Measurement Techniques

- Primary measurement tool: Oscilloscope
  Other lab tools: Logic Analyser, Gain-Phase Analyser, Spectrum Analyser…
- Visualisation of electrical signals in the time domain
  - Visualisation of voltages through voltage probes (standard)
  - Visualisation of currents through current probes and current amplifiers
- Advanced scopes: Visualisation of signals in the frequency domain (FFT)

Measurement Techniques/DSO

High speed digital design:
Use a DSO with adequate bandwidth!

Features of modern scopes

•Type: Digital Storage Oscilloscope (DSO)
•Channels: 2 (standard), 4 (better)
•Bandwidth: 100MHz … >5GHz
•Sampling rate: 200MS/s …
•Memory: 1kpts … Mpts
•Advanced triggering
•Signal analysis
•8/10/12 bit vertical resolution with 1% vertical precision
•Export of data (USB)
•Remote control (GPIB)

Digital storage oscilloscopes allow to capture and view events that may only happen once. Note the DSO's relatively poor vertical characteristics.

Measurement Techniques/DSO

Primary Limitations of Scopes

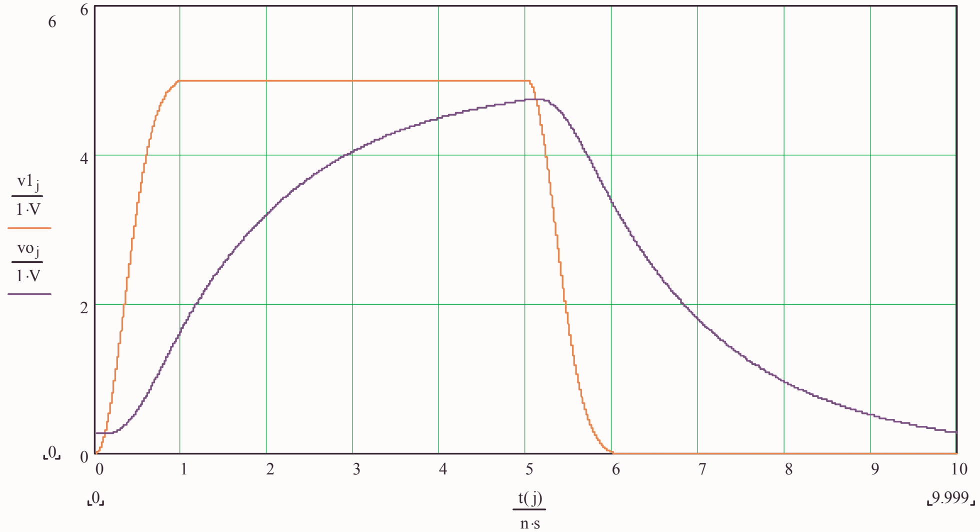
- Vertical sensitivity. Most scopes offer a range of 10mV/div … 10V/div
- Limited bandwidth

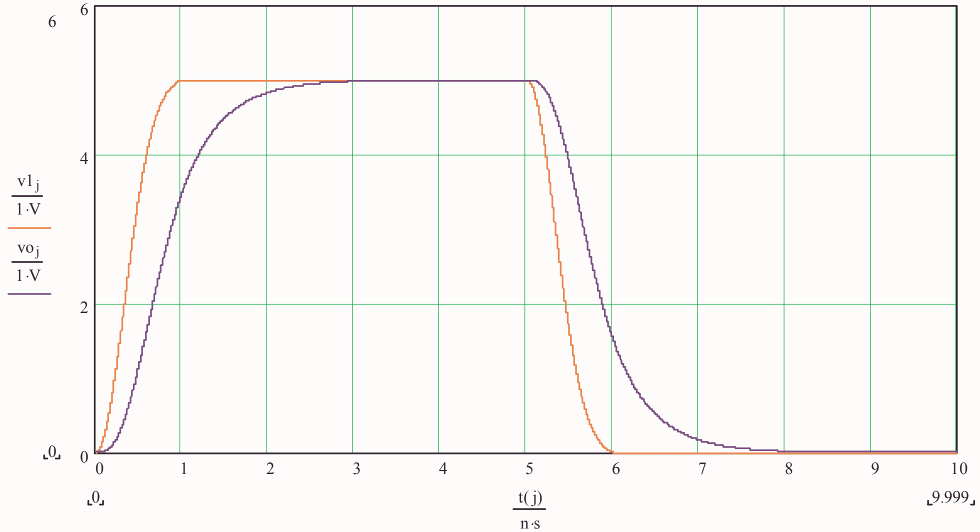
With respect to High-Speed Digital Design

- Vertical sensitivity of DSOs adequate for most digital situations
- Bandwidth!

