Oscilloscopes

Plot measured voltage as a function of time, in near real-time.

All the oscilloscopes used today are Digital Storage Oscilloscopes (DSOs).

- All allow you to simultaneously view two or more input signals at the same time (2 or more channels).
- Signals are captured into internal memory and are also displayed once the acquisition time has passed.

4 basic things that must be set:

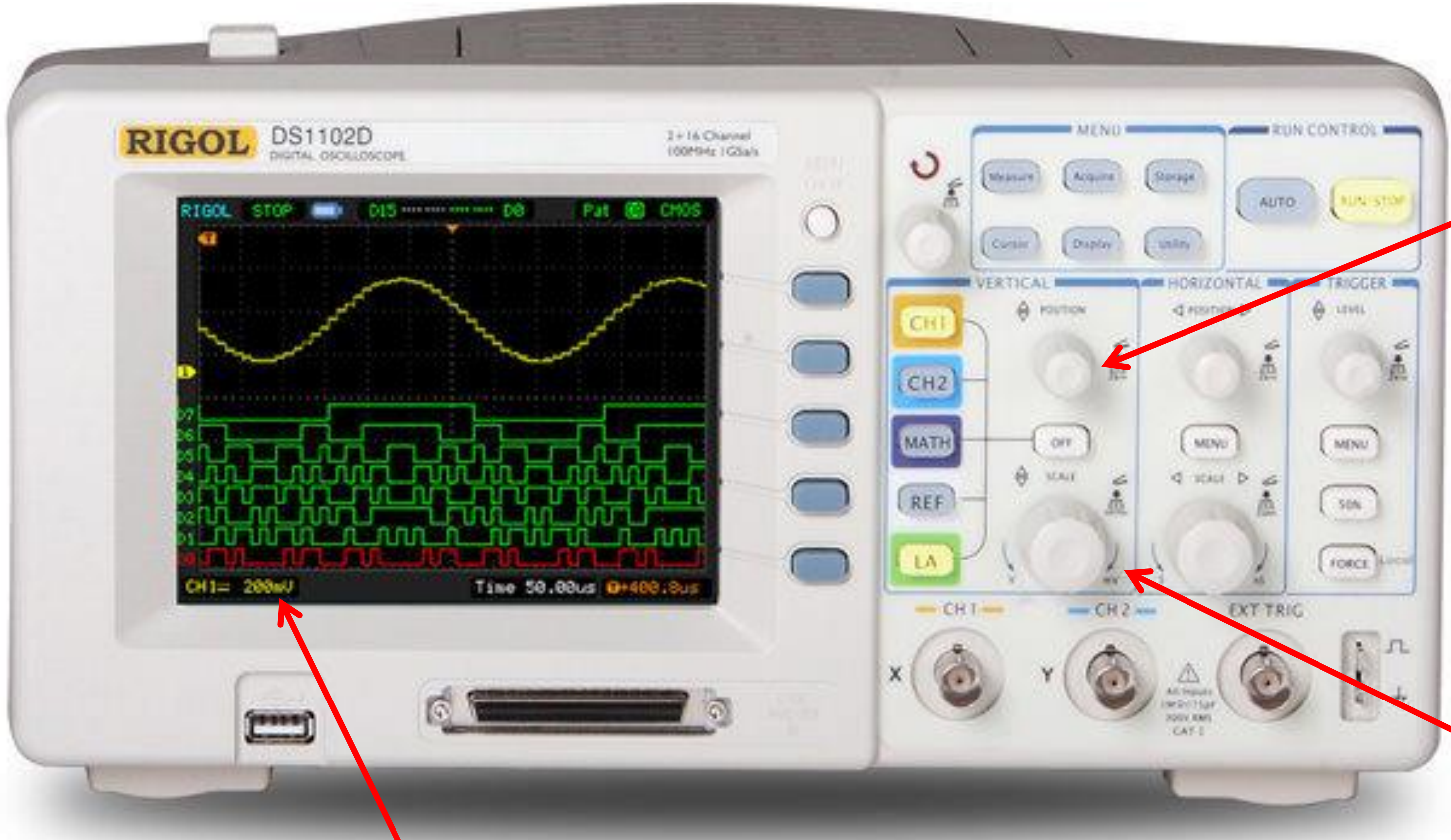
Recommend that you set up a DSO in this order:

1. **Vertical control** (**Volts/division)**:
Sets the voltage range corresponding to your signal.

