



EECS 210: Electrical Engineering I

Laboratory Manual

By: Prof. Gabriel M. Rebeiz
The University of Michigan
EECS Dept.
Ann Arbor, Michigan

Introduction:

This laboratory manual combines six experiments designed to introduce you to the world of electronics and electrical signals. We will concentrate on applications to audio circuits. Please approach the labs with curiosity and a "what if ...?" approach. Ask questions and try other circuits if you wish (keeping always safety in mind).

Laboratory Safety:

The voltages and currents encountered in your experiments are not dangerous. You will, however, be working with laboratory equipment connected to the 120 V, 60 Hz AC voltage. This voltage can be lethal under certain conditions. It is therefore extremely important that you observe safe laboratory procedures at all times and follow the instructions carefully.

- Immediately report all dangerous conditions (stripped 120 V, AC lines; sparks in laboratory equipment; loose wall socket; ...) to your laboratory instructor. Report any condition even if you are not sure of the hazardous level.
- For fire, medical, police, notify your laboratory instructor or call 911.
- No student is permitted in the lab alone at any time. The student must be accompanied at all times by a laboratory partner and/or the laboratory instructor. This rule is observed for regular and make-up lab sessions.
- If any equipment breaks, please report it immediately to the instructor.
- Any student who knowingly imposes a dangerous electrical situation on himself, other students or the lab instructor (ex.: stripping 110V lines; electrocuting himself or other students, ...) will be denied access to the laboratory and will receive a failing grade in the class (F).
- Remember: Safety, Safety, Safety! When in doubt, ask your instructor and do not touch it!

Honor Code:

The Honor Code applies to all laboratory work, which means the pre-lab preparation, the experiments and the final lab report. You are expected to include the following Honor Code statement on all your work:

"I have neither given nor received aid on this report, nor have I concealed any violation of the Honor Code."

Collaboration Policy:

You are encouraged to work with your laboratory partner and/or with a group of friends on the pre-lab, lab-reports and homework problems. However, you cannot copy the work of anybody else (enrolled in the class or not). You must write your own work without looking at anybody's work. You are allowed to help (or receive help from) your colleagues in the form of discussing the work, explaining the problem and even telling (or learning) in detail how to solve a problem (verbally with few sketches). But you cannot copy the final (or near final) work of anybody.



Grading Policy:

Laboratory	20%
Quiz I	20%
Quiz II	20%
Final Exam	30%
Homework	10%

The grading policy of each lab is:

Pre-Lab Report	25%
Data Taken in Lab	25%
Post Lab Reports	50%

Important Rule:

Any student missing a lab (not present in the lab) with no proper or reasonable excuse will get a "0" grade on that specific lab and will have his/her final letter grade reduced by a full letter (for ex.: A⁻ → B⁻). Any student missing two labs with no proper excuse will automatically get a failing grade (F) on the entire course.

Laboratory Procedures:

This laboratory manual combines six experiments designed to introduce you to the world of electronics and electrical signals. We will concentrate on applications to audio circuits. Please approach the labs with curiosity and a "what if ...?" approach. Ask questions and try other circuits if you wish (keeping always safety in mind).

The experiments are designed to be performed within the 3-hour laboratory time. During each laboratory period, you will be expected to carry out one experiment, to record the experimental data, to make a few computations to determine how it agrees with expectations, perhaps plot some graphs, and then answer some questions concerning the experimental work. The laboratory instructor will then sign on your notebook before you leave the lab. You will then prepare the final lab report which is due one week after your lab session. To successfully complete the experiments in one lab period, you must come prepared to the laboratory. You should read the experiment in advance and answer the pre-lab questions. The pre-lab counts for 25% of the lab grade and must be turned in at the beginning of the lab. Also have the following:

- 1) Your notebook (numbered pages).
- 2) An INK pen (color is a plus).
- 3) A calculator capable of *sin*, *cos*, *log*, *Ln*, *e^x* functions.
- 4) A ruler!

