Using the 34401A Multimeter

The University of Texas at Arlington
Electrical Engineering Department
Electric Circuit Lab I

In order to measure **resistance**, **DC and AC voltage** and **current**, as well as **frequency** *we* will use the 34401A digital multimeter (DMM).

The 34401A has a built-in microprocessor, *memory* and other electronics components that give it numerous features such as built-in **math** functions, recording and storing up to 512 readings, giving the *maximum*, *minimum* and *average* of the readings.

34401A Multimeter

- **6 1/2 digit**, high performance digital multimeter
- AC/DC **voltage** measurements
- AC/DC **current** measurements
- 2 and 4 wire **resistance** measurements
- **Frequency** and Period measurements
- **Math** functions

For **resistance** measurements, one connects the DMM over the resistor.

Notice that for **voltage** measurements one puts the multimeter in ***parallel*** with the circuit element so that one measures the voltage ***across*** the element.

In case of a **current** measurement, one must put the DMM in ***series*** with the element in order to measure the current ***through*** the element. That involves <u>breaking</u> the circuit in order to insert the multimeter in the circuit loop.

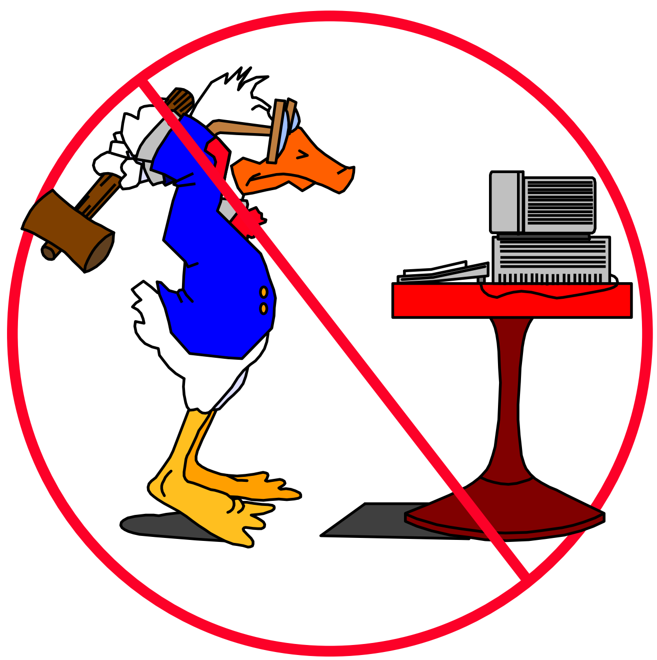
In the following we will discuss the use of the DMM in more detail for resistance, voltage and current measurements.

Protect Instrument

1) Inductive Devices (e.g. transformers, chokes/inductors) induce very high transient voltages.

2) Measuring resistance: Avoid contacting probes with live circuits when in resistance modes.

3) Measuring Current: Do not connect probes across voltage source.



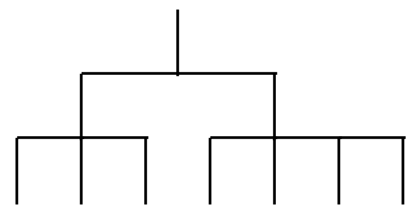
Starting Multimeter

- To perform a complete **self-test**, hold down the shift key for more than five seconds as you turn on the multimeter.
- *The display will indicate whether test passed. Error messages will be displayed if a failure occurs.*

000.002 mVDC

Menu at a Glance

Menu is organized in a top-down tree structure with 3 levels



To turn on menu **Shift** **On/Off**

To move left or right: < >

To move up or down: V Λ

To enter command: Auto / Man

A: Meas Menu → **B: Math Menu** → **C: Trig Menu** → **D: Sys Menu** → **E: I/O Menu** → **F: Cal Menu**

- A: Meas Menu — 1: AC Filter 2:Continuity
- B: Math Menu — 1: Min-Max
- C: Trig Menu — 1: Read Hold
- D: Sys Menu — 1: RDGS Store
- E: I/O Menu — 1: HP-IB ADDR
- F: Cal Menu — 1: Secured

Math Functions

To make **null** (relative) measurement — Null

To store **min/max** readings — Min Max

To make **dB** measurements — Shift dB

dB = *reading in dBm* **-** *relative value in dBm*

To make **dBm** measurements — Shift dBm

dBm = $10 \cdot \mathrm{Log}_{10}$ (*reading* ^{2}*/ reference resistance/ 1mW)*

Limit testing (Access through Menu)

Triggering

Auto-trigger: Continuously takes readings at fastest rate possible for present configuration. Default.

Single trigger: Manual trigger by pressing Single
One reading or specified number of readings (Sample count).

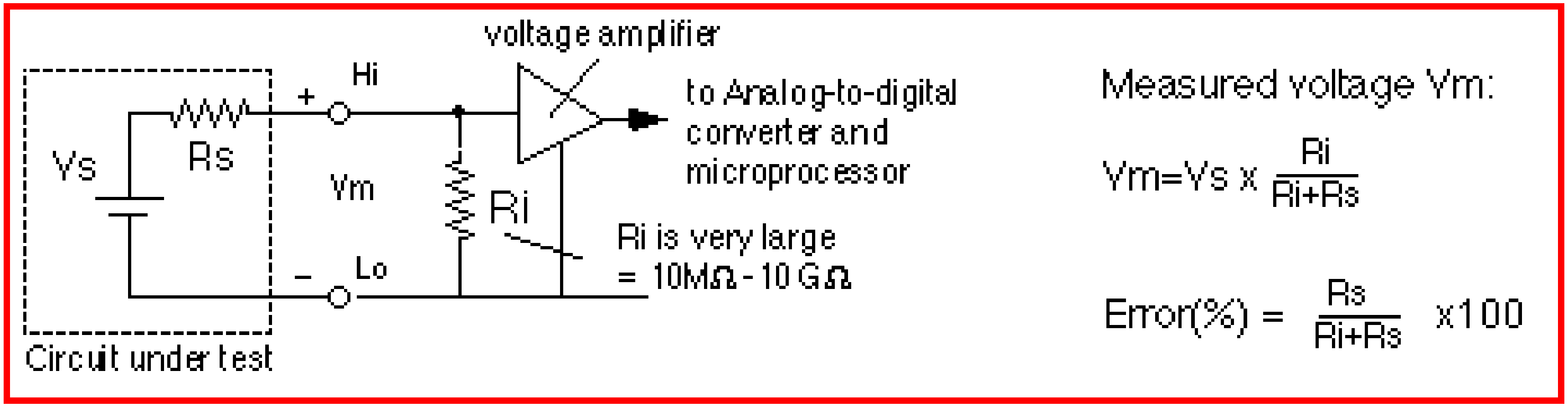
Number of samples: Number of readings meter takes with each trigger: 1 to 50,000. Default is 1.

Reading hold: Select by pressing Shift Auto/Hold
Captures and holds a stable reading on the display.

(1) <u>Voltage</u> measurement

Principle of measurement

A DC voltage is measured by using a voltage amplifier and an analog-to-digital converter as schematically shown in the following. A microprocessor further manipulates the data before displaying the results.



Schematic of the DMM as a DC voltage meter.

To measure a voltage, connect the nodes over which one wants to measure the voltage between the HI and LO input terminals of the DMM.

In order to activate the DMM for DC measurements you have to select the DC Voltage function by pushing the **DC V** button on the front panel.

The **Math** functions, such as Max/Min and average, can be activated (in a similar fashion as was done for the resistance measurements). Also, the range can be selected manually by pushing the **Man/Auto** key in the Range menu.

Errors due to the internal resistance

An ideal voltmeter has an *infinite* input resistance so that it will not draw any current from the circuit under testing.

However, in reality, there is always a *finite* input resistance Ri. As a result, one has a voltage divider that will cause the voltage Vm one sees at the input of the voltmeter to be slightly different from the actual voltage Vs one wants to measure.

The 34401A has a relatively large input resistance of at least 10Mohm (depending on the selected voltage range) so that the error will be small as long as Rs << Ri.

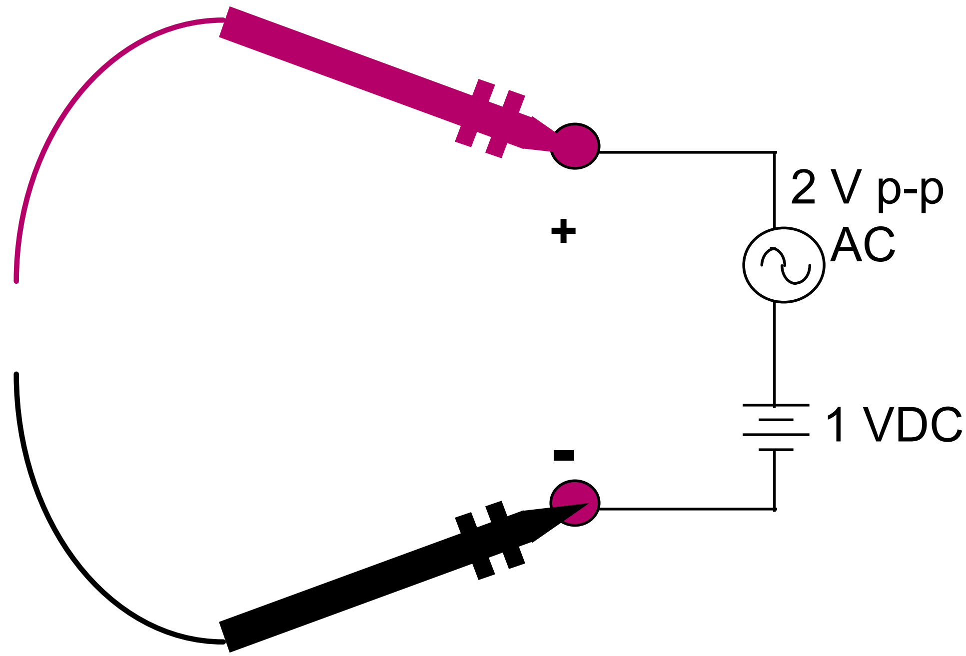
CAUTION:

Do not exceed the maximum allowable voltage input (1000V DC).

Also, never apply a voltage over the current input terminal (I) of the DMM.

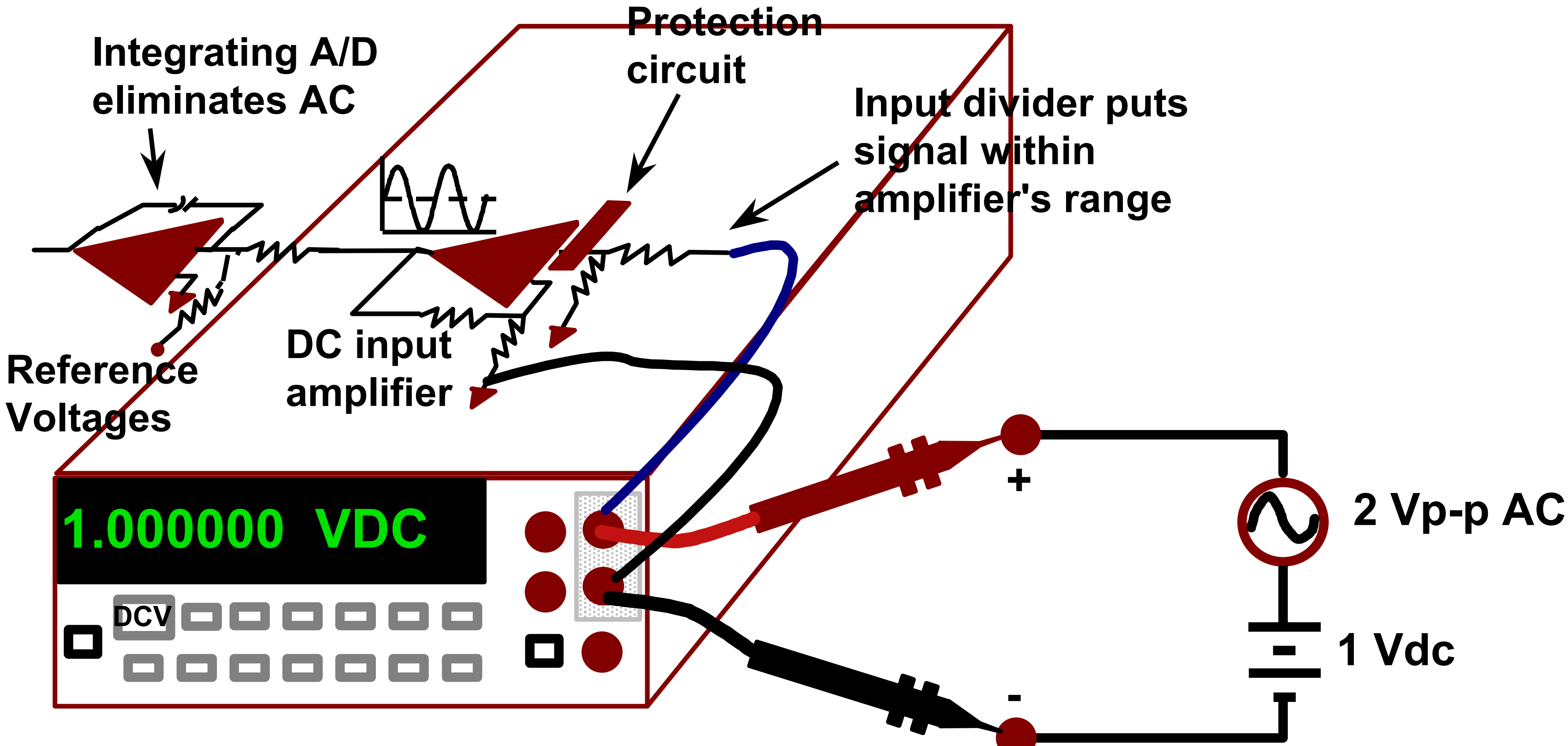
Measuring DC Voltage

1.000000 VDC

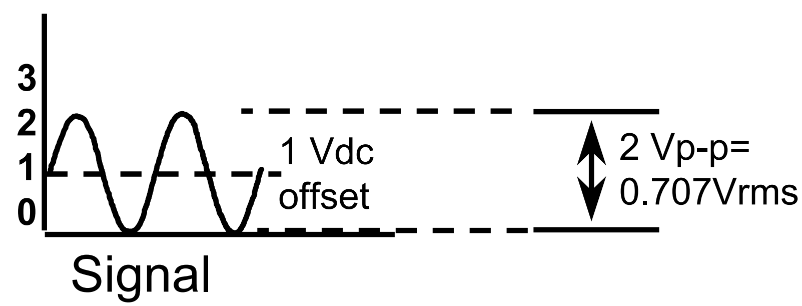


Note: measurement indicates only DC portion of signal

Measuring DCV



*"Terminals" switch in "FRONT"
* Press DCV
* Note measurement indicates only the dc portion of signal



