1. Summary

PYE Scientific Instruments: Portable Wheatstone Bridge (Four Decade Pattern) 7440/G, S/N 31,232 HRSA Dec 2019

High absolute accuracy spec for series (+/- 0.02%) arm, and ratio arms (+/- 0.01%). Four decade pattern of series arm resistors: 10x 1Ω, 10x 10Ω, 10x 100Ω, 10x 1kΩ. Four decade pattern of multiply (LHS) and divide (RHS) arms: each arm with 1Ω, 10Ω, 100Ω, 1kΩ values. All resistors made with manganin coils. Galvanometer indicator with pushbutton Initial and Final keys for damped and protected indication of bridge balance. Battery pushbutton with locking on position. Switch for shorting across meter, or isolating meter (for using external meter).

Terminal posts available for: external meter; ‘bridge arm series’ for adding extra decades and balancing DUT lead resistance; ‘FOR BALANCING RESISTANCE’ to balance DUT lead resistance; and ‘SERIES’ to provide a 4-decade variable standard resistance (limited to <0.5W dissipation in any one step of any decade).

Span of standard resistances is from 1Ω to 11,110Ω using just the decade switches from Series to Series (HI) terminals, but increases to 13,110Ω using the 1kΩ multiply and divide switches (from SERIES to the RHS X terminal).

Power dissipation of any step or any decade, including the multiplier/divider settings, must not exceed 0.5W, and preferably kept below 0.1W (tbd). A 4Ω resistor is in series with the battery terminals to alleviate risk of accidental damage.

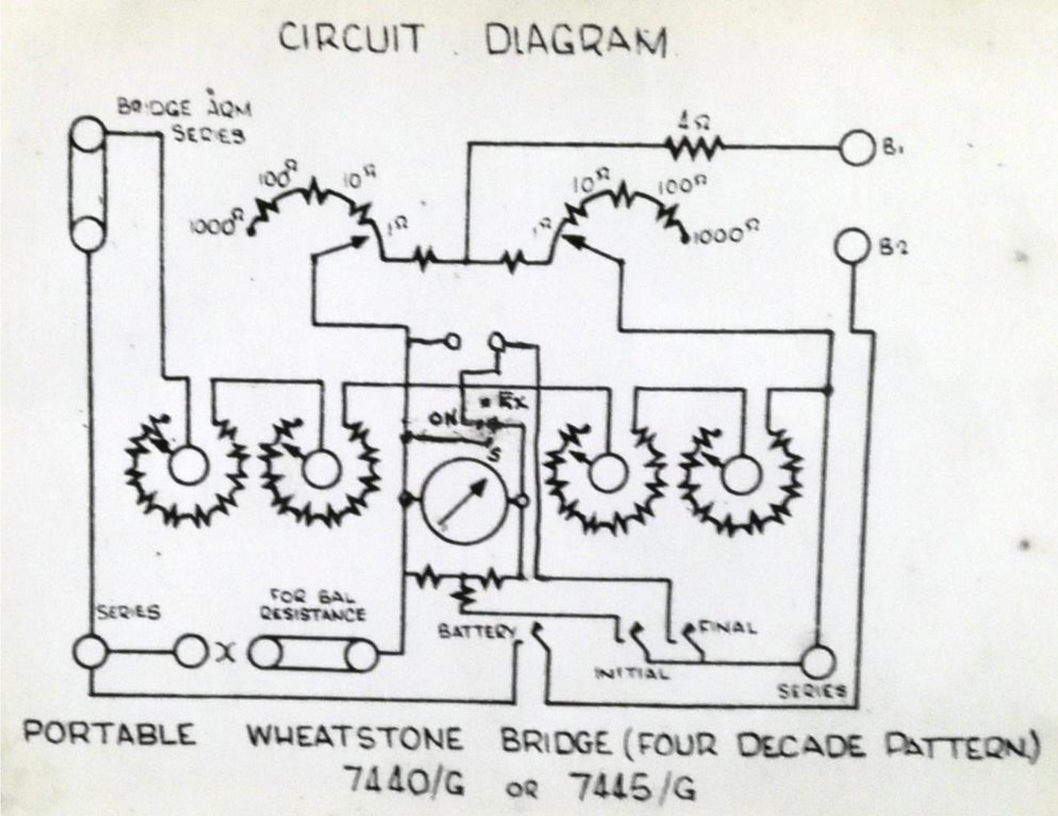
R.H.Cunningham P/L S/N 025. Possibly a test lab instrument within R.H.Cunningham. R.H.Cunningham P/L registered in Dec 1949 in Victoria, and deregistered 1999. Changed to AV Australia in 2000 (Audio Visual Australia P/L).

Circa early to mid 1950, based on Operating Manual Oct-1951 date and S/N.

