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VR-006

Vintage Radio Application Note

RECONDITIONING AND IMPROVING THE HEATHKIT HM-102 RF POWER METER



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SECTION I - INTRODUCTION & OVERVIEW

This paper is a vintage radio technical document that describes the reconditioning and improvement of a Heathkit HM-102 RF power meter. This unit was introduced by Heathkit back in 1970 as an accessory to the Heathkit SB- and HW-series HF amateur transceivers, the SB-200 and SB220 linear amplifiers, and other equipment. It is capable of measuring RF power levels up to 2,000 watts in two scales (0-200/0-2,000) in the 80-10 meter amateur bands. It also measures SWR, with the scale calibrated up to 3:1.

The HM-102 features a detachable sensor head that can be located remotely from the display unit. This is convenient in that the bulky and cumbersome RF signal input and output coaxial cables do not have to be routed to the display unit on the operator console.

The HM-102 performs well for an instrument employing passive analog technology. Although it is not designed or built to laboratory instrument standards as is the Bird Model 43 RF power meter, it is likely as good or better than similar instruments built today if the modifications presented in this paper are implemented. Since the HM-102 can still be found on eBay and through other sources at modest prices, it is a good value for those with the time and inclination to recondition it. This paper also presents significant improvements that both add convenience and improve measurement accuracy.

I procured my HM-102 on eBay and found it to be mostly functional and in good mechanical condition. Only modest effort was required to recondition it and implement the improvements.

I strongly recommend that those of you interested in pursuing this project first obtain the HM-102 manual. This document is available at www.mods.dk.

I conclude this introduction with a word of caution regarding RF power measurement accuracy. RF power metrology is difficult at best, requiring very elaborate test setups that often employ calorimetric measurements for good accuracy. This being the case, it is not realistic to expect modestly priced instruments designed for a cost-conscious amateur radio market to have calibration accuracy traceable to precision standards. Since the buyers of these instruments cannot easily verify accuracy, there is a significant probability that the advertised accuracy specifications are exaggerated in many cases.

Visit my N6DC vintage radio website at www.rdfproducts.com/N6DC.Vintage.Radio.htm for possible revisions to this paper as well as other vintage radio technical articles.

SECTION II - SUMMARY CIRCUIT DESCRIPTION

The HM-102 design is quite conventional, employing a small ferrite transformer to sample the RF signal and using germanium diodes to detect the forward and reflected power. A novel feature of the HM-102 is that it includes a semi-precision RF voltmeter circuit (employing a 1% precision resistor) to aid in user calibration.

A passable (though abbreviated) circuit description is presented in the manual. The HM-102 schematic is presented in Figure 1.

The fundamental principle underlying most SWR detectors is that if there are no standing waves on the transmission line (i.e., if the SWR is 1:1), then the line voltage and current at the sampling point will be in-phase. As the SWR rises, however, the line voltage and current will begin to exhibit a relative phase shift that's magnitude correlates to SWR.

To obtain a proxy indication of the line voltage, a capacitive voltage divider using low value capacitors is employed. To obtain a proxy voltage indication of the line current, a toroidal transformer is employed (i.e., the "pickup coil" as illustrated in Figure 1).