All engineers use exclusively ink and lab reports with numbered pages. This is extremely important in companies where patent issues and prior work or knowledge of work may be challenged in a court of law at anytime. So, it is good for you to start learning the correct way to handle data. If you make a mistake, neatly cross it out and continue on. If a graph is incorrect, cross it out too with a large X, put a line and continue. No points will be deducted for a crossed out material, as long as it is neat. However, lab reports with hash marks all over the



place, data presented in haphazard fashion and general sloppiness will suffer as much as 50% penalty (in severe cases) on the final grade.

The following guidelines will result in a good lab report:

1. Always put a Unit (V, A, Hz, ...) after every input or answer. Underline or circle your answer.
2. Always label the axis on a graph and put the units too.
3. When using an equation, write it out first in analytical form (Ex.: $R_p = R_1R_2/(R_1 + R_2)$) and then substitute the data.
4. Sketch a circuit diagram neatly and label the component values.
5. Sketch an experimental diagram and label the equipment used.
6. Comment on the agreement or lack of agreement with the calculated values. Also comment if the measured results are unexpectedly too high or too low. It is rather o.k. to have done an unsuccessful experiment (I do it all the time) but it is NOT o.k. to accept the data as it comes without thinking about it, questioning if it makes sense, and knowing finally what went wrong!

An important note: Sometimes the experiment is done correctly but you end up having to make the difference between two large numbers which are very close to each other (Ex.: $2.772V - 2.771V = 1\text{ mV}$). The 1 mV difference could be read as 0-3 mV due to equipment limitation (accuracy). If this voltage is divided by 0.1 mA for example, the answer could change from 0-30 Ω ! So, be careful of the data you take, of the change in the data and of the resolution or accuracy of your measurement equipment.

In the lab report (due one week later), you are asked to further analyze your results, answer few questions and calculate few things. The lab report should not be long (around 4 pages) and should be written in your lab notebook (stick graphs with glue into lab notebook). Please write down any special difficulties you encountered in the lab and your suggestions for any improvements (highly appreciated).

Laboratory Experiments:

The laboratory procedures will be as follows:

1. **Pre-Lab:** Due the date of the laboratory. Each student submits his/her own copy of the pre-lab and signs the Honor Code.
2. **Experiment:** The student works with a partner and they both take the data in separate notebooks. All laboratory data will be written in INK on a laboratory notebook. The lab notebook must have numbered pages and be the kind to which pages cannot be added. The lab instructor will look at the data and sign on your notebook at the end of the experiment.
3. **Laboratory Report:** A short lab report is due exactly one week later in the lab. Each student will write his/her own lab report on the notebook and sign the Honor Code.

You have only 6 laboratory experiments, down from 10-12 in EECS 216. However, these experiments are a bit more involved and require that you learn quickly how to use the measurement equipment. Therefore, the first two experiments are crucial to your success in the lab! They are designed to teach you the various equipment we use and how to measure voltage, current, time, frequency,

Laboratory #1: Check the validity of KVL and KCL equations. Learn how to use the equipment. Use the oscilloscope to display signals in time and frequency domains.



- Laboratory #2: 1. Test a battery and measure its internal resistance.
2. Test a touch-tone telephone keypad and determine the frequencies sent when you press 1, 2, ... 0, #, *.
- Laboratory #3: Test an audio power amplifier and measure its transfer function (gain vs. frequency) from 10 Hz–100 kHz. The goal is to test an amplifier in its linear region and to get an introduction to some amplifier limitations or non-linearities such as bandwidth, power consumption, clipping and the generation of high-order (harmonic) frequencies, and maximum output current.
- Laboratory #4: Build and test a low-level (μV - mV) differential amplifier using an op-amp (typically used for microphones). Measure V_{OS} , I_b and CMRR. Measure the temperature using a thermocouple and a differential amplifier.
- Laboratory #5: Build and test a 100 Hz – 10 kHz variable gain Audio amplifier using an op-amp. Do signal summing (audio mixer). Study intermodulation products.
- Laboratory #6: Build and test an audio tone control amplifier (treble frequencies 1-20 kHz) using an op-amp. Measure the frequency response. See the effect on speakers.

