WELCOME TO PHYC 307L
Junior Lab II

Spring Semester 2019

Instructor: Dr Michael Hasselbeck

Challenging Modern Physics experiments

Require independent problem solving – harder than intro physics labs

10 experiments available; must do 6

1) Speed of Light
2) Balmer Series
3) Poisson Statistics
4) Planck's Constant
5) Compton Scattering
6) Electron Diffraction
7) Ratio e/m
8) Franck-Hertz experiment*
9) Electron spin resonance*
10) Millikan oil drop: electron charge*

* Should be attempted later in semester

First week lab (everyone): Review of oscilloscope and R-C circuits

Students work in teams of no more than 2

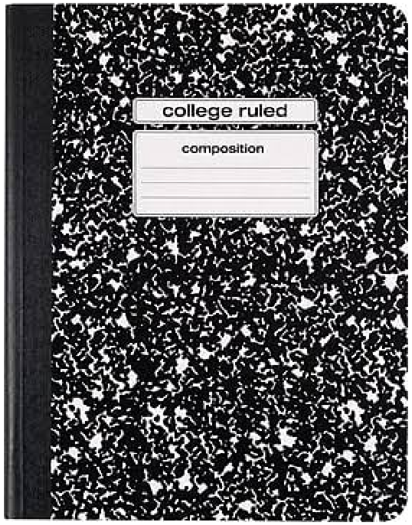
Teams change every 2 weeks (except morning session)

There is a free week at end of semester for makeup

UNM policy prevents access to labs outside of scheduled times

Course material: Laboratory Composition Book
UNM bookstore, office supply stores, online

THIS



NOT THIS

Everything else you will need is on the class webpage (Lab instructions, Syllabus, etc)

Linked on the Physics & Astronomy Dept website

How grading works

25% Performance during the lab session. Did the experiment work?

25% Lab Notebook. A neat, organized, thorough notebook is essential! Record everything...setup diagrams, intermediate results, problems encountered, things not understood. Doing this will slow you down, but there are no bonus points for finishing quickly.

25% Lab Reports. Every lab requires a formal report that is due one week after completion of an experiment. The short deadline forces documentation while the experience is still fresh. No minimum page requirement. Scientific writing should be concise and efficient. Present results with graphs, charts, tables, and images.
Late reports will be penalized 20% per day.

25% Final Quiz. End of semester. Multiple choice covering concepts from lectures and labs. Not everyone will have done the same labs, so there will be a pool of questions to choose from. < 1 hour.

WRITING A SCIENTIFIC PAPER

ABSTRACT: A series of measurements were performed to measure the charge of the electron. An experimental value of $1.6 \pm 0.2 \times 10^{-19}$ C was obtained, in good agreement with the established value.

INTRODUCTION: The charge of the electron is a fundamental constant of physics. It was first measured by R. Millikan and co-workers in 1913 [1]. As experimental techniques improved, the accuracy...

EXPERIMENT: A sketch of the experimental setup is shown in Figure 1. A mist of drops is injected...

RESULTS AND DISCUSSION: Results are summarized in Table I. Experimental errors are attributed to...

CONCLUSIONS: The experiment gives the fundamental electron charge with an accuracy of approximately 12%. This is limited by...

REFERENCES:

[1] R.A. Millikan, “On the Elementary Charge and the Avogadro Constant”, Phys. Rev., **2**, 109 (1913).

MONDAY LECTURES

Will cover error analysis, probability, statistics, and scientific writing

Some lecture material will be on the final quiz

Lectures will happen only in the first part of the semester. When the lectures conclude, students in Tuesday session do not need to attend on Mondays. Monday sessions will start at 14:00 instead of 13:00.

Oscilloscope or Multimeter?

Multimeter

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

DC Voltage	Continuity
AC Voltage	Resistance
DC Current	Capacitance
AC Current	

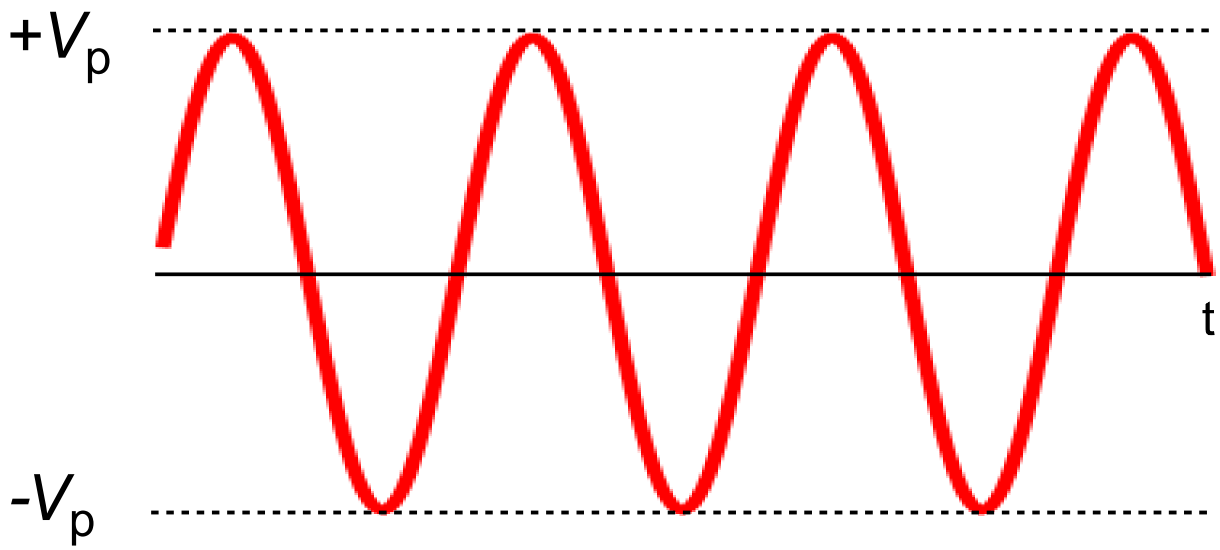
Multimeter

Measurement given as a single number

What about signals that change as a function of time?

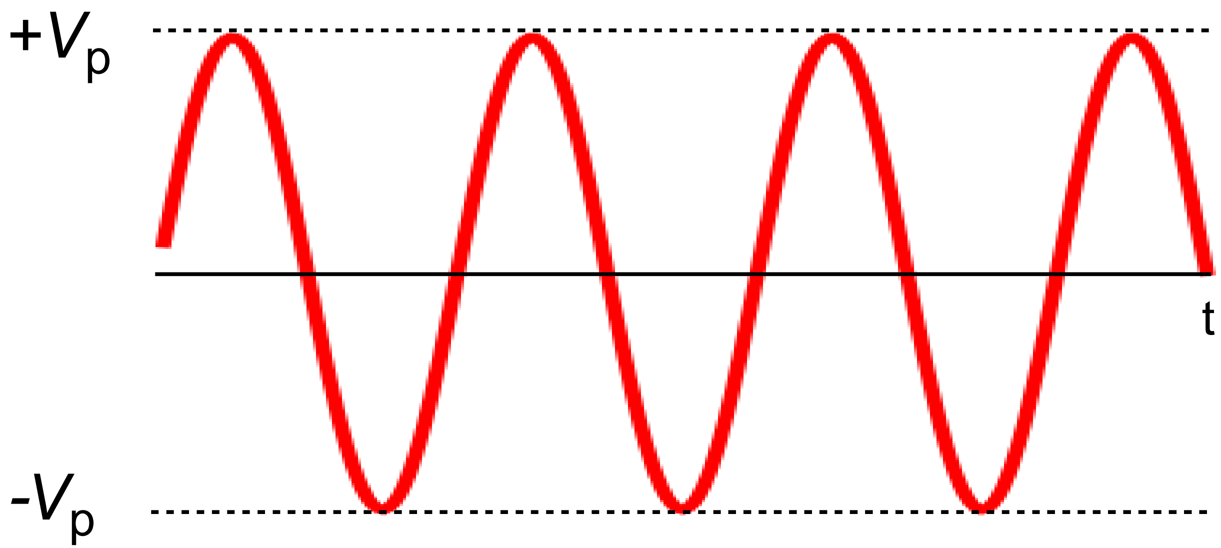
Periodic, time-varying signals can sometimes be characterized by a single number: **Root-Mean-Square (RMS)**

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

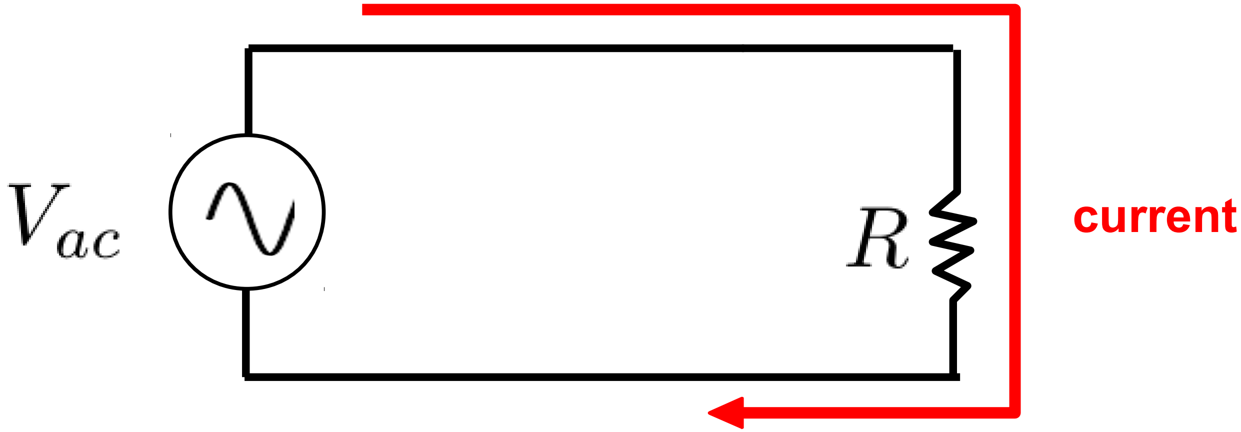


The average voltage of a pure sine wave is identically zero.

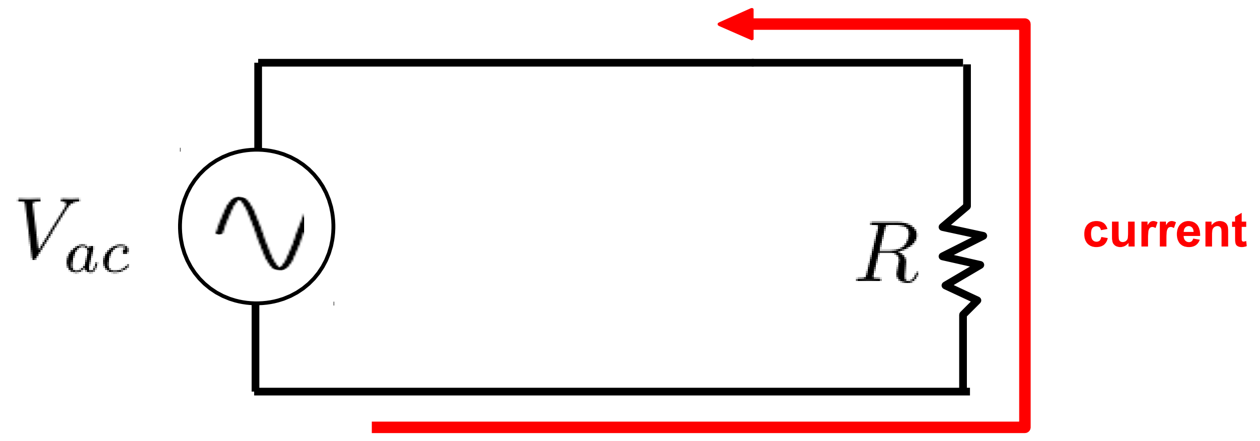
$$V(t) = V_p \sin(\omega t)$$



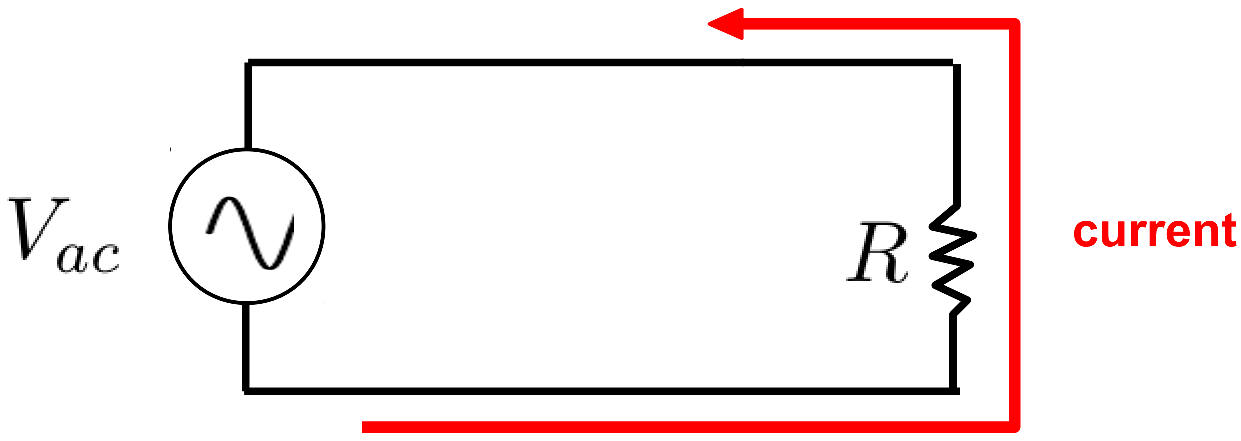
We know that an AC voltage can deliver plenty of power to a load



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

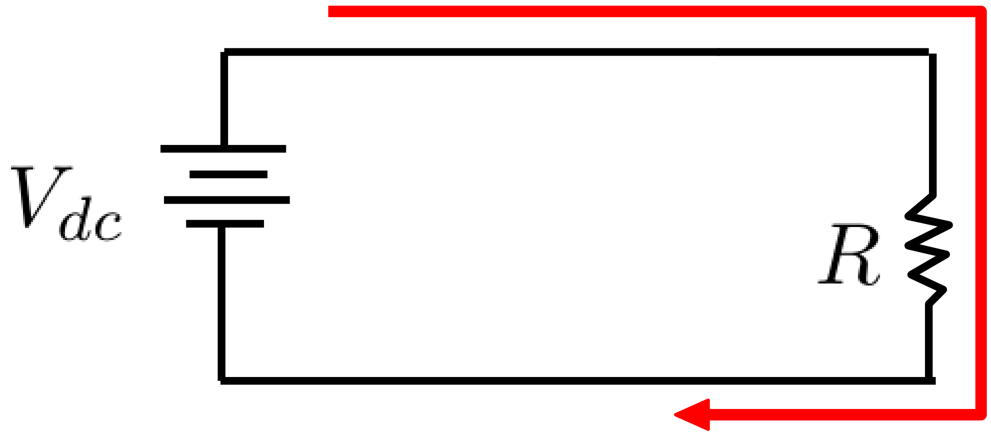


We know that an AC voltage can deliver plenty of power to a load



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

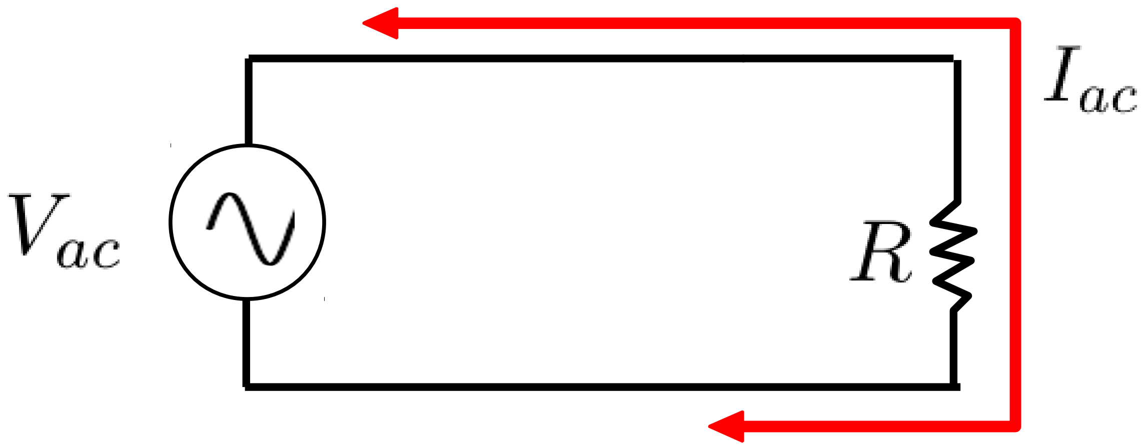
This is easy in a DC circuit: Use Ohm's Law



$$\text{POWER} = \frac{V_{dc}^2}{R}$$

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

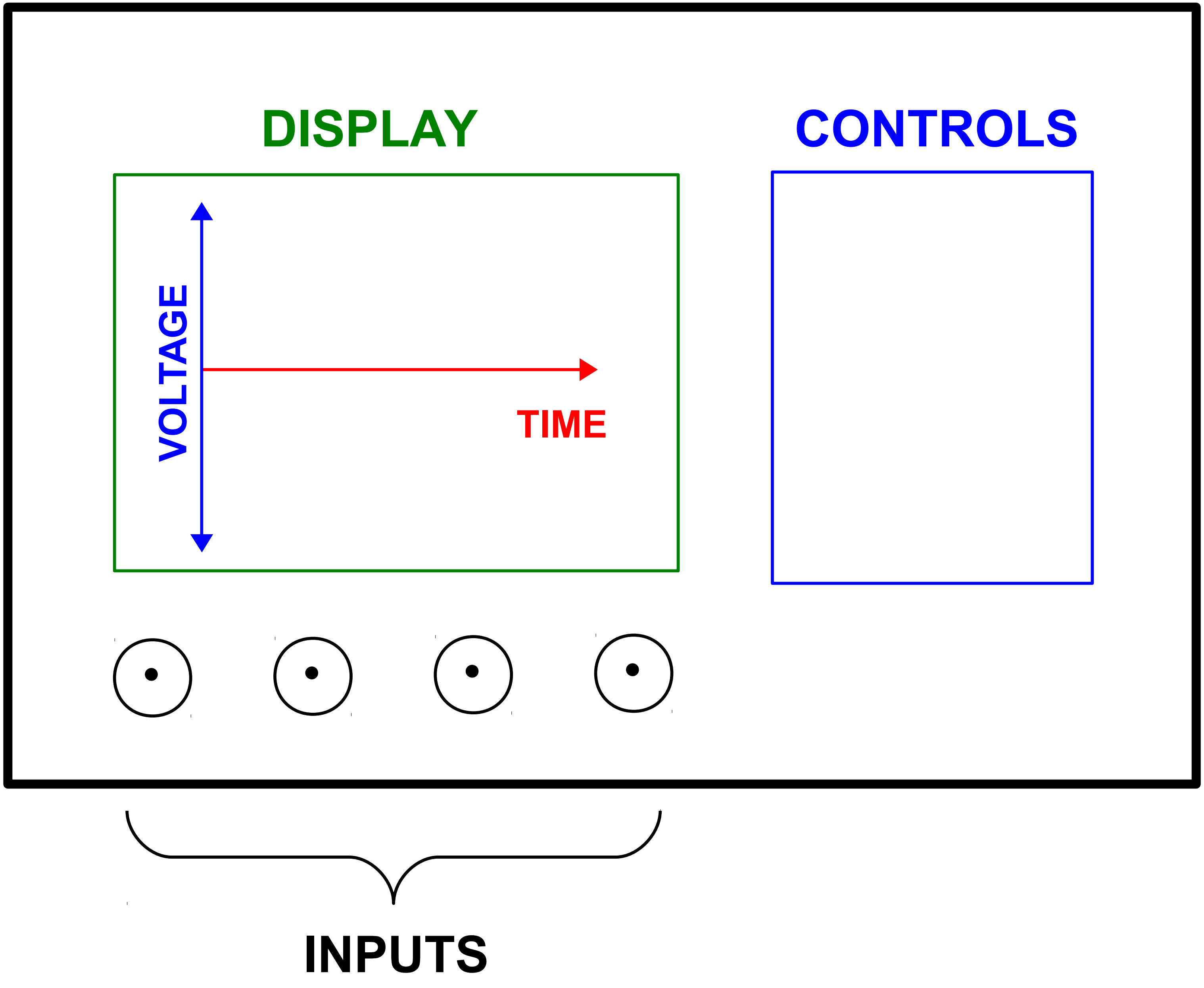
AC power dissipation $= \dfrac{V_p^2}{2R}$

