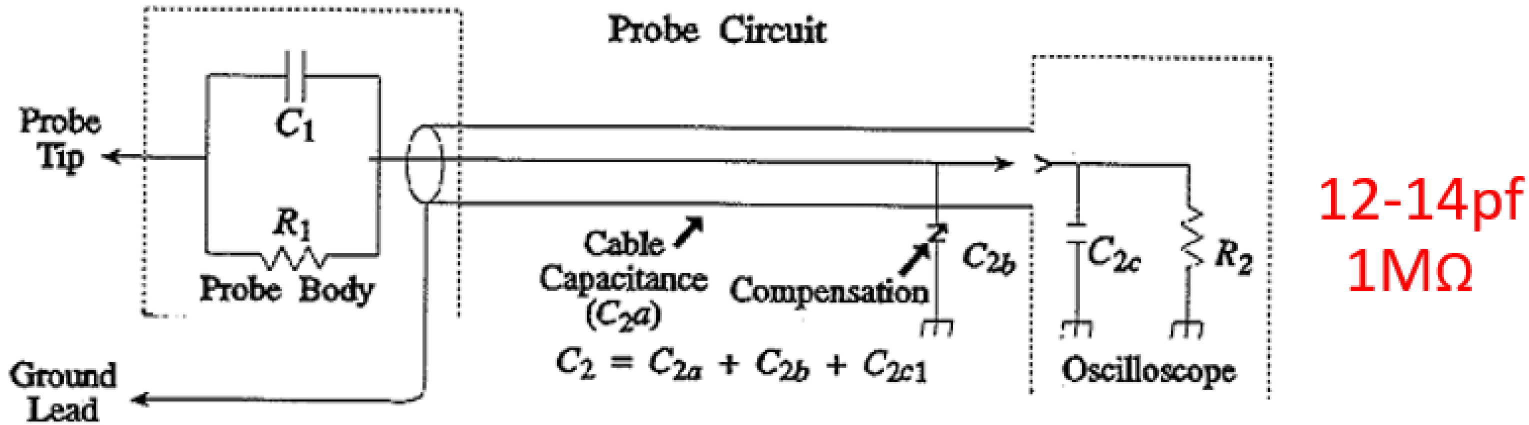
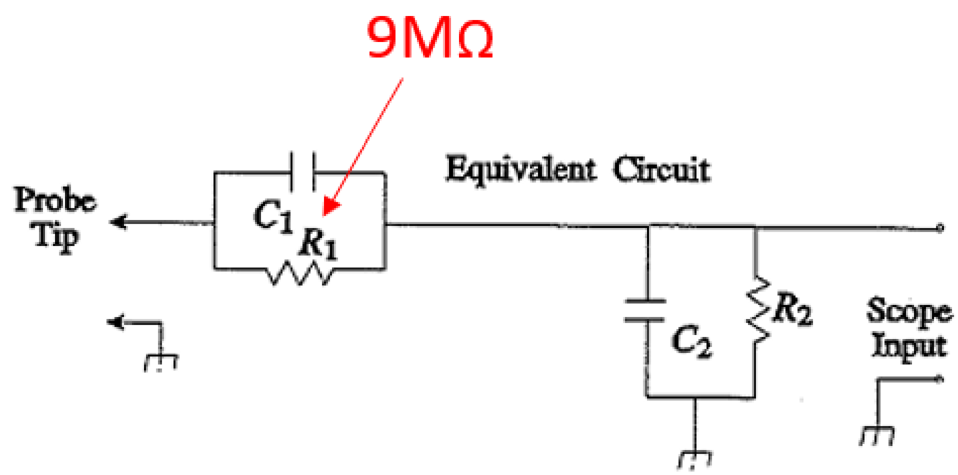
Types of oscilloscopes (DEMO)

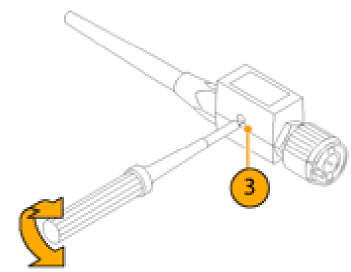
- Examples
    - Analog
    - DSO
    - DPO
    - Equivalent sampling scope