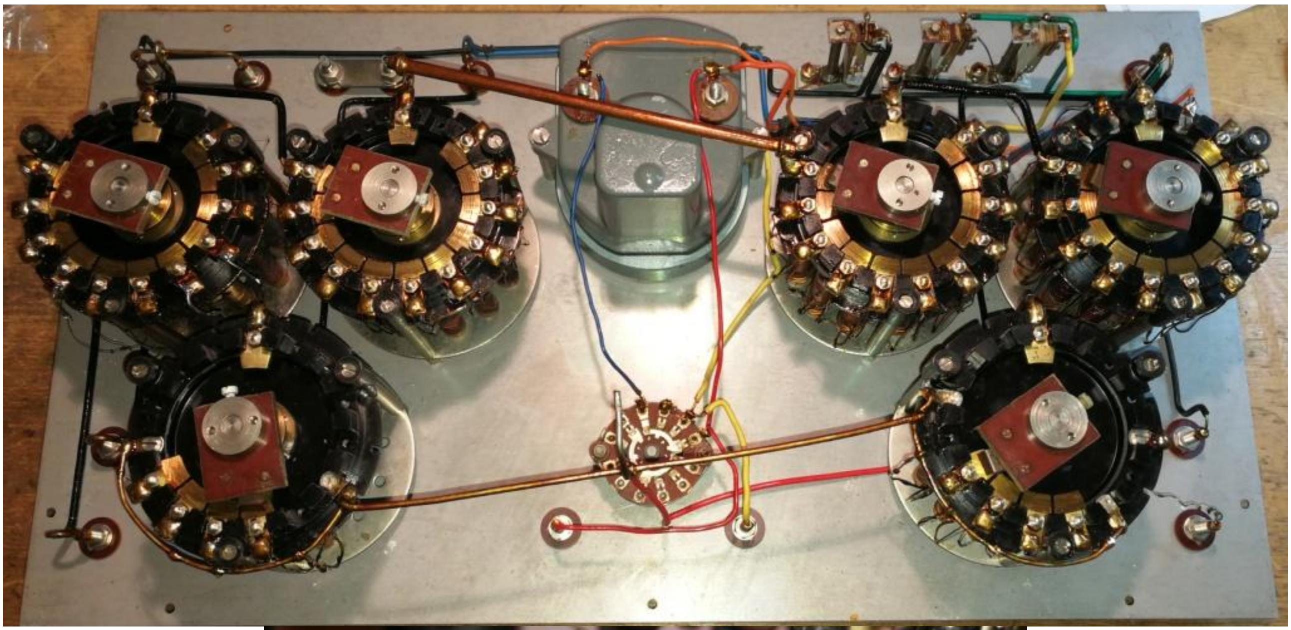
VG external condition and internal condition. Unmodified. 4 broken 1kΩ sections at the lead-in wires in the series arm ‘1000’s’ section. 1 broken 1kΩ section at the lead-in wires in the RHS (Divide) ratio arm section. Final pushbutton needs lube. Meter on/shorted switch shaft seized.

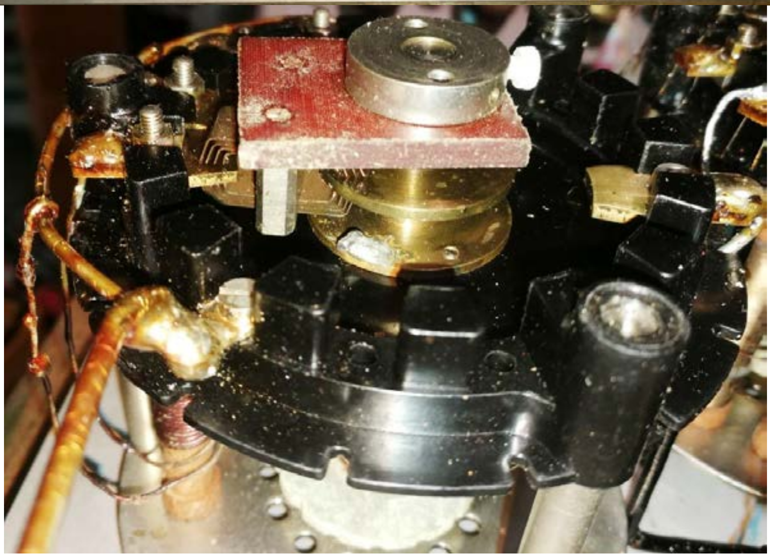
Galvanometer is used with an Ayrton-Mather type of 3 resistor shunt to provide critical damping of the meter movement for Initial and Final pushbutton actions. The shunt resistors are wire-wound on the same bobbin located on the Units decade, with main divider of 140Ω and 1.7Ω, and 1.9Ω to the Initial pushbutton. The meter has a resistance of about 18Ω and sensitivity of 11uA/div (so about +/-28uA or 0.5mV FS) with Final, and about 10mV FS with Initial.

The external meter is only connected with the Final pushbutton, and can either shunt the internal meter (Switch ON), or not (Switch EX). With the internal meter in circuit, and the Final pushbutton on, about ~16Ω connects between the bridge balancing nodes.



Note that multiplier and divider resistors are separate coils, and not as shown in single line diagram above.





2. Changes

- Repaired the 5 broken 1kΩ section wires.
    - 1k in RHS (Divide) ratio arm needed ~0.36Ω added in series (1//1//1.8//10 trimpot)
        - Trimpot varies total from 0.2 to 0.38Ω.
- Unseized the switch shaft.
- Lubricated the press buttons.
- Cleaned the switch terminal wiper/tops, as they can take a wipe or two to provide negligible contact resistance. Couldn't easily clean underside wiper contact of inner ring wiper contacts.
- 0k-9-10-0 setting adjusted using Hamon technique. 3 paralleled groups of 3 series steps in Hundreds (300//300//300=100Ω) were compared with position 10 of Tens (=100Ω). Similar with 9k-9-10-0 (where 1kΩ compared to 1kΩ). Then step 10 adjusted with 1:1 comparison for hundreds and for thousands. Then 10:1 multiplier configurations were bridge nulled against 0k-10-10-0 Hamon divider. Then 1:1 multiplier/divider configurations were voltage balanced. Likely precision of multiplier/divider ratios now better than rated 0.01%. Precision of 9:1 and 10:1 ratios with Hamon terminals likely better than 0.002%.
- Front panel 4mm sockets added for Hamon 100Ω Sense, and Hamon 1kΩ Sense, and for multiplier/divider ratio arms mid-point.
- Included a battery powered galvanometer preamp to provide about 10x better resolution from meter. Preamp based on modern AZ opamp and powered from 5Vdc socket (eg. via external USB 5V battery brick). Preamp drives the Ayrton-Mather resistors and meter so as to maintain damped response. Preamp connects to meter using EX switch setting on existing switch pole. Spare pole used to energise preamp. Preamp input hardwired to bridge balance node and to ON node (ie. opamp pos input connected when FINAL pushed, otherwise pos input grounded by 1M leak). Preamp has a gain of 680x to provide a net gain of about 10x, based on the 64x attenuation of the damping network and meter resistance. Opamp drives a series 1kΩ to allow at least a 2V swing. Gain resistors do not need to be special, as change or drift has no consequence. Offset is trimmed to zero but can move due to leakage currents for different bridge configurations. 5V battery connection via barrel socket via RC filter with 20Hz corner (to filter any noise from USB battery brick) and 0.1V drop (0.5mA for CA3160, 0.2mA for LTC2054).

