Digital Scopes and Signal Fidelity

- Time domain measurements
- Pulse generators
- Digital sampling oscillascopes
- Transmission lines and impedance matching
- Lab exercise

Time Domain Measurements

- Pulsed LIV measurements avoid heating
  - 10-100 ns
  - duty cycle (pulse width/period) < 1%
- Carrier lifetime from transient PL
  - 100fs – 1ns
- Modulation characteristics and eye diagrams
  - 10ps – 1ns

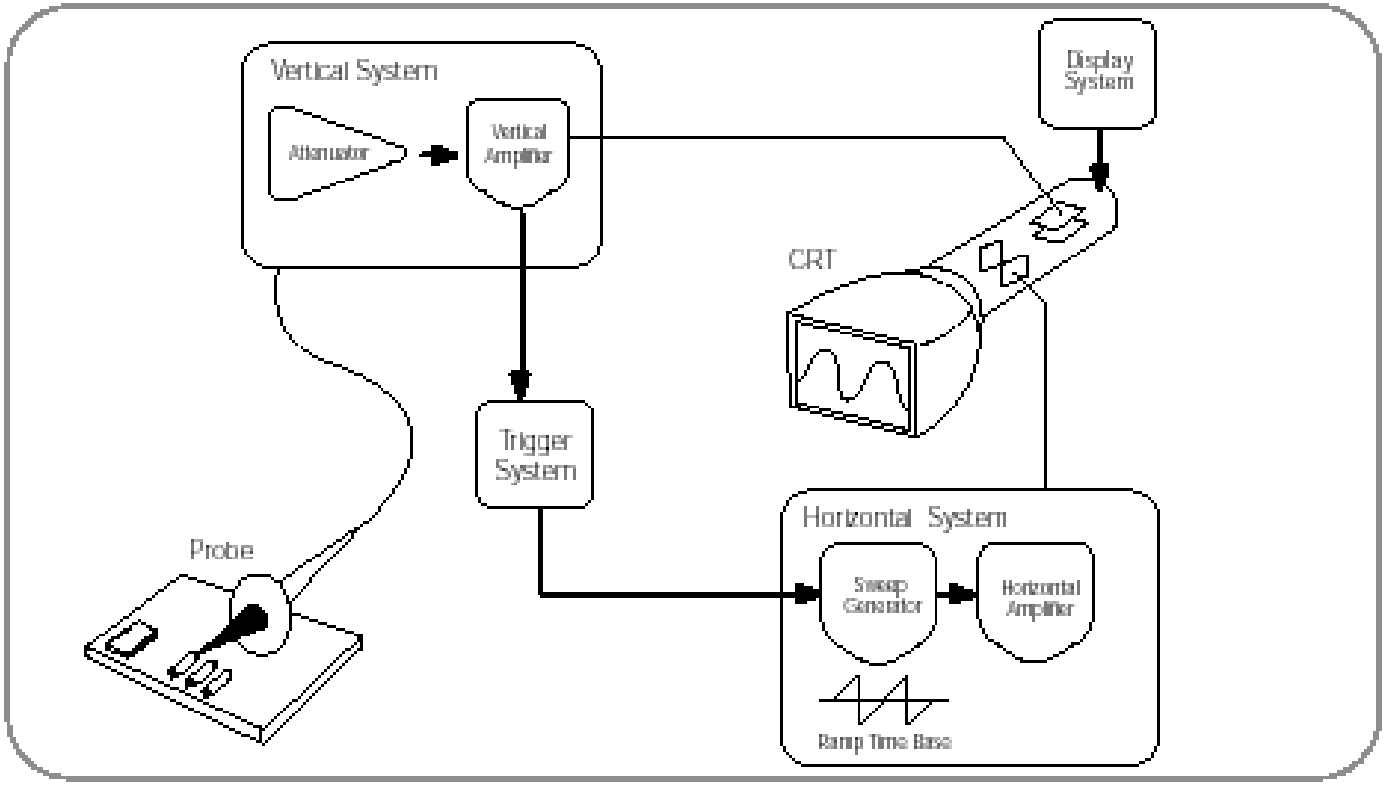
Pulse Generators

- Waveforms: sine, triangle, sawtooth, square, pulse
- Frequency/ repetition rate/ period
- Duty cycle = pulse width/period
- Amplitude and offset
- Trigger modes: continuous, external, gate
- Output impedance, rise and fall times, jitter
- Tolerance to load mismatch