Range and Resolution

Range	100 mV	1 V	10 V	100 V	1000 V (750 VAC)
Maximum Resolution	100 nV	1 μV	10 μV	100 μV	1 mV (750 μVAC)

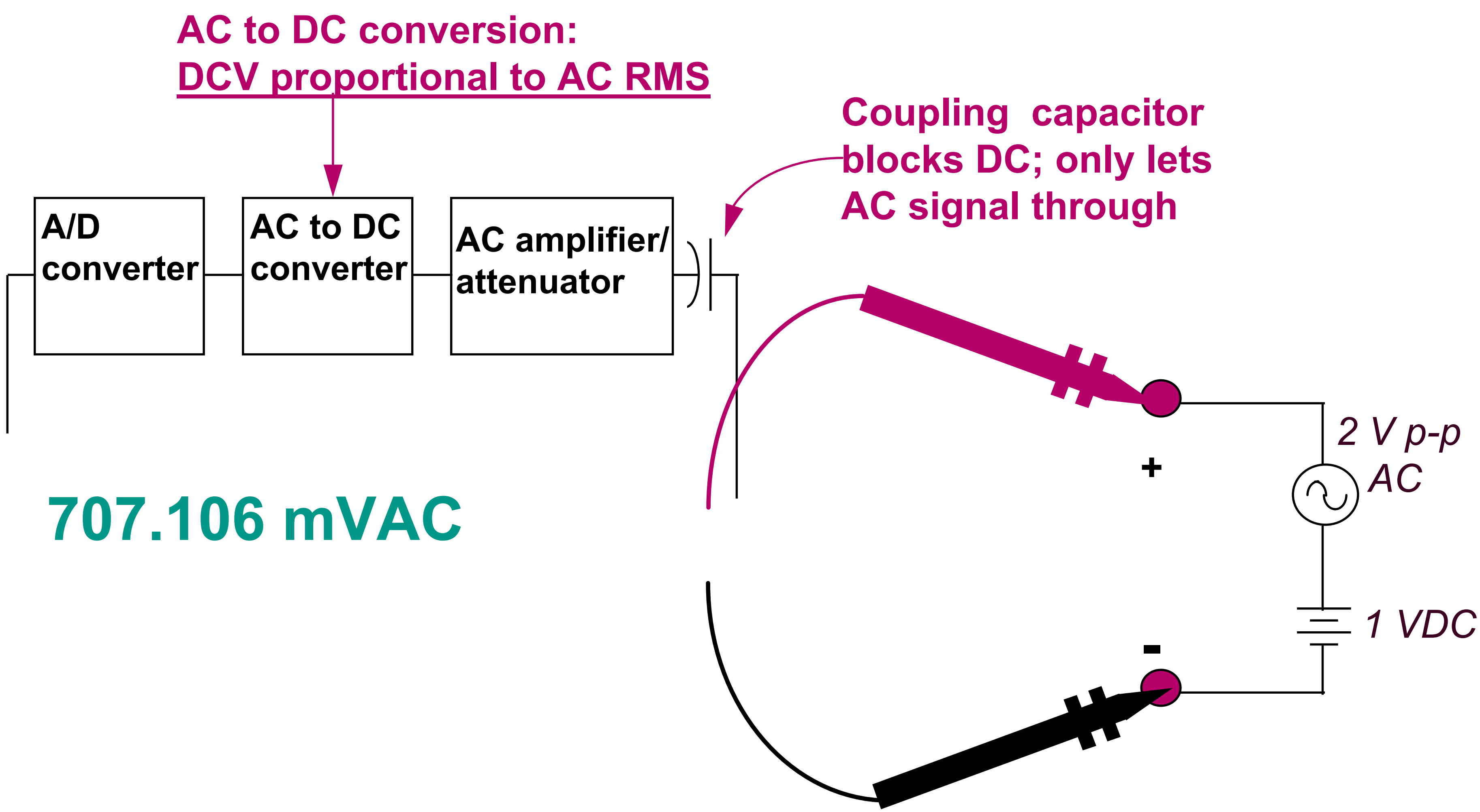
Resolution Choices & Integration Time

Integration Time**		Resolution Choices	
.02	PLC	Fast 4 Digit	Fastest, Least Accurate
.2	PLC	Fast 5 Digit	
1	PLC	* Slow 4 Digit	
Default → 10	PLC	* Slow 5 Digit * Fast 6 Digit	
100	PLC	Slow 6 Digit	Slowest, Most Accurate

* Equivalent to Pressing "Digits" key on front panel.
**In Power Line Cycles (PLC).

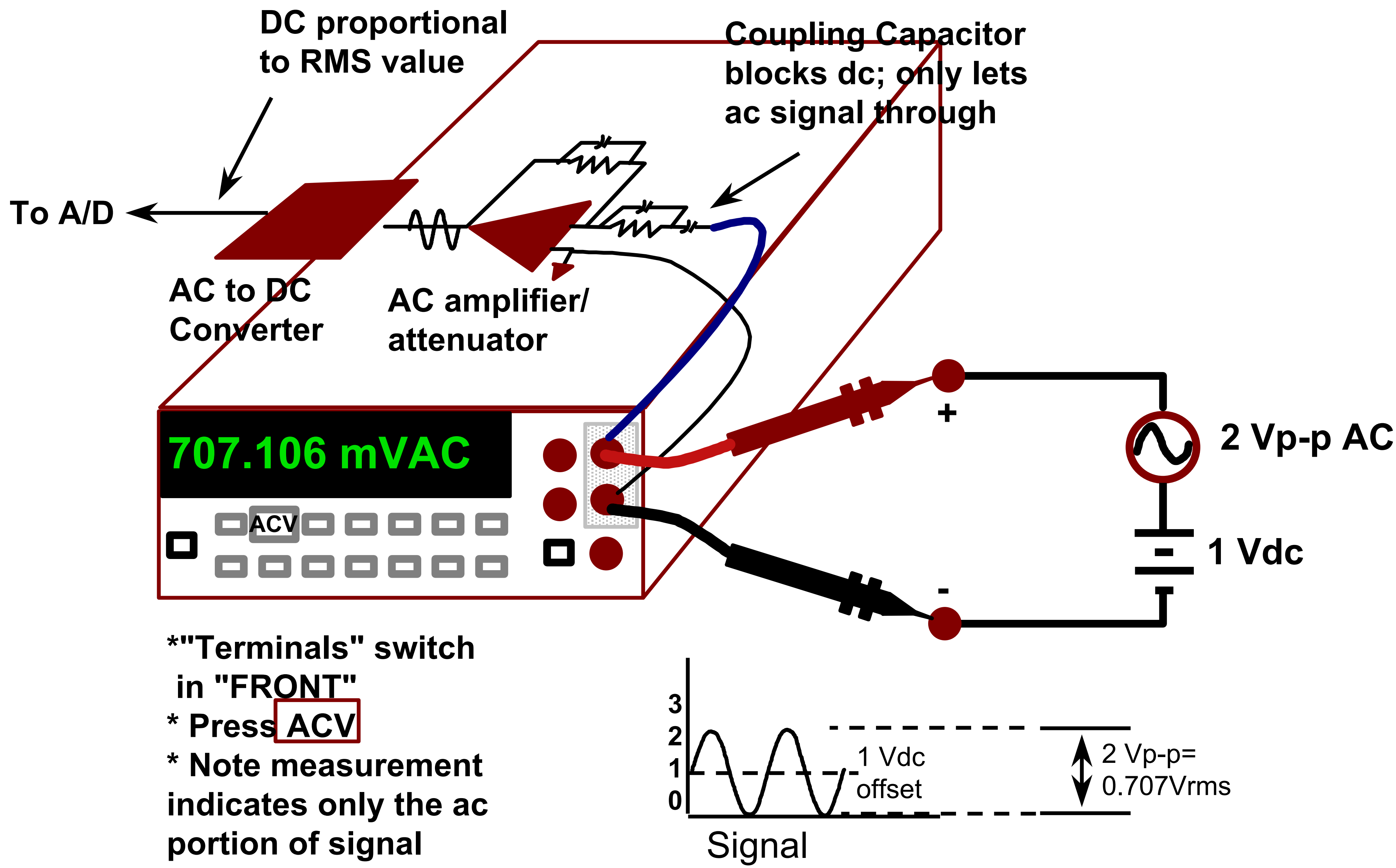
Note: Integration times of .02 and .2 do not provide power-line noise rejection characteristics.

Measuring AC Voltage



Note: measurement indicates only the AC portion of signal

Measuring ACV



* "Terminals" switch in "FRONT"
* Press ACV
* Note measurement indicates only the ac portion of signal

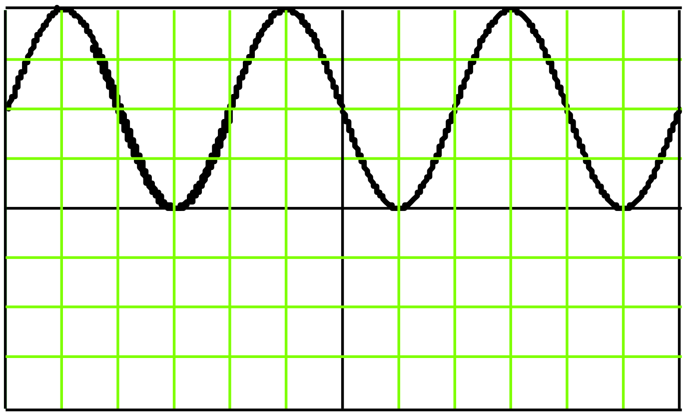
AC Filter

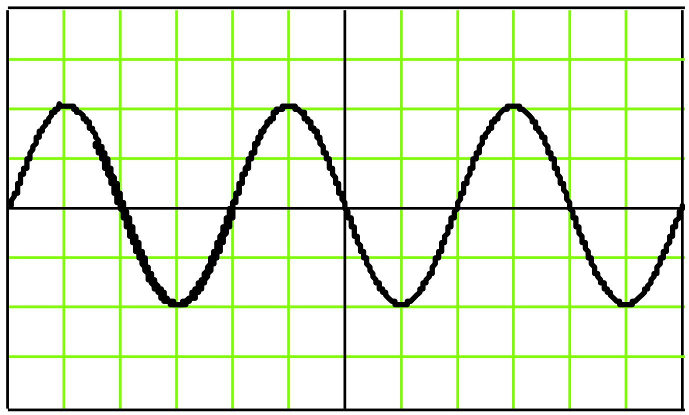
Frequency	Range*	Time to settle
3 Hz and above	Slow	7 sec.
20 Hz and above	Medium	1 sec.
200 Hz and above	Fast	0.1 sec.

*Selectable through the measurement menu

AC-Coupling vs. DC-Coupling

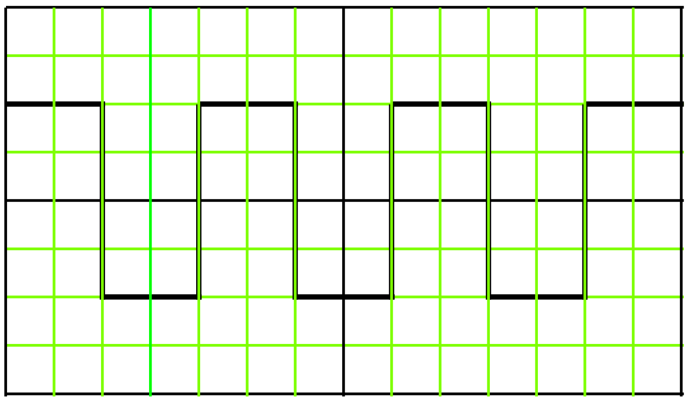
AC-Coupling-Advantage

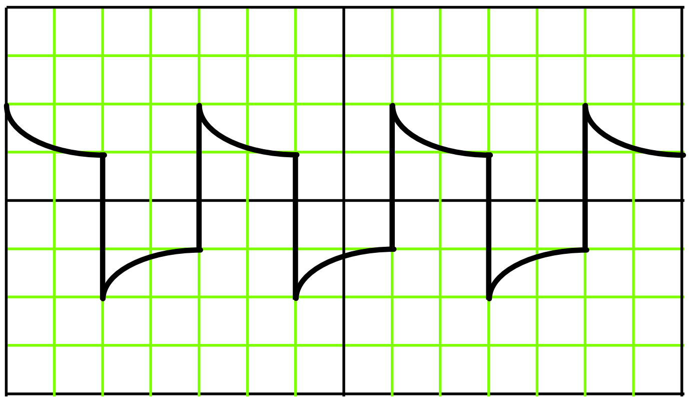




*Removes DC Portion of Signal

AC-Coupling-Disadvantage





*Low Frequency waveforms can be cut-off

Vrms: Root-Mean-Square

- Instantaneous power to a resistor is: $P = \frac{v(t)^2}{R}$
- Average power to a resistor is:

$$Pavg = \frac{Vrms^2}{R} = \frac{1}{R}\left(\frac{1}{T}\int_{to}^{to+T} v(t)^2\,dt\right)$$

Solving for Vrms:

$$Vrms = \sqrt{\frac{1}{T} * \int_{to}^{to+T} v(t)^2\ dt}$$

- A given Vrms AC has the heating (power) effect of a VDC with the same value.

