Heathkit of the Month (HotM) #97:
by Bob Eckweiler, AF6C

HEATHKIT

AMATEUR RADIO - SWL
Heathkit SA-2040
Antenna Tuner

Figure 1: Heathkit SA-2040 Full Legal-Limit Antenna Tuner

Introduction:

In the second half of 1979 Heathkit released the SA-2040, a no-frills, full legal-limit, antenna tuner (**Figure 1**). Heath's previous antenna tuner, the AC-1[1] first appeared in a Heathkit ad in the September 1953 issue of ***Radio News***. The AC-1 continued to be sold until the AT-1 transmitter was replaced by the DX-20 HF CW transmitter in late 1956.

In the 1950s a revolution in ham equipment began. The new rugged 6146 transmitting tube became popular along with the pi-network output circuit designed for 50 - 75Ω coaxial cable. Coax became the feedline of choice due to its ease of use, and 50 and 75Ω resonant antennas became very popular. A well designed pi-network could tune a load with an SWR of up to 3 to 1 allowing reasonable bandwidth around the resonant frequency. The average ham shack no longer needed an antenna tuner. For those still using non-resonant wire antennas the venerable E.F. Johnson *Matchbox* tuner line was widely available. Over this period few antenna tuners were marketed in the ham magazines, though construction articles appeared occasionally, and many users of wire antennas home-brewed their tuners. In the 70's, as newer radios came on the market, many using less rugged TV sweep tubes and others using easily damaged RF power transistors with their broad-band output coupling, antenna tuners quickly entered back into the vogue.

[1] Notes appear at the end of this article.

Here is a link to the index of Heathkit of the Month (HotM) articles:
http://www.w6ze.org/Heathkit/Heathkit_Index.html

Heathkit reentered the antenna tuner market with the SA-2040 antenna tuner. The SA-2040 originally sold for $149.95, a price it held for about two years during an inflationary period. By the fall of 1981 the price rose to $154.95 and by the winter of 1982/1983 it reached $169.95. It was no longer offered in the fall 1983 catalog.

Heathkit offered two other full legal-limit antenna tuners, the SA-2060 (followed by an 'A' version) and the SA-2500 automatic tuner. The original SA-2060 was offered starting in 1981 and sold alongside the SA-2040 for a couple of years. These tuners may be covered in a future HotM article.

The Heathkit SA-2040:

While the SA-2040 has been referred to as a basic no-frills tuner, this is not in reference to its matching capability. What it lacks are the capabilities that are easily handled externally, such as SWR measurement and antenna switching. The SA-2040 is a clone of Lewis McCoy-W1ICP's *Ultimate Transmatch*[2]. The SA-2040 is capable of tuning into loads with an SWR as high as 10:1[3], though Heath

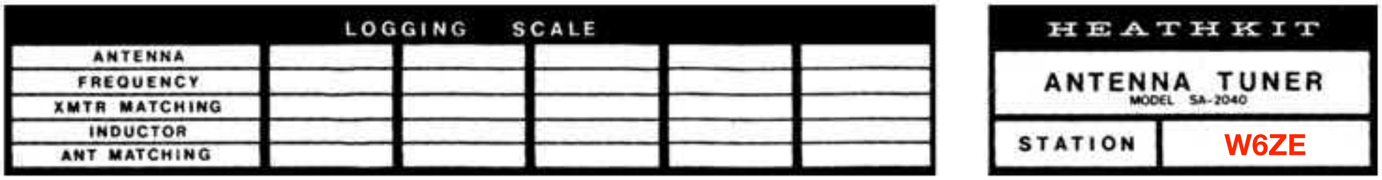

Figure 2: On the front panel is an erasable place to write settings as well as a place to add your station call letters.

specified its matching output impedance only as “wide-range”. Specifications are shown in Table I.

The SA-2040 has a 50Ω input and has outputs for a coaxial cable connected antenna, a single wire non-resonance antenna and a balanced-feedline antenna. This last output is coupled via an internal 1:4 toroidal balun transformer. Only one antenna at a time should be connected to the multiple outputs.

The SA-2040 measures approximately 5⅝” H x 14¾ W x 14” D and weighs 10½ lbs. Internally it has only four electronic components: two large high-voltage variable capacitors, a roller inductor and a balun coil. They are liberally spaced apart due to the high RF voltages that can be present in the tuner. Both capacitor rotors are at a high RF potential so the extension shafts are made of insulating material. The input capacitor has two sections, each section is 125 pF. This is not a differential capacitor; the sections track with the same capacitance. The rear stator section on this capacitor is directly grounded by the mounting feet. The rotor section and remaining stator section are isolated from ground by ceramic end-plates. The output capacitor has a single 170 pF section with both the rotor and stator sections isolated from ground by ceramic end-plates. The roller inductor is 12 µH. The hot end is the rear shaft. The front cold end, the roller contact and its shaft and tensioners are grounded.

