OPTICS LAB TUTORIAL:
Oscilloscope and Spectrum Analyzer

M.P. Hasselbeck

Oscilloscope or Multimeter?

Multimeter

- Battery powered
- Hand-held
- Very portable
- Variety of measurements possible

DC Voltage

AC Voltage

DC Current

AC Current

Continuity

Resistance

Capacitance

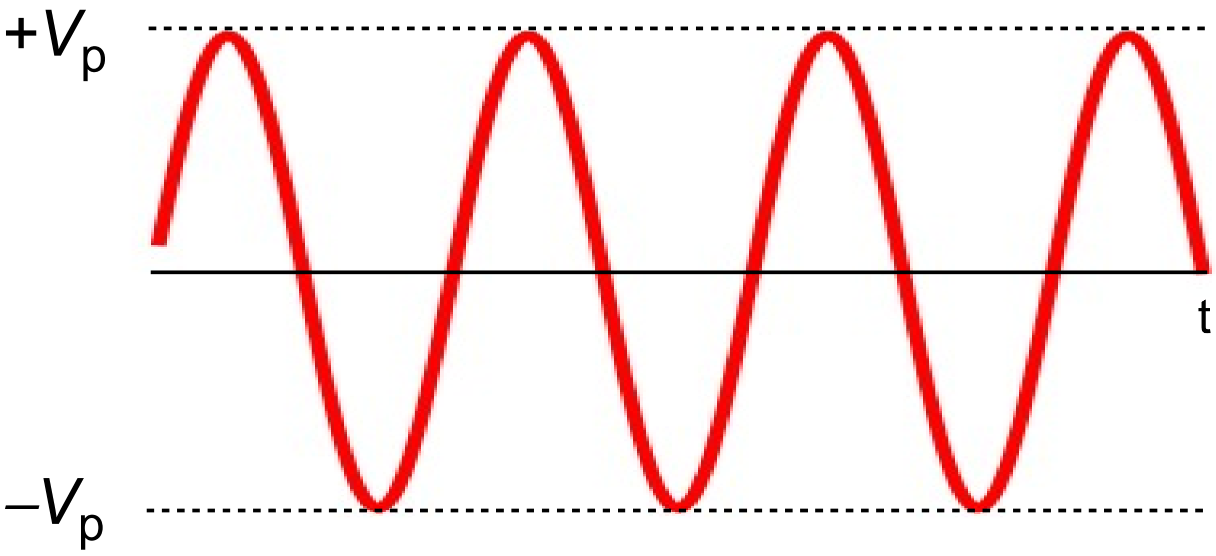
Multimeter

Measurement given as a single number

What about signals that change as a function of time?

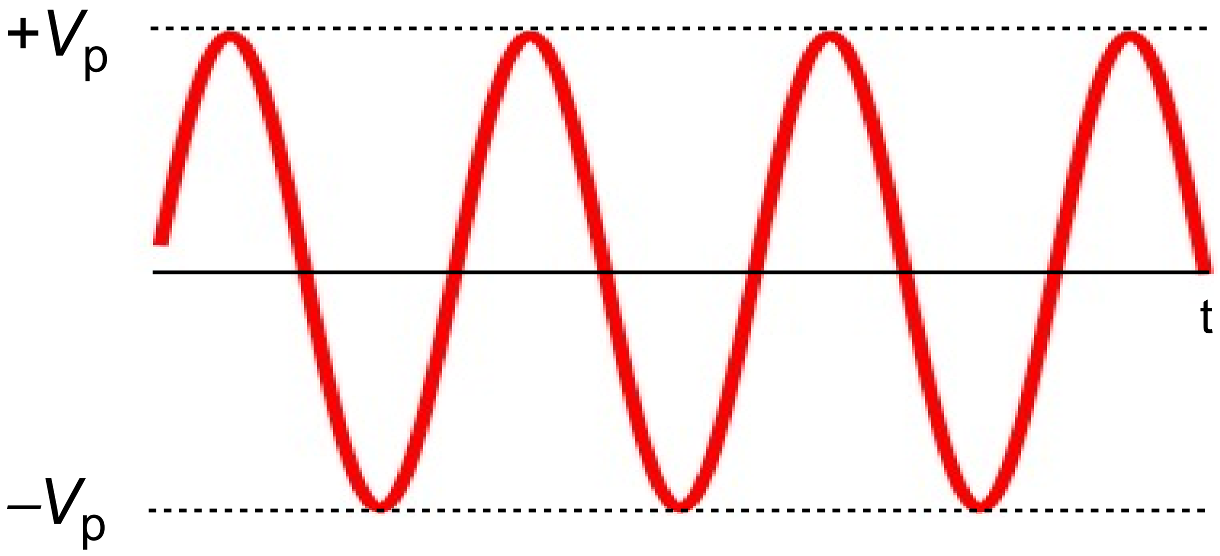
Periodic, time-varying signals can sometimes be characterized by a single number: **Root-Mean-Square (RMS)**

$$V(t) = V_p \sin(\omega t)$$

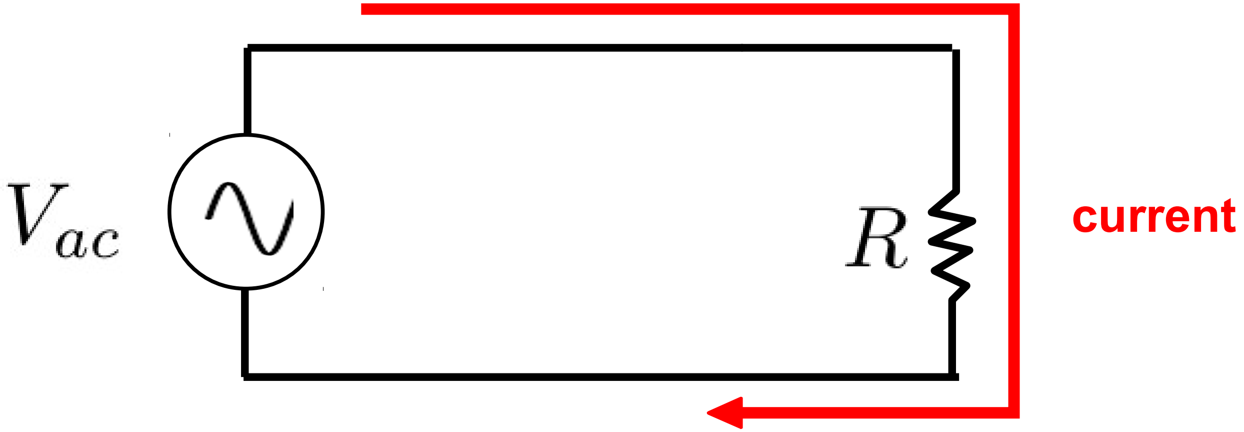


The average voltage of a pure sine wave is identically zero.

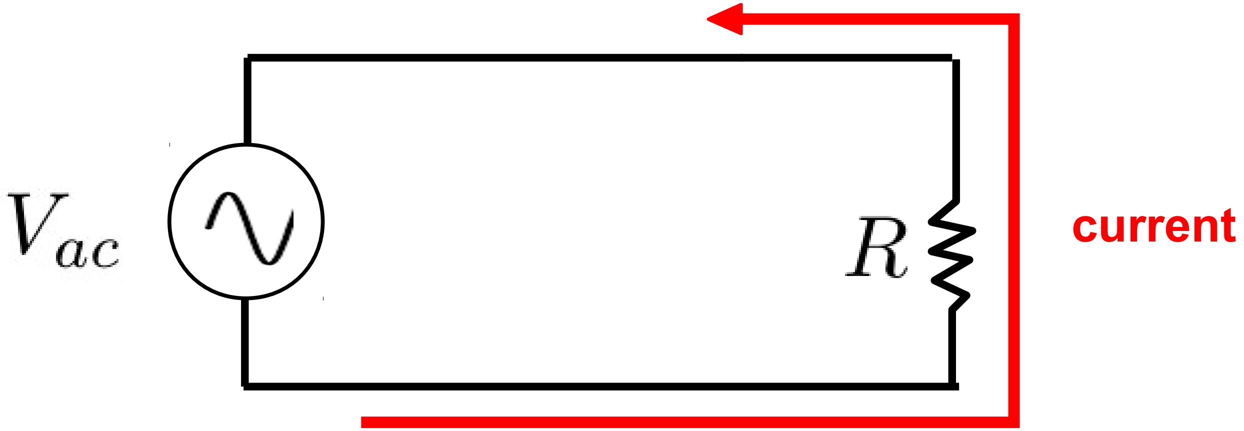
$$V(t) = V_p \sin(\omega t)$$



We know that an AC voltage can deliver plenty of power to a load



We know that an AC voltage can deliver plenty of power to a load



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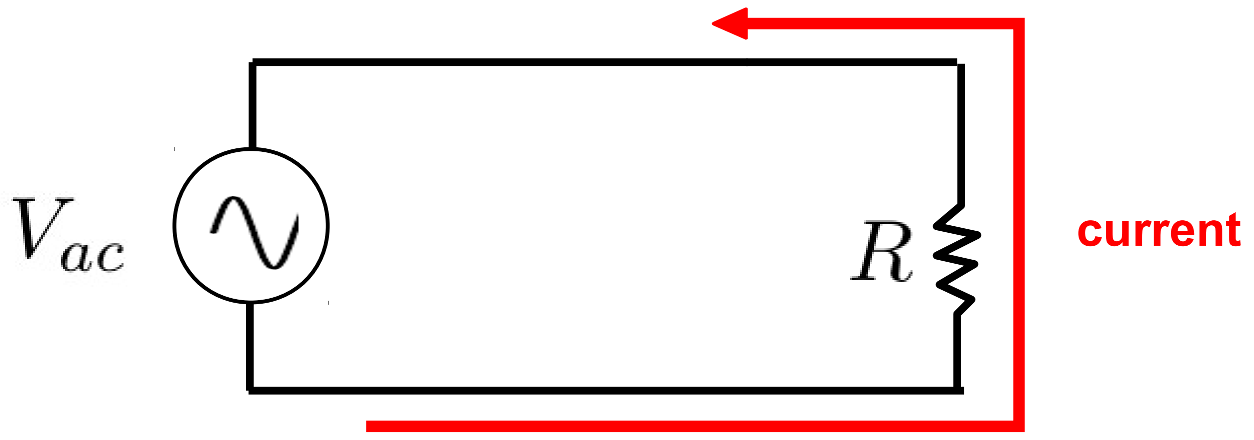
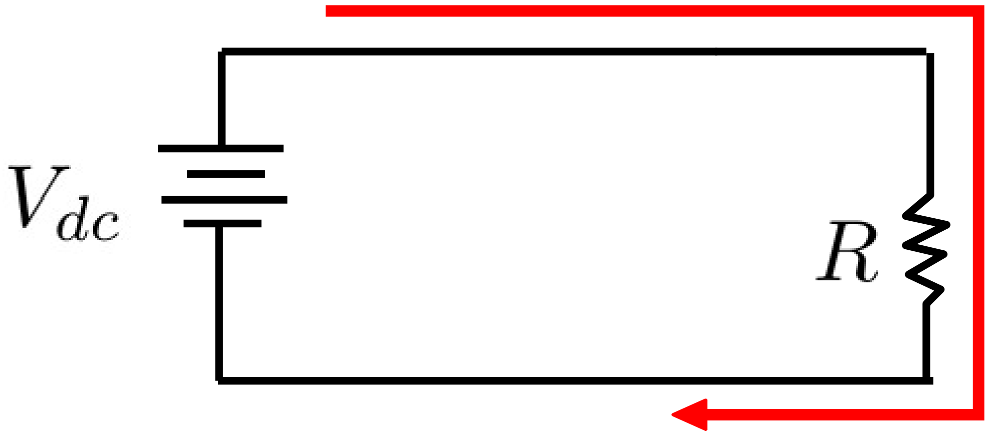


How do we calculate this power if the average voltage and current is zero?

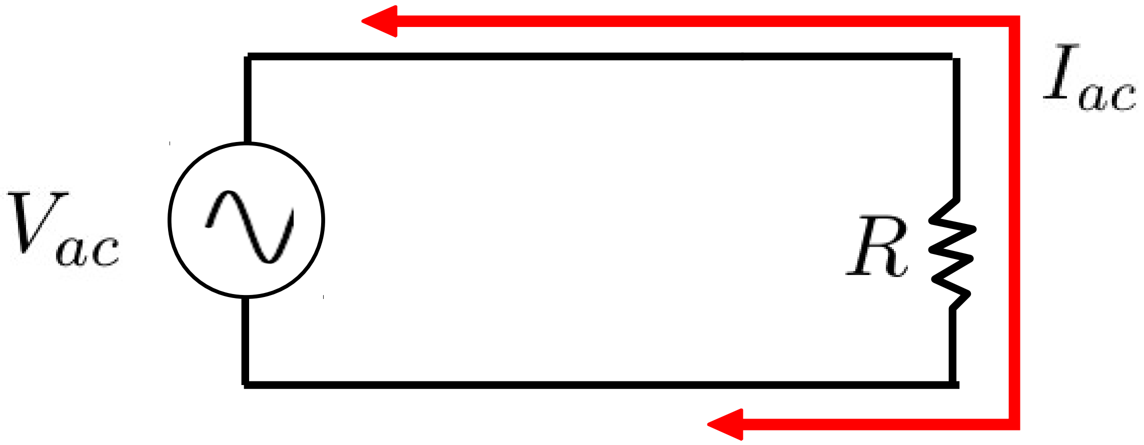
This is easy in a DC circuit: Use Ohm's Law



POWER = $\dfrac{V_{dc}^2}{R}$

Power dissipated in an AC circuit is time dependent:

$$P(t) = V_{ac} I_{ac} = \frac{V_{ac}^2}{R}$$



What is the energy delivered in **one period**?
Temporally integrate the power over one period:

$$\frac{1}{T}\int_0^T P(t)dt = \frac{1}{TR}\int_0^T V_p^2 \sin(\omega t)^2 dt = \frac{V_p^2}{2R}$$

DC power dissipation = $\dfrac{V_{dc}^2}{R}$

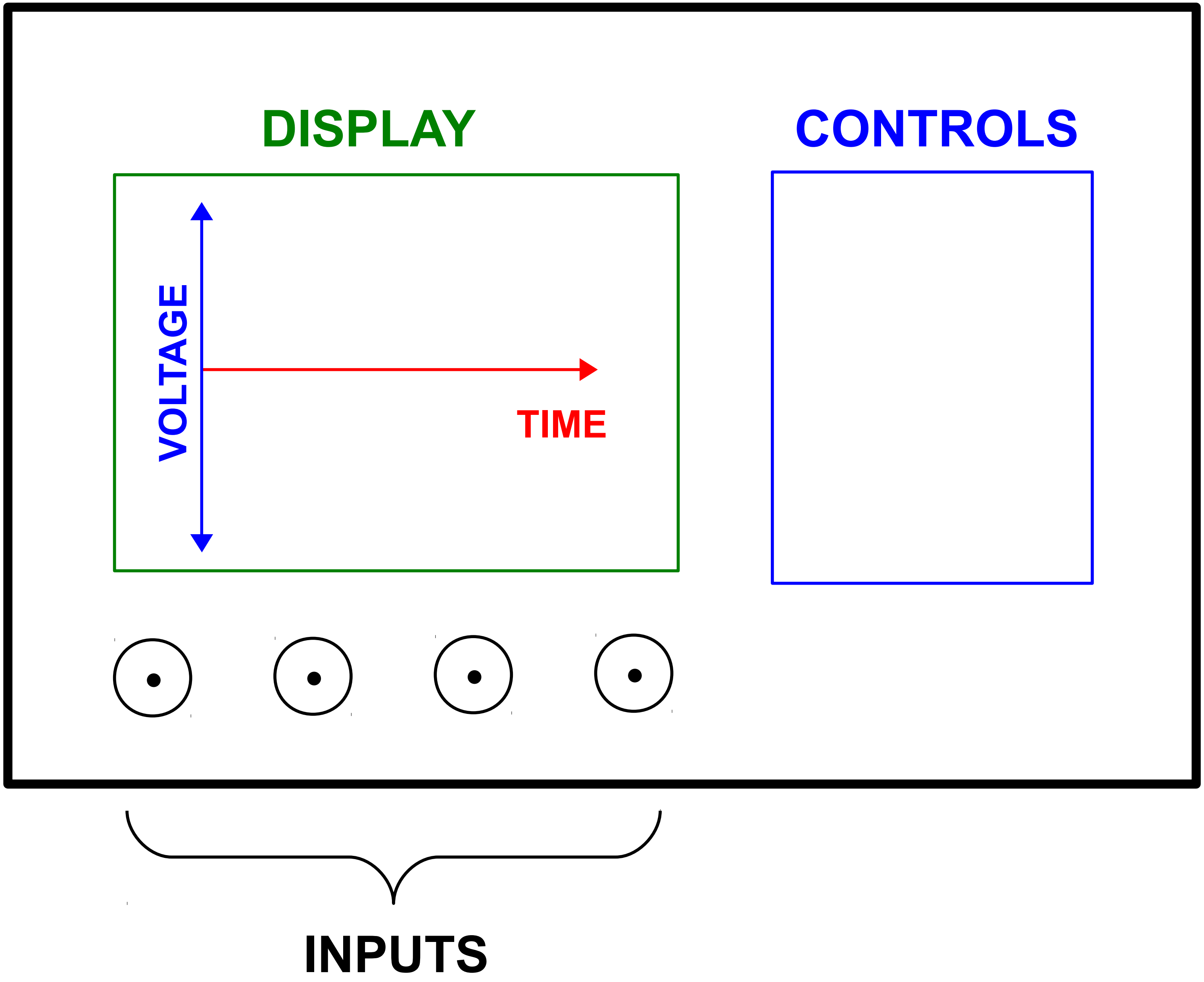
AC power dissipation = $\dfrac{V_p^2}{2R}$

AC voltage producing
power dissipation equivalent $V_{RMS} = \dfrac{V_p}{\sqrt{2}}$

- An RMS measurement assumes a stable, periodic signal
- Characterized by a single value of voltage, current
- Measured with a multimeter or oscilloscope

The situation is often not that convenient!

