# Basic Electronics Series

## Panel Meter Range Extension
## Analog Meters

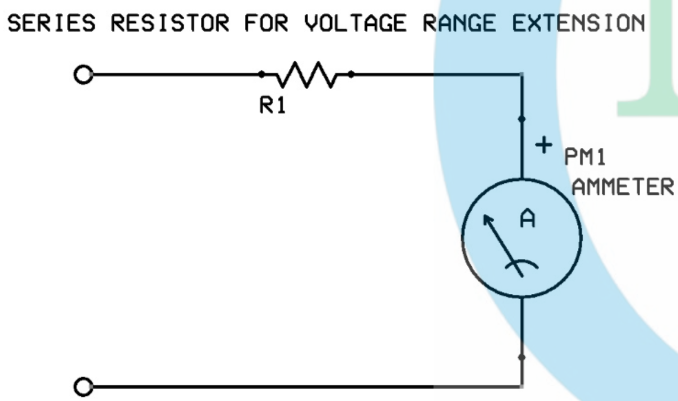
# Introduction

- From time to time, it may be necessary or desirable to have a panel meter read and display values that are beyond the native capability of the meter movement.
- This can be accomplished by extending the meter's effective range.
- This modification can be made for both current meters (ammeters) and voltage meters (voltmeters).

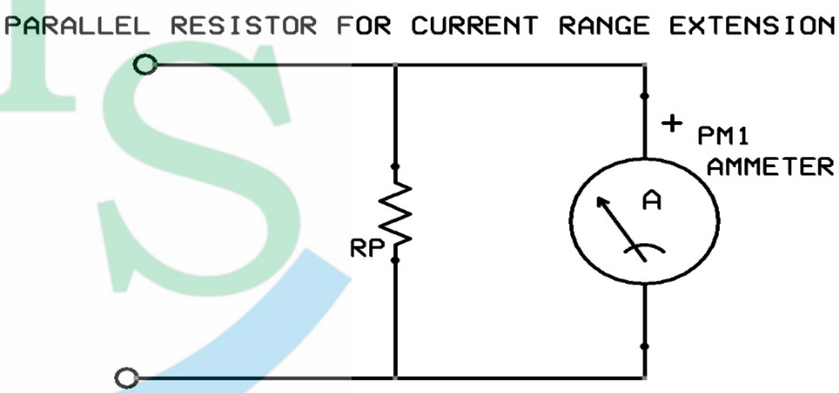
- The range extension is accomplished by adding a resistance of a calculated value to the meter circuit…
  - For voltmeters, the resistance is added in series with the meter.
    - Voltmeters are connected in parallel to the circuit under test, and we therefore need to increase the circuit resistance to raise the effective meter circuit resistance and reduce circuit loading by the meter.
  - For ammeters, the resistance is added in parallel to the meter circuit.
    - Ammeters are connected in series with the circuit under test, and we therefore need to reduce the circuit resistance to reduce the voltage dropped by the meter.

# Sample Circuits

## Voltmeter – Series Resistance




## Ammeter – Parallel Resistance




Under the skin, a voltmeter *is* an ammeter calibrated to read voltage…

# Values of Interest

- There are several values in which we are interested when working with this topic…
  - $R_M$ -- the through-resistance of the basic meter movement
  - $I_M$ -- the current through the meter movement
  - $V_M$ -- the voltage across the meter movement
  - $M$ -- the multiplication factor desired
  - $R_S$ -- the series resistance needed for the range extension desired
  - $R_P$ -- the parallel resistance needed for the range extension desired

