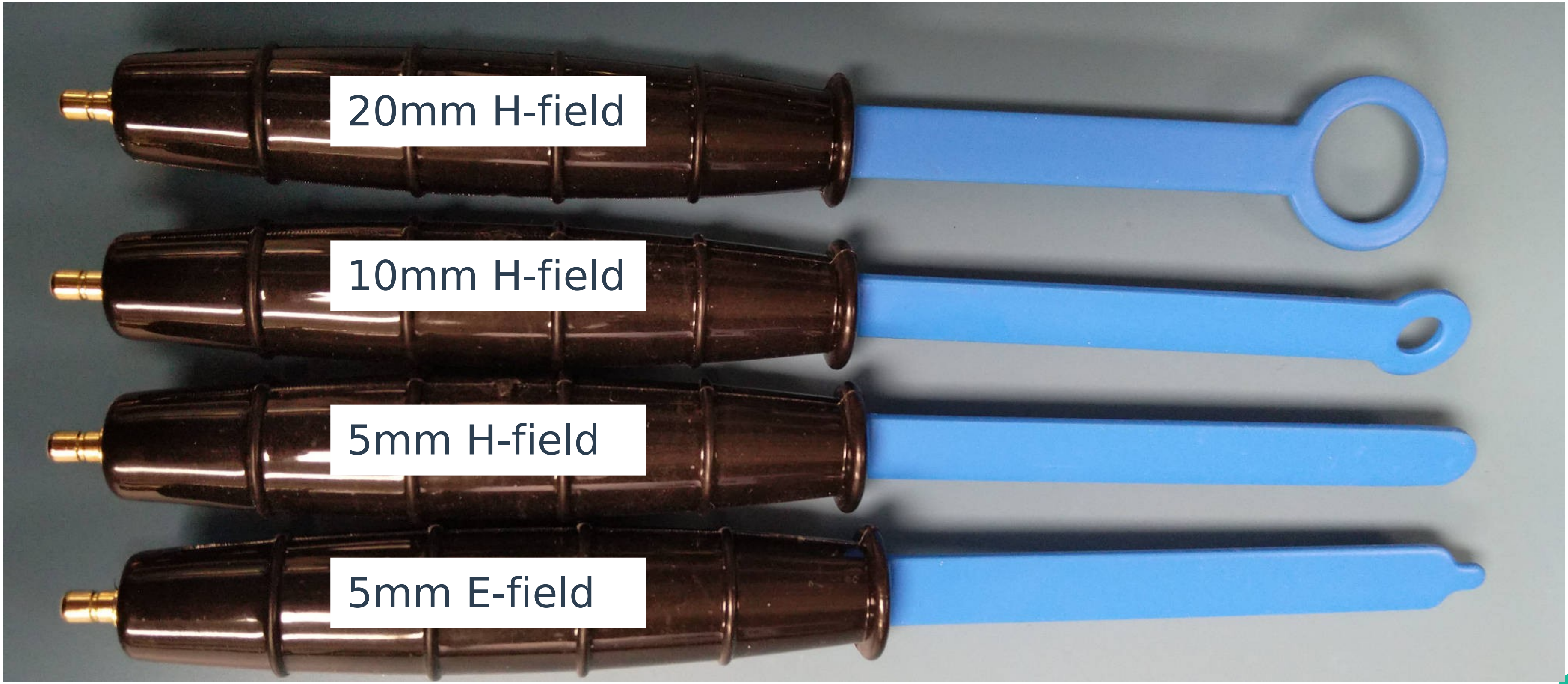
- Power integrity measurements
- Millivolt signals on large DC bias

Nearfield Loop Probes

Nearfield Loop Probe

- **Variants available for both H- and E-fields**
- **Short range RF pickup**
- **Typically used for EMC testing**
  - Precompliance
  - Tracking down source of a failure

Nearfield Loop Probe (Tekbox TBPS01)



Nearfield Loop Probe

- **Coupling varies with distance from DUT**
  - Not useful for quantitative intensity measurements
  - But allows precise physical location of emitter to be found
- **Often used for ratiometric EMC measurements**
  - Place probe a fixed distance from DUT
  - Compare field strength before / after some change
- **Ratio doesn’t scale 1:1 with far field strength**
  - But usually close enough if you add some safety margin