2. **Coupling**:
Choose whether you wish to remove any DC component to the signal and only see the variation.

3. **Horizontal control** (**Timebase)**:
Choose the timescale on which you wish to observe the signal.

4. **Trigger**:
You need to specify the condition for starting the capture of the signal, and if you want to do so repetitively.



A DSO similar to ones in the 3rd year lab

Offset control

- A separate offset control is provided so that signals can be moved from the vertical centre of the screen.
- Can also be used to offset a signal with an average DC level to only show the AC part.

Channel voltage control (here CH1 is selected).

1. Voltage range control ("Vertical")

- Sets the range of voltages over which to capture and display.
- Always is a major control on the front of the DSO.
- Often one control per channel.
- The range selected is indicated on the screen. Traditionally the value indicated corresponds to a major division of the screen grid, *and not the total voltage window* (i.e, volts per division, V/div).

2. Channel coupling

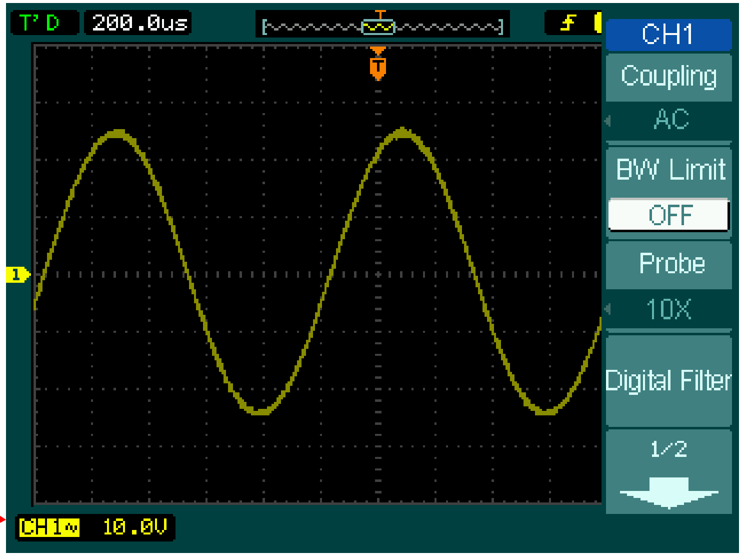
Here you decide if you wish to see the voltage of the signal relative to the ground of the input (DC coupled), or if you only want to see the time varying part (AC coupled).

DC coupling:

- The usual default setting.
- The actual voltage of the signal between the two inputs of a single channel is displayed.

- Location of 0 V.
- Position on screen can be shifted with the position control.

Channel coupling indicator



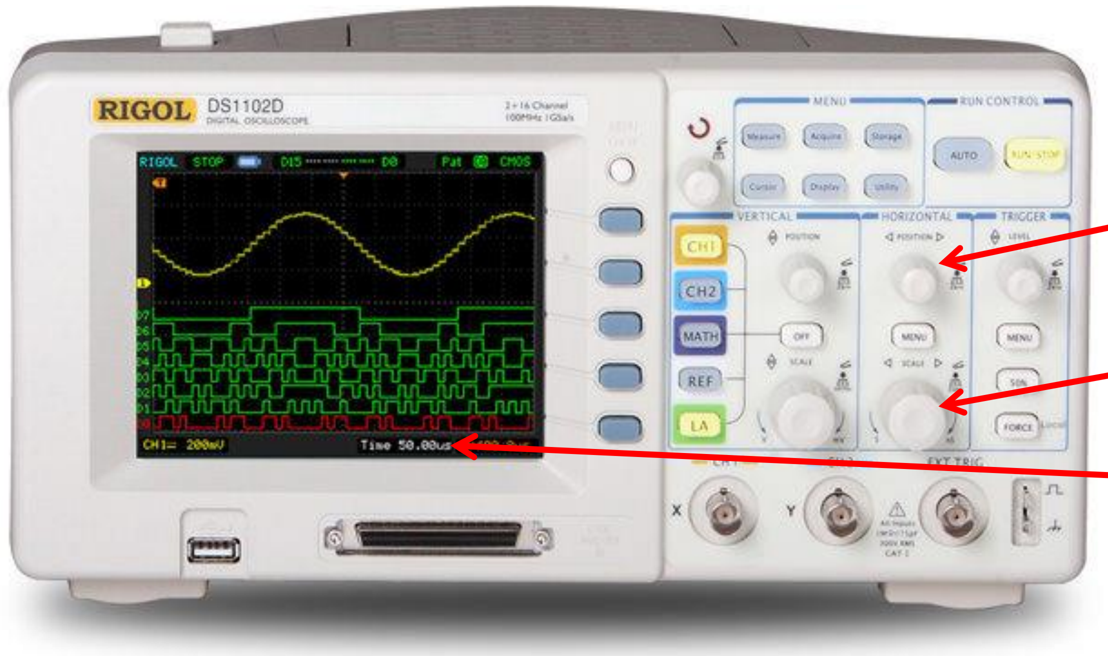
- Coupling settings are found in the channel settings menu.
- DSOs differ in how to access this.