The front panel is bare aluminum covered with a self-adhesive-backed sheet of “vinylite”[4] that contains the panel markings. This panel is medium-dark gray with black trim and black and white lettering. It includes a window to allow viewing the turns-counter. There is also an erasable table area where one may mark down settings for later reference as well as a place to put the station call-letters using supplied vinyl lettering. This area is shown in **figure 2**. The cabinet is painted black, and the rear panel is painted a light gray with black lettering.

Heathkit SA-2040 Specifications

Frequency Range	3.5 – 30 MHz (80, 75, 40, 30, 20, 17, 15, 12, 10 meter bands)
Power Capability (input)	SSB: 2 KW PEP CW: 1 KW
Input Impedance:	50 Ω
Impedance Transformation:	4:1 (balance to unbalanced) balun
Output Impedance:	Wide range

Table I

The SA-2040 Controls and Connections:

The front panel of the SA-2040 has three large control knobs. On the left, **TRANSMITTER MATCHING** adjusts the dual-section input capacitor. The dial is marked 0 - 100 in 5 unit increments over 180°; every other increment is numbered. In the center, **INDUCTOR** controls the roller inductor. It has no dial markings, but to the left of its knob is the window of a turns-counting dial. Every full turn of the inductor is represented by 10 counts on the dial. The inductor has about 25 turns or 250 counts. On the right, **ANTENNA**

MATCHING adjusts the output capacitor and is marked in a similar manner as the TRANSMITTER MATCHING control.

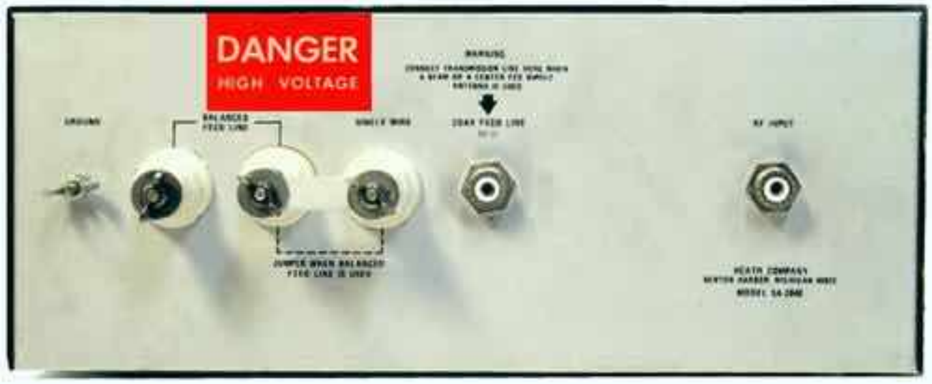

Figure 3: Heathkit SA-2040 Rear Panel. Outputs are on the left. Input is on the right.

The input and outputs are all located on the rear panel (**Figure 3**). Viewed from the rear, (left to right) are: a ground terminal with a wing nut; two large ceramic feedthrough insulators (J5 and J4) for a parallel feedline; a large ceramic feedthrough insulator (J3) for a single-wire antenna; a UHF coax connector (J2) for a coaxial antenna; and finally another UHF coax connector (J1), for the input from the transmitter. A large space is left between J1 and J2 to help prevent them from being mixed-up. When using a parallel feedline a connecting strap must be connected between the middle and right ceramic feedthrough insulators (J4 and J3). This strap may be stored across J5 and J4 when not using a parallel feedline. Wing nuts are used on these insulators to expedite secure connections.

The SA-2040 Construction:

Heathkit refers to the SA-2040 assembly as a “two evening project”. After the parts are checked assembly begins. Here is where you get a surprise. No need to fire up the soldering iron yet, first you have to assemble the two large variable capacitors and the continuously variable inductor. Then the balun toroids must be prepared and wound. Finally you’ll be heating the iron to tin the balun leads and solder on a pair of screw lugs.