Nearfield Loop Probe

- Start with sensitive probe for long range scanning
- Move to smaller one to pin down exact source
- May need external LNA for weak signals

Nearfield Loop Probe: Strengths

- **Very broadband (most go to several GHz)**
- **Only real option for benchtop EMC testing**
  - Calibrated antenna in anechoic chamber is definitive
  - But they’re big and expensive!
- **Allows spatial location of emitter to be found**

Nearfield Loop Probe: Weaknesses

- **Very sensitive to exact position**
  - Not useful for quantitative measurements
- **Ultra specialized**
  - Not useful for much besides EMC testing

Nearfield Loop Probe: When to use

- **Identifying the source of an EMC problem**

Current Probes

Current Probe: Types

- Current transformer
- Hall effect
- Rogowski coil
- Flux gate
- Anisotropic magnetoresistive (AMR)
- Shunt resistor and differential probe

AMR Positional B-Field Probe (Little Bee)

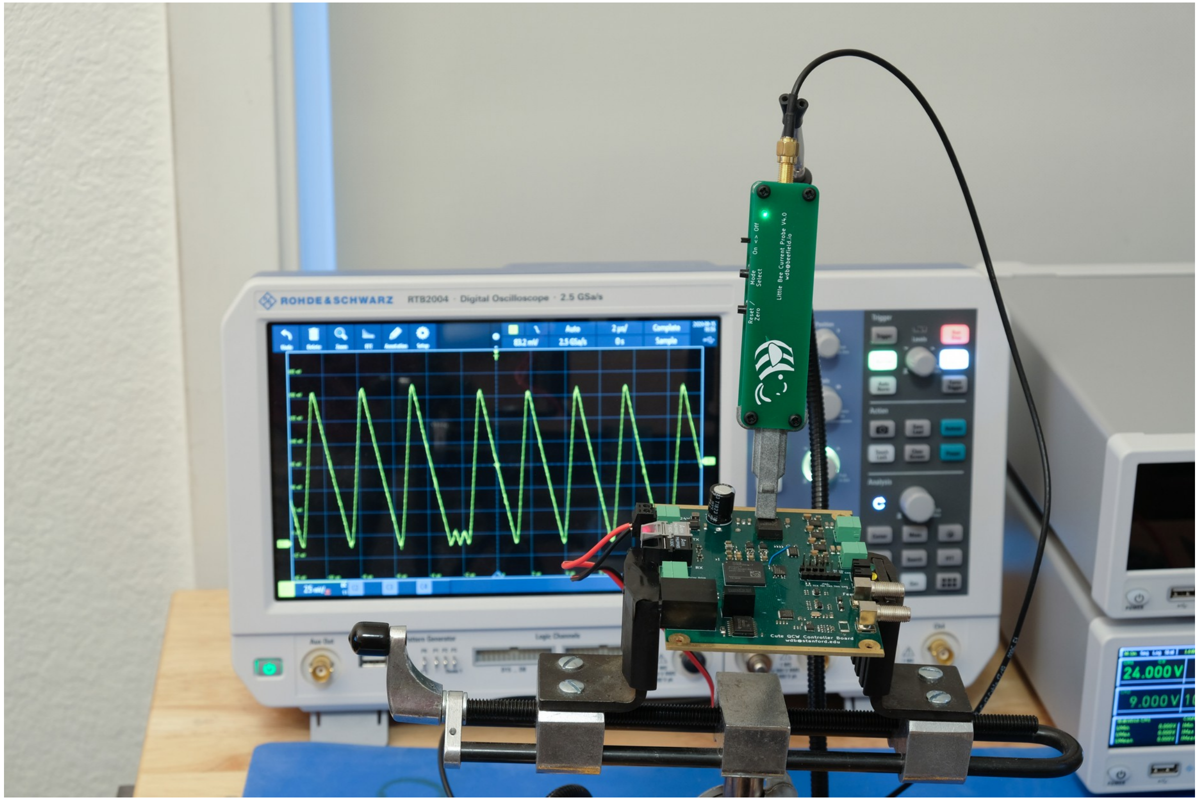


Photo courtesy of Weston Braun (Stanford)