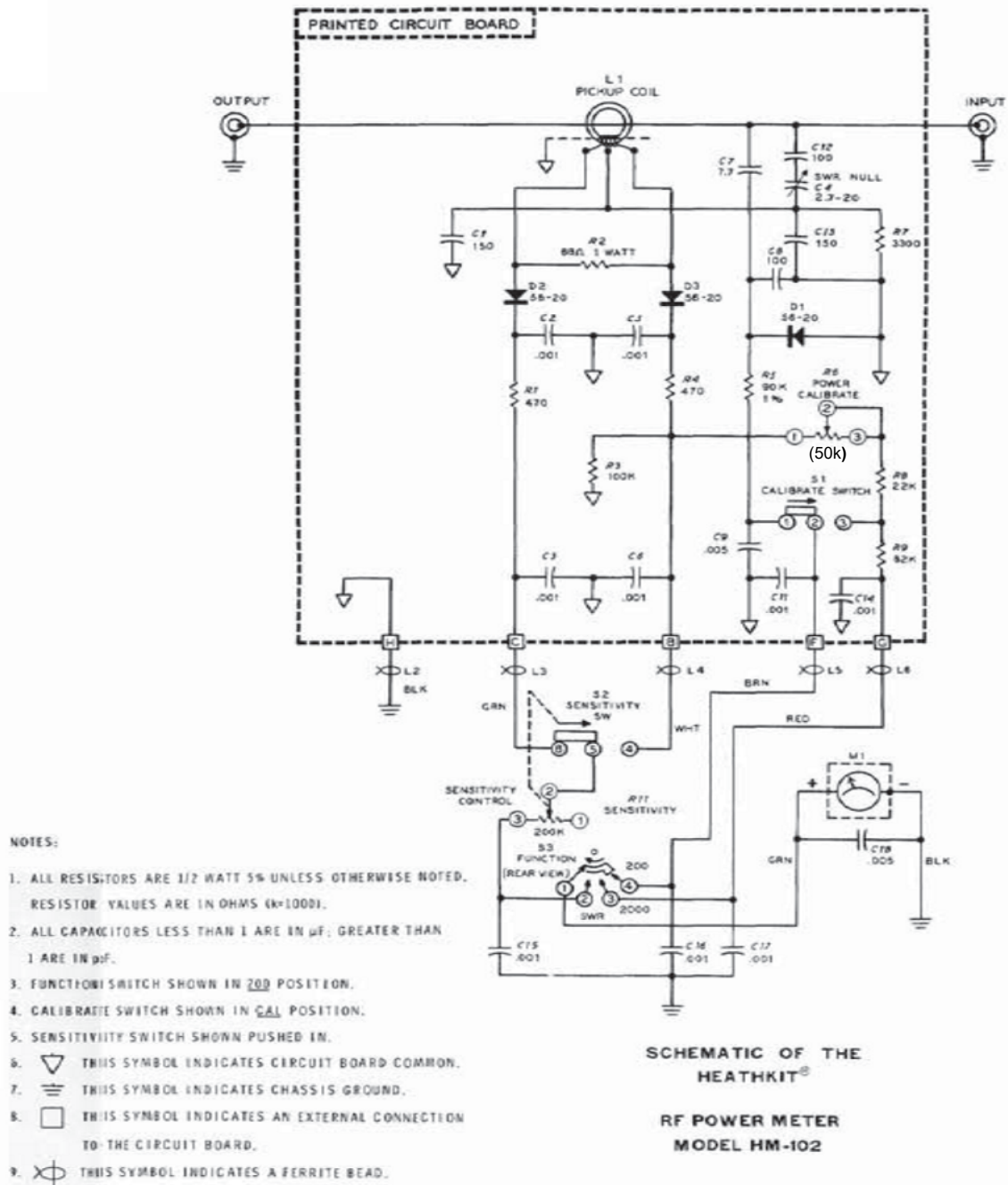


Figure 1 - Heathkit HM-102 RF Power Meter Schematic
(Note: Meter movement is 0-100 microamperes)

SECTION III - CLEANING, RE-SOLDERING, TESTING, & CALIBRATION

In my unit, both the POWER CALIBRATE and FUNCTION switches (S1 and S3, respectively) were intermittent. I fixed this using spray TV tuner cleaner by spraying a liberal amount of cleaner into the switch contacts and then exercising the switches vigorously to allow the cleaner to dislodge accumulated dirt and oxidation. Since these units are over 40 years old, I recommend this step as a preventive measure even if these switches appear to be functional. When doing this, *exercise caution not to allow the spray to get inside the meter.*

As with all Heathkits, the quality and reliability depend to a great extent on the skill, care, and attention to detail of the assembler. I resoldered all the joints and recommend that you do the same. (This task is not time-consuming since there the HM-102 does not have very many parts.) Be sure to check for any solder bridges and remove any solder or other debris from the circuit board.

Also, look for any burned or otherwise damaged components and replace them. If damaged components are found, inspect the wiring carefully since it is possible that the problem may have been caused by an assembly error (i.e., it is possible that the unit never worked correctly).