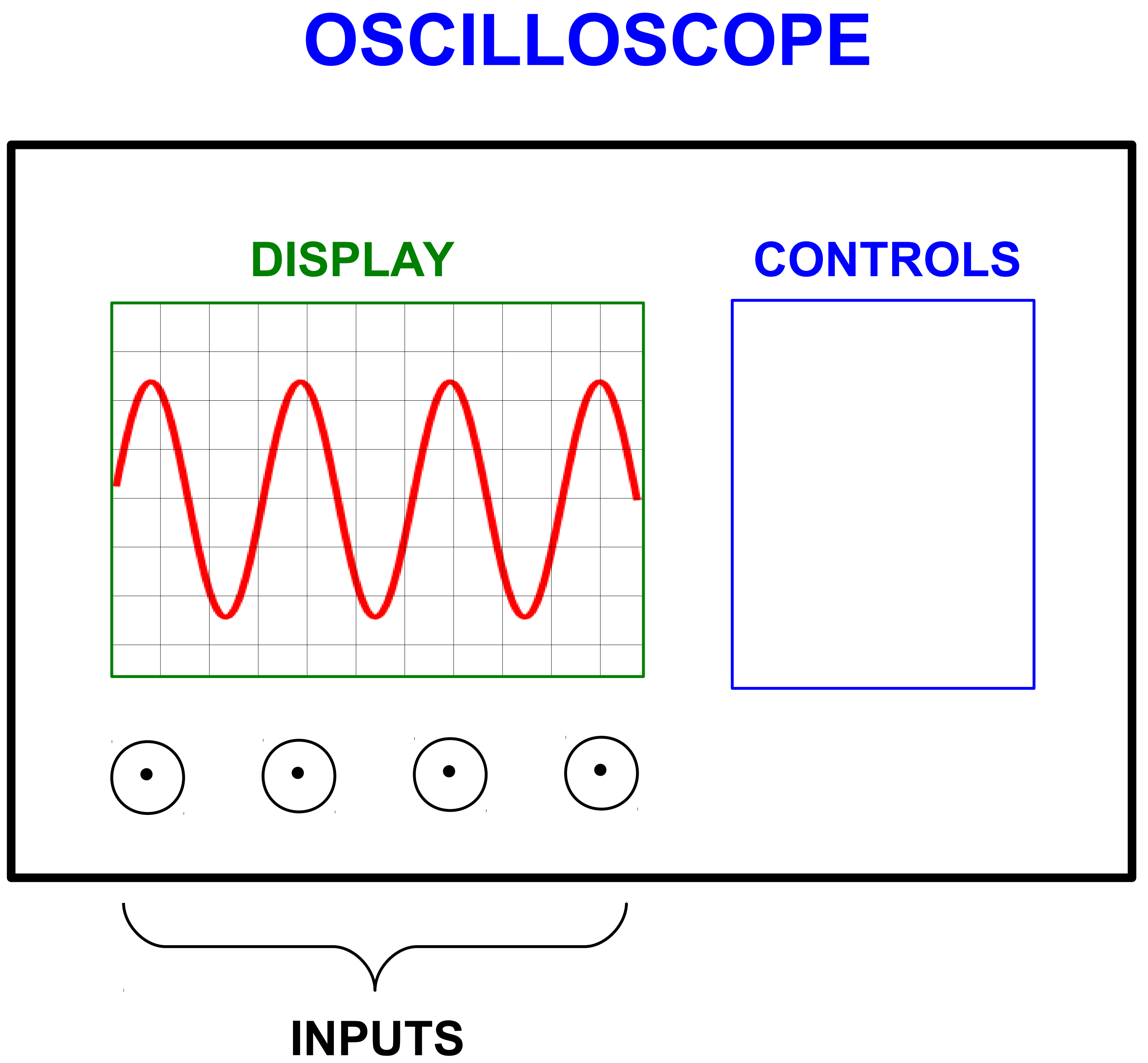
AC voltage producing power dissipation equivalent $V_{RMS} = \dfrac{V_p}{\sqrt{2}}$

- 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



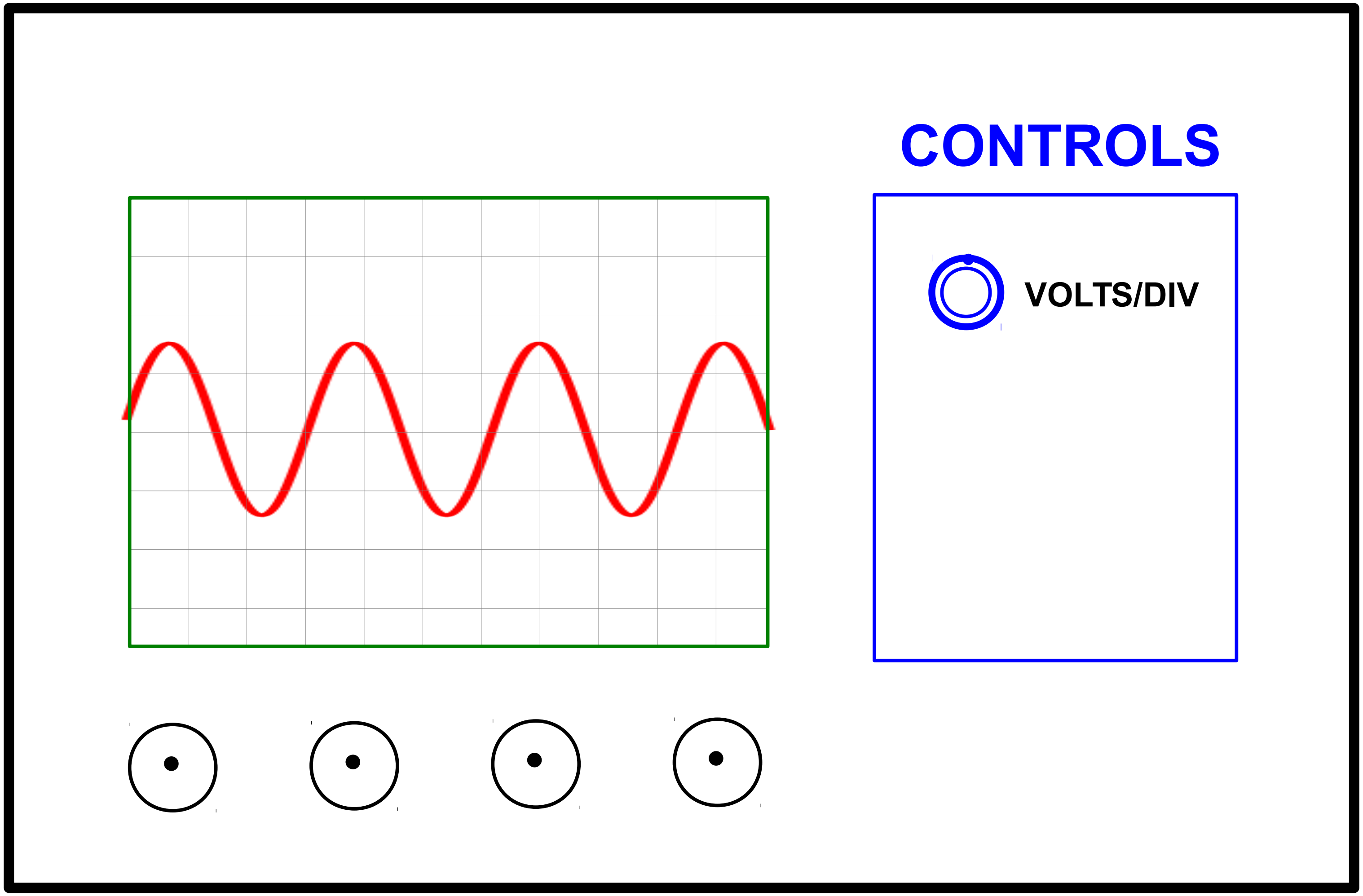

OSCILLOSCOPE
DISPLAY
CONTROLS
INPUTS

ANALOG: Cathode ray tube, swept electron beam

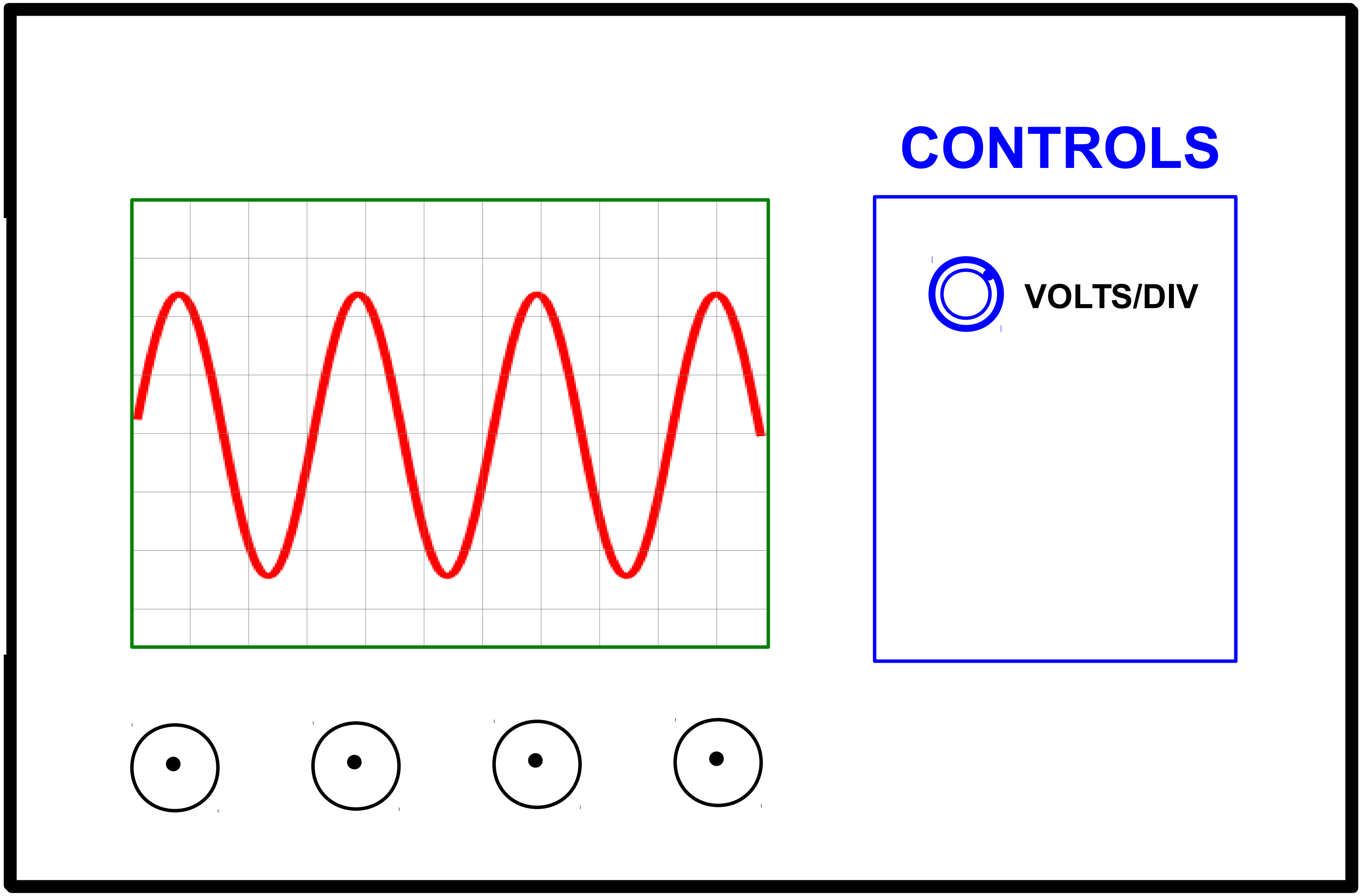
DIGITAL: A/D converter, LCD display

Although physical operation is completely different, controls are nearly identical