What do bandwidth numbers mean?
Can you measure a 99MHz signal using a scope with a 100MHz bandwidth?
What exactly do you mean by “a 99MHz signal”. Sine wave? Bitrate?

Measurement Techniques/DSO/Bandwidth





Example Parameters

•Signal: fcycle=100MHz with Tr/Tf=1ns

•Top: Scope BW = 100MHz

•Bottom: Scope BW = 350MHz

Signal distortion:

Signal harmonics are attenuated and phase-shifted by different amounts.

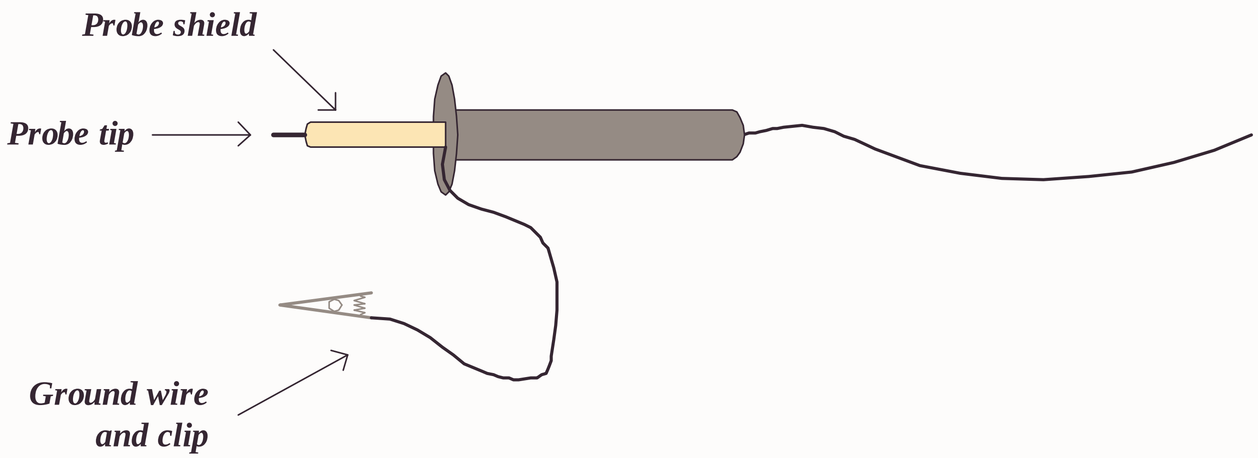
remember that $$f_{knee} \approx \frac{0.35}{Tr_{10\%-90\%}}$$

Measurement Techniques/DSO/Probes

Scope probes establish a connection between the circuit under test (CUT) and the scope.
Mission of scope probes: "Extract minimal energy from the CUT and transfer it to a scope with maximum fidelity".

Scopes can only measure what they can "see" at their input ports. Choosing proper probes is vital for your measurement system.