Current Probe: Strengths

- **Doesn’t require breaking circuit to add shunt**

Current Probe: Weaknesses

- **Some can only see AC**
- **Most are mechanically fragile**
  - Hall sensor on ferrite core is extremely impact sensitive
- **Most have to clamp around a wire**
  - Difficult to measure signals on PCB
  - Provide wire loop test points if planning to measure current
- **Typically designed for 10s or 100s of amps**
  - Hard to measure really small currents

Current Probe: When to use

- Power supply design
- Motor control applications

High Voltage Probes

High Voltage Probes

- **Many different designs for different applications**
  - HV passive
  - Fiber isolated
  - HV differential

High Voltage Passive Probes

- **Classic R-C divider architecture**
- **Much higher attenuation**
  - Teledyne LeCroy PPE5KV is 100:1, 5 kV max

High Voltage Fiber Isolated Probe

- **Measuring small signal on huge DC offset**
  - Teledyne LeCroy HVFO108 has 35 kV common mode range
  - Amplitude ranges from ±1V to ±40V
- **Isolated front end driving optical fiber TOSA**
- **ROSA feeds scope input**
- **Often not a simple linear system**
  - Fiber transceivers have poor linearity
  - HVFO108 uses FM over the fiber

High Voltage Differential Probe

- **Active differential probe for HV applications**
- **Pico TA044 ($1075)**
  - 70 MHz B/W
  - Switchable 100:1 / 1000:1 attenuation
  - 700 V RMS / 5 kV RMS differential range
  - 2.5 kV RMS common mode range

HV Probe: Strengths

- **Extends range of scope to several kV**

HV Probe: Weaknesses

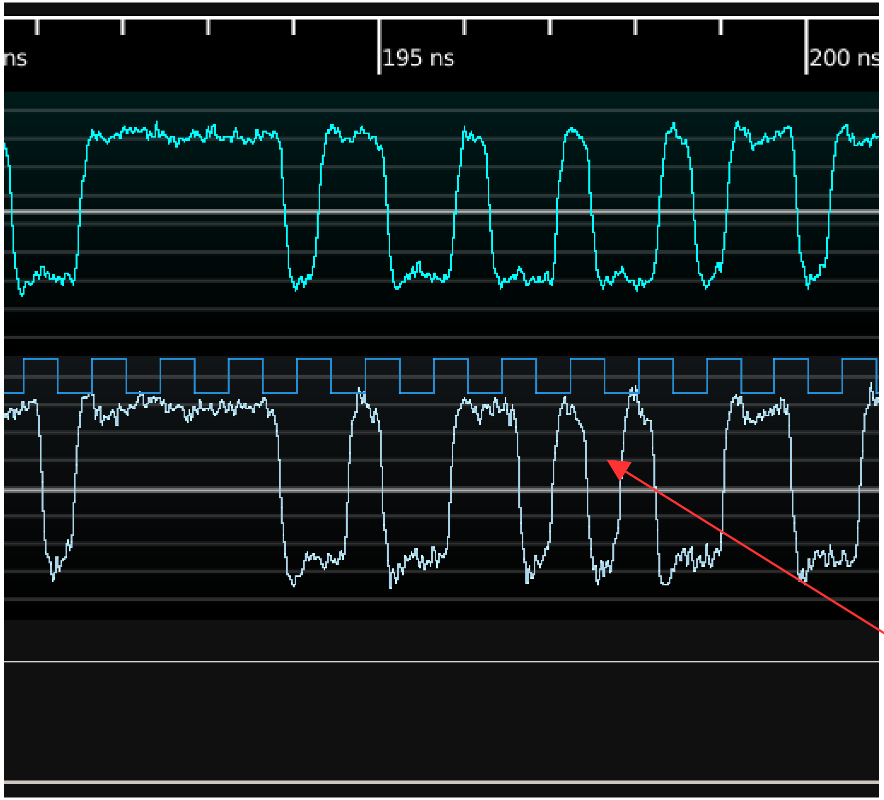
- **Active probes often need batteries for remote head**
  - Can’t be powered directly by scope
  - Some fancier ones include isolated DC-DC supplies
- **Passive probes have frequency derating**
  - Often can’t hit rated BW and voltage at once
- **Low bandwidth (tens to low hundreds of MHz)**