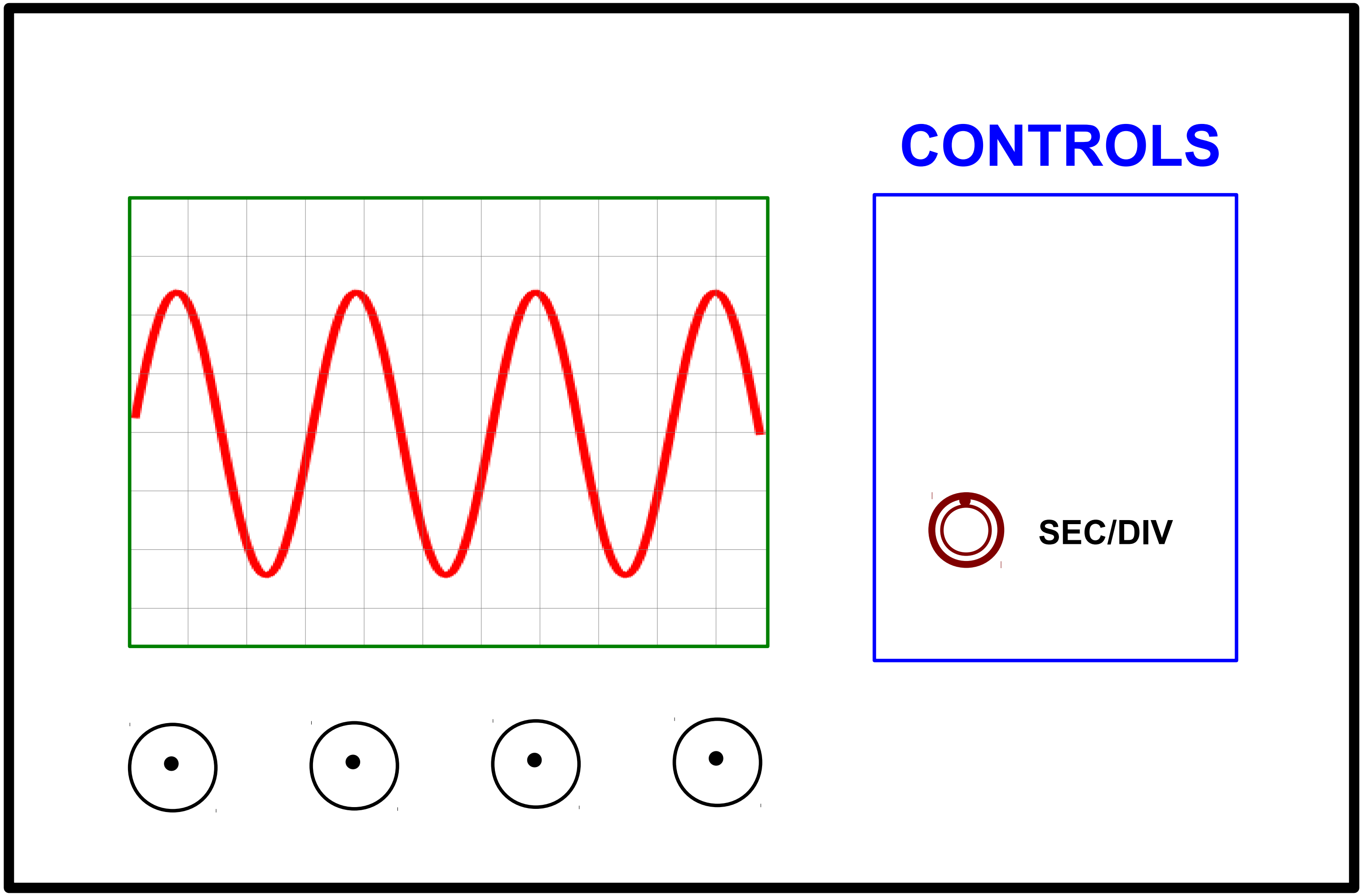
DISPLAY ADJUSTMENT



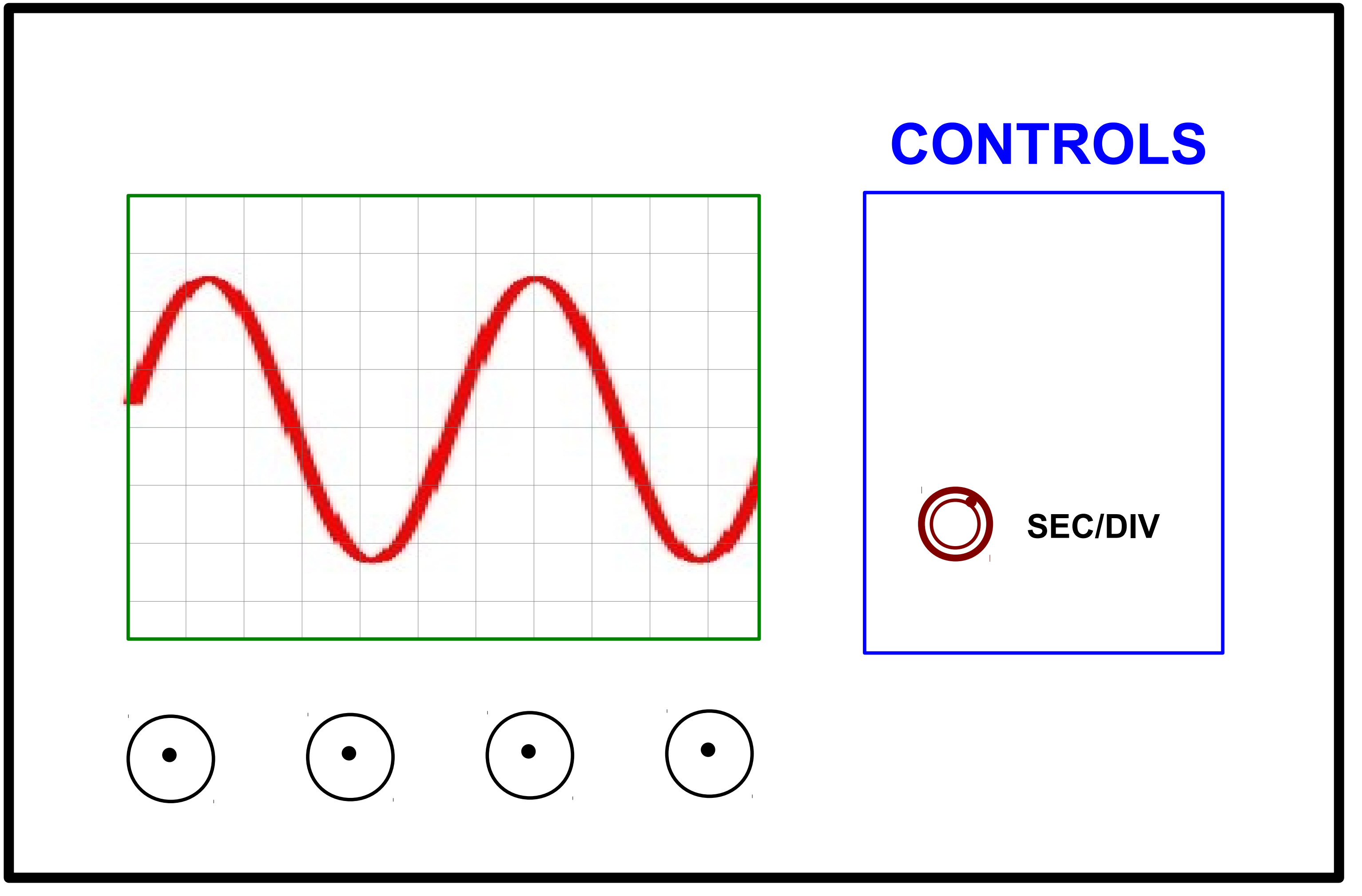
DISPLAY ADJUSTMENT



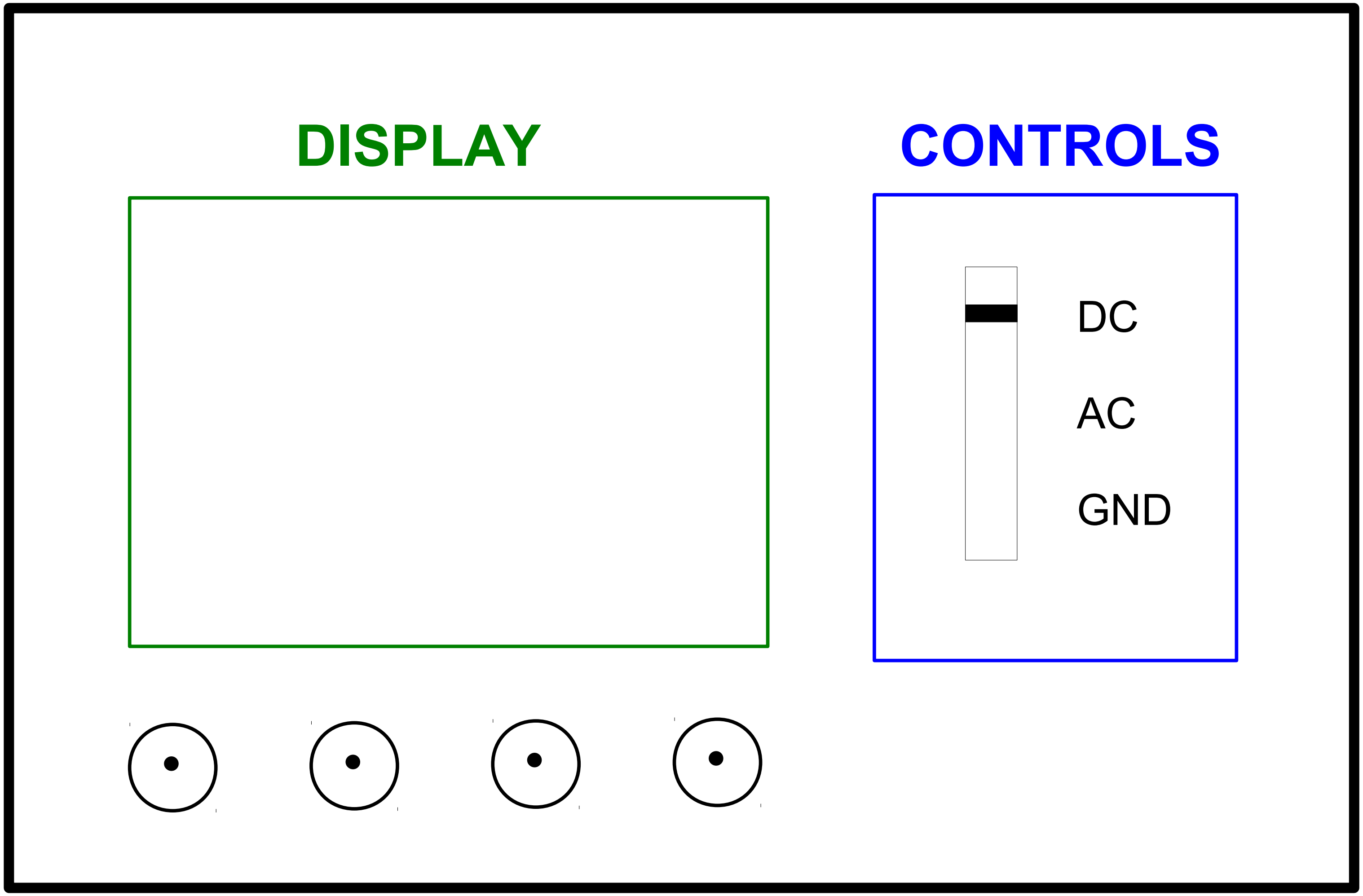
DISPLAY ADJUSTMENT



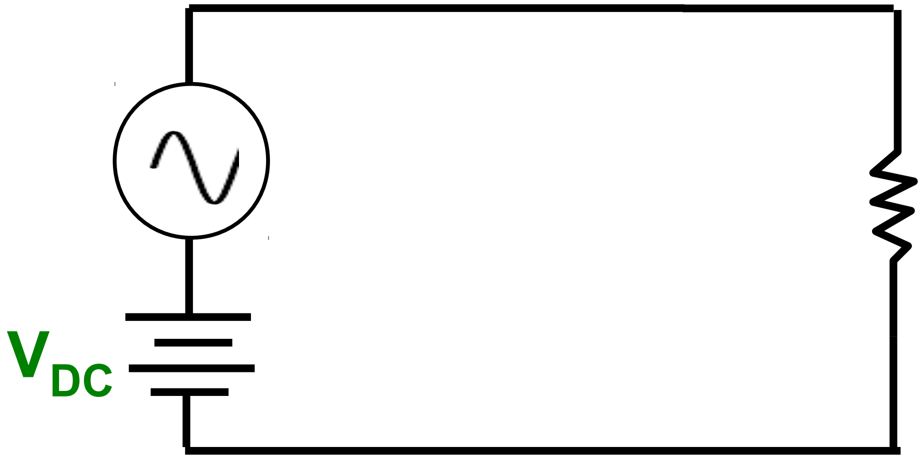
DISPLAY ADJUSTMENT

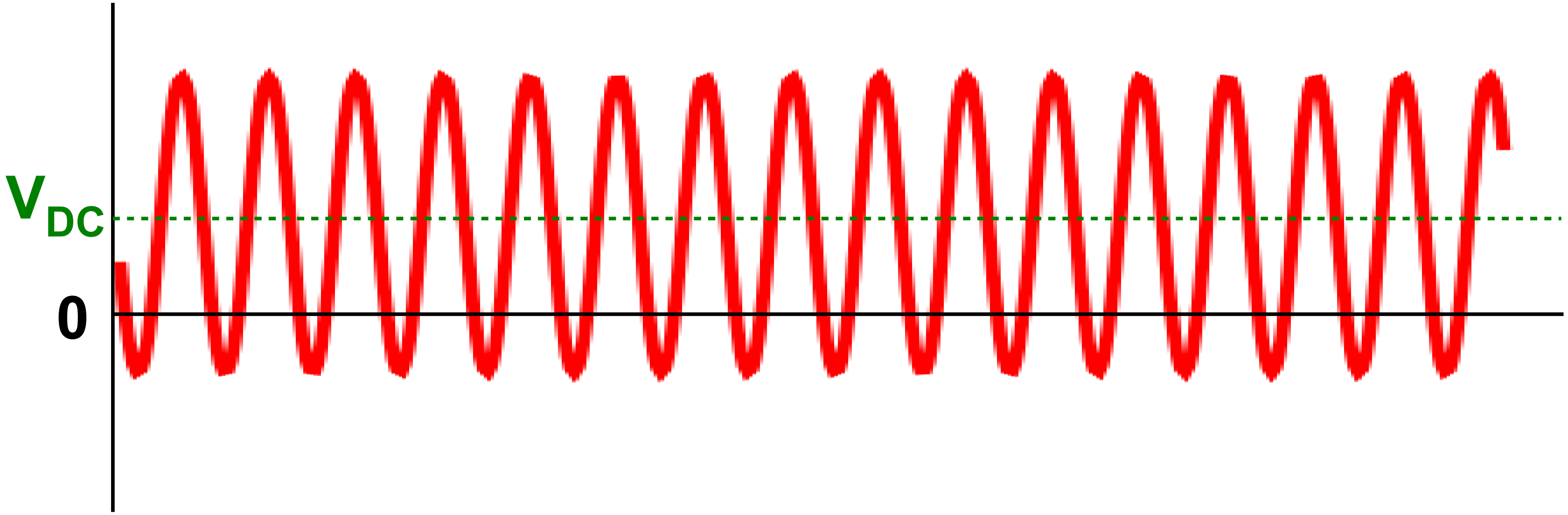


DC coupling, AC coupling, and Ground

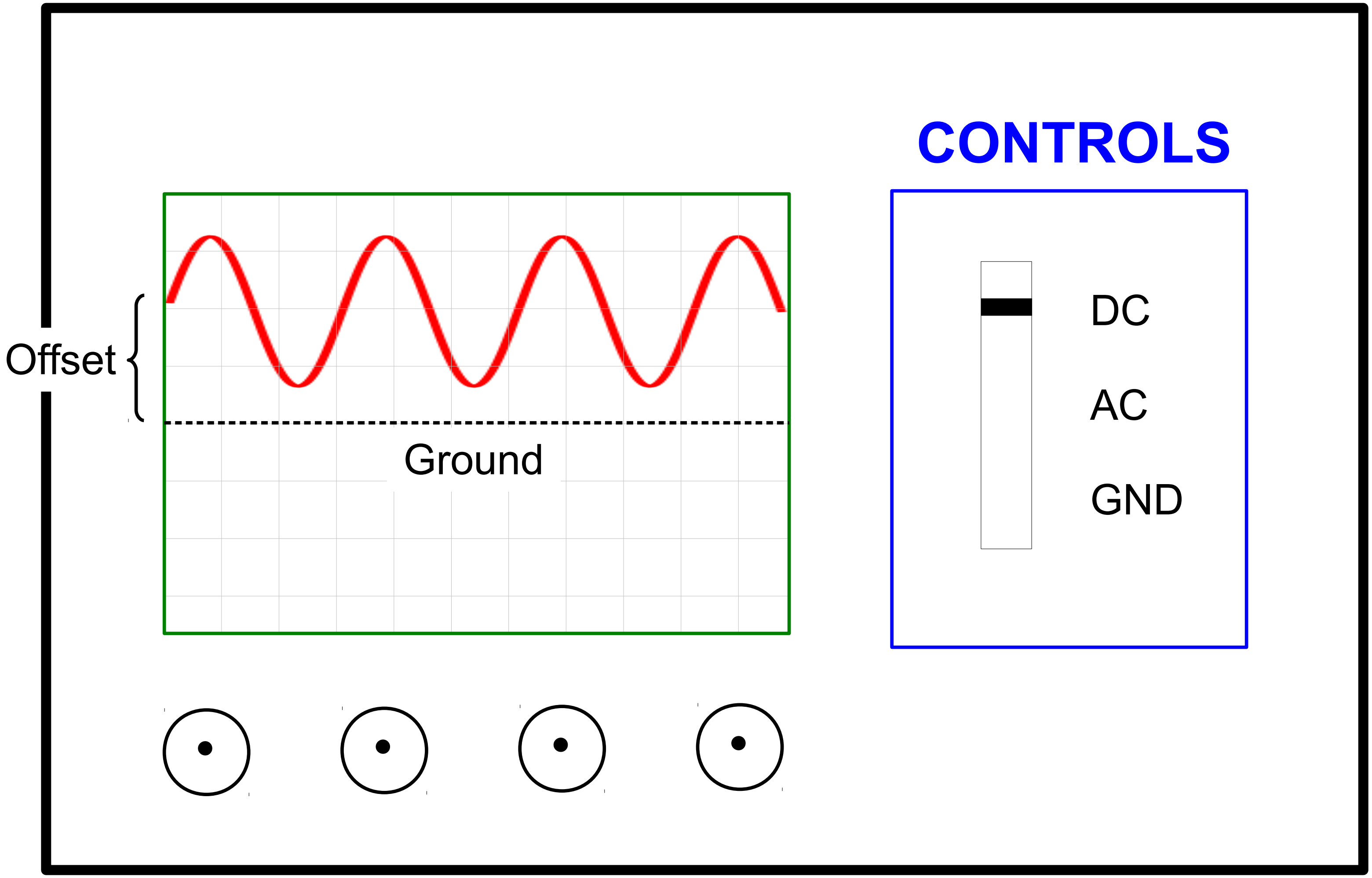


EXAMPLE: Sinusoidal wave source + DC offset