<u>ANTENNA MATCHING Capacitor Assembly</u>:

First the ANTENNA MATCHING capacitor **C2** is built. The rotor section, (**Figure 4**) assembles with a hex shaft, two control nuts, nineteen 17/64” spacers and eighteen rotor plates. Next, the front capacitor plate is assembled by adding two ceramic insulators to the metal front plate using four #8 screws and eight fiber washers. Then the stator assembly (**Figure 5**) is built using two 6¾" #10-32 threaded rods, four large fiber washers, eight nuts, four 3/16” spacers, thirty-two 17/64” spacers, seventeen stator plates and the previously assembled front plate. The rotor and stator sections are then mated adding conical and

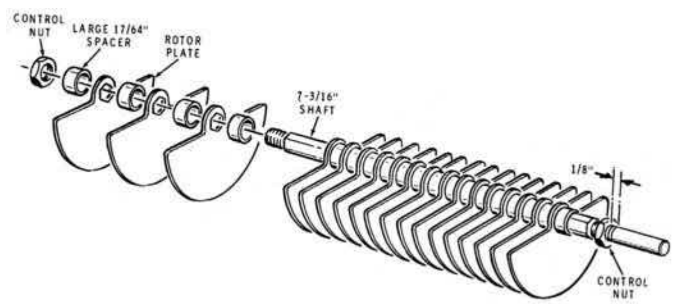

Figure 4: C2 Rotor Assembly; from Heathkit Manual.

forked springs, and lubrication is applied using grease supplied with the kit. Next, the capacitor rear plate is assembled, in a similar fashion to the front plate, and installed. Finally a knob is temporarily installed on the capacitor shaft and nuts are adjusted so the stator plates are centered between the rotor plates (**Figure 6**). Rotational tension is adjusted as necessary, the knob is removed, and C2 is set aside. The assembly of C2 takes up five pages in the manual and a full page in the

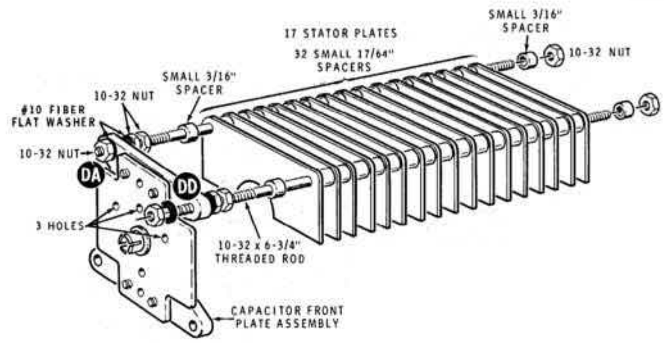

Figure 5: C2 Stator Assembly; from Heathkit Manual.

separate large illustration booklet using four pictorial, four detail and three inset drawings.

TRANSMITTER MATCHING Capacitor Ass'y:

The dual-section TRANSMITTER MATCHING capacitor **C1** (**Figure 7**) is assembled next. Its assembly is a bit more complicated since there are two separate stator sections. The C1 assembly also takes up five manual pages as well as two pages in the illustration booklet.

Roller INDUCTOR Assembly:

The continuously variable rotary inductor **L1** is then assembled. The silver-plated inductor comes mounted on a ceramic drum with shafts attached. End plates and the roller contact mechanism are assembled around the rotor inductor. Assembly of L1 takes four pages in the manual and another page in the illustration book.

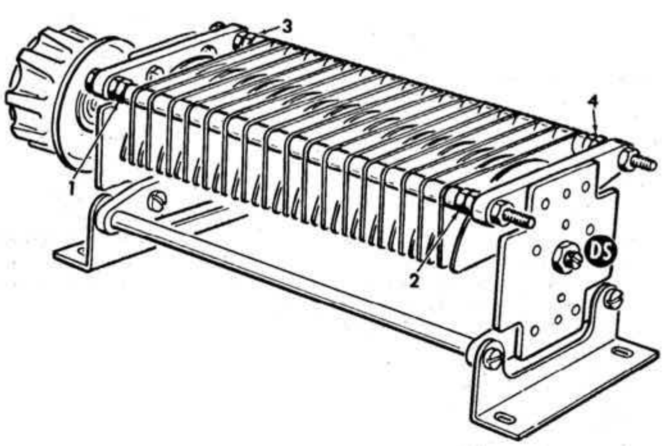

Figure 6: Completed C2 showing plate spacing adjustments; from Heathkit Manual.

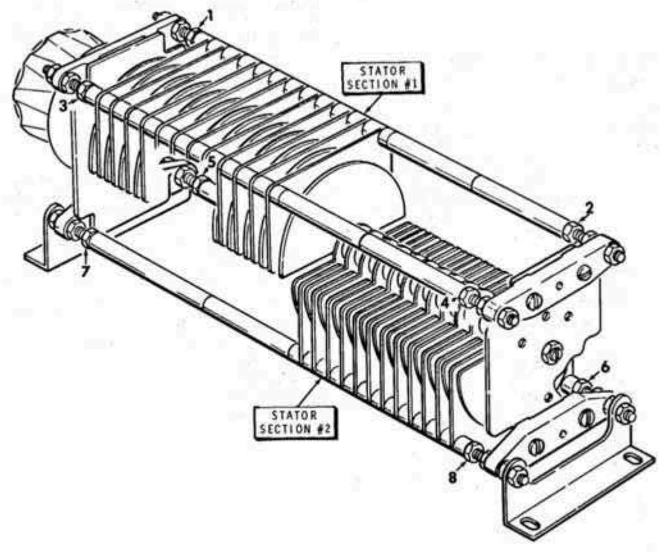

Figure 7: Completed C1; from Heathkit Manual.

