Number 55: Ayrton Current Shunt Circuit:

(TechTalk #130)

by: Bob Eckweiler - AF6C

INTRODUCTION:

Heathkit of the Month # 124 discusses the EUW-18 Laboratory Meter. This meter is a standard 1 mA milliammeter with an internal meter resistance of 50Ω and with two scales 0 –5 and 0–15. Originally it came with four shunts to allow the meter to measure 1.5 mA, 5.0 mA, 15 mA and 50 mA full-scale. Unfortunately the shunts were missing when the meter was acquired, but a 150 mA shunt was made using three paralleled 1.0 Ω 1% resistors.

Recently, Chuck Penson WA7ZZE: sent me a textbook: *Electronics for Scientists*, by H. V. Malmstadt and C. G. Enke; these are the engineers who inspired the **Malmstadt–Enke Instrumentation Lab** by Heath. In it I found a discussion of the Ayrton shunt circuit. It was a circuit I was familiar with, having worked in aerospace instrumentation for nigh-on 35 years, but never had heard it called by that name.

Reading the discussion, I thought it might be a practical solution to replace the missing shunts for the EUW-18 lab meter. If I was

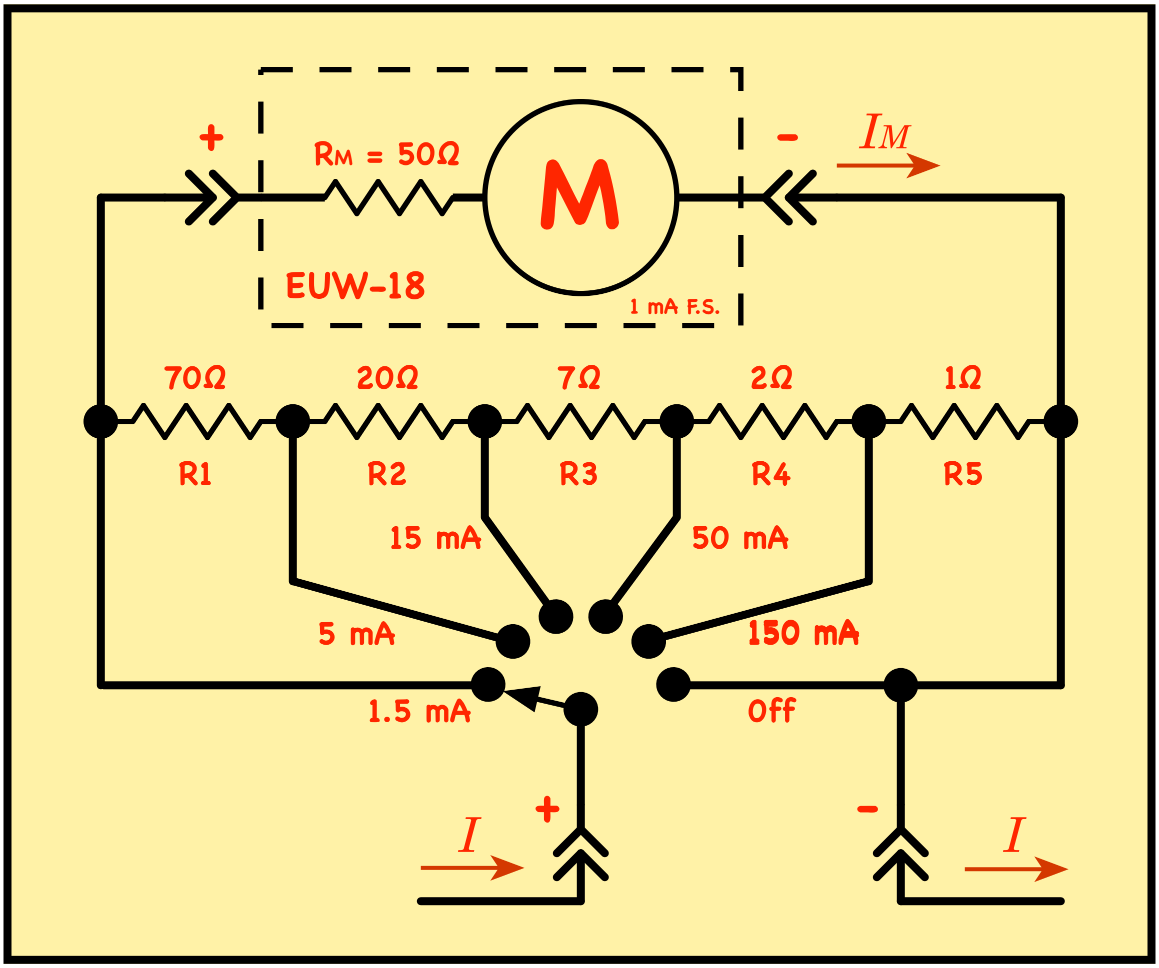

Figure 1: Ayrton Shunt Circuit for the Heath EUW-18 Lab Meter.

lucky, the resistor values needed would be close to standard 1% values available at electronic parts dealers.

The Ayrton Shunt:

Figure 1 is my schematic of an Ayrton shunt designed for the EUW-18 Laboratory Meter. The shunt allows switch selection of one of five ranges between 1.5 mA and 150 mA in 15, 50 steps to match the meter scales. It also has an OFF position which effectively disconnects the meter.

Figure 2 is a simplified schematic showing the basic circuit. The current to be measured, ***I***, is split into two resistive paths, one is the resistance ***r***. the other is the resistance composed of ***R* - *r* + *Rm*.** ***N***ote that ***r*** is different for each switch position, as shown in Figure 1. The two resistance paths are in parallel, so they both have the same full-scale voltage across them. For the left branch:

$$E = I_m(R_m + R - r) \qquad \text{(Eq. 1)}$$

and, for the right branch:

$$E = (I - I_m)r \qquad \text{(Eq. 2)}$$

Setting Eq. 1 equal to Eq. 2 yields:

$$(I - I_m)r = I_m(R_m + R - r) \qquad \text{(Eq. 3)}$$

Expanding, then simplifying:

$$Ir - I_m r = I_m R_m + I_m R - I_m r$$

The two $(-I_m r)$ terms cancel, and:

$$\frac{I}{I_m} = \frac{R_m + R}{r} \qquad \text{(Eq. 4)}$$

The values chosen for the meter in this discussion come from the specification of the meter used in the EUW-18 Lab meter:

$$I_m = 1\text{ mA}, \qquad R_m = 50\Omega$$

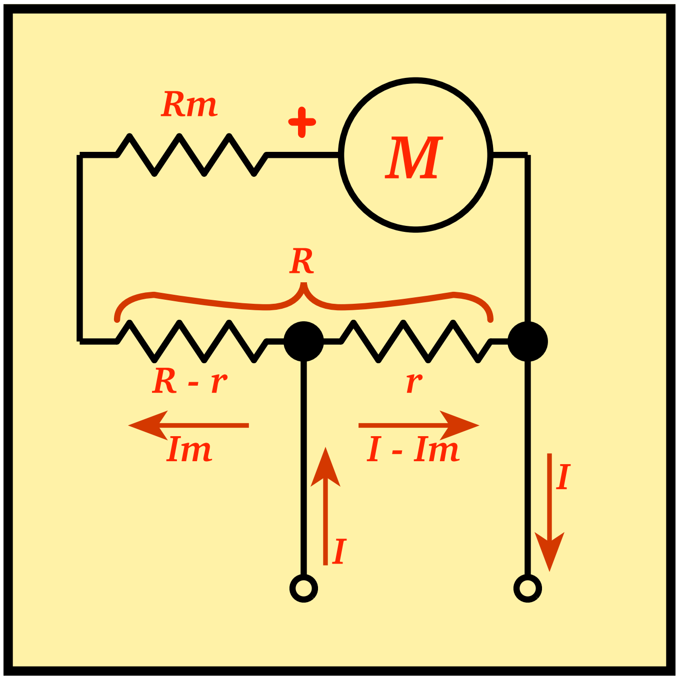

Figure 2: Basic Ayrton Shunt Circuit

Other meters may have different values.