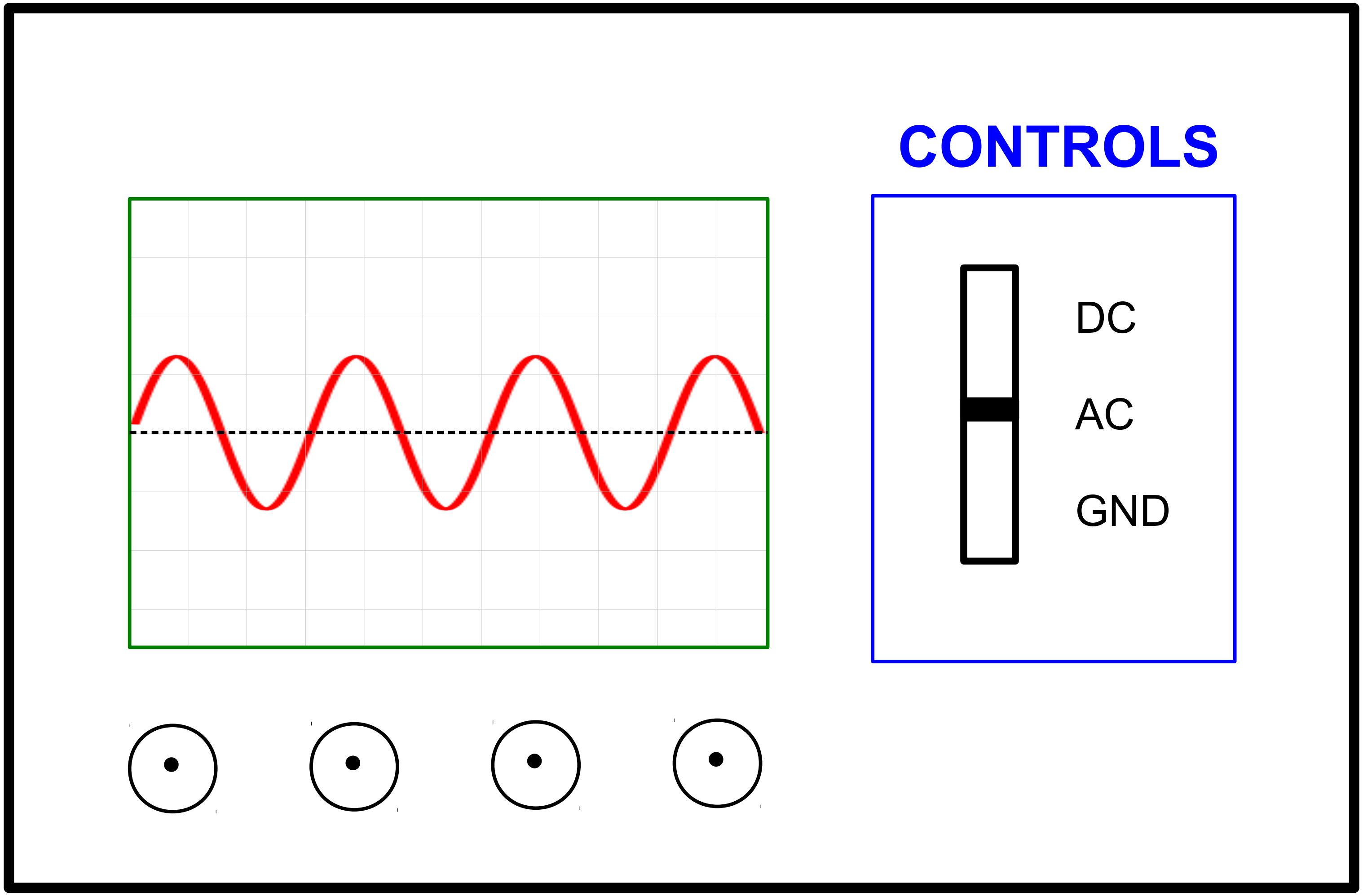




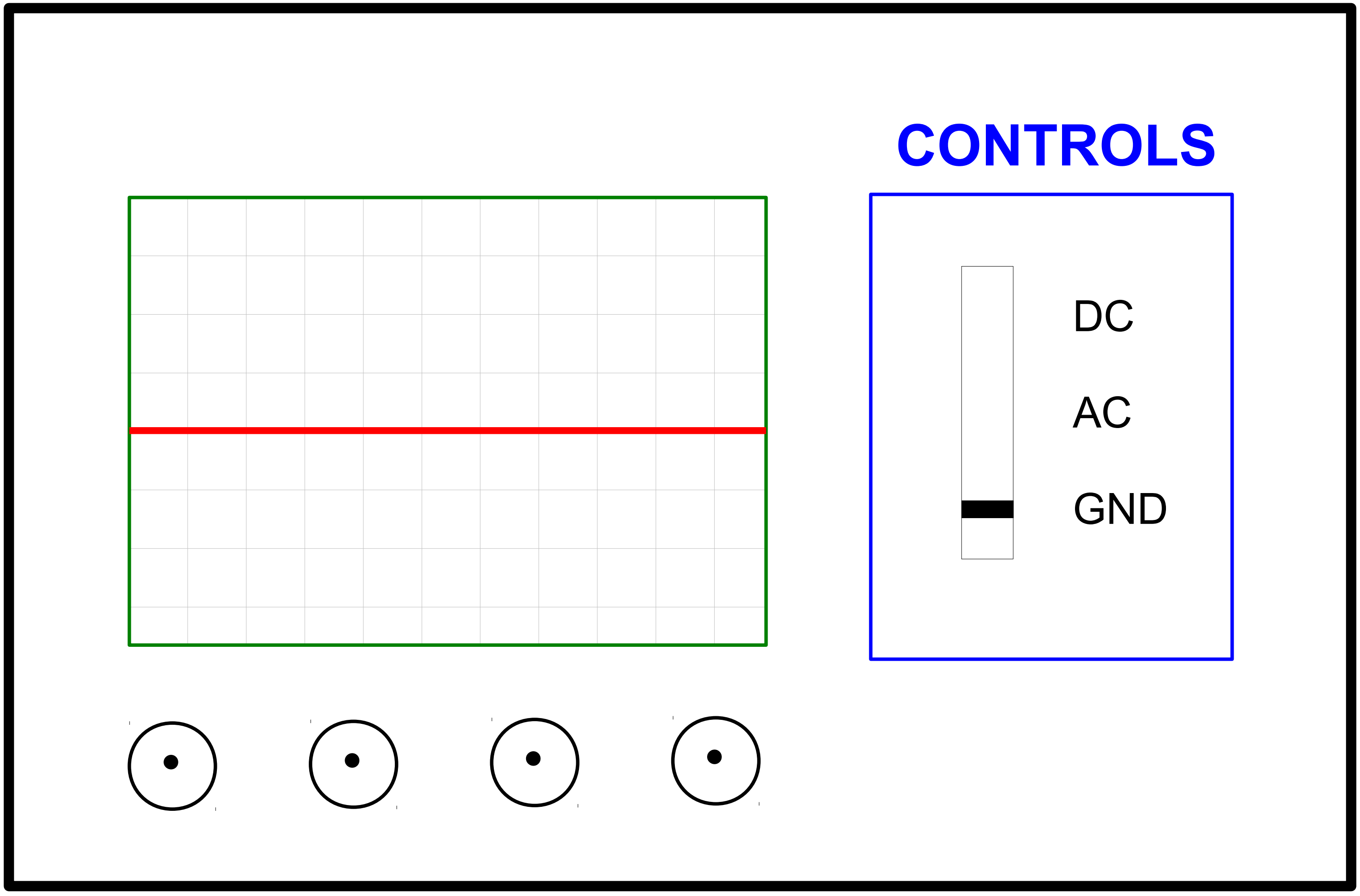
DC COUPLING



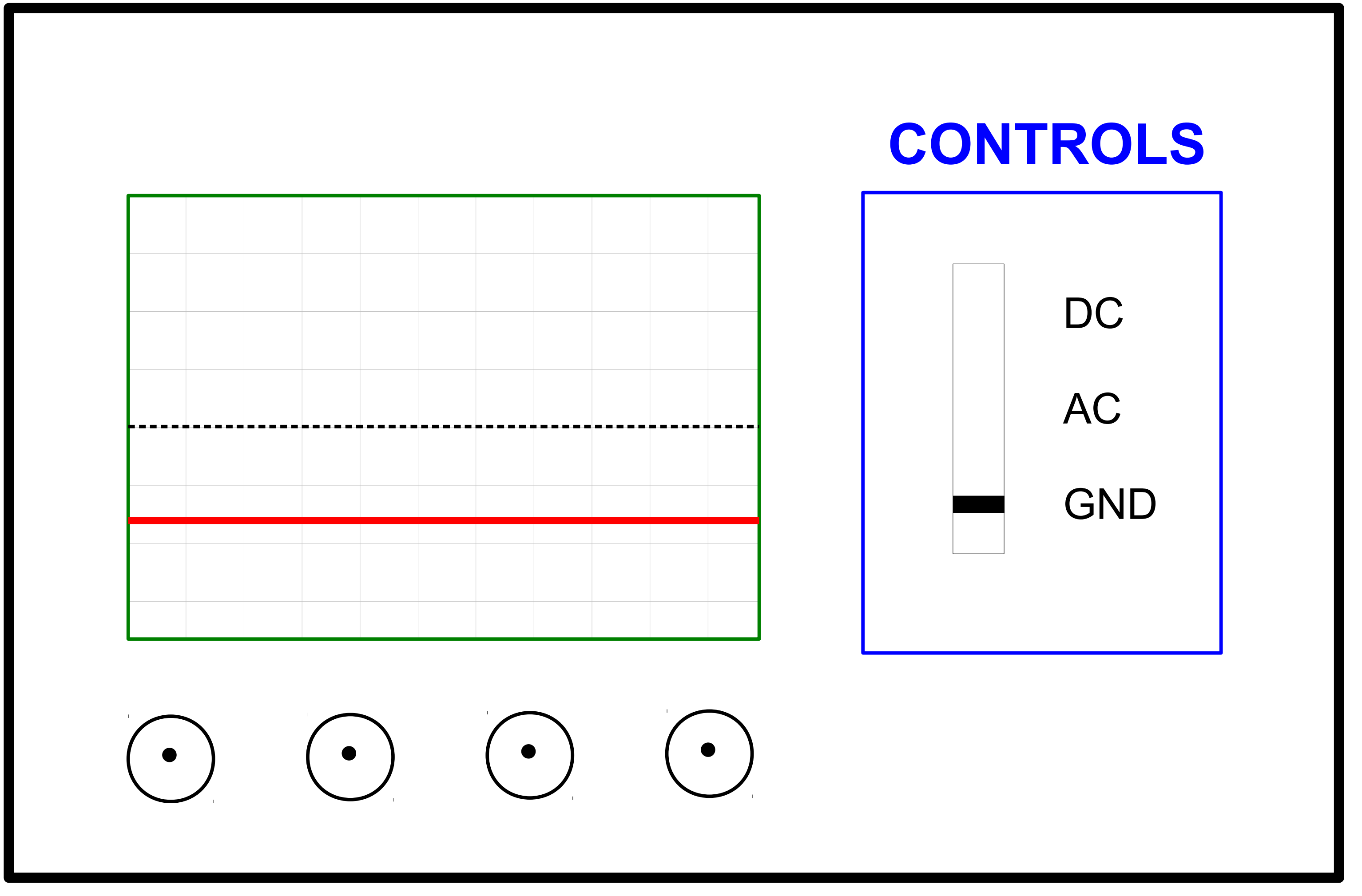
AC COUPLING



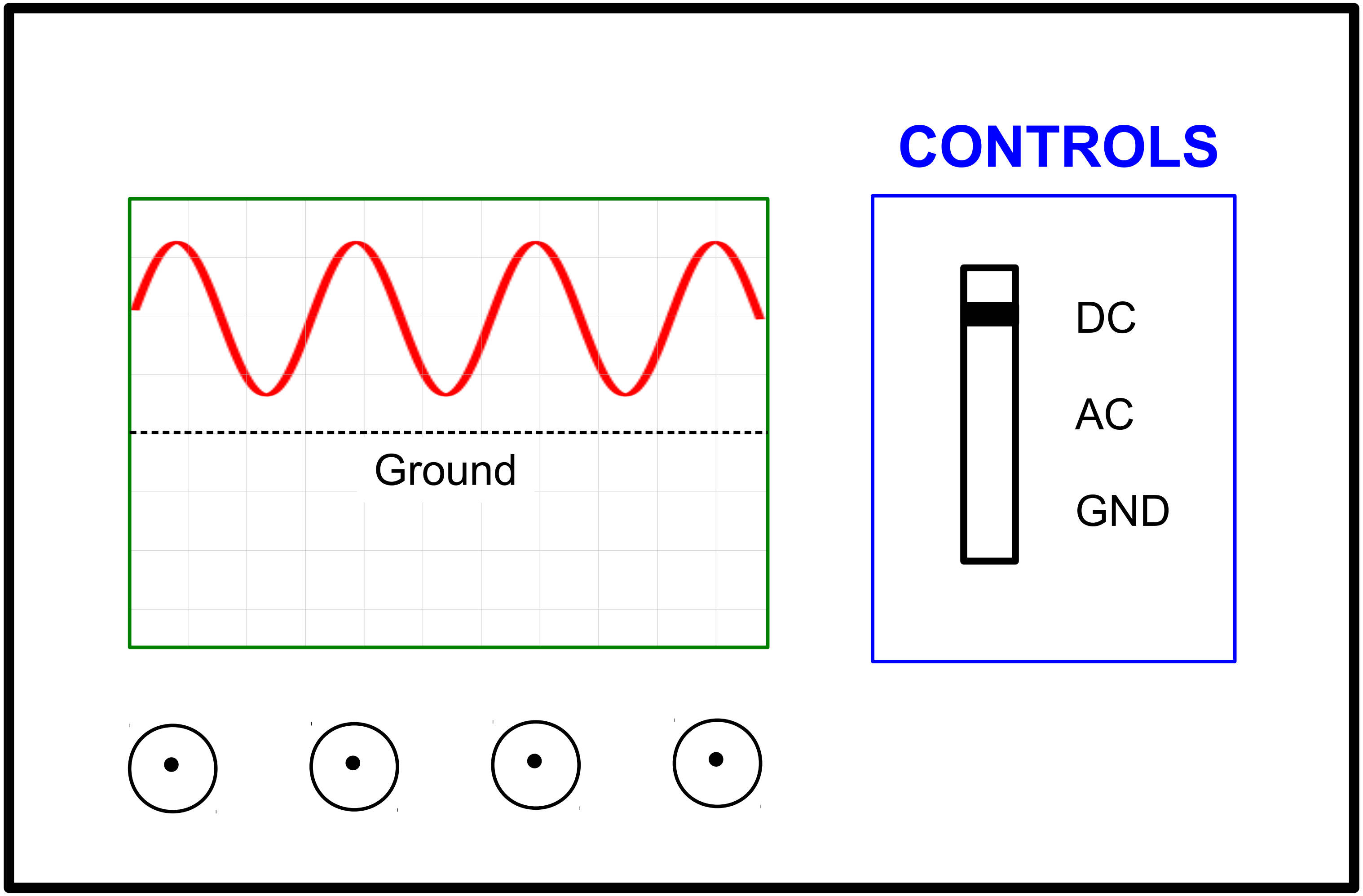
GROUND: Defines location of 0 Volts



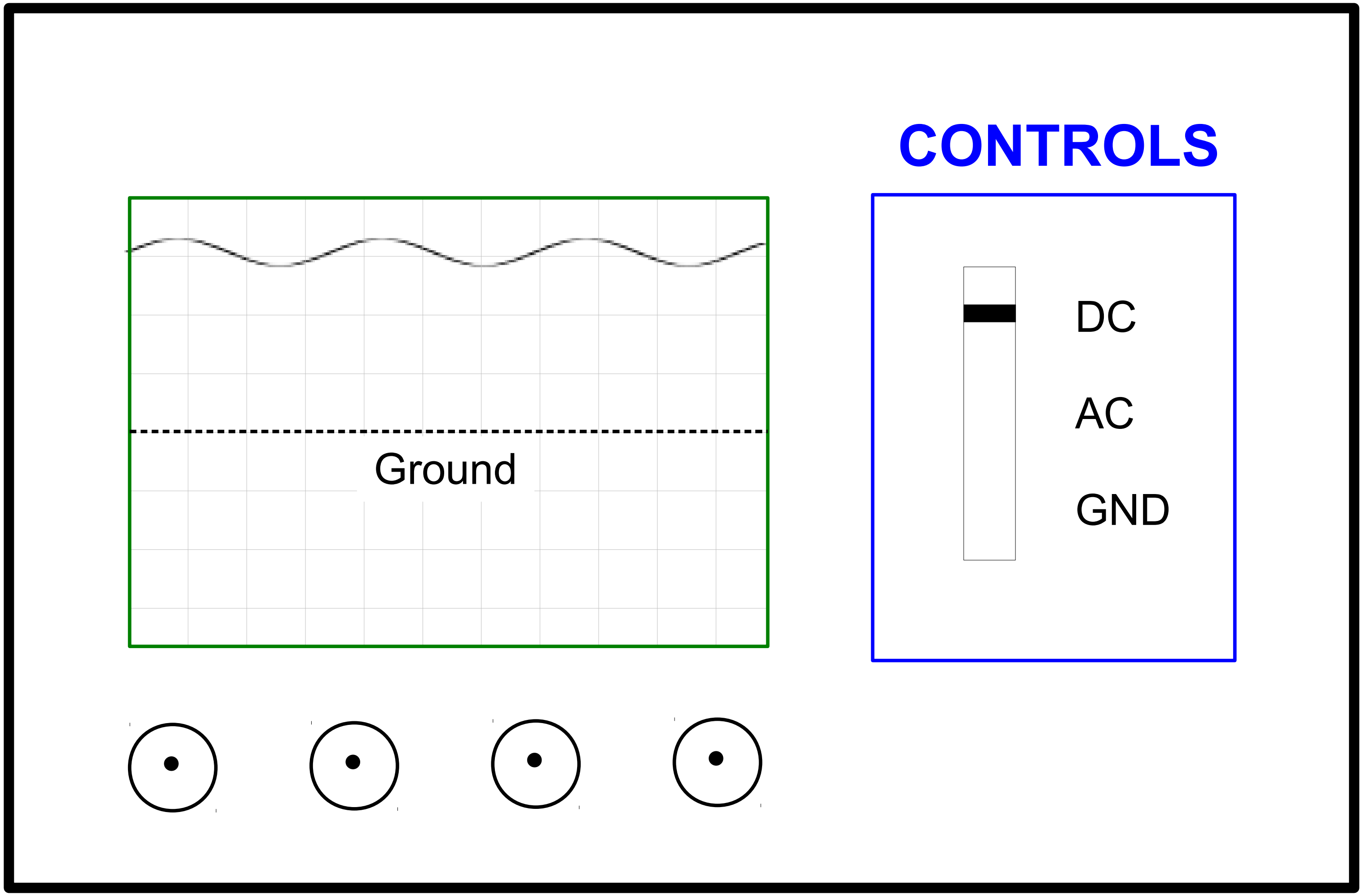
GROUND can be positioned at any convenient level



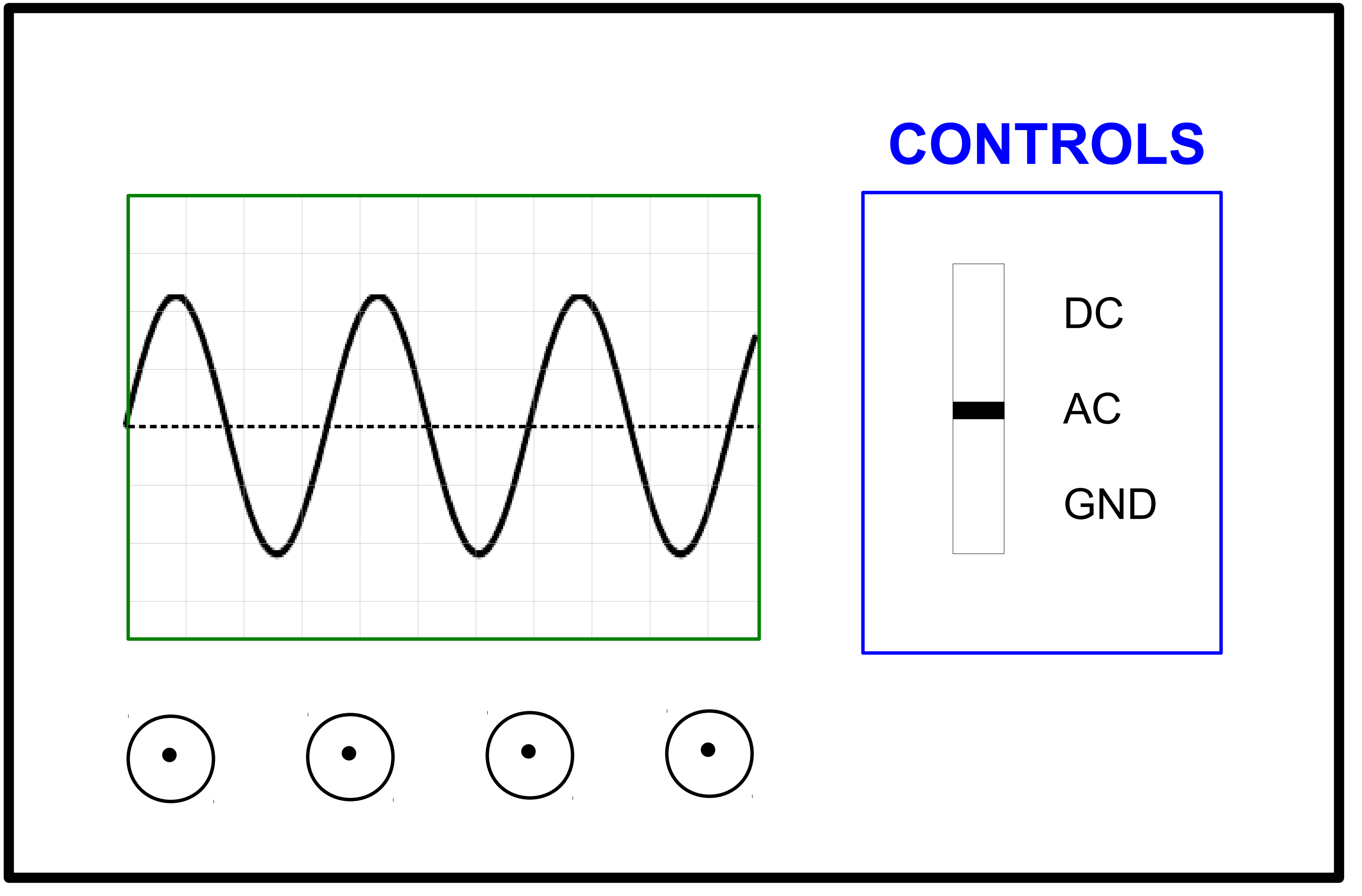
Why bother with AC coupling when DC coupling shows everything?