OSCILLOSCOPE



DISPLAY

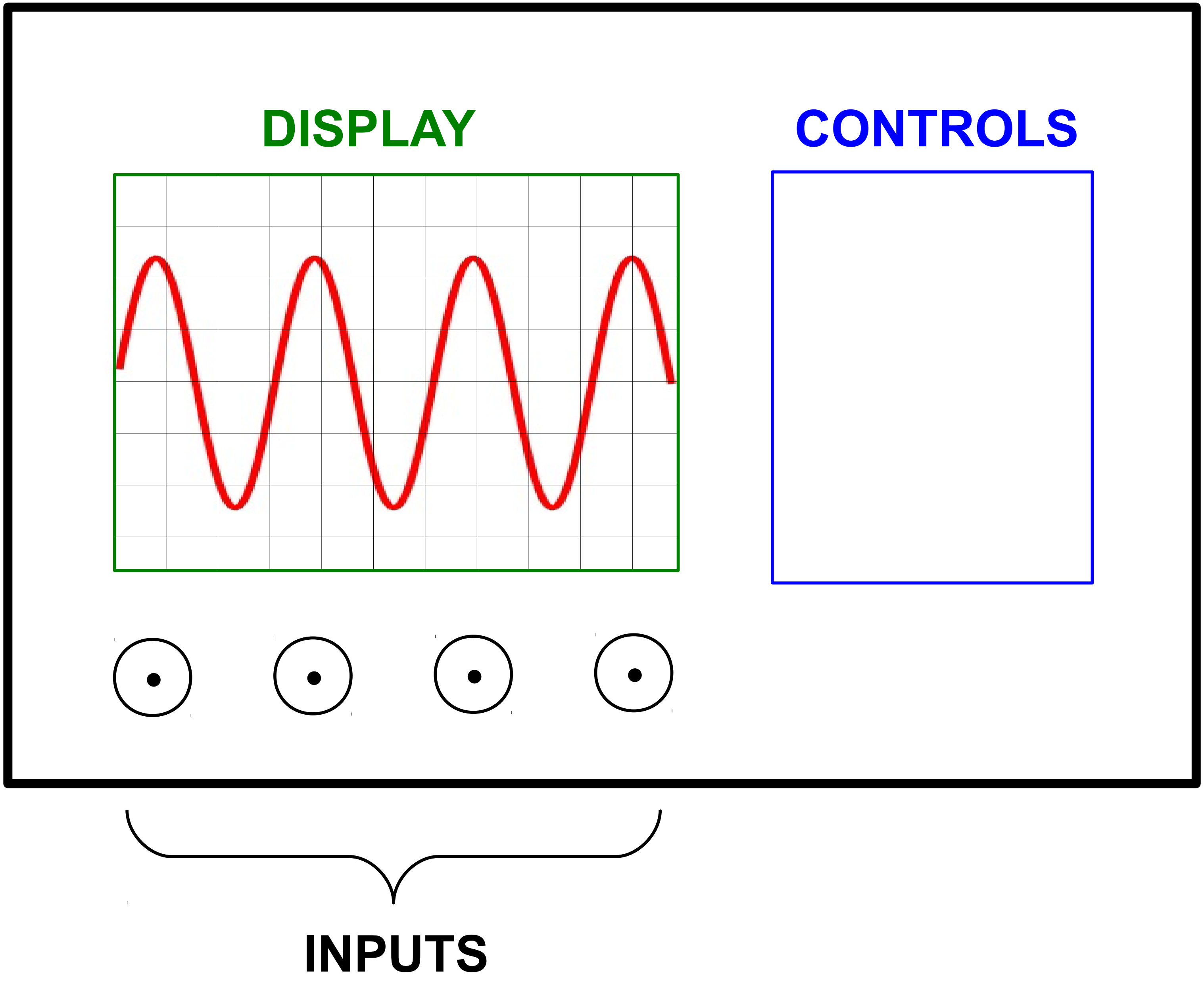
CONTROLS

VOLTAGE

TIME

INPUTS

OSCILLOSCOPE



DISPLAY

CONTROLS

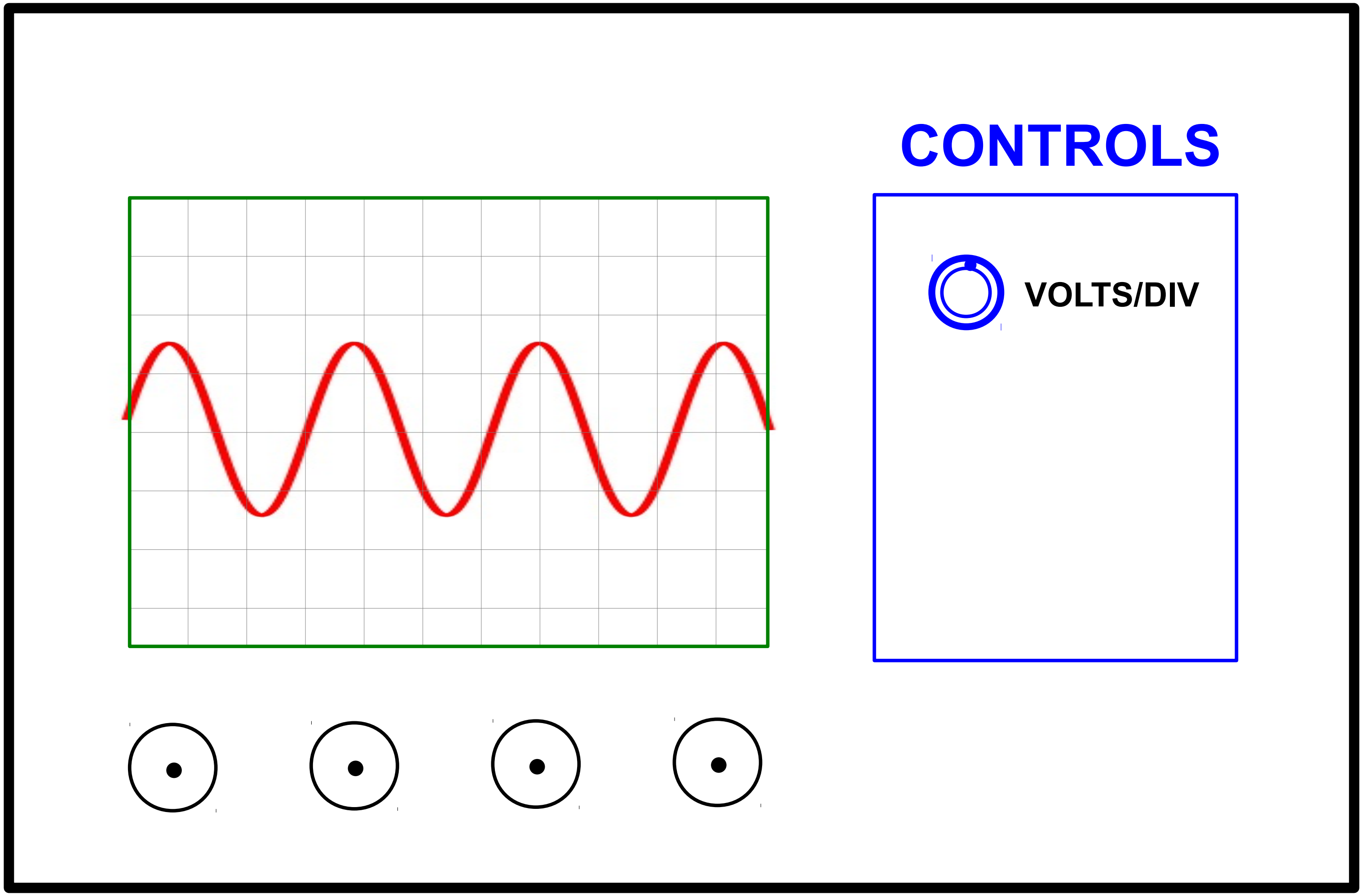
INPUTS

ANALOG: Cathode ray tube, swept electron beam

DIGITAL: A/D converter, LCD display

Although physical operation is completely different, controls are nearly identical

