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VR-004

Vintage Radio Application Note

RECONDITIONING THE HEATHKIT MODEL TT-1/TT-1A TUBE TESTER

Rev. A04/03-19/vr_apl_004
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Original Writing: December 2011

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SECTION I - INTRODUCTION & ACKNOWLEDGMENT

Anyone with a serious interest in vintage radio repair and restoration needs a quality tube tester. Without a tube tester, it is very difficult to determine the condition of vacuum tubes (most of which are decades old and likely in used condition), which are the key components of vintage radios.

Although I am old enough to have first studied electronics back in the early 1960s when vacuum tubes were prominent and even still being used in new designs, I can't claim to be a tube tester expert. Until very recently, my entire experience with tubes testers was limited to the ones that were available to the public in drugstores very long ago and the TV-7 portable tube tester that I used during my time as an Army electronics technician (also very long ago).

Even so, the experience that I have gained on this topic as a result of reconditioning two Heathkit TT-1 tube testers has made me much more knowledgeable on this subject to the point where I believe that this experience can be helpful to other vintage radio enthusiasts. With this in mind, the purpose of this paper is to pass along the benefits of this newly-gained experience to those who wish to acquire and recondition their own TT-1 tube testers.

As a bonus feature, this paper also presents TT-1 functional equivalent schematics for various calibration and test procedures presented in the Heathkit assembly manual. Since the circuitry as presented in the Heathkit schematic is very difficult to trace, these functional equivalent schematics greatly simplify circuit tracing and troubleshooting.

To conclude this introduction, I would like to acknowledge Mr. Kent Nickerson, who wrote the excellent and insightful paper "Refurbishment and Verification of the Heathkit TT-1 Tube Tester". With the benefit of the knowledge acquired from this paper, I was able to select the Heathkit TT-1 as the tube tester I wanted to procure. This paper was also a source of valuable information as to how to recondition the TT-1.

Kent Nickerson's paper is a good read and I recommend it to all vintage radio enthusiasts considering acquiring a tube tester (and especially readers considering the TT-1). Readers can download his paper and (other related technical papers) from his website at www.kw.igs.net/~knickerson/heathkit.html.

Also, 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.

**** DANGER ****

The Heathkit TT-1 tube tester contains dangerous high voltages that can be ***lethal if contacted****. Those intending to work on the TT-1 should be well versed in working on equipment with high voltages present and be completely familiar with all necessary safety precautions. Those unfamiliar with these safety precautions or inexperienced in working on equipment containing high voltages should not remove the TT-1 chassis from its case.*

SECTION II - SELECTING AND PROCURING A TUBE TESTER

A. EMISSION VERSUS TRANSCONDUCTANCE TUBE TESTERS

Fundamentally there are two categories of tube testers. The simplest and least expensive of these are emission testers. In addition to checking for filament continuity, leakage and shorts, emission testers also test plate (or cathode) current. Essentially, they configure the tube under test as a diode and measure the plate or cathode current (i.e., which is a function of the thermionic emission capacity of the heated cathode). This relatively simple emission measurement is then used as a proxy indication of tube transconductance (the assumption being that transconductance declines along with emission as the tube ages). Although emission testers are useful, they do not directly test the premier feature of most vacuum tubes, which is their ability to amplify signals. The primary virtues of emission testers then are their simplicity and economy.

This shortcoming is remedied in transconductance (Gm) tube testers. In addition to conducting all of the tests that can be done with the simpler emission testers, transconductance tube testers also measure the ability of the tube under test to amplify a signal under specified bias conditions. Transconductance tube testers thus provide a fuller, more meaningful, and more dynamic tube performance evaluation than emission testers.

Since transconductance tube testers are more complicated instruments than their emission tester counterparts, they are significantly more expensive. Even so, most serious vintage radio enthusiasts will want the vastly improved capabilities of a transconductance tube tester.

B. SELECTING A TUBE TESTER MODEL

When I first began searching for a tube tester, I strongly considered a TV-7 (see Figure 1). The TV-7 and it's A/B/C/D upgrades were widely used by the U.S. and Allied militaries for decades. My consideration of this unit was based mostly on my familiarity with it during my time as an Army electronics technician (although at that time I never gave much thought as to what was inside the TV-7).

Figure 1 - TV-7D Tube Tester

In the fullness of time, I learned that the TV-7 is a rugged, time-honored and field-tested unit with an excellent track record. On the negative side, however, this unit was designed primarily for compactness and portability. This in itself is not detrimental, but my concern was that a unit designed primarily for compactness might suffer from some design trade-offs as a price to obtain that compactness.