Measurement Techniques/DSO/Probes

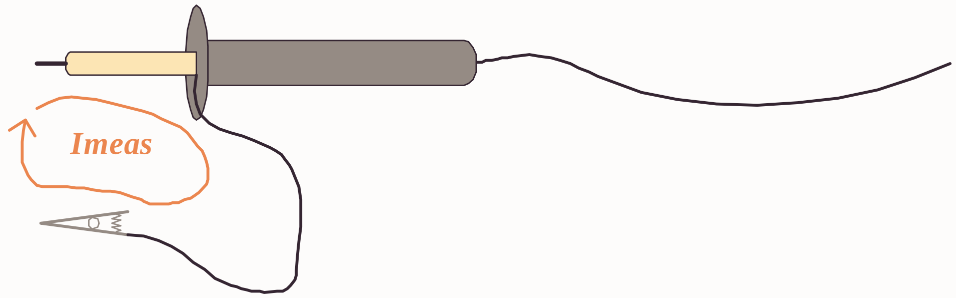


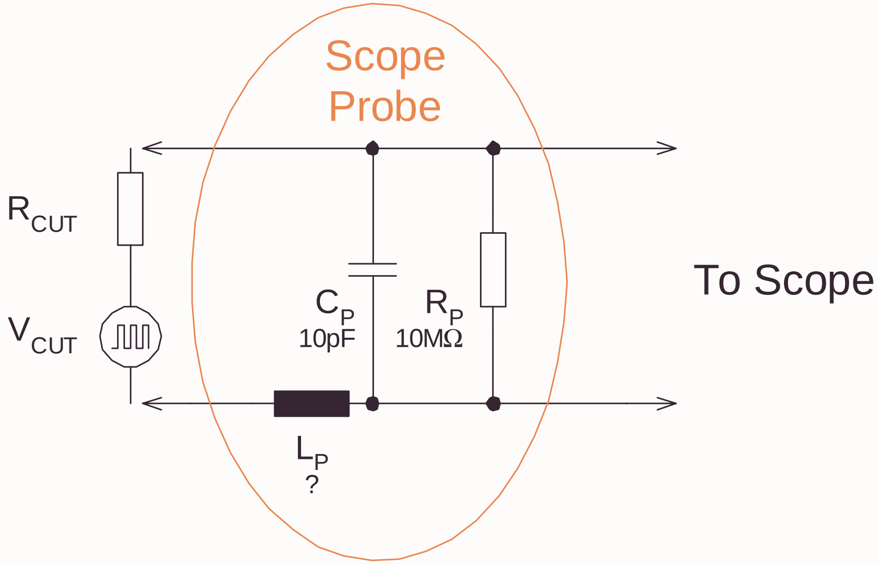
Primary factor degrading the performance of scope probes when used in high-speed digital electronics:

- Inductance of the ground wire

Watch out:
Bandwidth specifications of scope probes do NOT include the ground wire !

Measurement Techniques/DSO/Probes





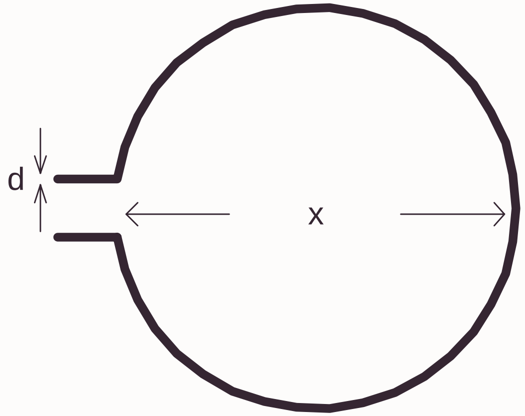
How does the inductance of the ground wire affect measurements?

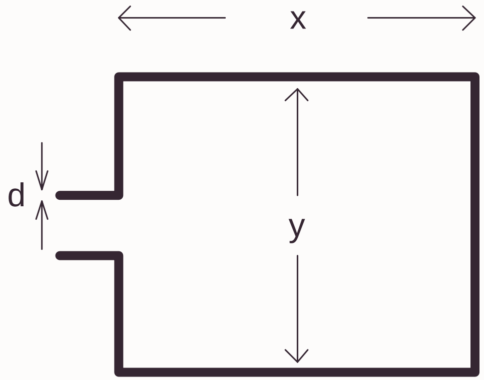
•Estimation of the ground loop inductance of the scope probe…

•Estimation how the ground loop inductance affects the rise time...

Measurement Techniques/Loop inductances

Estimation of self inductance of circular and rectangular loops:





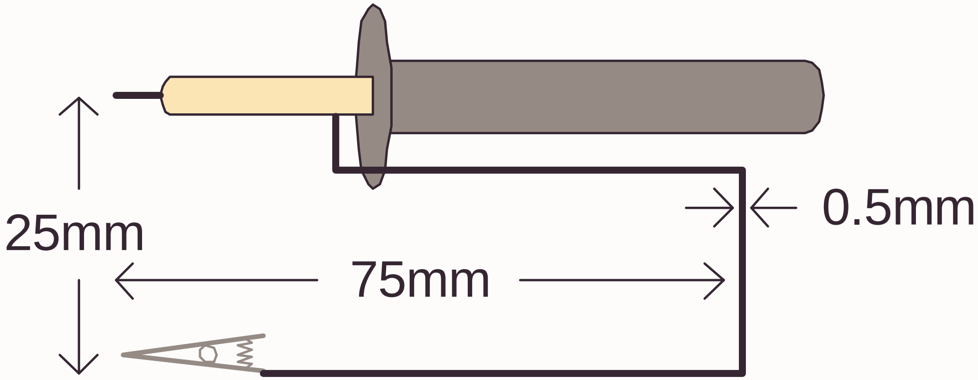
$$L_{circ} \approx 614 \frac{nH}{meter} \cdot x \cdot \left(\ln\left(\frac{8x}{d}\right) - 2 \right)$$