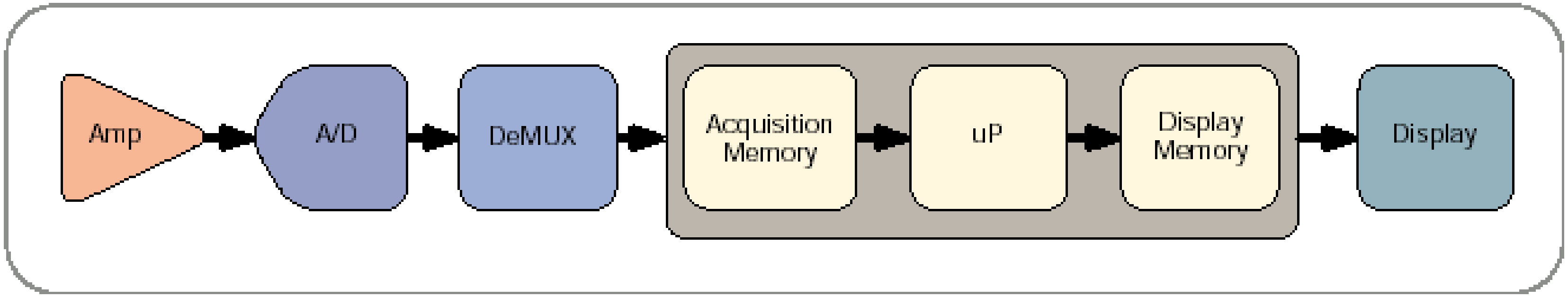
Digital Sampling Oscilloscopes

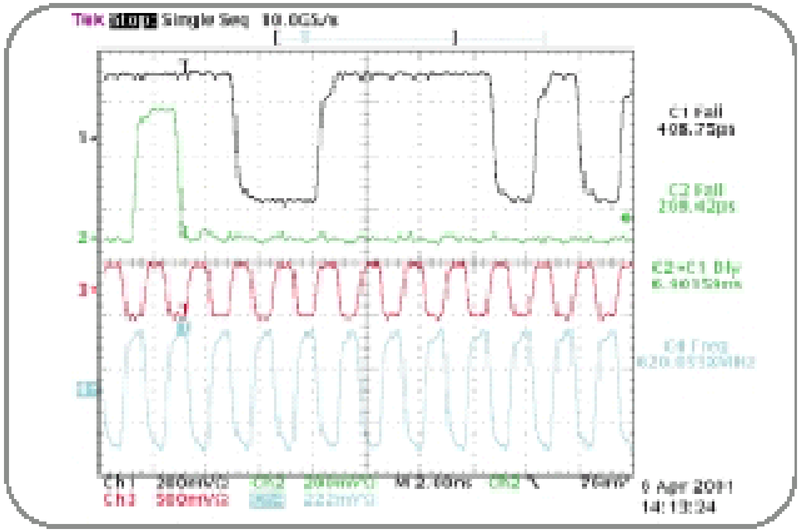
- Sampling and the Nyquist Theorem
- Sampling rate and bandwidth
- Front-end bandwidth
- Triggering and memory

Analog Oscilloscope



Digital Sampling Oscilloscope

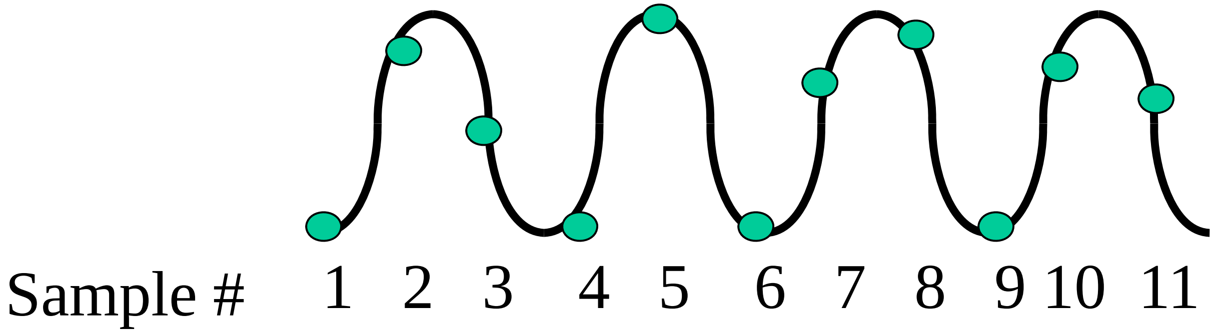




Advantages over analog scopes:

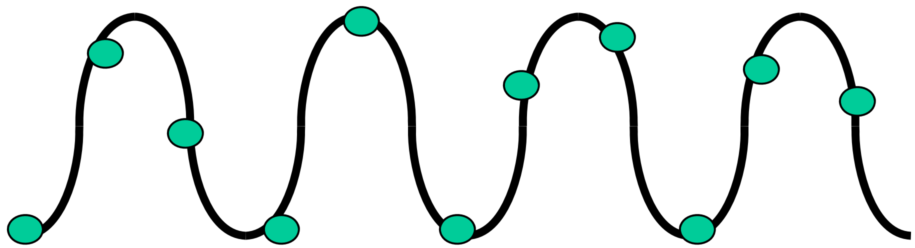
- Higher bandwidth
- Smaller, cheaper
- Advanced signal analysis