AC coupling:

- Used when your signal has a large DC offset and you only want to see the AC part in high resolution.
- Uses an internal capacitor to couple the input to remove the DC component.
- **Important:** For low frequencies (< ~5 Hz) the AC component will progressively become phase-shifted and attenuated (i.e. don't use this setting for low frequencies).

3. Timebase ("Horizontal")

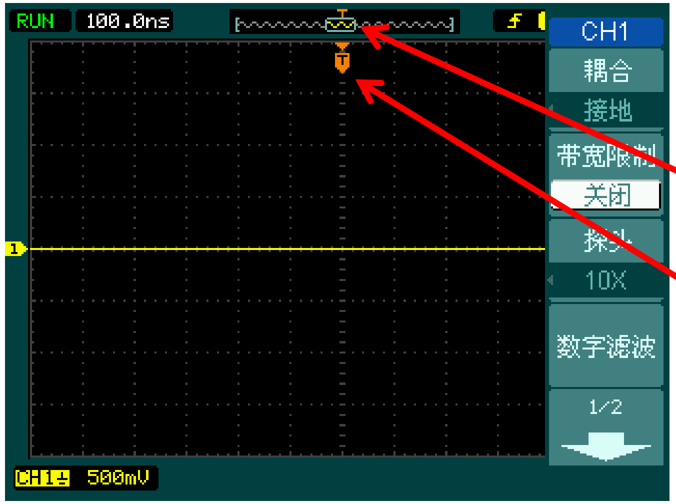
Here you set the timescale on which you wish to see (and capture) the signal.



Time offset control used to change where time=0 is displayed. T=0 is the trigger position (see later).

Timebase control (here in the "horizontal" section).

Time indicated is the time per division, not the total acquisition time.
Most DSO will have a 5 ns/div or shorter setting.



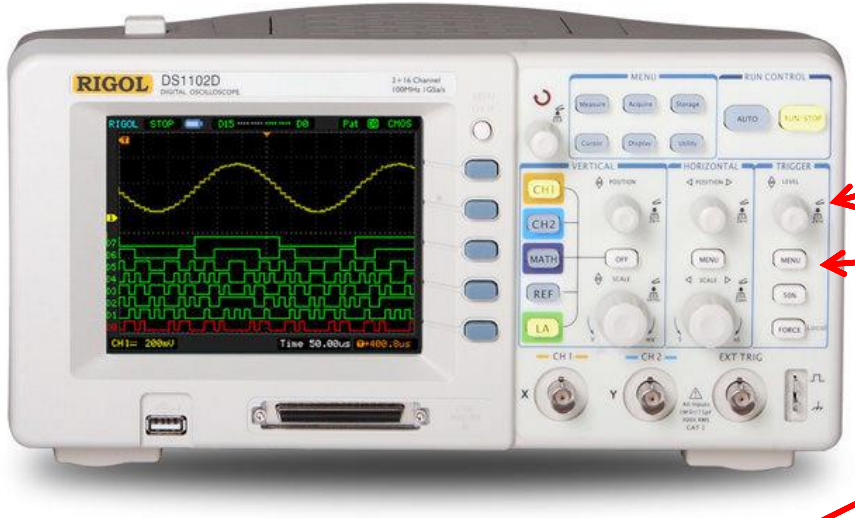
Usually the displayed part of the waveform is less than the total capture time.

Here the location of the displayed waveform within the total captured waveform is shown (boxed area).

The "T" indicated the trigger point in the waveform (T=0)

4. Triggering

This parameter sets the conditions for deciding when to capture your waveform.