Once the above maintenance actions have been completed, the HM-102 can be tested. The best way to do this is to carefully perform the calibration procedure presented in the manual. This will require an HF amateur transmitter and a low-SWR 50 ohm dummy antenna capable of handling the transmitter power level. Do not forget to first set the meter mechanical zero adjustment for a precise zero indication with no RF power applied.

The manual recommends conducting the calibration at a test frequency in the 40 meter band. If a Bird Model 43 RF power meter or other RF power meter of similar accuracy is available, this will also be helpful. Be sure to do the calibration procedure in sequence, starting with the SWR balance adjustment.

There is a subtlety associated with the power meter adjustment not fully explained in the manual. The HM-102 has a semi-precision RF voltage detector (comprising D1, R5, and associated components) that is used to calibrate the power meter. When the CALIBRATE switch is set to CAL, this RF voltage detector output is applied to the meter. Given the precision of this detector and the assumption that a low-SWR 50 ohm dummy load is employed, the circuit design is such that the meter indication will correspond closely to the true power level. (I confirmed this to be the case by simultaneously monitoring the power level with my Bird Model 43 RF power meter.)

Once this meter indication is established and noted, the CALIBRATE switch is then set to NORM and the POWER CALIBRATE control (R6) is then carefully adjusted for the same indication. This completes the power calibration procedure.

This raises an obvious question as to why the semi-precision RF voltage detector itself is not used as the power meter detector (as opposed to just being a calibration source for the actual forward power meter detector comprising D3 and its associated components). This is a reasonable question that is not directly addressed in the manual.

Apparently, this semi-precision RF voltage detector has good accuracy *only in the 40 meter band* (i.e., the band specified for the power calibration procedure). However, it is not a broadband detector as is the detector comprising D3 and its associated components. Thus, the semi-precision RF voltage detector is used only to establish a calibration reference that is then transferred to the broadband detector by adjusting R6 for the same indication. *It is therefore very important that the user not attempt this power meter self-calibration procedure on any band other than 40 meters.*

If you have access to a higher precision RF power meter (e.g., a Bird Model 43), I recommend using this superior instrument as your calibration standard rather than relying on the 40 meter band self-calibration procedure presented in the manual. In this case, leave the HM-102 CALIBRATE switch in the NORM position and carefully adjust the POWER CALIBRATE control (R6) for a matching power indication. Also, using the external calibration reference eliminates the requirement to perform the calibration only on 40 meters (although 40 meters is still a good choice).

For the 0-200 watt scale, it is best to use a transmitter with at least 100 watts output (i.e., sufficient power to obtain a reading on the upper portion of the meter scale). Note that there is no independent calibration adjustment for the 0-2,000 watt scale, so the calibration procedure should be done on whichever scale is most useful for the intended application. (A remedy for this design shortcoming is presented in Section VIII where an additional trim pot is added for separate 0-2,000 watt scale calibration).

After calibrating my HM-102 as discussed above, I found the overall accuracy for the 0-200 watt scale to be in reasonably good agreement with my Bird Model 43. If a Bird Model 43 or other accurate RF power meter is available, it makes good sense to calibrate the HM-102 at the power level that you mostly intend to use. In my case, I calibrated the 0-200 watt range at 100 watts and the 0-2,000 watt range at 600 watts (after adding a second calibration trim pot for the 0-2,000 watt scale as per Section VIII).

SECTION IV - HM-102 DESIGN DEFICIENCIES

During the course of my work on the HM-102, I found the following four design deficiencies that I judged to be serious enough to warrant corrective action:

1. SWR Sensitivity Control - I noticed that the SWR sensitivity control was very difficult to set for the required full-scale reading (i.e., the setting was very “touchy” and unstable) for my 100 watt output transmitter.
2. SWR Push Switch - When the SWR push switch was pushed in to provide the SWR reading, it tended to upset the SWR sensitivity control setting. (This push switch and the sensitivity control are on the same knob shaft.) This problem was further aggravated by the difficulty in setting the SWR sensitivity control as discussed above.
3. Carbon Composition Resistors - The circuit employs mostly carbon composition resistors. The unfavorable temperature and aging characteristics of carbon composition resistors makes most of them unsuitable for this instrumentation application.
4. Independent High/Low Power Meter Calibration Adjustment - In its unmodified form, the HM-102 has only one power meter calibration adjustment (even though it has two selectable power scales). An additional adjustment is required for good accuracy on both scales.