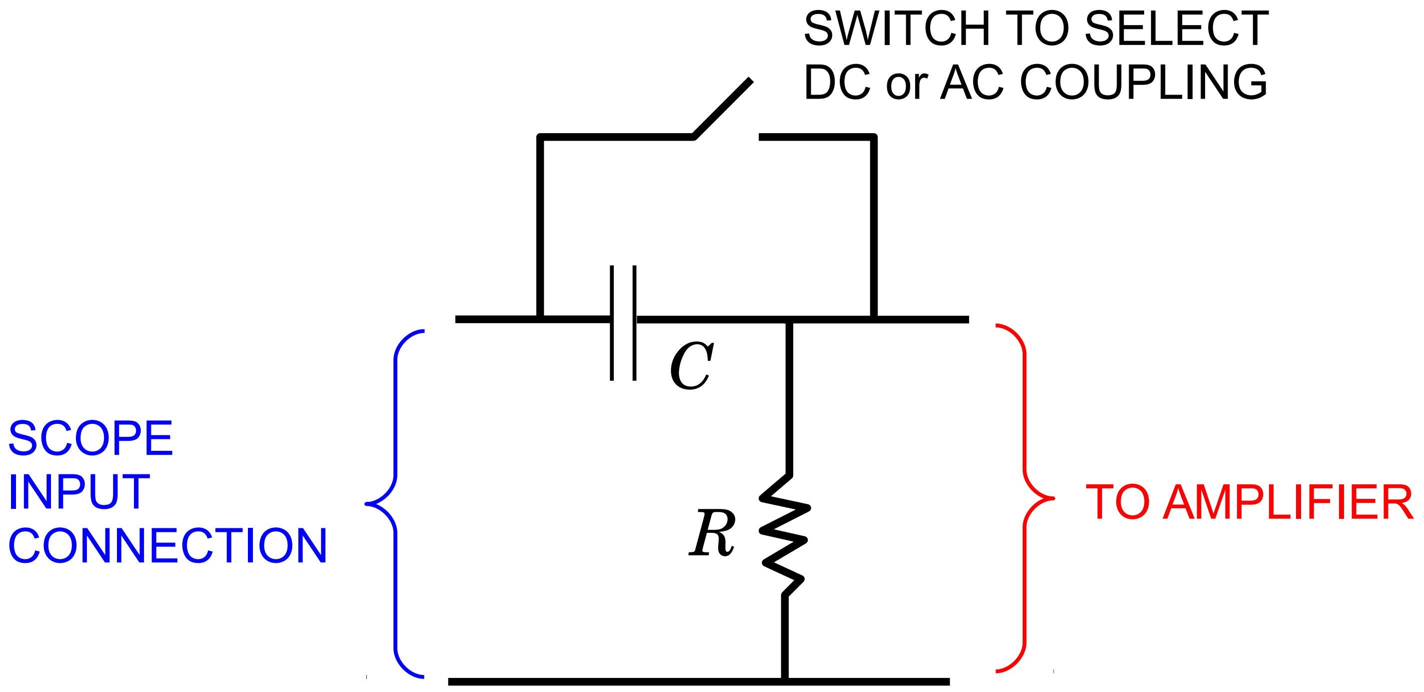
Often we have very weak modulation of a DC signal



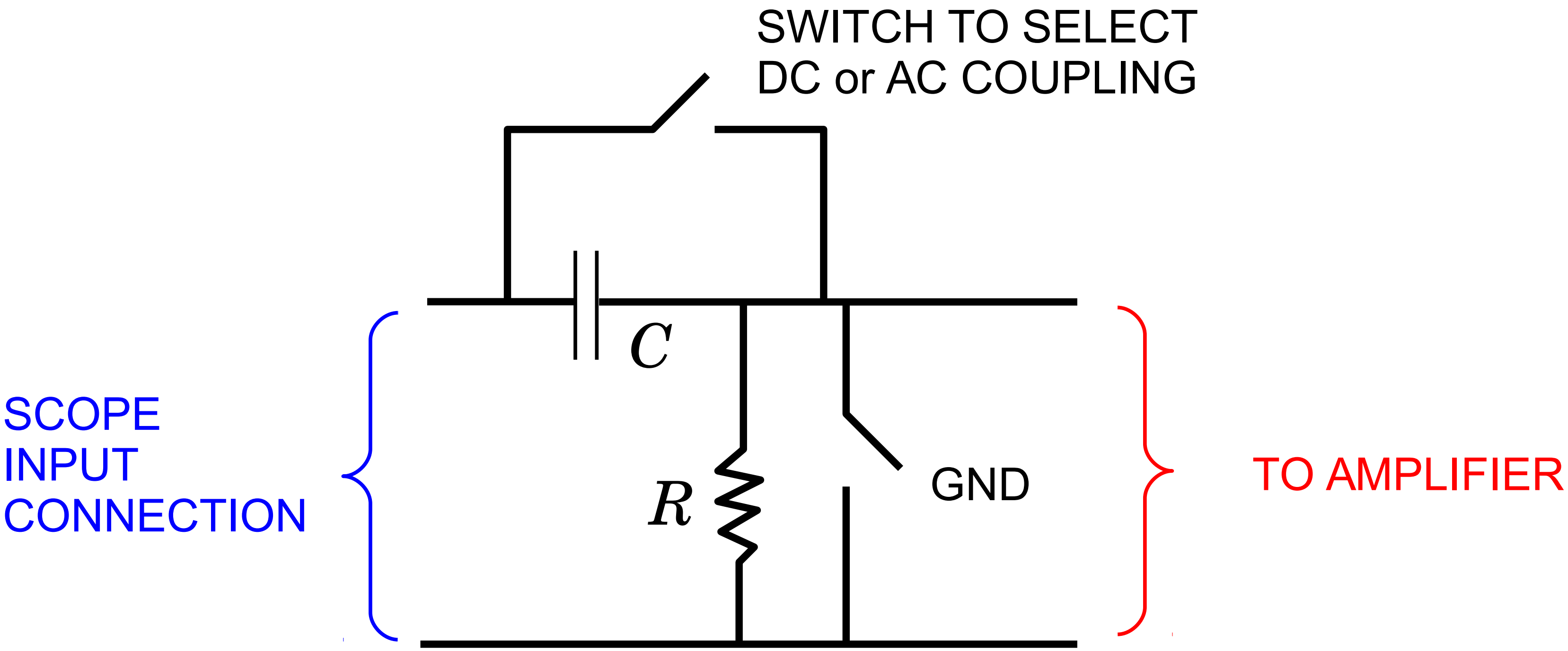
AC couple and change the vertical scale



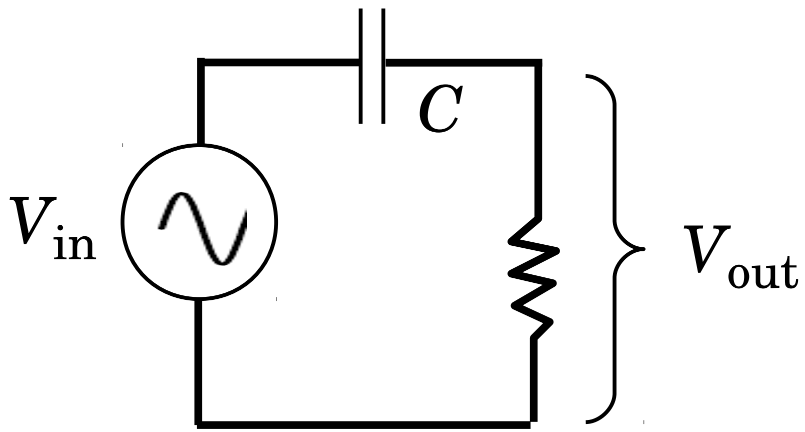
AC coupling implemented with an RC high-pass filter



AC coupling implemented with an RC high-pass filter

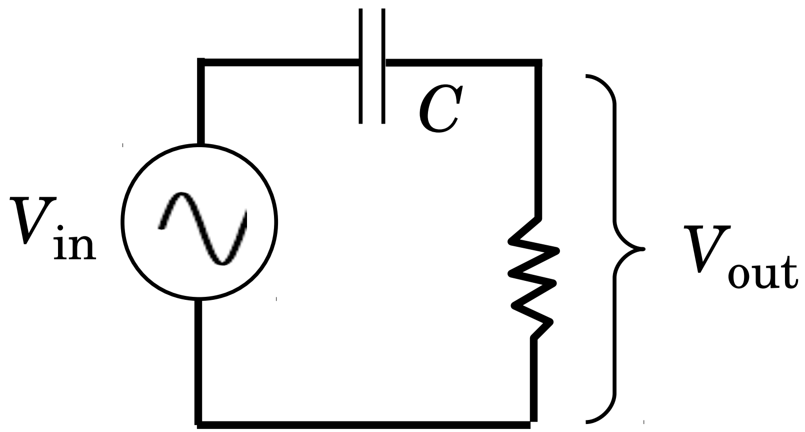


Harmonic analysis of RC high-pass filter

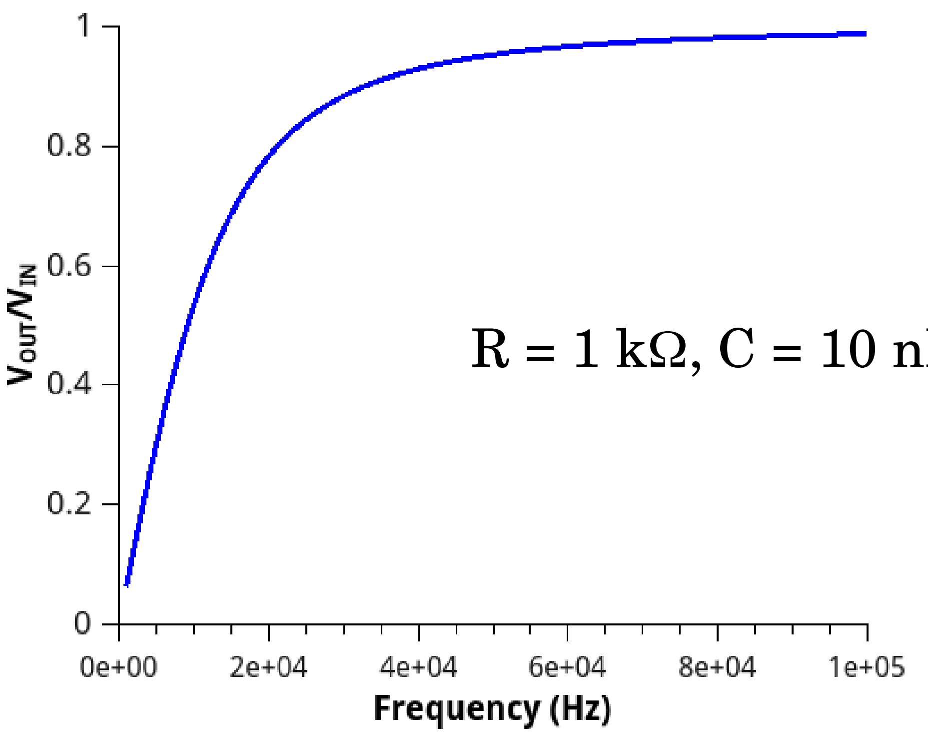


$$\frac{V_{OUT}(\omega)}{V_{IN}(\omega)} = \frac{R}{R + 1/j\omega C}$$

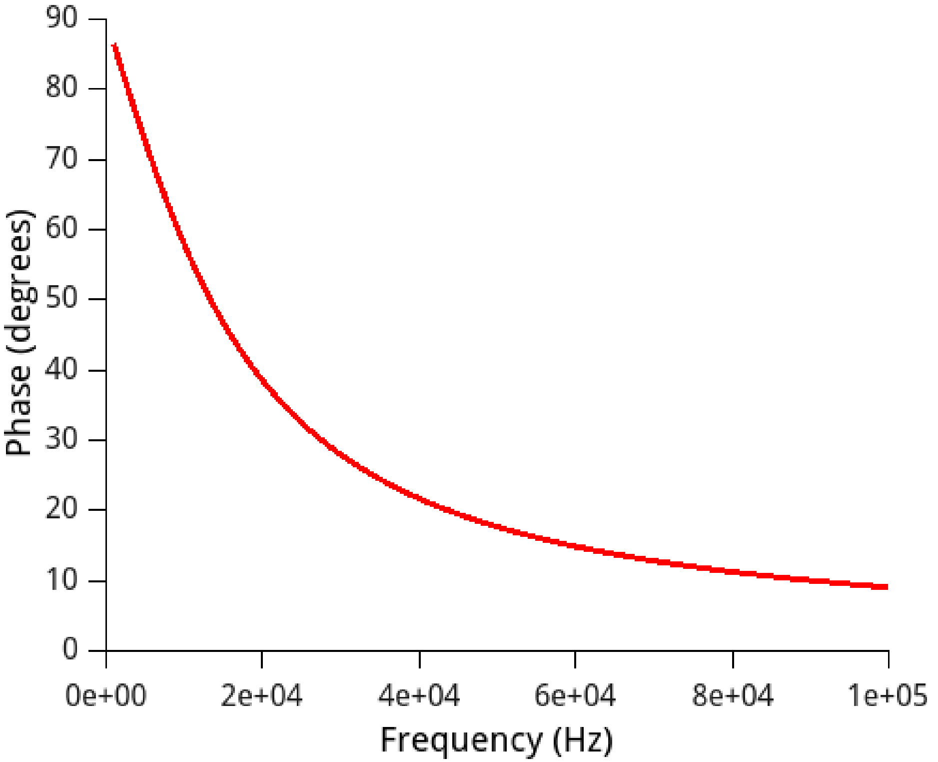
Harmonic analysis of RC high-pass filter



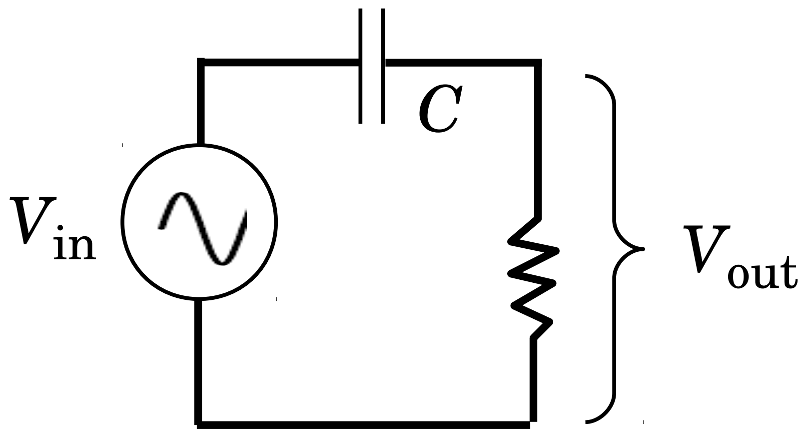
$$\frac{V_{OUT}(\omega)}{V_{IN}(\omega)} = \frac{R}{R + 1/j\omega C}$$



