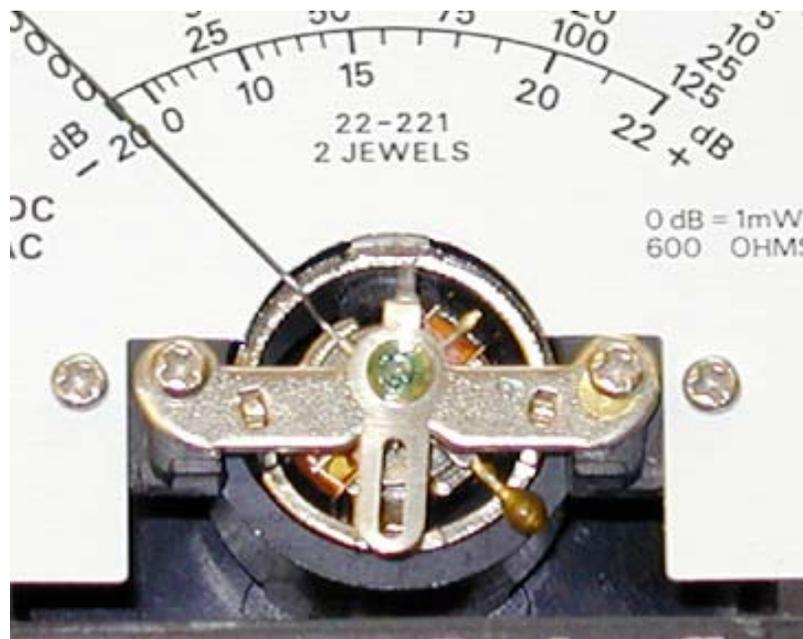# Exercise MM—About the Multimeter

Introduction

Our world is filled with devices that contain electrical circuits in which various voltage sources cause currents to flow. Electrical currents generate heat, light, and magnetic fields, and produce chemical effects. Any of these phenomena can be used to measure current. One of the simplest ways is to let the current flow through a coil of wire that is in a magnetic field and to measure the resulting torque on the coil by observing the deflection of a torsion spring. This is how your multimeter works, which we call a magnetic multimeter (MMM), in contrast to the standard term `analog'. Look at the meter itself. You can see the copper colored coil and one of the two spiral torsion springs (the other is at the back; they also lead current in and out of the moving coil). The MMM is a current meter with a range selector switch, so that with appropriate resistors and other parts it can measure voltages and resistances.

Figure 1: Coil and torsion spring

A meter has a needle that moves clockwise in proportion to the current flowing through the meter. The needle goes over various scales above a reflecting mirror intended to reduce parallax error—move your head so that you see the needle just above its reflection, and you'll be looking straight down onto the scale and be able to read the right number.

In this exercise you will use your MMM to measure the resistance of a resistor, the voltage difference between the terminals of a AA cell (battery), and the current that flows in a simple circuit consisting of the battery and a resistor.

The MM Kit contains one AA cell and one battery holder with a red lead (plus,+) and a black lead (minus,-). You may need to remove some of the insulation on the leads so that about $1/2\,in$, $12\,mm$, of bare wire is exposed. Do this with the wire strippers in your toolkit. The kit

also contains two $20\,\Omega$ resistors. You will also need one of the clip leads that you have just made.

There is a separate package in the top tray of the Red Box containing two AA cells, and four $500\,mA$ fuses. You should first open the back of the MMM and put in a $1.5V$ AA cell into the holder at the top of the MMM. Make sure the battery is placed with the + terminal connecting to the red wire. While the multimeter is open, notice that there is a fuse. If your multimeter is not working then there are two likely reasons. The first is that your test leads are broken or not making a good connection. The second reason is that the fuse may have blown. You have four spare fuses in your Red Box. The fuses may blow if you make a measurement with an inappropriate range selector setting, in particular the 250 DCA and Rx1 ranges.

Measuring Voltage, Resistance and Current with the Multimeter

Checking the MMM zero:

With the MMM lying flat on a table or desk and with nothing connected look down so as to line up the needle and its image in the scale mirror. The needle should bisect the 4 black zeros. Tap or swing the meter; the needle should still show zero. If not, your $5\,mm$ flat screw driver will just about fit the adjusting screw in the lower center of the meter. Turn carefully until the needle sits on zero.