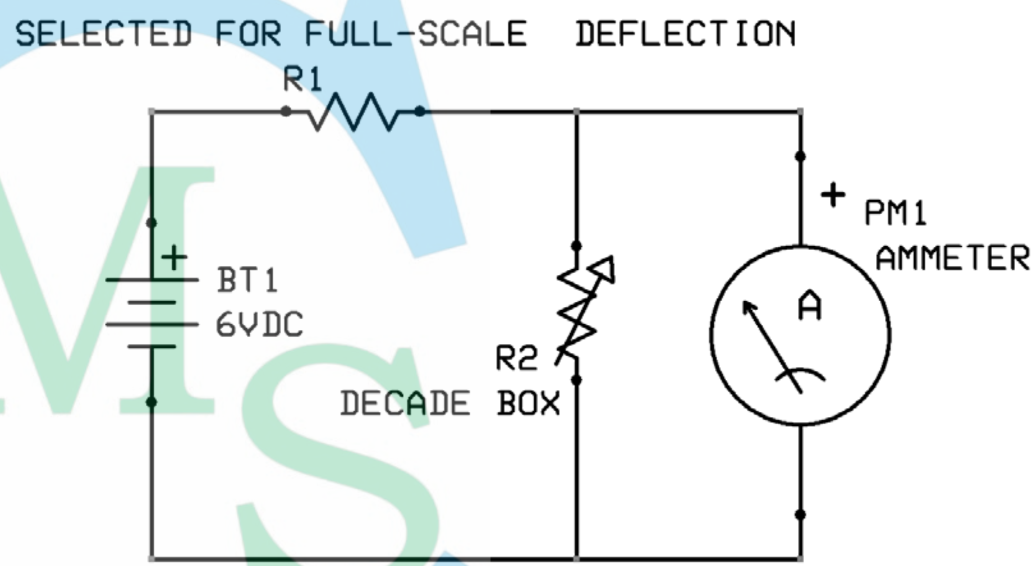
- One value is determined by the range extension desired:
  - $M$
- Some of the values are calculated using basic Ohm's Law equations:
  - $I_M$ and $V_M$
- Some of the values have specific equations outside of Ohm's Law:
  - $R_S$ and $R_P$
- One value must be determined through testing:
  - $R_M$

# Determining the Values

- The first value to be determined is $R_M$, or the resistance through the meter movement…
  - ***<u>NOTE:</u>  This value <u>cannot</u> be determined via a simple measurement of the meter with an ohmmeter, as the ohmmeter output current may well be greater than the maximum current that can safely be handled by the meter movement!***
- The $R_M$ value must be determined via bench testing as follows…

# Meter Through-Resistance

- This value can be determined using the test circuit shown at right.
- The value of R1 is selected to produce as close to full-scale deflection as is possible, and is based upon the supply voltage used.

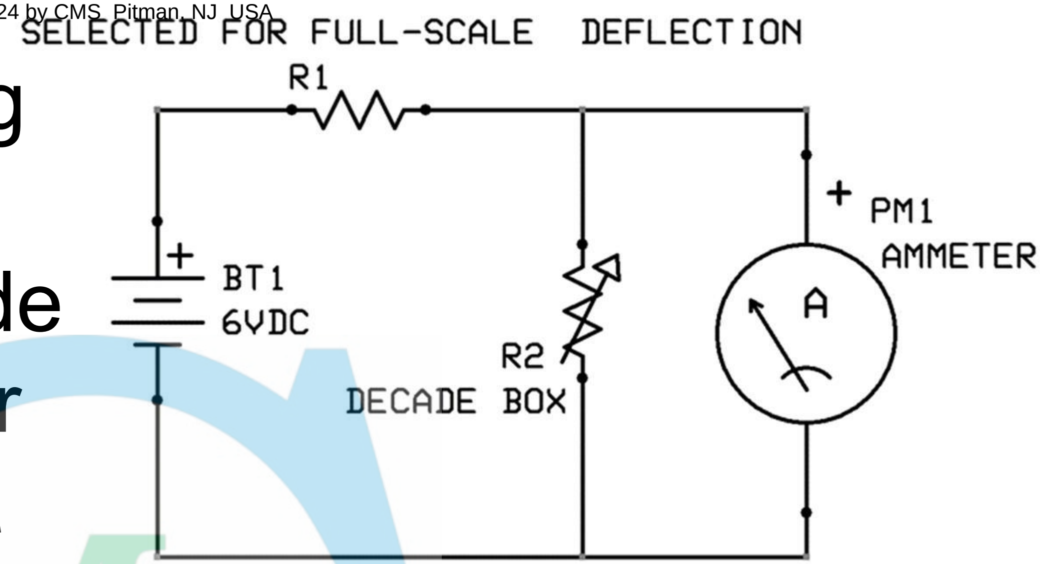



- Using Ohm's Law, we can determine that the value of R1 should be right around 6kΩ…

