Mid-Atlantic Antique Radio Club

Collecting and Preserving Our Electronics Heritage

METER REPLACEMENT

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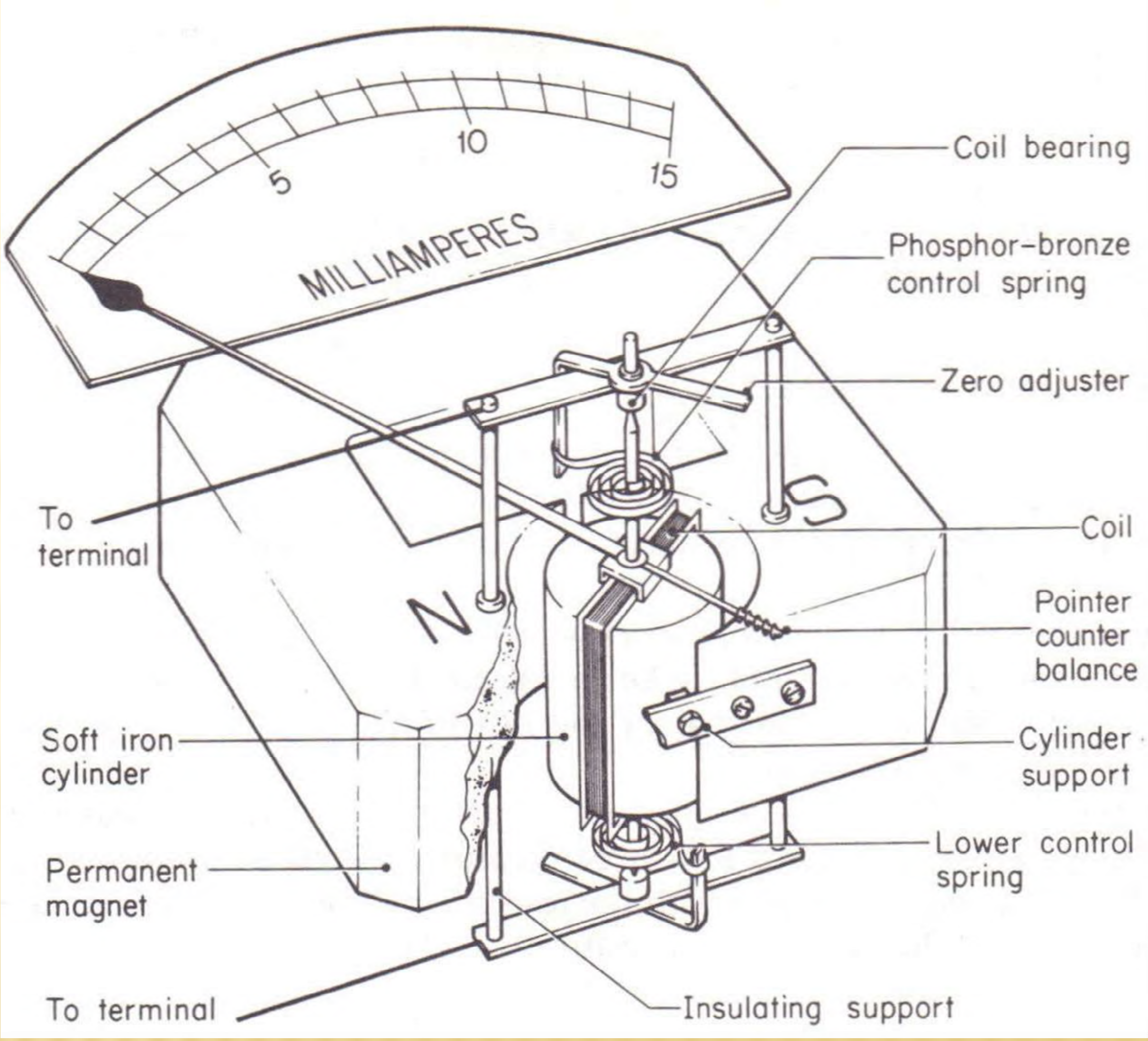
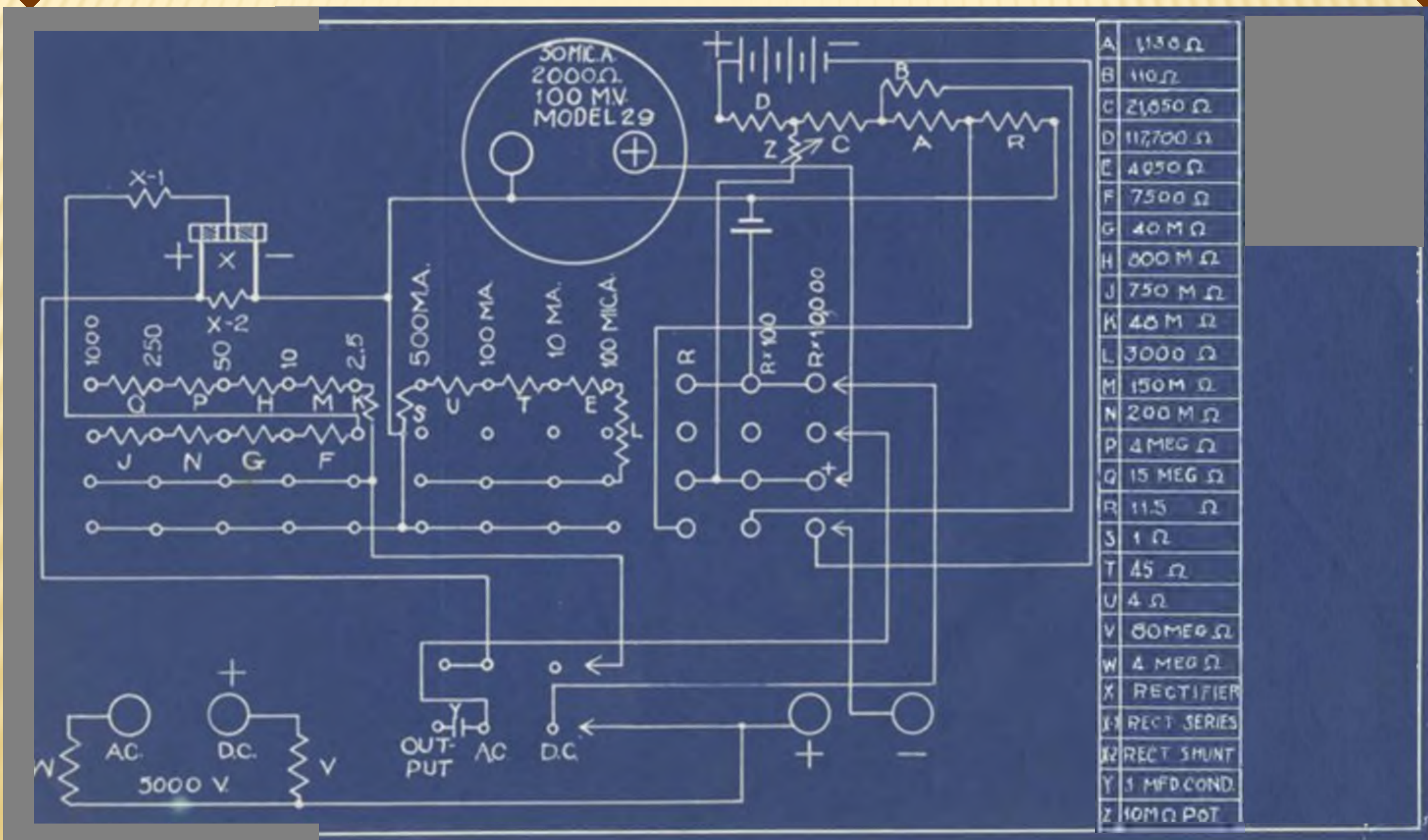
METER CONSTRUCTION – D'ARSONVAL MOVEMENT