Balun Transformer Assembly:

The balun transformer **T1** uses two large toroidal cores. Before winding the coil, each core is separately insulated with supplied glass-cloth tape, and then the two cores are placed atop each other and tape is wound around both cores along the full circumference. An eleven foot length of heavy stranded teflon-insulated wire is doubled over at its center and wound onto the toroid to create fifteen bifilar turns. A two-foot length of glass-cloth tape is then wound around the circumference of the coil to hold the windings in place. The doubled wire is cut apart, and the four wire ends are trimmed to length and tinned. Using an ohmmeter, the winding

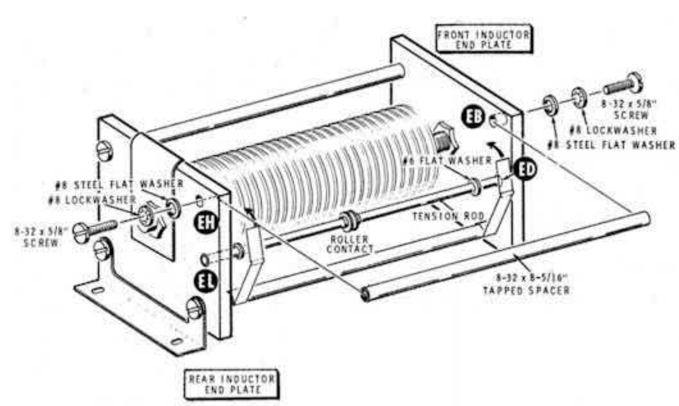

Figure 8: L1 during assembly; from Heathkit Manual.

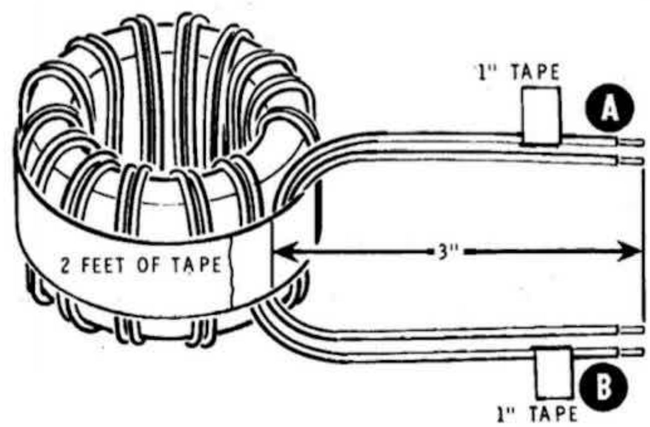

Figure 9: Assembled T1 balun; from Heathkit Manual.

leads are identified and marked with tape (**Figure 9**). The tape is placed on one winding at the starting end and on the other winding at the finished end. #10 lugs are then soldered on the two untaped leads. A ceramic feedthrough is used unconventionally to make a mounting post for the balun (**Figure 10)**. Assembling the balun transformer T1 takes five pages in the manual.

Chassis Assembly:

Once the two capacitors, roller inductor and balun are assembled, chassis assembly is started. The turns counter is assembled and mounted, the front panel "vinylite" face is mounted to the front panel, shaft bushings are installed for the three front panel controls, and the shaft with nylon gear is installed on the turns-counter shaft. On the rear panel the two UHF connectors, three large feedthrough insulators and grounding bolt with wing nut are mounted. The balun T1 is mounted next. The two taped leads are soldered to a ground lug on the inside of the chassis at the grounding bolt, and the two remaining leads are attached to feedthroughs. The roller inductor, and two variable capacitors are aligned with and mounted to the chassis and attached to insulated shafts that fit through the bushings on the front panel. A beveled nylon gear is first mounted on the inductor shaft that meshes with the gear on the turns-counter shaft. The turns-counter is calibrated and the gears are tightened.