Real-time Sampling



- Acquisition of single event
- Expensive to implement

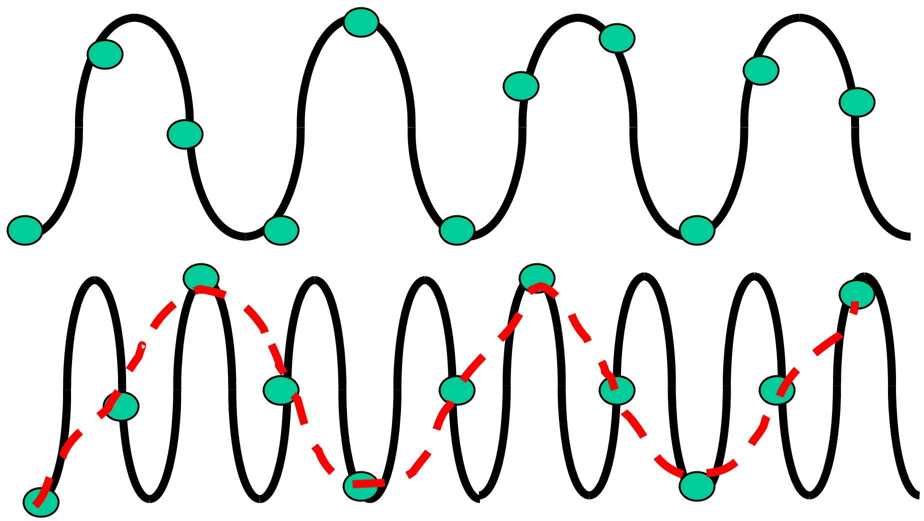
Equivalent-Time Sampling



Sample # 9 6 2 11 5 1 8 3 4 10 7

- Requires repetitive signal
- A few sampes per trigger: slow acquisition of trace
- Easily implemented: cheap and common

Sampling and Nyquist Theorem



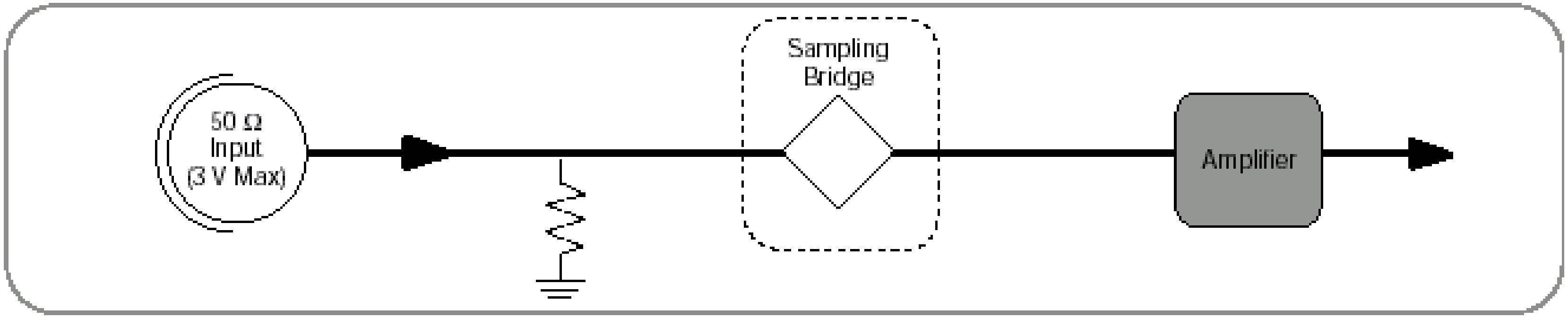
Properly sampled

Undersampled

To avoid "aliasing", sample at least as fast as:

- Nyquist theorem: 2x maximum signal frequency
- Practice: 4x maximum signal frequency

Front End



Scope bandwidth determined by

- Sampling frequency
- Amplifier bandwidth or anti-aliasing filter
- BW =.35 / rise time

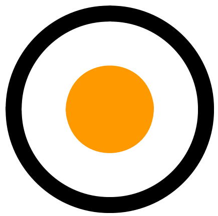
Triggering and Memory

- Analog scopes used complex triggering to begin CRT sweep
- Digital scopes acquire data continuously into large buffer, and use the trigger to determine which data block to show

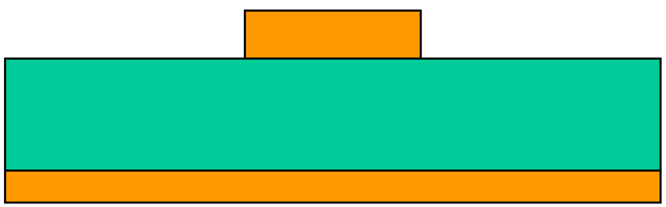
Electrical Reflections

- Impedance
- Waves on transmission lines
- T-line characteristic impedance and mode shape
- Reflections at impedance discontinuities
- Ringing
- Characterization
- Impedance matching
- Tricks of the trade