- Permanent magnet
- Soft iron cylinder and coil
- Control springs
- Zero adjuster
- Coil bearings
- Pointer counter balance
- Terminal feeds



ONE METER – MULTIPLE APPLICATIONS

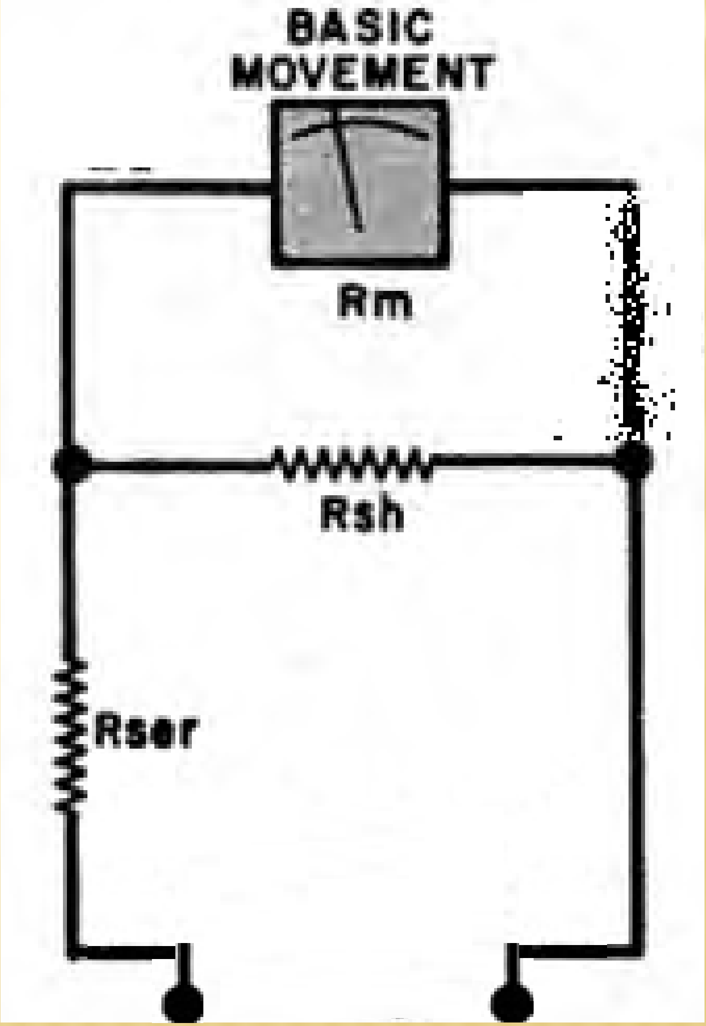


METER CHARACTERISTICS

- Most meters are very linear
- Full Scale (f.s.) Sensitivity
  - Generally in milliamperes (mA) or microamperes (μA) (higher values achieved using shunt resistors)
  - Determined by the number of windings - the more windings, the greater the magnetic field generated, and the more sensitive the meter
- Internal Resistance
  - ohms (Ω)
  - Also determined by the number of windings - the more windings, the greater the internal resistance

METER 'TRIMMING'

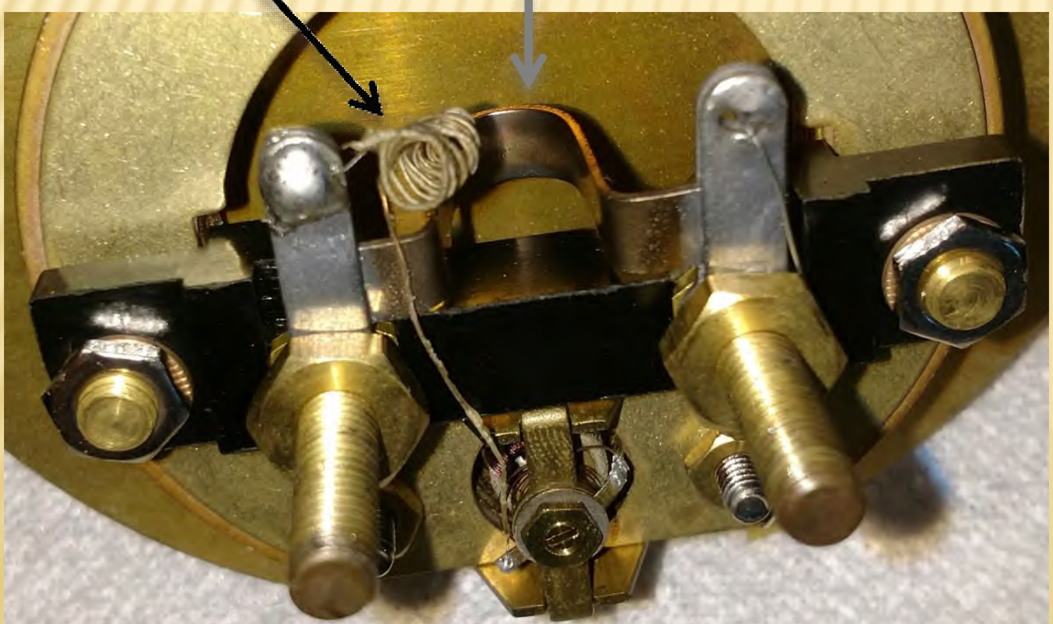
- Many meters use a resistor in series (Rser) to bring the meter up to the desired Internal Resistance (Rm)
- Meters can also have a shunt (Rsh) to adjust their f.s. sensitivity
- Resistors may be internal or external to the meter



METER RESISTOR EXAMPLES

In series wire coil resistor to bring meter up to internal resistance

In parallel shunt resistor to reduce total meter f.s. sensitivity (10 A meter, low resistance shunt)



In parallel wire spool shunt resistor to reduce total meter f.s. sensitivity

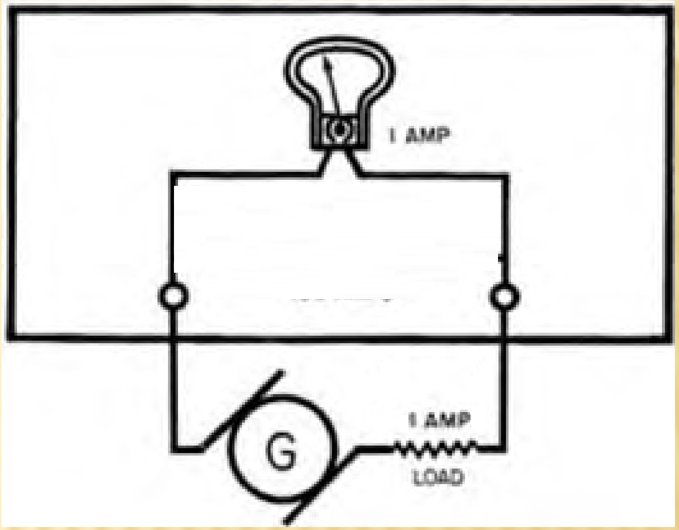
METER USES

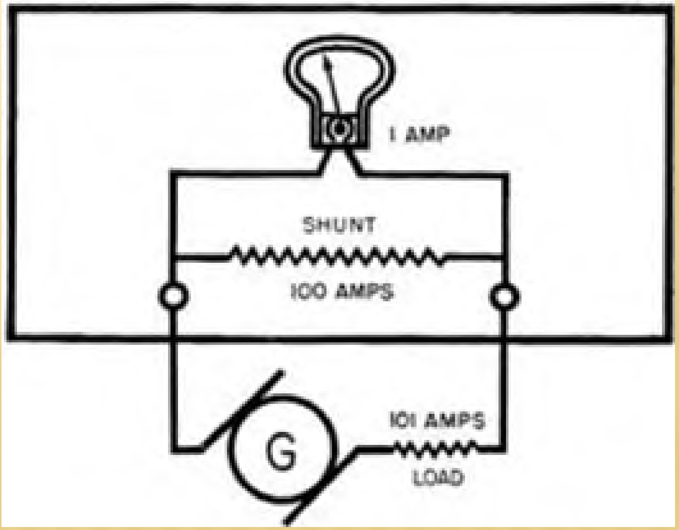
- D'arsonval meters measure D.C. amperage (current) when positioned in series to the load
  - Shunt resistors (in parallel to the meter) allow the same meter to have lower sensitivity and measure higher amperages
- D'arsonval meters positioned in parallel to the load measure D.C. voltage
  - Resistors in series to the meter (multipliers) allow the same meter to measure higher voltages
- D'arsonval meters can also be used as an ohmmeter
- D'arsonval meters used un conjunction with a diode bridge will measure A.C.