To do:

- Set up at least one extra decade using 10kΩ steps, and 100kΩ steps, and insert via the Bridge Arm Series terminals, and confirm.
- Extend copper wire voltage sensing to a DB15 connector for each decade. This should allow 1:1 external voltage comparison between steps using a common constant current, as well as a total decade 1:1 comparison against steps in the next higher decade.
    - May allow confirmation of differences between steps, and then pursuing minor adjustments to reduce differences, then rechecking. Check if increasing or decreasing is easier, and if sum of decade equals the average of steps in next decade up, so that those steps can be micro-adjusted, and then move up the decades. Do a Hamon divider-sum comparison before moving to the next decade up.
- Fit an internal pocket to allow a temperature probe to be inserted.

3. Measurements

HP3497A S.N. xxx on 16/12/2019. Uncalibrated 1mA current source and 0.1V, 1V and 10V ranges, and no cross-comparison of 0.1V, 1V and 10V ranges, although no noticeable inaccuracy compared to uncalibrated Keithley 197, and new Aneng AN8009. In summary:

- Can't confirm balance arm accuracy (unless the internal mid-point test stub is used), but appears to still be about +/-0.01% except for 1000 range.
- The Decade series arm accuracies show each step is typically about -0.05%, but total accuracy is still typically within -0.02%, 1Ω steps need bridge balancing to remove residual 16mΩ, and 1,000Ω steps have drifted more (probably due to over-power stress).

1mA current source; 'Series' terminal to 'For Balancing Resistor' terminal; Kelvin connection.

Series arm	DCV	Measurement	% error	Multiplier	Divider	% diff
1 - 1	0.002001	2.001Ω	+0.05%	1.	1	
10 - 1	0.010994	10.994Ω	-0.055%	9.994	1	
100 - 1	0.100963	100.963Ω	-0.037%	99.963	1	
1000 - 1	1.00060	1000.60Ω	-0.04%	999.60	1	
1 - 10	0.010996	10.996Ω	-0.036%	1	9.996	+0.02%
1 - 100	0.100972	100.972Ω	-0.028%	1	99.972	+0.009%
1 – 1000 **	1.00020	1000.20Ω	-0.08%	1	999.20	-0.040%

Repeatable readings +/1 LSD. ** before trim to 1k added.

1mA current source; 'Series' terminal to 'Bridge Arm Series' terminal. Kelvin connection.

"Units"	DCV	Measurement	% error	Step	% diff
0 0 0 0	0.000017	0.017 Ω			
0 0 0 1	0.001016	1.016Ω	+1.6%	0.999Ω	
0 0 0 2	0.002016	2.016Ω		1.000Ω	
0 0 0 3	0.003015	3.015Ω		0.999Ω	
0 0 0 4	0.004013	4.013Ω		0.998Ω	
0 0 0 5	0.005011	5.011Ω		0.998Ω	-0.2%
0 0 0 6	0.006011	6.011Ω		1.000Ω	
0 0 0 7	0.007010	7.010Ω		0.999Ω	
0 0 0 8	0.008009	8.009Ω		0.999Ω	
0 0 0 9	0.009007	9.007Ω		0.998Ω	
0 0 0 10	0.010006	10.006Ω	+0.06%	0.999Ω	

Repeatable readings +/1 LSD.

"Tens"	DCV	Measurement	% error	Step	% diff
0 0 0 0	0.000016	0.016 Ω			
0 0 1 0	0.010012	10.012Ω	+0.12%	9.996Ω	-0.04%
0 0 2 0	0.020006	20.006Ω	+0.03%	9.994Ω	-0.06%
0 0 3 0	0.030001	30.001Ω		9.995Ω	
0 0 4 0	0.039997	39.997Ω		9.996Ω	
0 0 5 0	0.049994	49.994Ω		9.997Ω	
0 0 6 0	0.059999	59.999Ω	-0.001%	10.005Ω	+0.05%
0 0 7 0	0.069985	69.985Ω	-0.021%	9.996Ω	
0 0 8 0	0.079992	79.992Ω		9.997Ω	
0 0 9 0	0.089982	89.982Ω	-0.02%	9.990Ω	-0.1%
0 0 10 0	0.099971	99.971Ω	-0.029%	9.989Ω	-0.11%

Repeatable readings +/2 LSD.

“Hundreds”	DCV	Measurement	% error	Step	% diff
0 0 0 0	0.000016	0.016 Ω			
0 1 0 0	0.099974	99.974Ω	-0.026%	99.958Ω	-0.04%
0 2 0 0	0.19995	199.95Ω	-0.025%	99.98Ω	-0.02%
0 3 0 0	0.29993	299.93Ω		99.98Ω	
0 4 0 0	0.39987	399.87Ω		99.94Ω	
0 5 0 0	0.49982	499.82Ω		99.95Ω	
0 6 0 0	0.59978	599.78Ω		99.96Ω	
0 7 0 0	0.69973	699.73Ω	-0.039%	99.95Ω	-0.05%
0 8 0 0	0.79968	799.68Ω		99.95Ω	
0 9 0 0	0.89963	899.63Ω		99.95Ω	
0 10 0 0	0.99960	999.60Ω	-0.04%	99.97Ω	

Repeatable readings +/2 LSD.