Knowledge Level Needed for Lab Experiments:

- Lab #1: – Time and frequency domain (f , T , V_{rms}).
– Fourier series representation (For ex: square-wave).
– KVL and KCL (For ex: voltage divider).
– The dB scale.
- Lab #1 Report: – Solving two loops using model or loop analysis.
– MatLab for adding sinusoids.
- Lab #2: – Batteries, battery charge, internal resistance.
– Introduction to telephone systems.
– Harmonics of a signal
- Lab #2 Report: – No new material needed.
- Lab #3: – Introduction to audio systems.
– Amplifiers, gain and transfer function, bandwidth.
– Concept of clipping and non-linear behavior.
– DC and AC power.
– Total harmonic distortion (THD).
- Lab #3 Report: – No new material needed.
- Lab #4: – Ideal op-amps (Golden Rules).
– Inverting and non-inverting configurations.
– Introduction to non-ideal op-amps (bias currents, offset voltage, common-mode rejection ratio, ...).
- Lab #4 Report: – No new material needed.
- Lab #5: – Op-amp summers.
– Good introduction to intermodulation products.
- Lab #5 Report: – No new material needed.




- Lab #6:
 - Frequency domain solution of circuits.
 - Phase of signals and transfer functions.
 - Concept of poles and zeroes.
 - Complex numbers.




- Lab #6 Report:
 - Duality of frequency and time domain representations (or how to get the time domain response from a transfer function measurement).

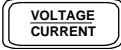
The Agilent 3631A Power Supply

The Agilent 3631A has three power supplies, a +6 V supply capable of delivering 5A, and two supplies of +25 and -25 V capable of delivering 1A each. The \perp (ground) output is the reference ground and is connected to the ground of the building. This is why it is important to connect the COM (common) terminal of the ± 25 V supplies, and the (-) terminal of the +6 V supply to the \perp (ground) reference.


Looking now at the control keys:

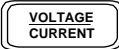
1. The  key turns the output ON or OFF.

2. **To Set the Output Voltage:**
 - a. Press the , ,  keys to select the power supply to be set.


 - b. Press  key so that the Volt Display is active.


 - c. Use the circular control knob to set the output voltage. Use the arrow keys for selecting the resolution.

3. **To Set the Maximum Output Current:**
 - a. The  key lets you select the maximum current that the power supply can deliver (up to 5A for the 6V and 1A for the ± 25 V supplies). This is basically your current protection feature.

 - b. Press the  key so that the Current Display is active.

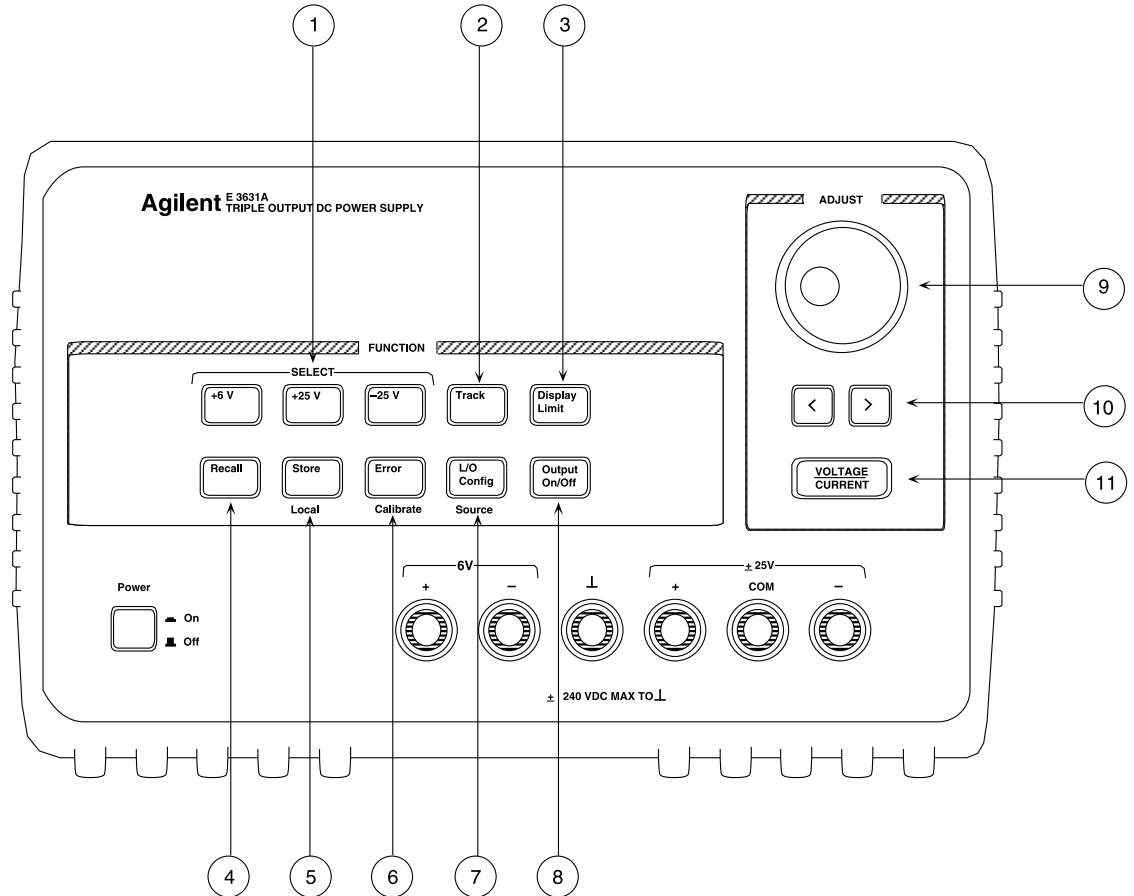
 - c. Use the circular control knob and the resolution keys to set this limit (if needed).