Chassis Wiring:

Wiring the components together is done by straps and short lengths of #10 bare wire. Two silver-plated straps are used. One connects L1 to C1 and C2; the second connects C2 to the J3 feedthrough. A short piece of #10 wire connects J1 to a lug that bolts to

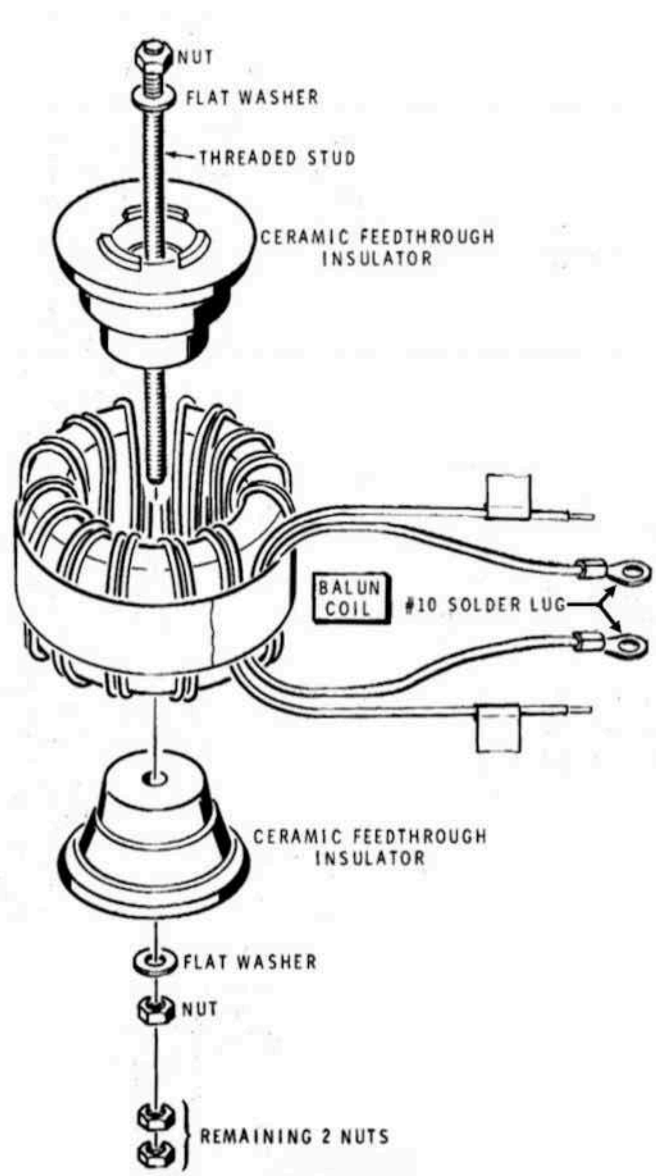

Figure 10: T1 balun mounting, see text; from Heathkit Manual.

C1; another short piece of #10 wire connects J2 to a lug that bolts to J3.

This completes the soldering. In all four leads were tinned, four solder lugs were soldered to the ends of those wires and three other soldering connections were made.

Final Assembly:
After the "Blue Label" that contains the kit's model and series numbers is attached to the inside rear of the chassis, the feet are installed. Heathkit offers a choice of the kit sitting flat or tilted at an angle by adding extensions to the two front feet. Knobs are attached, and after a thorough inspection the cabinet is attached using eight black machine screws.

SA-2040 Circuit:
The SA-2040 circuit diagram is shown in **Figure 14** at the end of the article. It is one of two popular design derivatives of the Tee-matching network (Tee-Transmatch[5]). The basic Tee-Transmatch network is shown in **Figure 10A**. It does a good job of matching even very high SWR loads (The W8ZR antenna tuner[6] can match up to an SWR of 16:1). What it lacks is good harmonic attenuation, especially if improperly tuned. **Figure 10B** is a modification of the Tee-Transmatch called the *Ultimate* Transmatch previously mentioned. It adds another section to the input variable capacitor to ground and was said to have better harmonic suppression. Later it was found that the extra capacitor added little if any performance advantage. An "improved circuit", called the SPC network, "*because the word 'ultimate' had already been used*", is shown in **Figure 10C**. SPC stands for "series, parallel capacitance". The SPC did do a better job of harmonic suppression and was described in the ARRL Handbook for many years. It did have two drawbacks, the first being the tuning was