- Basics of triggering
    - Pre & post trigger events

- Probe compensation
- Current and differential probes


Probe Circuit
Probe Tip
C_1
R_1
Probe Body
Ground Lead
Cable Capacitance (C_2a)
Compensation
C_{2b}
C_{2c}
R_2
Oscilloscope
$C_2 = C_{2a} + C_{2b} + C_{2c1}$
12-14pf
1MΩ


9MΩ
Equivalent Circuit
Probe Tip
C_1
R_1
C_2
R_2
Scope Input


3

Measurements, record length, and sampling rate (BENCH #3)

Built in tutorial: burst square signal

Equipment:

TEKTRONIX TBS 2000 Series scope

RIGOL DG 1022

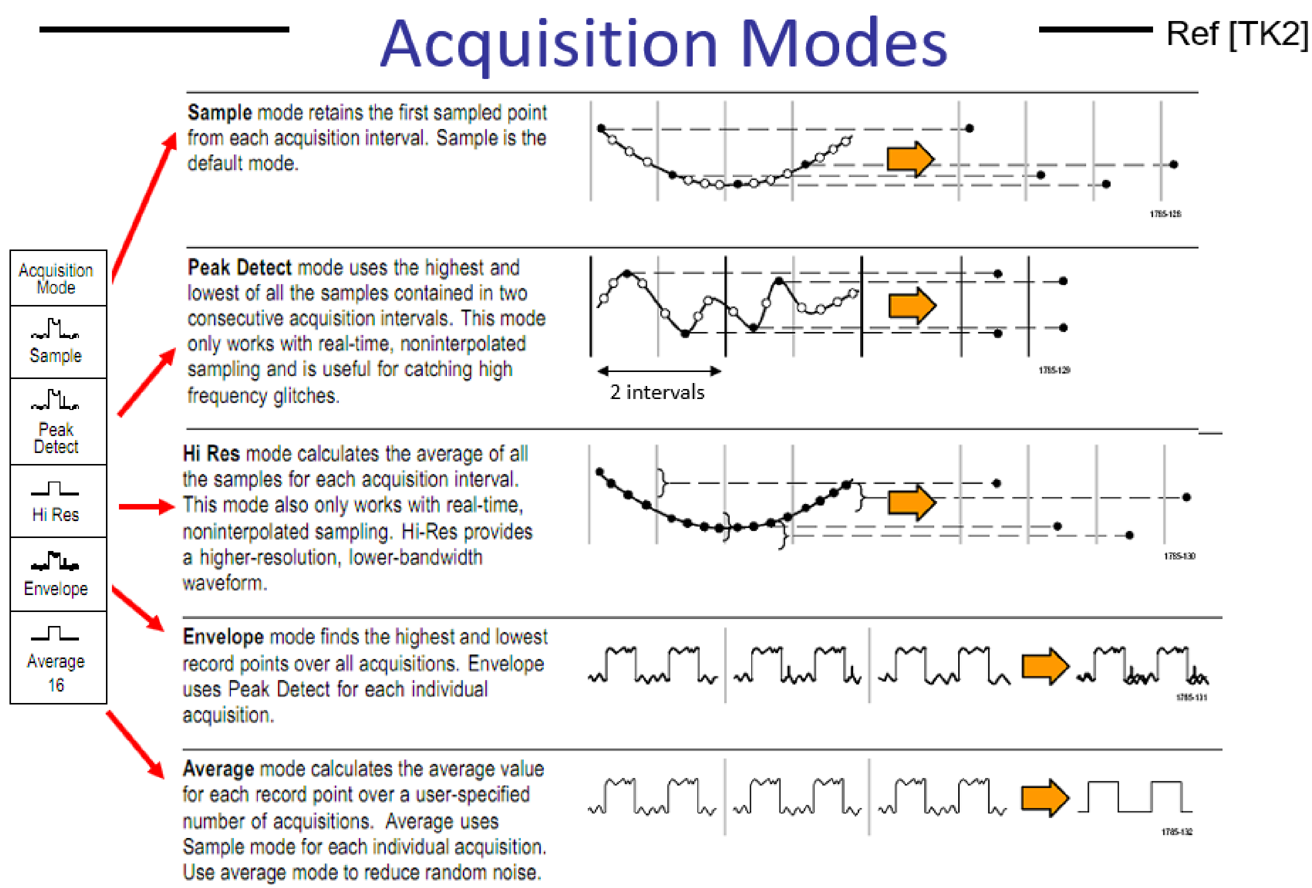
1. Press the scope tutorial button (icon of a graduation hat), and select
   4. Burst Width Measurement
   Read the background instructions
2. Set the DG1022 CH1 to
   Square wave, Frequency 20KHz, Amplitude 2Vpk-pk
   Turn CH1 output ON
   Burst ON, burst period 1ms, Cycles = 5 Cyc, Trigger > TrigOut ON
   Notice that on the back of the instrument the External Trig /FSK/Burst output is connected to another channel of the scope.
3. Trigger the scope on the burst trigger signal
4. Select auto scale
5. Use the [Measure] menus to select
   Time Measurement, Burst width