The other issue that concerned me was that of restorability and maintainability. A tube tester as compact as the TV-7 is difficult to work on due to its very high component density. Since the very newest TV-7 is likely over 30 years old, restoration, maintenance, and repair would likely be required. My preference therefore was for a larger unit whose components were more accessible and easier to work on. Even so, for someone less concerned about maintenance issues, a working TV-7 in good condition would be an excellent choice (although a clean, working unit would likely cost up to $1,000).

Figure 2 - Hickock 539C Tube Tester

Another model that is well thought of by vintage radio enthusiasts is the Hickock 539C (see Figure 2). Since this unit was not designed primarily for compactness, it is very feature-rich (even to the point of having multiple meters). Also, since this unit is much larger than the TV-7, it overcomes most of the TV-7 component accessibility and maintenance issues. Like the TV-7, however, a clean, working 539C in good condition would likely cost up to $1,000.

The Heathkit TT-1 (see Figure 3) is more similar to the 539C than the TV-7. Although the TT-1 is less elaborate than the 539C, it is nonetheless a fine instrument that can be relied upon to test tubes with reasonable accuracy. My understanding is that the TT-1 design is very closely based on that of the Weston 981. The TT-1 was first sold in 1960 as Heathkit's flagship tube tester and remained in production well into the '70s.

The most positive aspect of the TT-1 in my mind is that since it was designed to be built as a kit, its components are inherently accessible and the unit is relatively easy to maintain and repair. Also, Heathkit was world-famous for its well-written and well-illustrated documentation, and the TT-1 assembly and operational manuals fully meet these high standards.

Figure 3 - Heathkit TT-1 Tube Tester (taken from Kent Nickerson's website)

On the downside, like all Heathkits, most TT-1s were likely assembled by someone untrained in electronic assembly techniques. As a result, prospective buyers should expect that they may have to deal with uneven workmanship and quality issues and be willing and able to do corrective rework as a result. Since the TT-1 has a large number of switches, controls, and sockets all interconnected by point-to-point wiring with no printed circuit boards, the possibility of assembly errors is higher than for most Heathkits.

The prospective TT-1 buyer should therefore have the necessary technical skill to do extensive troubleshooting if the unit does not work properly.

This would be especially important if there are wiring errors. To help facilitate such troubleshooting, extensive information on this topic is provided in Section IV (Troubleshooting the TT-1) and Appendix A (TT-1A Chassis Photos).

C. <u>HEATHKIT TT-1 VERSUS TT-1A</u>

The TT-1A is an expanded version of the original TT-1 that includes the TTA-1-1 supplemental socket adaptor assembly (see Figure 4). This adaptor (which is installed in the lid of TT-1A protective wooden case) was introduced in 1962 to accommodate newer vacuum tubes developed after the introduction of the original TT-1. These newer tubes include miniature Nuvistors and 12-pin Compactrons.

<u>Figure 4</u> - TTA-1-1 Supplemental Tube Socket Adaptor Assembly (for TT-1A)

The TTA-1-1 was also sold separately so that TT-1 owners could upgrade their existing units to TT-1As. It is likely, however, that most vintage radio enthusiasts would not need the TTA-1-1.

Aside from the added TTA-1-1 socket adaptor assembly, there are no differences between the TT-1 and the TT-1A. Both of these units are therefore collectively referred to as the TT-1 for brevity in the remainder of this paper except in the few cases where this distinction is necessary for clarity.

D. <u>PROCURING A HEATHKIT TT-1 TUBE TESTER</u>

The best purchasing scenario is to find a TT-1 tube tester locally and verify first hand that it is in good working order before buying. Unfortunately, this is not possible in most instances.

Ebay is a convenient resource for tube testers with various models being posted frequently. The disadvantage of Ebay is that you must buy the product sight unseen from a seller unknown (the classical scenario for “caveat emptor”, or “let the buyer beware”). Although Ebay is structured to provide some element of buyer protection, in practice there is little you can do to avoid the risk of buying overpriced, shop-worn, and dilapidated junk misrepresented as a fine collector’s item. Although some sellers will claim that a product is operational, most will not back this claim up with any meaningful warranty (with the excuse that the product is being sold “as-is due to its age”) and will not accept returns.