Measure the resistance of the $20\,\Omega$ resistor

There are 3 resistance ranges, RX1, RX10, and RX1K (1K=1000). The ohmmeter operation depends on the $1.5V$ AA cell that is inside the meter. Essentially, current flows through the meter in inverse proportion to the resistance in the circuit. This accounts for the markedly non-linear green scale at the top of the meter.

In order to zero the meter before measuring resistance, short the test leads by connecting them together. Then adjust the OHMS ADJUST knob (located to the left of center of the MMM) so that the meter reads 0 ohms; the needle is then at its maximum deflection. When the test leads are not connected, (an open circuit), no current flows and the needle sits on the infinite resistance mark ,∞, all the way on the left side of the scale.

Set the range selector switch on the MMM to the RX1 range. Connect the test leads to the resistor. Measure the resistance. You may want to make other resistance measurements. For example make a thick line with a lead pencil and measure the resistance of the mark. Grasp the clips firmly and see what your resistance is. Touch the clips to your tongue.

Measure the voltage of the AA cell

Set the range selector switch on the MMM to the 5 DCV range. Place the AA cell in the battery holder. Connect the test leads to the leads from the holder. Measure the voltage.

Measure the current in a simple circuit

First set the range selector switch on the MMM to the 250m DCA range. Make a simple circuit consisting of the 20Ω resistor, the AA cell, and the MMM. You can do this by connecting the red lead of the MMM to the red lead (plus, +) of the AA cell holder. Use a clip lead to connect the black lead (minus, -) of the AA cell holder to one end of the 20 Ω resistor. Connect the black lead of the MMM to the other end of the 20Ω resistor. Measure the current in the circuit. What effect do you think the MMM has on the circuit?

About the Magnetic Multimeter

Introduction

The MMM will be one of your most important tools in this course. Please read the following explanation of the MMM. You may not be completely familiar with all the terminology. As the course develops, you will learn all the physical principles necessary to understand the MMM. So please keep on referring to the reading below if you have any questions about your MMM.

Your analog multimeter (we call them MMM—magnetic multimeters) is a "moving coil meter" with a needle whose deflection shows and measures the torque on a current loop placed in a magnetic field. That torque is proportional to the current, and a device that measures current is called an *ammeter*.

The multimeter consists of a cylindrical magnet (magnetized across a diameter) arranged coaxially with a cylindrical magnetic return path as shown in Figure 2.

Figure 2: Multimeter Coil

In the gap is a pivoted rectangular coil; you can see the top of it if you look down into the meter. Spiral springs, top and bottom, lead current in and out of the coil and also provide a restoring torque. Jeweled bearings provide a low-friction mounting as in some watches.

Current in the coil interacts with the radial magnetic field to generate tangential forces, and hence torques about the axis of rotation. These turn the coil until the magnetic torque is balanced by the torque of the spiral springs. The meter has a pointer or needle, which moves clockwise in proportion to the current flowing through the meter. The needle goes over various scales above a reflecting mirror intended to reduce parallax error—move your head so that you see the needle just above its reflection, and you'll be looking straight down onto the scale and be able to read the right number.

Any instrument that measure current will disturb the circuit under observation. (The coil itself has resistance.) There will be some voltage drop due to the resistance of the flow of current through the ammeter. An ideal ammeter has zero resistance, but a $0.1 - 0.2V$ drop is tolerable in our applications.

The range of an ammeter can be extended to measure higher currents by placing a resistor (called a shunt resistor) of resistance, R_s, generally lower than the coil resistance, *across* the meter coil. When connected in a circuit with flowing current I, the meter will read a fraction of that current say 0.1 I, with 0.9 I passing through the shunt. The meter scale can be calibrated so that it reads 10 times its original range.

To convert an ammeter into a voltmeter, a resistor (called a multiplier resistor) of resistance, R_m, generally higher than the coil resistance, is put in *series* with the meter coil. Suppose a current I through the meter coil produces a full-scale (FS) reading, that is FS deflection of the needle. The coil resistance is R_c, so the voltage across it, $V = I R_c$. Putting a multiplier resistor $R_m = 9 R_c$ in series with the coil means that it will take $10 V$ to produce a FS reading, so we now have another range and can calibrate and label the scale accordingly.