Trigger level setting

Trigger menu call up.

- **Mode**: Invariably, you wish to start acquiring when the waveform exceeds some level (“Edge”).
- **Source**: You can choose to trigger off any of the channels or the external trigger input.
- **Slope**: You can specify whether you want the triggering to occur when the waveform firsts rises above the threshold, or falls below.

Trigger menu

- **Sweep**:
  All DSOs have 3 options:

1. “**Normal**”. Trigger each time the trigger condition has been met (only after the last acquisition has finished).
2. “**Auto**”. Ignore the trigger, just trigger as soon as the last acquisition is done.
3. “**Single**”. Only acquire the waveform once.

Inputs:

Voltage range:

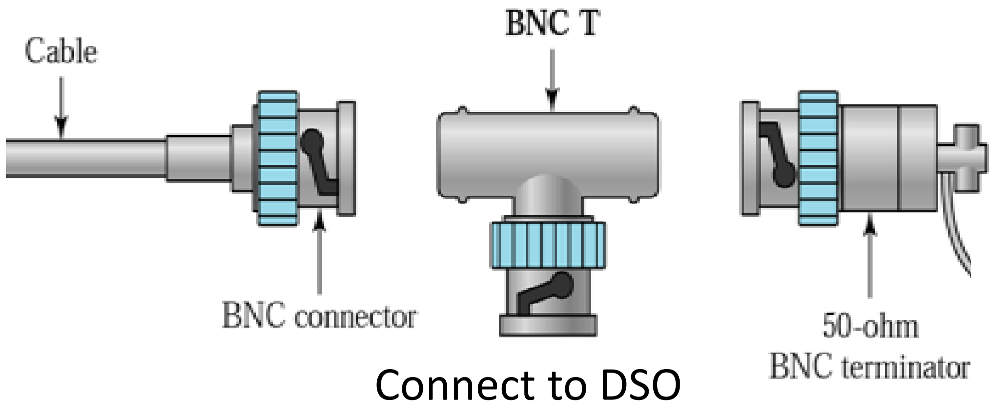
- Generally oscilloscopes measure from 2 mV/div up to 10 V/div.
- Most supplied probes have a “10x” setting to attenuate the input by a factor of 10 for “high” voltage work.
- Almost all DSOs have 8 bit (256 levels) input digitisation.
- **Only signals within the top and bottom voltage limits of the screen will be digitised.**

Input impedance:

- All “standard” DSOs have a 1 M ohm ($10^6\ \Omega$) input impedance option.
- Some DSOs have a selectable 50 Ω option, which is used with co-axial BNC connections to remove impedance mismatch induced artefacts. Do not use this setting with the supplied probes connected!
- **All high-frequency measurements (>1 MHz) with coax input cables require a 50Ω termination at the DSO if there is no 50 Ω input mode.** (more later on this)

A “through” terminator

Or:

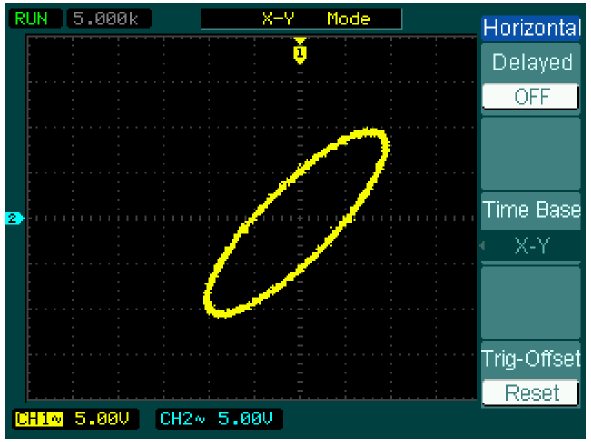


A tee-piece and 50Ω terminator connection

Other display modes:

X-Y mode:

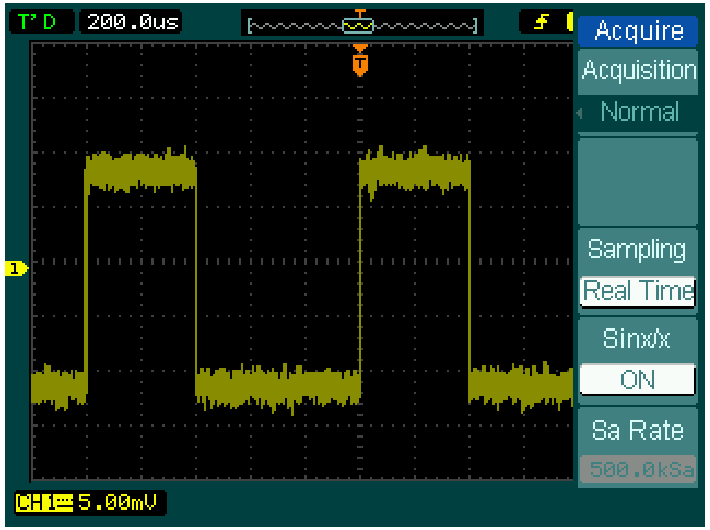
- Here you plot channel 1 against channel 2.
- Usually a setting under the “Time base” menu. (The conventional plot of voltage vs time is “Y-T” mode or similar.)
- Used for the SQUID and NMR experiments.

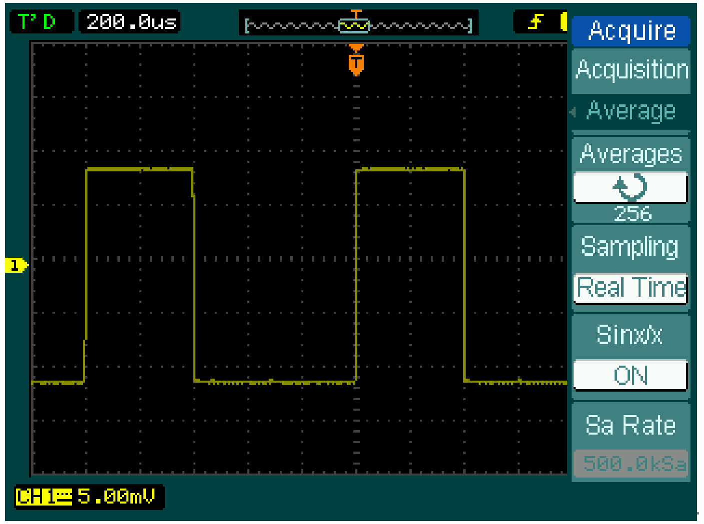


Averaging Mode:

- When this is selected, successive captured waveforms are averaged together.
- Useful with noisy or low level signals.
- DSOs vary in where this setting is located. For the Rigol unit shown here, it is accessed via the “Acquire” menu button.

Single acquisition





Averaged (256x) signal.

Additional tools:

All DSOs have:

- An auto setup button, where the DSO attempts to set up the parameters to display the waveform sensibly. Occasionally this works!
- Measurement cursors to allow measurements of voltage and time differences between positions on waveforms.
- Measurement tools to determine waveform parameters such as amplitude, frequency, relative phase, peak-to-peak voltage, etc.
- Maths tools to perform combinatorial manipulations on waveforms, such as finding the difference between two channels.
- Higher level processing, such as FFT spectrum calculation and display.
- Facility to save reference waveforms internally, and to export waveform files.

Oscilloscope specifications:

Bandwidth:

- This is the highest frequency the input electronics can accept before attenuation occurs (generally the -3 dB (71%) point).
- Most "standard" DSOs are between 50 and 500 MHz.
- Can get up to 110 GHz!

Keysight 110 GHz, 4 channel, 10 bit DAC, 256 GSa/s, 2GSa

Cost? USD 1.3M !!!

Sample rate:

- Usually the maximum sample rate is much higher than the Nyquist frequency (2x the bandwidth).
- E.g. most 50 MHz DSOs have a maximum sample rate of 2 G samples/s.

Memory depth:

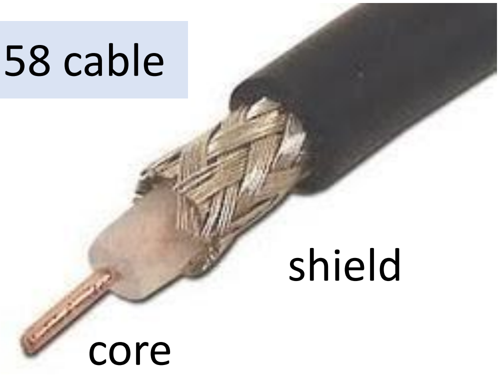
- The number of samples the memory can hold.
- This is quite variable, usually depending on the manufacturer and bandwidth.
- Many "basic" DSOs have a memory of 1 MSa or more.