AMMETER

- A 1 amp ammeter measures up to a 1 amp load as (as produced by generator [G])

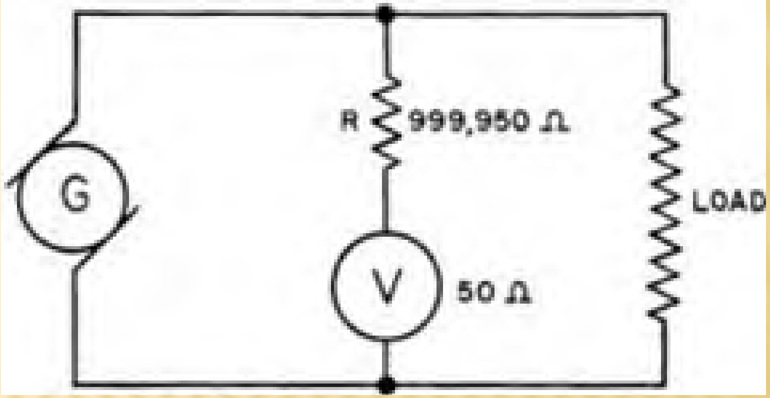
- Add a 100 amp shunt resistor and a 1 amp ammeter can measure up to a 101 amp load





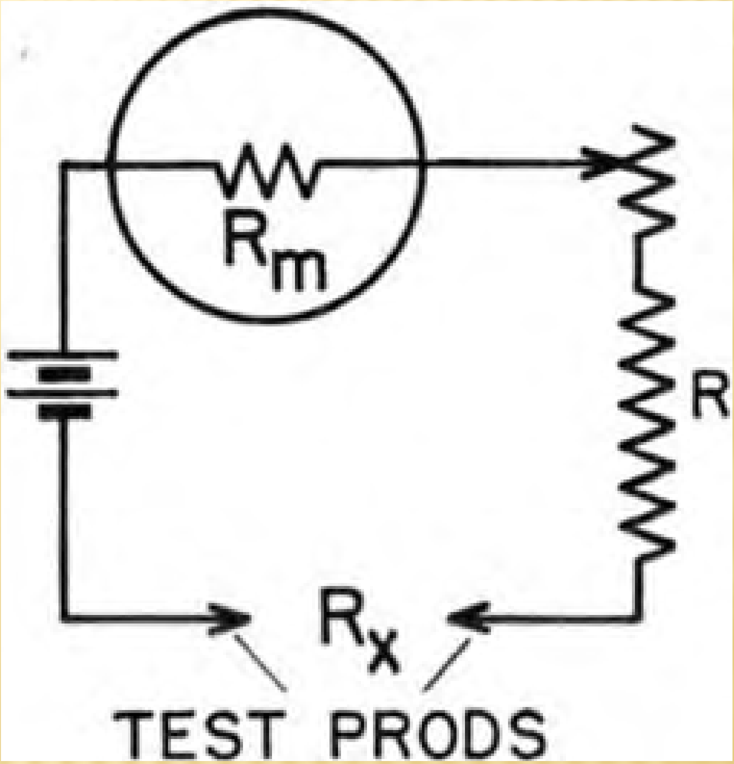
VOLTMETER

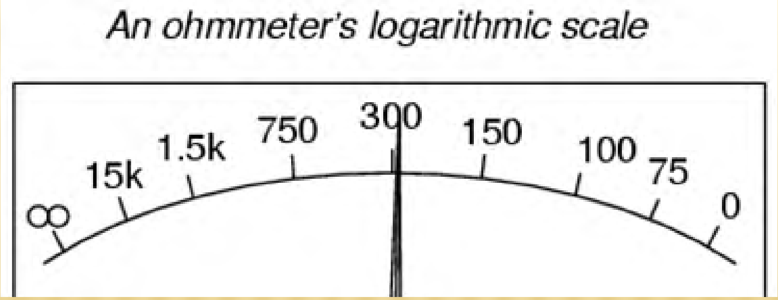
- The same voltage potential (from generator [G]) exists across the load and across the meter and multiplier resistor (R)
- If voltmeter has 50Ω internal resistance, and a f.s. sensitivity of 500 mA (.0005 A), and you add a 999,950Ω resistor in series with the meter, it presents a 1MΩ resistance across the voltage potential
- This 500mA ammeter will measure: V= IR = .0005A x 1,000,000Ω = 500V f.s. as a voltmeter
- Reduce voltage to 250V, meter will read half scale



OHMMETER

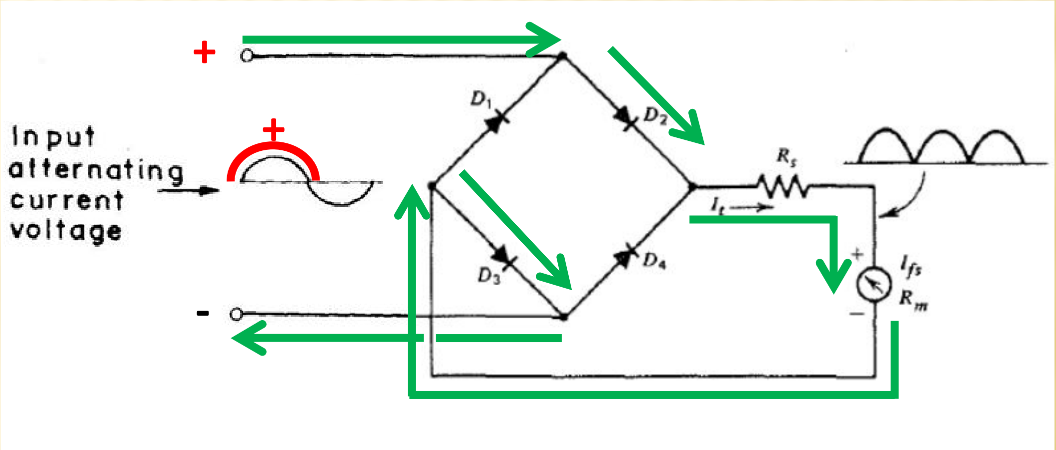
- Resistor (R) and the meter resistance (Rm) are in series with a D.C. voltage source and a variable resistor
- When test prods are shorted (0Ωs), the variable resistor is adjusted to cause the meter to read full scale – f.s. = 0Ωs
- Increased resistance across the test prods decreases circuit current and causes the meter to read less than f.s.
- Meter scale is calibrated to read resistance in ohms