4. **To Read the Output Voltage or Output Current:**
 - a. The  key also shows the output voltage and the output current of the power supply.

 - b. To measure the output current of the supply, make sure that the  key is not active.



The Front Panel at a Glance







- | | |
|-------------------------------------|---|
| 1 Meter and adjust selection keys | 7 I/O Configuration / Secure key |
| 2 Tracking enable/disable key | 8 Output On/Off key |
| 3 Display limit key | 9 Control knob |
| 4 Recall operating state key | 10 Resolution selection keys |
| 5 Store operating state / Local key | 11 Voltage/current adjust selection key |
| 6 Error / Calibrate key | |

The Agilent 33120A function Generator



The Agilent 33120A generates a whole range of waveforms with precise control on the frequency amplitude, waveform shape, offset voltage, etc. We will use only a small portion of its capabilities in EECS 210, but the Agilent 33120A will "shine" in EECS 211 with its AM, FM, FSK, etc. modulation features.



1. To Choose a Waveform:




Simply press the AC waveform keys,  for a sinewave,  for a square wave,  for a triangular wave or  for a sawtooth wave.

2. To Set the Frequency:

- a. Press the  key.
- b. Enter the frequency either by using the control (circular) knob and the horizontal (or vertical) arrows for choosing the significant digits. You can also enter the frequency numerically:
 - b1. Press 
 - b2. Enter the digits. For example 1•249
 - b3. Enter the unit. For example kHz (or Hz or MHz)

The sine and square waves can be set from 0.1 mHz to 15 MHz.
The triangular and sawtooth waves can be set from 0.1 mHz to 100 KHz.


3. To Set the Amplitude:



- a. Press the  key.
- b. Enter the amplitude by either using the control (circular) knob and the horizontal or vertical arrows for choosing the significant digits. You can also enter the amplitude numerically:
 - b1. Press 
 - b2. Enter the digits. For example 2.4
 - b3. Enter the unit. For example Vpp (or Vrms or dBm)
 - b4. You can also use the  key to enter values in mV.

The amplitude can be set from 100 mVppk to 20 Vppk.

4. To Set a DC Offset:

5.