RMS: Root-Mean-Square

*** RMS is a measure of a signal's average power. Instantaneous power delivered to a resistor is: $P = [v(t)]^2/R$. To get average power, integrate and divide by the period:**

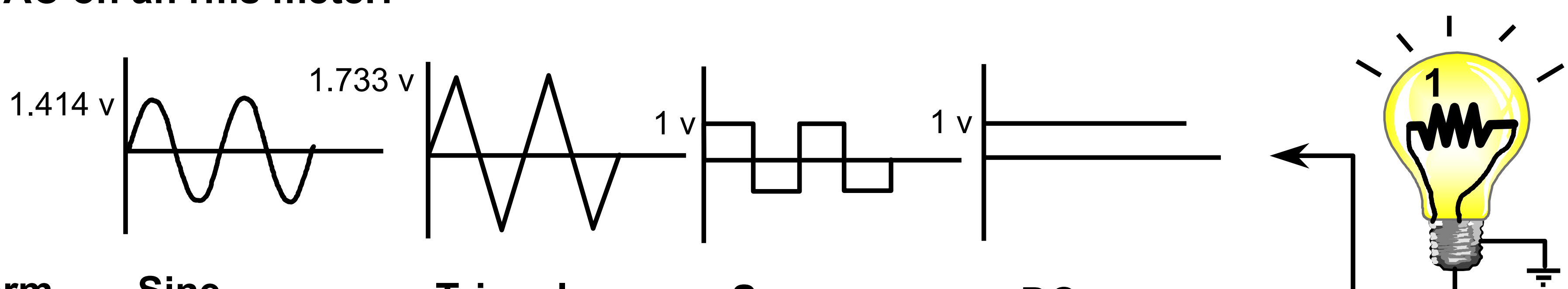
$$P_{avg} = \frac{1}{R}\left(\frac{1}{T}\int_{t_0}^{t_0+T}[v^2(t)]\,dt\right) = \frac{(V_{rms})^2}{R}$$

Solving for Vrms:

$$V_{rms} = \sqrt{\left(\frac{1}{T}\int_{t_0}^{t_0+T}[v^2(t)]\,dt\right)}$$

*** An AC voltage with a given RMS value has the same heating (power) effect as a DC voltage with that same value.**

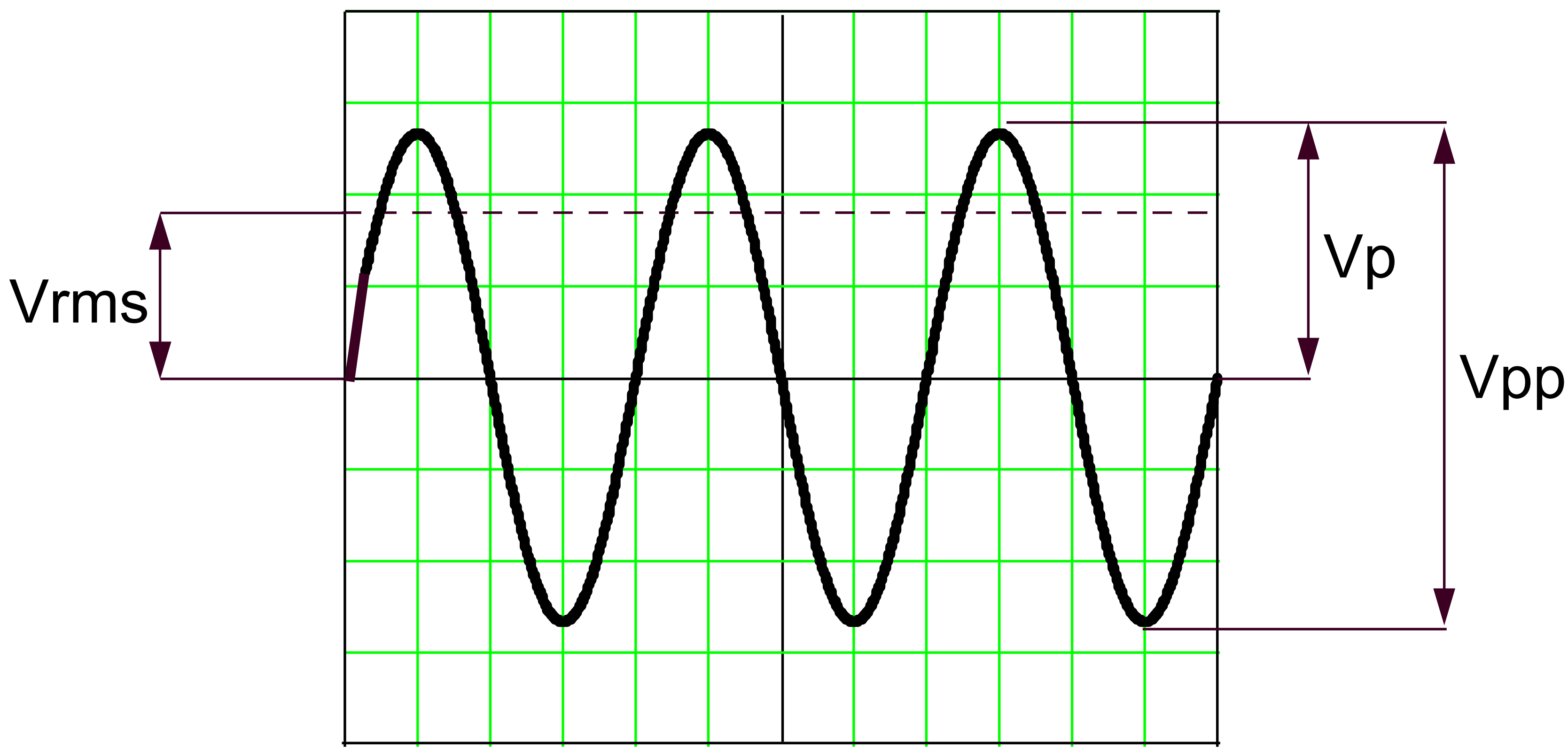
*** All the following voltage waveforms have the same RMS value, and should indicate 1.000 VAC on an rms meter:**



Waveform	Sine	Triangle	Square	DC
Vpeak	1.414	1.733	1	1
Vrms	1	1	1	1

All = 1 WATT

Peak to Peak



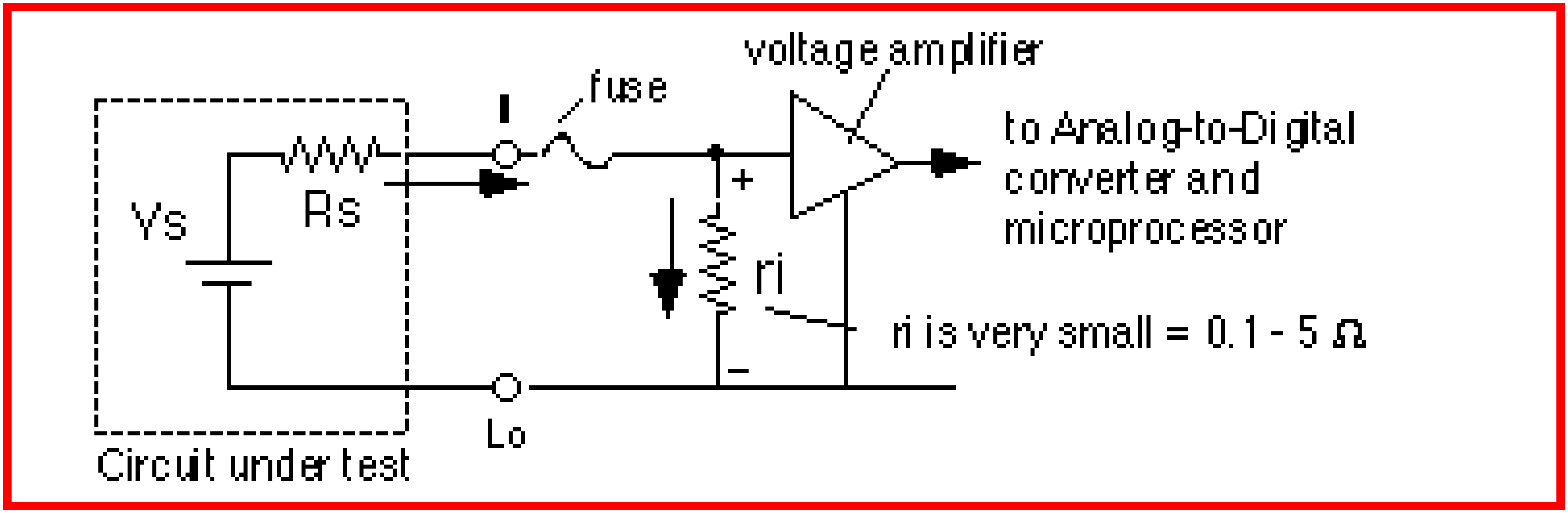
Vrms = Vp * .707 (Sine wave)

(2) Current measurement

Principle of the measurement

An ammeter senses the current flowing through its input terminals. The ammeter (or DMM) must be connected in *series* with the circuit such the same current flows through the DMM and the test circuit.

The principle of the current measurement is quite simple. The ammeter has a small resistance *ri* at its input terminals and *measures the voltage V* that the test current generates over this resistance in the following. The microprocessor then *calculates* the current, I=*V*/*ri*, according to Ohm's law.



Principle of DC current measurement.

To use the DMM as an ammeter, one connects the leads in which the current flows to the *current* (I) and LO terminals.

To activate the ammeter, one must also select the **DC I** key by pushing SHIFT and DC I button.

Error due to the non-zero input resistance

An ideal ammeter has a *zero* input resistance so that it does not disturb the current under test.

The *small* input resistance will cause a small voltage drop which gives a small error. Fortunately, the input resistance of the 34401A is pretty small (ri = 0.1ohm for 1 and 3 A range, and 5 ohm for the 10mA and 100mA ranges) and can, in most cases, be ignored as long as RS >> ri.

CAUTION:

Do not exceed the maximum allowable current input (3A DC).

Also, never apply a voltage over the current input terminal (I) of the DMM. This will cause a large current to flow through the small input resistor ri and can damage the DMM.

Measuring Current

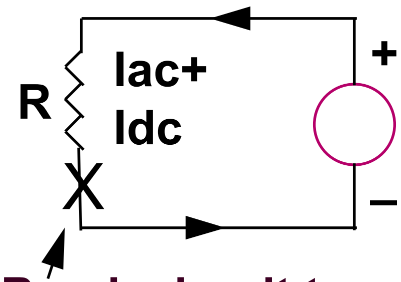
$$I = \frac{\Delta V}{r}$$

1.000000 ADC

SHIFT **DC I** **= Measure DCI**

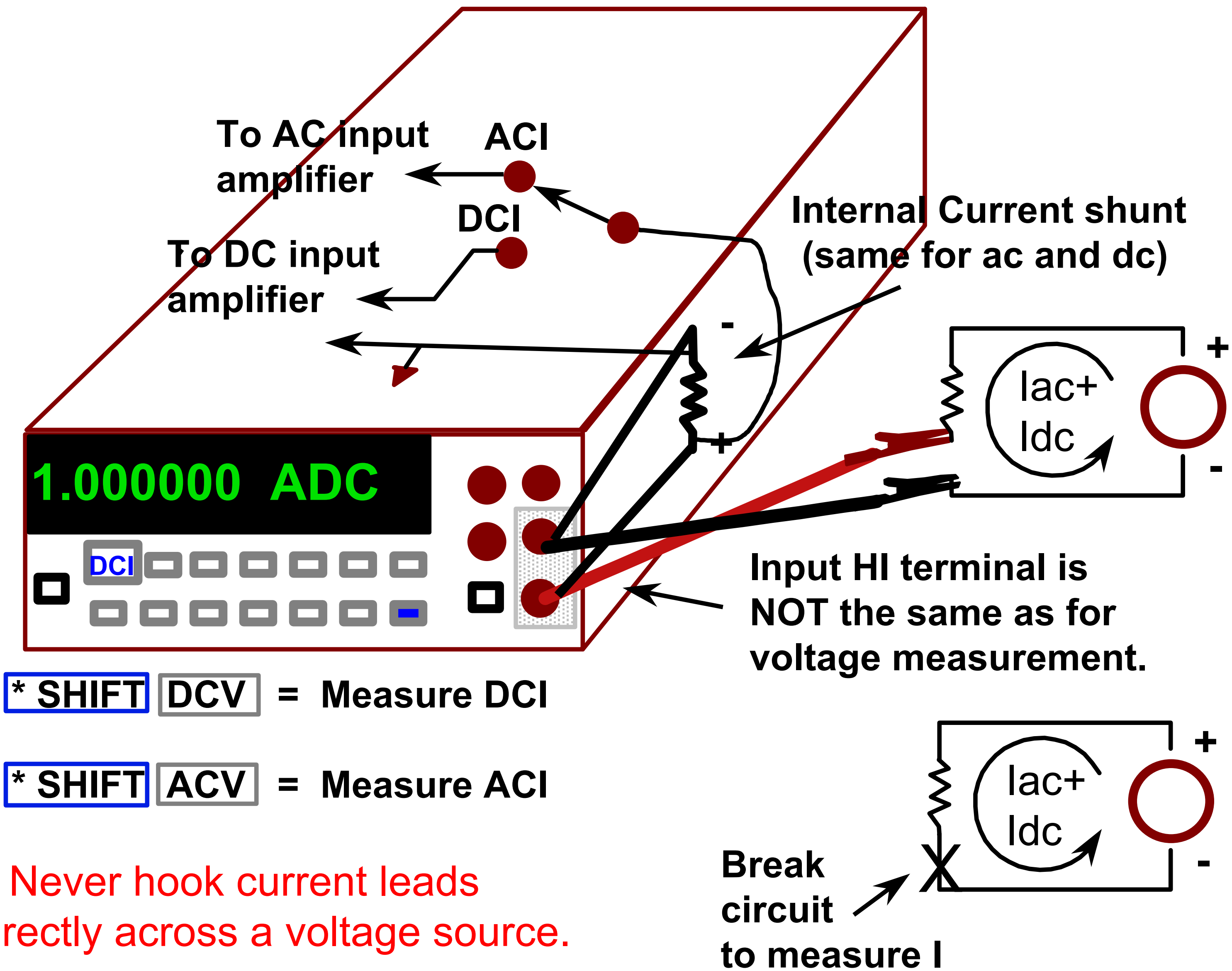
SHIFT **AC I** **= Measure ACI**

* **NEVER HOOK CURRENT LEADS DIRECTLY ACROSS A VOLTAGE SOURCE**



Break circuit to measure I

Measuring CURRENT



* SHIFT DCV = Measure DCI

* SHIFT ACV = Measure ACI

* Never hook current leads directly across a voltage source.