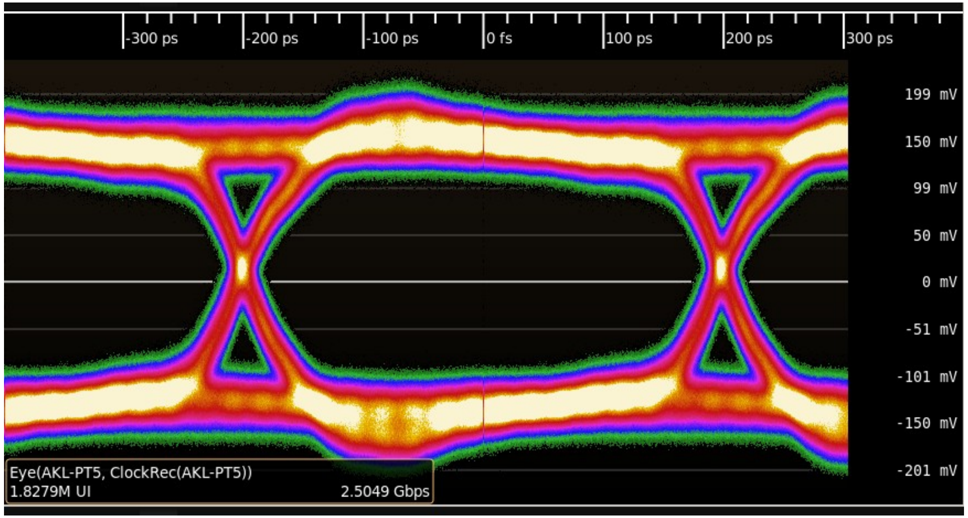
HV Probe: When to use

- Measuring high voltages
- If DC isolation is required for any other reason

Effects of Limited Bandwidth

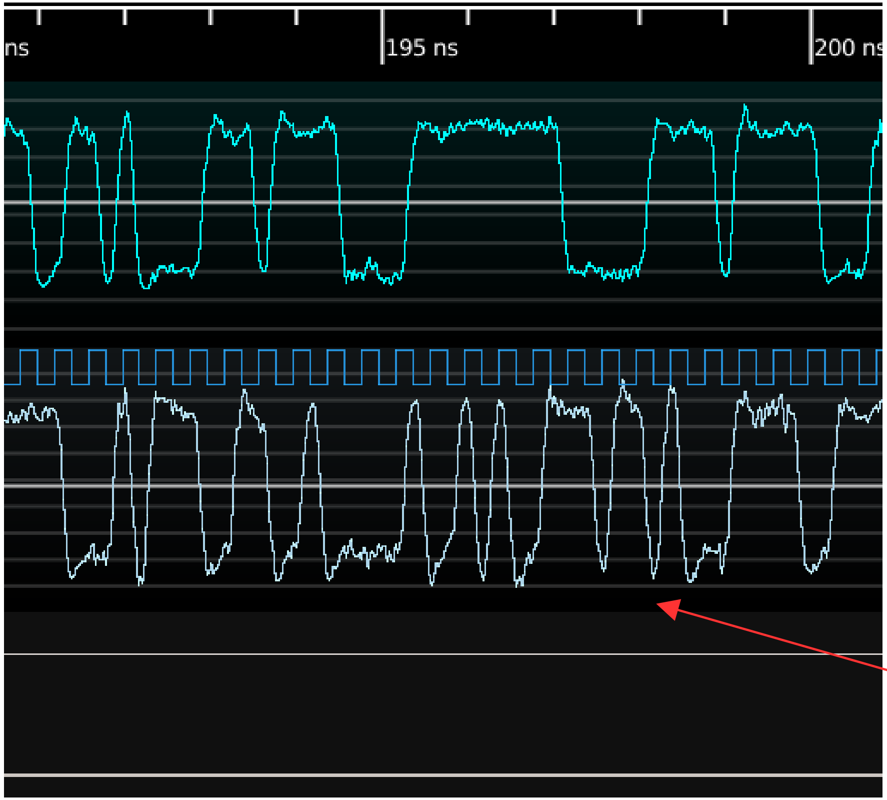
5 GHz probe, 2.5 Gbps signal