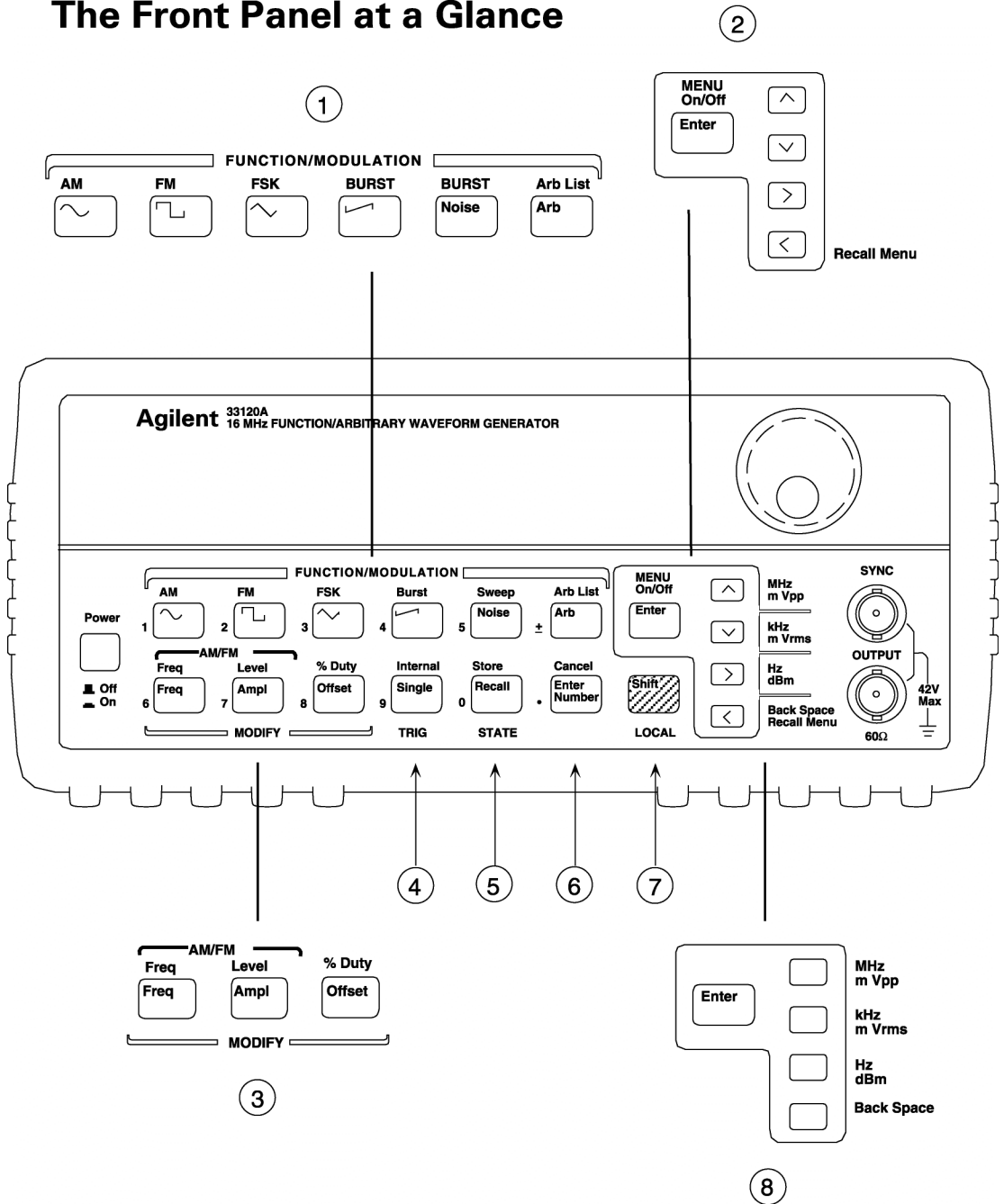
The  key allows you to add a DC offset voltage to any AC waveform. Normally, the offset is set to zero volts and the AC waveform has an average value of zero. However, in some cases, it is good to offset the AC waveform to simulate DC and AC inputs to a circuit.

- a. Press the  key.
- b. Enter the value by either using the control (circular) knob or using the  key, entering the number and choosing the units (V or mV).
- c. You can also choose a positive or negative offset using the \pm (green) key in the numerical entry.

5. **To Set the Duty Cycle:**

The % Duty key allows you to set the duty cycle of a square waveform only. It is easiest to select the value using the control knob (or using the menu).