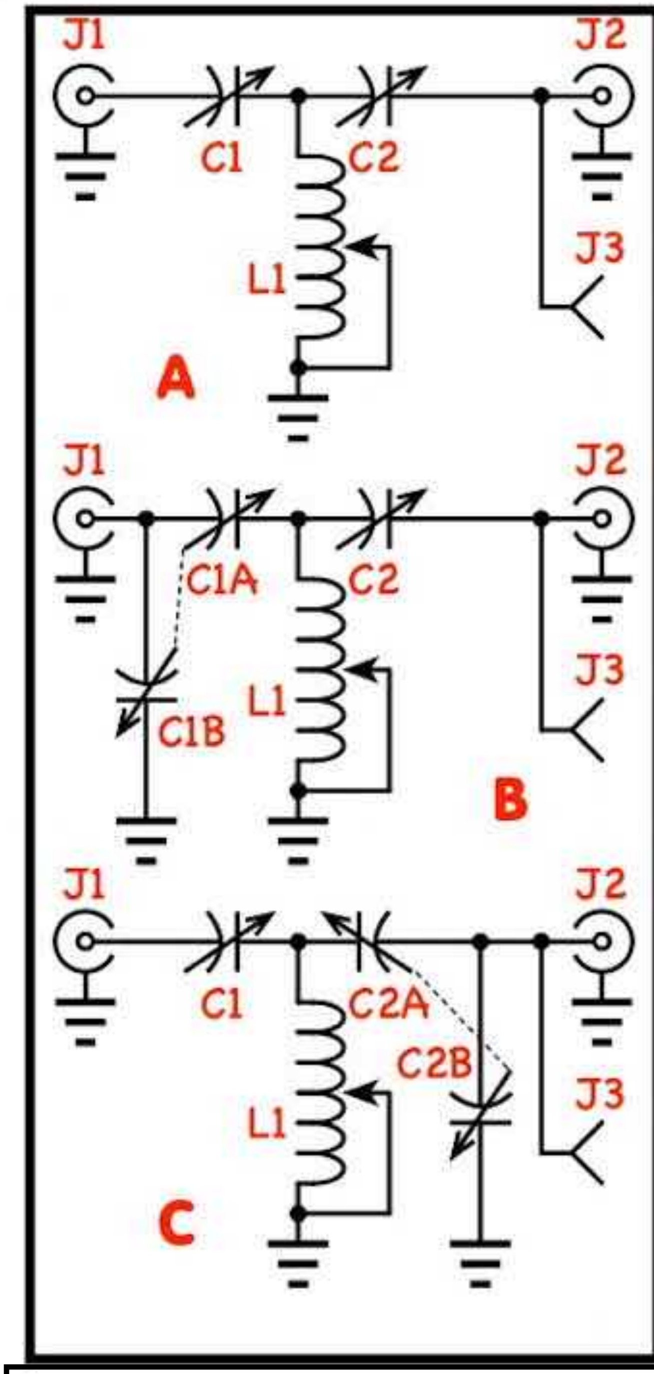

Figure 10: Three Popular Transmatch Schematics:
A: Tee Matching Network (Tee-Transmatch Network)
B: Ultimate Transmatch Network
C: Series Parallel Capacitance (SPC) Transmatch Network

In each schematic:

C1 (C1A/B)	Transmitter Matching Capacitor(s)
C2 (C2A/B)	Antenna Matching Capacitor(s)
L1	Inductor (Rotary or Multi-Tapped)
J1	Coax Input from Transmitter
J2	Coax Output to Low Impedance Antenna
J3	Feedthrough to Single Wire Antenna

very sharp, especially on the lower bands, and a vernier knob on the capacitors was needed to ease tuning. The second drawback turned out to be the one that killed the SPC design. It was found to be significantly more lossy than the other two. Heathkit never used the SPC circuit; the SA-2040 uses the *Ultimate* Transmatch circuit and the later SA-2060(A) and SA-2500 both use the Tee-Transmatch circuit. Not shown in the **Figures 10** is the balun often found in these tuners. It is shown in **Figure 11**.

Using the SA-2040:

Setting the three controls on the tuner properly is important. It is possible to get a low SWR at more than one setting, but the wrong setting will reduce harmonic suppression, be less efficient and can cause arcing across the tuning capacitors due to excessively high voltage. To properly tune-up using the SA-2040, and most other antenna tuners, an SWR bridge, placed between the transmitter and antenna tuner is needed. Fancier tuners, such as the SA-2060(A), have this capability built in. When using an external SWR bridge it should be dedicated to the tuner if the setup will be used on a day to day basis. Short lengths of 50Ω coax should be used to connect between the transmitter, SWR bridge and SA-2040.