- That value is calculated as follows:
  - $R_M = \frac{E}{I} = \frac{6.00}{0.001} = 6{,}000\Omega$
  - This equation uses the full-scale current value of the meter movement, which is 1mA (0.001A) and the source voltage shown in the diagram of 6.00V to derive the resistance needed.
  - While 6kΩ is *not* a standard resistor value, 6.2kΩ *is* a standard value, which will give us a meter deflection that is slightly under full-scale:
  - $I = \frac{E}{R} = \frac{6.00V}{6209\Omega} = 0.000966339A = 0.966mA$
    - *The value of 6209Ω was used as that was the actual measured value of the 6.2kΩ 1% resistor used.*

- It is acceptable that a resistor value greater than the initial 6kΩ is used, as it is better to end up with a meter deflection that is less than full scale instead of one that is more than full scale, which a lower-value resistor would have produced.
- Of course, if the specific calculated value of resistance is available, it should be used.
- Insert the resistor into a series connection with the meter and apply the specified test voltage via a suitable power supply.
- Note the exact meter reading.

- Once the meter reading has been obtained and noted, connect a decade resistance box, or other suitable resistance that is both variable and measurable, in shunt across the meter.
- This is indicated by the variable resistor R2 in the schematic diagram at right.




- Adjust the variable resistance until the meter deflection is right at 50% of its original deflection.
- Remove the power from the circuit.

- Without changing the resistance adjustment at all, remove it from the circuit and measure that resistance value.
  - With the meter at 50% of its original deflection, the current flow through R2 and the meter will be balanced, meaning that the adjusted value of R2 is the same as the resistance through the meter movement.
- Record that resistance reading for later use.
- In most cases, ammeter resistances are less than 100Ω, though that is not an absolute rule or limit. Meters may vary considerably.
- In my test case, the meter through-resistance or $R_M$ came in at 79.1Ω. Note this for later use.

# Multiplication Factor

- The value of M, or the Multiplication Factor, is based purely on the ratio of change desired from the original meter movement full-scale current level.
- It is determined using the following equation:
  - $M = \frac{(desired\ current\ maximum\ in\ mA)}{(initial\ current\ maximum\ in\ mA)}$
- If we want to make a 0-1mA meter able to display values from 0-50mA, the equation is:
  - $M = \frac{(desired\ current\ maximum\ in\ mA)}{(initial\ current\ maximum\ in\ mA)} = \frac{50}{1} = 50$

# Meter Current and Voltage

- The equation for determining the current through the meter $(I_M)$ is…
  - $I_M = \frac{6.00V}{(6209+79.1)\Omega} = \frac{6.00V}{6288.1\Omega} = 0.000954A = 0.954mA$
- That takes us to the equation for determining the voltage across the meter $(V_M)$…
  - $V_M = 0.000954A \times 79.1\Omega = 0.0754614\text{V} = 75.461\text{mV}$
- Note that here, only the meter resistance used as opposed the full circuit resistance as above.

- Those equations were simple variations of the basic Ohm's Law equation set.
- The through-resistance is based upon the form $R = \frac{E}{I}$ .
  - In this case, the full test circuit voltage is used, which is made up of the series limiting resistance (6209Ω) and the meter resistance (79.1Ω) for a total of 6288.1Ω, applied against the test voltage of 6.00V.
- The voltage across the meter is based upon the form $E = I \times R$, but because we are interested only in the voltage across the meter, we use only the meter resistance of 79.1 and the calculated meter current of 0.954mA.

# Those Other Equations

- The remaining equations are those for the series resistance for voltage range extension $(R_S)$ and the parallel resistance for current range extension $(R_P)$...
  - $R_S = R_M \times (M - 1)$, and
  - $R_P = \frac{R_M}{(M-1)}$.
- There is *one* other equation of interest…
  - $R_M = \frac{V_M}{I_M}$.