I/I_m is the ratio of the total current to the meter current. For the EUW-18 these ratios are 1.5, 5, 15, 50 and 150 for the five currents - 1.5 mA thru 150 mA.

To determine the actual resistances r_1 through r_5, start with the lowest current range (1.5 mA) where:

$$R = r = r_1 + r_2 + r_3 + r_4 + r_5 = r_{(1-5)}$$

Thus, from Eq. 4:

$$\frac{I}{I_m} = 1.5 = \frac{R_m}{r_{(1-5)}} + \frac{R}{r_{(1-5)}} = \frac{50}{r_{(1-5)}} + 1$$

$$r_{(1-5)} = \frac{50}{0.5} = 100\Omega \qquad \text{(Eq. 5)}$$

And ***R***, the sum of $r_1 \ldots r_5$, is **100 ohms**.

Now we look at the switch in the next lowest current position, 5 mA. Now the ratio between I/I_m is 5, and now:

$$r = r_2 + r_3 + r_4 + r_5 = r_{(2-5)}$$

Again, using Eq. 4:

$$\frac{I}{I_m} = 5 = \frac{R_m + R}{r_{(2-5)}} = \frac{50 + 100}{r_{(2-5)}}$$

$$r_{(2-5)} = \frac{150}{5} = 30\Omega \qquad \text{(Eq. 6)}$$

repeating for the next three positions of the switch results in:

$$r_{(3-5)} = 10\Omega \qquad \text{(Eq. 7)}$$

$$r_{(4-5)} = 3\Omega \qquad \text{(Eq. 8)}$$

and $r_5 = 1\Omega$ (Eq. 9)

Now it is simple to find the actual resistor values R_1 through R_5 by using the results of Eq. 5 through Eq. 9:

$$R_1 = r_{(1-5)} - r_{(2-5)} = 100 - 30 = 70\Omega$$

$$R_2 = r_{(2-5)} - r_{(3-5)} = 30 - 10 = 20\Omega$$

$$R_3 = r_{(1-3)} - r_{(1-2)} = 10 - 3 = 7\Omega$$

$$R_4 = r_{(4-5)} - r_5 = 3 - 1 = 2\Omega$$

$$R_5 = 1\Omega$$

20Ω, 2Ω and 1Ω are standard 1% values. 70Ω and 7Ω are not. However, the closest 1% values are 69.8Ω and 6.98Ω respectively, which is within 0.2%, and well within the 1% tolerance of the 1% resistors.

Resistor Wattage:

When working with shunts it is always wise to make sure the resistors can handle the current. Remember, the wattage dissipated in a resistor increases as the square of the current, so it can increase quickly with increasing current. In the case of the circuit of **Figure 1**, the currents are all quite small. Still it is worth checking:

The maximum current each resistor will see when the meter is reading full-scale is:

$$W_R = I^2 R$$

Table I shows the maximum power in milliwatts that each resistor will dissipate. 250 mW (¼-watt) resistors, in the worse case will give more than a 10 fold safety margin.

RESISTOR DISSIPATION CHECK

#	I mA	I² mA²	R Ω	W mW
R1	0.5	0.25	70	0.02
R2	4.0	16.0	20	0.32
R3	14.0	196.0	7	1.37
R4	49.0	2401.0	2	4.80
R5	149.0	22201.0	1	22.20

TABLE I: RESISTOR MAX POWER DISSIPATION

Ayrton Advantages and Disadvantages:

The Ayrton current shunt has advantages of a simple design, superior meter protection, often uses more common resistor values, and allows shunts to be hot switched.

However, it has one significant drawback; it tends to introduce a higher voltage drop than the standard shunt. For the EUW-18, the standard shunts cause a full-scale voltage drop of 50 mV independent of the shunt current. The Ayrton shunt designed in this article has different voltage drops for each shunt, ranging from 50 mV on the 1.5 mA position to 149 mV on the 150 mA position. This may or may not be a problem and needs to be considered when making measurements.

73, from AF6C

This article is based on the TechTalk article that originally appeared in the July 2024 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.