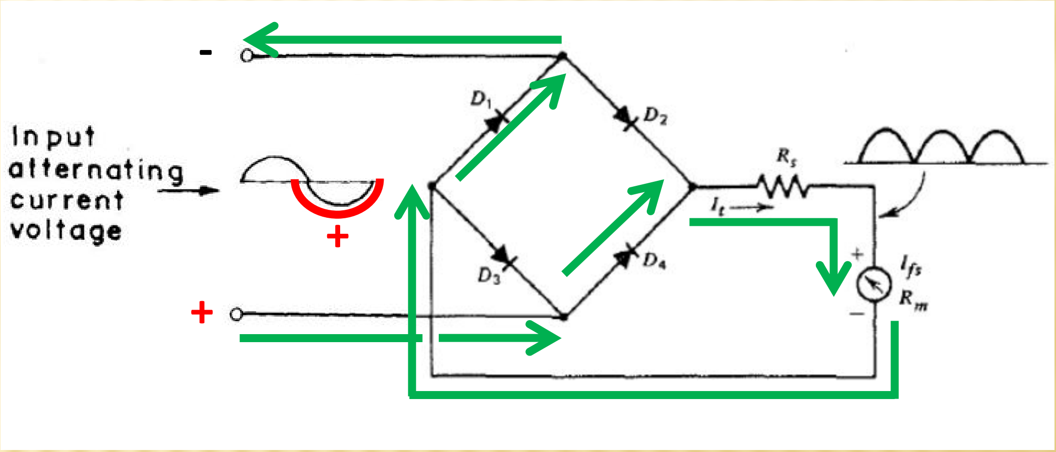
A.C. VOLTMETER

- D'arsonval meter measures D.C. amperage
- When A.C. voltage is positive at the top lead and negative at the bottom lead, current flows through Diode D2, through the in series multiplier resistor (Rs), through the meter, through diode D3, and to the bottom lead



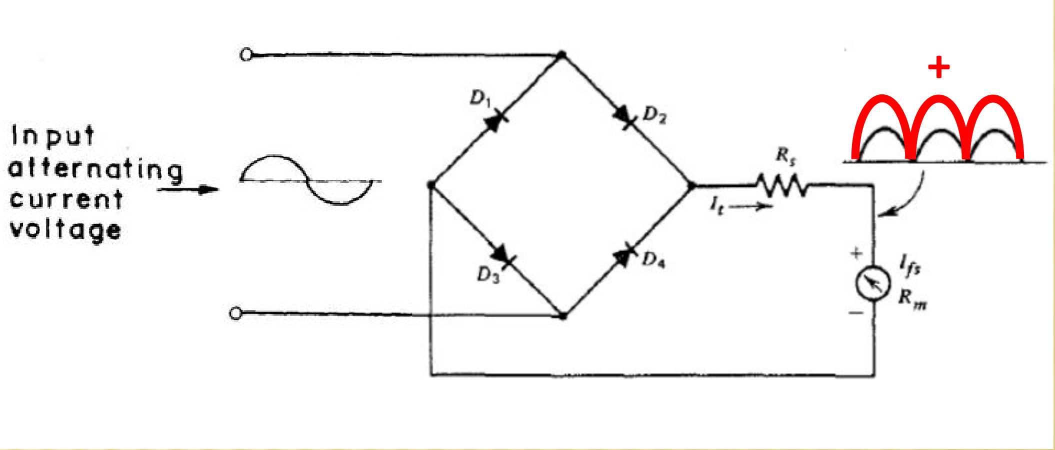
A.C. VOLTMETER

- When A.C. voltage is positive at the bottom lead and negative at the top lead, current flows through Diode D4,
  through the in series multiplier resistor (Rs), through the meter, through diode D1, and to the top lead



A.C. VOLTMETER

- The meter reads the route mean square (RMS) of the voltage



METER ISSUES

- Sticky meter – Pointer stops at some point on the scale
  - Usually caused by lint, dirt, or metal chips touching the coil or pointer
  - Remove debris with a small sharp object or masking tape
  - Do not touch the delicate springs or coil
- Friction – slow movement, and when tapped, point moves
  - Usually caused by dirty or dull pivots, or cracked bearings
  - May be able to loosen the jewel screw, or may not be repairable
- Balance – Meter zeros differently when horizontal or vertical
  - Usually caused by poorly adjusted pointer counter balance
  - Pointer may have adjustable weights, a flexible "tail weight" which is bent until balanced, or adding weight using quick-drying paint or shellac
- Static charge affecting meter movement
  - Use an antistatic spray, or make your own (8oz water, 2 oz rubbing alcohol, and a drop or two of dishwashing liquid soap)
- Check for loose internal resistors – re-solder
- Burnt springs or coils are not repairable – must replace the meter

METER REPLACEMENT

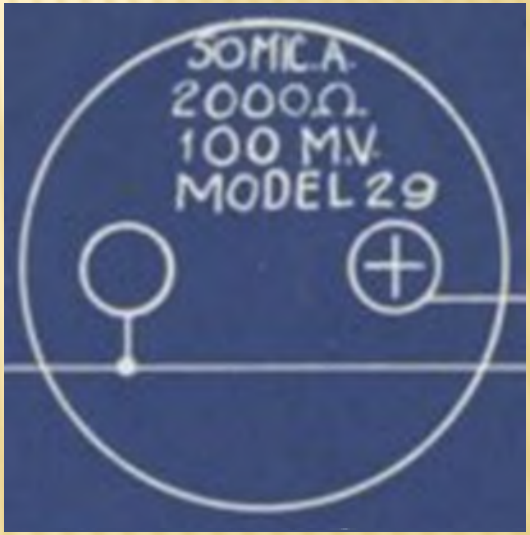
- “Any moving-coil meter can be replaced with another of the same or greater sensitivity” – Alan Douglas
- Most meter movements can be refurbished and custom designed to suit just about any metering need imaginable
- The process is relatively simple

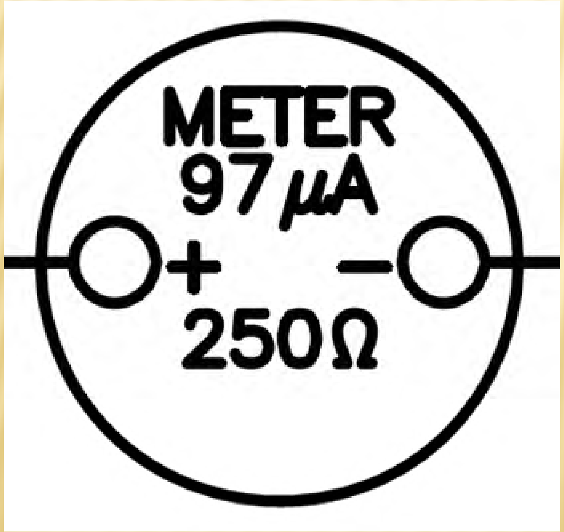
DETERMINING A SUITABLE REPLACEMENT METER

- The replacement meter must have:
  - the same or less f.s. sensitivity (in amps, mA, or µA)
  - the same or less equivalent f.s. voltage determined by multiplying the f.s. amperage by the internal resistance in ohms (generally in mV)
- Schematics usually show the required meter sensitivity and internal resistance
- Will want the meter to have the same characteristics as the original meter
  - Same shape (round, rectangular, square)
  - Same size
  - Same style (glass lens, plastic lens, classic look, modern look)
  - Same movement arc (typically 90 degrees)

STEP 1 - DETERMINING REQUIRED METER SENSITIVITY

- Most schematics show meter characteristics
- Simpson Multimeter - 50 mA f.s.
  2,000Ω internal resistance,
  100 mV f.s. = 50mA x 2,000Ω

