Lab Experiment Number 1

Analog and Digital Ammeters

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Abstract

Ideally, using an ammeter to make a measurement of a circuit would give the value of the measured quantity. Practically, however, adding an ammeter to a circuit changes the characteristics of the circuit due to the properties of the physical ammeter. Taking these internal properties into account, one can minimize the impact of the addition of the meter, use an ammeter to measure voltage, and extend the usable range of an ammeter. Using measurements taken from an analog multimeter, a digital multimeter, and an oscilloscope, the internal characteristics of an ammeter were calculated. Making use of these characteristics and laws governing how circuits work, it was demonstrated how an ammeter's useful range can be extended.

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Introduction

Adding an ammeter to a circuit to take a measurement changes the characteristics of the circuit due to the internal properties of the meter. Knowing these properties, calculations can be done to eliminate, or at least minimize the effect on the measured value of adding the ammeter. Using relationships between voltage, resistance, and current in a circuit, the properties can be determined when compared to theoretical values. Knowing how a circuit responds to elements also leads to the ability to extend the useful measurement range of a meter.

Background and Theory

An ammeter has an internal resistance associated with it. When added to the circuit, the circuit responds in accordance to Ohm's law, $I = V / R$, where I is current, V is voltage, and R is the total resistance of the circuit.

In parallel circuits, voltage across each branch is identical due to Kirschoff's Voltage Law, which states that the sum of voltages around a closed loop in a circuit must be zero. Using KVL and Ohm's Law, it can be shown that a supplied current will divide among a circuit's branches in a way that proportional to the resistance of each branch. Thus, the circuit's response to the addition of an element like a meter can be approximated as the ratio of the measured voltage to the theoretical voltage.

Procedure, Results, and Calculations

The circuit in Figure 1 was constructed with the DC power supply (represented by V_s and M1), the analog multimeter (represented by M2 and R_m), the oscilloscope (represented by CH1), and the decade box (represented by Rdb).

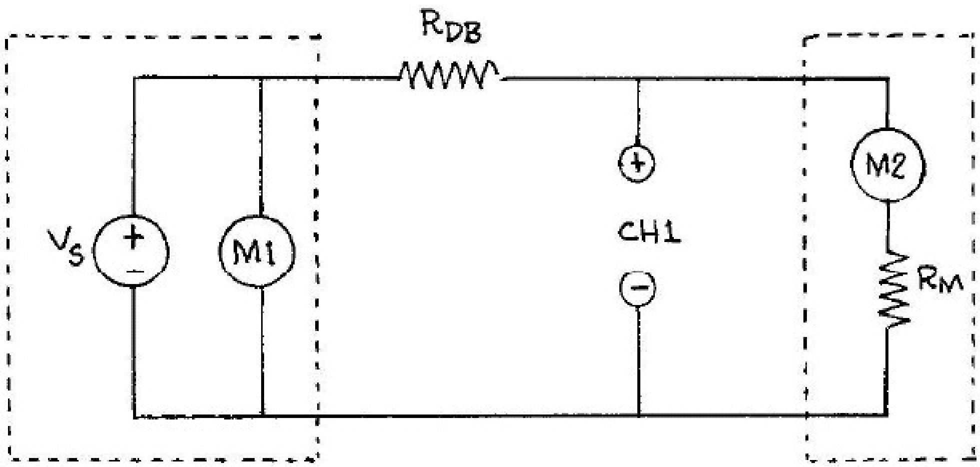

Figure 1 [1]

1) The DC power supply was switched on to give power to the circuit. The decade box was set to 10 kΩ. The digital multimeter was set to the 1mA scale. The voltage of the power supply was increased M2 (the analog multimeter) read 1 mA. The values of M1 (the DC power supply) and CH1 (the oscilloscope) were recorded in Table 1.1. The voltage of the power supply was adjusted until M2 read 0.8 mA, 0.6 mA, 0.4 mA, and 0.2 mA, and measurements of M1 and CH1 were recorded in Table 1.1 for each step.

M2 (mA)	M1 (v)	CH1 (mV)
1.0	10.1	100.0
0.8	8.1	80.0
0.6	6.1	60.0
0.4	4.1	40.0
0.2	2.1	19.0

Table 1.1: 1mA scale

Due to Ohm's law, I = V / R, the value of R_m, the ammeter's internal resistance, can be calculated by R_m = CH1 / M2. The results of this calculation are recorded in Table 1.2. These results show that at higher currents the resistance of the ammeter is higher.