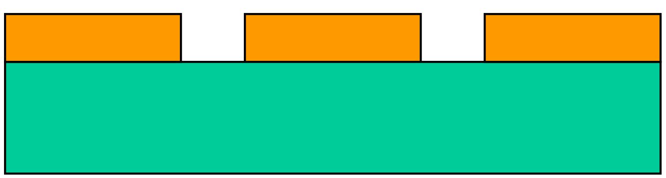
Transmission Lines



Coax
- Flexible
- Reconfigurable
- DC-40 GHz



Microstrip
- Hybrid circuits (MCMs)
- DC-50 GHz



Coplanar Waveguide
- Minimizes lead inductance
- DC->100 GHz

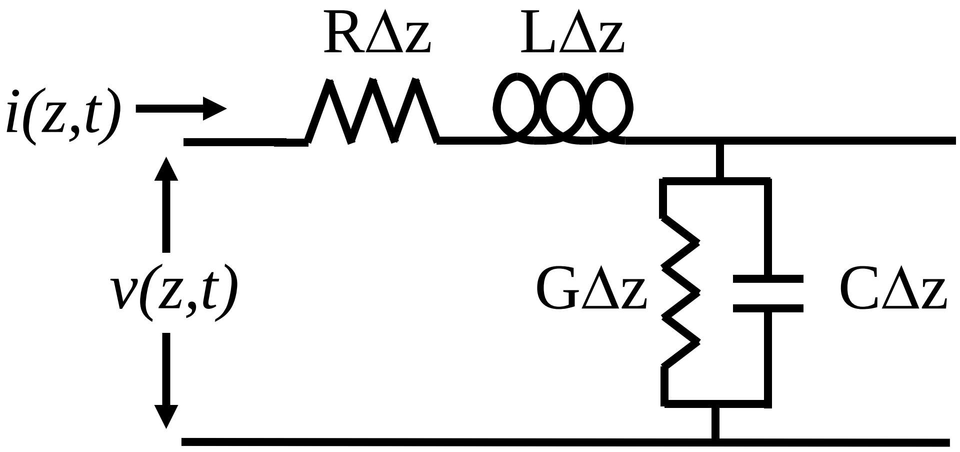
T-Line Characteristics

Lumped Element: $Z = Z_r + jZ_i = R + j\left(\omega L - \dfrac{1}{\omega C}\right)$

Transmission Line: $u = \dfrac{1}{\sqrt{LC}}$ where L,C are now *per unit length*

Propagation velocity: = $u = \dfrac{1}{\sqrt{LC}}$

Waves on Transmission Lines



$$-\frac{\partial v(z,t)}{\partial z} = Ri(z,t) + L\frac{\partial i(z,t)}{\partial t}$$

$$-\frac{\partial i(z,t)}{\partial z} = Gv(z,t) + C\frac{\partial v(z,t)}{\partial t}$$

$$V(Z) = V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z} \qquad I(Z) = I_0^+ e^{-\gamma z} + I_0^- e^{\gamma z}$$

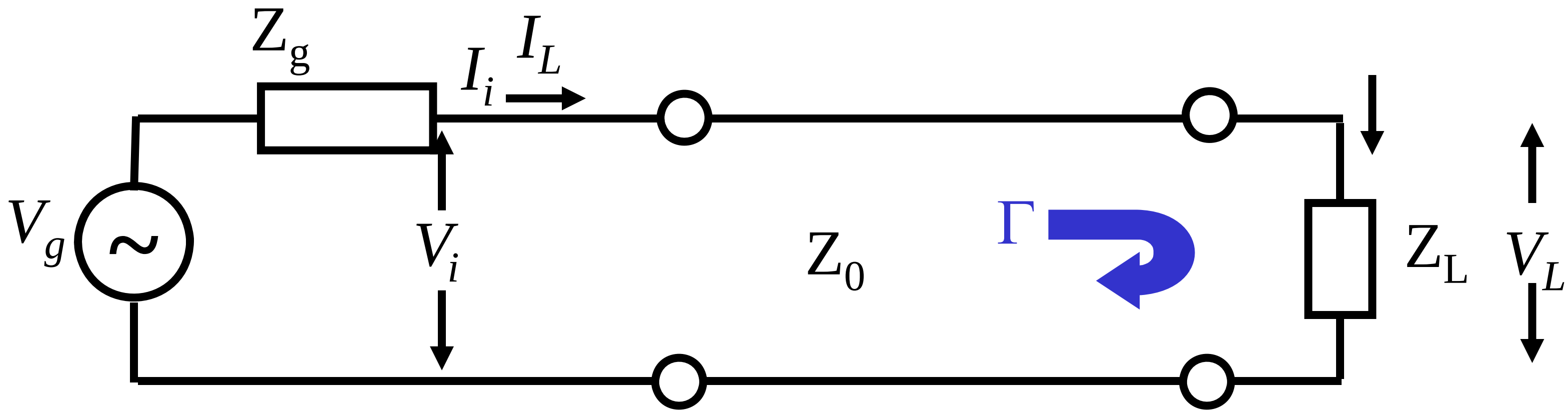
where $\quad \gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$

Common Characteristic Impedances

- 50 Ohm Coax (commonly with BNC connector)
- 75 Ohm Coax
- 300 Ohm Twin lead (antenna wire)