(3) Resistance measurements

Principle of 2 wire measurement

The DMM measures a resistance by applying a known DC voltage over unknown resistance in series with a small resistance Rm . It *measures the voltage* over the resistance Rm as shown in the following Figure (a). The DMM (remember the DMM has a built-in microprocessor) can then *calculate* the unknown resistance R.

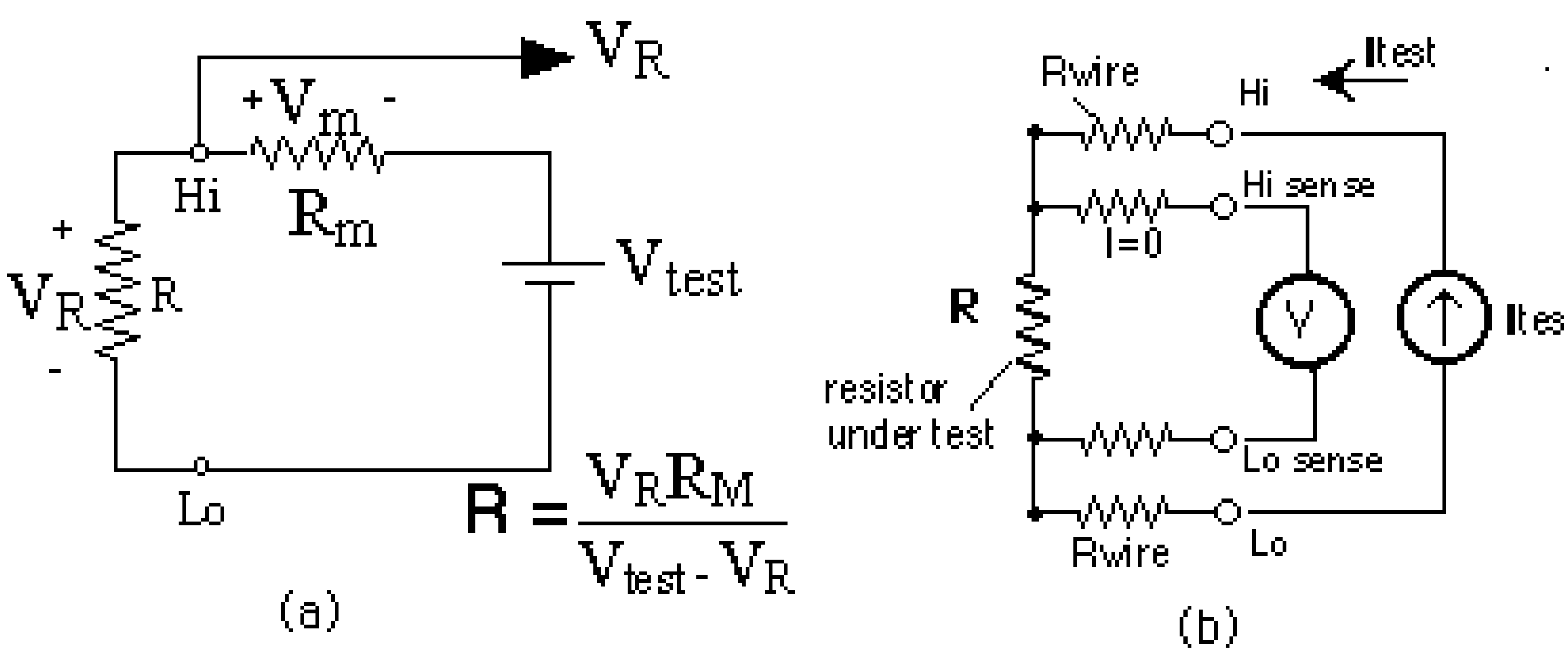
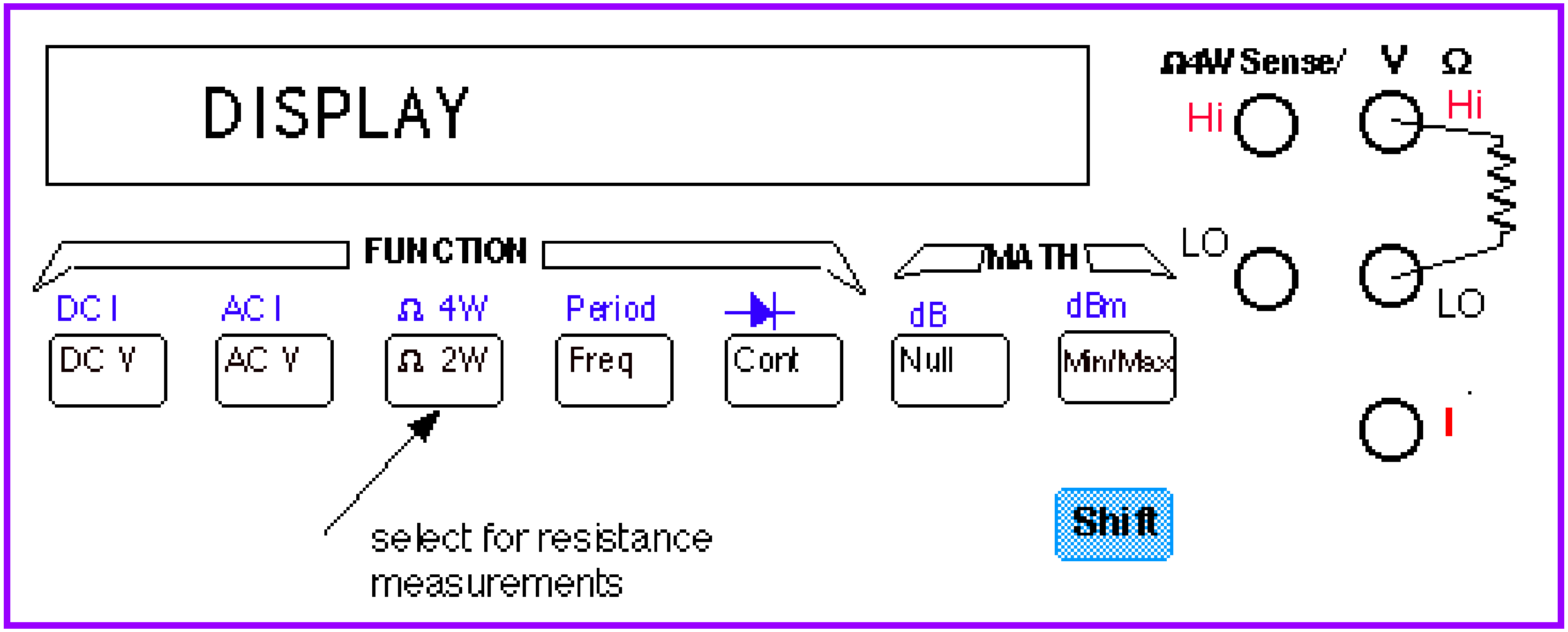


Figure (a) Two-wire resistance measurement; (b) four-wire measurement.

To use the DMM for resistance measurements, connect the resistor to the terminals labeled **HI (V Ω)**and **LO**, select the resistance measurement function by pushing the **[Ω]** button (one of the function keys) on the front panel as shown below.

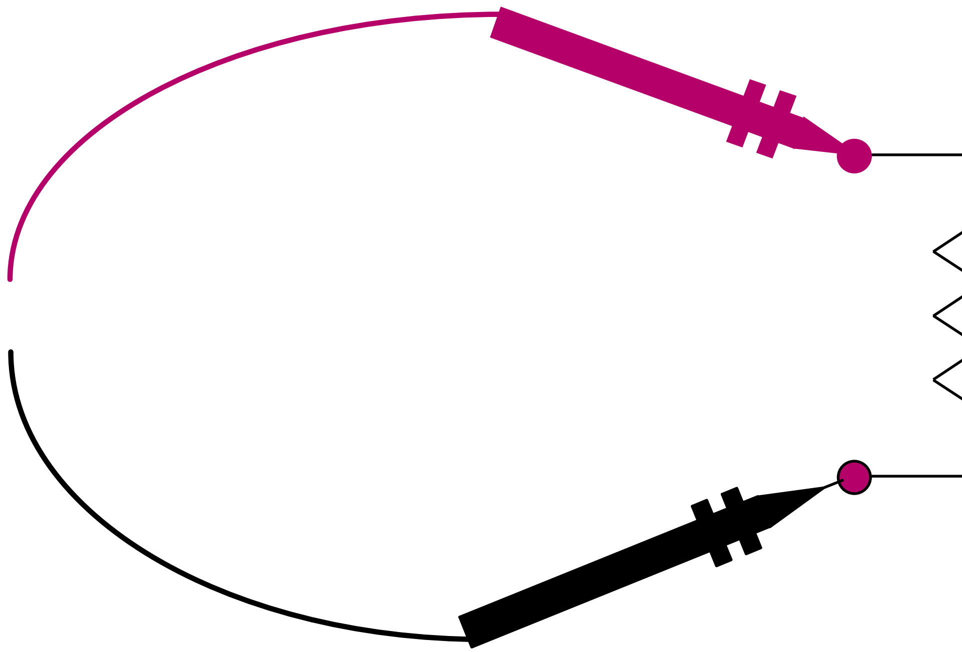
Notice that the selection keys are annotated in black and blue. To select the function in blue, you must first select the blue **SHIFT** key.



Function buttons to select
resistance, voltage, current or frequency

Measuring Resistance 2-wire

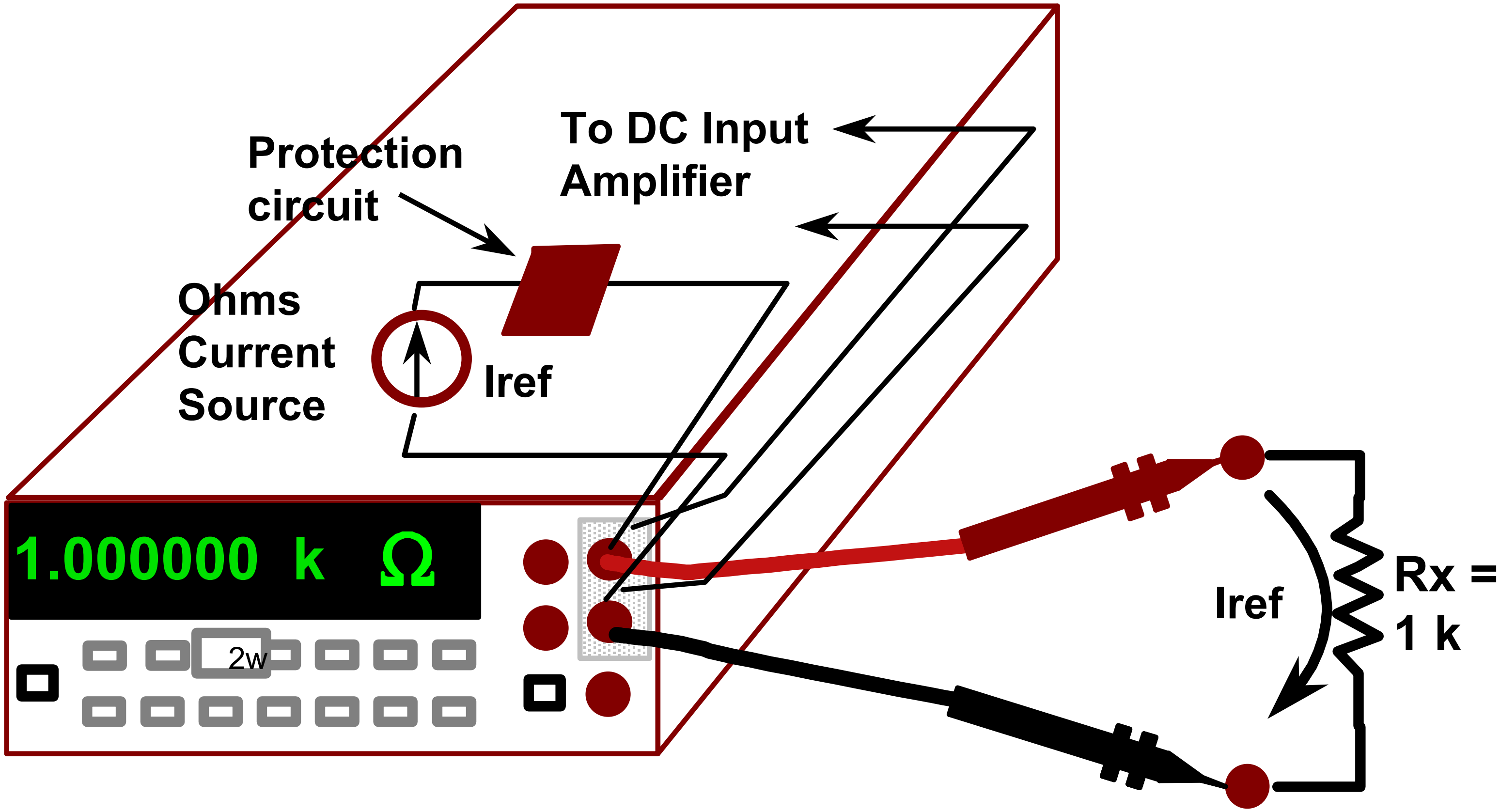
1.000000 kΩ



- Press **Ω 2W**
- Resistance measured includes lead resistance

*To eliminate the lead resistance:
- Short leads together
- Press **NULL**
- Lead resistance will be subtracted from reading

Measuring Resistance
Two-Wire Technique



*"Terminals" switch in "FRONT"

* Press 2W
* Since voltage is sensed at front terminals, measurement includes all lead resistance

* To eliminate the lead resistance:
* Short leads together
* Press **Null**
* Original value will now be subtracted from each reading

Small Resistance Measurement

Measurement errors and NULLing function

When one measures the value of a resistor one connects the resistor to the DMM input terminals using cables.