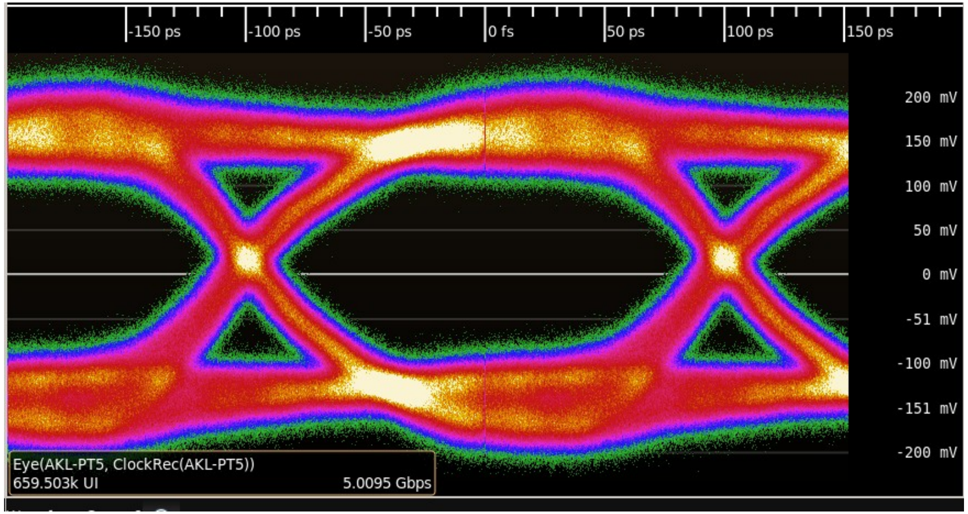




Separate rise / stable / fall regions
Bits are equal amplitude

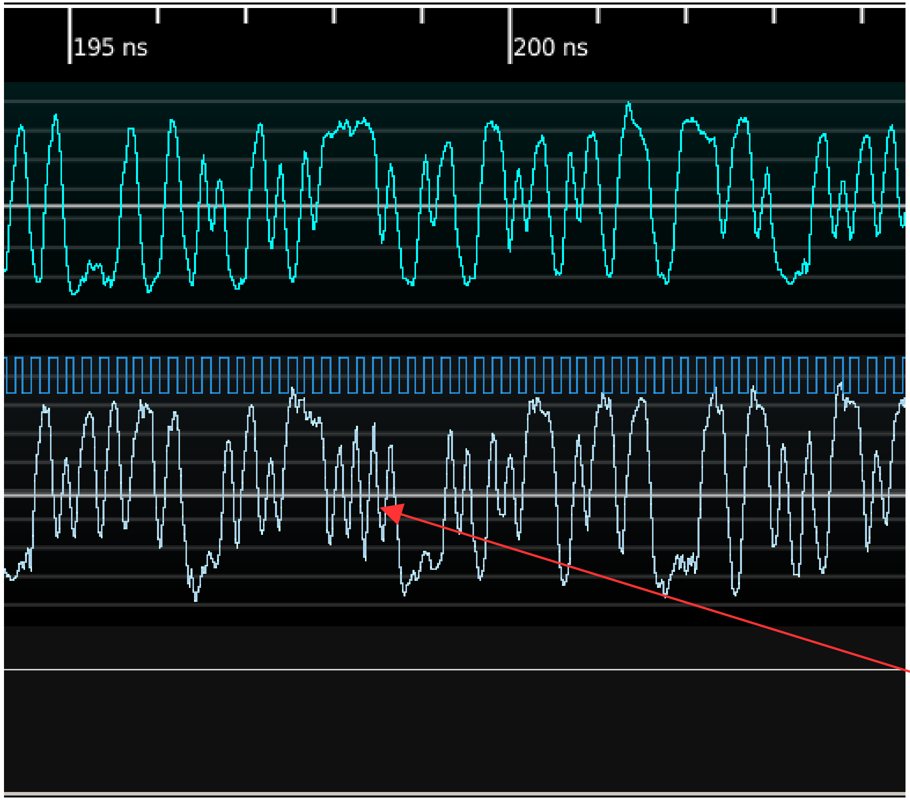
5 GHz probe, 5 Gbps signal

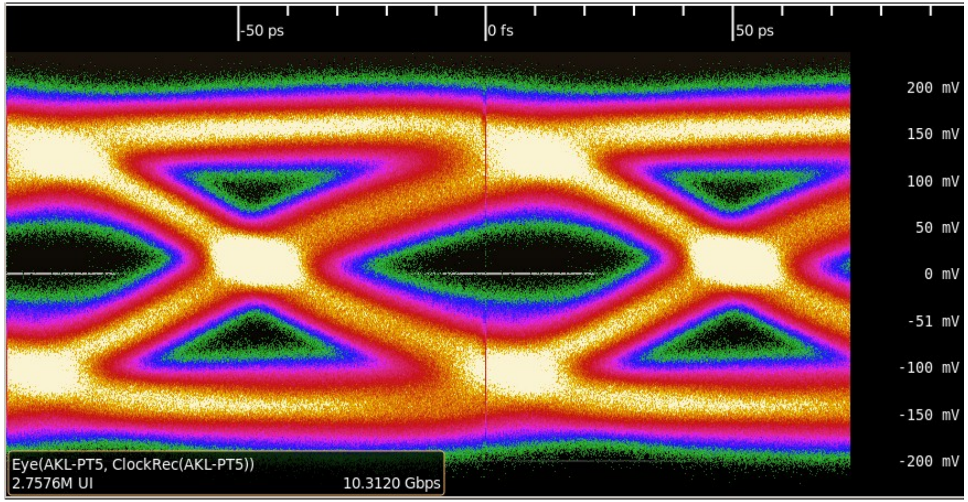




Bits look more sinusoidal
Still roughly equal amplitude