Also, as happened to me, there is the real possibility that the reader may have to purchase two units on Ebay to ultimately cobble together one that actually works. As a case in point, I ultimately purchased two TT-1As. The first TT-1A I purchased on Ebay looked “primo” in the photos, was advertised as a working unit, and was priced accordingly. Although the unit was clean and in good mechanical condition, it did not work properly. In fact, the unit could never have worked properly since it had numerous wiring errors that required a great deal of time and effort to troubleshoot and track down.

To help remedy this, I subsequently purchased a second lower-priced “junker” TT1-A that I bought as a source of parts and also as a standard of comparison to help troubleshoot the “primo” unit. Although this “junker” was shop-worn and dilapidated, it was at least wired correctly. With a modest repair effort, I was able to recondition this “junker” unit to full “like-new” operation. Using this repaired “junker” unit as a standard of comparison, I was then able to repair the “primo” unit.

With the benefit of hindsight, there was a silver lining in the dark cloud with respect to the nonfunctional “primo” unit. Since the original owner never was able to make this “primo” unit work properly, it did not get much use (which, no doubt, is the reason it remained in “primo” condition).

E. NECESSARY DOCUMENTATION

Both an assembly and operational manual were published for the TT-1. Both of these manuals are essential for successful reconditioning, testing, calibration, and operation of this unit. It is likely, however, that the purchased unit might not include one or both of these manuals. If this is the case, one can purchase good-quality repro manuals from Don Peterson at Data Professionals. Data Professionals supplies reprinted manuals for most Heathkit products. Most of these manuals include B-size (11" x 17") fold-out drawings as appropriate for schematics and illustrations. Data Professionals is a great Heathkit legacy documentation resource and can be accessed on-line at www.d8apro.com.

Many TT-1s are shipped with the operational manual only. The assembly manual, however, is a “must have” if any troubleshooting is necessary. At the risk of belaboring this issue, it goes almost without saying that used equipment that was last built in the 1960s will sooner or later require maintenance and troubleshooting. Although the TT-1 is not a high-tech product, its switching and wiring is very complicated and cannot be properly troubleshooted without the benefit of its full documentation.

F. TUBE DATA ISSUES

Although the TT-1 includes a roll-chart with setup and test data for a large number of tubes, many new tube types emerged during the years the TT-1 was in production. Since it was impractical to replace these roll-charts to accommodate the necessary updates, Heathkit published supplemental tube data lists that were updated periodically.

The final edition of this publication was released in Nov 1978. TT-1 owners will want to have this final edition since it is the most comprehensive (and likely the most accurate) listing published by Heathkit. Also, since aging roll-charts are likely to be fragile and difficult to maintain, it is a good idea (and really no less convenient) to use the tube data book rather than the roll-chart.

Good quality repro versions of this publication can be obtained from Don Peterson at Data Professionals (www.d8apro.com) at for a modest price. Before ordering, check with Don to confirm that this is the final Nov 1978 release.

A similar tube data document I found on the internet looks very similar to the Heathkit Nov 1978 release but does not contain any Heathkit company information. This appears to be independently compiled but formatted similar to the Heathkit publication. I have posted this PDF document (TT-1A_Tube_Data_Nov_1978.pdf) on my vintage radio website at www.rdfproducts.com/N6DC.Vintage.Radio.htm.

Kent Nickerson has also compiled and posted a similar publication on his website at www.kw.igs.net/~knickerson/heathkit.html. Unlike the above-mentioned tube data publications, this document is in editable (.txt) format. Also, Kent has corrected errors he has found in the original listings and updates this document periodically.

My personal preference is to rely on a printed copy of the TT-1A_Tube_Data_Nov_1978.pdf document rather than the roll-chart. In addition to eliminating the roll-chart wear and tear and maintenance issues, this PDF document is far more inclusive. Also, it is easy to mark this document up to correct the errors (these same errors exist on the roll-chart as well). In addition it is more convenient to use than the roll-chart.

I believe that the roll-chart is way too out-of-date. Although my TT-1 was produced in 1969, its roll chart is missing tube types that were published on Heathkit's Jan 01 1964 release of its TT-1/TT-1A supplemental tube data list. This leads me to suspect that the original roll-charts that were printed for the earliest TT-1s manufactured in 1960 were used for many years (and possibly never replaced by updated reprints for the entire TT-1 production life cycle).

Another excellent resource is GE's "Essential Characteristics" tube reference manual. Kent Nickerson believes that this is the tube data source that was used by Heathkit for the TT-1A tube listings. This manual is therefore likely the best available ultimate reference for correcting whatever errors may still exist in the TT-1A tube listings.