If the resistor one measures is very small, it is possible that the resistance of the cables themselves are comparable or even larger than the resistance of interest.

The 34401A DMM has a handy way to overcome this problem by using the NULL feature. The front panel of the DMM has a button labeled **NULL**. To null the wire resistance, one *shorts* the ends of the test wires together and then presses the NULL button. You can disable the NULL function by pushing the button again.

The 4-wire method

For really accurate measurements of small resistances, there is a clever method one can use: i.e. the 4-wire method, as shown in the following figure.

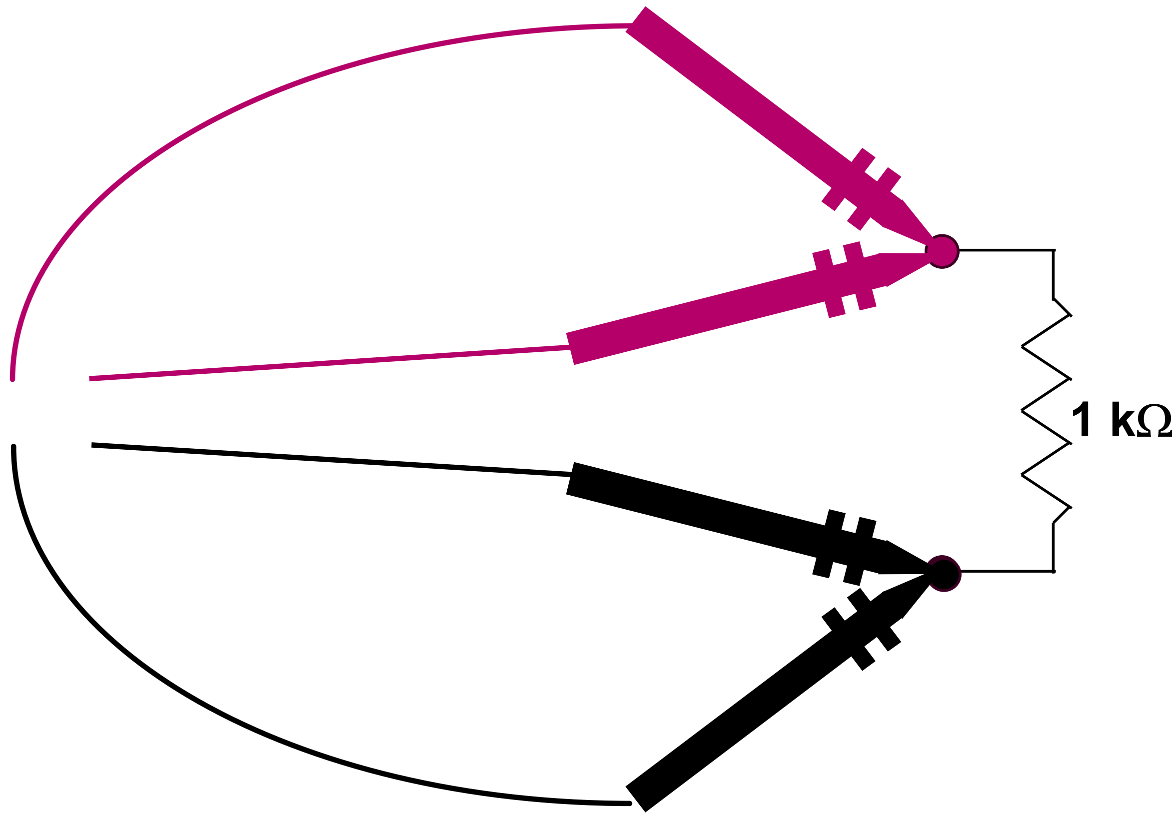
The DMM supplies a test current through the resistor, as in the 2-wire method, but measures the voltage over the resistance with two other terminals. The two leads used for the voltage do not conduct any current, so that the *lead and contact resistances do not influence the measurement*. The **four terminals** for the 4-wire method are shown on the front panel.

CAUTION:

When doing a resistance measurements, it is **safest to disconnect all voltage sources** before connecting the DMM to the circuit. Putting a large voltage over the input terminals of the DMM may **damage the meter**.

Measuring Resistance 4-wire

1.000000 kΩ

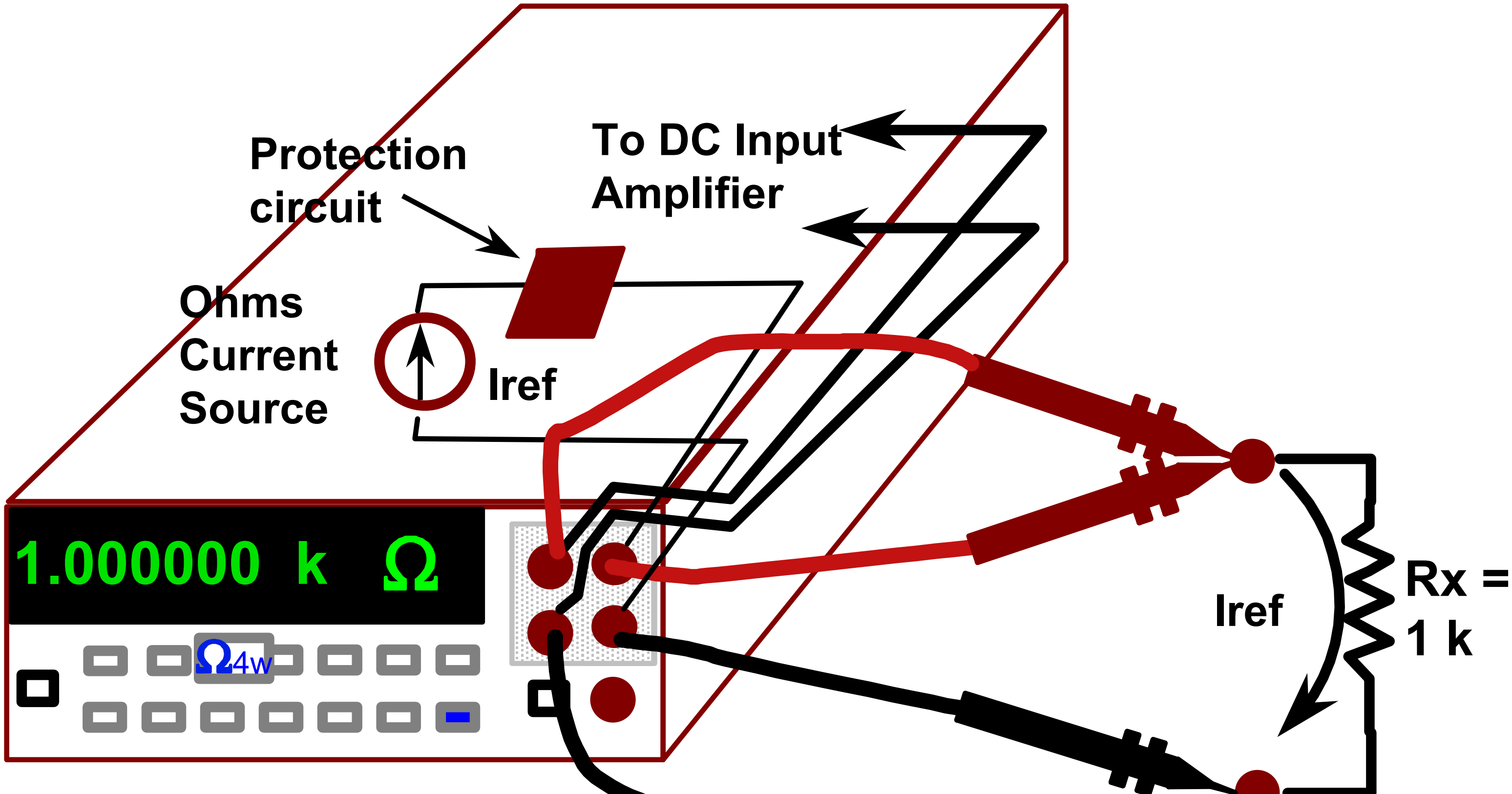


* Turn off "Null"

* Press SHIFT Ω4W

* No error due to lead resistance

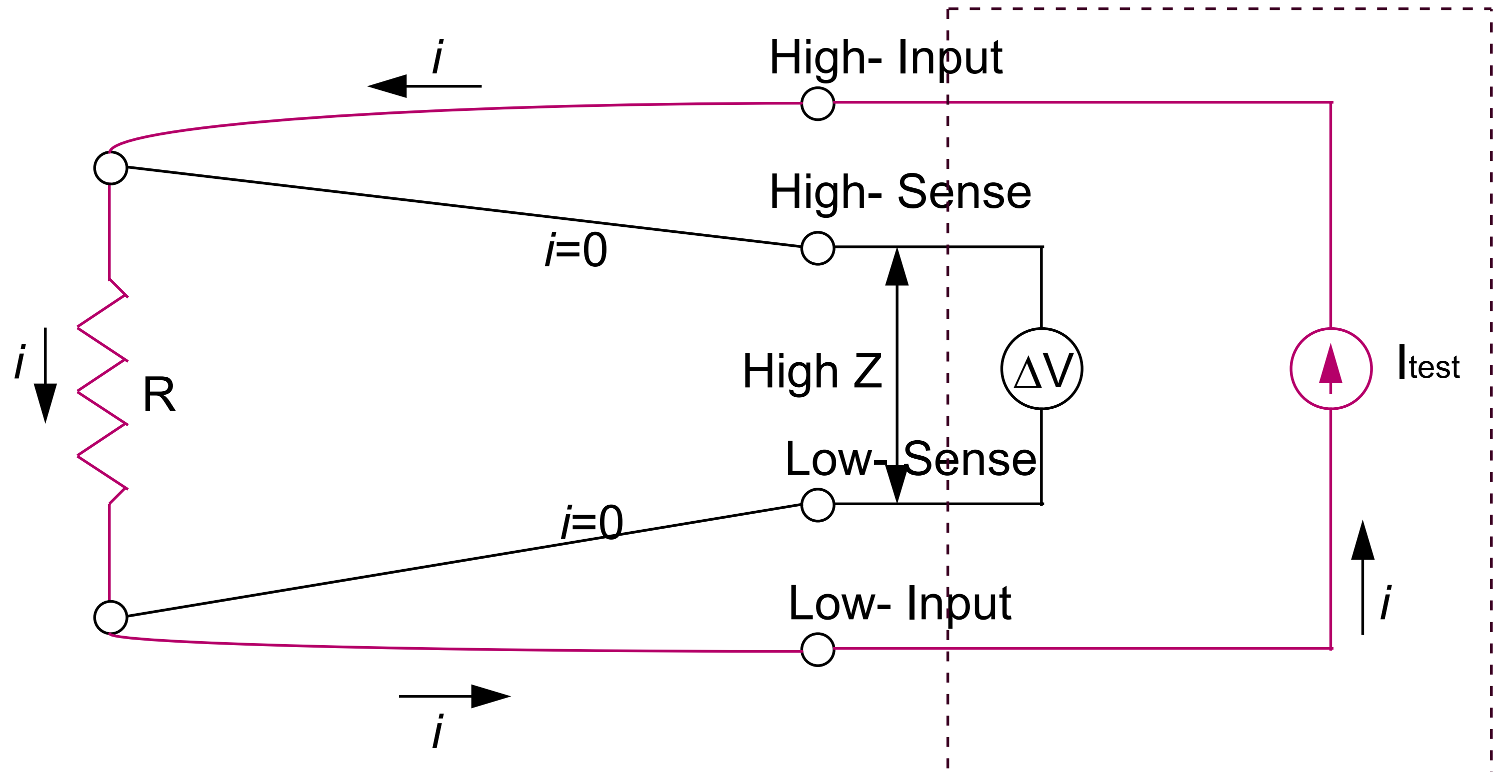
Measuring Resistance
Four-Wire Technique