“Thousands”	DCV	Measurement	% error	Step	% diff
0 0 0 0	0.000016	0.016 Ω			
1 0 0 0 **	0.99941	999.41Ω	-0.059%	999.39Ω	-0.06%
2 0 0 0	1.9990	1999.0Ω		999.6Ω	-0.04%
3 0 0 0	2.9987	2998.7Ω		999.7Ω	
4 0 0 0 **	3.9978	3997.8Ω		999.1Ω	-0.09%
5 0 0 0	4.9976	4997.6Ω		999.8Ω	
6 0 0 0	5.9965	5996.5Ω	-0.058%	998.9Ω	-0.11%
7 0 0 0 **	6.9954	6995.4Ω		998.9Ω	-0.11%
8 0 0 0 **	7.9947	7994.7Ω		999.3Ω	
9 0 0 0	8.9941	8994.1Ω		999.4Ω	
10 0 0 0	9.9937	9993.7Ω	-0.063%	999.6Ω	-0.04%

Repeatable readings +/1 LSD. ** repaired elements: +0.22Ω for 1k unit; +1//1.8Ω for 4k & 7k units; +1Ω for 8k unit;

B1 series resistance measured at 4.3Ω nominal to centre-tap.

4. Operation

Maintenance:

- Caution when removing from wooden case – avoid LHS end from scraping on wooden ledge, as 1k section lead-ins are exposed.

Operation:

- Preferably only connect battery for short duration to take a measurement. Although the max limit is 0.5W per step or setting, preferably use a 0.1W per step limit, so 1Ω steps limited to 300mA; 10Ω steps to 100mA; 100Ω steps to 30mA; and 1000Ω steps to 10mA.
- If using a 12V battery for bridge excitation then don't use 1, 10 or 100Ω multiplier/dividers (unless the lower arms are known to be >100Ω)
- For low ohm measurement, balance for the 1 – 1000 ratio arm setting.
- When finished, set the meter switch to shorted.
- To make a measurement of external resistance 'X', firstly balance the bridge with a short across 'X' and the set the 4-decade reference to 0k-0-0-0, and either insert a short section of wire in place of the 'Bridge Arm Series' link, or alternatively the 'For Balancing Resistance' link, to achieve null movement of the galvanometer needle. Then remove the short across 'X' and adjust the 4-decade reference to again achieve a null movement. When using the galvanometer preamp, a null may not be achievable as the needle will swing to one side, and then to the other side for a step change of 1Ω, in which case an estimate to about 0.2Ω may be determined.

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Example measurements:

1k62Ω 0.1% Welwyn RC55

Ratio arms	Battery voltage	Series arm	Idut ; Pdiss Bridge / DUT
1000 – 1000	+20V	1k6195	7.6mA; 0.06W / 0.09W
100 - 100	+20V	1k6205	
10 - 10	+20V	1k6205	12.3mA; - / 0.245W
1 - 1	+20V	1k610	12.5mA; - / 0.25W

1Ω 1% 0.25W MF

Ratio arms	Battery voltage	Series arm	Idut ; Pdiss Bridge / DUT
1000 - 1000	+4V		4mA; 0.016W / -
100 - 100	+4V		40mA; 0.16W / -
10 – 1000	+3V	100	200mA; 0.4W /
1 – 1000	+3V	1000	600mA; 0.36W / 0.36W

330mΩ 5%
Bridge balanced for short-circuit with 10 – 10 ratio arm setting with wire 'for balancing resistance'.
Bridge balanced for short-circuit with 1 – 1000 ratio arm setting with 2Ω for 'bridge arm'.

Ratio arms	Battery voltage	Series arm	Idut ; Pdiss Bridge / DUT	Balance
1 – 1000	+3.5V	339	660mA; 0.44W / 0.14W	10 - 10
1 – 1000	+3.5V	320		1 - 1000

HP3497A measures .000316V at 1mA = 0.316Ω using Kelvin connection. Aneng AN8009 measures 313mV.

1MΩ 1% 0.4W MF

Ratio arms	Battery voltage	Series arm	Idut ; Pdiss Bridge / DUT
1000 – 10	+20V	10000	
1000 - 1	+20V	1000	

HP3497A measures 10.0015V at 10uA = 1.000MΩ

10MΩ 5% 0.4W MF

Ratio arms	Battery voltage	Series arm	Idut ; Pdiss Bridge / DUT
1000 – 1	+20V	9800 +/-100	

Aneng AN8009 measures 9.80 and 9.82MΩ

Fluke 19.999k 0.01%.

- Use two in the series arms to check ratio arm balance levels

10R 0.05%

Sept 2022, K197 indicates some drift in higher thousands. K197 may be reading a little high on 200R range, and 0.05R high when measuring units.
K197 measurements of ratio arms are the same except:

- 100-1 reads 100.979 (from 100.963)
- 1-100 reads 100.992 (from 100.972)

Ratio arm tolerance using Fluke 19.999k 0.01% (factory batched for 0.5ppm/K) lower arms connecting to 'For balance resistance' and RHS 'Series', and 24Vdc battery to bottom of 19.999k arms, and the B1. The two 19.999k resistors were recently measured as being 'the same' to at least 0.01%. Pico meter across the midpoint external terminals:

- 1000-1000: 396uV/390uV (swapped lower to upper arms).
- 100-100: 33uV/36uV (swapped lower to upper arms).
- 10-10: 22uV/22uV (swapped lower to upper arms).
- 1-1: 20uV/19uV (swapped lower to upper arms).

