Heathkit of the Month #88:
by Bob Eckweiler, AF6C

ELECTRONIC TEST EQUIPMENT

Heathkit AW-1
Audio Wattmeter.

Introduction:

In September of 1953 Heathkit introduced the AW-1 Audio Wattmeter. This meter measures the power output of audio amplifiers up to 50 watts. Over its lifetime it sold for $29.50. The AW-1 continued in production until around 1960. During that time it underwent one significant circuit change and at least three style and front panel changes, yet the model number continued to be AW-1. One style of the Heathkit AW-1 is shown in **Figure 1**.

Figure 1: A late 1954 or early 1955 AW-1 with red jewel pilot light. Photo By Keith Greenhalgh[2].

Heathkit AW-1 Audio Wattmeter:

All U.S.[1] AW-1 wattmeter models include built in non-inductive load resistors for 4, 8 16 and 600Ω. These load resistors are rated for 25 watts continuous and 50 watts intermittent. Full-scale (f.s.) power ranges are from 5 mW to 50 W in five decade ranges. The AW-1 uses a single 12AU7 dual-triode, a selenium rectifier and four crystal diodes.

The various styles and front panel changes will be discussed later in the article. The single circuit change, which occurred just a few months into production, involved changing the four-position rotary **LOAD** switch to a nine-position rotary switch. An AW-1 with the four position **LOAD** switch is shown in Figure 2 (a drawing from a 1953 Heathkit flyer). The original four positions are **4Ω, 8Ω, 16Ω** and **600Ω.** Each position is connected to the selected internal load resistor. On the later nine position switch the first four positions are identical to the original four, the fifth position, marked **OFF**, disconnects the input from the meter and load, and the last four positions are identical to the first four except no connection is made to the internal load resistors. The user is supposed to provide an external load, such as the speaker or an external load resistor. The nine switch positions are marked **4Ω, 8Ω, 16Ω, 600Ω,**

Here is a link to the index of Heathkit of the Month (HotM) articles:

http://www.w6ze.org/Heathkit/Heathkit_Index.html

1. Notes will be found at the end of the article.

Figure 2: The Winter 1953 flyer ad for the original AW-1. Notice four-position LOAD rotary switch on the left.

OFF 4Ω, 8Ω, 16Ω and **600Ω**. Above the first four positions is the marking **INT. LOAD** and above the last four positions is the marking **EXT. LOAD.** This change allows the meter to be left hooked up across a speaker during normal listening.

The AW-1U European Audio Wattmeter:

In Europe Heathkit sold an AW-1U version of the audio wattmeter. It is very similar to the US model except for a few details. The instrument is designed for 200 to 250 VAC 40-60 cps power and has a DPST AC power switch, that breaks both sides of the 230V AC line. Also the internal load ranges are **3Ω**, 8Ω **15Ω** and 600Ω, and the load divider resistor chain values are adjusted accordingly. It appears that the European version of the AW−1 only came with the nine-position load switch. It also underwent style changes during its production run.

Here's a bit of trivia: What we call *solder terminal strips*, the British call *tagstrips*!

The AW-1 Specifications:

Table I shows the published specifications for the AW-1.

Heathkit AW-1 Audio Wattmeter

Freq. Response:	±1 db 10 cycles to 250 kc.
Wattage Range:	0-5 milliwatts, 50 milliwatts, 500 milliwatts,5 watts, 50 watts.
DB Range:	Total range, -15 db to + 48 db, scale -5 to +18 db (1 mw @ 600Ω). Five switch selected ranges from -10 db to + 30 db.
Load Resistors:	4, 8, 16, 600 Ω non inductive 25 watt
Power Ratings:	up to 25 watts maximum continuous duty, 50 watts maximum intermittent. Duty cycle at 50 watts is 3 minutes. Cabinet is ventilated for efficient cooling.
Multipliers	Precision 1% resistors.
Meter:	4½" 200 microampere movement
Tube:	12AU7 dual triode - voltage amplifier, current amplifier.
Solid State devices:	Selenium power rectifier. Crystal diode (4 ea.) bridge meter rectifier.
Dimensions:	7-3/8 high, 4-11/16 wide, 4-1/8 deep
Power Rqmts.:	105-125 volts AC 50/60 cycle, 6 watts.
Net Weight:	3-3/4 lbs.
Shipping Weight:	6 lbs.