"Essential Characteristics" was apparently published from 1951-1973 and is now out of print. However, reprints and originals are available from Amazon and other internet sources at modest pricing. It is best to obtain one of the later versions of this publication.

I have the final 1973 14th edition which I purchased in good used condition from Amazon. This copy was reprinted by Antique Electronic Supply in Tempe, Arizona. This book still appears to be available from that same source. More information is available on their website at www.tubesandmore.com/sites/default/files/pdfs/pages130-147.pdf.

Finally, tube data sheets can be found on-line for most tube types. This is an excellent resource for detailed tube data.

G. TUBE TESTER RECONDITIONING/RECALIBRATION SERVICES

There are a few small business enterprises set up to recondition and recalibrate tube testers. Since I have no experience with them, I can offer no opinion as to the quality of their work. Similarly, I do not know what tube tester models they accept or how much they charge for their services.

Such a service might be a good option for tube tester owners who lack electronic troubleshooting skills. For those who do have such skills, however, it seems reasonable to first make a best effort to attempt to repair and recondition their tube testers themselves.

Tube testers are not difficult to understand on a conceptual level and in fact are fundamentally low-tech instruments. Their complexity lies in the fact that their large number of switches, controls, and sockets make signal tracing and wiring verification difficult and tedious. As a result, troubleshooting these instruments requires patience and persistence.

H. ADDITIONAL THOUGHTS

A tube tester designed using today’s technology and components would be far superior to the TT-1 and, for that matter, any of the tube tester models of yesteryear. By today’s standards, the TT-1 and competing tube tester models of that era seem crude and imprecise. Even so, when looked at through the prism of the technology of the 1950s and 1960s when the these tube testers were designed along with the economic constraints associated with designing an affordable instrument, the TT-1 stands out as a well-engineered unit that balances reasonable performance against modest pricing.

SECTION III - RECONDITIONING THE TT-1

A. OVERVIEW

In this Section, detailed procedures are presented to replace various TT-1 components following an initial inspection and evaluation. Upon completion, the unit is then run through the test and calibration procedures presented in the Heathkit TT-1 assembly manual. Chassis photos are presented in Appendix A to help readers identify the substituted components and their locations.

B. INITIAL INSPECTION AND EVALUATION

The first step in reconditioning the TT-1 is to visually inspect the unit (with no AC power connected) to confirm that it is safe to power-up. To accomplish this inspection, it is necessary to remove the main chassis from its protective wooden case. To do this, first remove the 6 wood screws and washers from the case underside. Once done, the main chassis can be lifted up out of the wooden case.

Next, carefully inspect the chassis wiring and components to confirm that there are no burned parts or other signs of obvious damage. Also confirm that there are no disconnected wires or shorts. The primary purpose of this inspection is to confirm that it is safe to connect the unit to AC power.

Assuming that the unit appears to be undamaged and in safe condition, connect the AC power cord, plug this power cord into a 115 VAC power outlet, turn the power on (refer to the operational manual as required), and observe the unit carefully for any signs of component overheating or other distress. If such distress is observed (or heard or smelled), turn the unit off immediately, disconnect it from the AC power source, and begin troubleshooting.

Also check the AC power cord to verify that it is not frayed or otherwise unsafe to use. The AC power cord for one of my TT-1s was intermittent and had to be replaced. Although I was unable to find an exact replacement, I was able to adapt a detachable AC power cord typically found on AC adaptors for laptop computers. Since the pin sockets were too far recessed into the plug insulation to make reliable connection with the TT-1 2-prong AC power jack, I had to carefully shave down the plug end (using a grinding wheel) for a good fit.

If the unit appears to power-up normally, try to conduct an actual tube test as per the instructions in the operational manual and make note of any problems. Next, conduct the preliminary verification tests and calibration procedures as per the assembly manual. Again, make note of any variances.

The verification test procedures can be found immediately prior to the assembly manual roll-chart installation section. The calibration procedures can be found immediately following the roll-chart installation section. These procedures are not difficult to conduct but are involved and must be followed very carefully. (It may be helpful to repeat these procedures one or more times as required to achieve a complete understanding.)

The primary purpose of this evaluation is to establish a performance baseline (i.e., to determine how well the instrument functions before replacing old components and making modifications). This baseline is especially important for subsequent troubleshooting in the event that a mistake is made when replacing these old components or making modifications.