The ideal voltmeter should draw no current, corresponding to the zero voltage drop across the ideal ammeter. But in any moving coil meter currents produce torques which deflect springs and keep them deflected. Electrical power deflects the springs during the short time that the needle is moving and is also dissipated in the coil resistance as long as the needle is deflected.

Test Leads

The test leads are generally placed into the two pin jacks on the lower left of the MMM; black into –COM and red into +V-Ω-A. Note the warning label that the inputs for these cannot exceed the maximum values of 500V DC, 1000V AC, 250mA DC (Figure 8). When you want to measure DC voltages up to $1000 V$, put the positive test lead into the pin jack labeled DC 1000V while leaving the black lead in –COM.

Range Selector Switch

The meter can measure current, dc voltage, resistance, or ac voltage depending on the setting of the range selector switch. There are four types of positions: DCA for dc current, DCV for dc voltage, OHMS for resistance, and ACV for ac voltage. Each position has several ranges; for example OHMS has three ranges: RX1, RX10, and RX 1K.

Figure 3: Pin Jacks

Figure 4: Range Selector Switch

Scales

There are four scales on the MMM. The top non-linear scale in green is used to measure resistance in ohms and ranges from ∞ to 0 reading left to right. Directly beneath the green scale is a red scale to measure AC. There are no markings on this scale. The black DC scale is divided into 10 large divisions over an angle of about 80 degrees; each large division is further divided into 5 small divisions. Alternate large divisions are labeled with 4 numbers. To the left, these are all zero. On the right are 5, 10, 25, 125; the voltage that produces full scale readings on the corresponding DCV range.

Figure 5: Scales

For example, if you set your range selector switch to 25 DCV then each large division corresponds to $2.5V$. When the needle points to full scale deflection, the voltage is $25V$. (Notice that there is no $10V$ full scale switch setting.) When the switch is set to the 500 & 1K setting, each large division corresponds to $50V$ or $100V$ depending on which pin jack the positive lead is inserted into. The non-linear bottom scale (also in black) measures decibels (dB), a logarithmic unit associated with sound level. This scale has the zero setting at $-20\,dB$ and then ranges from 0 to $22\,dB$ moving from left to right.

Current-Voltage Measurements

DC current Ranges (DCA)

First we'll consider the dc current ranges. DCA, ('DC' stands for direct current), 'A' stands for amperes so DCA means direct current amperage). There are two DCA current ranges, 250m and 50μ(250 mV). The more sensitive 50μ(250 mV) range can also be used to measure voltage. When the dial is set to 50μ(250 mV) the resistance of the meter is $5000\,\Omega$. If the needle deflects to full scale, then $50\,\mu A$ flows through the meter. This corresponds to a voltage difference

$$V = I\,R = (50\mu A)(5000\,\Omega) = 2.5\times10^{-1}\,V = 250\,mV\ .$$

So this setting can measure voltages between $0V$ and $250\,mV$.

Besides this most sensitive range, there is a $250\,mA$ range marked 250mDCA. This puts in a $1\,\Omega$ shunt resistor in parallel across the $5000\,\Omega$ of the meter itself. Thus when current causes $250\,mV$ to appear across the shunt and the $5k\,\Omega$ meter resistance, a current of $250\,mA$ passes through the shunt while $50\,\mu A$ passes through the meter giving full-scale deflection. Many of the MMM's have a fuse to protect the meter from overload on this range, otherwise the $1\,\Omega$ resistor will burn out inside the meter.

DC voltage Ranges (DCV)

There are 4 DCV range switch positions 5, 25, 125, and 500 & 1K, selected by turning the range selector switch. DC stands for direct current, so DCV means direct current voltage. Selecting the various DCV ranges introduces more resistance in series. The resistance of the meter on any DCV range is always the full scale reading in volts times 20,000 ohms/volt $[\Omega]/[V]$, a number that characterizes this meter as a dc voltmeter. For example, on the $25V$ setting, the resistance is

$$R_{25V} = (25V)(20,000\,\Omega/V) = 500k\,\Omega = 5.0\times10^{5}\,\Omega\ .$$

Table 1 shows the full scale value, the resistance of the meter on that range, and the power dissipated in watts through the meter for the DCV and DCA ranges.