The modifications to correct these four design deficiencies are presented in detail in the Sections that follow.

SECTION V - IMPROVING THE SWR SENSITIVITY CONTROL

As per Section IV, I found the SWR SENSITIVITY control very difficult to adjust for a full-scale reading. At first I thought that this 200k pot (R11) was just unstable after 40 years of aging. My first effort to remedy this problem was to clean this pot with spray TV tuner cleaner, but this did not help. Next, I replaced the pot, but this also did not solve the problem.

I finally realized that the true issue was a design deficiency that occurred as a result of the fact that this pot had to cover an exceptionally wide adjustment range. Based on the HM-102 specifications, this pot has to be able to adjust for a full-scale SWR reading for power levels from 10-2,000 watts. This is too wide an adjustment range to be accommodated well by a single-turn non-precision pot, especially at the lower power levels.

The most elegant approach would have been to replace this pot with a higher quality multi-turn unit. However, I was looking for a simpler solution using parts already on-hand.

Since I really had no application requiring a full-scale reading for power levels much below 100 watts, I addressed the problem by accepting less adjustment range. More specifically, rather than requiring that the HM-102 be able to obtain a full-scale SWR reading for power levels down to 10 watts, I decided that for my requirements there was no reason why this lower boundary could not be raised to 50-60 watts. This allowed me to place a fixed resistor in series with the pot, which in turn made the full-scale sensitivity adjustment smoother, less critical, and more stable.

Since the original 200k pot was very old and likely unreliable, I replaced it with a newer one. Since its value is not critical and I had a 100k pot on hand, I used this plus an 18k 1/4W carbon film series resistor. With this improvement, the full-scale SWR SENSITIVITY adjustment for my 100 watt output transmitter is now smooth, stable, and easy to set.

You may need to substitute a different series resistor value based on your own specific lower-boundary power measurement requirements. This is best done by trial and error. (A larger fixed resistor value makes the adjustment easier to set, but raises the lower power boundary.)

This added fixed resistor can be easily installed directly on the SENSITIVITY pot and does not require access to the circuit board. Also, if you replace this pot, you must also do the modification presented in Section VI since installing a standard (non-custom) replacement pot will not permit installation of the concentric push-pull forward/reflected SWR switch. (The modification presented in Section VI eliminates this push-pull switch in favor of an added front-panel toggle switch.)

SECTION VI - ADDING A SEPARATE FORWARD/REFLECTED SWR SWITCH

As discussed above, the original HM-102 design employs a push-pull forward/reflected SWR switch that is co-located on the same shaft as the SWR sensitivity control. To measure SWR, this switch knob is pulled out and the SWR sensitivity control then adjusted for a full-scale indication. Once done, the switch knob is pushed back in so that the meter directly reads SWR.

The difficulty with this arrangement is that pushing the switch knob back in can result in the SWR sensitivity control setting being inadvertently jarred, thus resulting in a faulty reading. This problem was especially acute prior to implementing the SWR sensitivity control modification presented in the previous Section, and remains a problem even after the modification.

To remedy this, the push-pull switch was eliminated in favor of a single-pole double-throw miniature toggle switch (wired identically to the SPDT SENSITIVITY switch S2 in the schematic). This added switch was installed on the HM-102 front-panel between the two knobs as illustrated in Figure 2, and is far more convenient to use than the original push-pull switch. Although not labeled in Figure 2, the FORWARD position is to the left and the REFLECTED position is to the right as per standard convention.



Figure 2 - Reconditioned HM-102 with Added Forward/Reflected Toggle Switch

SECTION VII - REPLACING THE CARBON COMPOSITION RESISTORS

Although carbon composition resistors were widely used in Heathkits and other vintage equipment, this type of resistor is notorious for drifting in value over temperature and time. As a result, they have been almost universally abandoned in most applications in favor of more stable carbon film resistors.