R = 1 kΩ, C = 10 nF



Harmonic analysis of RC high-pass filter

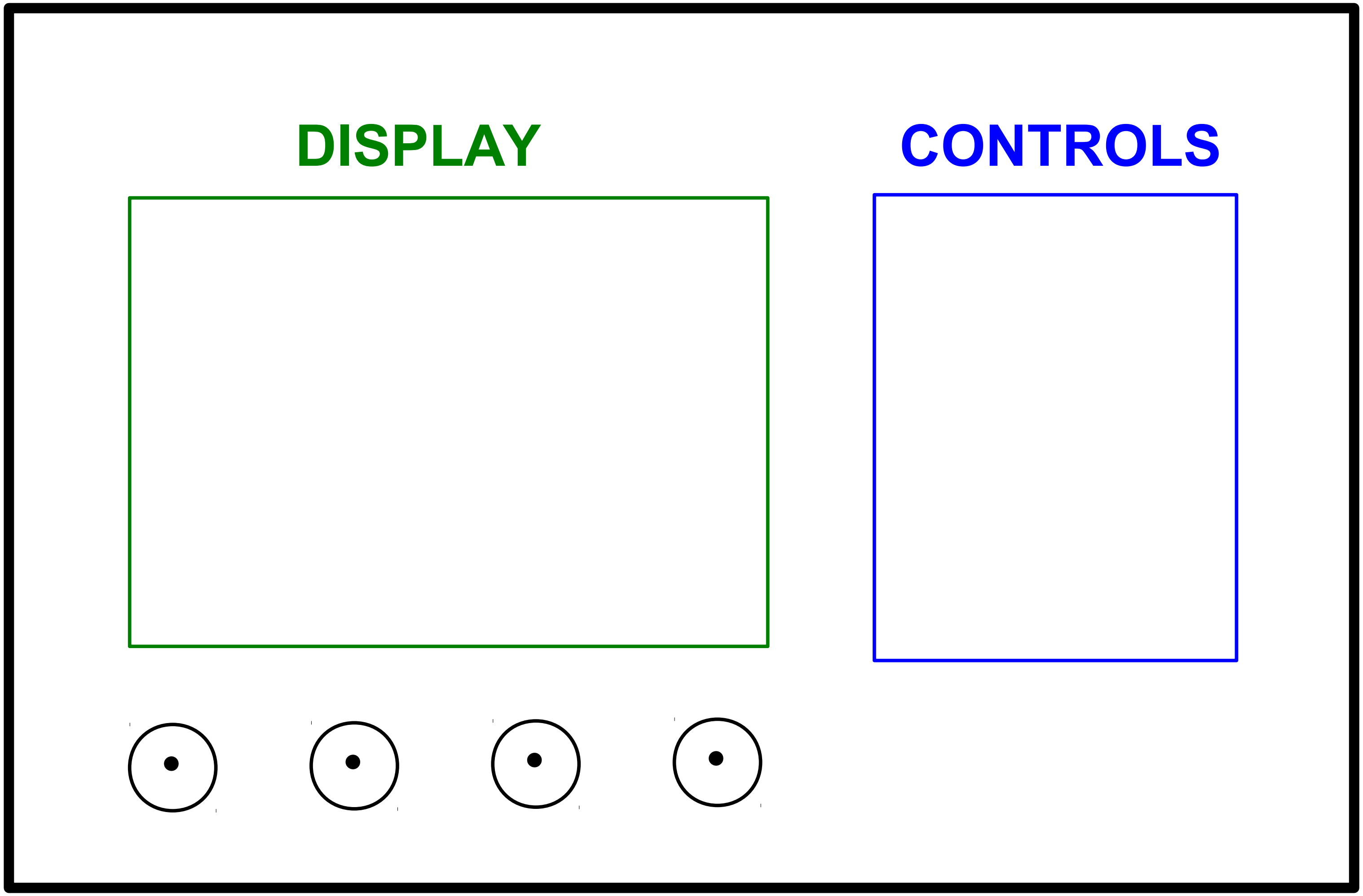


$$\frac{V_{OUT}(\omega)}{V_{IN}(\omega)} = \frac{R}{R + 1/j\omega C}$$

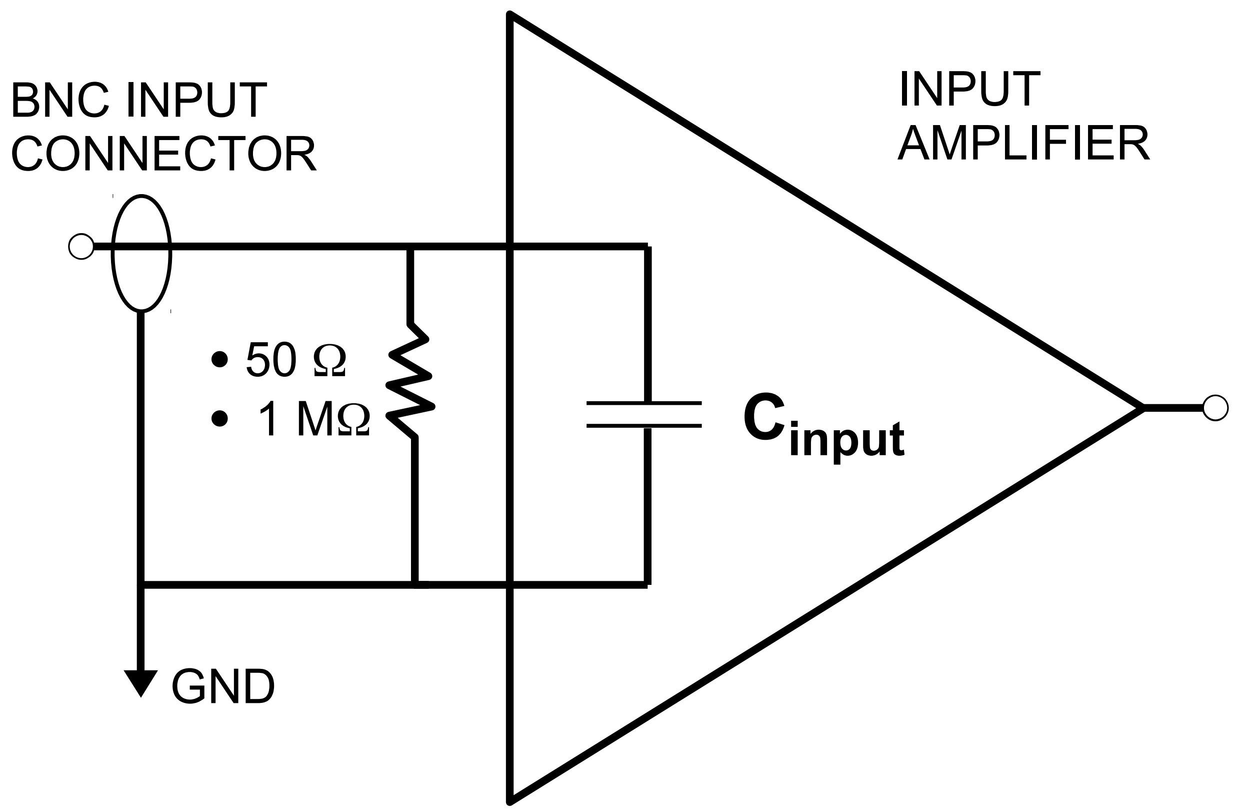
A typical oscilloscope has an *RC* high-pass cutoff in the range 1—10 Hz when AC coupling is used

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

INPUT RESISTANCE: 50 Ω or 1 MΩ?

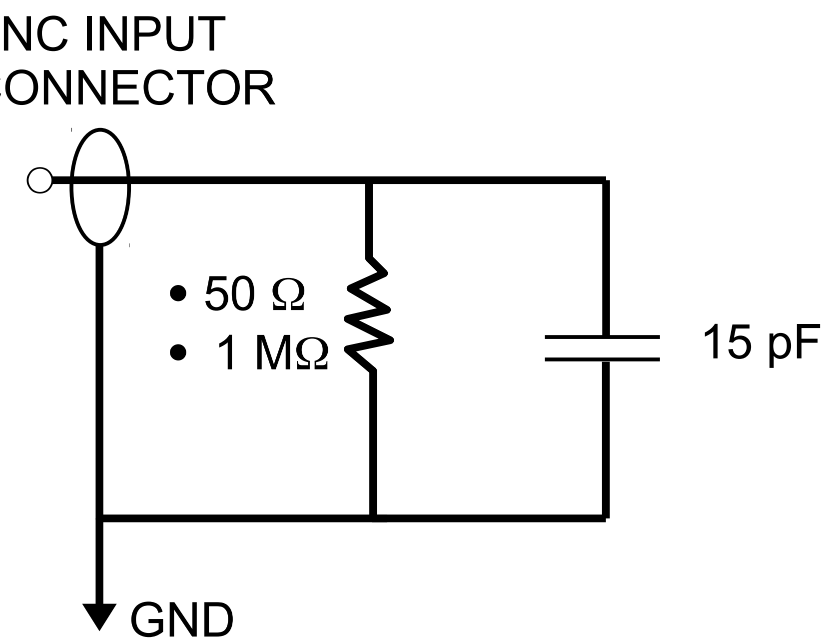


All oscilloscopes have stray (unavoidable) capacitance at the input terminals: C_{input} = 15—20 pF