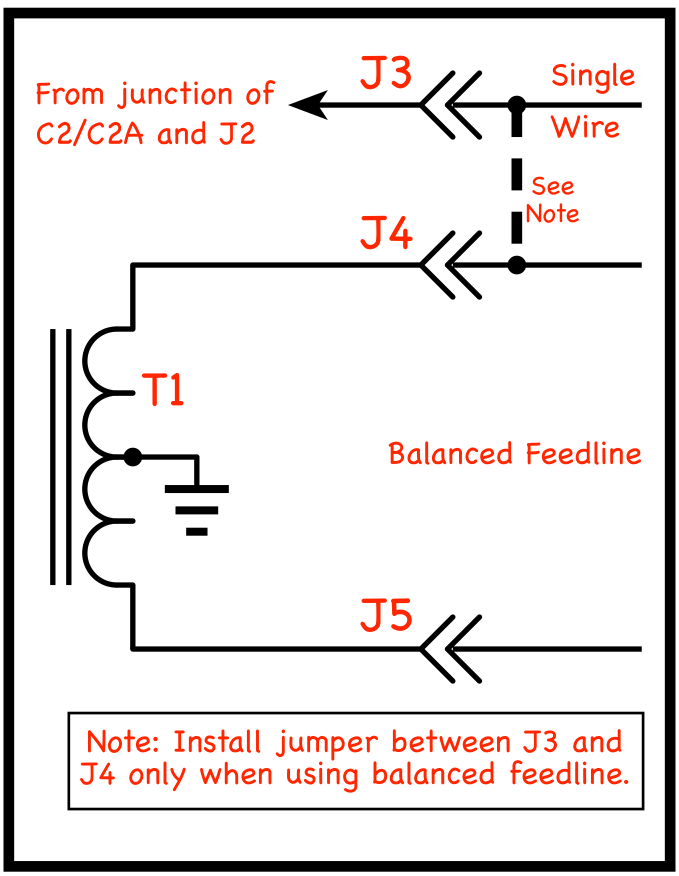

Figure 11: A toroidal balun (T1) may be added to any of the Transmatch networks discussed for a balanced feedline.

In Lew McCoy's article[7], that introduced the circuit used in the SA-2040(A), he gave basic adjustment instructions, here is the author's interpretation:

1. Start with C1 and C2 at maximum capacitance (fully CCW), and L1 at maximum inductance for 80/75 meters, about half inductance for 40/30 meters, about quarter inductance for 20/17 and about eighth inductance for 15/12/10 meters.
2. Apply just enough power to get a full-scale reading in the forward direction on the SWR bridge.
3. Set the bridge to read reflective power, and slowly adjust L1. At some point the reflected power will dip sharply; adjust for a minimum.
4. Now adjust C1 and C2, and touch-up L1 for a perfect match.
5. Now you may increase power to the level desired. You may want to touch-up the settings at the higher power.
6. If you change frequency check the match, and touch-up C1, C2 and L1 to correct the match if needed.
7. More than one match often is encountered. Always select the match that uses the highest capacitance settings.

Figure 12: Interior view of the SA-2040. C1 is on the left, and C2 is on the right. Behind C2 is the balun T1. The Inductor L1 is in the center. Photo by Bob Koller - KG7EMO; used with permission.

To aid initial operation, Heathkit provided a table of starting points for the initial settings for 80 through 10 meters (non-WARC bands only). For each band, settings are given for the low and high end of the band and a third around mid-band. This table may be found in the manual.

Make note of your settings for each antenna you use so you can make adjustments quickly when making large frequency excursions or changing bands. Note that things like moisture and obstacles can cause you to have to adjust your settings somewhat. Sudden major changes warrant a physical check of the antenna before transmitting at high power.

Comments:

Today many solid-state radios come with some sort of antenna tuner built-in or available as an accessory that mounts internally. These tuners generally provide only a coaxial output. They help match the transmitter to an antenna that is resonant at one frequency in the band by making the antenna capable of being resonant across the whole band, or in the case of 80/75 meters across a larger part of the band.

If you are using a non-resonant antenna such as a long-wire or end fed antenna, or an antenna fed by parallel feed (such as twin-lead) then a full-fledged antenna tuner such as the SA-2040 is recommended.

From the Author:

Suggestions are always appreciated for kits of interest to research and write about. April will soon be upon us and, as some know, I often try to pick an unusual kit to write about in celebration of April Fool's Day. Suggestions for April are also welcome, though I believe I have found an unusual one for 2020. Due to the holidays I probably won't have an article for January, which could make the April article #100.

In HotM #95 I wrote about the A-1 Audio Amplifier, the first hi-fi kit offered by Heathkit. I'm still looking for any documentation anyone has on that kit. I have not found the original schematic, though one dated August 18, 1948 is on the web. Unfortunately this turns out to be a schematic later released by Heathkit so users could upgrade their A-1 to the A-2. That schematic uses a 6SL7 preamplifier tube while the original uses a 6SN7. If you have an A-1 or the documentation, please contact me. You may email me by clicking on the link at the bottom of the copyright box.

73, from AF6C

Notes:

1. Discussed in Heathkit of the Month #13.
2. Lewis McCoy W1ICP, *The Ultimate Transmatch*, QST July 1970, p. 24.
3. Paul Pagel, N1FB, *Heath SA-2040 Antenna Tuner* Product Review, QST November 1980 pp. 49, 50.
4. ibid.
5. Lewis McCoy W1ICP, *The 50-Ohmer Transmatch*, QST July 1961 p. 30. '[Transmatch is a] *generic name coined by the editors* [of QST] *to apply to any type of matching network inserted between a transmitter and a transmission line. There has been an obvious need for such a term, since "antenna coupler" is inadequate both technically and psychologically.'*
6. James Garland, W8ZR, *The EZ-Tuner* [Part 1], QST April 2002, pp 40 - 43.
7. McCoy W1ICP 1970.