* Turn off "Null"
*"Terminals" switch in "FRONT"
* Press ▬ 4W
* Voltage is now sensed directly at the resistor, so lead resistance is not a factor

* Because input impedance of DC Input Amplifier is so high, no current flows through sense leads, hence no lead resistance error

4-Wire Resistor Measurement



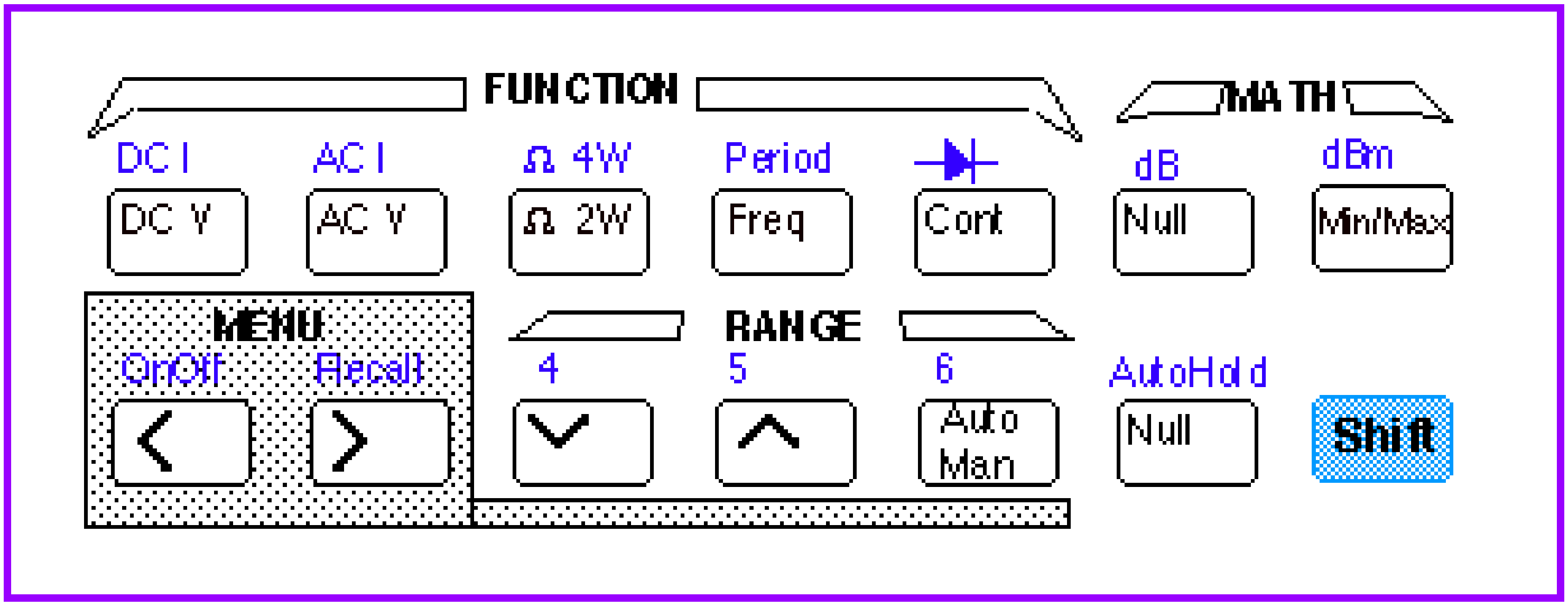
$\Delta V = I_{test} * R$

$$R = \frac{\Delta V}{I_{test}}$$

Range *selector*

The multimeter *automatically* selects the range using the auto-ranging feature.

However, you can also *manually* select a fixed range (e.g. 1KOhm or 1MOhm) using the **Auto/Man** button on the front panel (under Range/Digits) buttons. The **'down'** arrow selects the lower range and the **'up'** arrow the higher range.



Function, Math, Range and Menu keys

Additional features of the 34401A:

average, max and min value

One often needs to take a series of data points to find the **average** value of the measured variable. Instead of doing this by hand, the 34401A has a built-in feature that does this for us. Also, you can ask for the **maximum** and **minimum** values during the measurement interval.

To enable this feature, push the **Min/Max** button (one of the Math buttons) on the front panel. You will see the *Math* annunciator lit on the front display. Also, the DMM will make short beeps indicating it is taking readings and storing the MAX, MIN, the Average value, and the total COUNT.

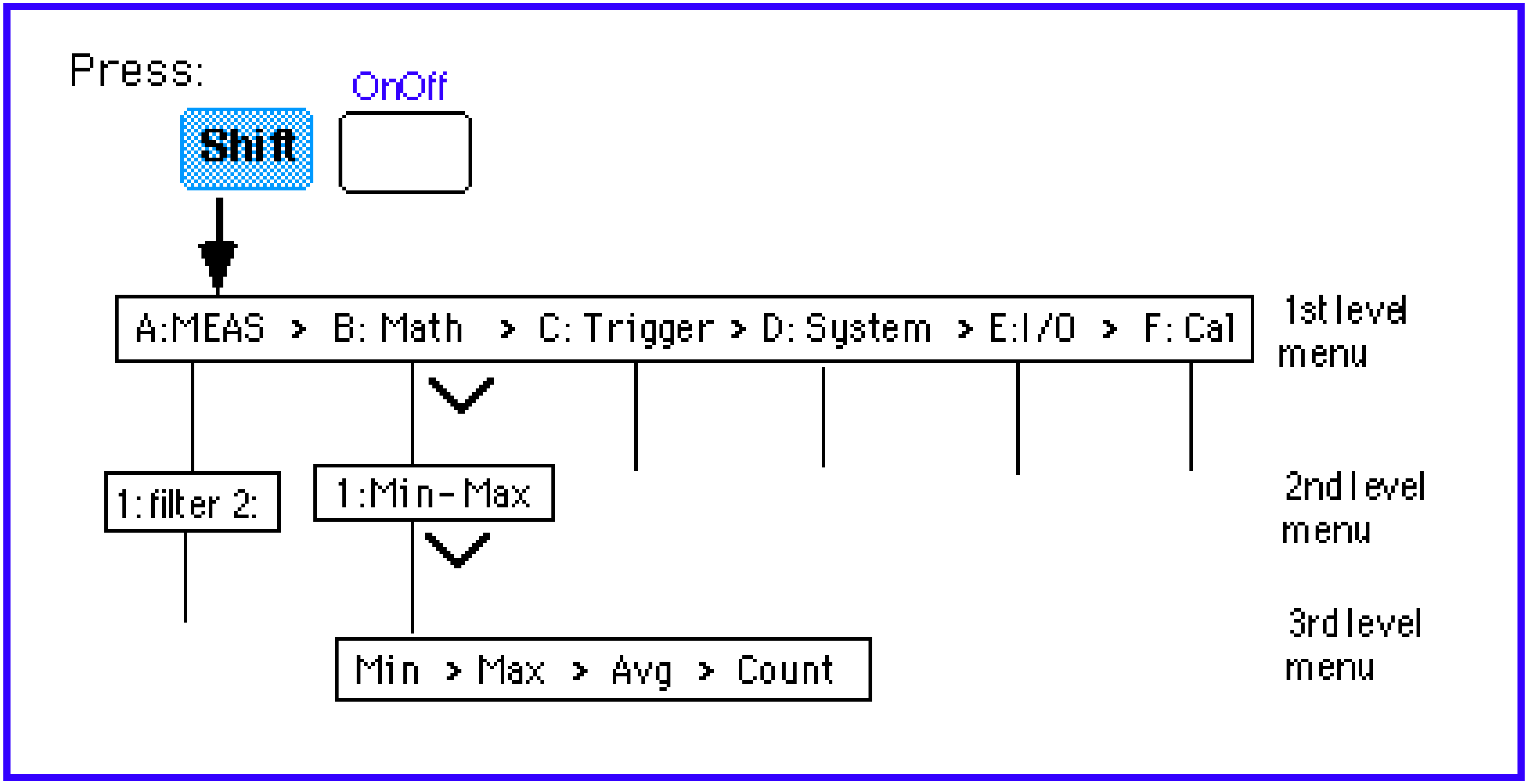
Push the Min/Max button again to stop the readings.

To access these stored numbers, you have to turn the Menu on by pressing the On/Off key (**SHIFT <**) on the front panel.

Then, use the **>** or **<** keys until you are in the MATH (B) menu. You can now *go down* to the "parameter level" of the selected MIN-MAX menu by pressing the "down" button until you see the desired parameter menu (1:MIN_MAX) displayed. Push once more the "down" button.

Once you are in the MIN-MAX menu you can use the > or < buttons to *scroll* through the menu and read the values.

The menu is organized in a top-down *tree structure* with three levels, as schematically shown in the following.



The front panel menu organization.

The MIN-MAX feature can be used for **resistance** measurements as well as for **voltage**, **current**, and **frequency** measurements.

Power rating of resistors

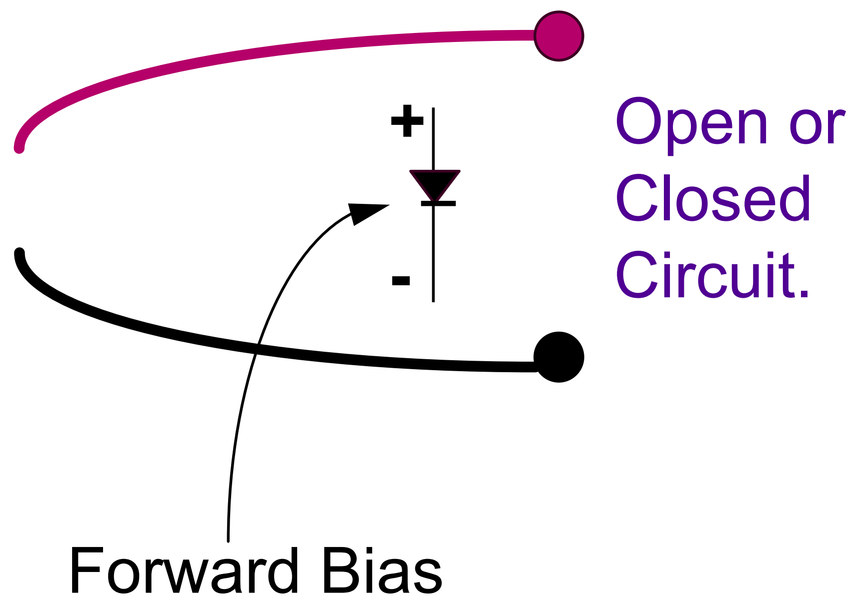
In addition to the value and tolerance of a resistor, the power rating is another important characteristic. It tells how much power the resistor can dissipate before being damaged by overheating. Resistors come in different power ratings: 1/8, 1/4, 1/2, 1 and 2 Watts are typical values.

Lets look at an *example*.

Suppose you are using a 1 kohm resistor with a 0.25W power rating. The maximum DC voltage and current the resistor can tolerate is than Vmax=sqrt(P.R)=15.8V and Imax=sqrt(P/R)=15.6mA.

Exceeding the power rating will result in poor reliability and early break-down of the circuit. The power rating depends on the physical size of the resistor, the larger the size, the larger the power rating will be.