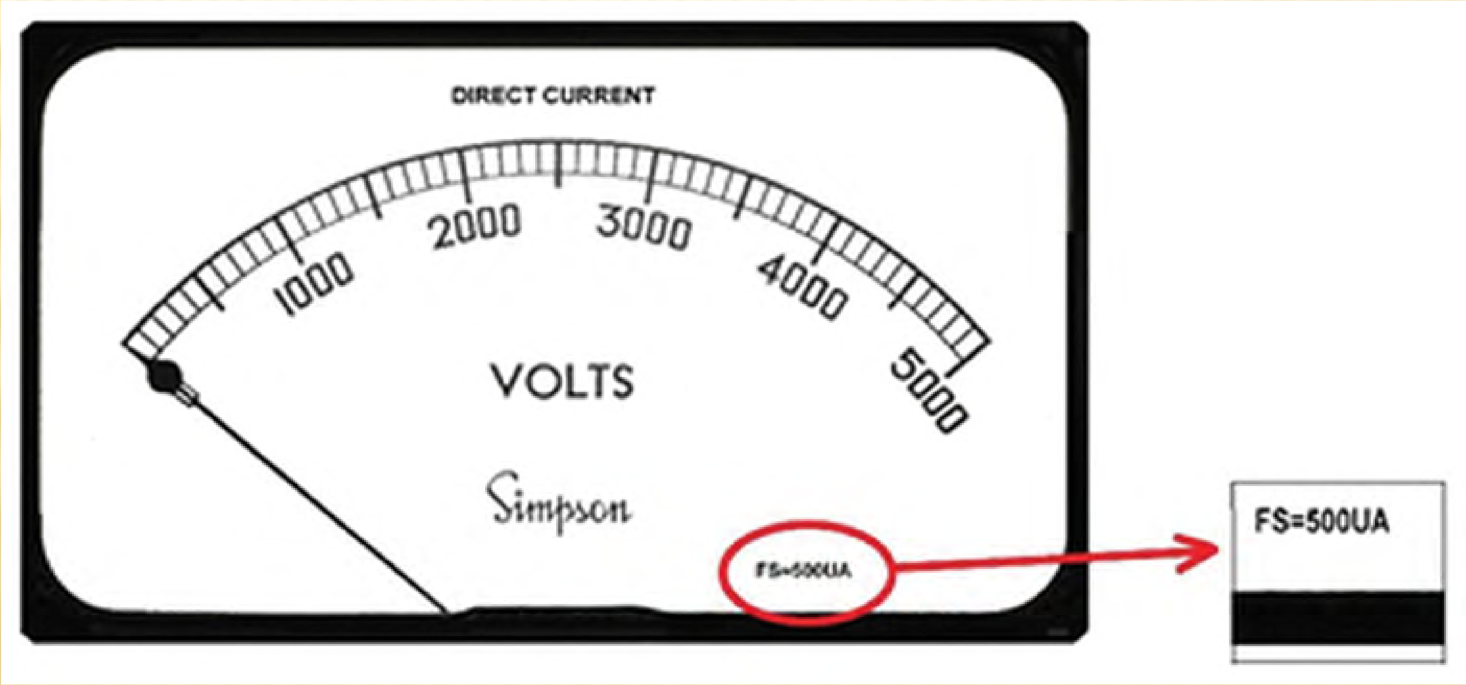




- Hickok 539A
  97µA f.s.
  250Ω internal resistance,
  24.25 mV f.s. = 97µA x 250Ω

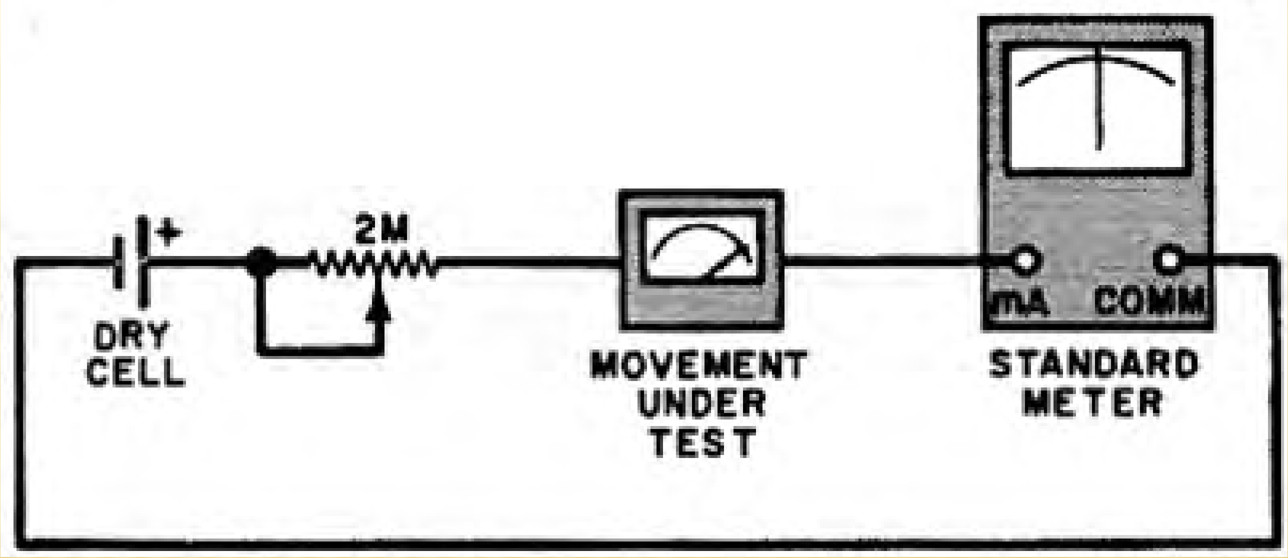
STEP 2 - DETERMINING METER SENSITIVITY

- Some meters show f.s. current on the meter face
- f.s.=500µA - indicating need for a 10 MΩ series multiplier resistor
- Best to measure to ensure it is in spec



STEP 2A - DETERMINING METER SENSITIVITY

- Using a 1.5V battery, a 1MΩ or 2MΩ pot, and an ammeter, measure the f.s. sensitivity
- Turn pot to max before connecting the battery
- Adjust until the meter under test swings to full scale
- Both meters in series read the same current
- Measure the f.s. amperage



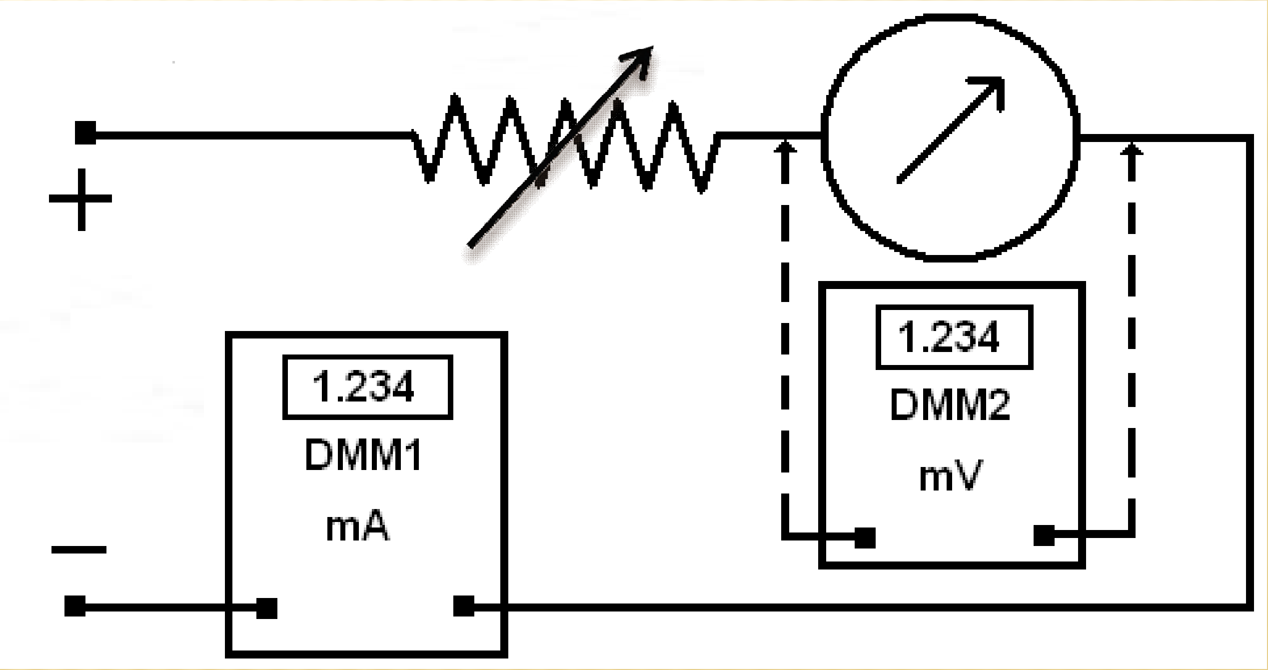
STEP 2A - DETERMINING METER SENSITIVITY

STEP 3 – DETERMINE INTERNAL RESISTANCE

- WARNING – The current supplied by an ohmmeter can damage the movement
- NEVER USE AN ANALOG VOLT METER TO MEASURE INTERNAL RESISTANCE
  - A Simpson 260 can supply 100mA into a low resistance
- Unless you know the meter internal resistance is > 1mA, DO NOT USE A DIGITAL OHMMETER TO MEASURE INTERNAL RESISTANCE
  - Even a self-ranging digital ohmmeter can exceed the meter f.s. limit