NOTE: This article was originally written to appear in the December 2019 issue of ***RF*** but was held until January of 2020 due to circumstances beyond the control of the author.

Figure 13: Ad for the SA-2040 Antenna Tuner from the Fall 1980 Heathkit Catalog (#850)

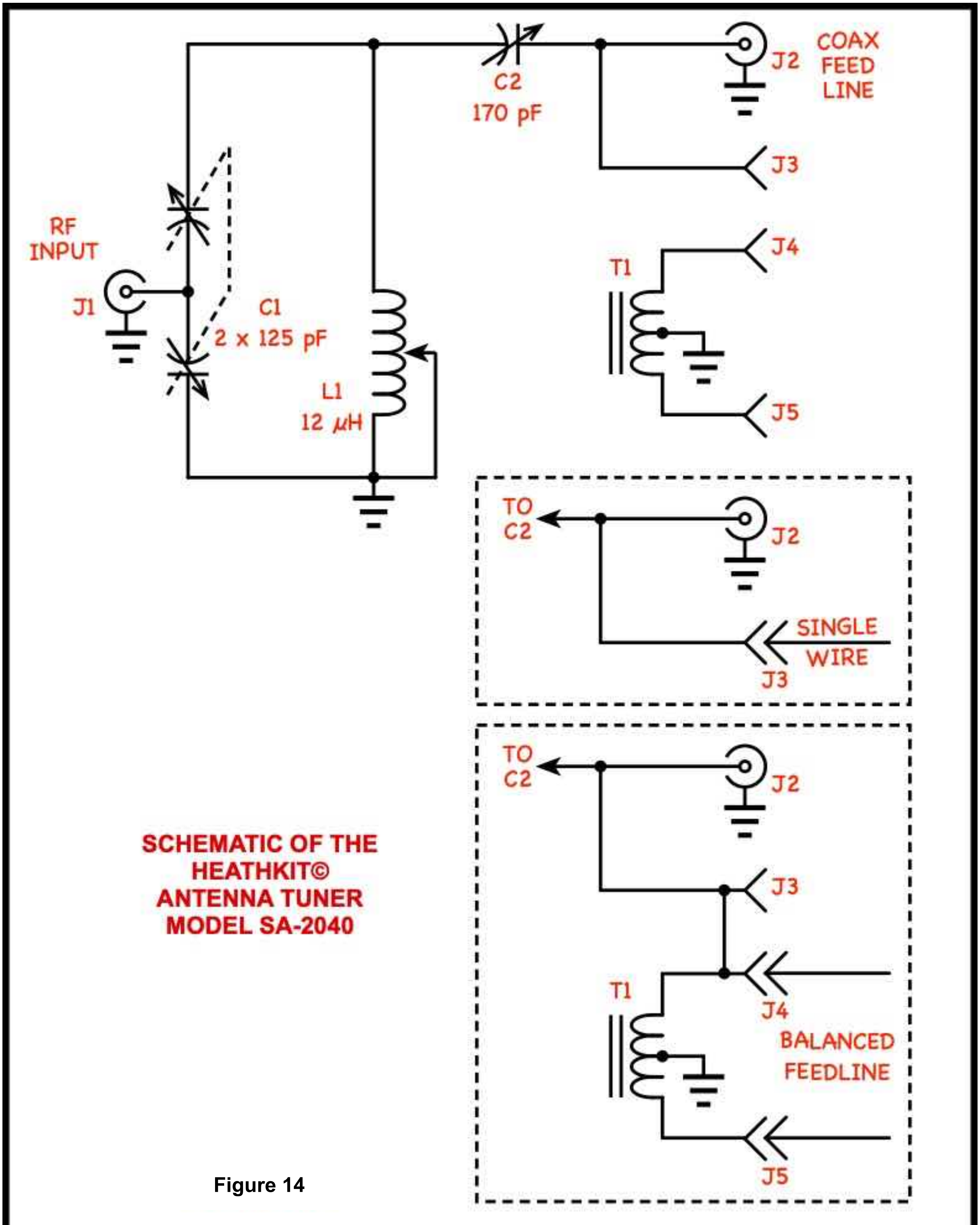
COAX
FEED
LINE
J2
C2
170 pF
J3
RF
INPUT
J1
C1
2 x 125 pF
L1
12 µH
T1
J4
J5
TO
C2
J2
SINGLE
WIRE
J3
TO
C2
J2
J3
T1
J4
BALANCED
FEEDLINE
J5
SCHEMATIC OF THE
HEATHKIT©
ANTENNA TUNER
MODEL SA-2040

Figure 14