Adding 0.25Ω to RHS ratio 1k reduces balance from 420uV to 149uV.
Adding 0.33Ω to RHS ratio 1k reduces balance from 420uV to 57/49uV.
Adding 0.5Ω to RHS ratio 1k reduces balance from 420uV to 122/127uV.
Balanced at 0.5//1.73 =0.356Ω added to RHS 1k ratio.

Ratio arm tolerance using 2x 10Ω 0.05% HOLCO H8 Y (same batch) lower arms connecting to 'For balance resistance' and RHS 'Series'. Each arm measures #1= 9.998 and 9.999 on K 197 Kelvin (<2mA test), but unable to confirm relative difference using CCS and Pico, so likely within 0.01% match (1 LSD).

Max per resistor power dissipation to be under 10% (0.0125W), so <0.35V or 35mA. Given 4Ω in series with B1, and lowest arm resistance of 11Ω, the max bridge voltage wanted is 0.35+0.28 = 0.63V. Using a 6V battery requires additional 5.4V/.07A= 82Ω in series to B+. Pico meter across the midpoint external terminals.

Bottom arms adjusted to give best balance for 10-10 upper ratio: shorting link across red-red terminals, and battery to #2 blue terminal.

- 1000-1000: 36uV/38uV (swapped lower to upper arms).
- 100-100: 16uV/5uV (swapped lower to upper arms).

- 10-10: 19uV/5uV (swapped lower to upper arms).
- 1-1: 22uV/26uV (swapped lower to upper arms).
- Differences minimised by avoiding 4mm cable interconnects and alligator clips.

Don't want to do a 10Ω & 10kΩ lower arm test using 1 and 1000 upper arms, as supply voltage will need to reduce to maintain 10R resistor current.

So outcome is just to add 0.39Ω in series with 1k leg of RHS ratio arm and retest.

5. Hamon divider setup

The 4 decade series arm can be set up as Hamon dividers by using the 100Ω step decade for 9:1 divider top arm, and the 1kΩ and 100Ω step decades as a 99:1 divider top arm, when the 10Ω and 1Ω step decades are configured as a 100Ω divider bottom arm (ie. decade settings of 0k-9-10-0, and 9k-9-10-0). End terminals were the SERIES (Hi) terminal, and the BRIDGE ARM SERIES terminal.

The 10Ω and 1Ω step decades can be set for 100Ω either as 9x10+10x1 = 99.976, or 10x10+0x1= 99.980, from the SERIES (Hi) terminal to the 100 decade switch. Hamon 1:1 matching for 9:1 divider using three shorted 100Ω decade sections (300//300//300=100) was done using the 10x10+0x1 setting, with 0.022//0.22//0.22 (=0.018Ω) added to end step of 10Ω decade.

The three shorted 100Ω decade sections were then disconnected and the lower three decades set for 9-10-0 (900+100+0=1000) used to 1:1 Hamon match to the three shorted 1kΩ decade sections (3k//3k//3k=1k). Matching required the 8k step modification (of 1Ω series) to be increased to 1+0.22.

Two additional Hamon Sense terminals were then added to the front panel to connect to the link between the 10 and 100 decades, and the link between the 100 and 1k decades, to provide new connection points for using 9:1 and 99:1 Hamon dividers (or 10:1 and 100:1 as per next section).

6. Multiplier/divider ratio performance

Multiplier/divider ratios can be checked from the following balance conditions:

- Voltage from LHS multiplier (Balancing R) terminal, and Series (Hi) terminal, to midpoint should be balanced for 1:1, 10:10, 100:100, 1000:1000 multiplier/divider ratios.
    - Each switch connects individual 1Ω, or 10Ω, or 100Ω, or 1000Ω into circuit (ie. not as shown in circuit diagram).
    - Reference voltage current constraints limit 10V reference for 1000:1000, 1V ref for 100:100, and 0.1V for 10:10 ratios.
- A bridge with Hamon divider on one side, and multiplier/divider on other side should balance, with zero potential difference between Hamon Sense terminal and multiplier/divider midpoint. However, Hamon divider ratio is 9:1 (ie. not 10:1), and 99:1 (ie. not 100:1) so need to make it 10:1 and 100:1.
    - The basic Hamon 9:1 divider (0k-9-10-0) can be modified to a 10:1 ratio by using the '10' setting on Hundreds (ie. 0k-10-10-0).
    - The basic Hamon 99:1 divider can be modified to a 100:1 ratio by also using the '10' setting on Hundreds (ie. 9k-10-10-0).

- The 100Ω ‘10’ step in the Hundreds decade needs to be matched to the 10 setting of the Tens decade using a 1:1 voltage balance setup.
  - Use a 0k-10-10-0 setting but with Hundreds decade ‘9’ tap shorted to ‘0’ tap. End terminals are still the SERIES (Hi) terminal, and the BRIDGE ARM SERIES terminal, with the Hamon 100 Sense terminal as voltage balance mid-point.
  - 1M5 added in parallel to Hundreds decade 10 step for balance.
- Hamon divider has its low R end connected to the Series (Hi) terminal (ie. to the RHS divider ratio arm end), so can only test LHS:RHS ratios of 1000:100, 1000:10, 100:10, 100:1, 10:1 (ie. multiplier ratios).
  - LHS 1000 needed 2M88// to null with RHS 100 for 0k-10-10-0 Hamon
  - LHS 1000 balanced with RHS 1000 (RHS already with adjustment)
  - LHS 100 balanced with RHS 100 with tweak of LHS lead
  - LHS 100 nulled with RHS 10 with tweak of RHS 10 lead for 0k-10-10-0 Hamon
  - LHS 10 balanced with RHS 10 with tweak of LHS 10 wire end
  - LHS 10 nulled with RHS 1 with RHS 1 wire end tweak for 0k-10-10-0 Hamon
  - LHS 1 balanced with RHS 1 with (680+150)//LHS 1

7. Comparison with Fluke 19k999 matched pair in bridge configuration

1:1 ratio using the PYE were compared to a Fluke 19k999 matched pair of 0.01% resistors in a bridge circuit with 12Vdc battery supply, and Pico M3510A as null voltmeter, and matched leads connecting PYE end terminals to bridge.