The Front Panel at a Glance



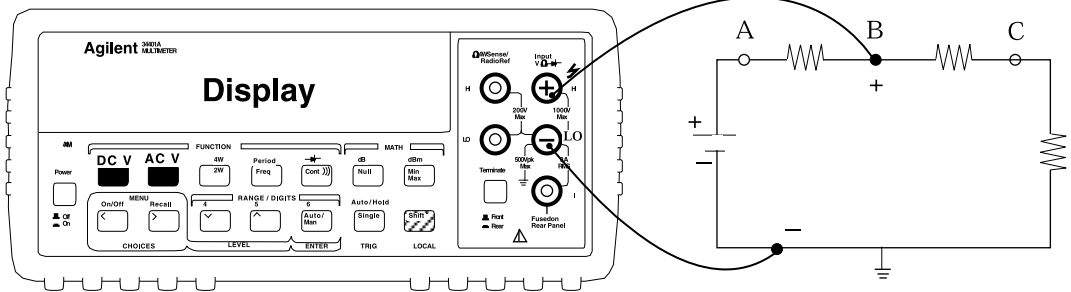
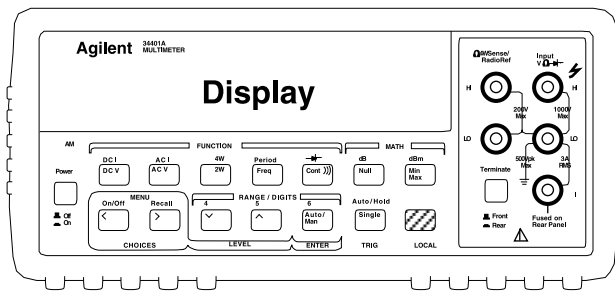
- | | |
|---|---------------------------------------|
| 1 Function / Modulation keys | 5 Recall / Store instrument state key |
| 2 Menu operation keys | 6 Enter Number key |
| 3 Waveform modify keys | 7 Shift / Local key |
| 4 Single / Internal Trigger key
(Burst and Sweep only) | 8 Enter Number "units" keys |



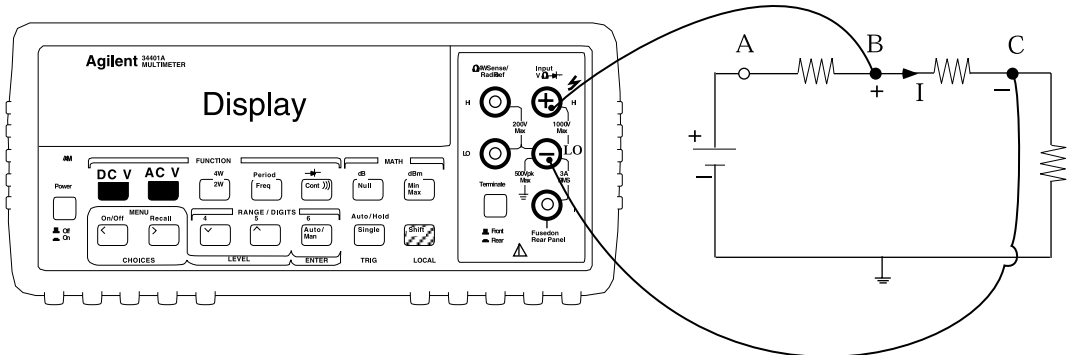
The Agilent 34401A Multimeter

The Agilent 34401A multimeter is a high precision, 6 1/2 digit multimeter, capable of measuring V, I, resistance, freq, time, etc. for DC and AC signals. Throughout the lab experiments, we will only use a small portion of its capabilities, but you are encouraged to learn all what you can about it.