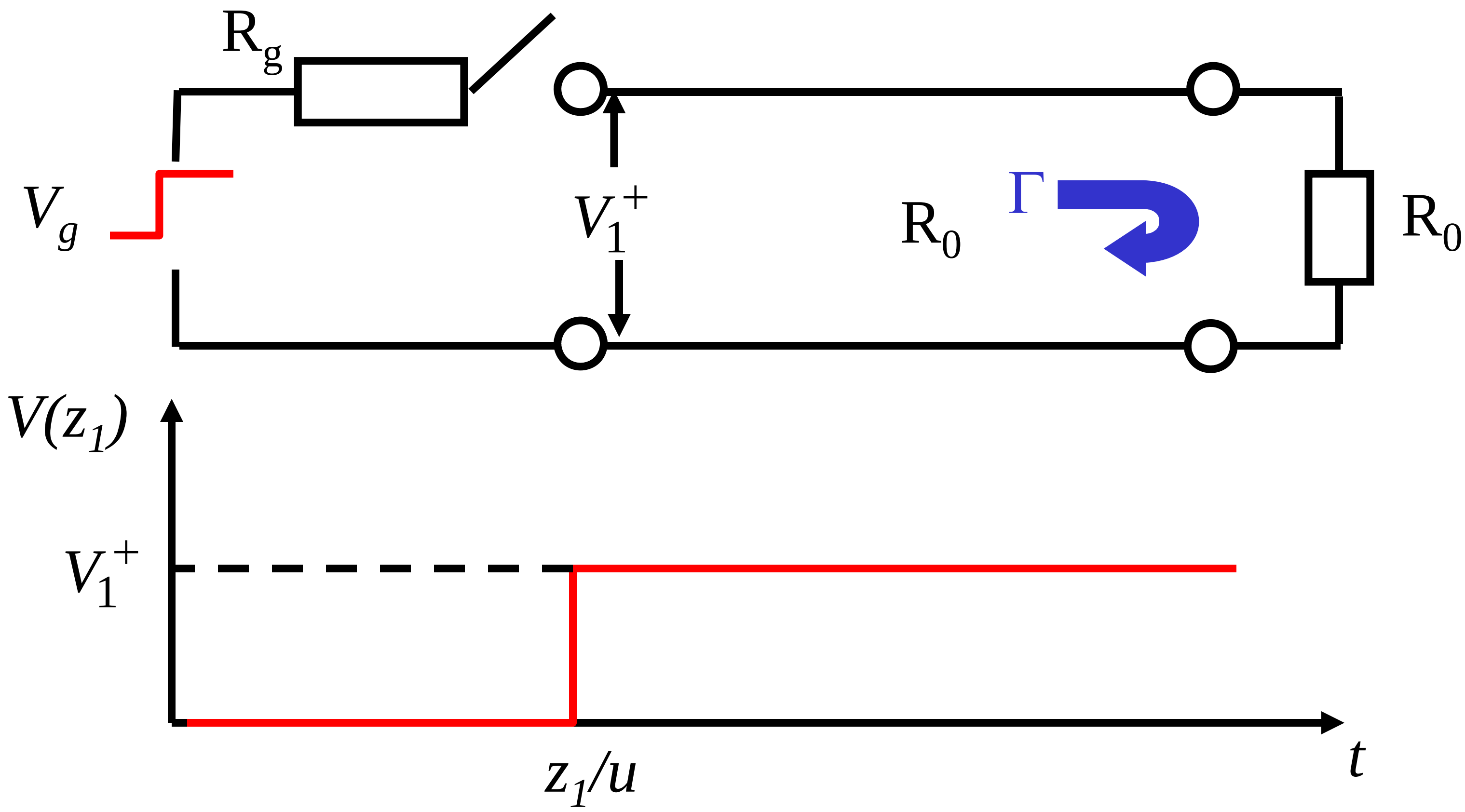
Not All 50 Ohm Coax is the same: Mode mismatch causes loss

Reflections at Impedance Discontinuities



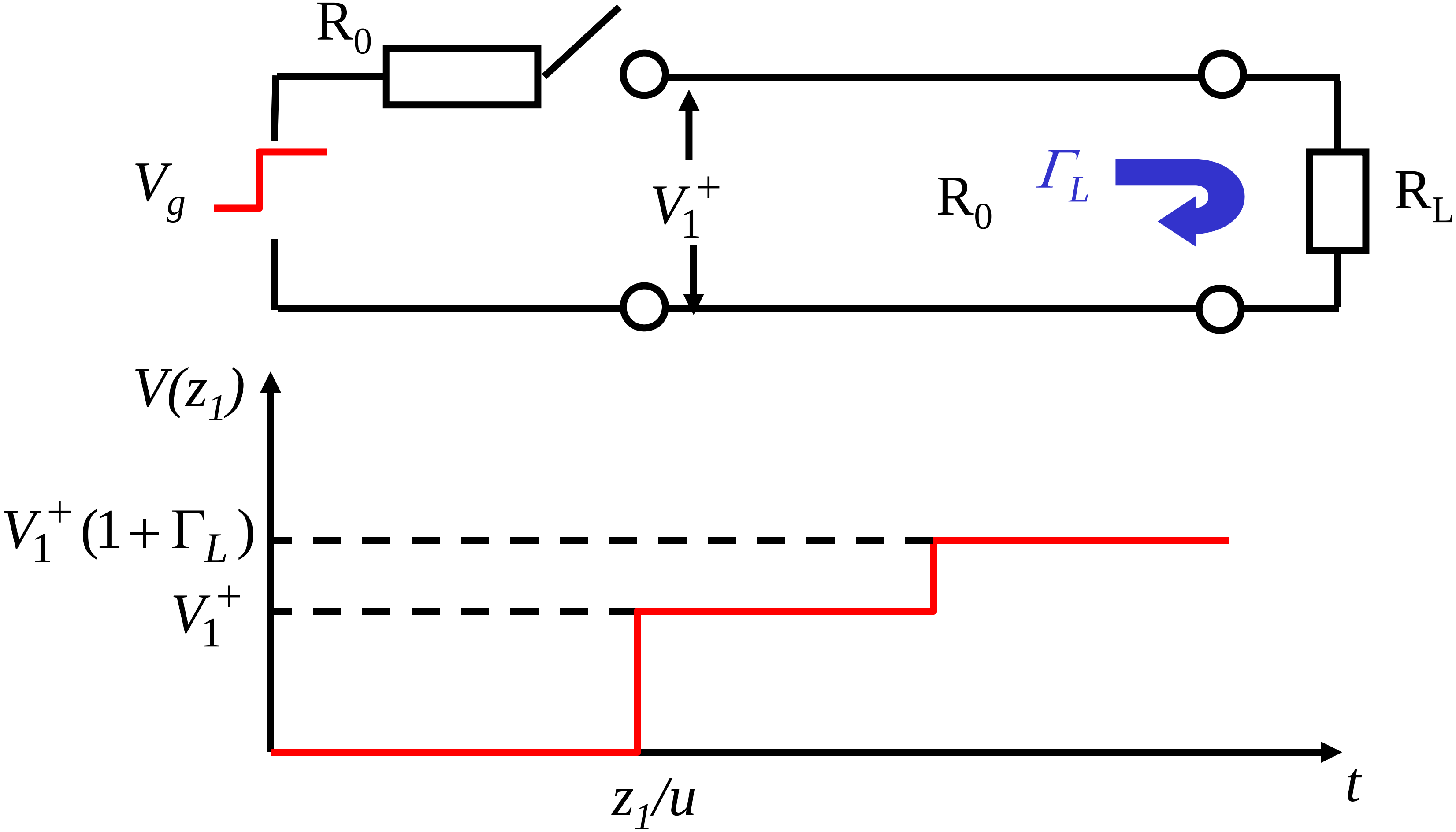
Voltage Reflection Coefficient $$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = |\Gamma| e^{j\theta}$$