C. CLEANING, MECHANICAL INSPECTION, AND CORRECTIVE MAINTENANCE

Most TT-1s will likely need a thorough cleaning after 40+ years. This can be done using normal techniques, but exercise caution not to rub off the silk-screened control labels. In this regard, it is better to use mild cleaning agents rather than solvents.

Since most TT-1s were built by people lacking formal training in electronic assembly techniques, it is a good idea to conduct a (belated) quality and workmanship inspection. In addition to inspecting solder joints, the unit should be inspected for solder balls, solder splashes, and any other debris that may be lodged in the chassis, wiring, or on components. Of course, all foreign objects should be removed as part of this process.

It is possible that some of the many TT-1 switches may have become intermittent after 40+ years. This can usually be remedied using spray switch contact cleaner.

CAUTION

Be careful to prevent contact cleaner over-spray from soiling the paper roll-chart. If this precaution is not taken, the paper will become permanently stained.

Check the paper roller mechanism to verify that it rolls smoothly and that the thumb wheels don't drag. This mechanism may require adjustment, and it is also possible that the roller springs may need replacement.

Verify that all hardware is tight. Also, replace any missing hardware.

D. SOLDERING

In light of the fact that bad soldering was always a major cause of defective Heathkits, it is important to inspect all solder joints to verify that there are no unsoldered or poorly soldered connections. On a related note, when replacing components as discussed below, it is important to be especially vigilant when soldering. Since the existing 40+ year old solder joints will likely be heavily oxidized (and even corroded), good soldering will be more difficult than usual.

E. DIODE REPLACEMENT

The TT-1 employs five R200 200 PIV/200 mA silicon diodes (CR1-CR5) for power rectification and steering. The R200 was a very early silicon diode manufactured by CODI Semiconductor that has been out of production for over 30 years.

Modern silicon diodes are far superior and much more reliable. I therefore recommend that all five of these diodes be replaced by 1N4007s (rated at 1,000 PIV). The 1N4004, 1N4005, and 1N4006 are equally suitable with PIV ratings of 400, 600, and 800 volts, respectively. All 1N4000-series diodes are rated at 1.0 A continuous forward current and can handle surges up to 30 A. They are very inexpensive and readily available from multiple sources.

Exercise caution when changing out these diodes. Some of these diodes are wired directly to wafer switch contacts, so care must be taken to avoid breaking an irreplaceable switch wafer. Rather trying to unsolder the diode leads from the switch contacts, it is better to just clip out the old diodes and then solder the replacement 1N4007s to the remaining leads.

CR1 and CR2 are buried inside a wiring bundle on the rear-wafer of switch SK (see Figure 11 chassis photo). To gain access to these diodes, temporarily remove the switch from the front-panel for better access. Similarly, temporarily remove switch SW to gain better access to CR3 (see Figure 15 chassis photo).

F. FIXED RESISTOR REPLACEMENT

In contemporary electronic equipment employing modern carbon-film and metal-film fixed resistors, these resistors are non-maintenance items that mostly never fail. Most electronic equipment built in the 1960s, however, employed the earlier carbon composition resistors whose values were unstable and tended to drift upward with age and use.

Since the TT-1 was manufactured back in the 1960s, it employs mostly carbon composition resistors, many of which will likely have drifted significantly upward in value over the years. Since many of these resistors will likely be out of tolerance as a result, they should be replaced. Fortunately, the TT-1 contains only a modest number of resistors so this task is not as formidable as it might at first seem.

Most of these resistors can be tested in-circuit using a precision digital ohmmeter (most digital ohmmeters have sufficient precision for this test). In some cases, it may be necessary to change certain switch settings to eliminate back-loop shunt resistance paths that would otherwise invalidate the measurement. In a few cases, it might even be necessary to temporarily disconnect a resistor lead to obtain a valid measurement.

The TT-1 uses both 5% and 10% tolerance carbon composition resistors. Since the 10% resistors are non-critical in value, I did not take any action on these except for the ones that were out of tolerance. Not surprisingly, all of these that were out of tolerance were on the high side. To correct this, I soldered appropriate values of modern 1/4 watt 5% carbon film resistors in shunt with the originals so as to pull the overall values back down to within 5% of their nominal values. My thinking underlying this expedient procedure was that these original 40+ years old carbon composition resistors were already fully aged and not likely to drift significantly further in value. Carbon film resistors are readily available from multiple sources.