Table One: resistance and power characteristics of DCV and DCA ranges on MMM

Range	Resistance in ohms [Ω]	Power in milliwatts for full scale deflection [mW]
5V	$100\,k$	0.25
25V	$500\,k$	1.25
125V	$2.5\,M$	6.25
500V	$10\,M$	25.0
1000V	$20\,M$	50.0
250mV (50µA)	$5\,k$	0.0125
250mA	1	62.5

The DCV range 500 & 1K is one range selector setting. When the positive test lead is in the +V-Ω-A, the full scale deflection corresponds to $500\,V$. When the positive test lead is in the pin jack labeled DC 1000V, the full scale deflection corresponds to 1000V.

AC voltage ranges (ACV)

Suppose the ac input voltage is $V(t) = V_0 \sin(2\pi f t)$ where V_0 is the amplitude. A half-wave rectifier is inserted in series with the various resistors so that the ac has a dc component. The meter is insensitive to the fast variation of the output voltage across a load, so it will read the time averaged dc voltage $\langle V \rangle$. Each ac scale is then calibrated by various resistors to indicate the root-mean square value $V_{rms} = V_0 / \sqrt{2}$.

For non-sinusoidal waveforms, or for ac superimposed on dc (average in time not zero), the readings of the meter will most likely not be meaningful.

For ac you read the scales whose divisions and associated numbers are printed in red. Full-scale deflection corresponds to your choice of range for the root mean square voltage indicated on the rotary setting. At low voltages, the diode is not linear, (this is due to the small forward drop voltage) as can be seen from the small displacement of the red ac marks at the low end of the scale, from the corresponding black dc ones directly below.

The resistance of the meter on any ACV range is always the full scale reading in volts time 10,000 ohms/volt, a number that characterizes this meter as an ac voltmeter.

Resistance-Ranges (RX)

There are 3 resistance ranges, RX1, RX10, and RX1K. The ohmmeter operation depends on the $1.5V$ AA cell that is inside the meter case. Essentially, current flows through the meter in inverse proportion to the resistance in the circuit. This accounts for the markedly non-linear green scale at the top of the meter.

In order to zero the meter, short the test leads by connecting them together. Then adjust the OHMS ADJUST knob (located to the left of center of the MMM) so that the meter reads 0 ohms; the needle is then at its maximum deflection. When the test leads are not connected, an open circuit, no current flows and the needle sits on the infinite resistance mark ∞ all the way on the left side of the scale.

Half scale readings (that is with the needle pointing straight up parallel to the edge of the case) are: $24\,\Omega$, $240\,\Omega$ and $24,000\,\Omega$ on the RX1, RX10, and RX1K ranges, respectively.