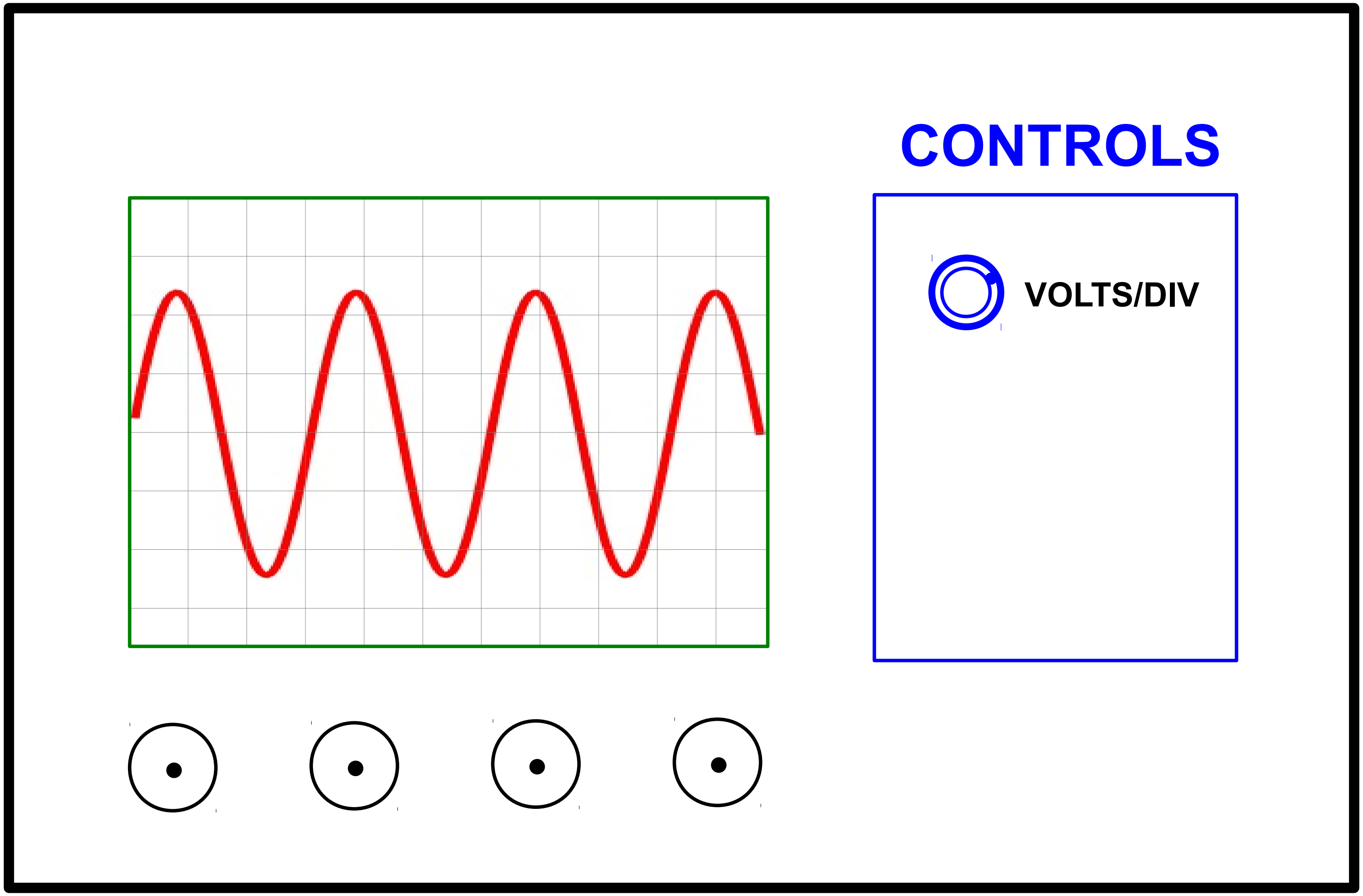
DISPLAY ADJUSTMENT



CONTROLS

VOLTS/DIV

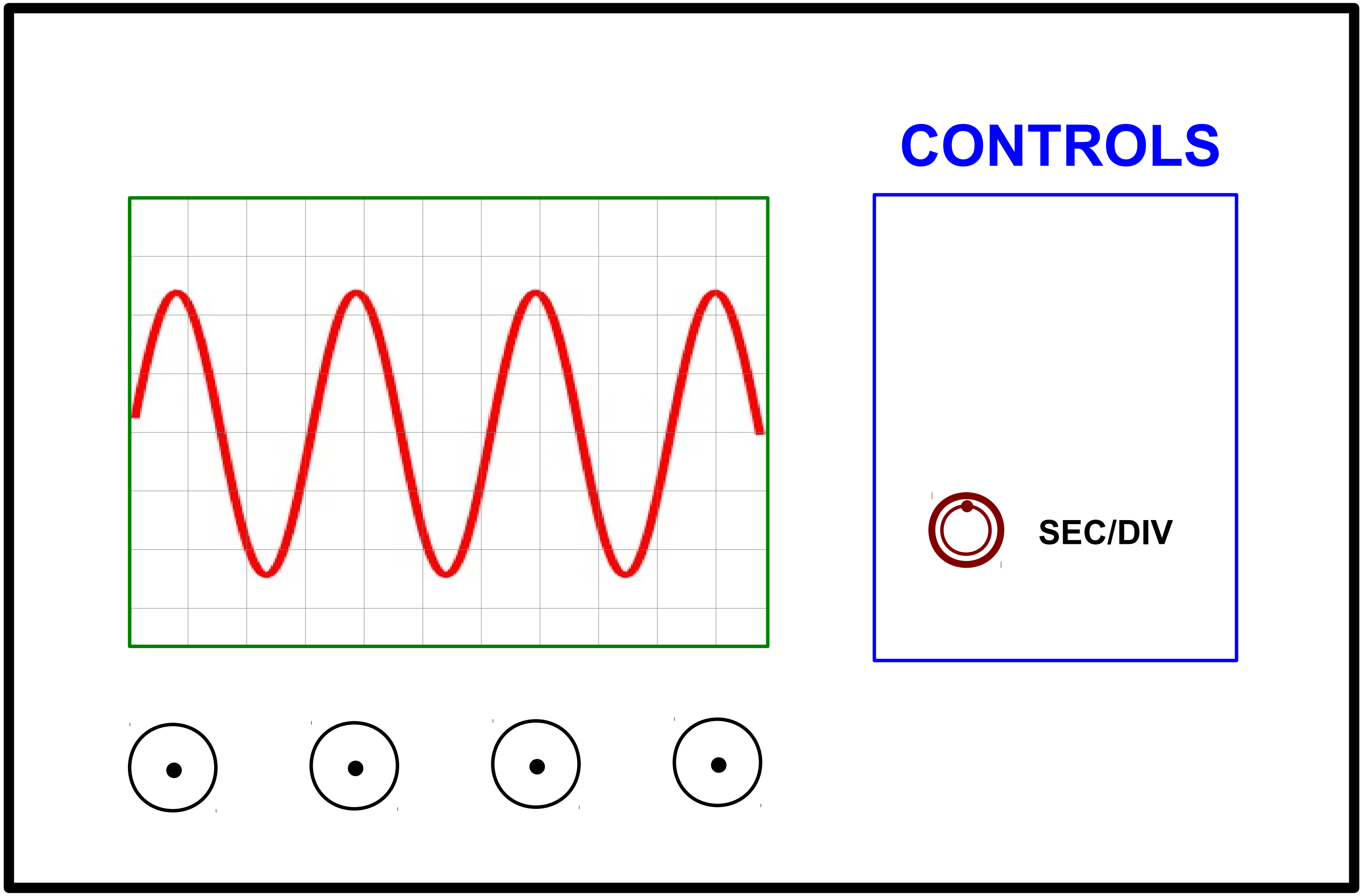
DISPLAY ADJUSTMENT



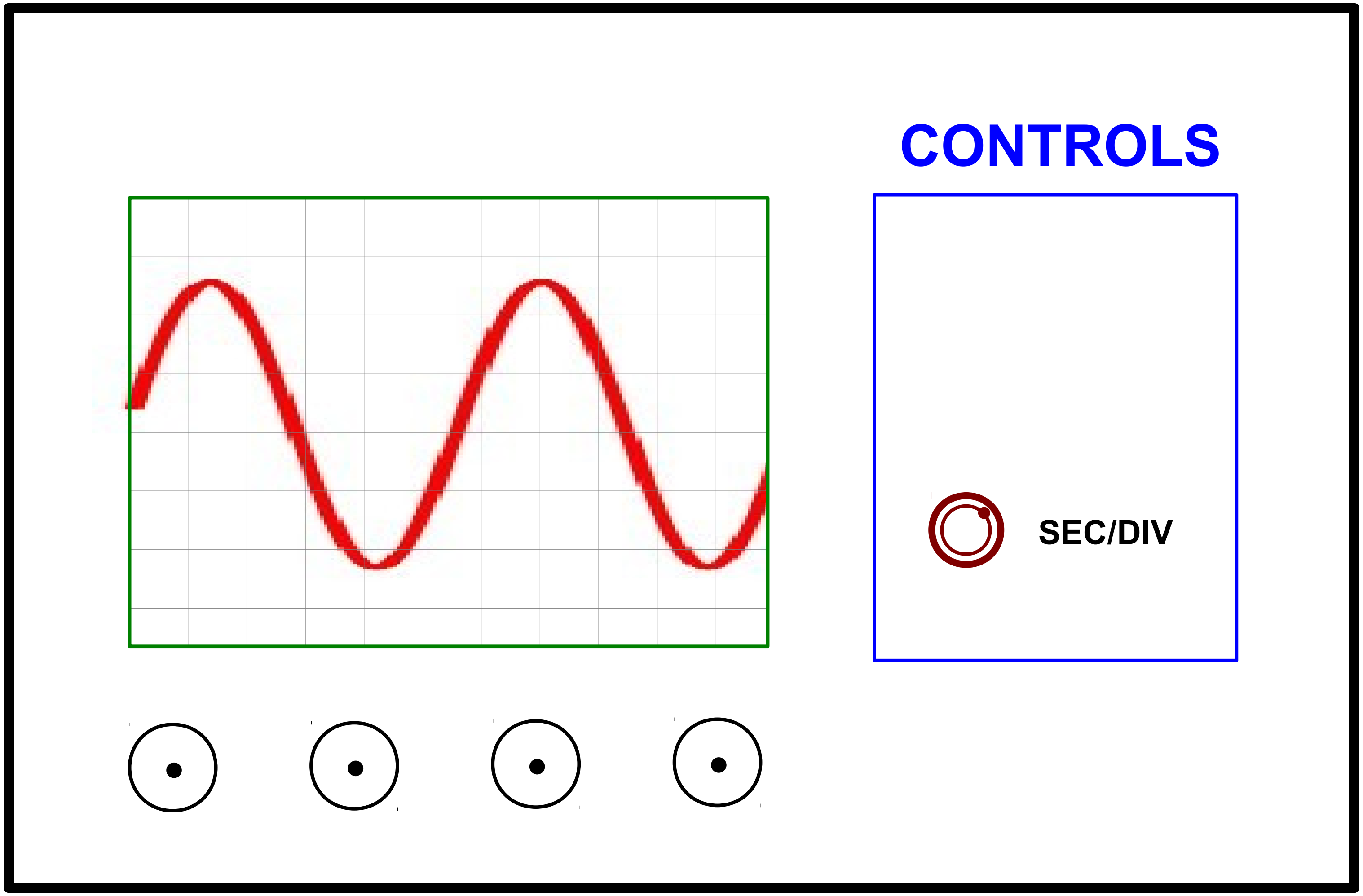
CONTROLS

VOLTS/DIV

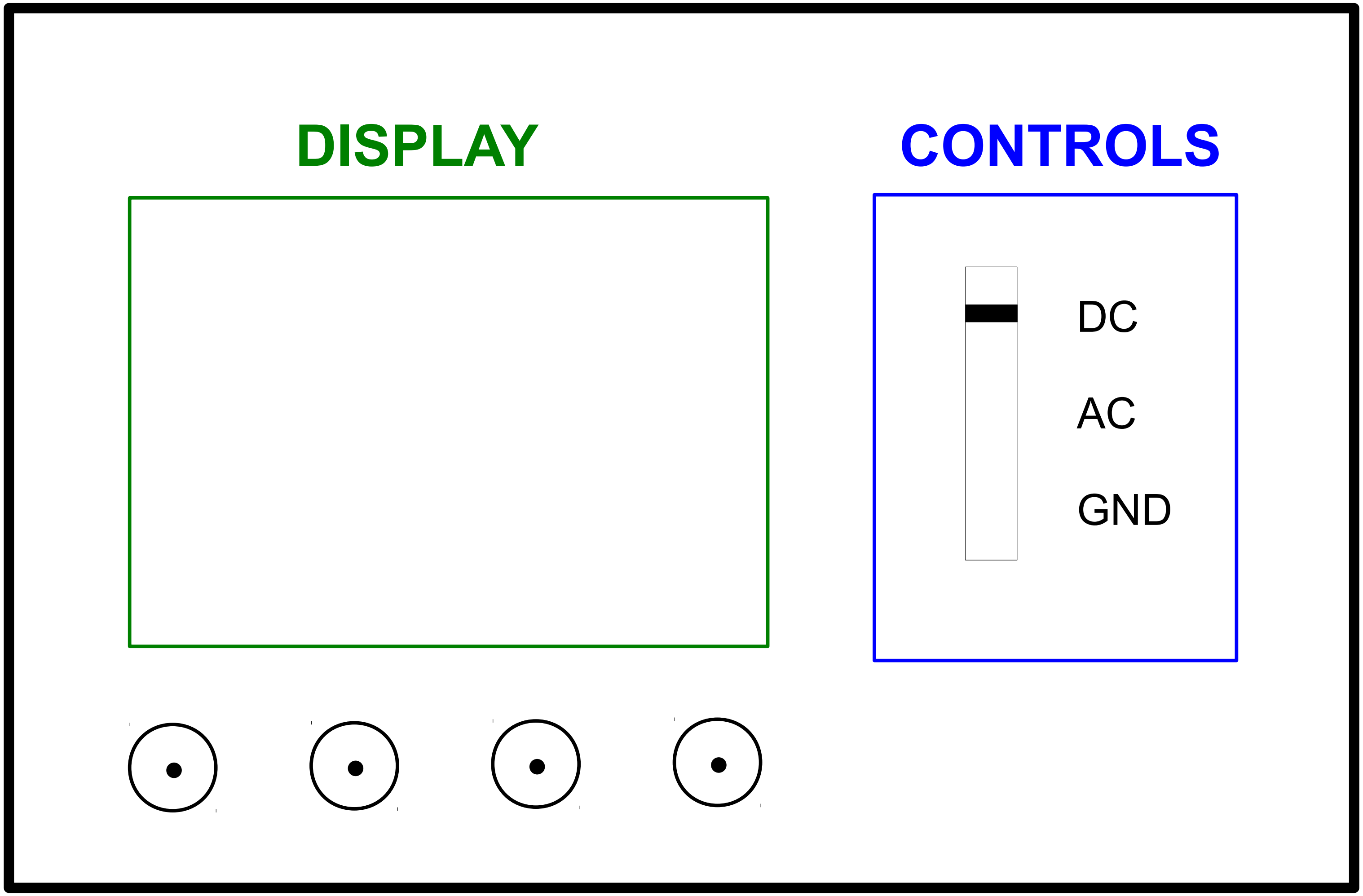
DISPLAY ADJUSTMENT



DISPLAY ADJUSTMENT



DC coupling, AC coupling, and Ground



DISPLAY

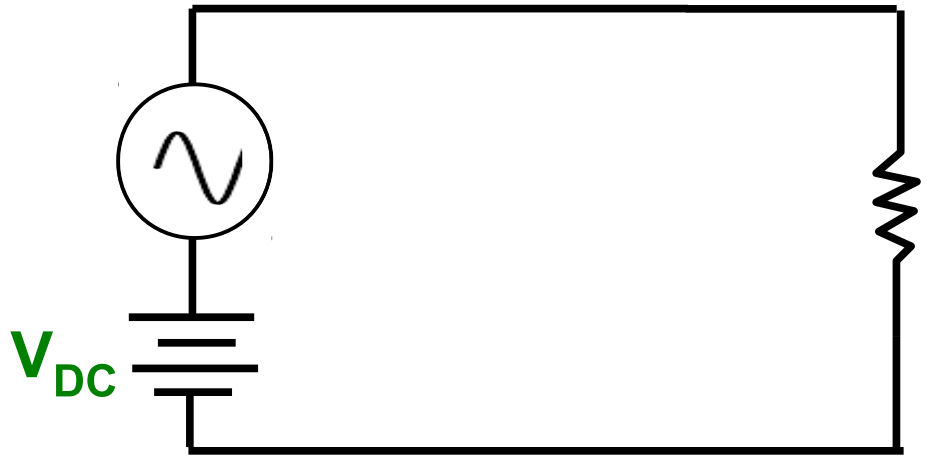
CONTROLS

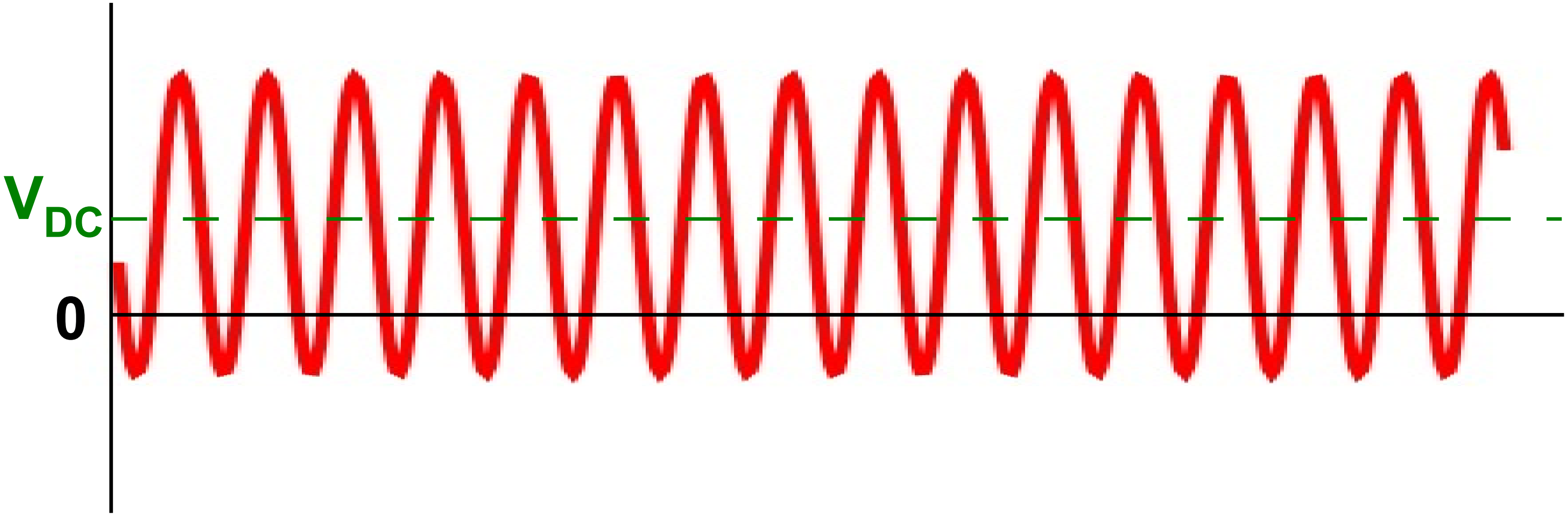
DC

AC

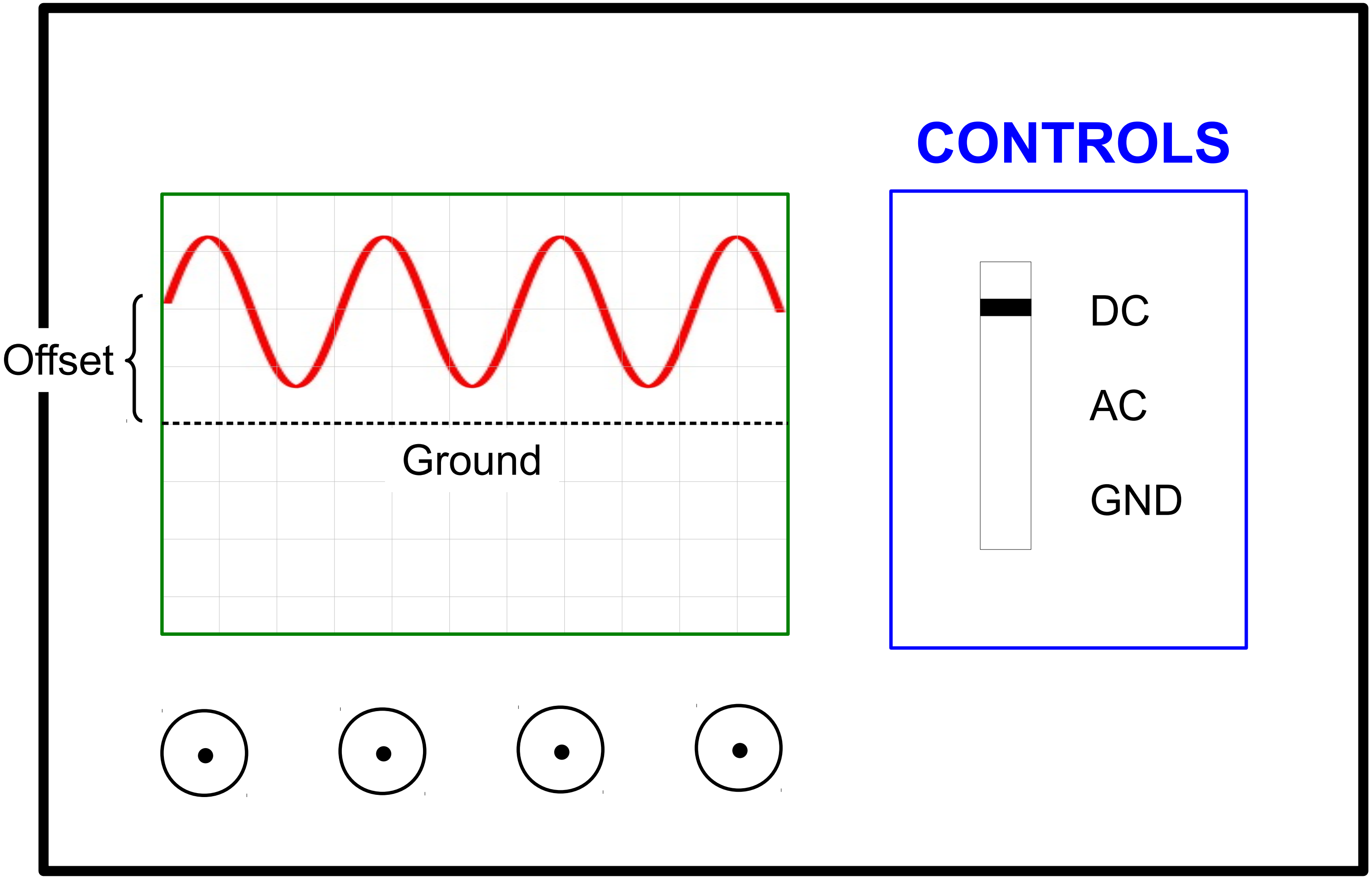