- Measuring Voltages:** Voltages are measured in parallel with a circuit. The DC V (or the AC V) key should be selected. The example below shows how to measure V_B (V_B is positive):

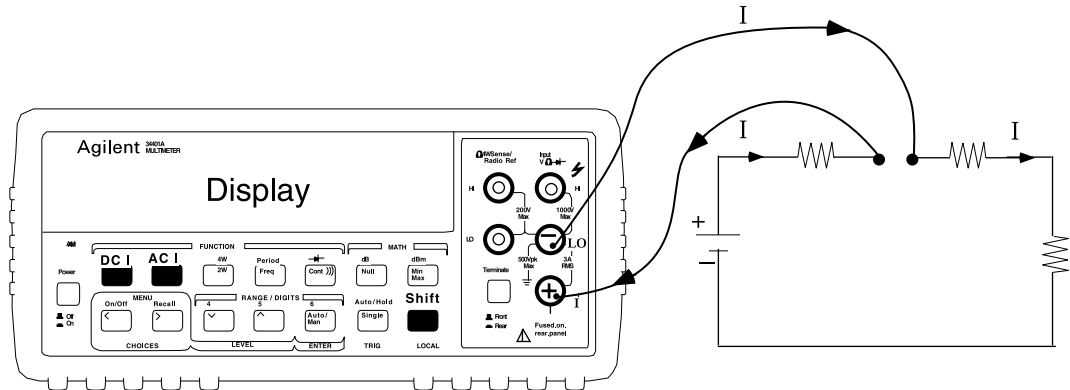


The example below shows how to measure V_{BC} (V_{BC} is positive):



The input resistance of the voltmeter is 10 MΩ. This means that it will not load the circuit and result in a large measurement error if the resistances are 300 kΩ or smaller (see lab report assignment).

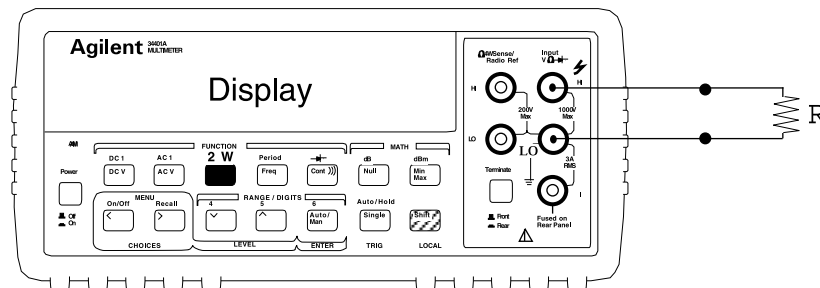
2. **Measuring Currents:** Currents are measured in series with a circuit. Basically, the current passes by the multimeter so that it can be measured. The DC I or AC I keys should be selected using the blue Shift key. The example below shows how to measure I (I is positive):



The input resistance of the ammeter is 0.1Ω for the 1A and 3A ranges, and 5Ω for the 10 mA and 100 mA ranges. This means that it will not load the circuit and result in a large measurement even for most resistance values ($100 \text{ k}\Omega$ to 2Ω).

In order to measure a current, you need to break the circuit and re-route it to the multimeter. This is not possible in finished I.C. boards and is the main reason why technicians/engineers mostly measure voltages and calculate I using $V = IR$.

3. **Measuring Resistances:** In order to measure a resistance, the multimeter imposes a small voltage (mV level) on the resistor and measures the resulting current. The resistance is then $R = V/I$. Two wire (2w) resistance measurements are easy: Connect the resistor as shown below and press the 2W button.