STEP 3 – DETERMINE INTERNAL RESISTANCE – USING A VOLTMETER

- A simple method of measuring internal resistance is to measure the current at full scale deflection with a digital ammeter (DMM1), and the voltage drop across the meter (equivalent f.s. voltage) with a digital voltmeter (DMM2)
- Apply Ohms Law:
- R=V(f.s.)/I(f.s.)

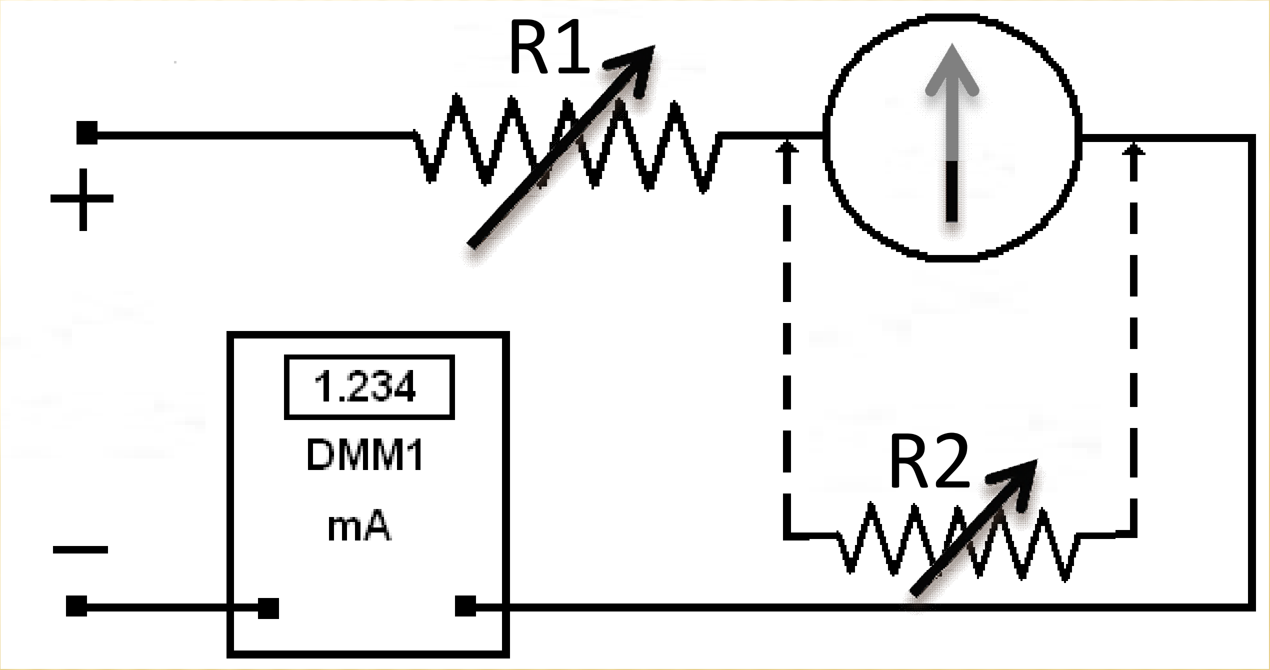


STEP 3 – DETERMINE INTERNAL RESISTANCE – USING A VOLTMETER

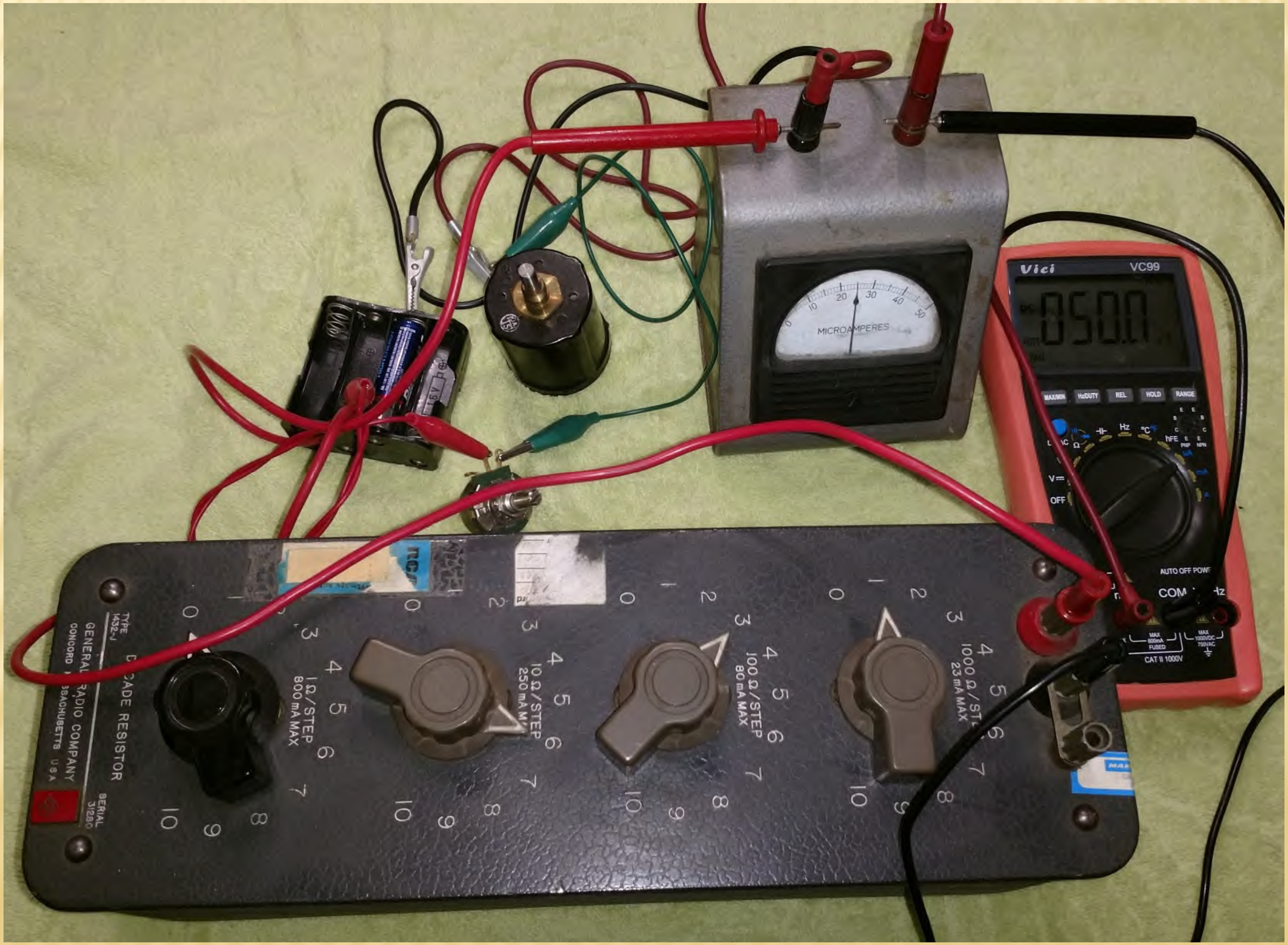
- R = V(f.s.) / I(f.s.)
- R = 68mV / 50µA
- R = .068 V/.00005A
- R = 1,360 Ω