The TT-1 also employs some 1% precision resistors. In my units, none of these were out of tolerance so I did not replace them. Even so, these should all be checked for proper value.

Finally, the TT-1 employs some power resistors. In my units, these were also all in tolerance so I did not replace them.

Any resistors that look burned or smell cooked should be replaced. Keep in mind, however, that a burned resistor may be symptomatic of a wiring error that will eventually have to be tracked down and corrected.

G. VARIABLE RESISTOR (POTENTIOMETER) REPLACEMENT

Heathkit wisely employed good-quality potentiometers in the TT-1 that were built to last. All of the pots in my two units worked satisfactorily with the exception of the Set Line pot on one of the units which had been damaged by a wiring error made by a previous owner. (Fortunately, I was able to repair this irreplaceable component.) Use spray contact cleaner on pots that perform erratically (i.e., that seem intermittent or “scratchy”).

H. CAPACITOR REPLACEMENT

1. **Overview** - Of all the components in the TT-1, it is the capacitors that are most prone to the adverse effects of extreme aging. Electrolytic capacitors are especially prone to failure after 40+ years, especially given the fact that electrolytics built in the 1960s were less reliable than their modern counterparts. I therefore recommend that these all be replaced with more reliable modern units.

   Non-electrolytic capacitors built in the 1960s had a tendency to develop electrical leakage problems over time. Even very small amounts of electrical leakage can be troublesome in high impedance vacuum tube circuits, especially given the high voltages. As a case in point, even very slight leakage in a DC blocking capacitor feeding a high impedance vacuum tube grid circuit can result in unwanted positive grid bias.

   Finally, the TT-1 employs an unusual (and likely custom-made) 3-section oil-filled capacitor. The section values are 3.6/3.6/7.1 uF (+/- 3%) with all sections rated at 125 VAC. This capacitor is used for the three current-driven filament options (300, 450, and 600 mA), which will be explained in greater detail below. This capacitor must be carefully tested prior to use. If it is found to be faulty, it should be disconnected to prevent possible damage to tube filaments since it would likely be very difficult to replace. Fortunately, this capacitor is unnecessary for most users.

2. **<u>Electrolytic Capacitors</u>** - The TT-1 electrolytic capacitors are as follows:

20 uF/350V - (C2, C3, C7)
25 uF/25V - (C8, C13)
40 uF/150V - (C14)
100 uF/50V - (C16, C17)

Since these capacitors are used for filtering only, their replacements can be much higher in capacitance than the originals. My personal preference in selecting such replacements is to use capacitors up to about twice as high in value as the originals. This capacitance increase is sufficient to significantly improve filtering but usually not enough to result in subtle adverse affects. Of course, replacement capacitor voltage ratings must equal or exceed those of the originals. The replacement electrolytic capacitors I actually used for my two TT-1As are listed at the end of this Section (III-H-5).

Although it was standard Heathkit practice to use electrolytic capacitors rated for +85° C operation, I recommend using premium grade electrolytics rated for +105° C for better reliability. Also, I recommend using electrolytics that are specifically rated for rectifier filtering applications since these are better able to handle power supply ripple current.

For a fuller discussion of ripple current and other important issues associated with electrolytic capacitors, see Vintage Radio Application Note VR-001 ("Reconditioning and Modernizing the Heathkit HP-23 AC Power Supply"). The relevant paragraphs can be found in Section V of that paper.

3. **<u>Non-Electrolytic Capacitors</u>**

The TT-1 non-electrolytic (excluding oil-filled) capacitors are as follows:

.02 uF/600 V - (C5)
.05 uF/200 V - (C13)
.1 uF/400 V - (C1)
.22 uF/200V (2%) - (C12)
.5 uF/400 V - (C4)
4 uF/200 V - (C8)

Since suitable substitutes for most of these capacitors are readily available, they should be replaced. The only capacitor I did not replace in my two TT-1As was the 2% precision capacitor C12 (which I verified was in tolerance and not leaking). The replacement non-electrolytic capacitors I actually used for my two TT-1As are listed in Section III-H-5.

4. **<u>Oil-Filled Capacitors</u>**

The TT-1 oil-filled capacitors are as follows:

3.6 uF/125 VAC - (C10, C11)
7.1 uF/125 VAC - (C9)

These three capacitors are combined in a single large metal container and share a common terminal. These capacitors (suitably switched singly or in parallel combination) are used as a series reactance to run filaments in a "current-mode" intended for use in series-string filament operation. As discussed in greater depth below, this current-mode capability is actually somewhat redundant and can be dispensed with for most applications. For those readers who do not desire this capability, the four leads to these capacitors should be disconnected and the free wire ends insulated for safety as discussed below. Those readers desiring this capability, however, should conduct the capacitor validation test presented below.