(4) Continuity Test
& Diode Check

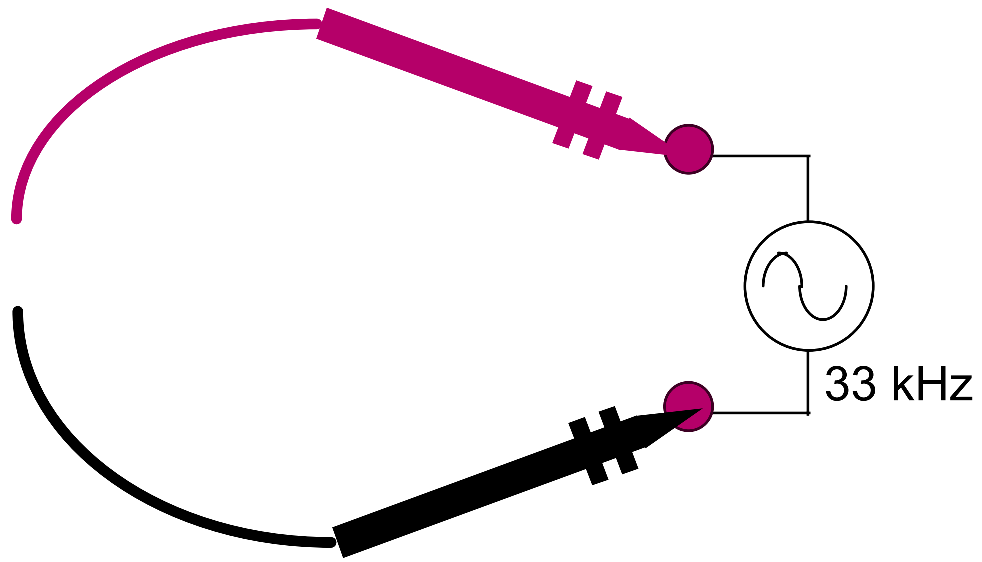


Cont = Continuity test

Shift [diode symbol] = Diode check

(5) *Measuring Frequency* & *Period*

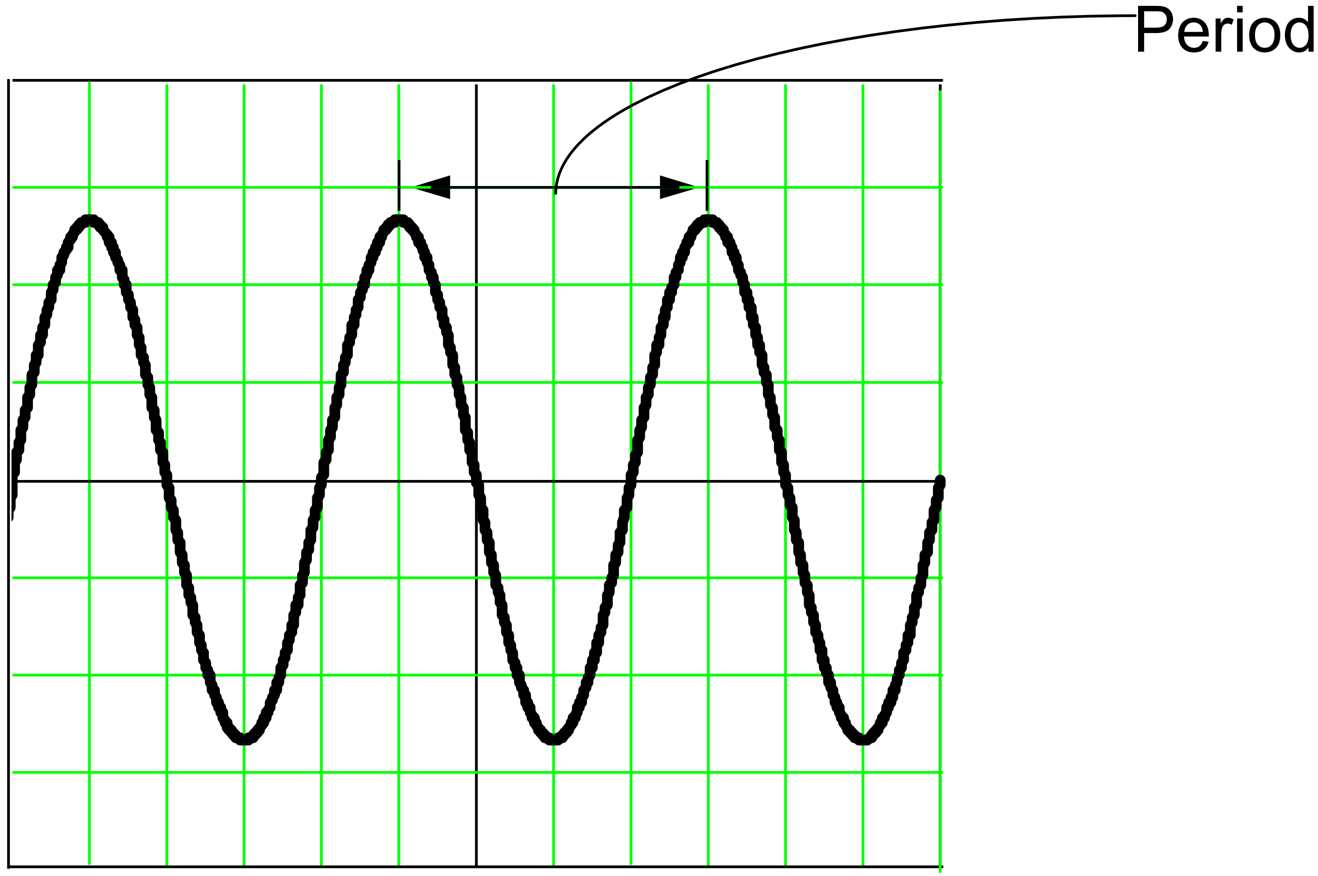
33.000,0   kHz



Freq = Measure Frequency

Shift Period = Measure Period

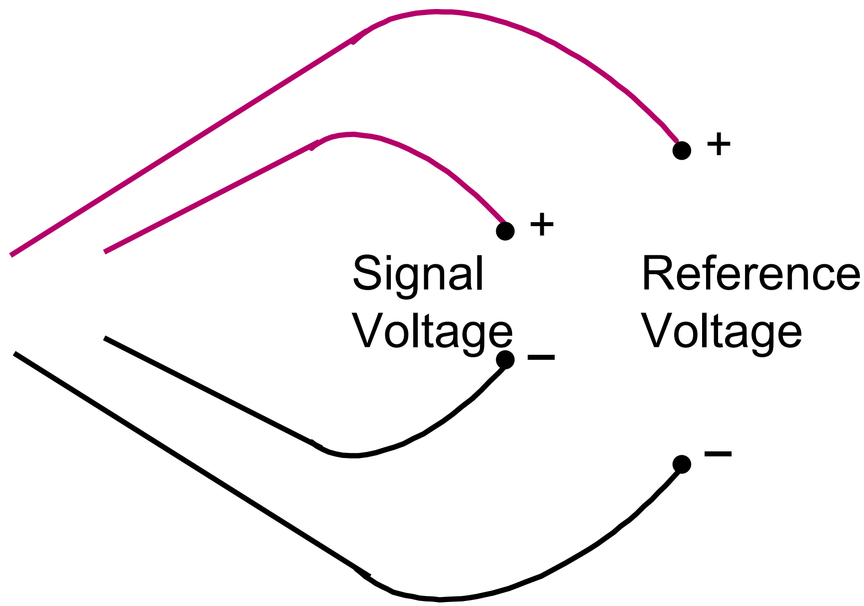
Frequency and Period



Frequency = 1/Period

(6) Ratio Measurements

DCV : DCV



$$\text{Ratio} = \frac{\textit{dc signal voltage}}{\textit{dc reference voltage}}$$

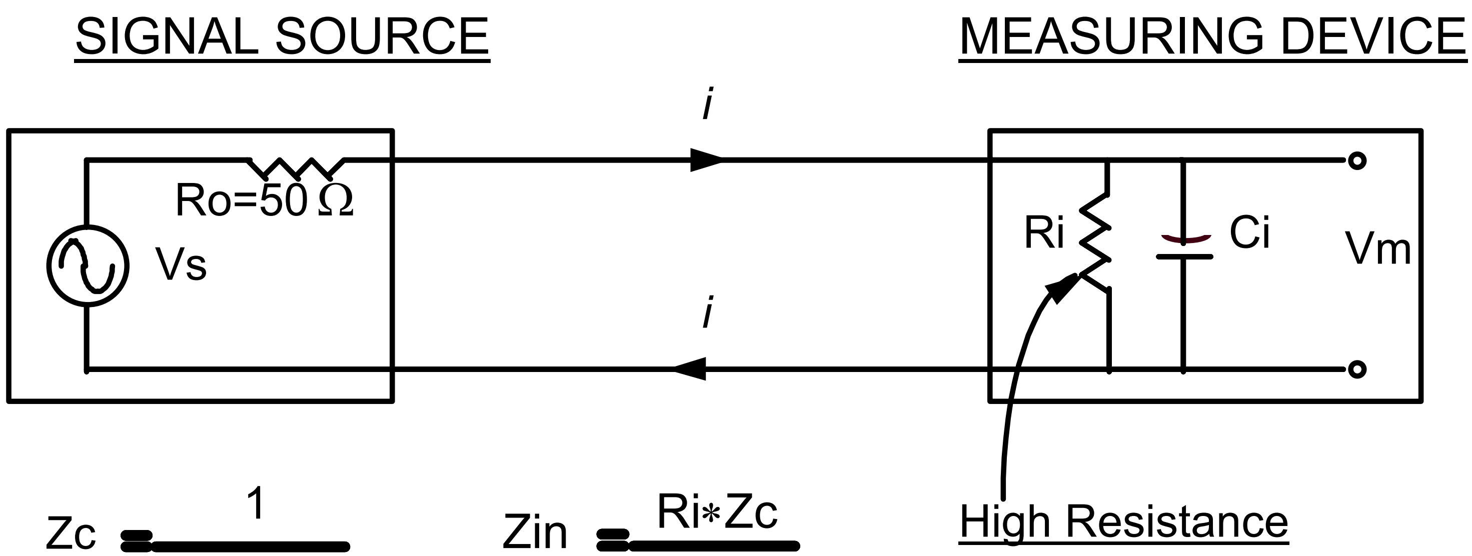
*To enable ratio measurements, use the MEAS menu.

Voltage RMS vs. Peak

Waveform	Vrms	Vp
sine	1.0	1.414
triangle	1.0	1.733
square	1.0	1.0
DC	1.0	1.0

* Peak voltage = 1/2 of Peak to Peak voltage

High Z Termination



$$Zc = \frac{1}{j\,2\pi f\,C}$$

$$Zin = \frac{Ri * Zc}{Ri + Zc}$$

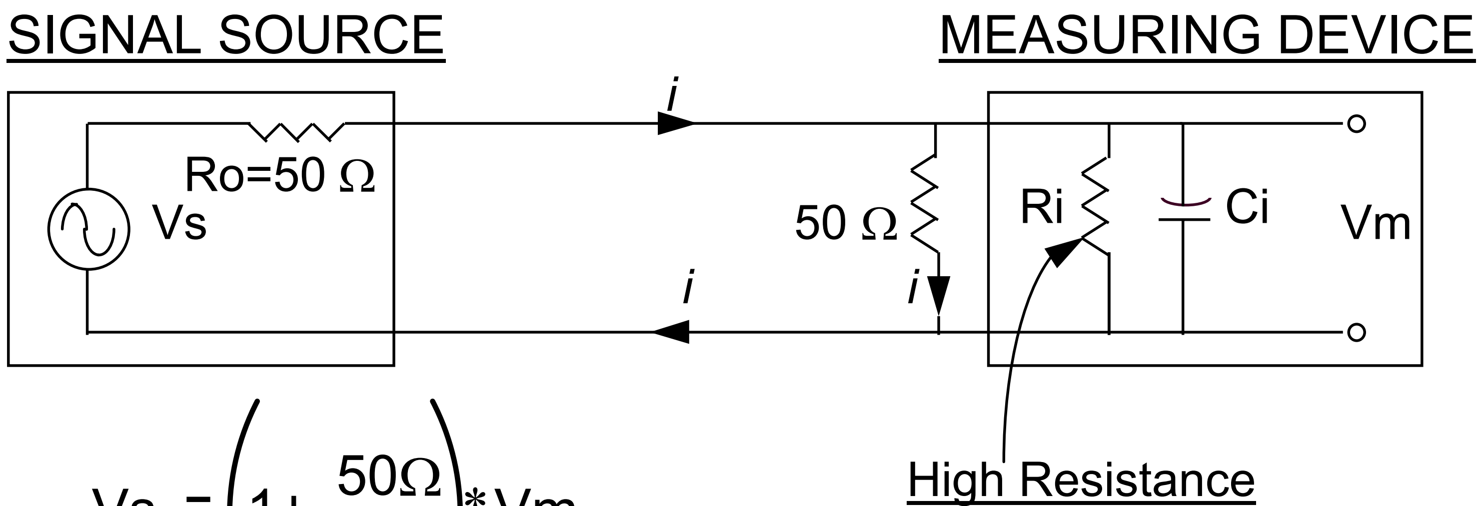
$$Vs = \left(1 + \frac{Ro}{Zin}\right) * Vm$$

. . . . for very large Zin, Vs $\cong$ Vm

As frequency increases, Zin decreases

For less than 1% error Zin $\geq$ 100 Ro

50 Ω Termination



$$Vs = \left(1 + \frac{50\Omega}{50\Omega}\right) * Vm$$

$$Vs = 2 * Vm$$

$$Vm = \left(\frac{1}{2}\right) * Vs$$

*Vm will not equal Vs, if Zin = Ro, but the ratio between them is 2:1.

- **Specifications (34401A)**
- **DC Characteristics**:
  - DC Voltage range and input resistance:
    - 0.1V, 1V, 10V: input resistance selectable 10MW or > 10GW
    - 100V and 1000V: Rin = 10MW
  - DC Current range and shunt resistance:
    - 10mA, 100mA: Rshunt= 5 W
    - 1A and 3A: 0.1 W
  - Resistance range: 2-wire and 4-wire method
    - 100 W, 1 kW, 10 kW, 100 kW, 1 MW and 100 MW
    - Input protection: 1000V
- **AC Characteristics**: true RMS
  - AC Voltage: from 3 Hz to 300 kHz (for accuracy specs consult the manual)
  - AC Current from 3 Hz to 5 kHz
- **Frequency and Period** measurement:
  - Frequency range: 3 Hz - 300 kHz
- Input voltage range: 100 mV to 750 V

Remote Interface

GP-IB (IEEE-488) Address:

Can be any value between 0 - 31. Factory set at 22.

Address 31 is talk only mode.

Adjustable only through the I/O menu.

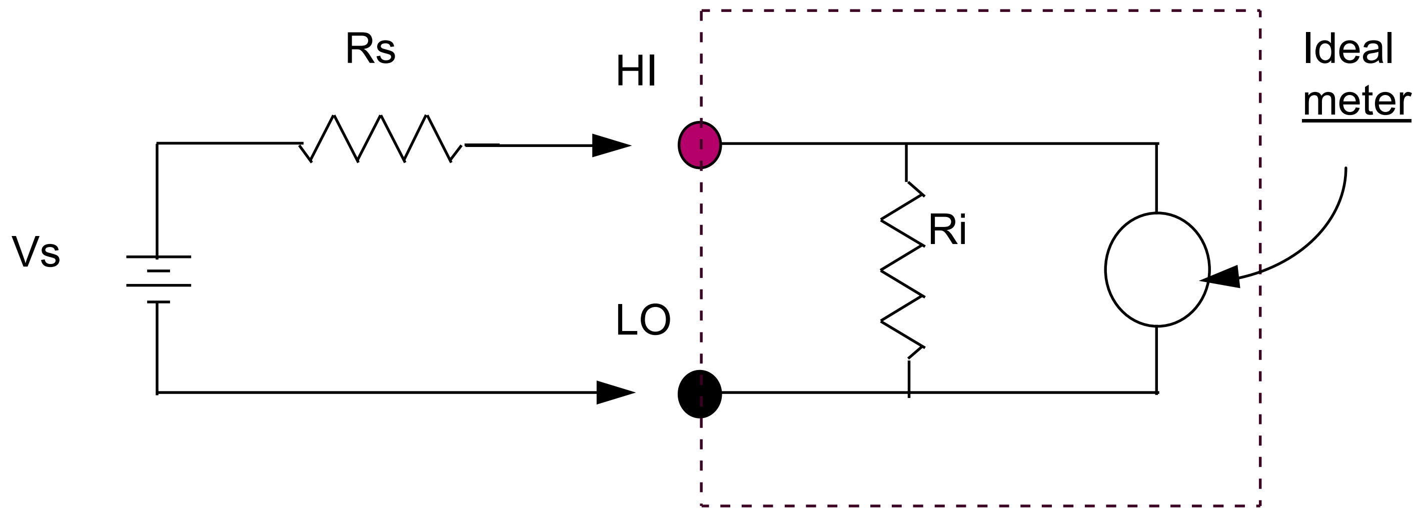
RS-232 Interface:

Baud rate must be selected (I/O menu): 300, 600, 1200, 2400, 4800, or 9600.