Coaxial Cables

The behaviour of coaxial cables is governed by transmission line theory.

The most common type is known as RG58 - the 3rd year labs use this almost exclusively.

RG58 cable



- The main specification is the cable impedance, which for most coax is 50 Ω.
- The main exception is TV coax cable (75 Ω).
- RG58 cables usually have BNC connectors attached (BNC= Bayonet Naval Connector).

BNC connector

Impedance: The effective resistance of an electric circuit or component to alternating current, arising from the combined effects of ohmic resistance and reactance due to inductive and capacitive components.

The DC **resistance** of the cable is close to zero (<0.04 Ω/m)

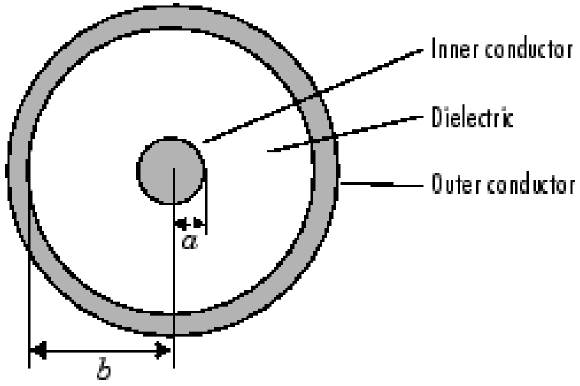
Why is coax used?

1. The core is shielded from electrical interference.

- Usually the outer shield wire is connected to the "negative" input on equipment, which is often earthed (like for DSOs).
- The shield stops EM signals from being picked up by the core (Faraday shielding).

2. Can be used to carry high frequency signals without distortion.

- Sending high frequency (>100 kHz) signals down wires causes distortion because at these frequencies the wire behaves as an inductor, not a true conductor (resistor).
- Coax cables have an engineered degree of capacitance, which modifies the inductive behaviour of the shield and core.
    - The impedance of the coax is: $Z = \sqrt{L/C}$
    - The velocity of propagation through the cable is typically ~ 0.66 c.

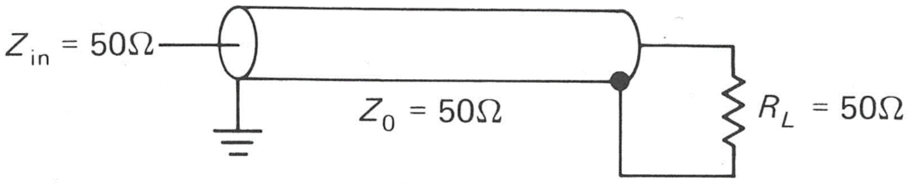


Cross section of a coaxial cable
The configuration is basically a cylindrical capacitor.

Coaxial cables have useful properties which come from transmission line theory.

Property 1:

- A coaxial cable terminated with its characteristic impedance will deliver the signal to the termination without reflecting any of the signal back to the source.



no reflections, all power goes to load

Property 2:

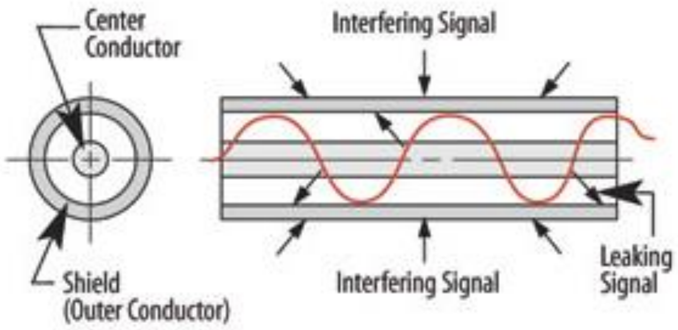
- The impedance at the input of a cable terminated with its characteristic impedance is equal to the characteristic impedance **at any frequency**.

- Terminating a coax line with 50 Ω resistor means that the coax behaves like a perfect conductor at all frequencies.
- The effect of mismatched termination is to cause reflected waves to back-propagate to the source which interferes with the signal.

Proper termination is essential when transmitting short pulses to avoid (interesting) distortion/reflection artefacts at the output.

Transmission line considerations:

For alternating signals, once the length of the transmission line exceeds about 1/10 wavelength of the signal in the cable, the behaviour is described by transmission line theory.