GND

EXAMPLE: Sinusoidal wave source + DC offset

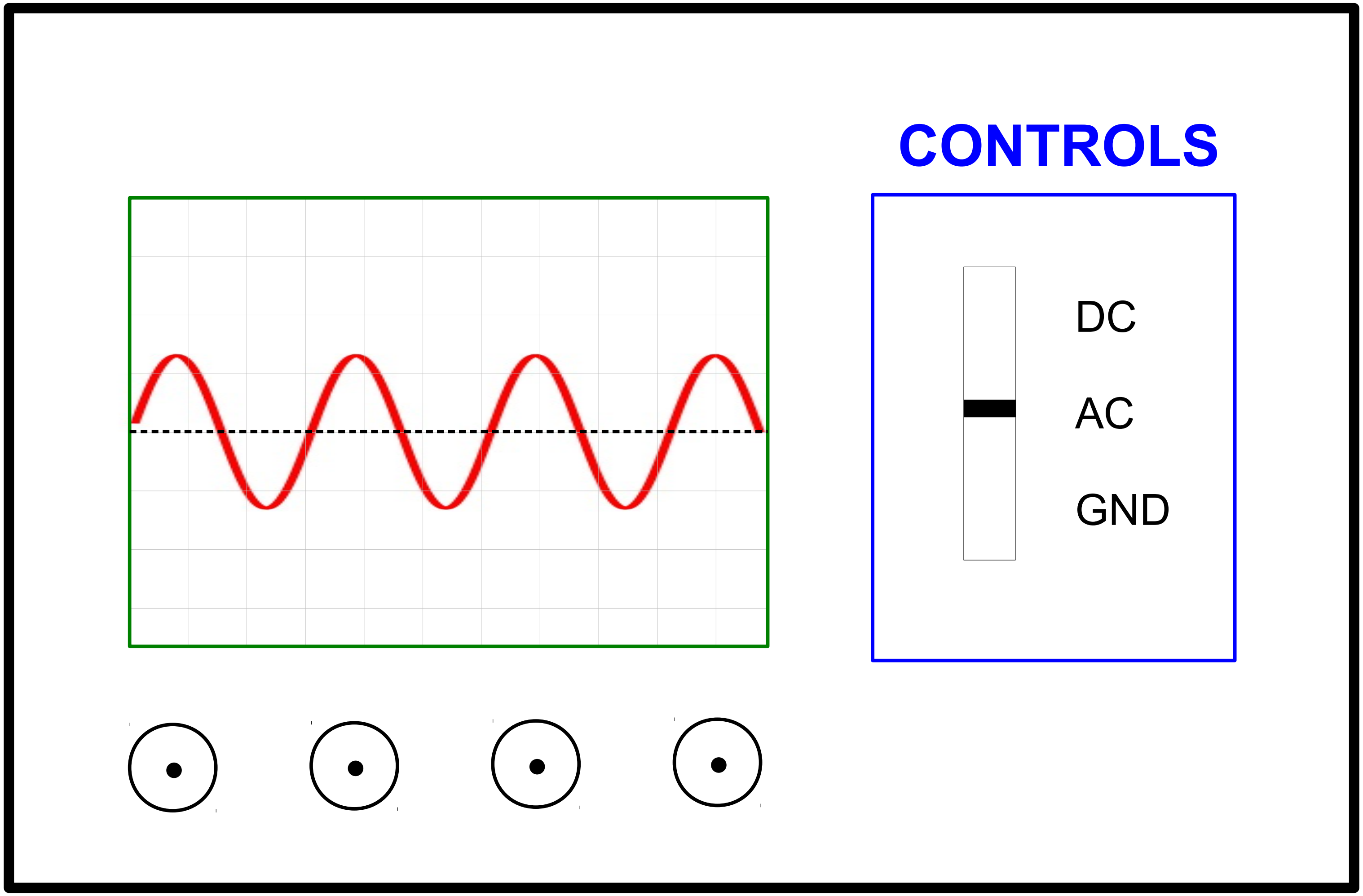




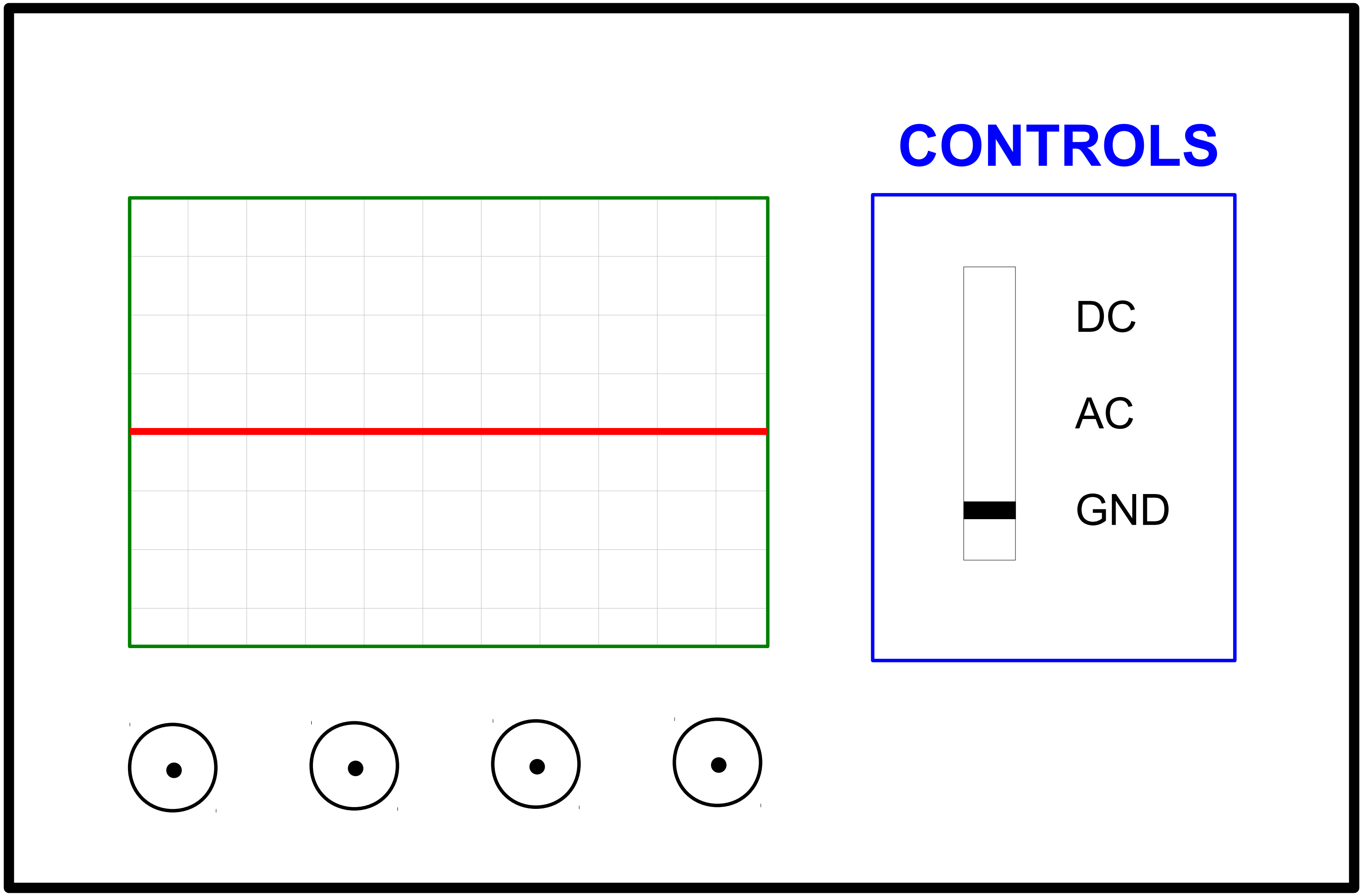
DC COUPLING



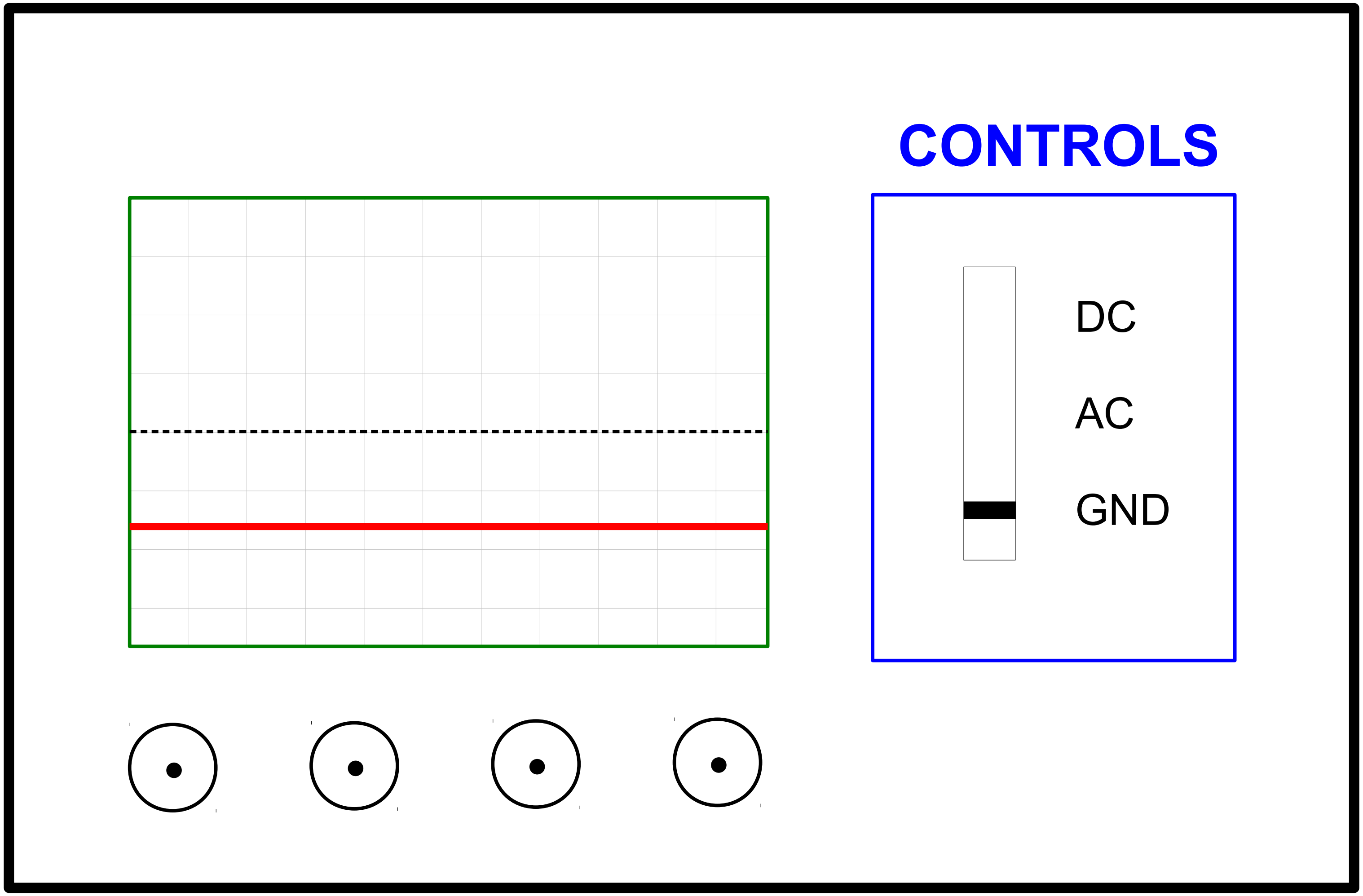
AC COUPLING



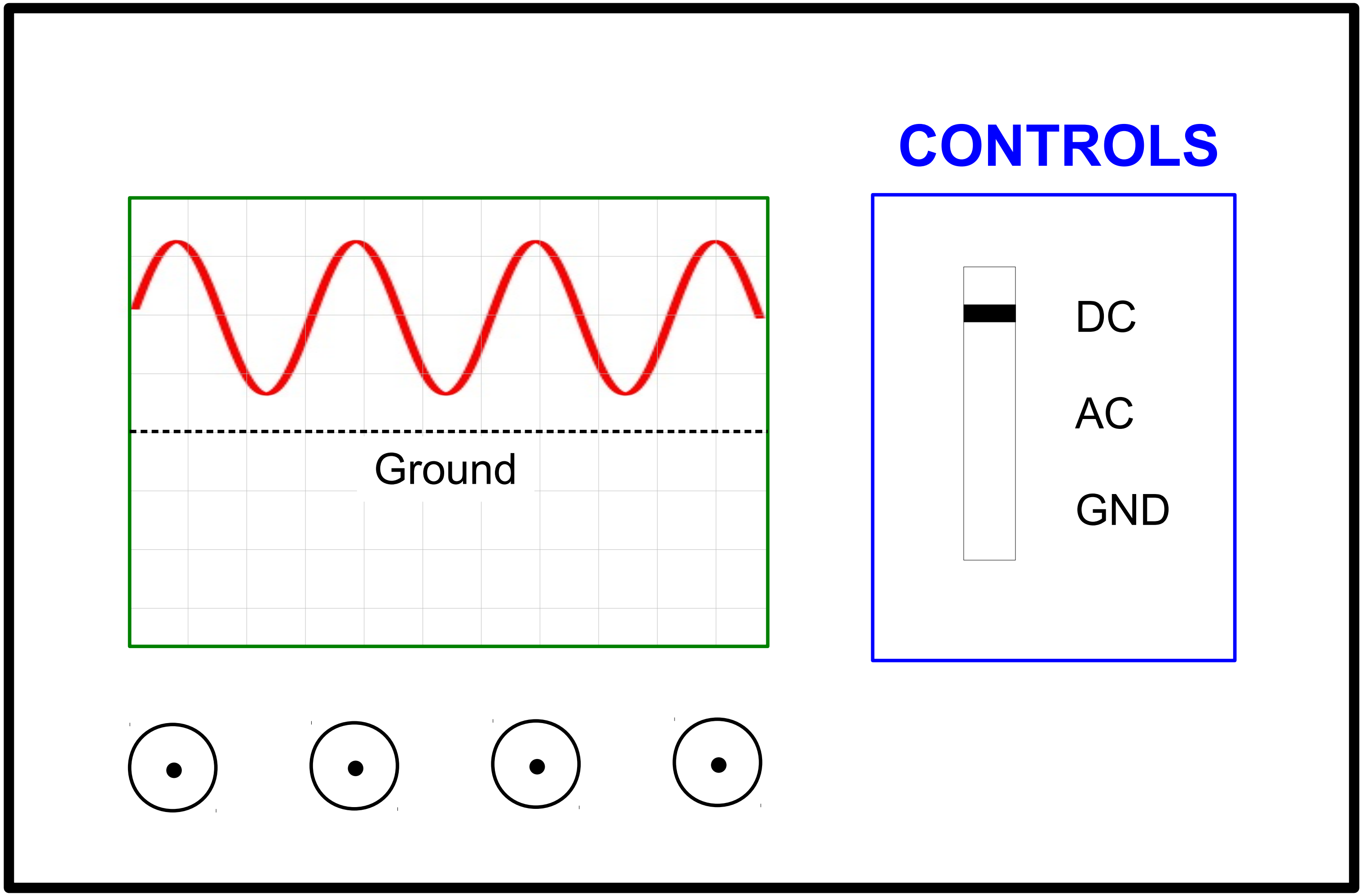
GROUND: Defines location of 0 Volts



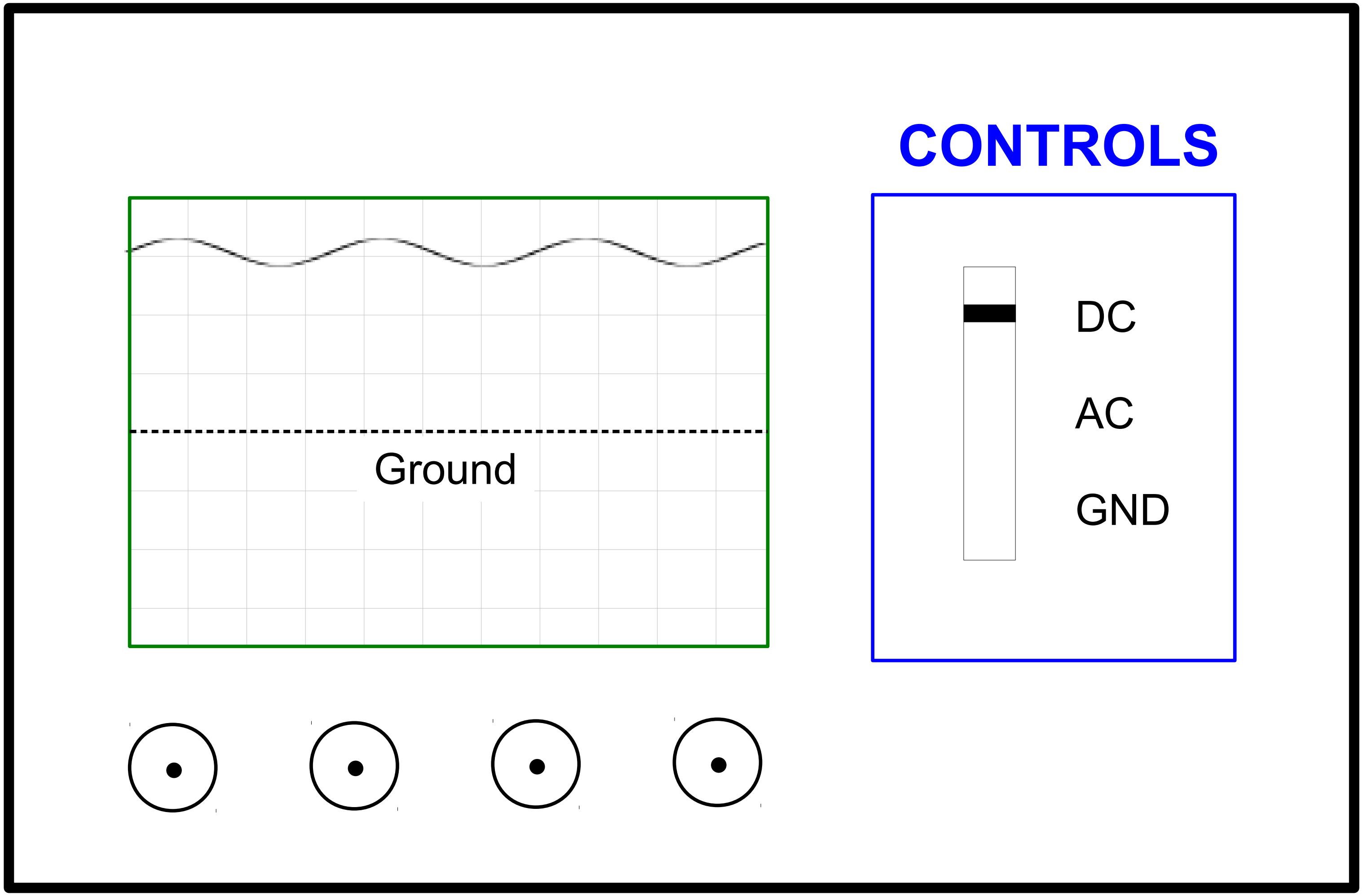
GROUND can be positioned at any convenient level



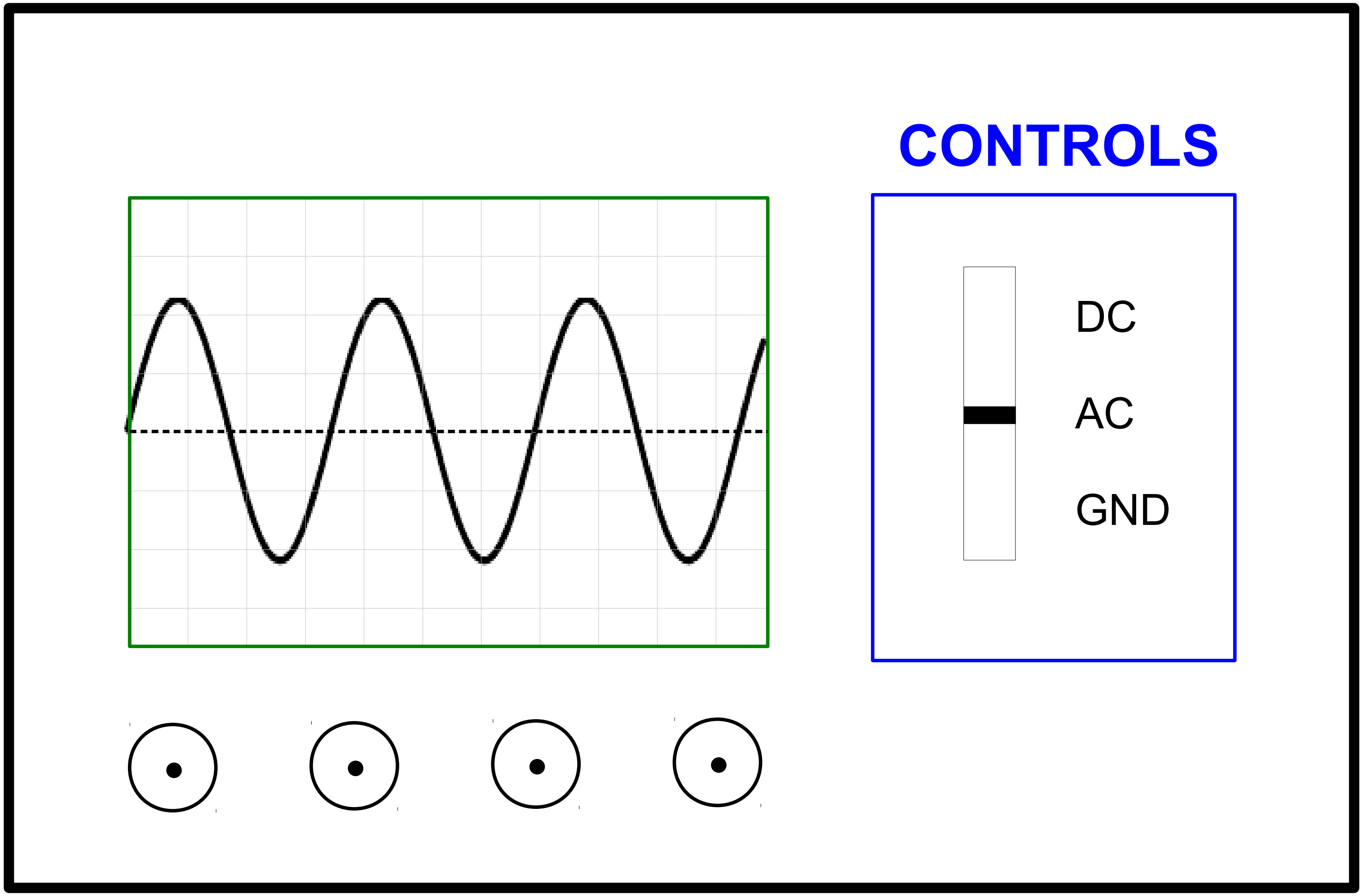
Why bother with AC coupling when DC coupling shows everything?