STEP 3A – DETERMINE INTERNAL RESISTANCE – USING A RESISTOR

- Another method of measuring internal resistance is to place a resistor decade box or a variable resistor across meter (R2)
- Increase the resistance of R2 until the meter reads half scale.
- Tweak R1 and R2 so that the digital ammeter (DMM1) reads exactly full scale current, and the meter under test reads exactly half scale
- R2 equals the meter internal resistance

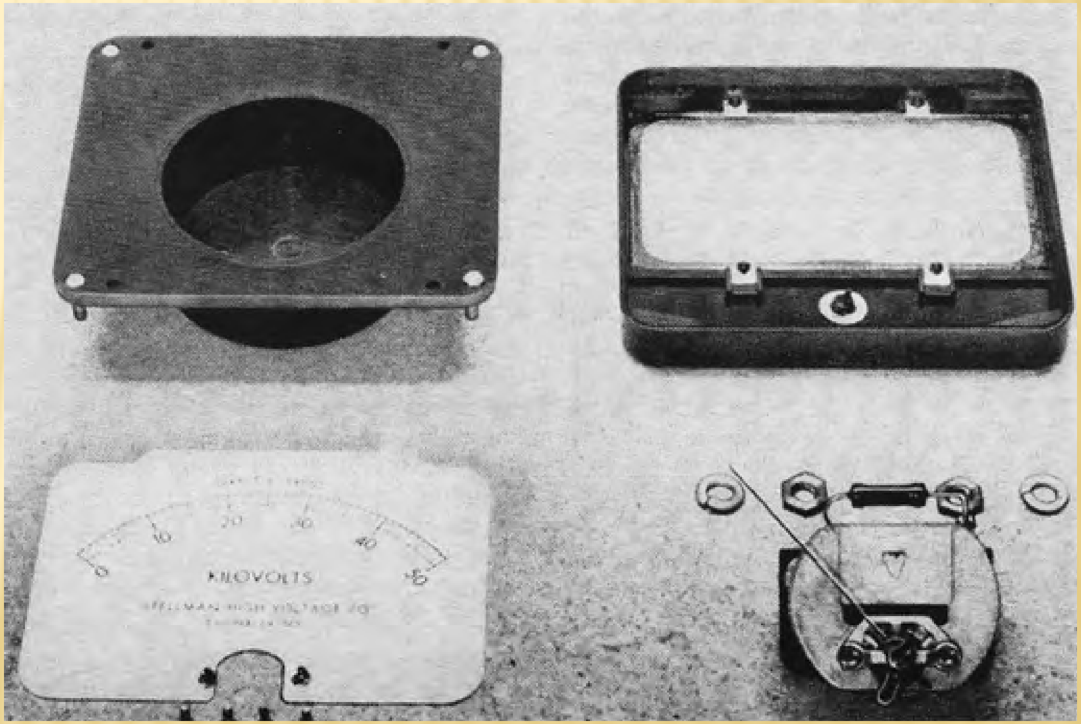


STEP 3A – DETERMINE INTERNAL RESISTANCE – USING A RESISTOR (1,360Ω)



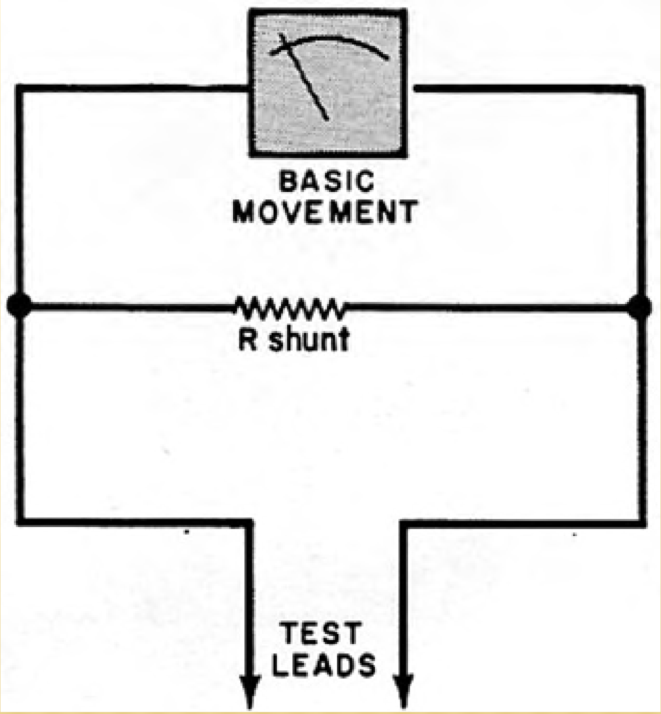
STEP 4 - CLEAN AND DISASSEMBLE CANDIDATE METER

- Clean away all foreign material from case
- Use warm water and soap (rubbing alcohol for greasy buildups)
- Internal resistors may be retained or disposed of (depending on desired use)



STEP 6 – DETERMINE SHUNT VALUE

- Knowing the Internal Resistance (IR) of the candidate meter (Rm), and its f.s. current (Im), we can calculate the shunt required to bring the meter to the correct sensitivity
- Rshunt = Rm x Im / Imax – Im
- To shunt a 50µA meter to handle a 100µA current, and the candidate meter has an internal resistance of 1,360Ω
- Rshunt = 1,360Ω x 50µA / 100µA - 50µA
  = 1,360 x .00005 / .0001 - .00005
  = 1,360 x.00005 / .00005
  = 1,360 Ω
- To shunt a 50µA meter to handle a 200µA current, with the same candidate (internal resistance of 1,360Ω)
- Rshunt = 1,360Ω x 50µA / 200µA - 50µA
  = 1,360 x .00005 / .0002 - .00005
  = 1,360 x .00005 / .00015
  = 453.33 Ω



STEP 7 – DETERMINE SERIES VALUE TO BRING SUBSTITUTE METER TO SAME IR

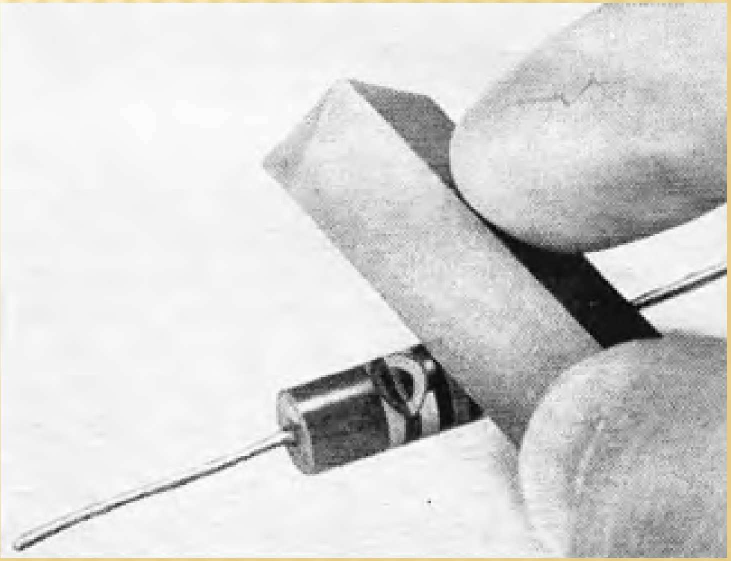
- Knowing the Internal Resistance (IR) of the candidate meter (Rm), and the shunt value required to bring the meter to the correct sensitivity (Rshunt), we can determine the total resistance of the shunted meter (Rt)
- Rt = Rm x Rshunt / Rm + Rshunt
- A 50µA meter with a 1,360Ω internal resistor, shunted with a 1,360Ω shunt
  Rt = 1,360 x 1,360 / 1,360 + 1,360 = 680 Ω
- If the original meter had a resistance of 700 Ω, we add a 20 Ω resistor to bring it to spec (680 Ω + 20 Ω = 700 Ω)
- A 50µA meter with a 1,360Ω internal resistor, shunted with a 453.33Ω shunt
  Rt = 1,360 x 453.33 / 1,360 + 453.33 = 340 Ω
- If the original meter had a resistance of 400 Ω, we add a 60 Ω resistor to bring it to spec (340 Ω + 60 Ω = 400 Ω)