Note also that on the resistance ranges the meter puts substantial current through the resistor being measured. Maximum currents are $0.05\,A$, $5\,mA$, and $50\,\mu A$ on the RX1, RX10, and RX1000 ranges, respectively. You can check out some of this by making measurements of one meter with another.
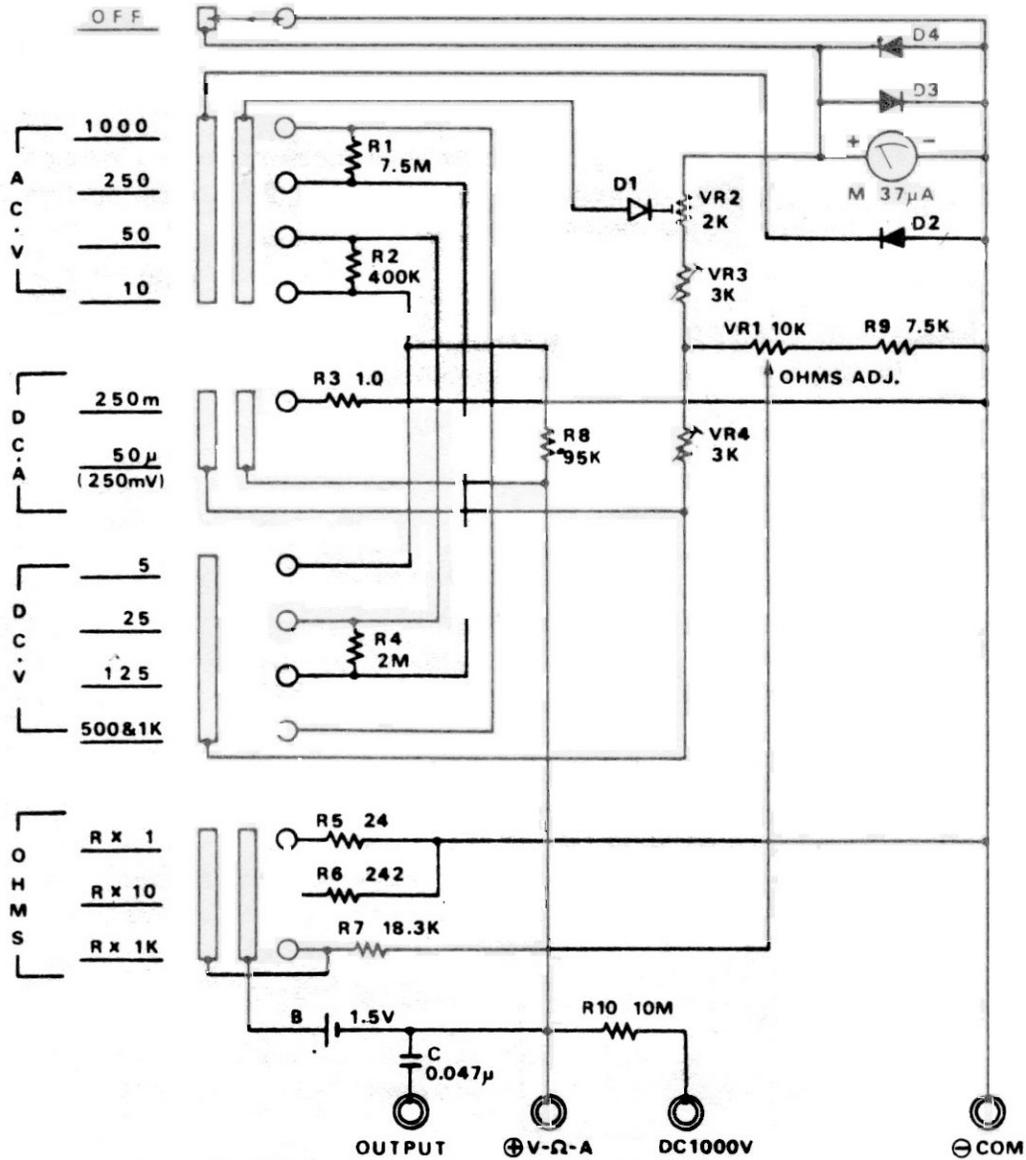
Meter Damage

Avoid dropping the meter. Keep its range switch on zero when it is not in use. This damps the motion of the coil and needle—you can see this by rotating the case back and forth in a horizontal plane and comparing the needle motion with the switch on a voltage scale and on OFF. Or: set the meter on the RX1K, connect the test leads and note the time that the needle takes to return to zero when the leads are disconnected. Compare that time with the time it takes the needle to return to zero when the leads stay connected but the range is switched from RX1K to OFF.

Besides the fuse, the moving coil is protected by resistors and a pair of back-to-back diodes across its windings. This means that it's hard to damage the meter coil except for the ranges with low resistance where resistors can be damaged by excessive currents (RX1 and 250mA ranges). However, it's good practice to start with high ranges, and not to measure the resistances of components that are wired into circuits, especially if power is on.

Figure 6 shows the circuit diagram for multimeter. Notice that when the meter range selected is 50μ(250 mV), it takes $50\,\mu A$ in the external circuit to produce full scale deflection, but only $37\,\mu A$ flows through the coil of the meter.

SCHEMATIC DIAGRAM

NOTE: (1) ALL RESISTANCE VALUES ARE INDICATED IN "OHM" (K = 10³OHM, M = 10⁶ OHM)

(2) ALL CAPACITANCE VALUES ARE INDICATED IN "μF" (P = 10⁻⁶μF).