Often we have very weak modulation of a DC signal



AC couple and change the vertical scale



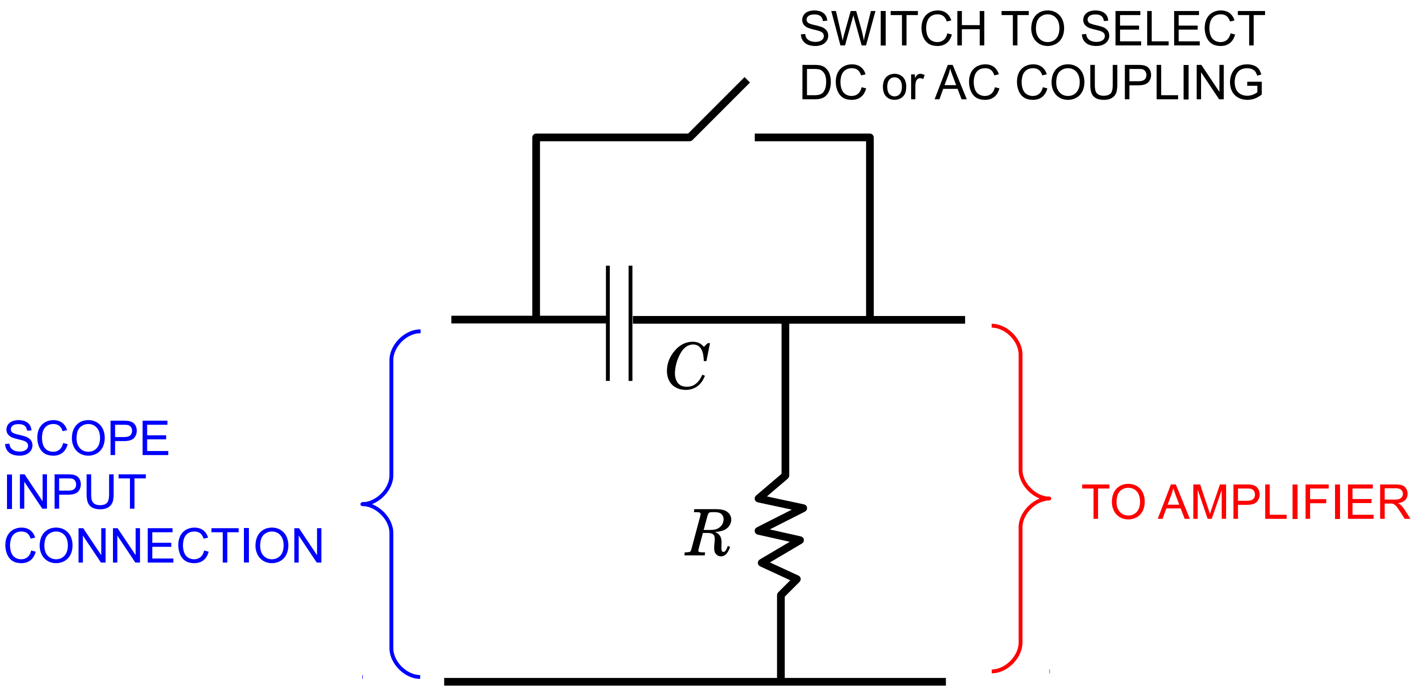
CONTROLS

DC

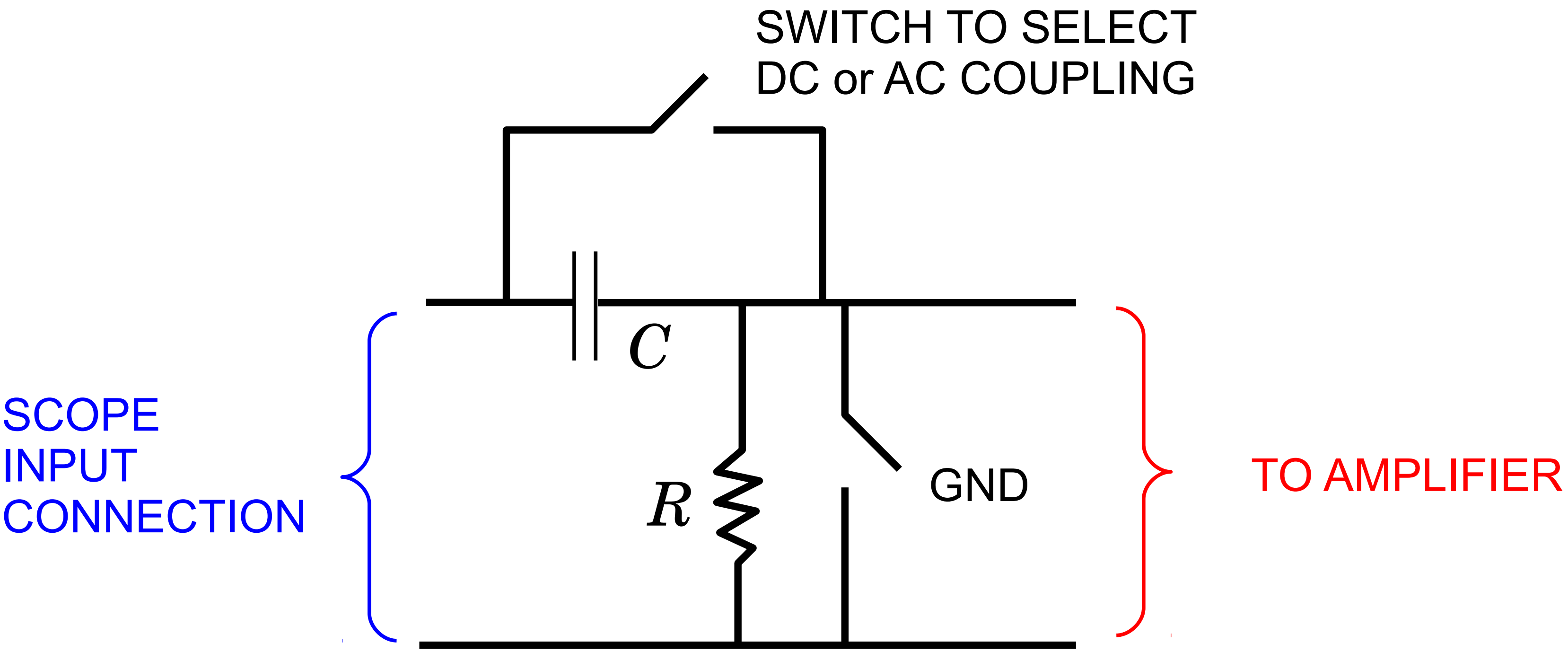
AC

GND

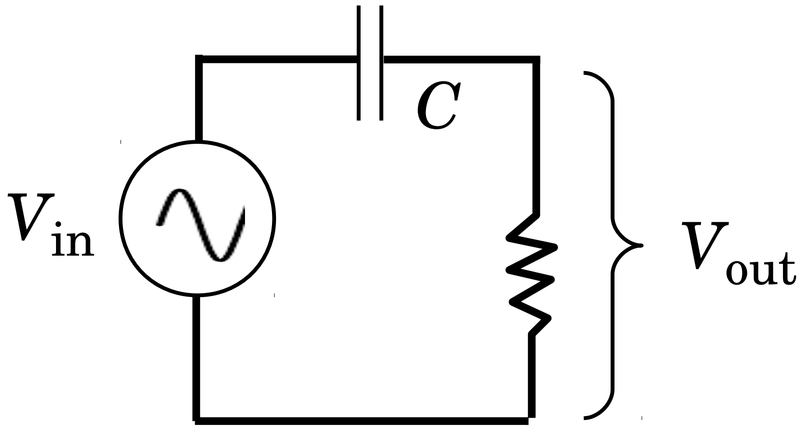
AC coupling implemented with an RC high-pass filter



AC coupling implemented with an RC high-pass filter

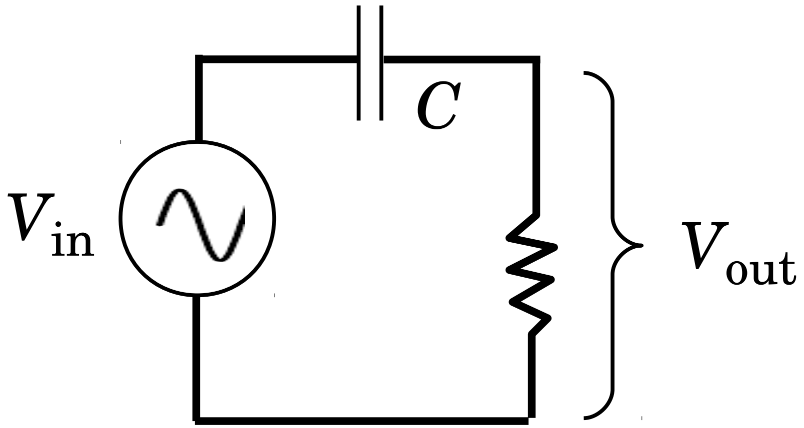


Harmonic analysis of RC high-pass filter



$$\frac{V_{OUT}(\omega)}{V_{IN}(\omega)} = \frac{R}{R + 1/j\omega C}$$

Harmonic analysis of RC high-pass filter



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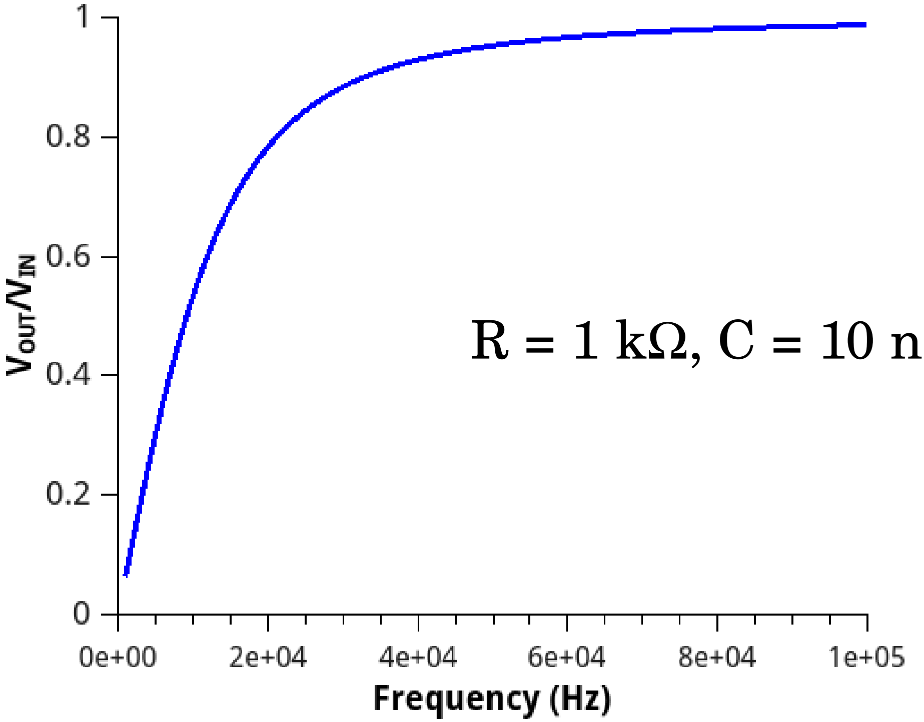
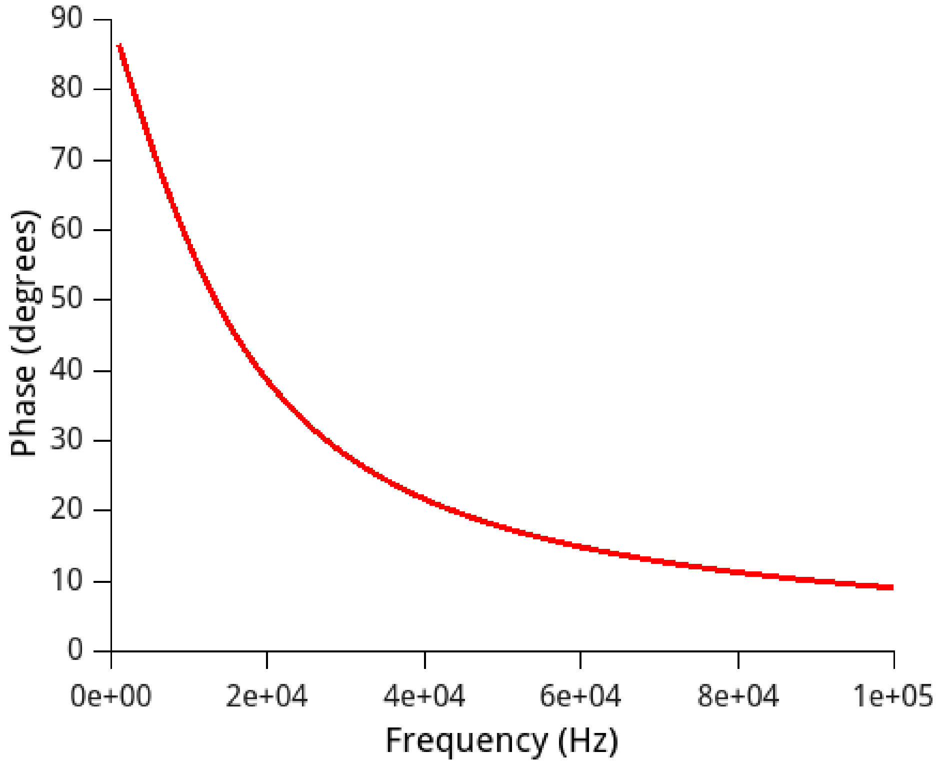


R = 1 kΩ, C = 10 nF



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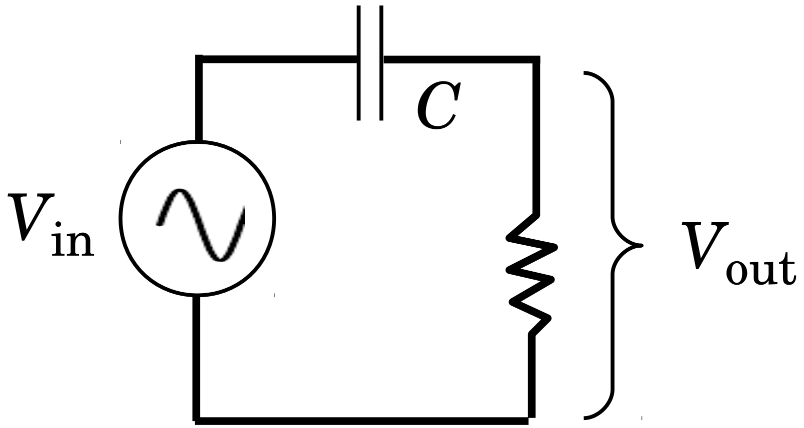
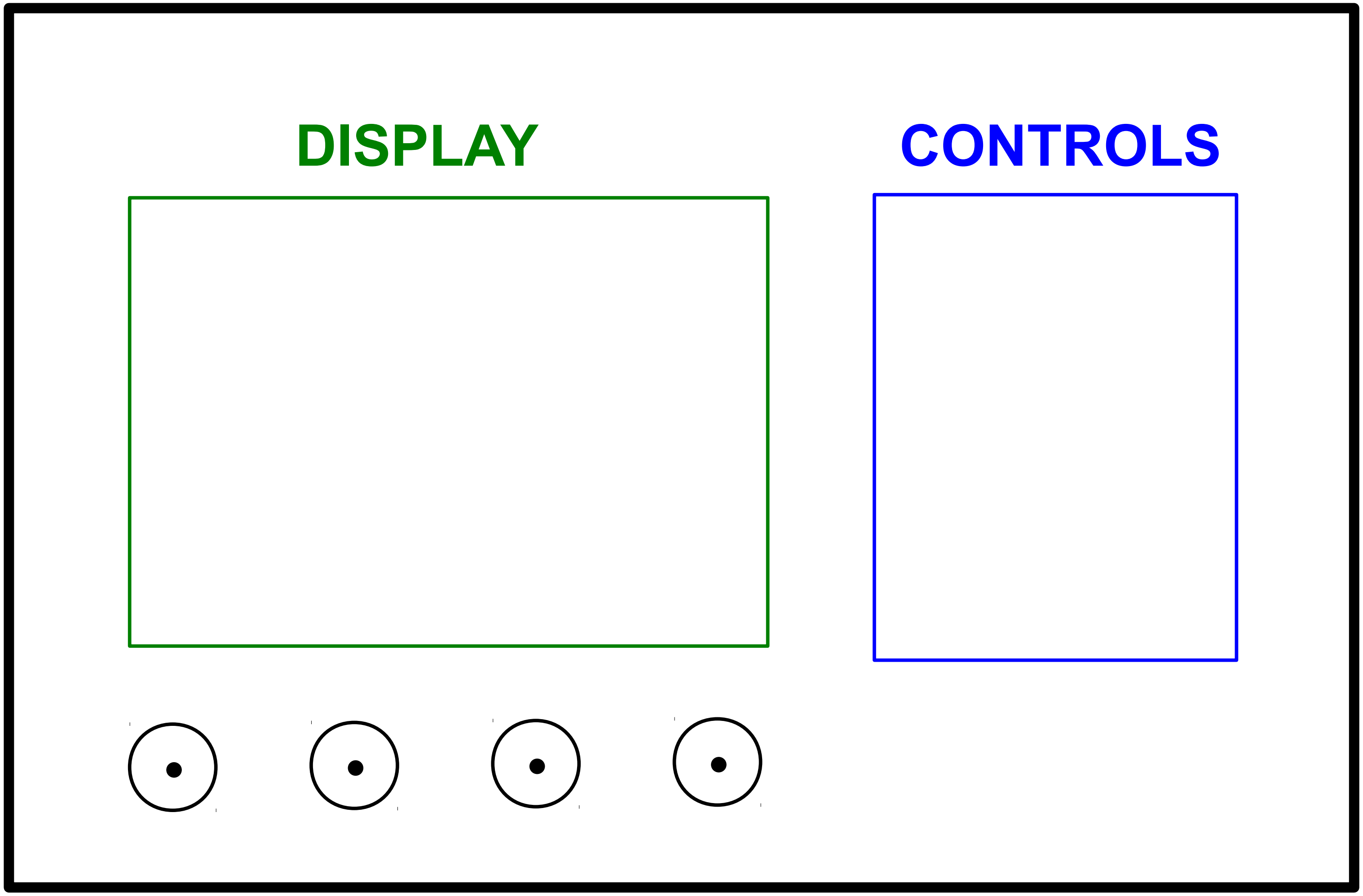


$$\frac{V_{OUT}(\omega)}{V_{IN}(\omega)} = \frac{R}{R + 1/j\omega C}$$

A typical oscilloscope has an *RC* high-pass cutoff in the range 1—10 Hz when AC coupling is used

Be careful when measuring slow signals:
AC coupling blocks more than just DC

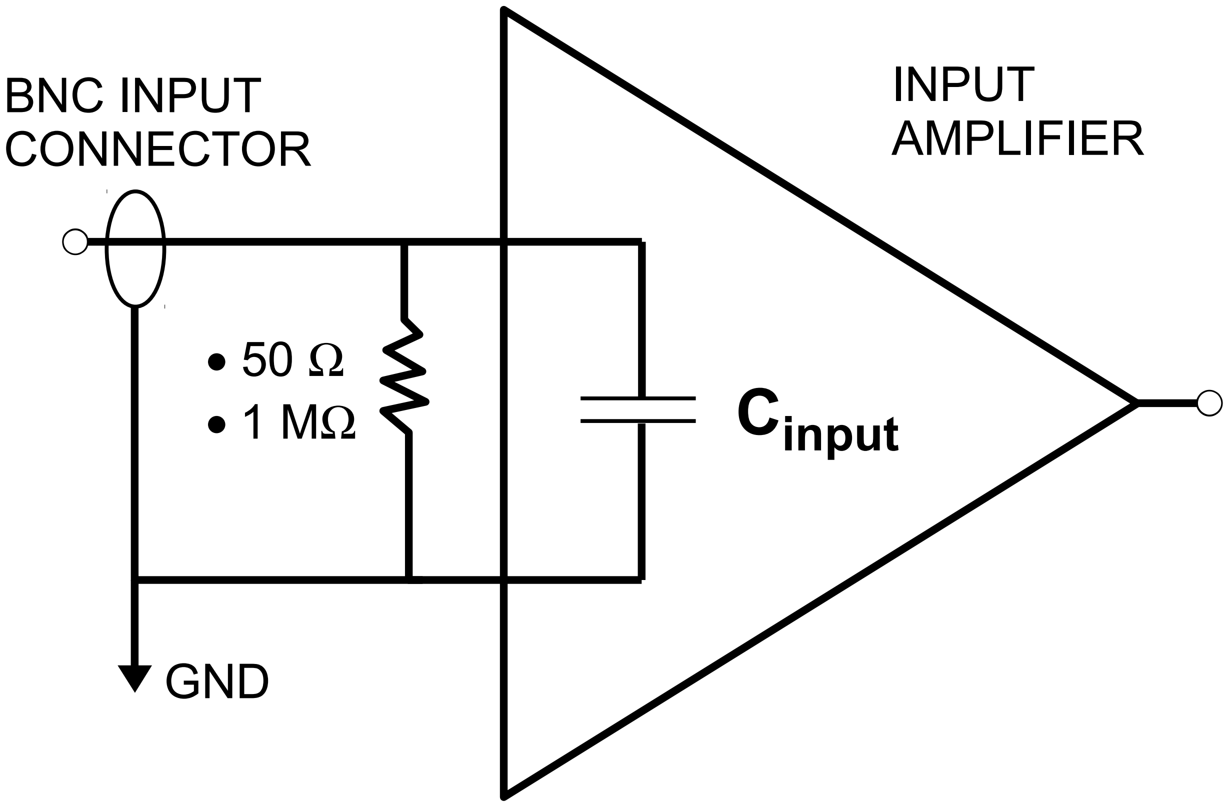
INPUT RESISTANCE: 50 Ω or 1 MΩ?