6. Does the measurement result make sense?
   Experiment by varying the burst parameters.
   Change the time base.
   Trigger on the burst signal itself.

Record length, and sampling rate

The TBS2104 screen has 800 x 450 pixels, if you compare that with the number of points being sampled (indicated on screen) you can see that the decimation of sampled points is quite large.

1. Explore [Acquire] [Mode] and compare with the class notes below



The TBS2104 oscilloscope is a 1GS/s, 20Mpts unit with 15 horizontal divisions
As you know:
Record length [pts] = time captured [s] * sampling rate [S/s]

2. Read the 'record length [pts]' and 'sampling rate [S/s]' from the lower right corner of the screen and calculate the corresponding 'time captured'
3. Compare your result with: Horiz scale [s/div] * 15 div
   Do they match?
4. Press [Zoom]
   what you see on the top is the complete record; in between brackets is the area zoomed in that is shown at the bottom.
5. The result you obtained for 'time captured' matches the complete record shown on the top. The Horiz scale/div for the complete record is shown on the top center.
6. Explore navigating the complete record by using the "Multipurpose button"

Notice:

- *at smaller time scales the relation: Record length = time captured * sampling rate, does not hold anymore. This is imposed by hardware limitations such as maximum sampling rate, memory capacity, and processing efficiency.*
- *You can notice that if you increase the horizontal time scale, the scope will automatically reduce the sampling rate such as to not overflow is memory limit of 20Mpts.*

Effect of record length on measurements

1. On the AWG turn off burst mode. You should see a square signal on the scope.
2. Set [Measure], Time = Rise time
3. Press [Acquire], explore the effect of the record lengths on the measured rise time

An accurate rise time measurement depends on several variables, including:

- High enough bandwidth and sampling rate, especially for fast signals.
- Enhanced signal processing, for example refined interpolation between sample points
- Smart features to automatically optimize settings, either by enforcing or warning.

You should see that the rise time is independent of the record length. This is one of the signs of a good scope.

Try to change the acquisition mode and see what effect it has on the measured rise time.
From this you can infer that the scope measurements on the are done from calculations using the original sampled points and NOT the decimated points shown on screen.

Oscilloscope bandwidth (BENCH #1)