CH1 (mV) /	M2 (mA) =	Rm (Ω)
253.0	1.0	253
204.0	0.8	255
152.0	0.6	253
98.0	0.4	245
45.0	0.2	225

Table 1.2: 1 mA scale

An alternate method of calculating R_m is $R_m = (M1 / M2) - R_{db}$, because the total resistance is $R_m + R_{db}$. The results of this calculation are included in Table 1.3. This data is less accurate and deviates from the previous method because the actual resistance of the decade box is within a fairly large tolerance, and the analog M1 and M2 meters are less accurate measures than the digital output of the oscilloscope.

M1 (v) /	M2 (mA) -	Rdb (kΩ) =	Rm (Ω)
10.4	1.0	10.0	400
8.4	0.8	10.0	500
6.3	0.6	11.0	500
4.1	0.4	12.0	250
1.9	0.2	13.0	-500

Table 1.3: 1mA scale

2) The decade box was set to 1 kΩ. The analog multimeter was switched to the 10 mA scale. The voltage of the power supply was changed until M2 read 10 mA, 0.8 mA, 0.6 mA, and so on, as in the previous step, and values for M1 and CH1 were recorded in Table 2.1. R_{db} was 10 kΩ in both sets of measurements.

M2 (mA)	M1 (v)	CH1 (mV)
10.0	10.5	260.0
8.0	8.5	209.0
6.0	6.3	156.0
4.0	4.1	101.0
2.0	1.9	47.0

Table 2.1: 10 mA scale

The calculation in Table 1.2 and 1.3 was repeated for the 10 mA scale and included in Table 2.2 and 2.3. Again, the differences in the calculated resistance are due to the tolerance of the decade box resistance and accuracy of the analog meters versus the oscilloscope.

CH1 (mV) /	M2 (mA) =	Rm (Ω)
260.0	10.0	26.0
209.0	8.0	26.1
156.0	6.0	26.0
101.0	4.0	25.3
47.0	2.0	23.5

Table 2.2: 10 mA scale

M1 (v) /	M2 (mA) -	Rdb (kΩ) =	Rm (Ω)
10.5	10.0	1.0	50.0
8.5	8.0	1.0	62.5
6.3	6.0	1.0	50.0
4.1	4.0	1.0	25.0
1.9	2.0	1.0	-50.0

Table 2.3: 10 mA scale

3 – 4) The analog multimeter (M2) in Figure 1 was replaced with a digital multimeter. The previous two steps were repeated and values for M1 and CH1 were recorded on the 2 mA scale and 20 mA scale in Tables 3.1 and 4.1, respectively.

M2 (mA)	M1 (v)	CH1 (mV)
1.0	10.1	100.0
0.8	8.1	80.0
0.6	6.1	60.0
0.4	4.1	40.0
0.2	2.1	19.0

Table 3.1: 2mA scale

M2 (mA)	M1 (v)	CH1 (mV)
10.0	10.1	105.0
8.0	8.1	84.0
6.0	6.1	63.0
4.0	4.1	42.0
2.0	2.1	21.0

Table 4.1: 20 mA scale

The calculation in Table 1.2 and 1.3 was repeated for the 10 mA scale and included in Table 3.2 and 3.3 and Tables 4.2 and 4.3. Again, the differences in the calculated resistance are due to the tolerance of the decade box resistance and accuracy of the analog meters versus the oscilloscope.

CH1 (mV) /	M2 (mA) =	Rm (Ω)
100.0	1.0	100.0
80.0	0.8	100.0
60.0	0.6	100.0
40.0	0.4	100.0
19.0	0.2	95.0

Table 3.2: 2mA scale

M1 (v) /	M2 (mA) -	Rdb (kΩ) =	Rm (Ω)
10.1	1.0	10.0	100.0
8.1	0.8	10.0	125.0
6.1	0.6	10.0	106.7
4.1	0.4	10.0	250.0
2.1	0.2	10.0	500.0

Table 3.3: 2mA scale

CH1 (mV) /	M2 (mA) =	Rm (Ω)
105.0	10.0	10.5
84.0	8.0	10.5
63.0	6.0	10.5
42.0	4.0	10.5
21.0	2.0	10.5

Table 4.2: 20 mA scale

M1 (v) /	M2 (mA) -	Rdb (kΩ) =	Rm (Ω)
10.1	10.0	1.0	10.0
8.1	8.0	1.0	12.5
6.1	6.0	1.0	16.7
4.1	4.0	1.0	25.0
2.1	2.0	1.0	50.0

Table 4.3: 20 mA scale

The circuit in Figure 2 was connected, with the DC power supply (represented by V_s and M1) , the digital multimeter (represented by M2 and R_{m1}), the analog multimeter (represented by M3 and R_{m2}), a 10 kΩ resistor, the decade box (represented by R_{db}), and the oscilloscope (represented by CH1). The resistor is added to the circuit to limit the current that goes through the ammeter, as not to damage it. The decade box acts as a "shunt", absorbing current that exceeds the largest value the ammeter can measure. The shunt resistance can be changed depending on the scale of the current to be measured, allowing only current the ammeter can accurately measure to flow through the ammeter.