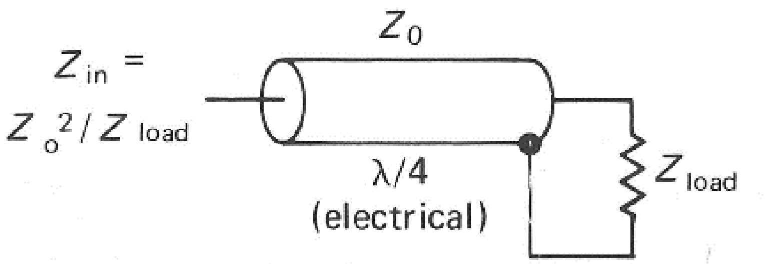
- Pulses are particularly susceptible to transmission line effects because the fast rise and fall times of edges (often ~1 ns) correspond to high frequency information (~GHz).

E.g., For a sine wave signal of 50 MHz, the wavelength in RG58 coax is about 4 m. Consequently, you will expect to See the effects of mis-terminated cables when your cable is longer than about 1 m.

Sometimes, terminating cables with something other than the characteristic impedance can be useful.

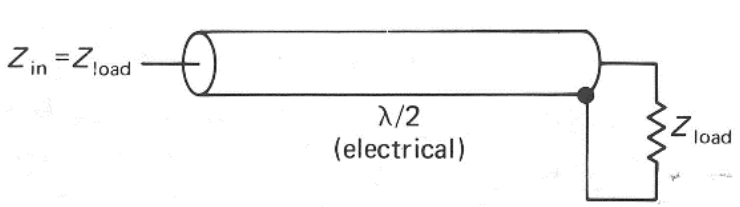
The behaviours below only occur for **one frequency** (i.e wavelength).

Coax that is a $n \times \frac{\lambda}{4}$:



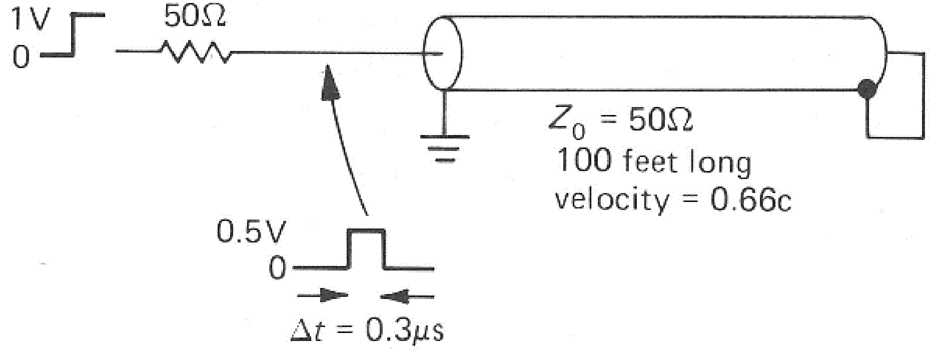
- No reflections back to the source.
- Can be used to impedance match the load to the source.

Coax that is a $n \times \frac{\lambda}{2}$:



- No reflections back to the source.
- Effective impedance is the load impedance.

Pulse creation by reflection:



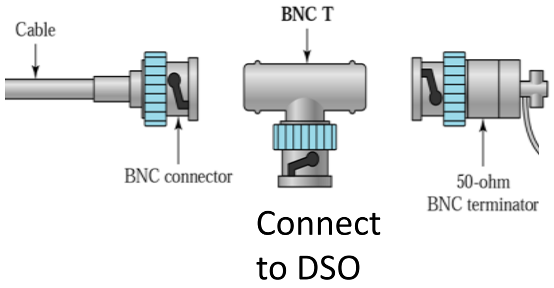
- Positive going step is inverted on reflection.
- The negative voltage step of the reflection cancels out the positive voltage of the step.
- Pulse width is set by the round trip time in the cable. ($t = 2 \times \frac{30}{0.66\ c}$)

In summary:

When using DSOs:

- Set your input impedance on the measuring channel to 50 Ω (if you can)
- If you cannot do this, use some sort of terminator at the DSO input.

A “through” terminator



A tee-piece and 50Ω terminator connection

When using other instruments:

Essentially all instruments (with BNC sockets) have an input impedance of 50 Ω already built in.
Do not use a terminator at the input.

Exercise