DISPLAY

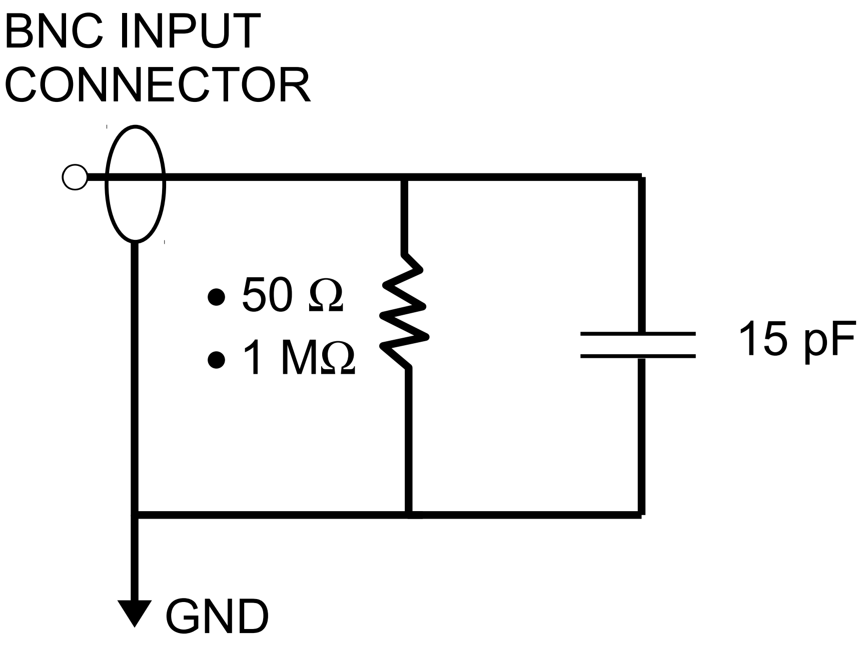
CONTROLS

All oscilloscopes have stray (unavoidable) capacitance at the input terminals: C_{input} = 15—20 pF



All oscilloscopes have stray (unavoidable) capacitance at the input terminals

$$Z_{in} = \frac{R_{in}}{1 + j\omega R_{in} C_{in}}$$



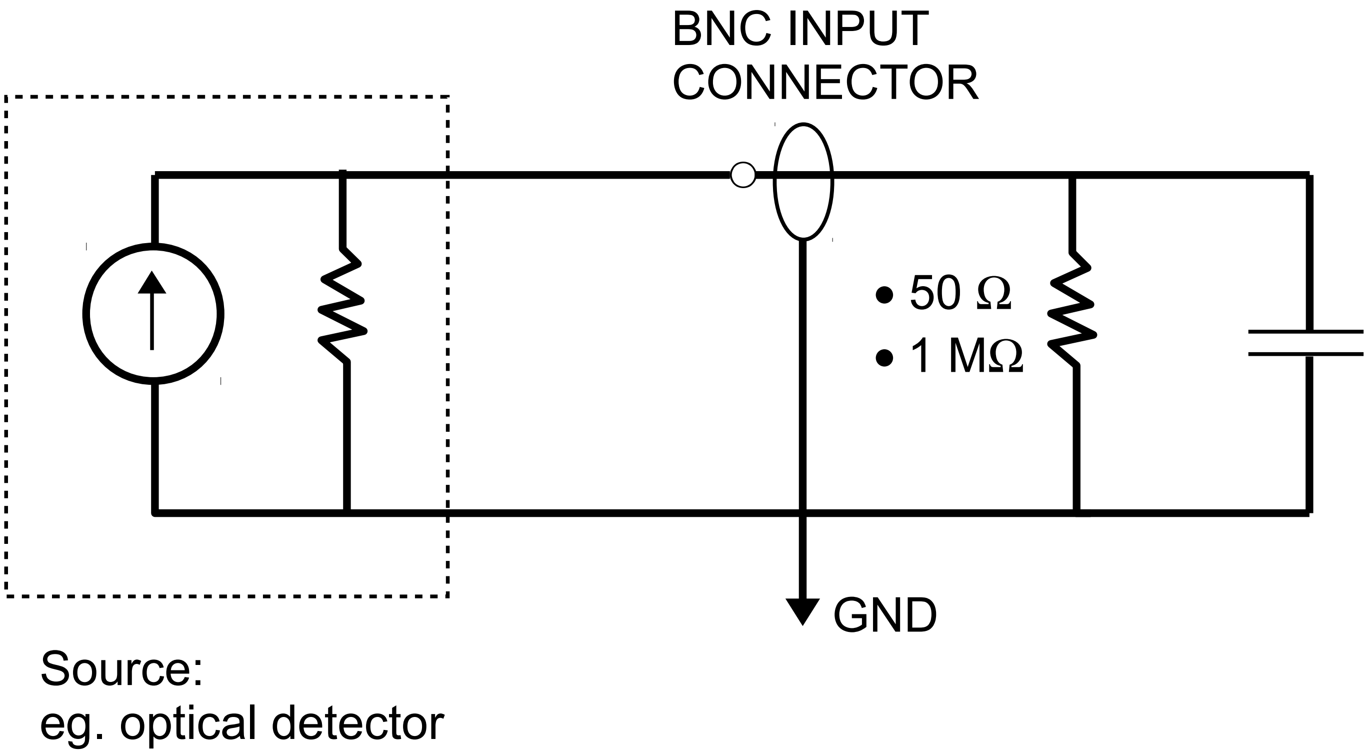
- 1 MΩ rolloff ~ 8 kHz

- 50 Ω rolloff ~ 160 MHz

Compensation possible with scope probe

Why do we use 1 MΩ if frequency response is so low?

ANSWER: Signal level (voltage) will drop enormously at 50 Ω unless source can provide enough current



TRIGGERING

Auto: Scope gives continually updated display

Normal: User controls when the slope triggers; Level, Slope
Trigger source: Channel 1, Channel 2, etc

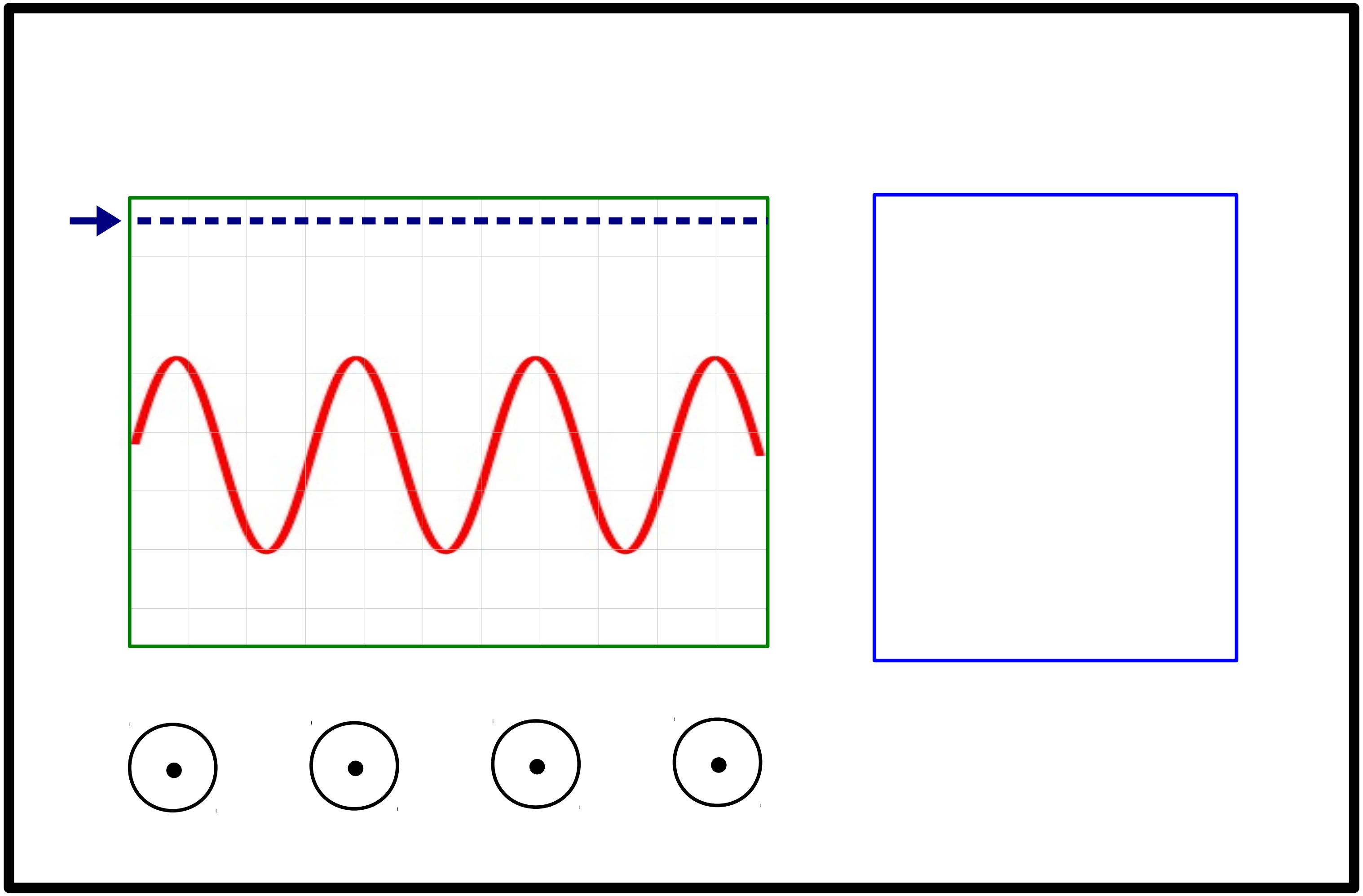
Line: Triggers on 60 Hz AC

Single event

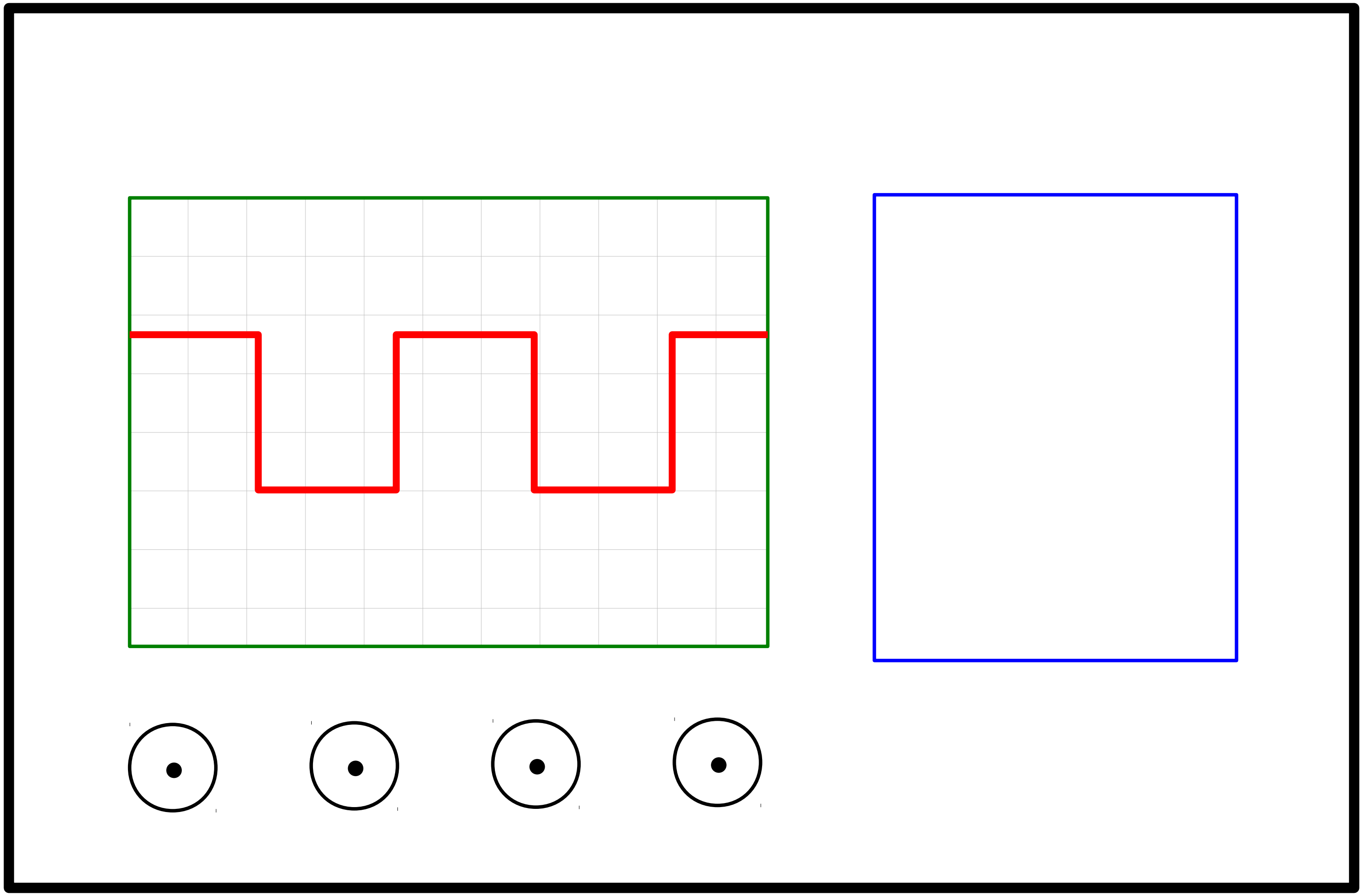
External

Use **Auto-Set** only when all else fails!