Figure 6: Circuit diagram for MMM

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Measuring Voltage, Resistance and Current with the Multimeter

- Measure the resistance of the $20\,\Omega$ resistor
- Measure the voltage of the AA cell
- Measure the current in a simple circuit

Measure the resistance of the $20\,\Omega$ **resistor:** In order to zero the meter, short the test leads by connecting them together. Then adjust the OHMS ADJUST knob (located to the left of center of the MMM) so that the meter reads 0 ohms; the needle is then at its maximum deflection. Set the range selector switch on the MMM to the RX1 range. Connect the test leads to the resistor. Measure the resistance. You may want to make other resistance measurements. For example make a thick line with a #2 pencil and measure the resistance of the mark.

Measure the voltage of the AA cell: Set the range selector switch on the MMM to the 5 DCV range. Place the AA cell in the battery holder. Connect the test leads to the leads from the holder. Measure the voltage.

Measure the current in a simple circuit: First set the range selector switch on the MMM to the 250mDCA range. Make a simple circuit consisting of the $20\,\Omega$ resistor, the AA cell, and the MMM. You can do this by connecting the red lead of the MMM to the red lead (plus, +) of the AA cell holder. Use a clip lead to connect the black lead (minus, -) of the AA cell holder to one end of the $20\,\Omega$ resistor. Connect the black lead of the MMM to the other end of the $20\,\Omega$ resistor. Measure the current in the circuit. What effect do you think the MMM has on the circuit?

Building the LVPS—Low Voltage Power Supply

Introduction

Low voltage is one of those relative terms—up to 25 volts [V] dc is low, and most people would call $1000\,V$ high. Power supplies provide energy from many different kinds of sources and at widely varying rates: gigawatts ($10^9\,W$) from nuclear plants to microwatts ($10^{-6}\,W$) from watch batteries. Sources of energy for power supplies include nuclear fission, burning of coal, oil, gas or wood, chemicals reacting, and sunlight, wind and tides. Power is delivered in electrical form as alternating or direct current (ac or dc) and in many combinations of current and voltage. Electrical power supplies in a narrow sense are really converters from one voltage/current combination to another—with, one hopes, only small power losses.

Project LVPS

In this project, you'll build a power supply that takes power at $120\,V$, 60 hertz [Hz] ac from a wall outlet and converts it to dc. The power supply is adjustable between $2\,V$ to $12\,V$ and can supply currents up to 1 ampere (A).
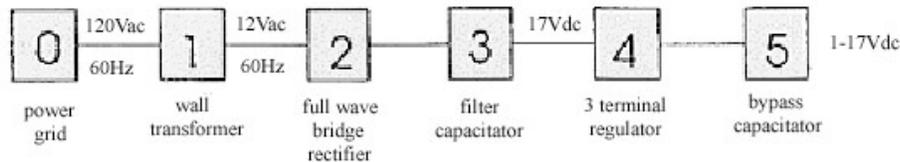

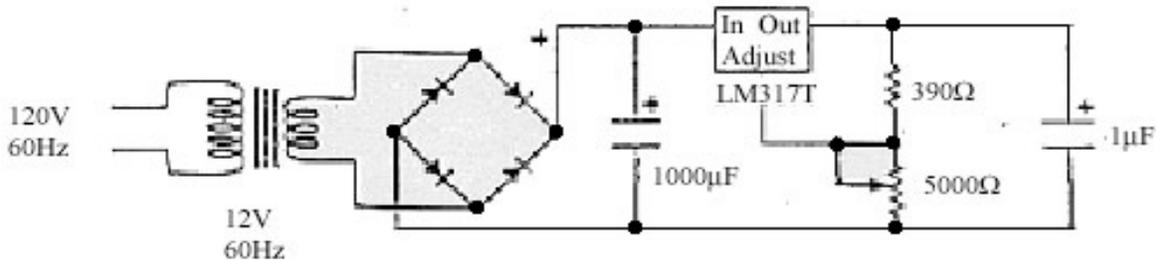**Figure 1: Block diagram of LVPS**

Background

The circuit diagram for the LVPS looks like

Figure 2: Circuit diagram for LVPS