Matched Load

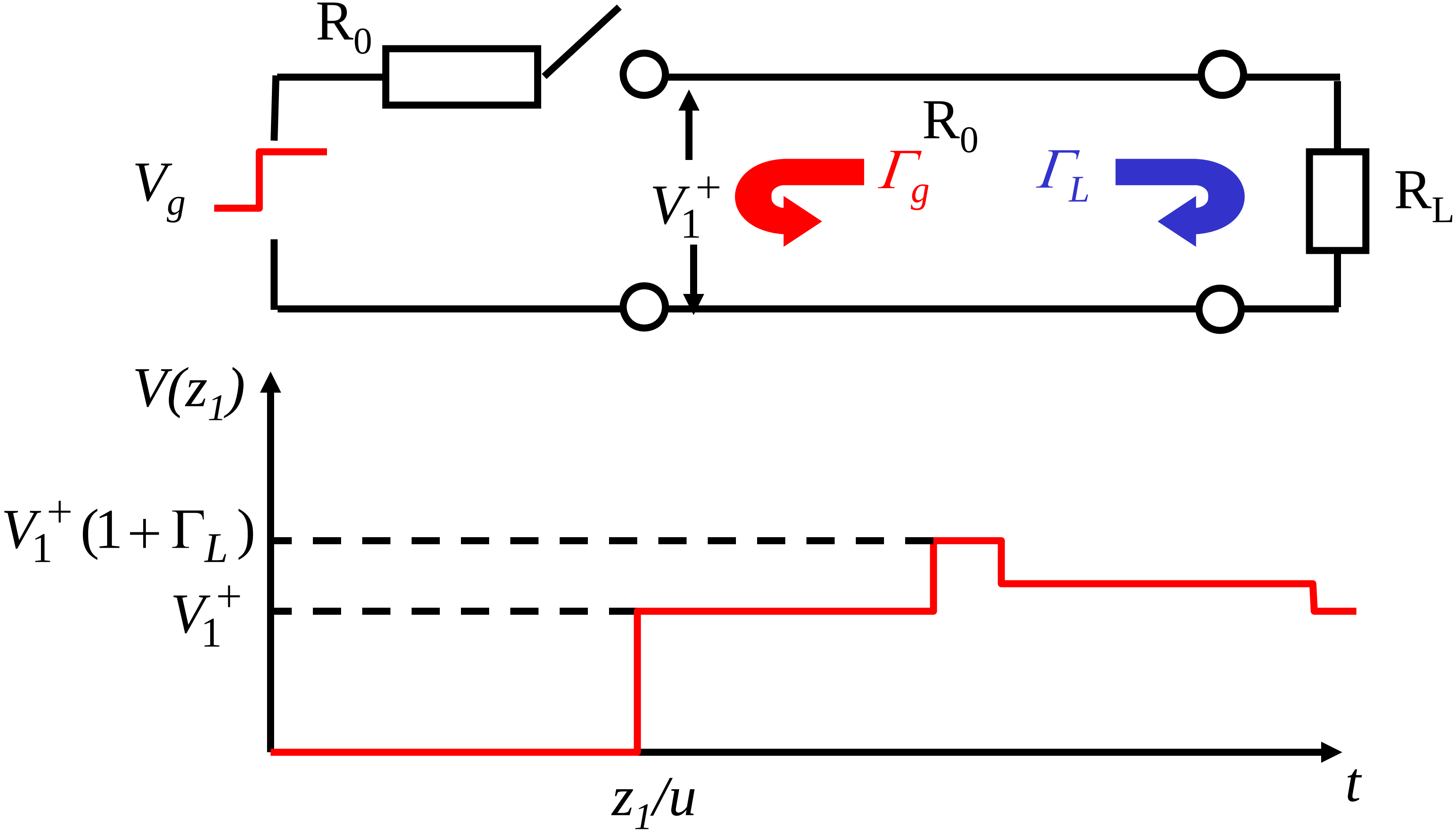


$$V_1^+ = \frac{R_0}{R_0 + Rg} V_0 \qquad I_1^+ = \frac{V_0}{R_0 + Rg}$$

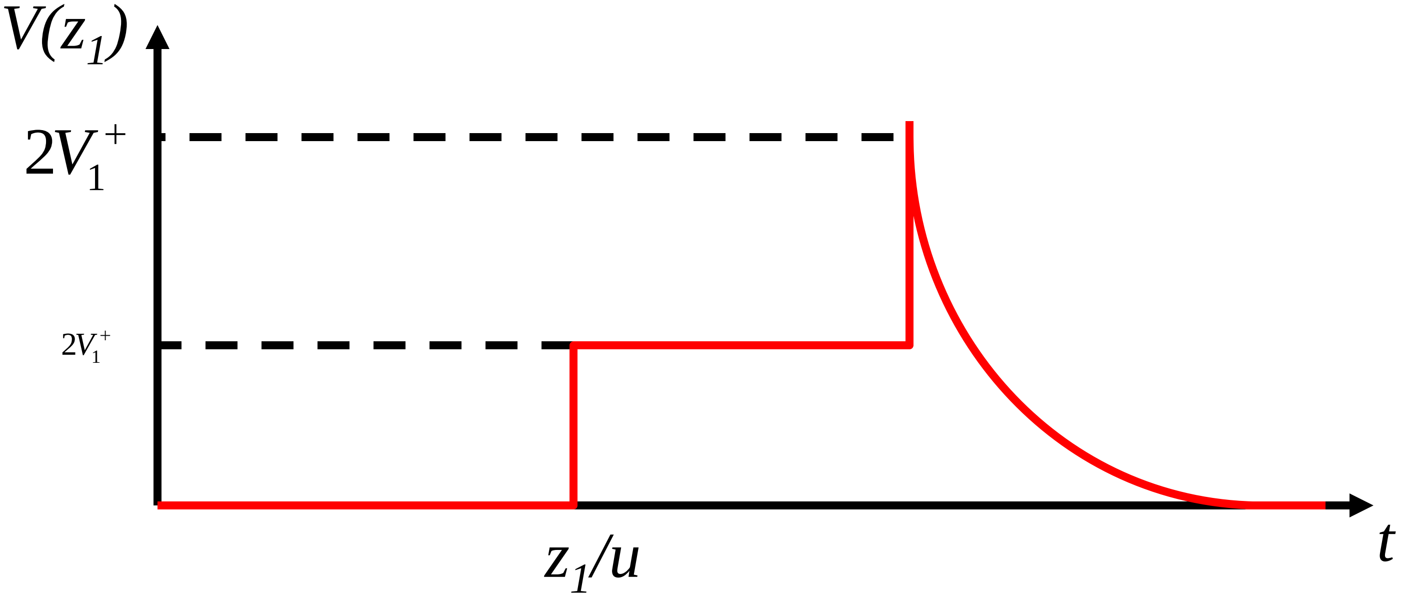
Reflections from Resistive Termination



Unmatched Generator Impedance

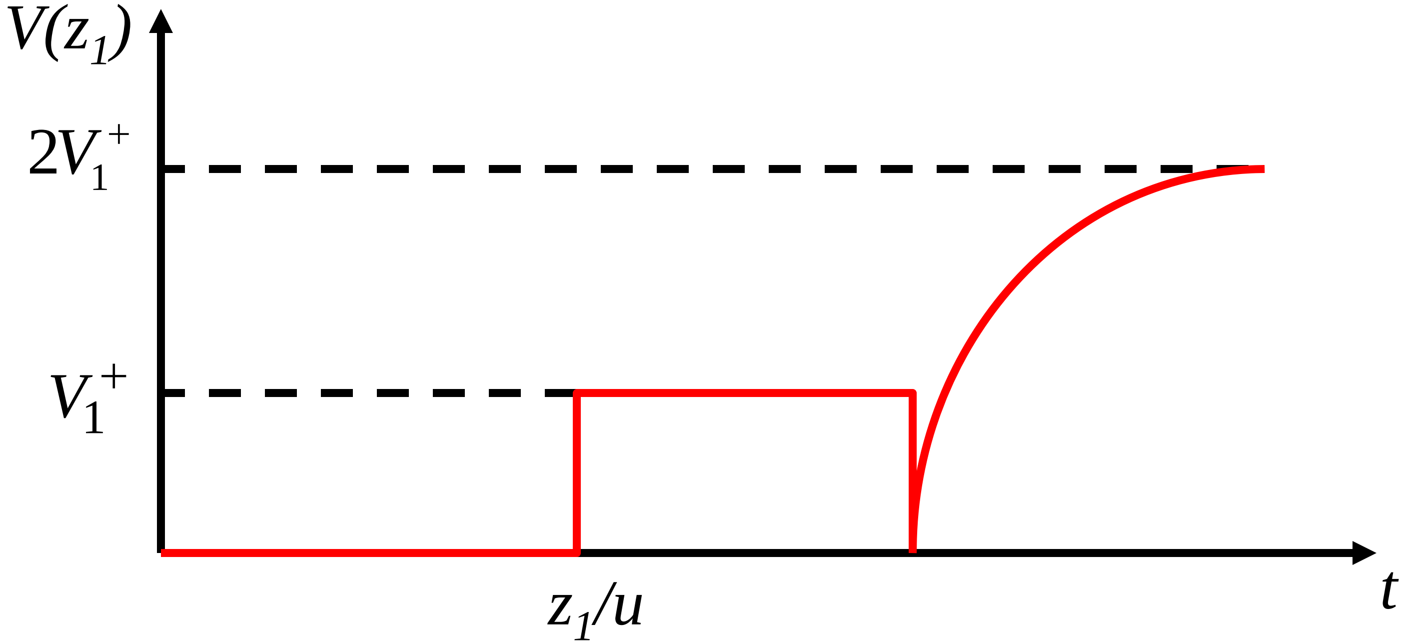


Inductive Load



$$V(t) = V_1^+ + V_1^- = 2V_1^+ e^{-\frac{(t-T)}{\tau}} \qquad \tau = L_{load} / Z_0$$

Capacitive Load