TABLE I: AW-1 Specifications

The AW-1 Controls and Front Panel:

The layout of the AW-1 is very basic with just a meter with **0 - 50 POWER** and **-5 to +18 DECIBELS scales**, two rotary switches, a SPST **ON-OFF** slide-switch for AC power, a pilot lamp assembly and two black binding posts.

The left rotary switch is the four or nine-position **LOAD** switch already discussed. The early four position switch is not marked as LOAD. The right rotary switch is the **RANGE** switch and has five positions: **-10 DB 5 MW, 0 DB[3] 50 MW, +10 DB 500 MW, +20 DB 5 W and +30 DB 50 W**. This switch is not marked RANGE on the early units that have the four-position LOAD switch. Two 5-way binding posts provide input. Both are black and the left one is marked **HI** and the right one **LO**.

The AW-1 Operation:

Measuring amplifier audio power with an AW-1 involves connecting the audio output to the binding posts (be sure the non-grounded audio output goes to the HI terminal) and selecting the correct LOAD switch position. The load should be marked at the output terminals of the audio amplifier being measured. Most have multiple outputs, so choose the output that you are using with your speakers, unless you want to measure a different output. Often the amplifier's power output rating changes for different loads.

If you have an AW-1 with the nine-position LOAD switch you can use an external load such as the Heathkit ID-5252 Audio Load or your speaker. Just be sure to use the correct external load position. The meter can even be left inline during normal use.

The maximum input to the AW-1 meter is 50 watts. However, that is an intermittent rating with a 3-minute duty cycle. Continuous operation is allowed up to 25 watts.

To measure power output, a sine wave audio oscillator, such as the Heathkit AG-8, is used to supply a constant audio input while the AW-1 reads the output power. Power changes can be read on the meter in watts or dBm. To get an idea of the amplifier's frequency response the input frequency may be varied and the corresponding output power plotted. Keep the input level constant.

Heathkit warns about changing the LOAD switch when power is being applied. It is also important that an external load be applied if the internal load is not in use. Running many audio amplifiers without a load can damage the amplifier.

The AW-1 Circuit:

The AW-1 circuit may be broken into four parts: The power supply, the AV voltmeter section, the load circuit and the range selector. A schematic of the later AW-1 is shown in **Figure 9**.

The Power Supply Circuit:

This circuit is a simple half wave transformer operated power supply using a selenium rectifier. The B+ powers only the AC voltmeter circuit which draws just over 1 ma. A high resistance (100KΩ) in the filter circuit assures very low AC ripple in the power supply output at the cost of a high drop in B+ voltage. The AC voltmeter circuit operates with a nominal B+ of just 35 volts. The transformer low-voltage winding powers the pilot lamp and the 12AU7 tube filaments and requires less than half an ampere.

The AC voltmeter Circuit:

The two stages of the 12AU7 tube form an AC voltmeter that is designed to create full-scale deflection of the 200 µA meter with an AC input of 0.14 volts RMS. The first section of the dual-triode 12AU7 provides an open-loop voltage gain of somewhat under 50. The second stage converts this voltage into an AC current which is coupled through a large 2 µF capacitor to the meter. Four germanium diodes form a full wave bridge to rectify the AC and provide a DC current to the meter.

The low side of the meter bridge is an AC signal almost identical to that at the top of the meter bridge. This AC signal is fed to the cathode of the voltage amplifier stage across a potentiometer. This voltage provides degenerative feedback, reducing the overall gain of the circuit and providing added circuit stability. The overall gain of the circuit is controlled by the potentiometer which sets the feedback level. It is adjusted during calibration to give a full scale reading when the input signal is 0.14 volts RMS.

The Load Circuit:

The load circuit consists of a two-pole rotary switch. One pole selects the load resistor, and the other pole selects a voltage divider to correct for the different load resistors. (See **Figure 3**)

The load voltage divider acts as a PI attenuator circuit, changing the circuit impedance from 8Ω, 16Ω or 600Ω to 4Ω, and at the same time provides the proper voltage attenuation to correct for the impedance change.