Since it is especially important that a measurement instrument use good quality and stable components, I replaced all the HM-102 fixed resistors with the exception of the 90.0k 1% precision resistor (R5). These replacement parts were a combination of 5% carbon film resistors and 1% metal film resistors as follows:

- R1 - 470 ohms 1/4W 5% carbon film
- R2 - 68 ohm 1.0W 1% metal film (see Note 1)
- R3 - 100k 1/4W 1% metal film
- R4 - 470 ohms 1/4W 5% carbon film
- R5 - Not replaced
- R6 - See Note 2 and Section VIII
- R7 - 3.30k 1/4W 1% metal film
- R8 - 22.0k 1/4W 1% metal film
- R9 - 56.0k 1/4W 1% metal film (see Note 3 and Section VIII)
- R10 - Not applicable (see Note 4)
- R11 - See Section V

Notes:

1. R2 was assembled using an appropriate series/parallel combination of on-hand 1/4W 1% metal film resistors to yield a composite value close to 68 ohms and a power dissipation rating exceeding 1W.
2. Trim pot R6's value is not annotated on the original schematic, but is 50k. This pot should be replaced with a multi-turn cermet type as discussed in Section VIII.
3. R9's value is predicated on the implementation of the Independent High/Low Power Meter Calibration Adjustment modification presented in the Section VIII. If this modification is not implemented, R9 should be 82.0k 1/4W 1% metal film.
4. R10 is an unused reference designator on the Figure 1 schematic.
5. All of the replacement resistors are available from Mouser Electronics and many other electronic component suppliers.

SECTION VIII - IMPLEMENTING AN INDEPENDENT HIGH/LOW POWER METER CALIBRATION ADJUSTMENT

The HM-102 power meter calibration adjustment as presented in the manual is done for the 0-200 watt low power range only as discussed above (since there is no independent power calibration adjustment for the 0-2,000 watt high power range). For this high power range, the calibration accuracy depends upon R9 (an 82k 5% carbon composition resistor that's value drifts with age and temperature). Thus, the high power range measurement accuracy depends upon how close this unstable 82k resistor is to the actual value required for good calibration. My guess is that 82k was the closest 5% standard value to whatever design center value was determined by the cognizant Heathkit engineer.

After carefully calibrating my HM-102 on its 0-200 watt range with a 100 watt output transmitter and using my Bird Model 43 as a calibration reference, I switched to the 0-2,000 watt range and noted an indication of only 75 watts. This is clearly an excessive error (even after accounting for the fact that the 0-2,000 watt range should be calibrated with a transmitter output power level of at least 500 watts or more so as to have the meter indication on the upper portion of its scale).

Clearly, R9 needs to be an adjustable rather than fixed resistor in order to facilitate an independent 0-2,000 watt range calibration adjustment. To this end, I changed R9 from an 82k 1/2W 5% carbon composition resistor to a 56.0k 1/4W 1% metal film resistor for better precision and stability. Next, I added a 50k 10-turn cermet trim pot in series with R9 to allow adjustment.

My first thought was that I would have to install the added trim pot on the remote chassis circuit board and then drill an access hole through the cover to allow adjustment. Upon further inspection of the schematic, however, I realized that this 50k pot could more conveniently be installed at pin 3 of the FUNCTION switch (S3) with the same result. This location is much easier to access and requires no additional hole. This was easily done by desoldering the red wire from S3-pin 3, soldering one of the two outer pins of the 50k pot to S3-pin 3 and then reconnecting the red wire to the 50k pot center pin. (The second outer pin is not connected.)

Keep in mind that there is a one-way interaction between the existing low power and the added high power calibration adjustments. Although the setting of the high power trim pot has no effect on the low power calibration, the setting of the low power trim pot does affect the high power calibration. The remedy is procedural - first do the low power adjustment, followed by the high power adjustment. (If the low power adjustment is subsequently changed, it will be necessary to redo the high power adjustment.)

Although not essential to this improvement, a related enhancement is to replace the 50k POWER CALIBRATE trim pot (R6) with a better quality part. Although the original R6 trim pot on my HM-102 adjusted smoothly and exhibited no symptoms of deterioration or age, I decided that a better quality part would be more suitable for an instrument calibration adjustment. Accordingly, I replaced R6 with a 50k 10-turn cermet trim pot. <>