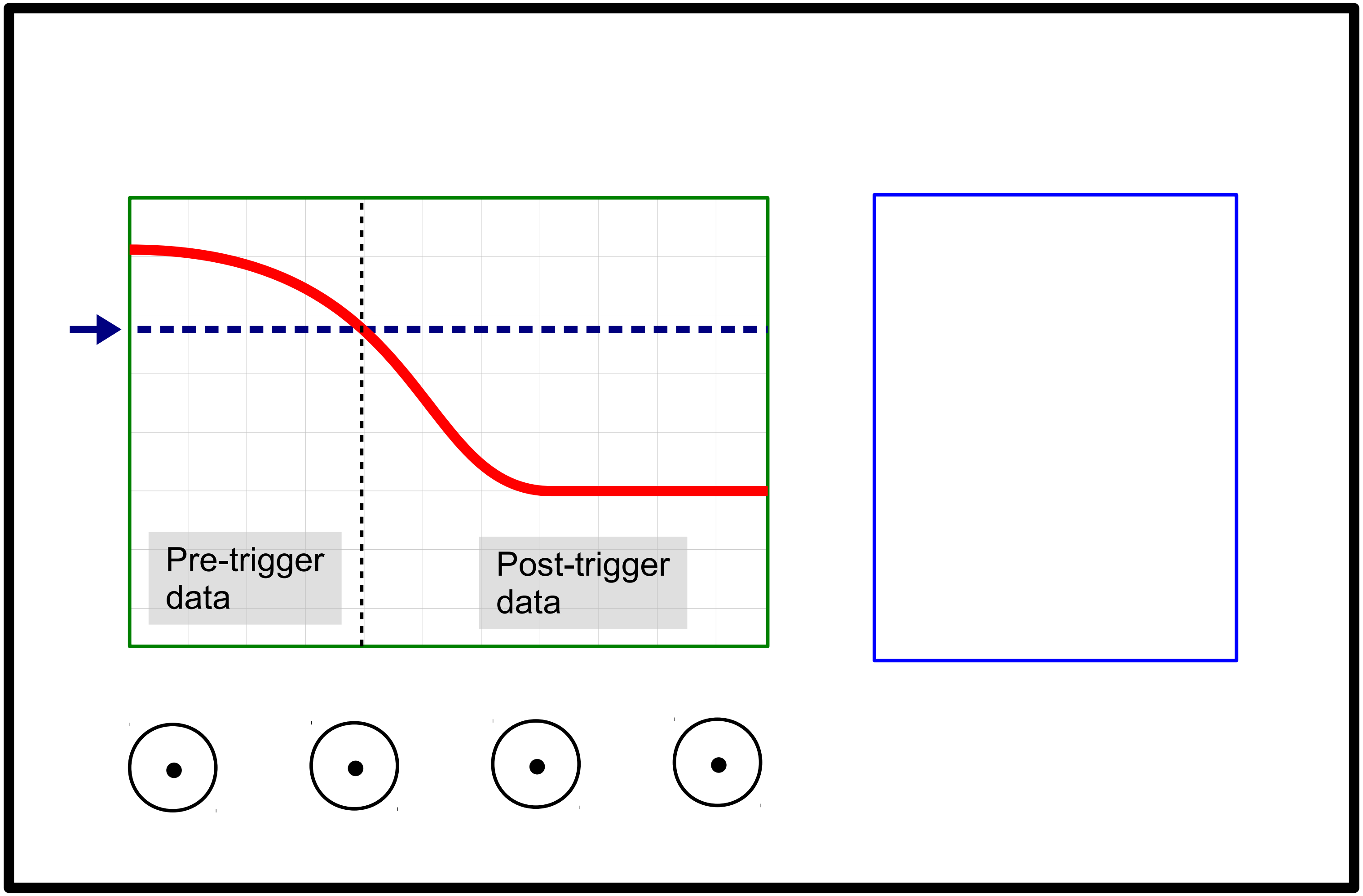
Setting normal trigger level



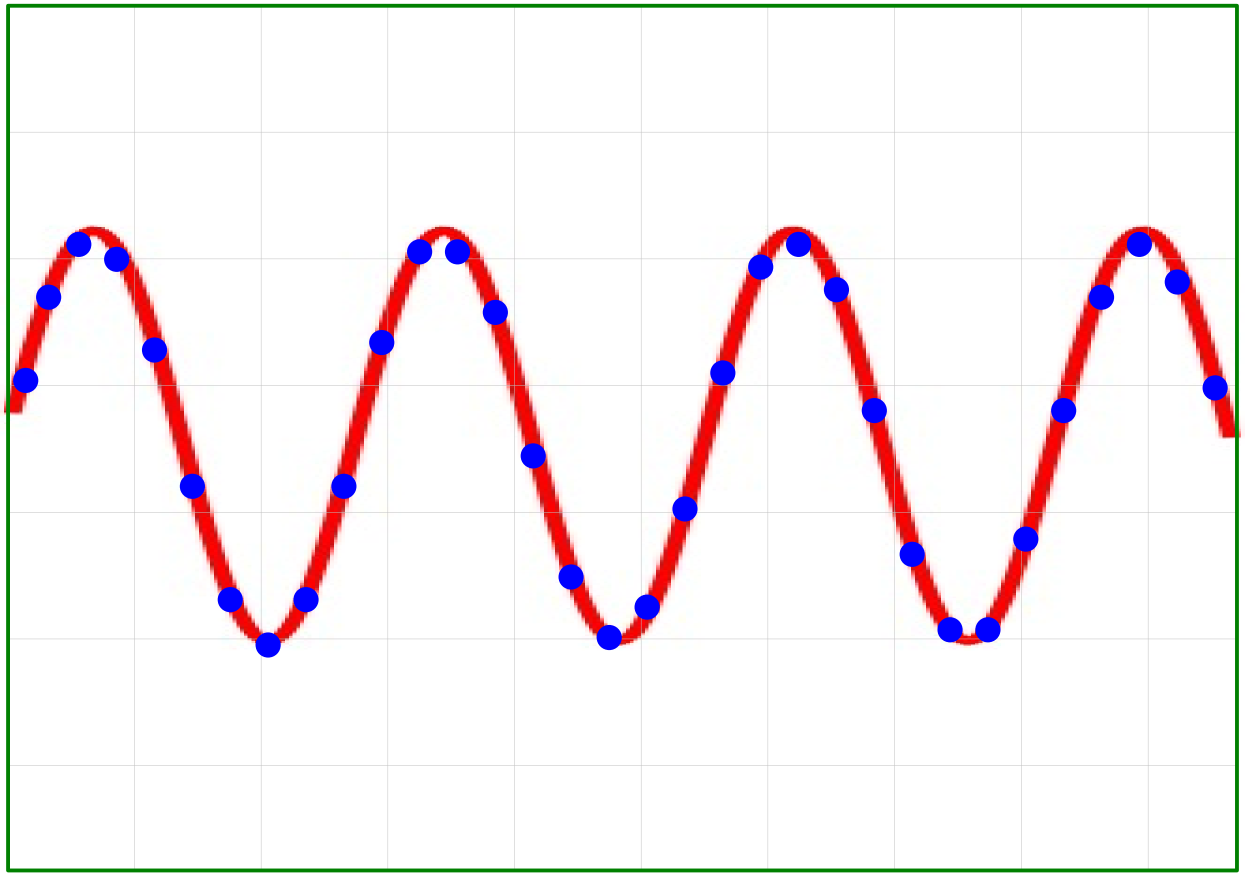
Example: Measure fall time of square wave



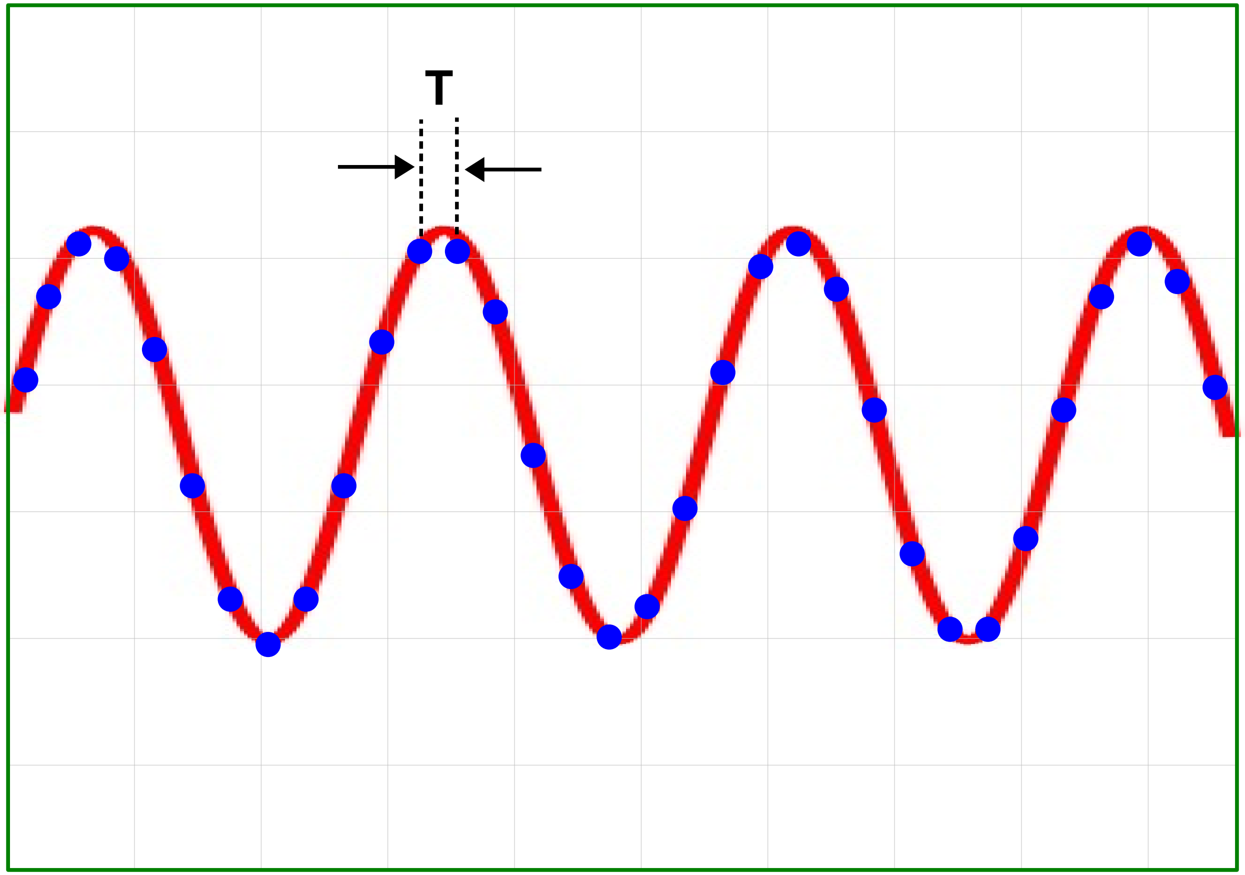
SOLUTION: Trigger on negative slope



DIGITAL SCOPE:
SAMPLING BANDWIDTH



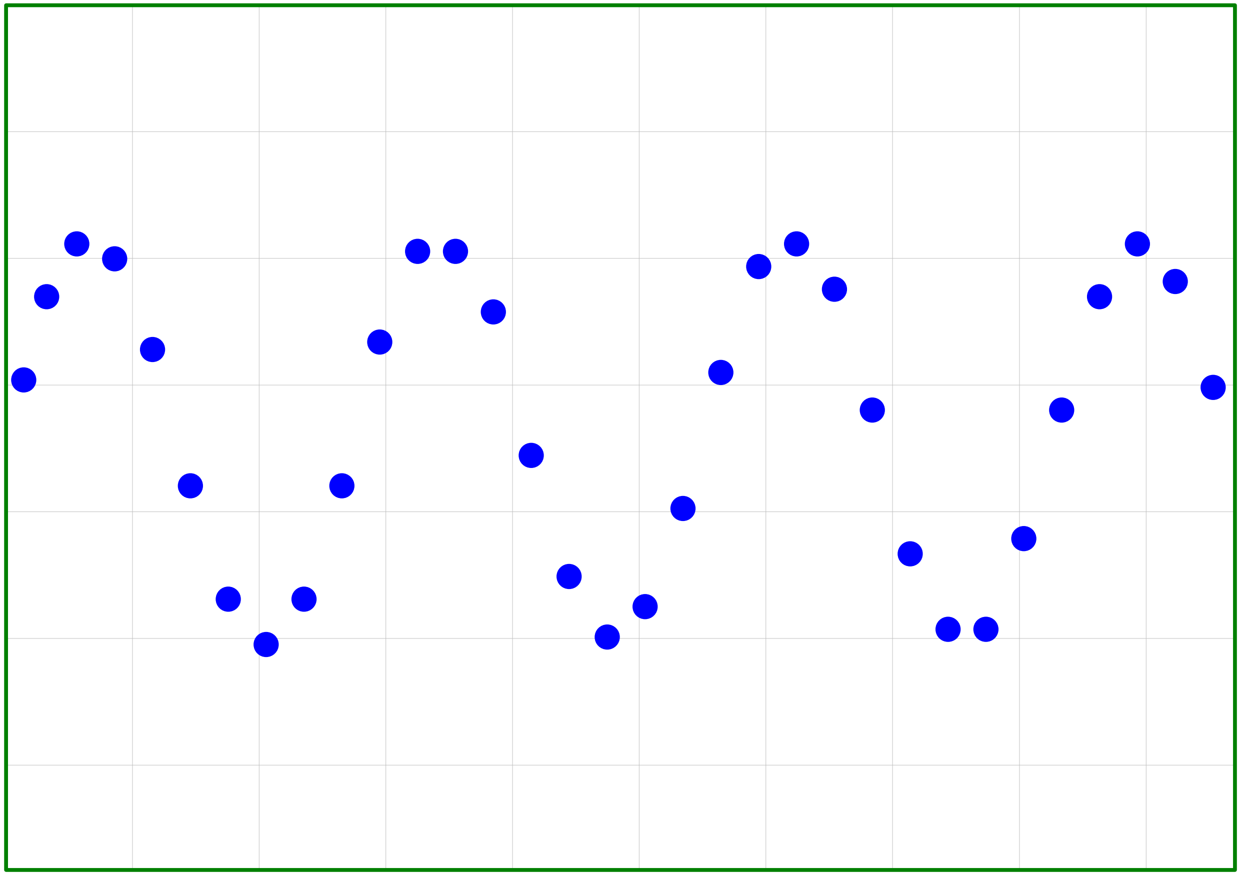
SAMPLING BANDWIDTH



Sample spacing: **T** (sec)

Sampling bandwidth = 1 / **T** (samples/sec)

SAMPLING BANDWIDTH



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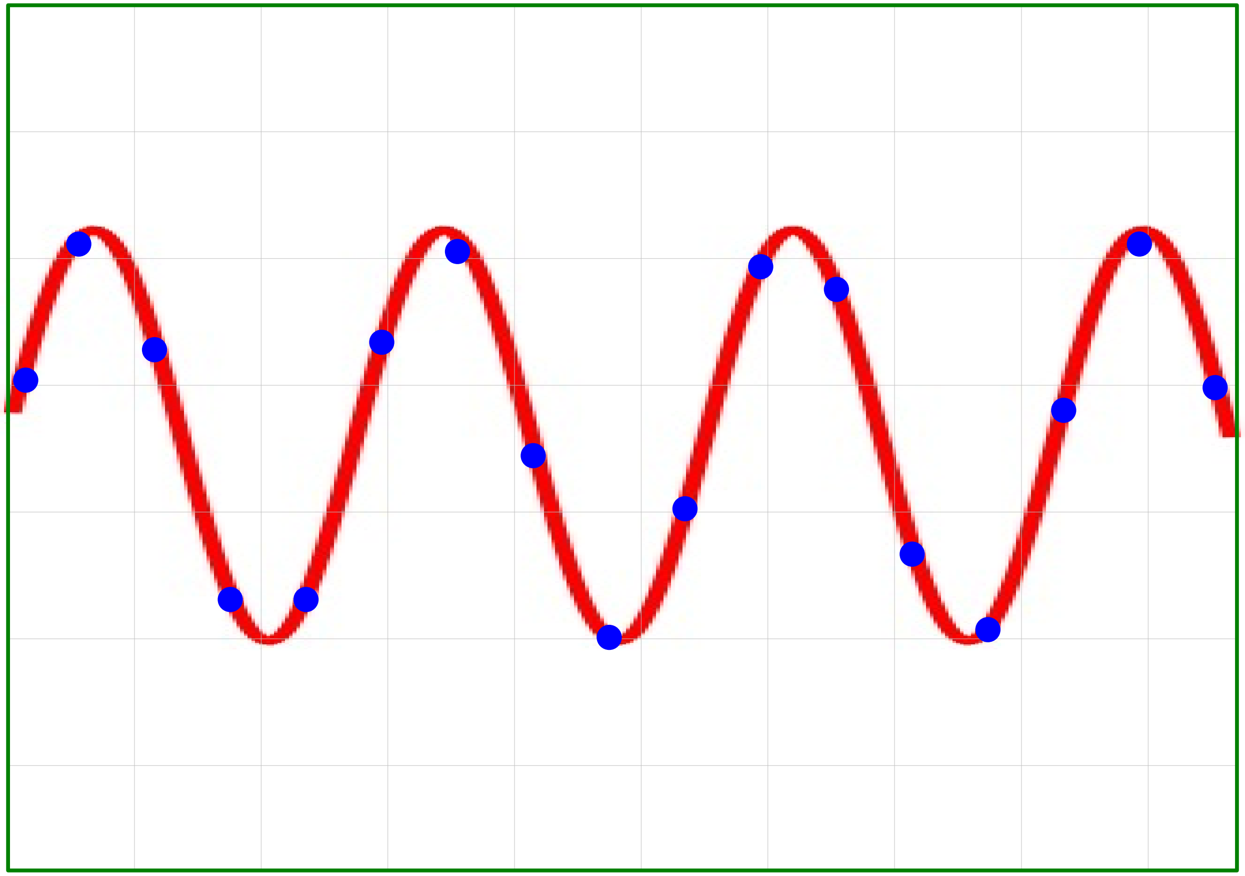
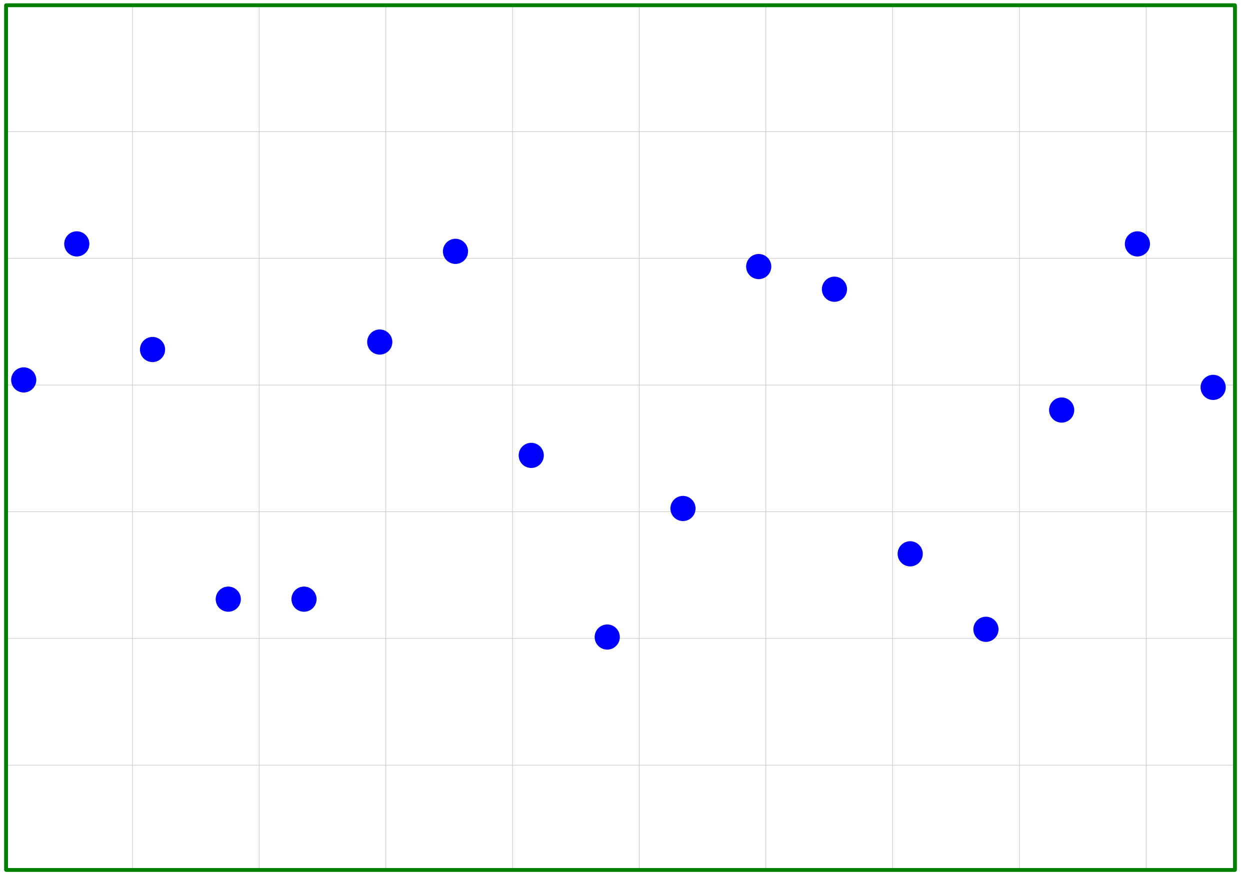