Note:
- valid for x>>d
- small influence of wire diameter

$$L_{rect} \approx 400 \frac{nH}{meter} \cdot \left(x \cdot \ln\left(\frac{2y}{d}\right) + y \cdot \ln\left(\frac{2x}{d}\right) \right)$$

Note:
- valid for x>>d and y>>d
- small influence of wire diameter

Measurement Techniques/Loop inductances



Example Parameters

- 500MHz passive probe
- Ground wire 25mm x 75mm x 0.5mm
- Probe capacitance 10pF

•Self inductance of ground wire loop is around 200nH (!)
•Self inductance and capacitance of the probe result in a signal rise time of 4.7ns
•The knee frequency of this signal is around 74MHz. The 500MHz probe has been degraded to a 74MHz probe by the ground wire.

The bandwidth of a passive probe can be substantially reduced by ground wires!

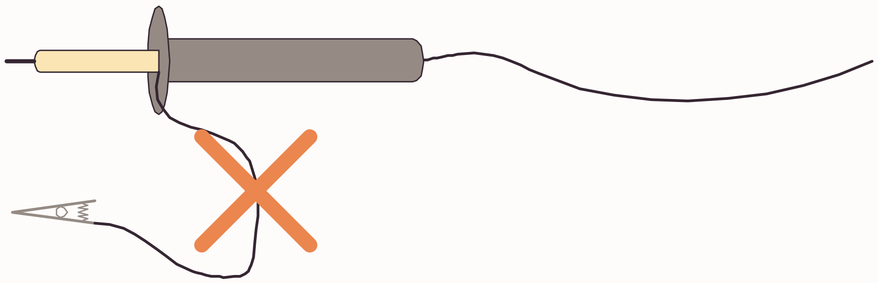
Measurement Techniques/Loop inductances

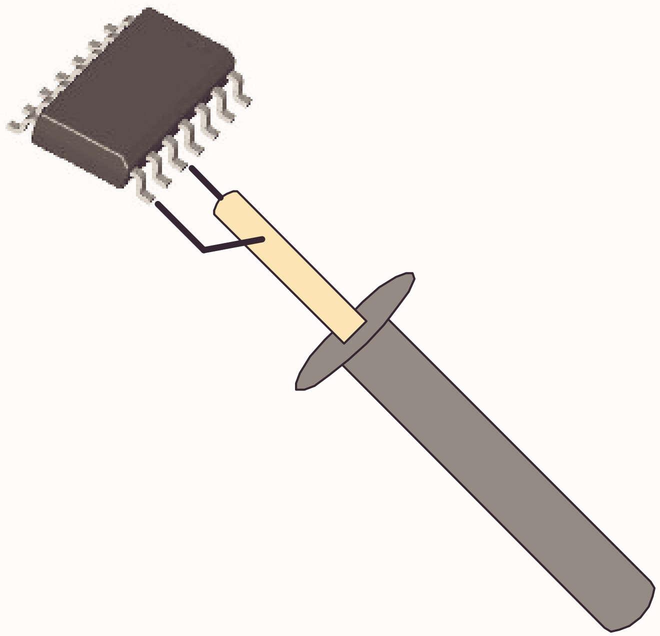
Therefore...

•Don’t use ground wires for measuring high-speed digital signals

•Use special probe tips (bare probe tip with probe collar directly grounded to circuit board)

•In general: Minimise loop areas





Measurement Techniques/DSO Pitfalls

More scope probe pitfalls...

•Capacitive loading of CUT due to scope probe.
Example: A 10pF probe represents an impedance of 136Ω to a signal with Tr=3ns

•Pickup of EM fields
- •For minimum magnetic field pickup: minimise ground loop area
- •Electric field pickup: hardly ever a problem in digital electronics
- •Popular trick of designers: Use scope probe as an EM field sensor

•Noise pickup due to probe shield currents

Remember: Composite rise time of scope probe and scope...

$$Tr_{composite} = \sqrt{\sum_{i=1}^{n} Tr_i^{\ 2}} = \sqrt{T_{probe}^{\ 2} + T_{scope}^{\ 2}}$$