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

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

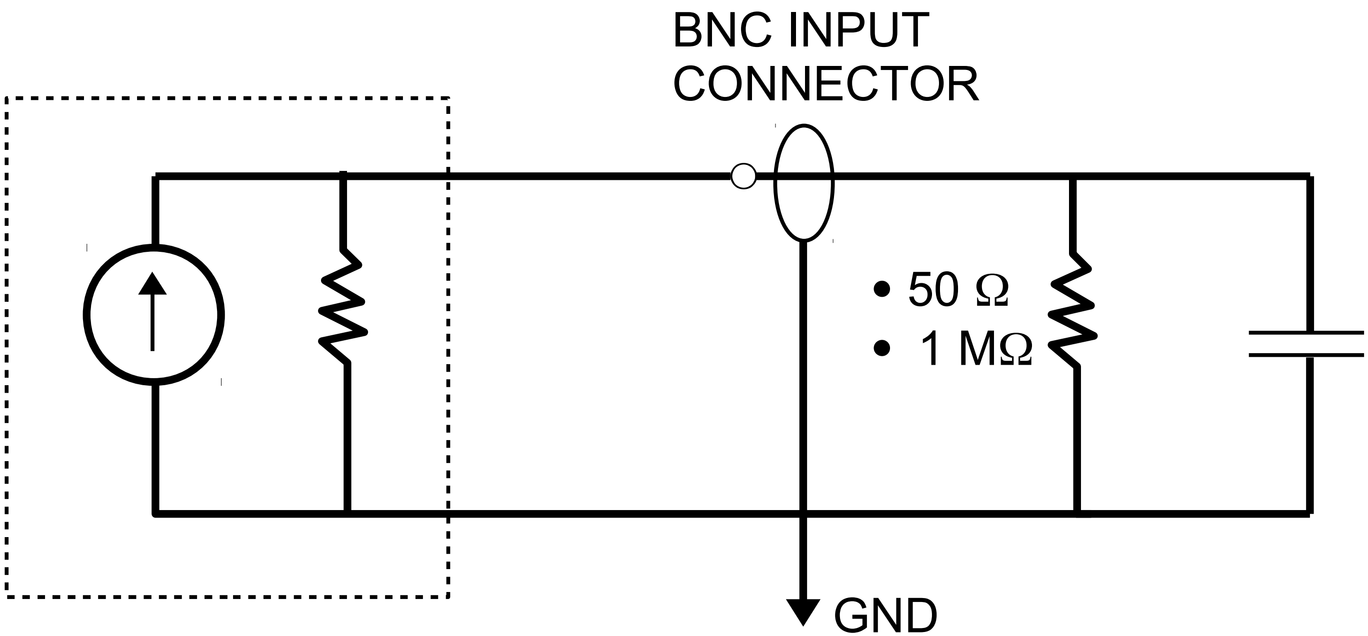


- 1 MΩ rolloff ~ 8 kHz
- 50 Ω rolloff ~ 160 MHz

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



Source:
eg. optical detector

TRIGGERING

Auto: Scope gives continually updated display

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

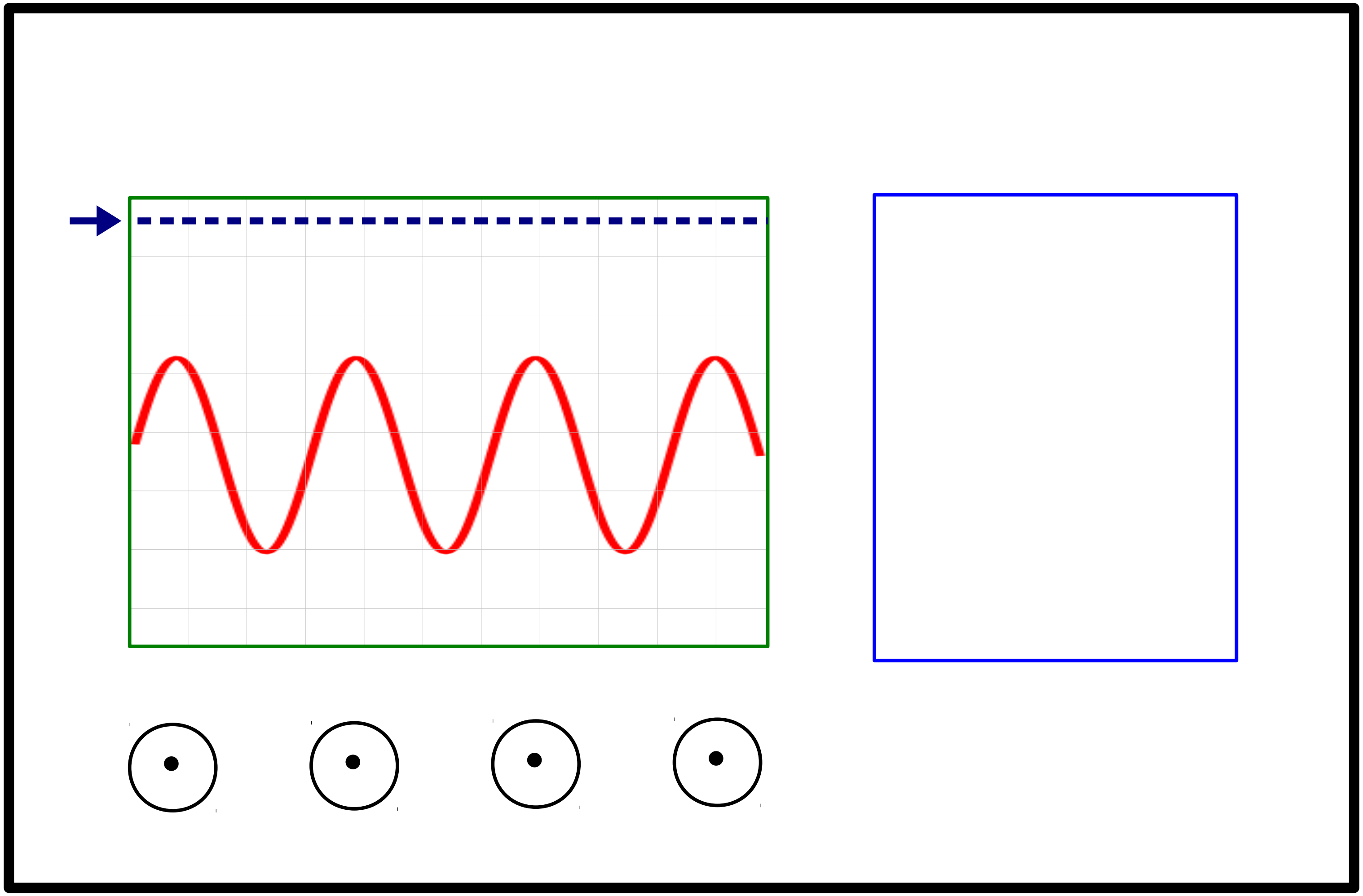
Line: Triggers on 60 Hz AC

Single event

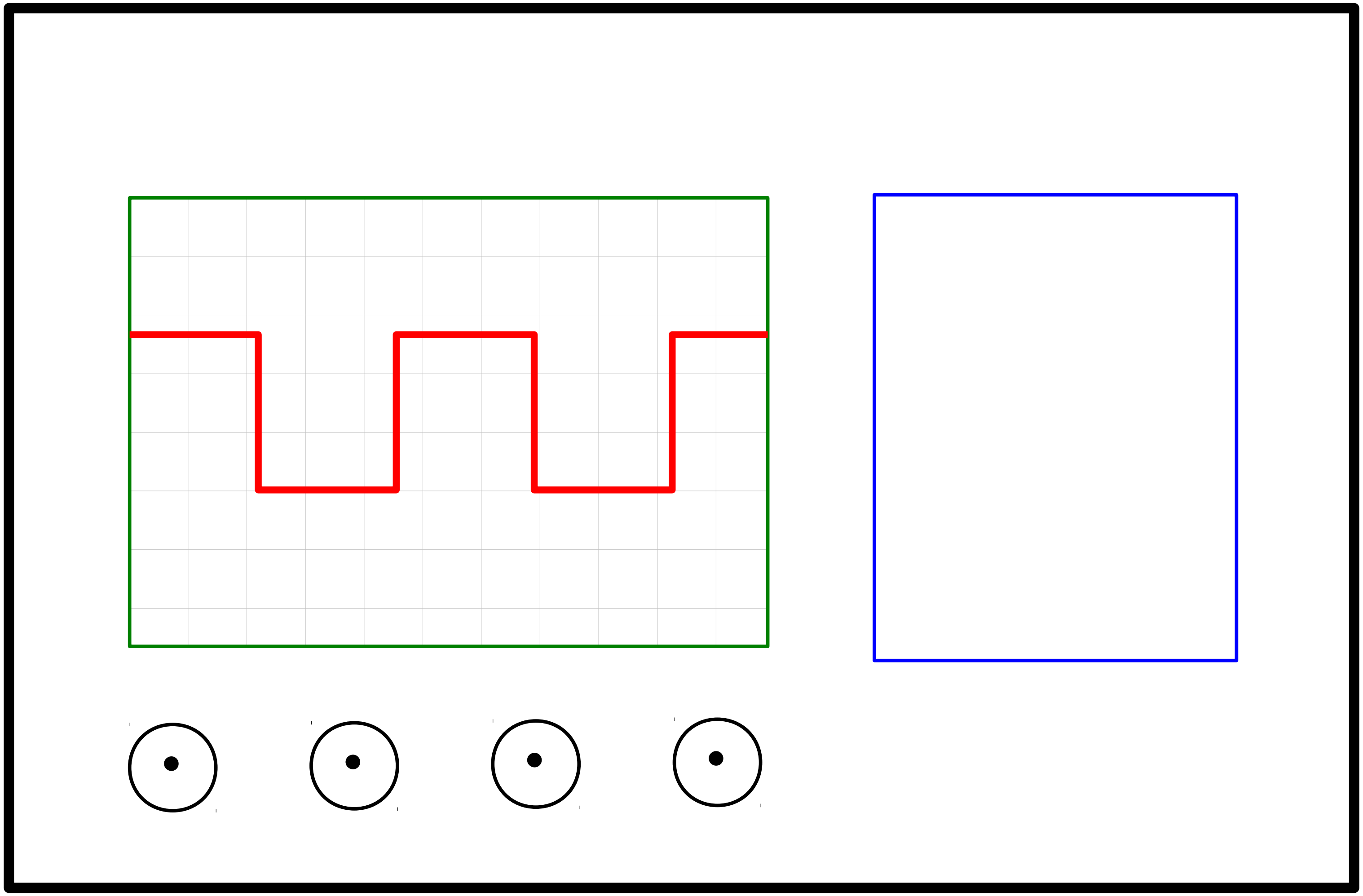
External

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

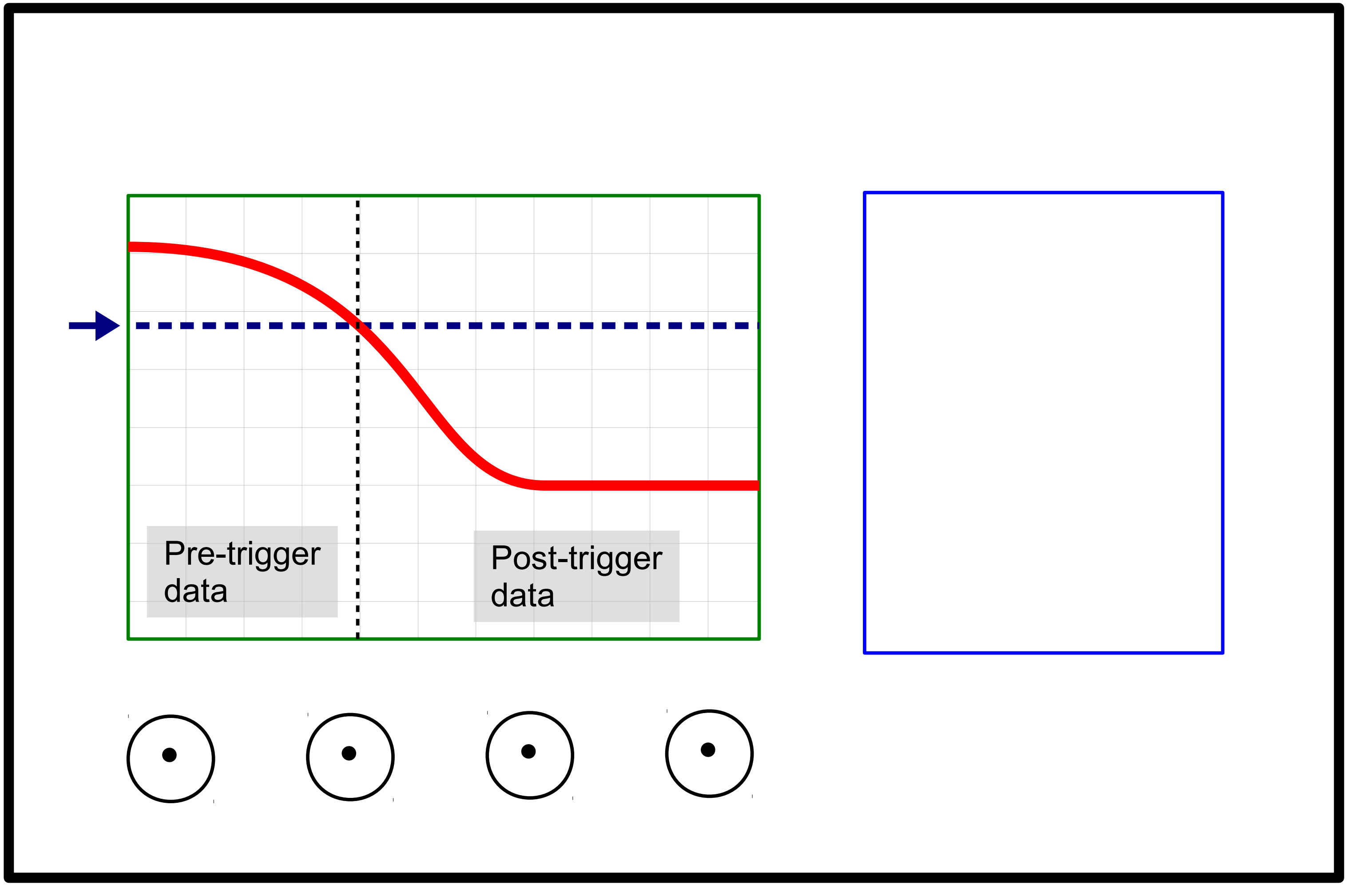
Setting normal trigger level



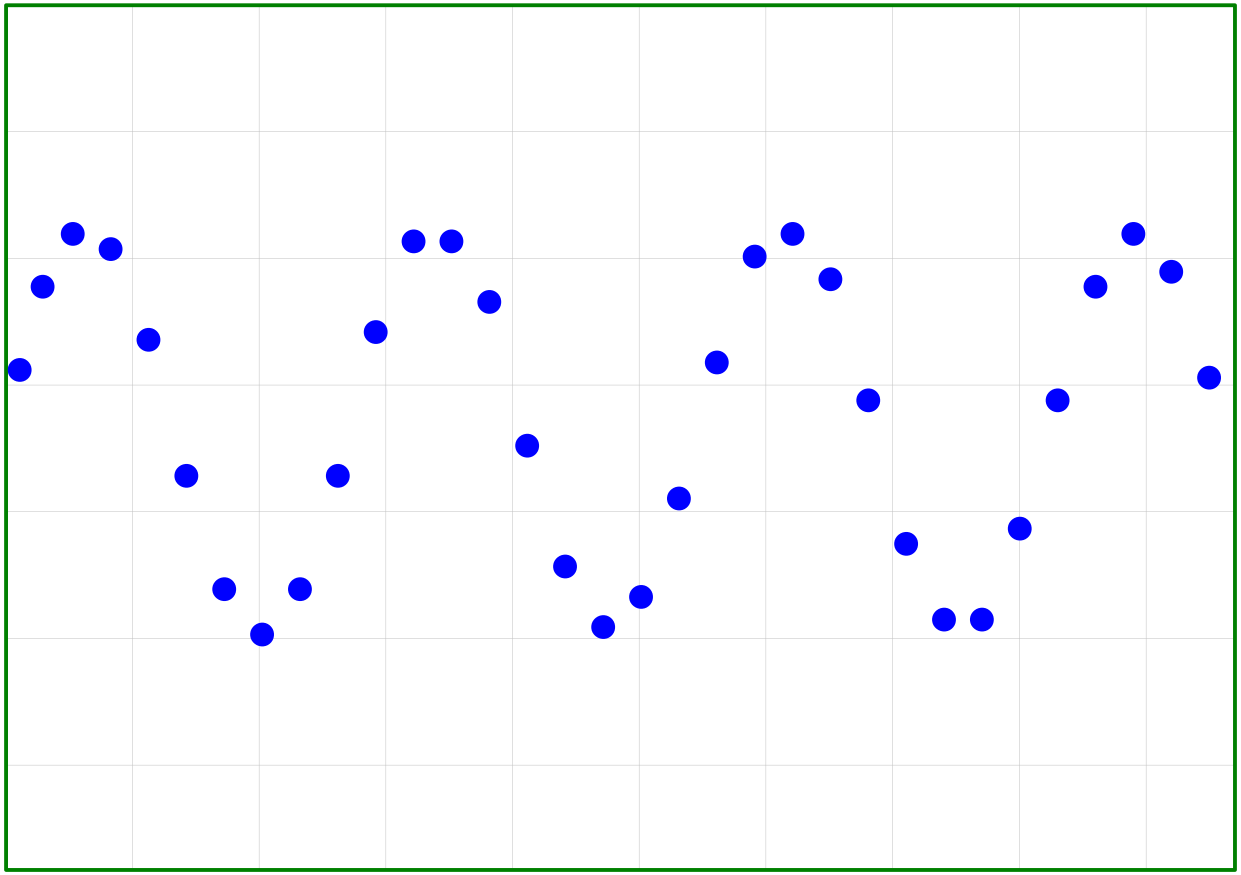
Example: Measure fall time of square wave



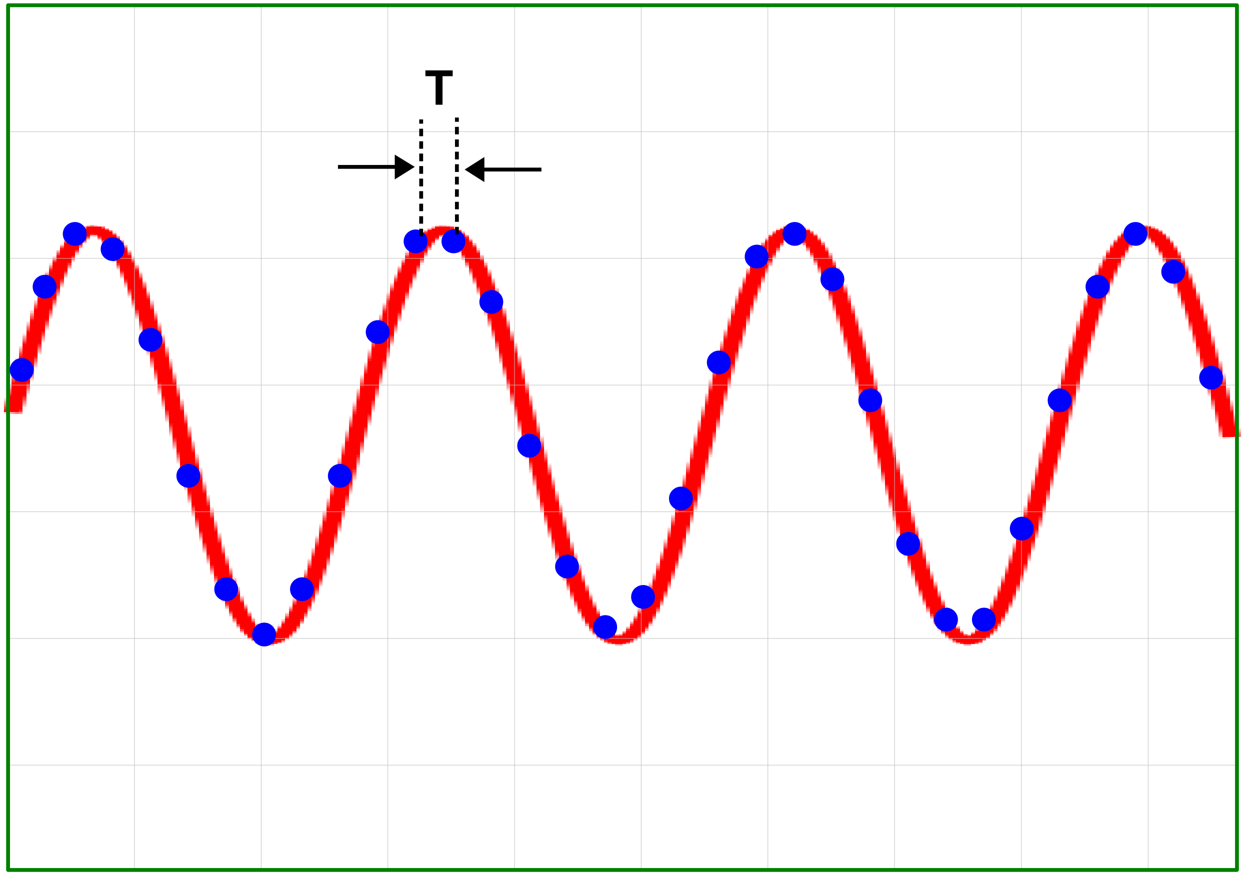
SOLUTION: Trigger on negative slope



DIGITAL SCOPE:
SAMPLING BANDWIDTH



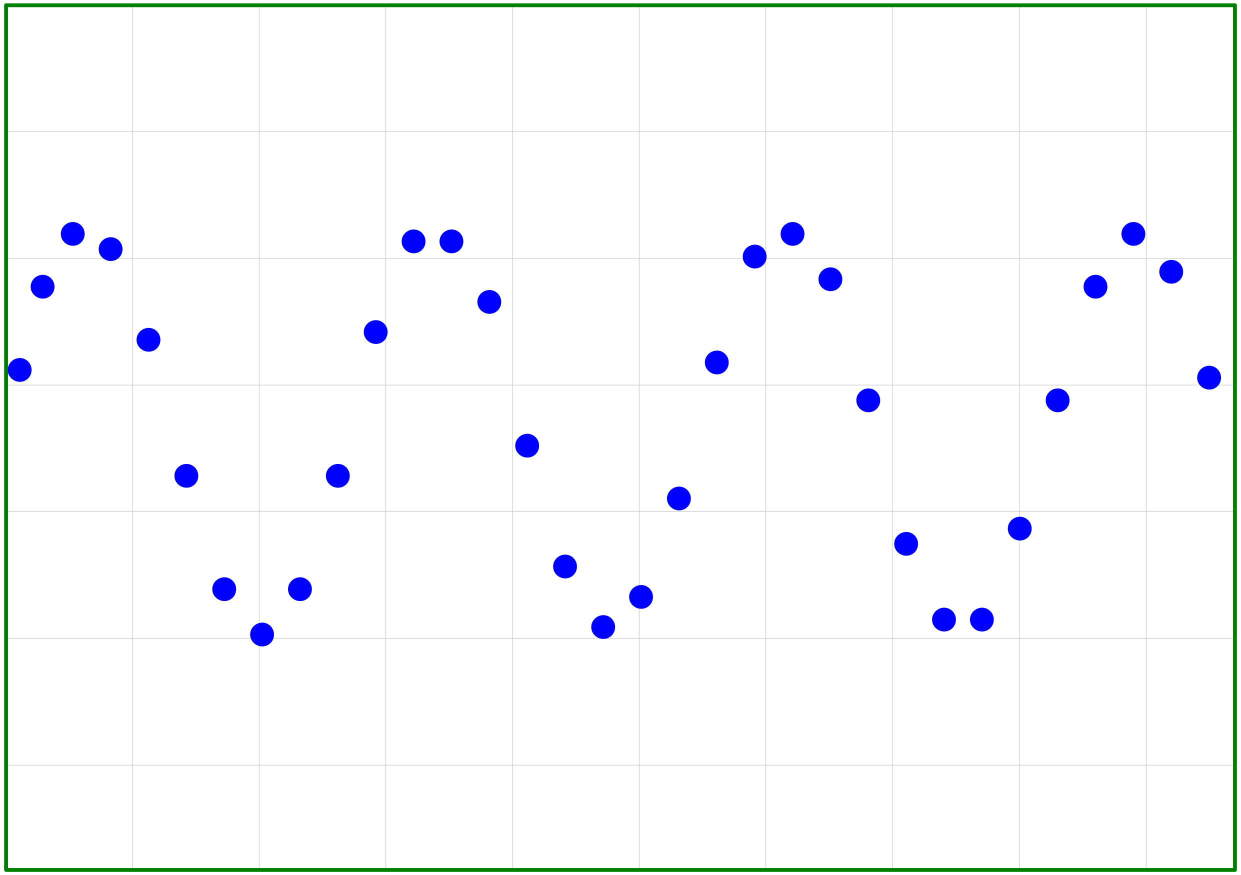
SAMPLING BANDWIDTH



Sample spacing: **T** (sec)

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

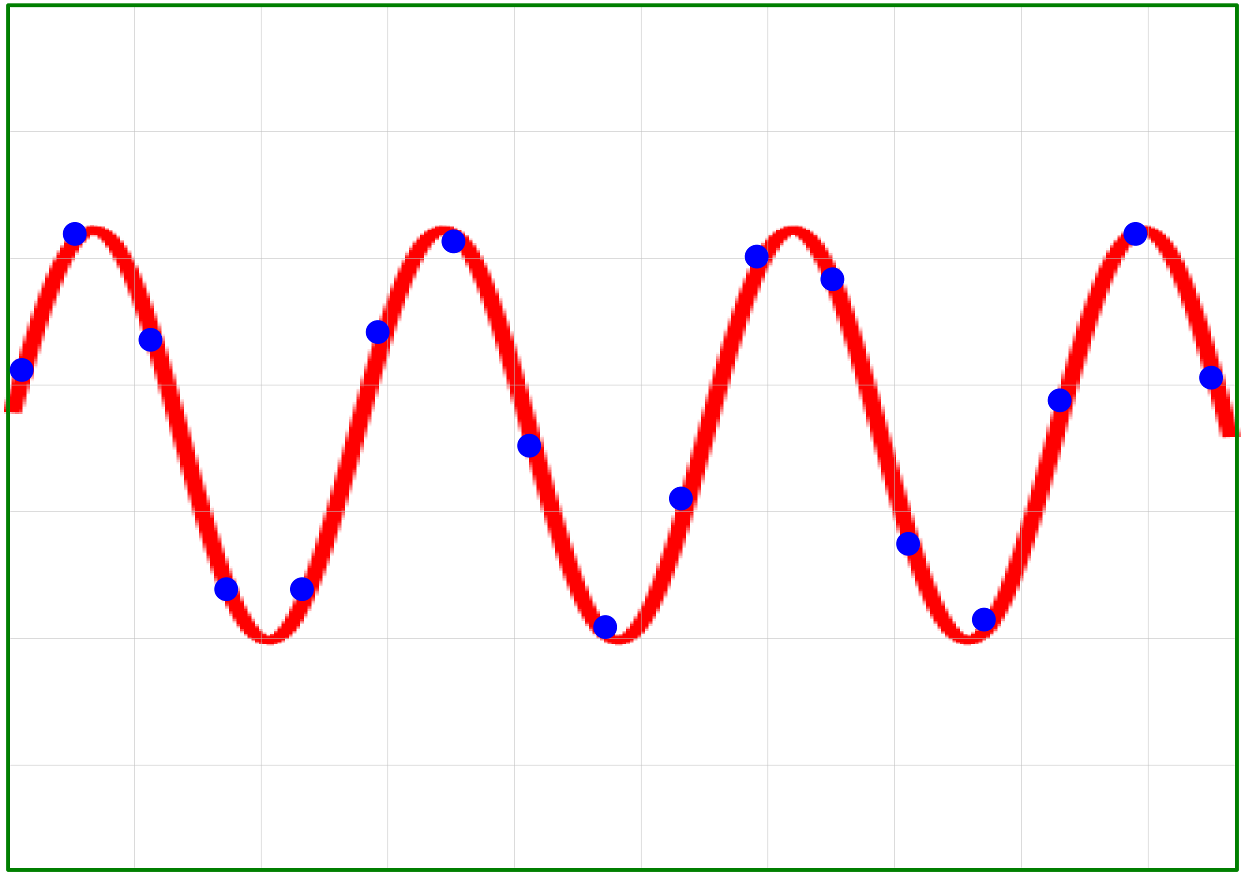
SAMPLING BANDWIDTH



Sample spacing: **T** (sec)

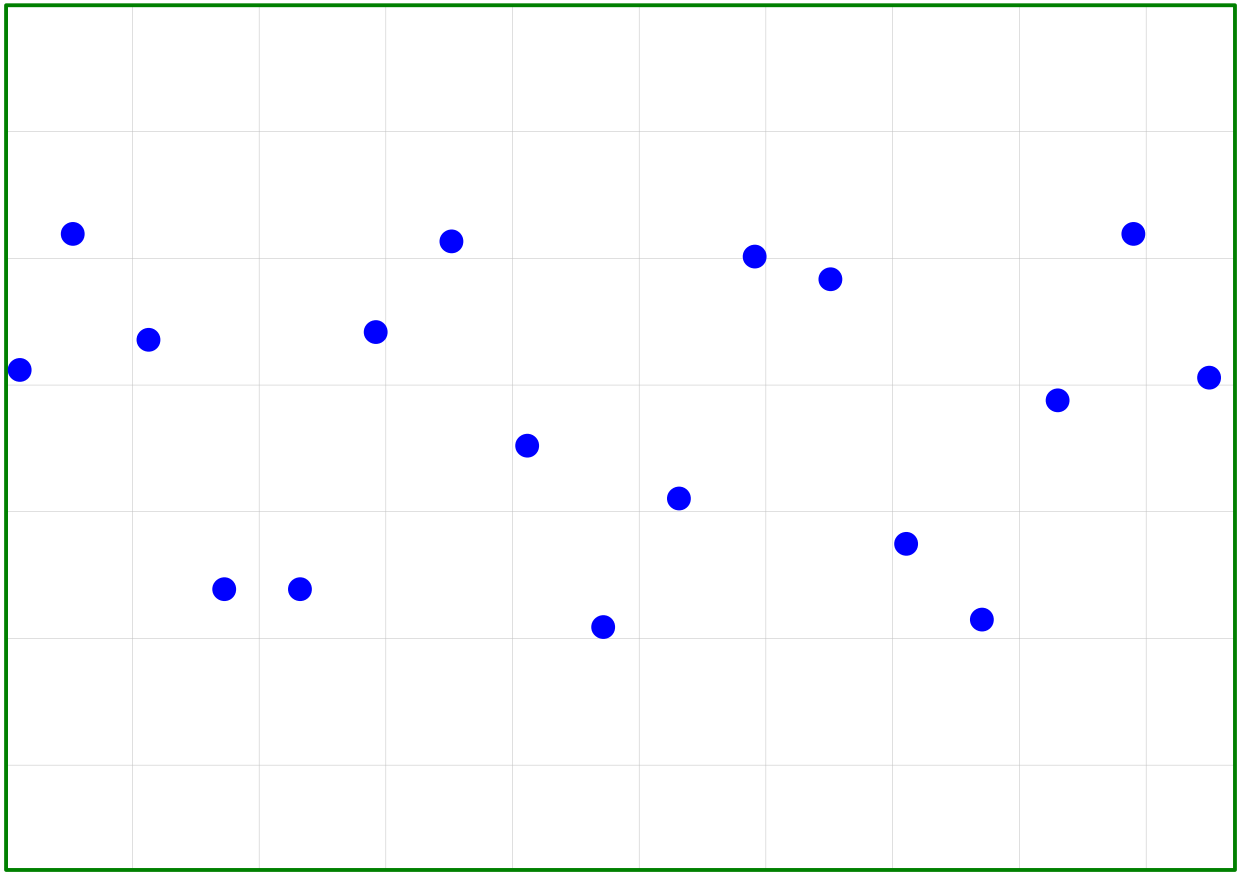
Sampling bandwidth = 1 / **T** (samples/sec)