From Ohm's power law, wattage is equal to the voltage squared divided by the current, or:

$$W = \frac{E^2}{R} \qquad (1)$$

But the power is being measured using a voltmeter. Rewriting equation (1):

$$E = \sqrt{WR} \qquad (2)$$

For a 4Ω load on the 5 mW range the voltage can be calculated by equation (2):

$$E = \sqrt{0.005 * 4} = \sqrt{0.02} = 0.14 \text{ volts}$$

This 0.14 volts is the voltage required to give full deflection on the AC voltmeter described previously. From equation (2) it is obvious that if the load resistor R is changed the voltage will also change. Yet the voltage needs to remain 0.14 volts when the load resistor is changed. This is what the load voltage PI attenuator does; it provides the required voltage correction for each of the load resistor settings. Note that 0.14 volts is only correct for 5 mW. The full scale voltages for all five ranges, calculated from equation (2), are:

Range:	**f.s. Voltage**:
5 mW	0.14 V rms
50 mW	0.45 V rms
500 mW	1.41 V rms
5 W	4.47 V rms
50 W	14.14 V rms

To calculate the required correction, which is designated K, for each value of load resistor, an equation may be derived:

$$E = \sqrt{WR} = K\sqrt{WnR}$$

or:

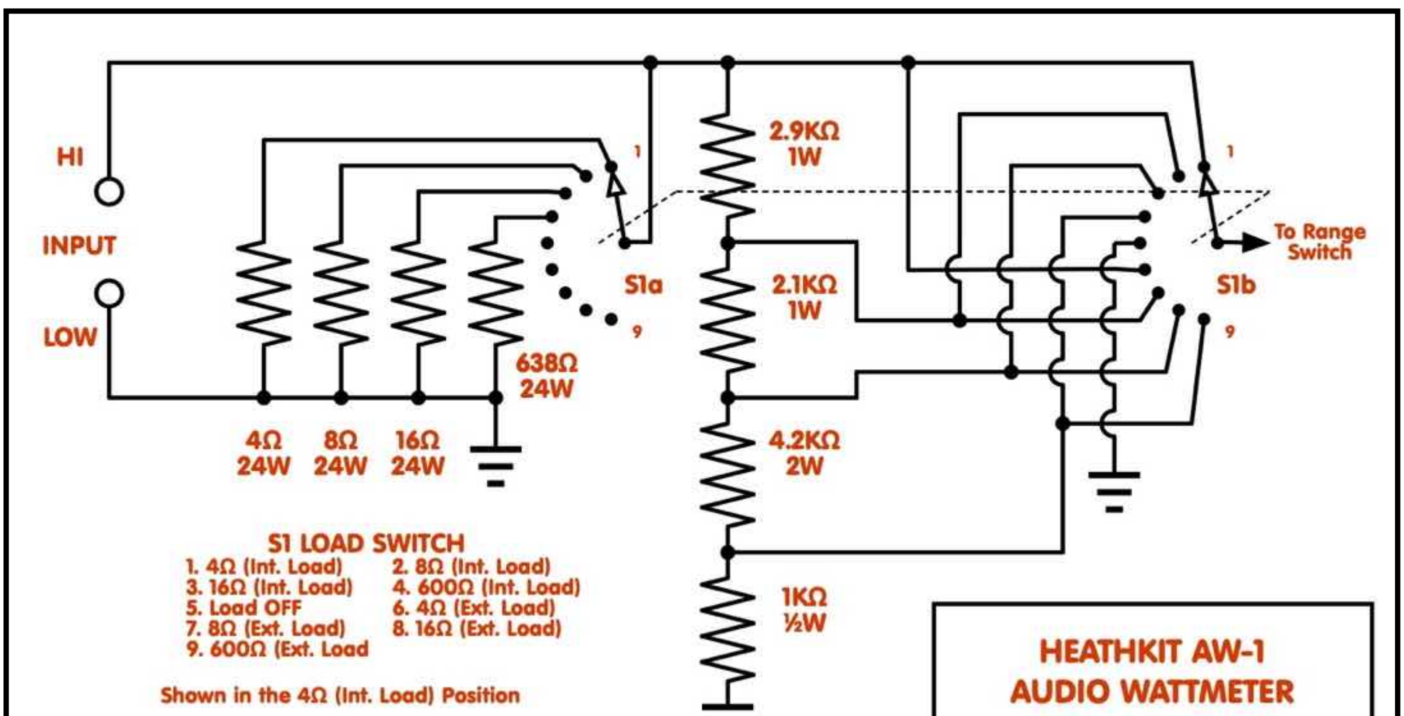


Figure 3

$$K = \frac{\sqrt{WR}}{\sqrt{nWR}} = \frac{1}{\sqrt{n}} \qquad (3)$$

Where R is 4Ω and n is the desired load resistance divided by R (4Ω). K may then be calculated:

Load Resistance	n	K
4Ω	1	1.00
8Ω	2	0.71
16Ω	4	0.50
600Ω	150	0.08

The corrections needed to keep the voltage at the correct voltage for the various load resistances is accomplished by the voltage divider. It consists of four resistors that total to 10 KΩ (R_T). The resistors, from top to bottom ,are: 2.9KΩ, 2.1KΩ, 4.2KΩ and 0.8KΩ. Solving the basic voltage divider equation[4]:

$$K = \frac{R_A}{R_T}$$

Load	R_A	R_T	K
4Ω	(1.9K + 2.1K + 4.2K+0.8K)Ω	10KΩ	1.00
8Ω	(2.1K + 4.2K + 0.8K)Ω	10KΩ	0.71
16Ω	(4.2K + 0.8K)Ω	10KΩ	0.50
600Ω	0.8KΩ	10KΩ	0.08

Notice that the two sets of K are the same.

A sharp eyed reader may notice that the 600Ω load resistor is actually marked as 638Ω while the others are the correct value. The added parallel resistance of the voltage divider is the reason for that. The 10 KΩ appears across the selected load resistor. While 10 KΩ across 16 ohms results in an error of less than 0.16%, (and this number is even smaller for the 4Ω and 8Ω loads), for the 600Ω load the error is over 5%. Thus a slightly larger 638Ω resistor is used, which, when in parallel with 10 KΩ, is very close to 600Ω.

The Range Circuit:

The range circuit (See **Figure 4**) sets the full scale wattage for each of the five range switch positions. On the 50 mW range the input voltage is 0.14 V. However, the voltage goes higher with each consecutive range position, which results from a ten-fold increase in power. From equation (2) one can see that if the power goes up by a factor of ten the voltage increases by a factor of $\sqrt{10}$ or 3.16. Thus the range divider provides attenuation in steps of 3.16. The divider resistors total to 100 KΩ. The resistor values are shown in Figure 4; feel free to calculate the range K values as a little exercise.

Here they are for the five range positions:

Sw. Pos.	Range (Watts)	Volts at Input:	K
1	5 mW	0.141	1.00
2	50 mW	0.447	0.316
3	500 mW	1.41	0.100
4	5 W	4.47	0.0316
5	50 W	14.1	0.010

These are full scale meter voltages. In each case the output voltage is 0.141 volts RMS.

AW-1 Calibration:

Heathkit has always found clever ways to calibrate their instrument kits without the need for a lot of test equipment. If test equipment is available Heathkit also often included instructions for more formal (read: more accurate) calibration.

The AW-1 is no exception. Simple calibration involves setting the AW-1 controls: LOAD to 16Ω and RANGE to 5 Watts. Then the HI input binding post is temporarily connected to the 6.3 volt filament voltage on the pilot light assembly. The resulting power being input is 6.3 volts across 16 ohms or 2.48 watts [From equation (1)]. The calibration control is then set to read 24.8 on the 0 - 50 POWER scale,