Parity selection (I/O menu): Even or Odd

Programming Languages	GP-IB	RS-232
SCPI Language	✓	✓
HP 3478A Language	✓	Not allowed
Fluke 8840A Language	✓	Not allowed

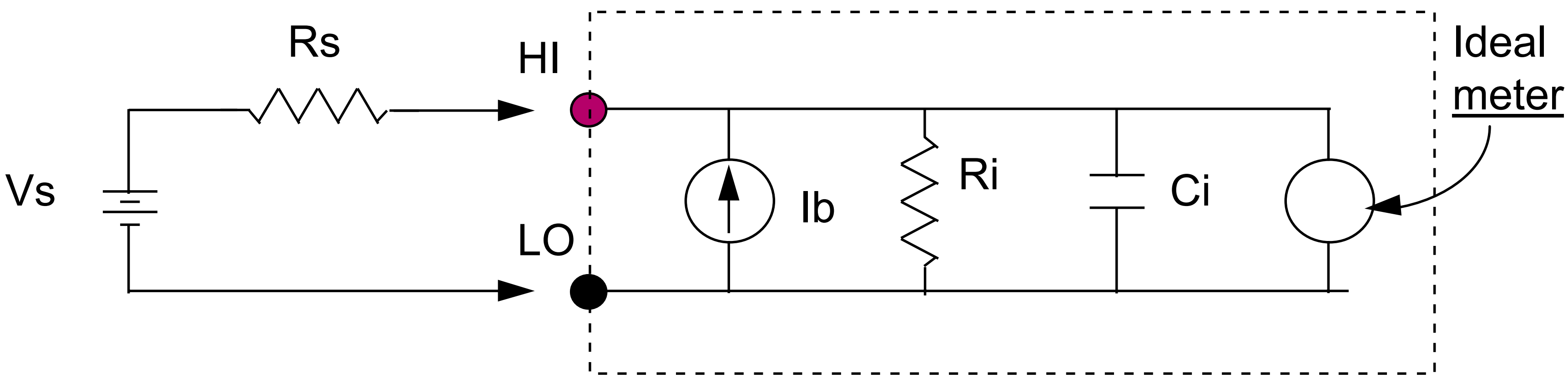
Loading Errors (DC volts)



Vs = ideal DUT voltage
Rs = DUT source resistance
Ri = multimeter input resistance
(10 MΩ or > 10 GΩ)

$$\text{Error}(\%) = \frac{100 * Rs}{Rs + Ri}$$

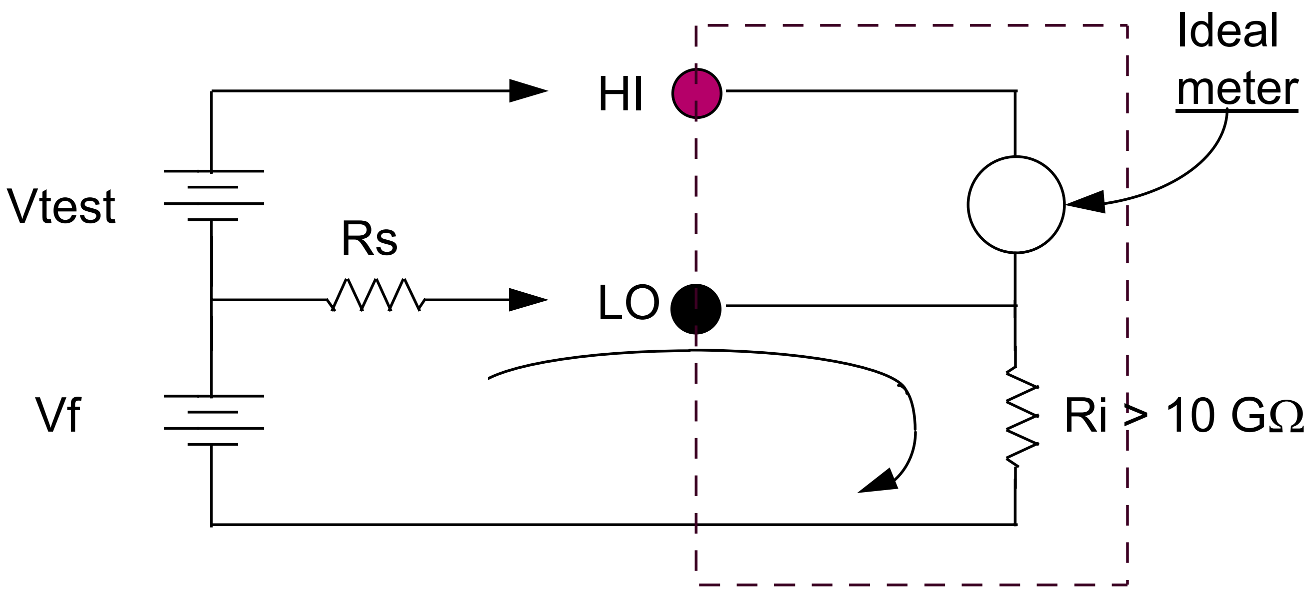
Leakage Current Errors



Ib = multimeter bias current
Rs = DUT source resistance
Ci = multimeter input capacitace

Error(v) $\cong$ Ib $*$ Rs

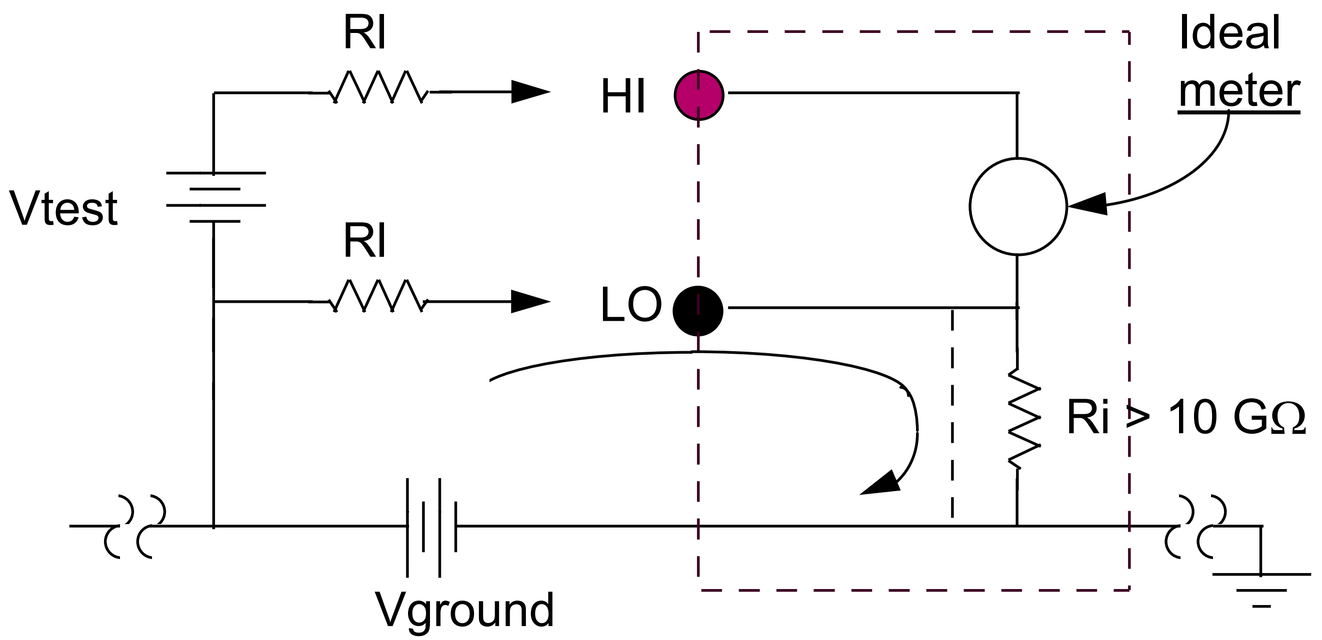
Common Mode Rejection (CMR)



Vf = float voltage
Rs = DUT source resistance imbalance
Ri = multimeter isolation resistance

$$\text{Error(v)} = \frac{Vf * Rs}{Rs + Ri}$$

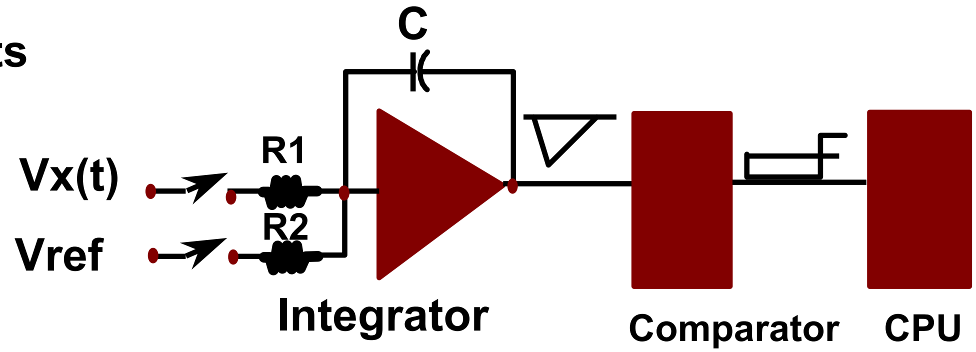
Noise caused by Ground Loops



Rl = lead resistance
Ri = multimeter isolation resistance
Vground = voltage drop on ground bus

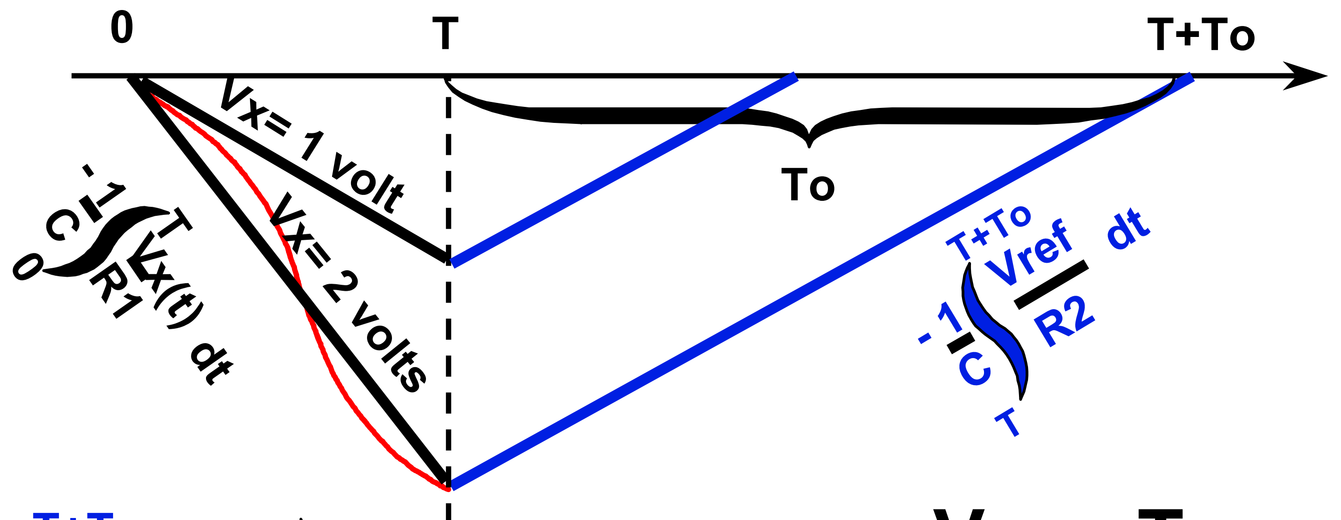
Integrating A/D

1) Converts voltage to time to digits
2) Integrator is a
   line-frequency filter
3) Integrator is
   a low-pass filter



Integrator:

$$Vout = -\frac{1}{C}\int_0^T i(t)\,dt$$



If R1=R2 ⇒ $\int_0^T Vx\,dt = \int_T^{T+To} -Vref\,dt$ ⇒ $T*Vx = To*(-Vref)$ ⇒ $\frac{Vx}{-Vref} = \frac{To}{T}$

T is fixed at one cycle of 50 Hz or 60 Hz to eliminate line noise; Vref is fixed; R, C and Time are all ratioed, so accuracy is excellent.

The DIGITAL MULTIMETER

Hints for Accurate Measurements:

- ☞ Measure as near full scale as possible
- ☞ Use a Ratio measurement whenever Possible **(Measure a RATIO rather than an absolute value)** .
- ☞ Before measuring, short the test leads together to check for offsets.

(Exception: RMS AC measurements)

Where to get more information

- ☞ 34401A User's Guide
- ☞ 34401A Service Guide