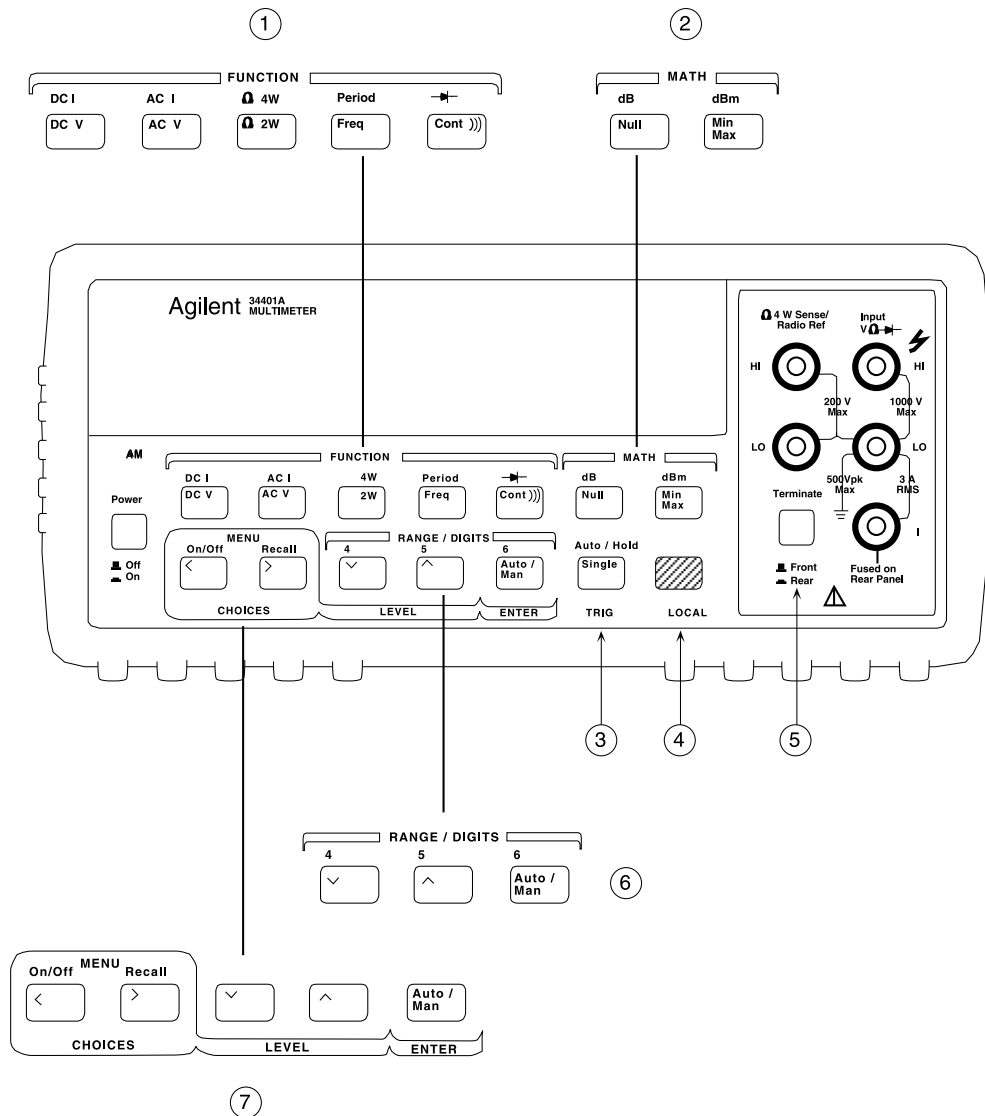
4. **Measuring AC Signals:** The multimeter can also measure the RMS values of AC waveforms (voltage or current, depending on the connection). The AC waveform can be sinewave, square-wave, triangular ... anything, since the multimeter only measures its RMS value (root mean square). The multimeter will also determine its frequency (Freq) and its period (Shift, Freq).

The RMS voltages measurement is accurate to 300 KHz, and the RMS current measurement is accurate to 5 KHz. The frequency and period are accurate up to 300 KHz but can go to 1 MHz with $V_{ppk} > 600 \text{ mV}$.



5. **Measuring Continuity** (Cont)))): Many times, it is necessary to check if a node is connected to another node (via a short-circuit). For example, you may want to follow a ground node in a complicated circuit. You can connect the two nodes to the (V, Ω) and (LO) inputs (just like voltage or resistance measurements) and the multimeter will beep if there is a short circuit.
6. **Setting the Resolution:** The resolution keys are set using the Range/Digit area. You can select 4, 5, 6 resolution digits, or simply Auto (for automatic selection).
7. **Single/Auto/Hold Measurements:** In noisy or time-varying measurements, the display is constantly changing and it may be helpful to take a single measurement or hold a measurement until it is deleted. This key does the job. Use the Auto setting to set the multimeter back into its normal operation.

The Front Panel at a Glance



- | | |
|---|---|
| 1 Measurement Function keys | 5 Front / Rear Input Terminal Switch |
| 2 Math Operation keys | 6 Range / Number of Digits Displayed keys |
| 3 Single Trigger / Autotrigger / Reading Hold key | 7 Menu Operation keys |
| 4 Shift / Local key | |