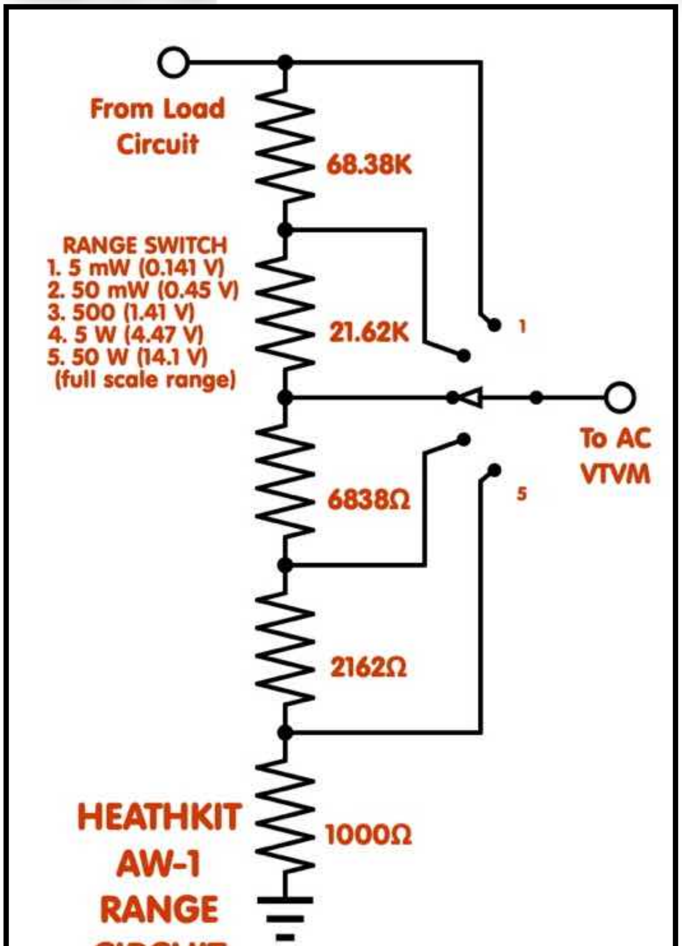


Figure 4

which is conveniently marked on the meter face as **CAL**.

Since the 6.3 volt filament voltage is only a nominal value, a more accurate calibration can be achieved by measuring the filament voltage with an accurate AC voltmeter, calculating the wattage for that voltage using equation (1) and using that as the CAL mark.

The European AW-1U is calibrated similarity, except, since it has a 15 Ω load instead of 16 Ω, the calibration wattage is 2.65.

AW-1 Styles:
When first introduced the AW-1 style was "Late Pre-Classic"[5, 6] with a beige front panel and maroon markings. See **Figure 2** and **Figure 5** for examples.

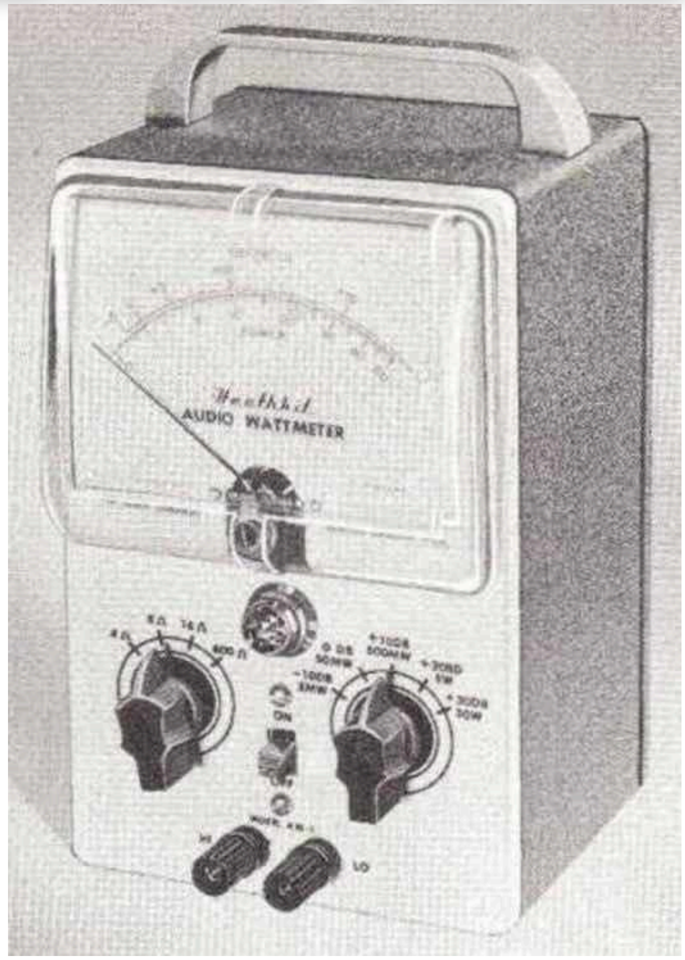


Figure 5: A drawing of the "Late Pre-Classic" style AW-1 with the four-position LOAD switch.

Sometime in early to mid-1954 the LOAD switch change was made. In Heathkit ads the "Late Pre-Classic" style AW-1 was only shown with the 4-position switch. However, **Figure 6** shows that style AW-1 with the nine-position switch from the collection of Jerry O'Reilly.