The Fluke pair had previously been:

- measured to within 0.1Ω of each other using Keithley 197 with 4W
- matched for voltage drop using a 0.1mA CCS to within 0.1Ω difference.
- matched in a bridge with two more Fluke 19k999 to <0.01Ω as a ratio.

PYE 1:1 ratio using end terminals of 1k-10-0-0 reference with Hamon 1k Sense mid-point terminal.

- ~ +/- 35uV null for Pico with swapped polarity inputs.

PYE 1:1 ratio using end terminals of 1k-9-10-0 reference with Hamon 1k Sense mid-point terminal.

- +/- 2-8uV null for Pico with swapped polarity inputs.
- This was the closest balance configuration.

PYE 1:1 ratio using end terminals of 1k-9-9-10 reference with Hamon 1k Sense mid-point terminal.

- +/- 74uV null for Pico with swapped polarity inputs.

A 1Ω change in one PYE arm caused a 3.1mV null imbalance. A 0.05Ω change in one PYE arm caused a 140uV null imbalance, indicating that closest balance configuration is within ~0.003Ω, and worst configuration is about 0.025Ω from balance to the Fluke pair.

The Fluke pair’s balance uncertainty appears to be similar to the PYE reference resistor using the Hamon 1k Sense terminal, which provides confidence that the Hamon related procedure used to trim the PYE reference resistance steps was appropriate.

8. Galvanometer resolution

Example measurement of 9.999k reference (2x Fluke 19k999 in parallel) using 1k:1k multiplier:divider, and 24V battery [for (1k+10k)//(1k+10k)=5.5kΩ load, 4.4mA 80mW total]. A reference arm 1Ω step was just discernible (~0.5 of minor tick on meter, so ~1-2% of FSD) with FINAL. Battery voltage could be raised significantly, but that becomes increasingly impractical.