- Let's explore the first equation, that for $R_S$…
  - $R_S = R_M \times (M-1) = 79.1\Omega \times 49 = 3875.9\Omega$
  - The closest standard value to that calculated resistance will be 3.9kΩ, which will be suitable for this use. Thus, for an 50X voltage rage increase with a meter having a 1mA full-scale current, the $R_S$ value would be 3.9kΩ.
- Now let's look at the next one, that for $R_P$…
  - $R_P = \frac{R_M}{(M-1)} = \frac{79.1}{49} = 1.61428\Omega \text{ or } 1.6\Omega$
  - The best option here would be a 1% precision resistor at that value.
  - However, the power rating of the resistor becomes important, as it will flow enough current to kick the power value up.

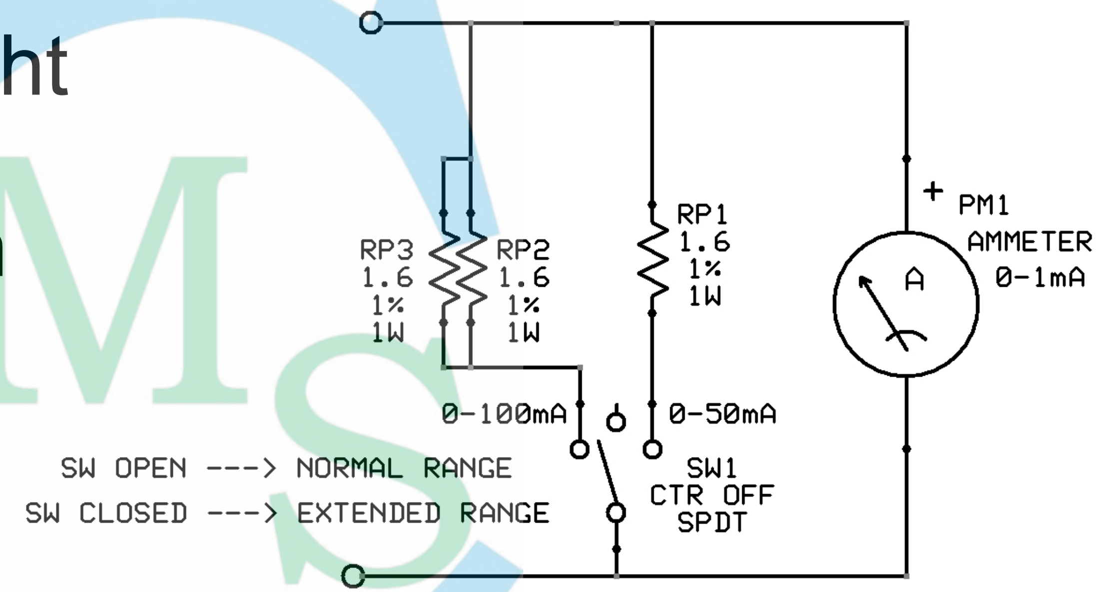
- In this situation, if we consider the highest voltage that will be impressed upon the circuit, we will find that we need more than the usual ¼-watt resistor here…
  - In the circuit for which this change is meant to be applied, the maximum voltage present will be 9VDC, and the maximum current will be the full-scale current value of the modified meter circuit, or 50mA.
  - Thus, $9VDC \times 0.050A = 450mW,$ meaning that at least a 500mW resistor is called for.
  - Because I like to build in some power headroom, I will opt for a 1W resistor here.

- All of this is being done to extend the current range of the built-in ammeter on a Radio Shack model 28-280 Electronics Trainer that I am giving to one of my grandsons.
- This unit has several red LED's installed, as well as some other goodies, and I want him to be able to accurately measure the current flow in the various circuits that he will build.
- However, the 0-1mA range of the ammeter is not sufficient – *e.g.,* the current draw of a typical red LED is somewhere between 20mA and 30mA – well beyond the meter's 0-1mA range limit.
- The fix is to extend the meter's current range.