BW and Frequency response of the R&S RTB 2004 scope

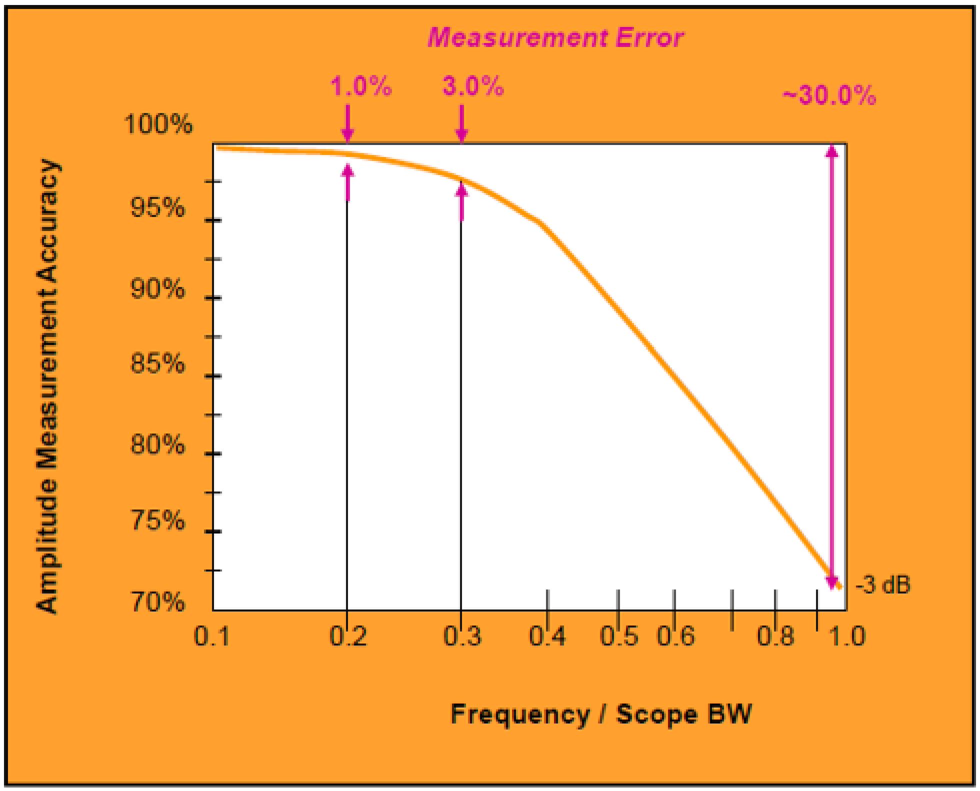
Equipment:

R&S RTB 2004 scope, 70MHz BW
R&S SMA100A RF Generator 9KHz-GHz

1. Turn ON and preset the RTB scope and the SMA100A generator
2. Connect the RF out of the generator to CH1 of the scope using a 50ohm feed through terminator.
3. At the lower left corner of the scope's screen make sure that C1 is set to 1:1 probe. If not, use: [Ch1] -> scroll down w. fingers to "Probe >" -> 1:1
4. Set the RF source to: Frequency 1MHz, Amplitude 10dBm
5. On the scope, select [Meas] -> Type = Peak Peak
6. Set the vertical scale to 200mV/DIV to make best possible use of the screen
7. Take note of the measured Vpp at 1MHz
8. Gradually increase the RF source frequency until reaching 70MHz
   Observe the effect on the measured amplitude

9. Calculate the ration of the Vpp@70MHz/Vpp@1MHz

10. Compare your results with the information on this plot:



Attenuation [dB]:

$$20 \bullet \log \frac{U_{measure}}{U_{DUT}}$$

$$20 \bullet \log 0.707 = -3dB$$

Amplitude Error	Amplitude Accuracy	Attenuation dB
1 %	99 %	-0.09 dB
3 %	97 %	-0.26dB
5%	95%	-0.45dB
10%	90 %	-0.9 dB

Exploring the type of frequency response using FFT:

1. Set the RF source to do a frequency sweep:
   a. Press [Diagram]
   b. With the arrow keys and pushing the rotary know to select ENTER set
      Start Freq = 1M
      Stop Freq = 100M
      Step Lin = 10K
      State = ON

What is happening on the oscilloscope screen?
Why is the signal getting smaller at higher frequencies?

2. Perform FFT
   a. On the scope press [FFT] , set:
      Start = 50M
      Stop = 100M
      [FFT] -> Waveform -> Max Hold

   b. You should see on the FFT plot a trace following the peak of the swept sinewave. You can adjust the vertical axis with the Vertical Scale and Offset buttons.