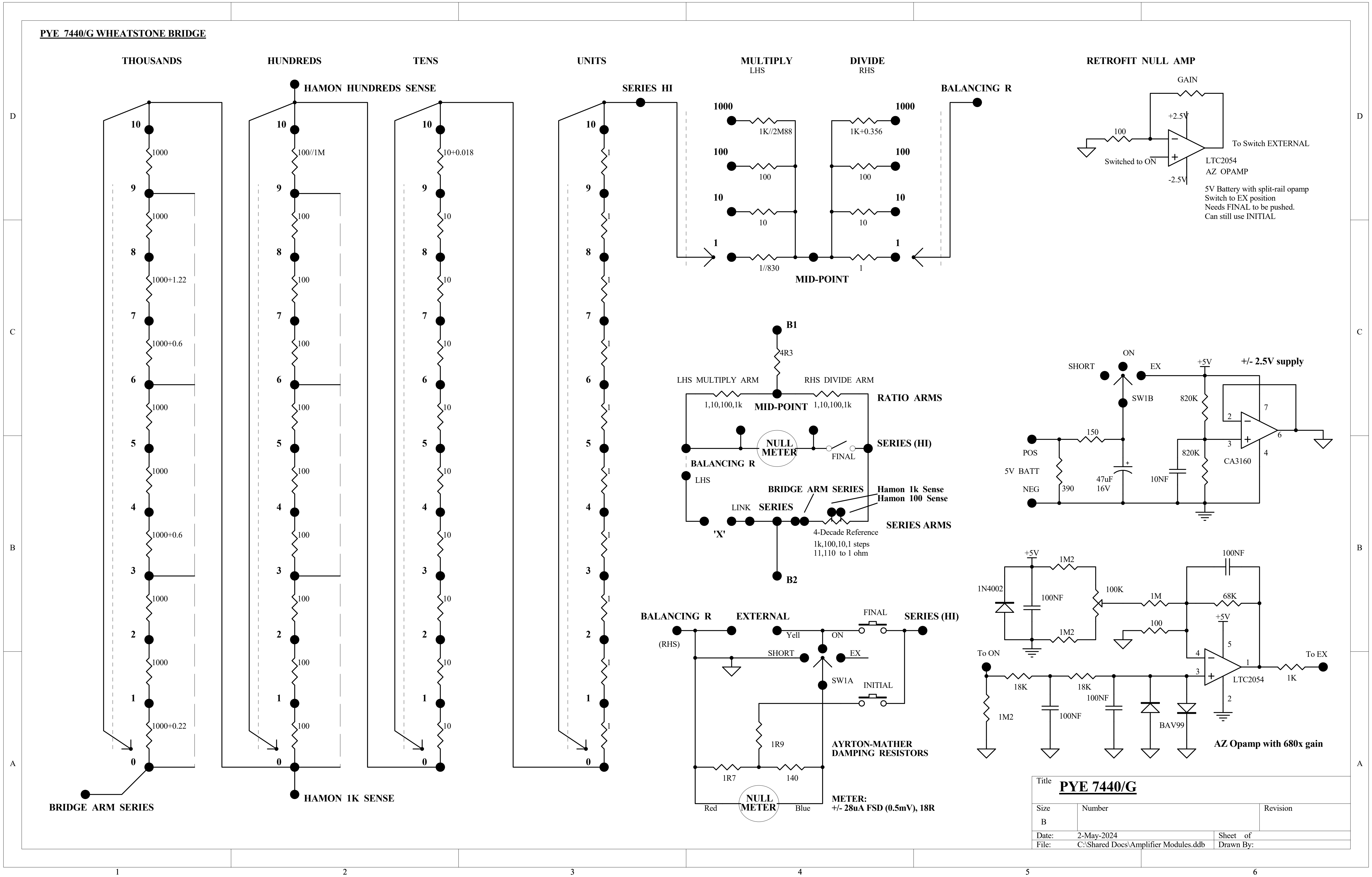
9. Galvanometer preamp

An LTC2054 AZ opamp is used to amplify the null voltage and drive the Ayrton-Mather damping network and galvanometer with a net gain of 10x
.
A 5V battery supplies the AZ opamp circuitry with +/-2.5V using another opamp to generate a mid-point 0V. The AZ opamp inputs include anti-parallel diode protection, and input offset trim, and the gain is set at 680x. The gain accuracy is not important. The opamp drives the meter and its damping resistors through a 1k to allow good output voltage swing from the opamp. The damping resistor network attenuates the drive signal by 64x, so an opamp gain of 680x provides a net gain of about 10x. The opamp input has two cascade RC filters to reduce bandwidth. The switch uses one pole of 3-contacts for the EX connection of the opamp to the meter, and one pole to connect the battery to the 5V supply rail, and one pole is still spare.

After the Initial pushbutton reading (and Initial is released), and then the Final pushbutton reading (which should be at most about 1-2 minor ticks, and the Final is released), the preamp is enabled by rotating the switch from the ON to the EX position. The meter needle may move from zero, and if needed it can be manually zeroed, and then the Final pushbutton is pressed. The Final pushbutton is then released, and the switch is then returned to ON.

Due to the sensitivity provided by the preamp, it is best to not make substantial bridge adjustments that could pin the opamp output to its limits of about +/-2V (ie. effective bridge voltage of 2/15=130mV, which is significantly more than 0.5mV for Final FS deflection, and 10mV for Initial FS deflection).

The preamp was used to make an example measurement of 9,999.5 Ω reference (2x Fluke 19k999 in parallel) using a 12V battery. The reference arm 1Ω steps could easily identify the balance to be an estimated portion of a 1Ω step. For the 1000:1000 multiplier/divider configuration the reading was about 10,001.6 Ω, and for the 100:100 multiplier/divider configuration the reading was about 10,002.8 Ω.


PYE 7440/G WHEATSTONE BRIDGE
THOUSANDS
HUNDREDS
TENS
UNITS
MULTIPLY
LHS
DIVIDE
RHS
RETROFIT NULL AMP
HAMON HUNDREDS SENSE
SERIES HI
BALANCING R
1000
1000+1.22
1000+0.6
1000+0.22
100//1M
100
10+0.018
10
1
1K//2M88
1K+0.356
1//830
MID-POINT
BRIDGE ARM SERIES
HAMON 1K SENSE
GAIN
+2.5V
-2.5V
Switched to ON
To Switch EXTERNAL
LTC2054
AZ OPAMP
5V Battery with split-rail opamp
Switch to EX position
Needs FINAL to be pushed.
Can still use INITIAL
B1
4R3
LHS MULTIPLY ARM
RHS DIVIDE ARM
1,10,100,1k
RATIO ARMS
NULL METER
FINAL
SERIES (HI)
LHS
LINK
SERIES
'X'
Hamon 1k Sense
Hamon 100 Sense
SERIES ARMS
4-Decade Reference
1k,100,10,1 steps
11,110 to 1 ohm
B2
SHORT
ON
EX
SW1B
+5V
+/- 2.5V supply
POS
5V BATT
NEG
150
390
47uF
16V
820K
10NF
CA3160
EXTERNAL
(RHS)
Yell
SW1A
INITIAL
1R9
1R7
140
AYRTON-MATHER
DAMPING RESISTORS
Red
Blue
METER:
+/- 28uA FSD (0.5mV), 18R
1N4002
1M2
100NF
100K
1M
68K
To ON
18K
BAV99
To EX
1K
AZ Opamp with 680x gain
Title PYE 7440/G
Size B
Number
Revision
Date: 2-May-2024
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File: C:\Shared Docs\Amplifier Modules.ddb
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SCIENTIFIC PYE INSTRUMENTS

PORTABLE WHEATSTONE BRIDGE
(FOUR DECADE PATTERN)

DESCRIPTION AND OPERATING INSTRUCTIONS

Cat. Nos. 7440/G & 7445/G

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Instruments for Industrial
and Academic Research.

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PORTABLE WHEATSTONE BRIDGE (FOUR DECADE PATTERN)

Cat. Nos. 7440/G and 7445/G.

DESCRIPTION AND OPERATING INSTRUCTIONS.

CIRCUIT.

These Bridges both have similar circuits and are operated in a similar manner but differ in respect of their ranges as follows:-

7440/G Series arm - decades in steps of thousands, hundreds, tens and units of ohms adjusted to an accuracy at any setting of ± 0.02%. Two Ratio arms each of 1, 10, 100, 1000 ohms adjusted to an accuracy of ± 0.01% of its nominal value.
Range. 0.001 ohm to 10 megohms.
Manganin Coils.

7445/G Series arm - decades in steps of hundreds, tens units and tenths of ohms adjusted to an accuracy at any setting of ± 0.02%. Two Ratio arms each of 1, 10, 100 and 1000 ohms adjusted to an accuracy of ± 0.01% of its nominal value.
Range 0.0001 ohm to 1 megohm.
Manganin Coils.