To digress for a moment for the benefit of younger readers who may be unfamiliar with this issue, low-end vacuum tube equipment often employed series-string filaments powered directly from the AC line to eliminate the expense of a filament transformer. (This equipment also generated the necessary plate voltages directly from the AC line as well so as to completely eliminate the need for an expensive plate transformer.)

To achieve this economy, a tube line-up was selected such that all the filaments used the same amount of current (typically 150 mA) and also so that the sum of the filament voltages equaled (or nearly equaled) the nominal 115 VAC line voltage. This allowed the filaments to be wired in series and powered directly from the 115 VAC line.

The most prominent equipment that employed this technique was the "All-American Five". The All-American Five was a generic category of low-cost AM broadcast superheterodyne receivers employing five tubes with series-string filaments. There were many manufacturers and models of these radios, which were mass produced in very large quantities from the mid-1930s through the early-1960s (both in the USA and overseas). A typical tube line-up for the later models using 7- and 9-pin miniature tubes was a 12BE6 (pentagrid converter), 12BA6 (IF amplifier), 12AV6 (AM/AGC detector and audio preamplifier), 50C5 (audio output amplifier), and a 35W4 (half-wave power rectifier).

<u>Figure 5</u> - Lafayette Radio HE-40
540 kHz-30 MHz "All-American Five"
AM/Shortwave Receiver

The final models eliminated the 35W4 (or other vacuum tube) rectifier in favor of a silicon diode (substituting an appropriate power resistor in place of the 35 volt filament). A typical later model (the Lafayette Radio HE-40 which was produced in the early 1960s) is illustrated in Figure 5. In addition to covering the 540-1600 kHz AM broadcast band, the HE-40 also covered the 1.6-30 MHZ shortwave bands in three additional band-switched ranges. The HE-40 (built by Trio in Japan) was a copy of the Hallicrafters S-120. These units were nearly identical in appearance, but the HE-40 included an S-meter that the S-120 lacked. The HE-40 was among the best and most elaborate of the All-American Fives. Realistically speaking, however, although the All-American Fives were skillfully engineered, they were designed primarily for economy rather than performance. While they performed adequately for AM broadcast band reception, even the best of them were marginal performers in the shortwave bands (particularly above 10 MHZ).

To return to the TT-1, it has provisions for current-driven filament sources that emulate these series-string filament circuits. To explain, in addition to driving the tube filament from a constant-voltage source (e.g., the 6.3 or 12.6 VAC transformer filament windings), the TT-1 also has the provision to create three selectable AC “constant-current” sources (300, 450, and 600 mA).

A constant-current source essentially comprises a high voltage in series with a high resistance that drives a load having a much lower resistance. With this setup, large changes in the load resistance result in only small changes in total circuit current. Thus, the load current is essentially constant, even with substantial changes in load resistance.

Rather than using a large power resistor to implement this constant-current source, the TT-1 employs the capacitive reactance of one or more AC capacitors to achieve the same result. The advantage of this approach is that these capacitors dissipate essentially no power (whereas a power resistor would dissipate a lot of power and run hot as a result).

C9 (with a capacitance of 7.1 uF) has a 60 Hz reactance of -j373.6 ohms. When placed in series with a typical 6.3 or 12.6 volt tube filament, the total series current when driven by the 115 VAC 60 Hz line is close to 300 mA. C10 (with a capacitance of 3.6 uF) has a reactance of -j736.8 ohms. When placed in series with a typical 6.3 or 12.6 volt tube filament, the total series current when driven by the 115 VAC 60 Hz line is close to 150 mA. By appropriately switching C9, C10, and C11 in parallel, constant-current sources of 450 and 600 mA can also be generated.