5 GHz probe, 10.3125 Gbps signal

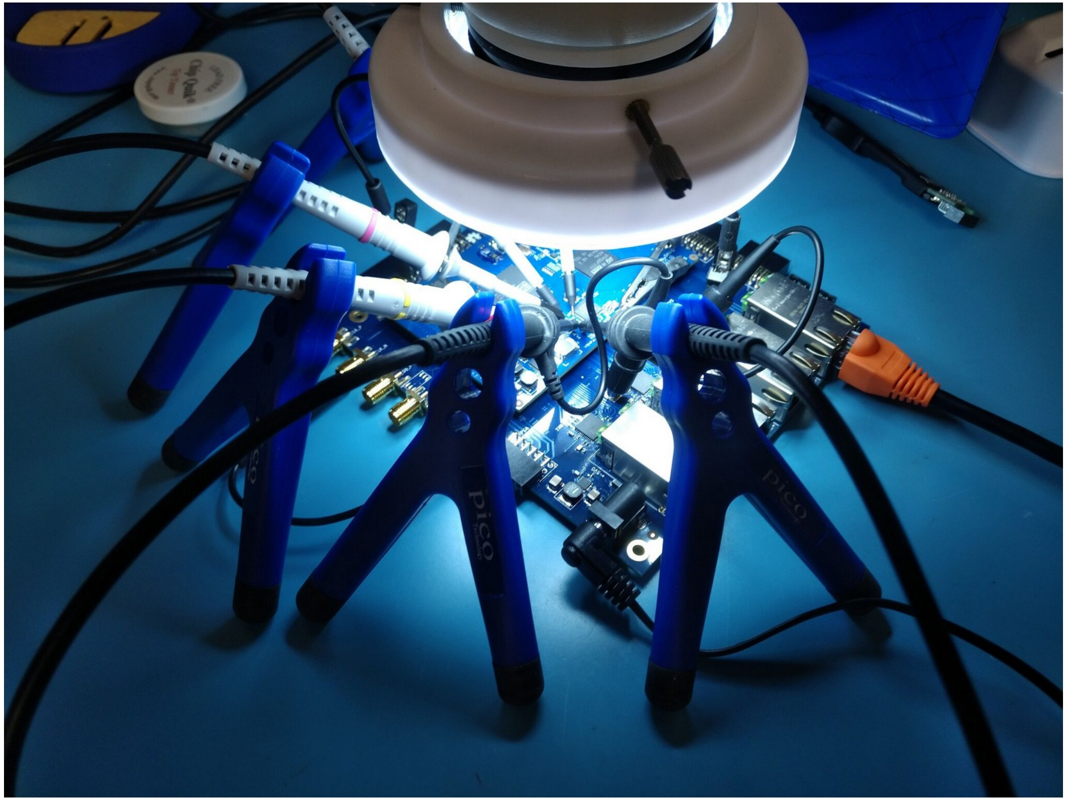




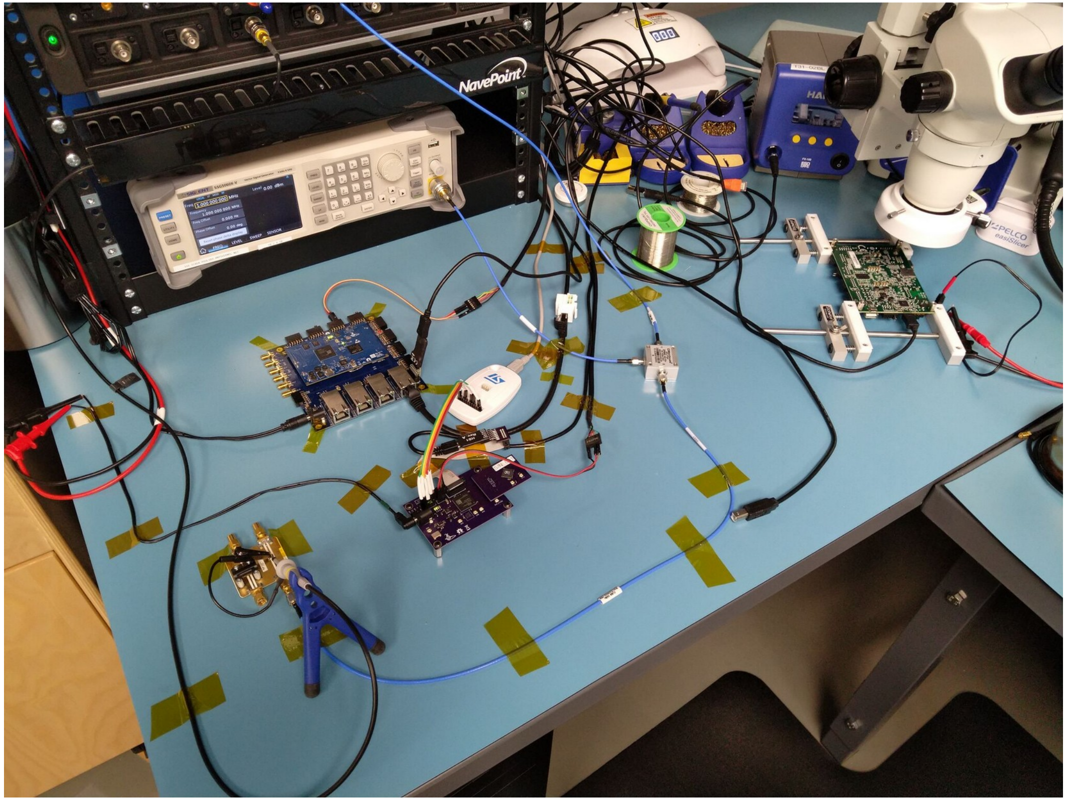
Fast toggles do not reach full amplitude
This leads to ISI

Miscellaneous Tips

Passive Probe Holders



Securing Cabling with Kapton Tape



Concluding Remarks

Conclusions

- **Huge range of options, prices, features**
  - Some general purpose, some very specialized
- **Easy to get garbage results with poor technique**
- **Understanding your probe helps you use it well**

Questions?