CREATING PRECISION RESISTORS

- Calculated value for needed resistor will not be readily available
- Arrange two or more resistors in series/parallel hookups to yield the required value

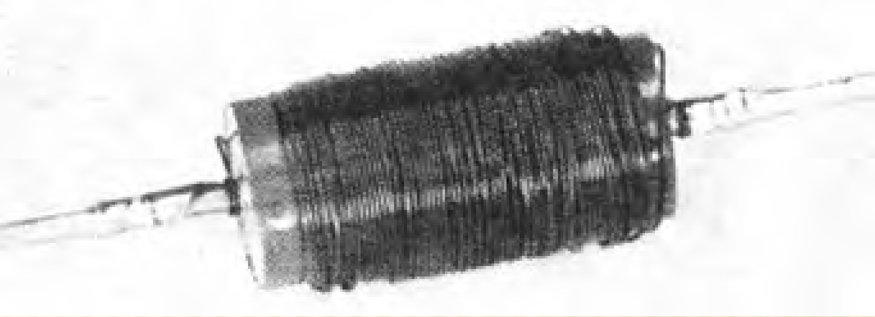
CREATING PRESISION RESISTORS

- Alternatively, "trim" an ordinary carbon resistor with a file
- Select a fixed resistor of slightly lower value than required
- Use a resistance bridge or an ohmmeter to monitor your progress
- Once trimmed to the proper value, coat the notch with coil dope or nail polish to seal out moisture



CREATING PRECISION RESISTORS

- For very low value resistors, wind your own
- Use enamel-coated copper wire wrapped around a high-value resistor (1 MΩ will do)
- Wire gauges and the resistance they yield are given in the Table
- After winding solder the wire's ends to the resistor leads
- Coat the assembly with coil dope or nail polish



RESISTANCE PER UNIT LENGTH OF COPPER WIRE AT 25° C

Gauge	Ohms per 1000 ft.	Gauge	Ohms per 1000 ft.
18	6.510	30	105.2
20	10.35	32	167.3
22	16.46	34	266.0
24	26.17	36	423.0
26	41.62	38	672.6
28	66.17	40	1069.0

STEP 8 – RELABEL THE NEW METER

- Can scan the original meter scale
  - Resize if necessary
  - Print on Card Stock or on vinyl media using either Inkjet or Laser printer https://www.papilio.com/ https://duradecal.com/
- Create a new meter scale
  - Tonne Software Meter http://www.tonnesoftware.com/

METER REPLACEMENT EXAMPLE

- Original Equipment Meter – Hickok 539A
  - 97μA f.s. sensitivity
  - 250Ω Internal Resistance
- Meter must have f.s. sensitivity < 97μA
- Meter must have equivalent f.s. voltage less than that calculated using V=IR
- V=97μA x 250Ω = .000097A x 250Ω = .02425 V or 24.25 mV
- Meter must have equivalent f.s. V < 24.25 mV

HICKOK TUBE TESTER METERS (PARTIAL LIST)

Ohm's Law
V=IR

Model	Sensitivity f.s.	Internal Resistance, ohms	Equivalent mV f.s.
I-177	1.4 mA	80	112
560 (KS 9237)	1.4mA	80	112
533A	500 µA	233	116
TV-3 *(with VOM 1k ohms per volt)*	200 µA	2365	473
TV-3C *(with VOM 20k ohms per volt)*	50 µA	1150	57.5
TV-10D	200 µA	2350	470
KS 15560	200 µA	2365	473
KS 15750	120 µA	1500	180
539C	115 µA	1500	172.5
750	280 µA	645	181
799	500 µA		
6000A	100 µA	1165	116.5
600	500 µA		
605 *(with VOM 20k ohms per volt)*	50 µA		
TV-7	200 µA	2355	471

POSSIBLE CANDIDATES

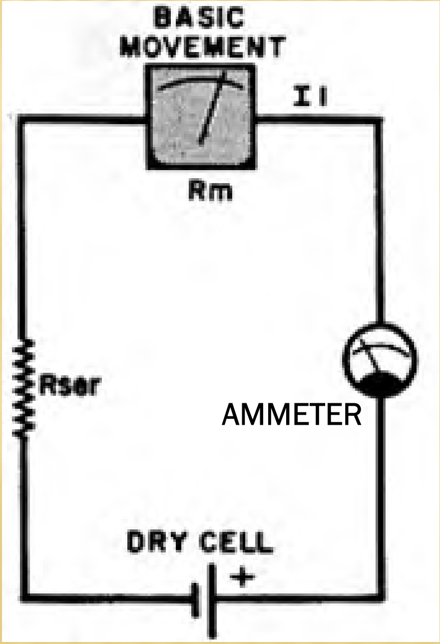
	O.E.	50µA Candidate	Simpson 50µA	50µA Meter from earlier
Sensitivity (f.s.)	97µA	50µA	50µA	50µA
Internal Resistance (R=V/R)	250Ω	<=485Ω	1,800Ω	1,360Ω
Equivalent f.s. Voltage (V=IR)	V=IR .02425 V or 24.25 mV	<=24.25mV	90mV	68mV
Comment			Not a viable candidate	Not a viable candidate

REFERENCES

- ***Tube Testers and Classic Electronic Test Gear*** – Alan Douglas, 2000
- ***How to Make Custom Meters from Salvaged Parts**, April 1974 Popular Electronics* - Prof. Robert Koval
- ***Analog meters - The joy of movement*** - David Ashton - April 12, 2015 - *https://www.embedded.com/electronics-blogs/embedded-down-under/4439175/Analog-meters---The-joy-of-movement*
- ***Analog meters - Getting the most out of your meter*** - David Ashton - APRIL 29, 2015 - https://www.embedded.com/electronics-blogs/embedded-down-under/4439317/Analog-meters---Getting-the-most-out-of-your-meter-
- ***Electricity - Basic Navy Training Courses, NAVPERS 10622*** – 1945 - *Chapter 18 ELECTRICAL METERS*
- ***Tonne Software*** - *http://www.tonnesoftware.com/*
- ***Papilo Vinyl Print Media*** - *https://www.papilio.com/*
  https://duradecal.com/

STEP 3 – DETERMINE INTERNAL RESISTANCE

- To determine the meter's Internal Resistance (Rm), use two resistors of known value, a 1.5V battery, an ammeter, and this circuit
- Chose a series resistor (Rser) using ohms law (V=IR) to result in a current (I1) that will cause the meter under test to read in the top third of the meter scale
- Record the current (I1) on the ammeter



STEP 3 – DETERMINE INTERNAL RESISTANCE

- Add a shunt resistor (Rsh) that is 1/10 to 1/20 the value of the series resistor to the circuit and record the current (I2)
- Knowing the resistor and current values, calculate the meter Internal Resistance (Rm) using this formula:

$$Rm = \frac{Rser \times Rsh \times (I1 - I2)}{Rser \times I2 + Rsh \times (I2 - I1)}$$