SAMPLING BANDWIDTH



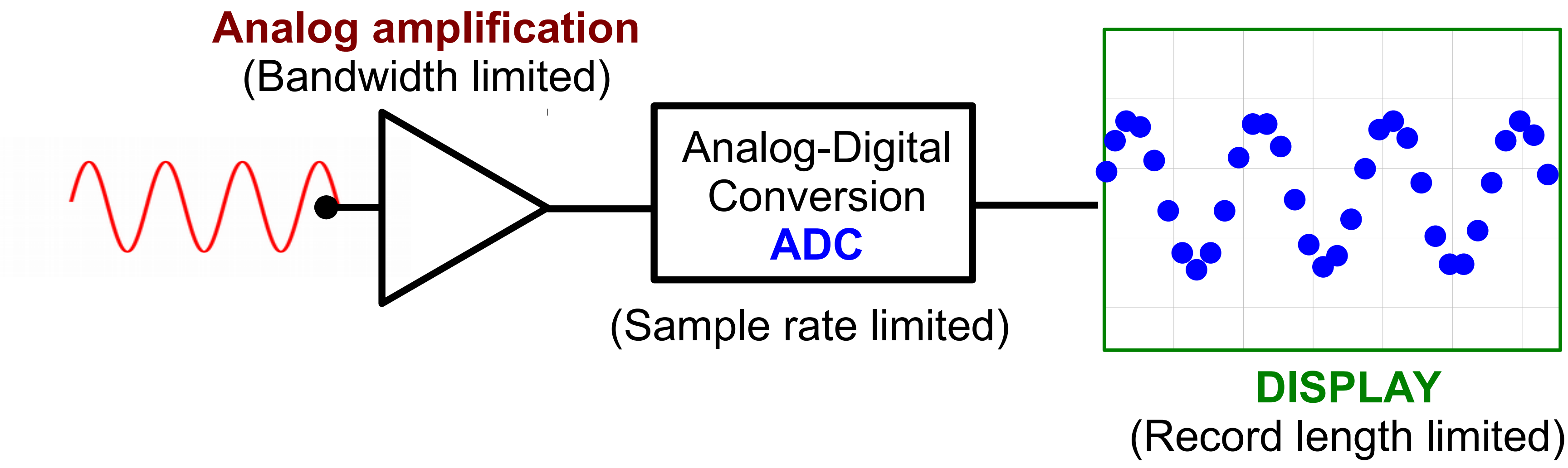
Reduce sample bandwidth 2x ⇒ Increase period 2x

SAMPLING BANDWIDTH

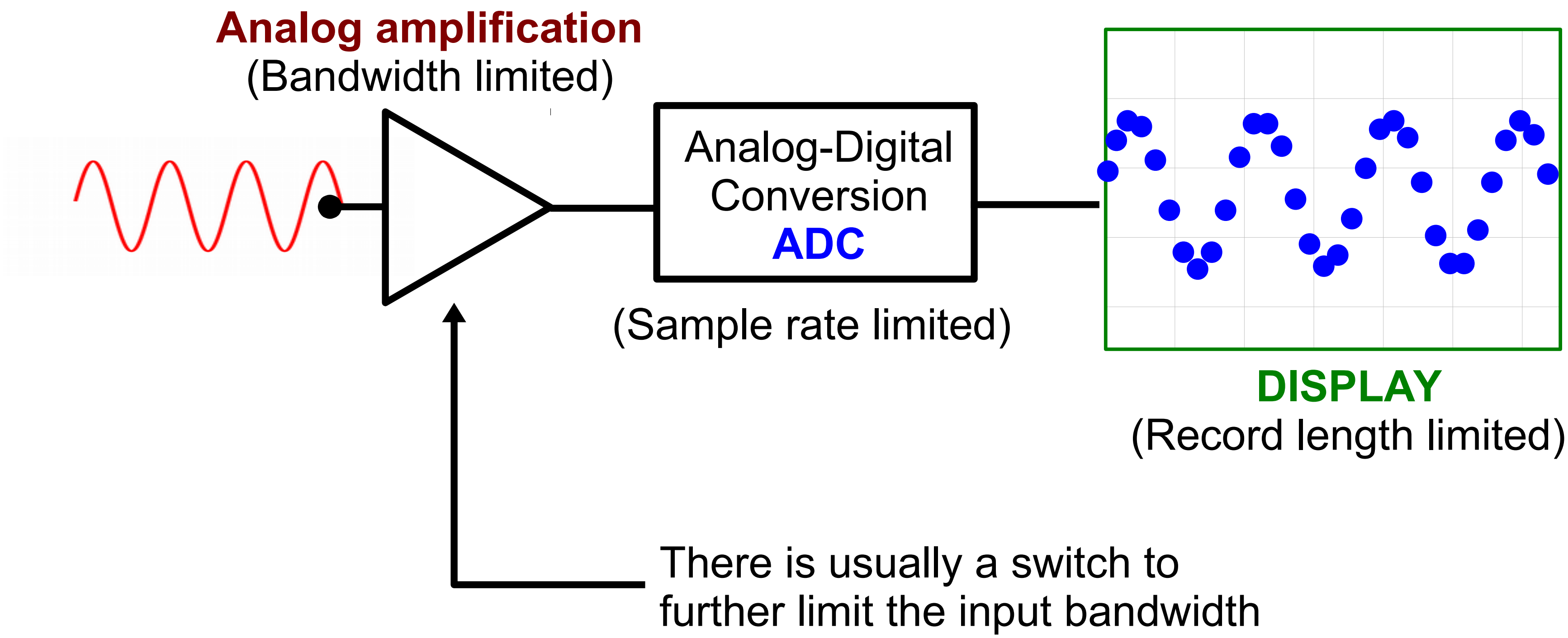


Reduce sample bandwidth 2x ⇨ Increase period 2x

ANALOG BANDWIDTH ≠ SAMPLING BANDWIDTH



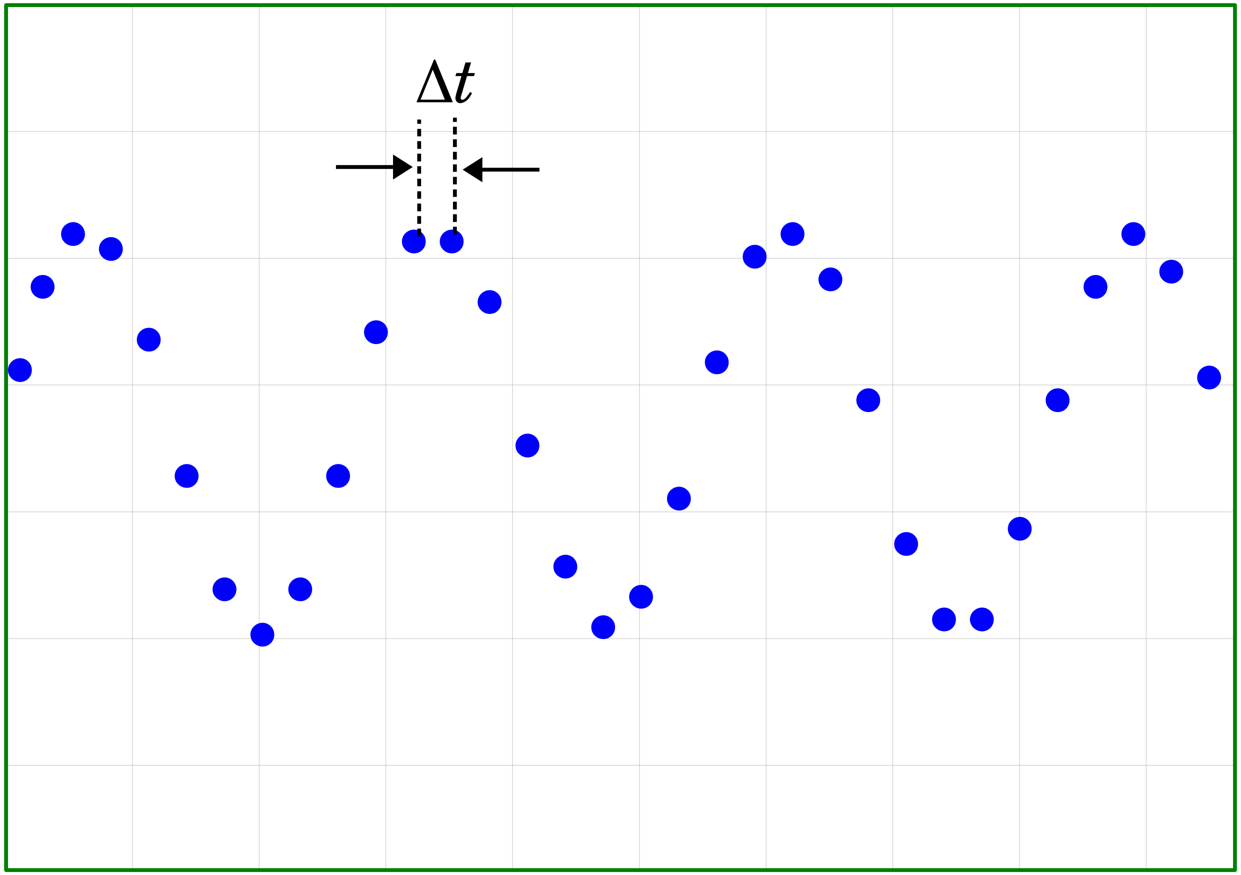
ANALOG BANDWIDTH ≠ SAMPLING BANDWIDTH



Nyquist theorem
Sampling theorem

Temporal spacing of signal sampling

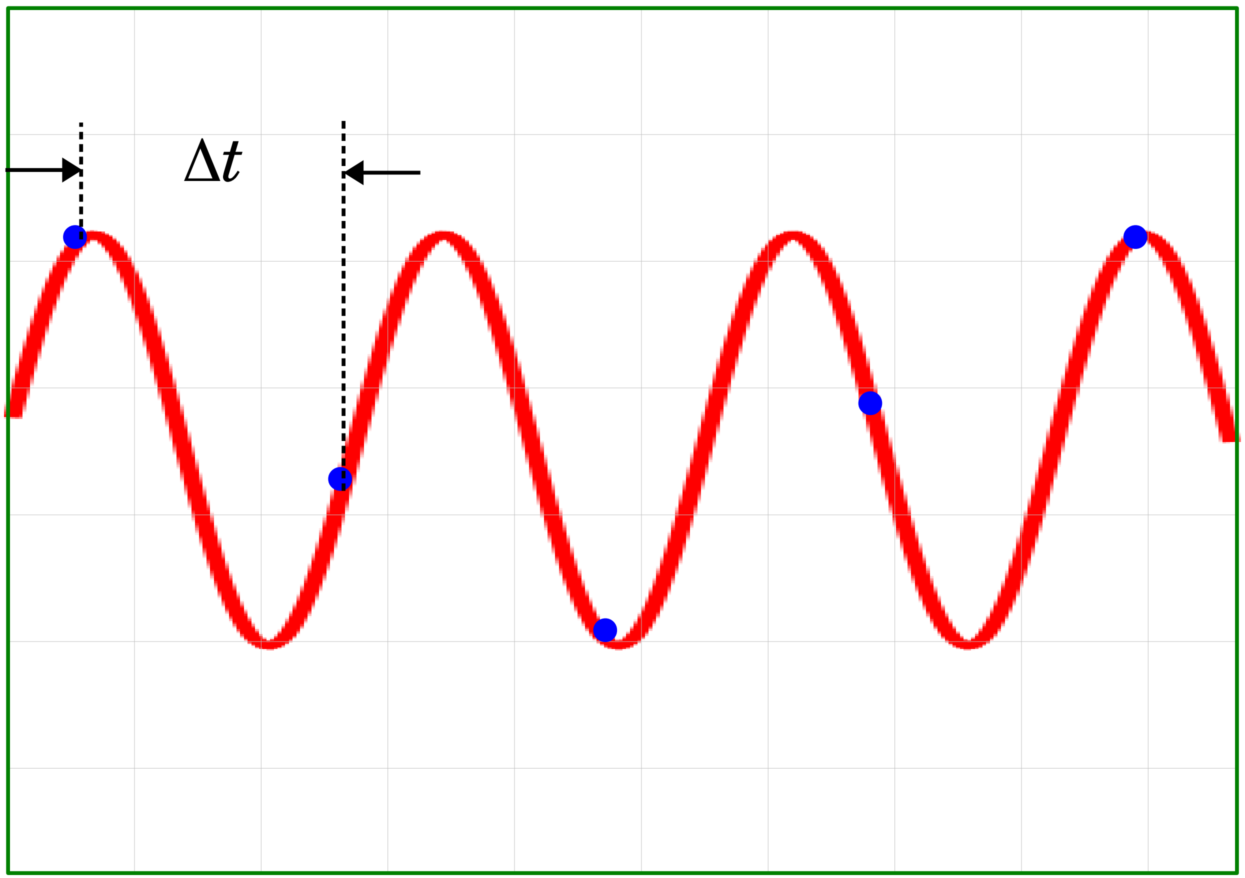
$$\Delta t \leq \frac{1}{2\nu}$$



Nyquist theorem
Sampling theorem

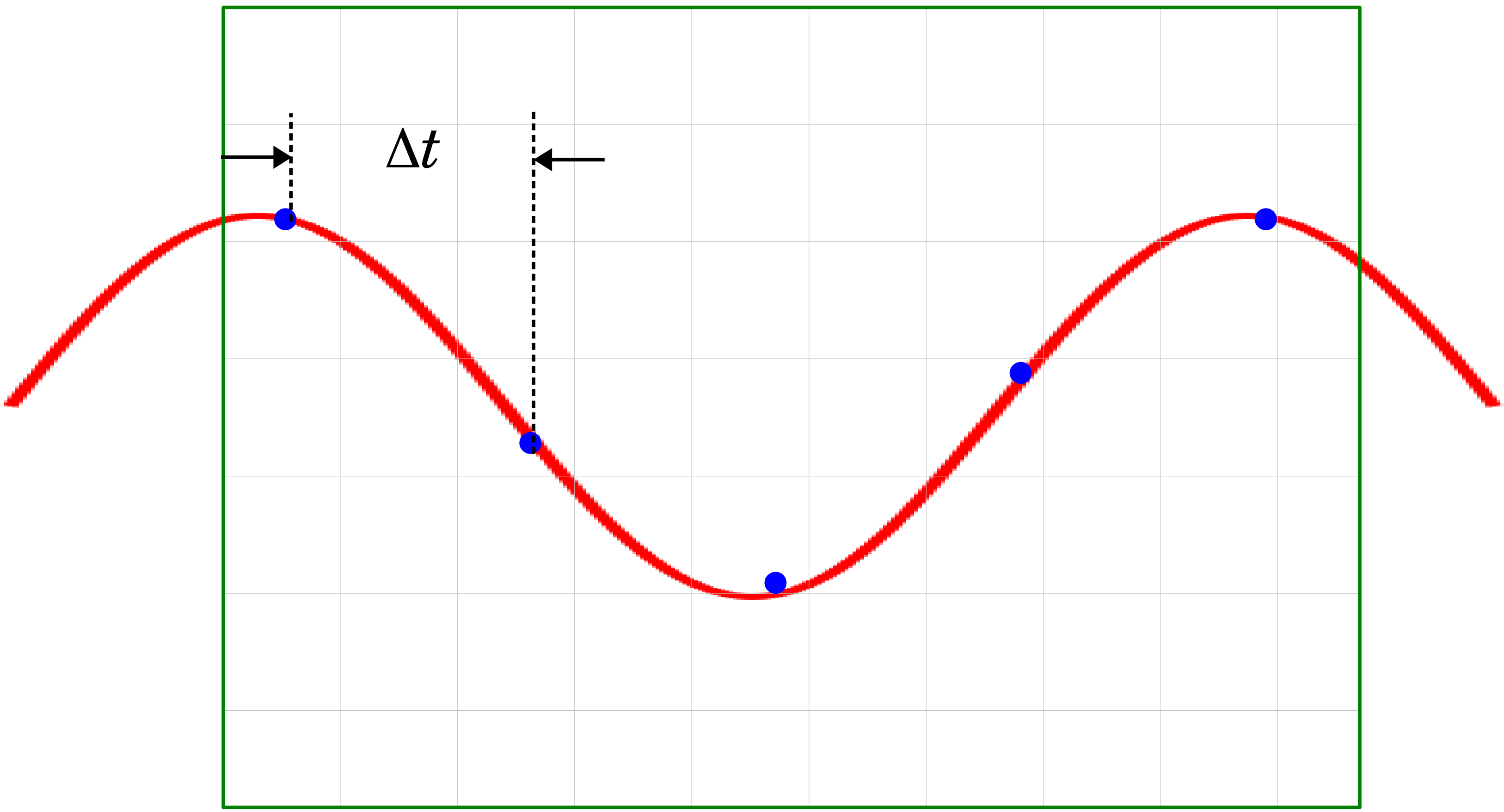
Temporal spacing of signal sampling

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



Nyquist theorem
Sampling theorem

Temporal spacing of signal sampling $$\Delta t > \frac{1}{2\nu}$$



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