In September of 1954 Heathkit change the style of the AW-1 to the "Classic I" style with the dark gray front panel with white lettering and markings, and a lighter gray cabinet. Figure 1 is an example of this third iteration of the AW-1 Audio Wattmeter.

From September of 1954 until the end of the AW-1 production in early 1960, the unit is known to have at least one other change. That is the pilot lamp which went from a red jeweled glass type to a simpler round plastic lens type. The reason for this is probably due to the surplus jeweled lamp sources drying up. The plastic lens socket assembly was an inexpensive replacement (See figure 7). By 1956 the AW-1 was taking a back seat in catalogs and ads to other, probably better selling, kits. In the 1956 and 1958 catalogs most kits were shown as large images and with their schematic. The AW-1 was not so prominently shown, just a small image and no schematic. In magazine ads it was often not shown at all. Heathkit continued using the same image for its ads so it is difficult to tell

Figure 6: A “Late Pre-Classic” style AW-1 with the nine-position LOAD switch. From the collection of Jerry O’Reilly. (Photo by Chuck Penson - WA7ZZE)

Figure 7: A “Classic I” style AW-1 with later green plastic pilot lamp lens (web photo).

when the pilot lamp change occurred. A guess would be in late 1956 as that was when the same pilot lamp began showing up on the oscilloscope line.

The plastic lens is green, as opposed to the red jeweled lamp. However a red plastic pilot lamp appeared in one image, which opened the possibility that Heathkit did use red plastic pilot lamps for a time; or perhaps someone just changed the lens cap? Recently another, different, AW-1 image has the same style red pilot lamp, increasing the possibility red was used, most likely early on.

AW-1 Summary:

If you work with Hi-Fi or stereo equipment, the AW-1 can be a handy instrument to have on your test bench. Even though it uses a tube, it will work with even the newest solid-state audio amplifiers.

73, from AF6C

Notes:

1. Heathkit released a European version, the AW-1U discussed later in this article.
2. Follow Keith Greenhalgh on Flickr for many detailed photos of Heathkits and other electronic equipment.
3. Zero dB is defined as 1 mW into 600Ω for the AW-1.
4. See sidebar for voltage divider discussion.
5. In Chuck Penson's ***Heathkit Test Equipment Products*** book he discusses six distinct design styles Heathkit used for their test equipment. See pages iv through vi.
6. ***Heathkit Test Equipment Products*** by Chuck Penson - WA7ZZE. ISBN 2014, 978-0-615-99133-7, available from amazon.com.

This article originally appeared in the November 2018 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.

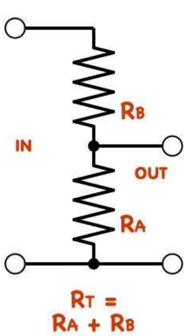
Always looking for Heathkit catalogs and literature.

Thanks - AF6C

Figure 8: A "Classic I" style AW-1 with a red plastic pilot lamp lens. Possibly a user change? Maybe a Heathkit change to initially replace the red jeweled lamp. (web photo).

The Voltage Divider:

The voltage divider is a circuit that a ham should become knowledgeable in. It is a simple circuit and is shown in the attached schematic. The output voltage is related to the input voltage by the voltage divider equation:



$$V_{out} = \frac{R_A}{R_A + R_B} V_{in}$$ or

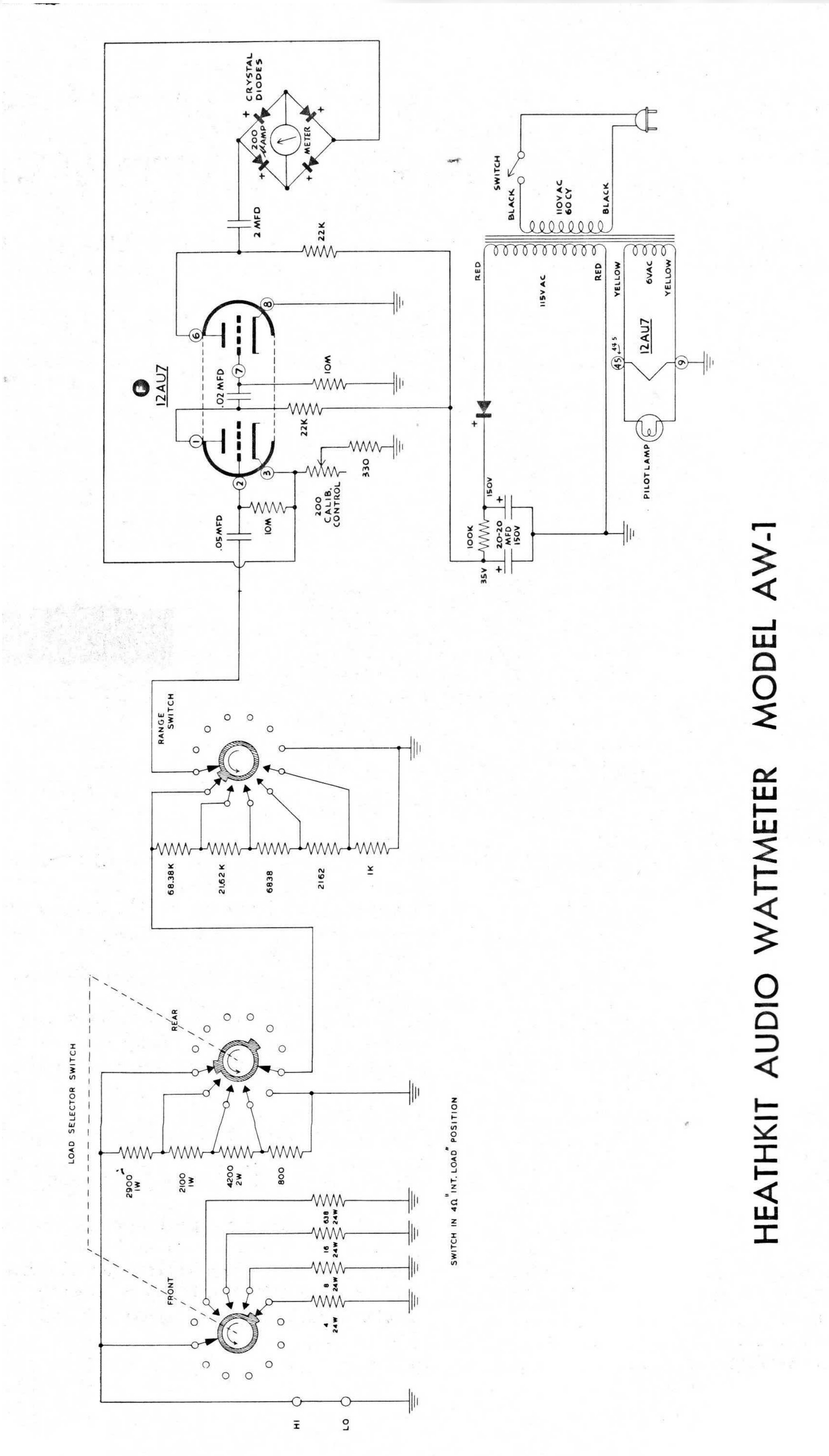
$$V_{out} = \frac{R_A}{R_T} V_{in}$$ where

$$R_T = R_A + R_B$$

When calculating R_A the external resistance across it must be considered unless it is significantly higher than R_A (>10 times at a minimum.)

A voltage divider has a Thévenin equivalent that can make circuit calculations much easier. It is beyond the scope of this sidebar, but can be found in basic circuit analysis text books and on the web, such as:

https://www.electronics-tutorials.ws/dccircuits/dcp_7.html


HEATHKIT AUDIO WATTMETER MODEL AW-1
CRYSTAL DIODES
200 μAMP METER
2 MFD
22K
12AU7
.02 MFD
10M
22K
.05 MFD
10M
200 CALIB. CONTROL
330
SWITCH
BLACK
110 VAC 60 CY
BLACK
RED
115 VAC
RED
YELLOW
6 VAC
YELLOW
12AU7
PILOT LAMP
150V
100K
20-20 MFD 150V
35V
RANGE SWITCH
68.38K
21.62K
6838
2162
1K
LOAD SELECTOR SWITCH
REAR
FRONT
2900 1W
2100 1W
4200 2W
800
638 24W
16 24W
8 24W
4 24W
SWITCH IN 4Ω "INT. LOAD" POSITION
HI
LO