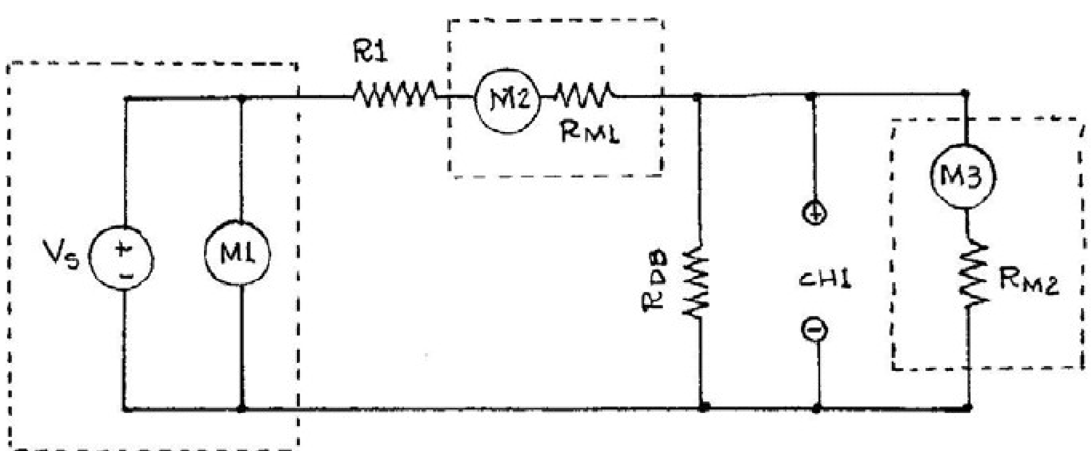

Figure 2 [1]

5) The decade box was set at 400 Ω and the analog multimeter set to the 10 mA scale. M2, the DC power supply voltage was adjusted to change M3 (the analog multimeter) to 10 mA, 0.8 mA, and so on. The values for M1, M2, and CH1 were recorded in Table 5.1.

M3 (mA)	M1 (v)	M2 (mA)	CH1 (V)
1.0	16.6	1.7	254.0
0.8	13.4	1.3	204.0
0.6	10.0	1.0	152.0
0.4	6.5	0.6	99.0
0.2	3.0	0.3	45.0

Table 5.1: Using R_{db} as a shunt, 10 mA scale

The internal resistance of the analog multimeter, R_{m2}, can be calculated with Ohm's law, as R_{m2} = CH1 / M3, because CH1 measures voltage and M3 measures current. The results of this calculation are included in Table 5.2. The calculated value corresponds with the value calculated earlier in the experiment, and supports the idea that the ammeter's resistance decreases as current decreases.

CH1 (mV) /	M3 (mA) =	Rm2 (Ω)
254.0	1.0	254.0
204.0	0.8	255.0
152.0	0.6	253.3
99.0	0.4	247.5
45.0	0.2	225.0

Table 5.2: 10 mA scale

The circuit in Figure 3 was connected, with the DC Power supply as V_s and M1, the digital multimeter on the 2 mA scale as M2 and Rm, the Analog multimeter on the 2.5 V scale as M3 and R'm, and the decade box as R_{db}, set to 1 kΩ. This circuit is using the analog multimeter to measure voltages rather than currents.