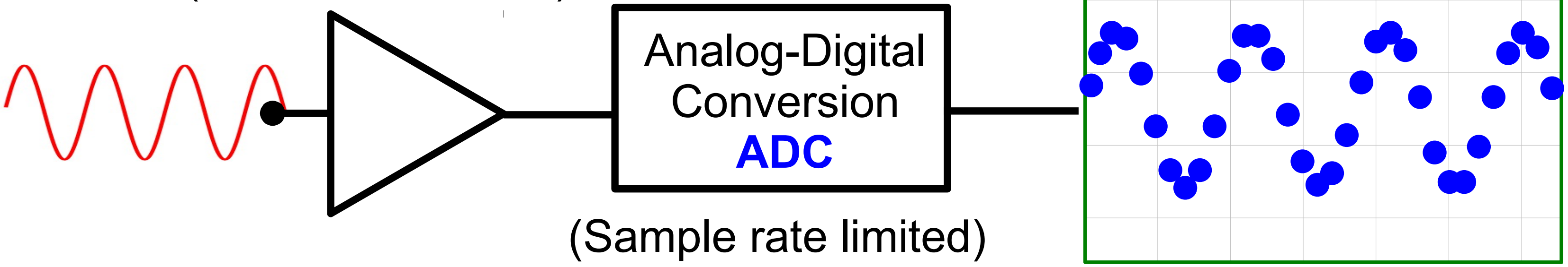
Reduce sample bandwidth 2x ⇨ Increase period 2x

SAMPLING BANDWIDTH



Reduce sample bandwidth 2x ⇒ Increase period 2x

ANALOG BANDWIDTH $\neq$ SAMPLING BANDWIDTH



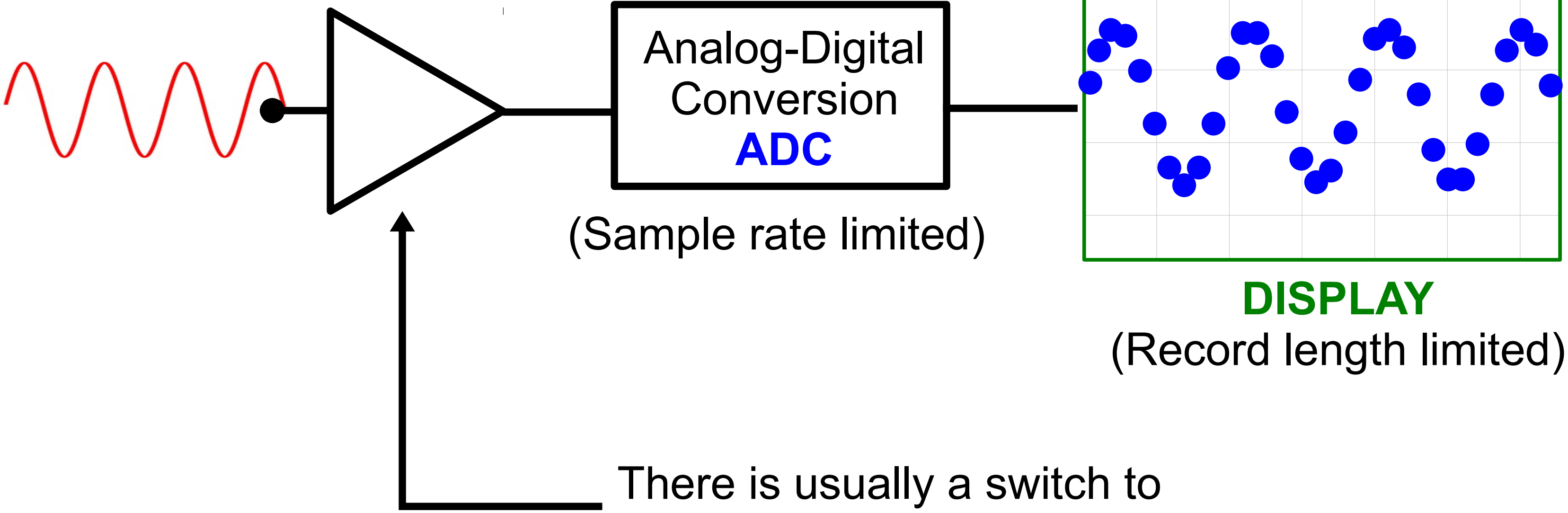
Analog amplification
(Bandwidth limited)

Analog-Digital
Conversion
ADC

(Sample rate limited)

DISPLAY
(Record length limited)

ANALOG BANDWIDTH ≠ SAMPLING BANDWIDTH



Analog amplification
(Bandwidth limited)

Analog-Digital
Conversion
ADC

(Sample rate limited)

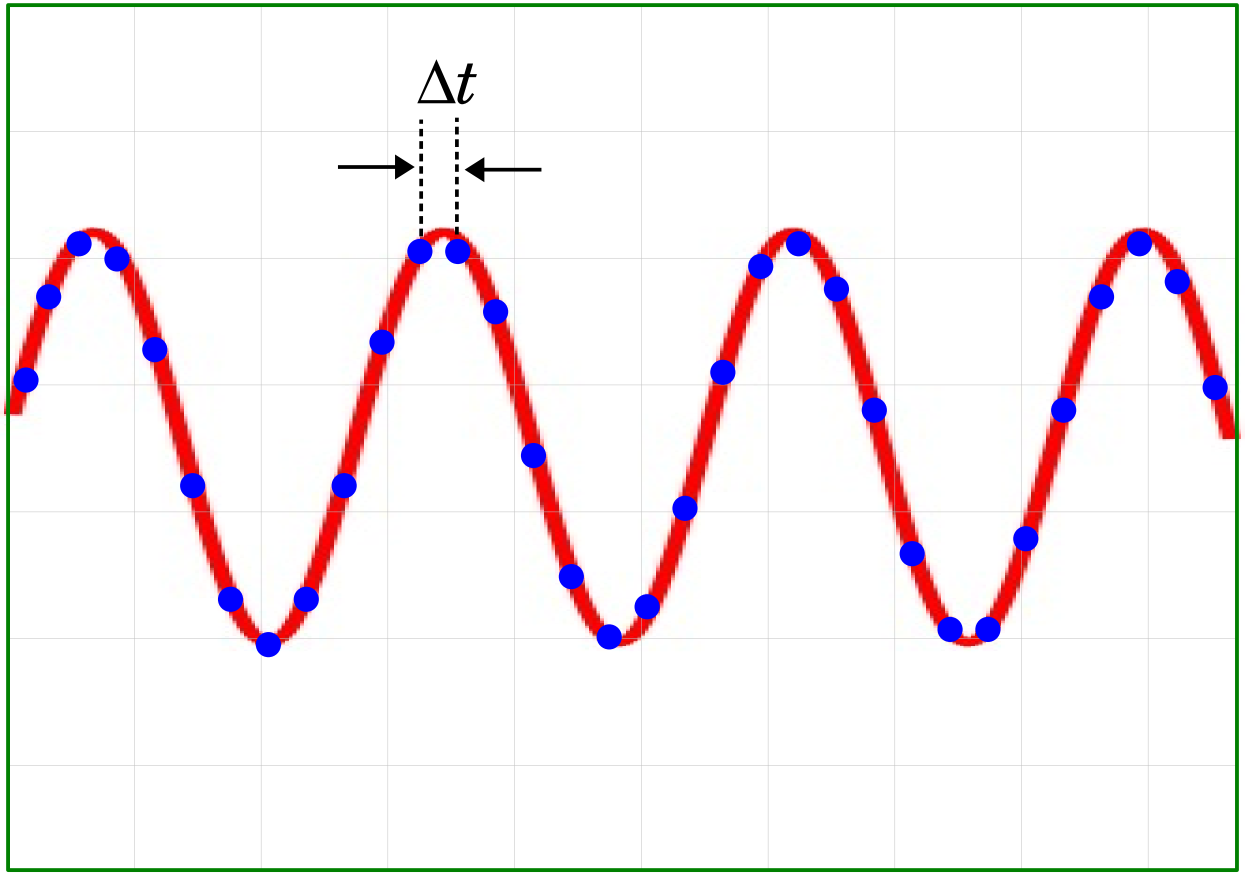
DISPLAY
(Record length limited)

There is usually a switch to
further limit the input bandwidth

Nyquist theorem
Sampling theorem

Temporal spacing of signal sampling

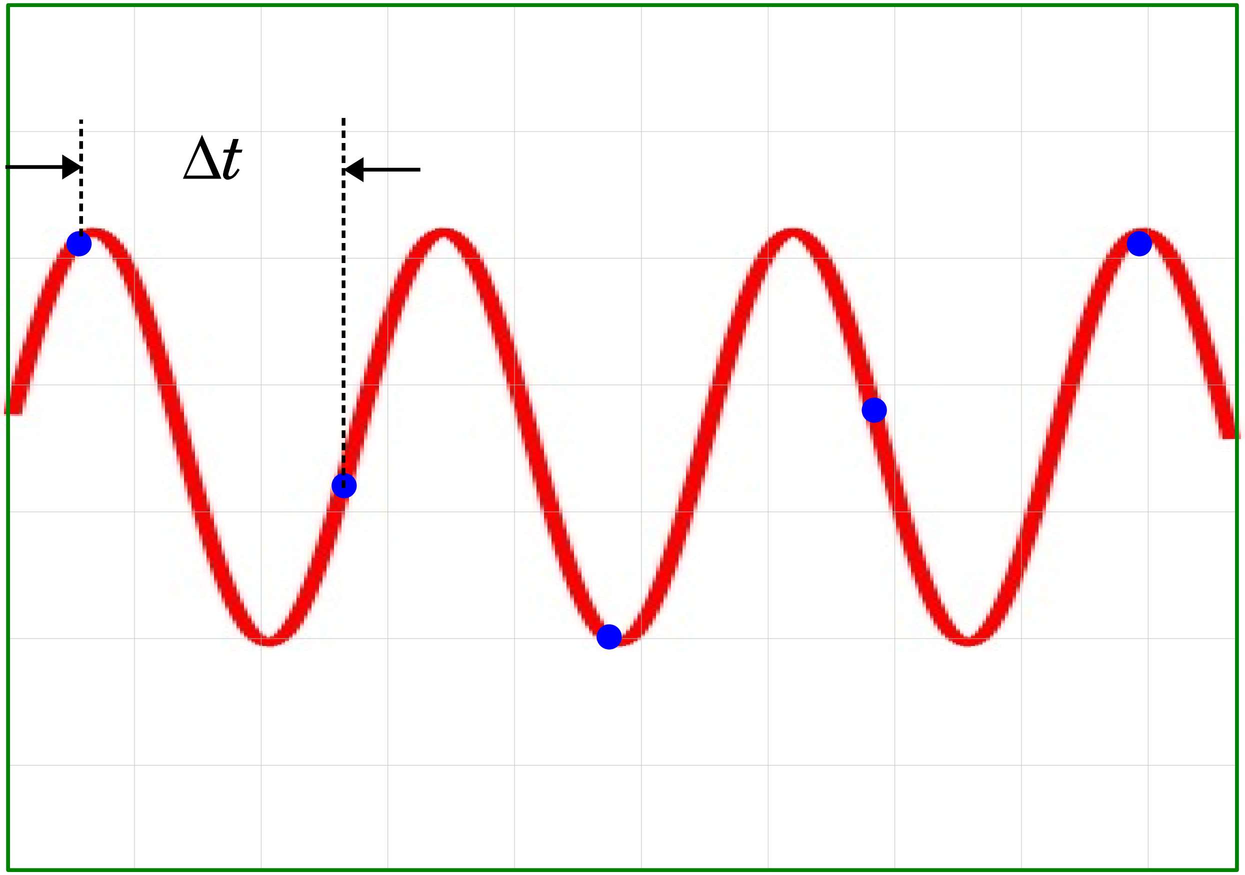
$$\Delta t \leq \frac{1}{2\nu}$$



Nyquist theorem
Sampling theorem

Temporal spacing of signal sampling

$$\Delta t > \frac{1}{2\nu}$$



Nyquist theorem
Sampling theorem

Temporal spacing
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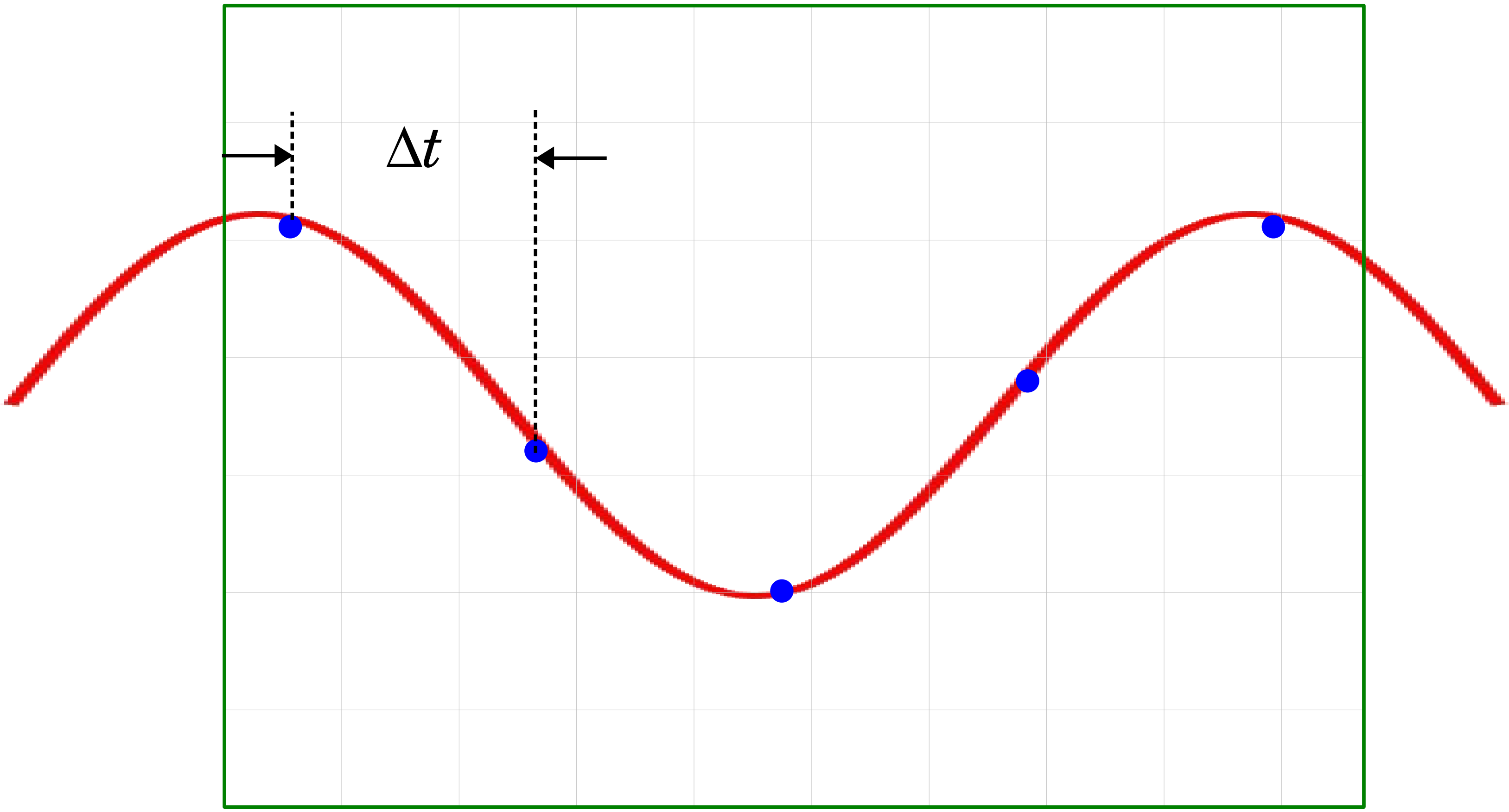


ALIASING

DIGITAL SCOPE: MEASUREMENT MENU

- Period
- Frequency
- Average amplitude
- Peak amplitude
- Peak-to-peak amplitude
- Rise time
- Fall time
- Duty cycle
- RMS
- Max/Min signals
- Horizontal and vertical adjustable cursors

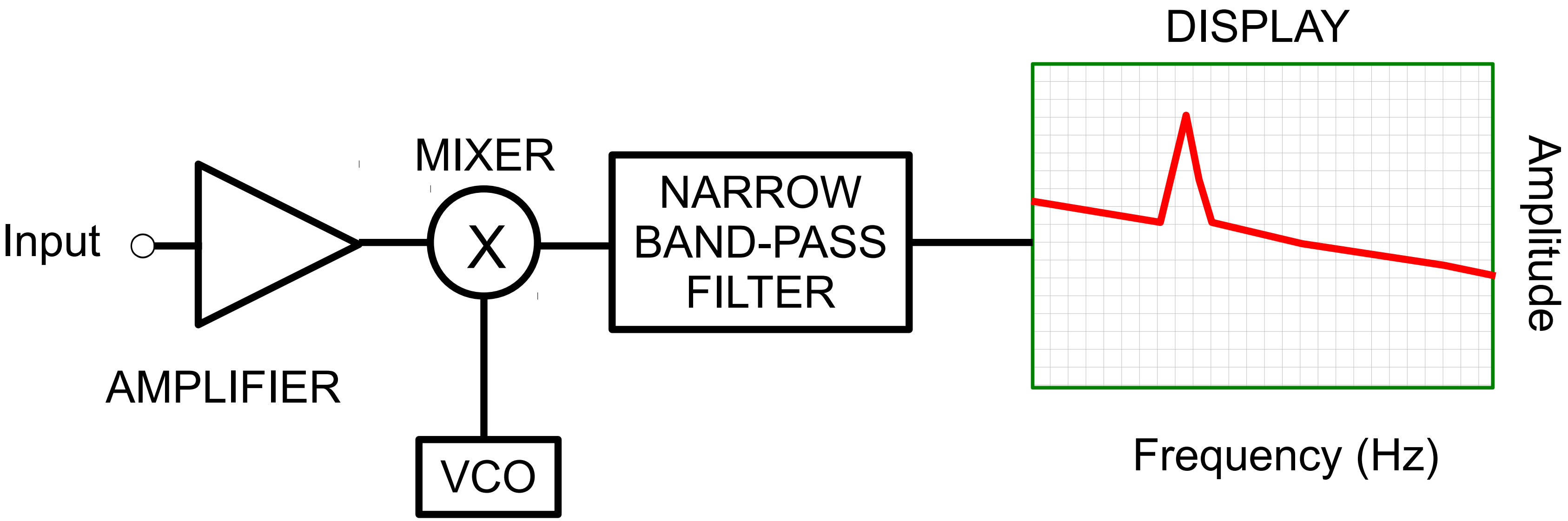
DIGITAL SCOPE: MATH MENU

Channel addition

Channel subtraction

Fast Fourier Transform (FFT):
Observe frequency spectrum of time signal

Spectrum Analyzer (Agilent N9320)



Operates like a radio with a very fast tuner

Spectrum Analyzer (Agilent N9320)

MENU SETUP

Start frequency

Stop frequency

Averaging

Markers

Vertical scale (dB or linear)

Autoscale vertical axis

Preamp available

Peak search

Operating range: 9 kHz – 3 GHz

Auto-tune rarely works

You should estimate where the expected signal will be