- This got me thinking about it, and I next wondered if the 50mA range increase is really enough.
- I decided that I wanted to add two new current ranges to this meter installation.
- I decided on the my original 0-50mA range extension, and I added a 0-100mA range extension as well.
- As shown on the next slide, adding these two ranges, and making them selectable, meant that I would need to install two parallel resistances *and a selector switch* to make the range changes possible.

# Dual Ranges Added to Meter

- The schematic at right shows how the two range extenders can be added to the original circuit.
- Note that the switch chosen has a center-off position, which reverts the meter to its base 0-1mA range.




- The next slide will discuss the second range extension.

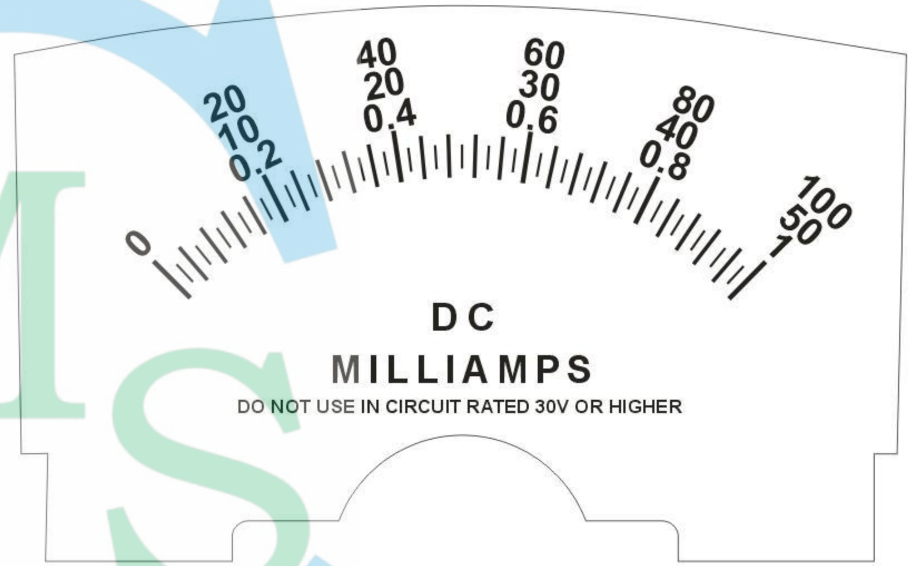
- In this case, the second range extension is to a level of 0-100mA, which changes the $R_P$ equation as follows:
  - $R_P = \frac{R_M}{(M-1)} = \frac{79.1}{99} = 0.7989\overline{89}\Omega$ or $0.80\Omega$
- This was almost predictable, as the range extension is twice what we sought originally, so the resistance required would have to be half of the original resistance needed, and it worked out exactly like that.
- The *power,* however, is a different story.

- With this change, the power handling capability requirement is now increased to a level of 900mW as can be calculated…
  - $9VDC\, x\, 0.100A = 900mW$
- This means that a 1W resistor is the minimum, and if I want my headroom, a 2W capability is called for.
- As luck would have it, I can achieve the required 0.80Ω by using two of the 1.6Ω resistors in parallel.
- This gives me the power capability of both of those resistors, for a total of 2W of power rating for the parallel pair.

# Radio Shack 28-280

# Meter Modifications

- I created a new face plate label for the panel meter on the unit, and installed it to the meter.




- I then installed a SPDT center-off switch to the panel under the meter.
- I finished by installing a new tag to the meter bezel with its new ranges listed there.

- This is the result of the modifications made to the meter installed on the Radio Shack 28-280 Electronics Trainer.
- Note the modified meter scale, the meter bezel label, and the switch with its positions marked below the meter.


# Conventional Uses

- As a final note, it should be understood that almost all commercially-produced multimeters use this methodology to control voltage and current ranges offered by the instrument.
  - The front panel Range or Function switch switches in the correct resistances in the correct circuit configuration for modifying the meter's ranges.
  - Series resistances switched in vary the voltage range, while parallel resistances switched in vary the current range.

# *Questions?*

***Please direct any questions or comments to me at chris@ad2cs.com.***