In each bridge a 4-ohm resistor is placed in series with the battery so that with all dials at their minimum setting the total current cannot exceed 1-amp with a 4-volt battery. Two pairs of terminals normally closed by links, are provided so that additional resistance may be introduced into either the unknown or the series arm. The use of these terminals is dealt with below. The ends of the series arms are also brought out to a pair of terminals so that this arm may be used as a standard resistance box when required.

An Ayrton-Mather type of shunt is built into the Galvanometer circuit to provide either critical damping with full sensitivity or critical damping with 0.01 sensitivity. The required sensitivities are selected by depressing the "Final" or "Initial" keys respectively. When the approximate balance at the beginning of a determination is being obtained the "Initial" key is depressed and the galvanometer is protected from the effects of excessive current. The "Final" key is then used to obtain an accurate balance.

If the sensitivity of the built-in galvanometer is inadequate for certain work, a more sensitive galvanometer (such as the Pye "Scalamp" Cat.No. 7901/S etc., or Taut-suspension reflecting galvanometer Cat.No.7901 etc.,) may be connected through an external tapper key to the terminal marked "Series" in the right-hand front corner of the panel and to the right-hand terminal of the pair marked "For Balancing Resistance". This galvanometer will then function when the external key is depressed. The built-in galvanometer will still function in conjunction with the panel keys and may be used for coarse balancing if desired.

OPERATION.

Connecting up the battery.

The battery is connected to terminals B1 and B2. When external resistance of 1,000 ohms or less is to be measured a 4-volt battery will give sufficient sensitivity. For higher values of resistance the ratio arms may be increased, and provided none of the four arms is less than 1,000 ohms the battery voltage may be increased to at least 40 volts to obtain sufficient sensitivity. It is not easy to give a general rule for the permissible battery voltage, but the value for any particular measurement may be worked out from the circuit on the assumption that the dissipation in any resistance coil must not exceed 0.5 watt.

Balancing the Bridge.

When measuring resistance of less than 100 ohms connect the leads from the resistor under test to the X terminals and short-circuit them at the resistor. Set the ratio arms to 10 ohms and the series arm to zero. Replace the link marked "For Balancing Resistance" by a length of stout copper wire. Operate the "Battery" and "Final" keys, and adjust the length of copper wire until the galvanometer gives no deflection.

If a balance cannot be obtained, replace the link, transfer the copper wire to the terminals marked "Bridge Arm Series" and obtain a balance. This operation will generally be necessary when the resistor leads are of noticeable resistance.

When measuring resistance of more than 100 ohms this balancing operation is unnecessary, and the links may be left undisturbed.

Measurement of external resistance.

If the balancing operation has been carried out, reconnect the resistor leads to the unknown resistor; otherwise, connect the unknown resistor to the X terminals by leads of low resistance. By adjustment of the ratio arms and series arm obtain a rough balance by pressing the "Battery" key and "Initial" key. Then obtain a more accurate balance by adjusting the series arm whilst pressing the "Battery" and "Final" keys. The value of the unknown resistance is then given by the sum of the reading of the series arm dials, multiplied by the ratio of the ratio arms.

Where possible the ratio arms should be set approximately to the same value as the unknown resistance. This cannot always be done, but the following general rule should be obeyed: use high values of ratio arms for measuring high resistances, and low values for low resistances.

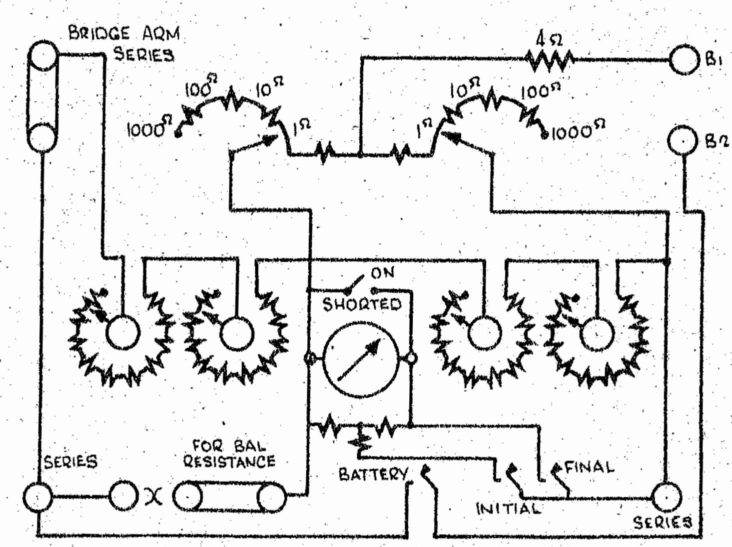
Extension of range.

The range of the bridge may be extended in either direction by removing the link marked "Bridge Arm Series", and inserting a fixed resistance or variable resistance box. The value of any such added resistand must of course be added to the setting of the series arm dials when calculating the answer. When the range is extended in the downwards direction, the process of balancing the bridge becomes essential, and must be carried out as described above.

Use as Standard Resistance.

The series arm is available as a variable standard resistance by connecting to the terminals marked "Series". When so used the dissipation in any one coil (i.e. one step of any decade) must not exceed 0.5 watt.

CIRCUIT DIAGRAM.



PORTABLE WHEATSTONE BRIDGE (FOUR DECADE PATTERN)
7440/G or 7445/G

Serial No: 11/1/10/10-51/PWB

ISSUED BY: W.G.PYE & CO.,LTD., "GRANTA" WORKS, CAMBRIDGE, ENGLAND.