What is happening on the FFT plot? Does the -3dB point matches what you measured before?
Before moving on to the next activity, turn RF off.

BW and Frequency response of the Keysight MXR scope

Equipment:

Keysight MXR scope, 2GHz BW
R&S SMA100A RF Generator 9KHz-GHz

1. Connect the RF generator to CH1 of the MXR scope.
2. Set CH1 to 50ohm input impedance
3. On the RF source set the frequency sweep to:
   Start = 1G
   Stop = G
   Step = 100K
4. Turn RF out ON

5. Observe the swept frequency on the scope, set the vertical scale to maximize use of the screen.
6. Set FFT measurement, adjust FFT settings
7. To mimic the trace Max Hold function of spectrum analyzers:
   Select top menu: Display -> Waveforms
   Source View = f1:FFTM(Ch1)
   Waveform Persistence = Infinite

What is happening on the FFT screen? What type of frequency response is this?
Using markers you can confirm that the scope BW is 2GHz.

Bandwidth and rising edge

Equipment:

Keysight MXR scope
Keysight 3600A AWG generator

1. Preset the MXR scope and the AWG

2. Disconnect the RF source and connect CH1 of the 3600A to CH1 of the MXR scope
3. Sep the AWG to: Square signal, Frequency 1MHz, Amplitude 1Vpp, Offset 0.5V, 50ohm load, output ON
4. With the scope measure the rise time (20-80% & 10-90%)
5. Using the scope cursors confirm the rise time measurements at 20-80% and 10-90%.
6. Based on your measurements above what is the *fknee* of this signal?

   $f_{knee} = 0.5 / RT_{signal}$ (10-90%)

   $f_{knee} = 0.4 / RT_{signal}$ (20-80%)

   What is the minimum scope bandwidth appropriate to measure this signal?
7. Using the table below consider what BW is required for 20,10,3% accuracy

Step 3: Calculate scope bandwidth

Required accuracy	Gaussian response	Maximally-flat response
20%	$f_{BW} = 1.0 \times f_{knee}$	$f_{BW} = 1.0 \times f_{knee}$
10%	$f_{BW} = 1.3 \times f_{knee}$	$f_{BW} = 1.2 \times f_{knee}$
3%	$f_{BW} = 1.9 \times f_{knee}$	$f_{BW} = 1.4 \times f_{knee}$

Table 1: Multiplying factors to calculate required scope bandwidth based on desired accuracy and type of scope frequency response

If you have time measure tr of the Rigol DG1022 at 1MHz, 1Vpp, 0.5Vdc

Exploring the capabilities of the MXR scope (BENCH #1)

Equipment:
MXR208A, 2GHz BW, 16GSa/s, 200Mpts
LeoBodnar Fast Pulse Pattern Generator, tr < 30ps

Built-in AWG generator

The MXR has a built in, one channel, 50MHz AWG

1. Set the scope CH1 input to 50ohm
2. On the scope: Setup -> Waveform Generator
   select a sine wave of amplitude 500mV, any frequency
3. Press the button [Wave Gen] to toggle on the built-in AWG output
4. Explore the options un the Waveform Generator window
5. Under Trigger -> Setup, browse the different types of triggers
6. Under the Setup -> Acquisition menu, explore settings for record length

Eye Diagrams

7. Set the waveform to PRBS, BPS 2MHz, Amplitude 500mY
8. Select: Analyzer -> Quick eye diagram
9. Observe the resulting eye diagram at the bottom and the PRBS at the top. Explore the top window, you can RUN/STOP the acquisition.
10. Experiment by adding noise on the waveform window
11. Change the PRBS BPS to 40MHz, and select again Analyzer -> quick Eye diagram

Scope rise time

12. Press [Default setup] and set [Wave Form] to OFF
13. Disconnect the source from the scope input
14. Connect the fast pulse generator.
15. Measure rise time and calculate the signal *fknee.* Is this scope BW adequate for this rise time?
16. On the Acquisition window change “Analog Sampling Rate” settings and observe the effect on the measured rise time.