$$V(t) = V_1^+ + V_1^- = 2V_1^+\left[1 - e^{-\frac{(t-T)}{\tau}}\right] \qquad \tau = Z_0 C_{load}$$

Impedance Matching

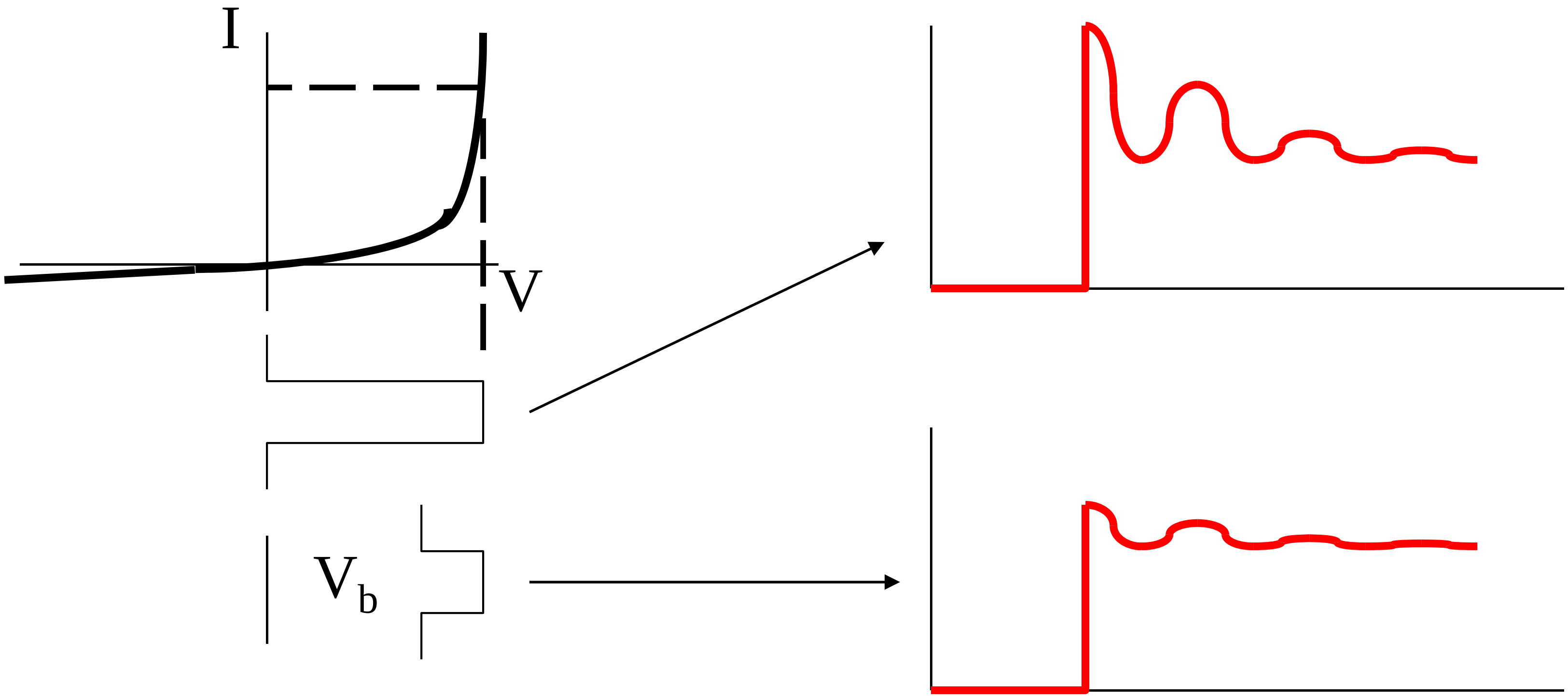
- Add impedance to produce a matched net impedance at load
- Frequency-dependent when reactance is involved:

  broadband matching is difficult
- Lumped-element (discreet components)
- Distributed (Transmission lines)

Some Tricks

- Keep lines short, relative to c/f
- Insure signal source is well matched to T-line
- Use Z-matched attenuator (pad) in front of mismatched load
- Pre-bias device to lessen voltage step required

Bias Can Reduce Ringing



Lab Exercise

- Play with scope and function generator.
- Look for aliasing as frequency exceeds #data points displayed
- Determine contents of black box by TDR

Credits

- Field and Wave Electromagnietics, D. Cheng
- www.tek.com/Measurement