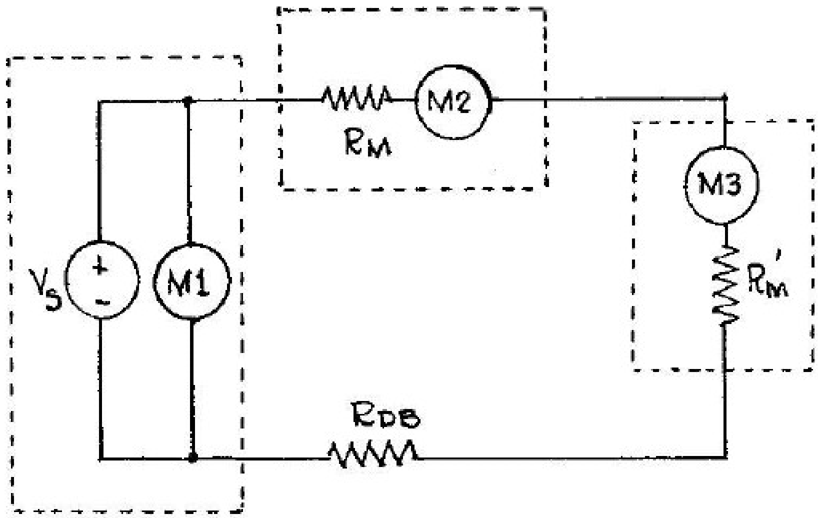

Figure 3 [1]

The M1 (DC power supply) voltage was set to 2.5 V, 2.0, 1.5, 1.0, and 0.5, and values for M1 and M2 recorded in Table 6.1. The table shows that M3 approximates the actual voltage of M1.

M1 (V)	M2 (mA)	M3 (V)
2.5	0.0506	2.7
2.0	0.0394	2.1
1.5	0.0291	1.6
1.0	0.0181	1.0
0.5	0.0072	0.4

Table 6.1: 2.5 V scale

Because the internal resistance of M2 (the digital multimeter) limits the current going into M2 (the analog multimeter), the resistance of the analog multimeter, R'm, can be approximated as the ratio between M3 and M2, M3 / M2. The results of this calculation are included in Table 6.2. The results of this table suggest that as voltages decrease, the value of R'm increases.

M3 (V) /	M2 (mA) =	R'm (kΩ)
2.7	0.506	5.3
2.1	0.394	5.3
1.6	0.291	5.5
1.0	0.182	5.5
0.4	0.072	5.6

Table 6.2: 2.5 V scale

The previous step was repeated with the voltmeter on the 10 V scale, and the DC power supply voltages (M1) set to 10 V, 6, 8, and so on. The results were recorded in Table 7. Again, using M3 as a voltmeter gives a reading that approximates the DC power supply's supplied voltage.

M1 (V)	M2 (mA)	M3 (V)
2.0	0.0091	1.9
4.0	0.0197	4.0
6.0	0.0301	6.1
8.0	0.0406	8.2
10.0	0.0505	10.2

Table 7.1: 10 V Scale

The calculations in Table 6.2 were repeated on the 10 V scale and recorded in Table 7.2.

M3 (V) /	M2 (mA) =	R'm (kΩ)
1.9	0.0091	208.8
4.0	0.0197	203.0
6.1	0.0301	202.7
8.2	0.0406	202.0
10.2	0.0505	202.0

Table 7.2: 10 V Scale

8) Using the digital multimeter's ohm meter, the resistances of the ammeters were measured on the scales used during the experiment.

- **Digital Multimeter**
  - 2 mA scale: 100.3 Ω
  - 20 mA scale: 10.4 Ω
- **Analog Multimeter**
  - 1 mA scale: 250.3 Ω
  - 1 mA scale: 25.44 Ω

These values confirm that the calculation done in Tables 1.2, 2.2, and 3.2 were more accurate measures of resistance than those in Tables 1.3, 2.3, and 3.3.

Conclusion

Introducing an ammeter into a circuit will produce a response in the circuit, depending on the characteristics of the circuit being measured. Thus, taking a measurement with an ammeter changes the voltages or currents being measured due to the ammeter's internal resistance. To find the change caused by adding the meter to the circuit, operations involving Ohm's law relations between resistance, voltage, and current are used. In this experiment, the voltage measured by the oscilloscope divided by the detected current gave a fairly accurate value for multimeter resistance. Other methods can be used, such as subtracting known resistance from the quotient of supplied voltage and detected current, but in this experiment were found to be less accurate due to higher tolerances in resistance characteristics and the change in resistance due to current.

Ammeters are valuable tools to an electrical engineer, and can be made more useful by simple manipulations in a circuit. For example, this experiment showed that a resistor acting as a "shunt" can absorb current that exceeds the range of possible measurements for the ammeter, thereby increasing the useful range of the ammeter.

References

1. "Experiment 1 – Analog and Digital Multimeters", University of Missouri-Rolla Electrical and Computer Engineering Department, 9 Sept. 2003, pp. 1 – 8.