In Kent Nickerson’s TT-1 refurbishment paper (see Section I above) he reported difficulty with the oil-filled capacitors in his TT-1 in that their values had risen with age and that they overheated when AC voltage was applied. The oil-filled capacitors in my two TT-1As fortunately were within their tolerances and did not overheat, but with Kent Nickerson’s experience in mind I recommend the following capacitor verification tests:

<u> DANGER **</u>**

The following tests require that 115 VAC mains power be applied directly across the oil-filled capacitors. Since AC mains power can be ***lethal if contacted****, exercise extreme caution when conducting these tests. As stated above, those intending to work on the TT-1 should be well versed in working on equipment with high voltages present and be completely familiar with all necessary safety precautions. Those unfamiliar with these safety precautions or inexperienced in working on equipment containing high voltages should not remove the TT-1 chassis from its case and should not conduct this test.*

a. Disconnect the TT-1 from the AC power source.

b. Disconnect the four wires from the oil-filled capacitor (comprising C9, C10, and C11). *Record the correct connections of these wires so that they can be properly reconnected after this procedure has been successfully completed.*

c. Measure the capacitances of C9, C10, and C11 to verify that they are within tolerance (the four capacitor terminals are appropriately marked, with “C” indicating the common terminal). If any of these three capacitors are out of their 3% tolerance specification, discontinue this test and do not reconnect the wires to the capacitors since they are unsafe to use. Insulate the exposed wire ends as per step g. below.

d. If the capacitors are within tolerance, carefully apply 115 VAC power across each of the three capacitors in succession and carefully observe the capacitor for any signs of heating or other distress. Leave the voltage applied across each capacitor for several minutes to confirm safe operation. If any distress is observed, immediately remove the AC power, discontinue this test, and do not reconnect the wires to the capacitors since they are unsafe to use. Insulate the exposed ends as per step g. below.

e. As a final test, repeat the above test but also measure the current through each capacitor. To conduct this measurement, I placed a 22 ohm 10 watt power resistor in series with each capacitor in succession (to simulate a tube filament) and then measured the current to confirm that it was close to the specified values (150 mA for the 3.6 uF capacitors and 300 mA for the 7.1 uF capacitor). This measurement can be conducted either directly with an AC milliammeter or indirectly by measuring the AC voltage drop across the 22 ohm series resistor and then computing the current using Ohm's Law. ***In either case, be sure that the measuring instrument is completely isolated from the AC line to ensure a safe measurement.***

   The measured current for the capacitors used in my two TT-1As was approximately 165 mA for the 3.6 uF capacitors and 320 mA for the 7.1 uF capacitors.

f. If the capacitors successfully pass all of the above tests, reconnect the wires to the capacitor terminals. For my two TT-1As, these connections were as follows:

Terminal	Wire Color
7.1	BRN
C	GRN/ORN
3.6	RED
3.6	GRN

g. If any of the capacitors do not pass the above test, leave all four wires disconnected and insulate the exposed ends using heat-shrink tubing or other materials suitable for safe high-voltage insulation.

As mentioned above, this current-mode filament drive capability is mostly redundant. As a case in point, the TT-1 roll-chart specifies a 300 mA current-mode filament switch setting for a 6AU6. However, the 6.3 VAC filament switch setting works equally well. Thus, there is no compelling reason to retain the current-mode filament drive capability, especially if the oil-filled capacitors are faulty.

As a final note on this topic, this current-mode filament drive capability does not work properly with 50 cycle power since the capacitive reactance at 50 Hz is 20% higher than at 60 cycles. For 50 cycle power, the 3.6 uF capacitors (C10 and C11) should each be shunted with .68 uF capacitors (these would be the closest 10% standard value). Similarly, the 7.1 uF capacitor (C9) should be shunted with 1.5 uF capacitors. Like C9-C11, these added capacitors would need to be rated for 125 VAC operation.

5. Replacement Capacitors

The actual replacement electrolytic capacitors I used in my two TT-1As were as follows:

TT-1 Capacitor	Replacement	Vendor/PN	Manufacturer/PN
20 uF/350V (C2, C3, C7)	47 uF/350V	Digi-Key Corp. P13553-ND	Panasonic EEU-ED2V470
25 uF/25V (C8, C15)	47 uF/63V	Digi-Key Corp. P13148-ND	Panasonic EEU-EB1J470
40 uF/150V (C14)	100 uF/200V	Digi-Key Corp. P13635-ND	Panasonic EEU-EE2D101
100 uF/50V (C16, C17)	220 uF/50V	Digi-Key Corp. P13131-ND	Panasonic EEU-EB1H221

The actual replacement non-electrolytic capacitors I used in my two TT-1As were as follows:

TT-1 Capacitor	Replacement	Vendor/PN	Manufacturer/PN
.02 uF/600V (C5)	.01 uF/400V (2 in parallel)	Digi-Key Corp. EF4103-ND	Panasonic ECQ-E4103KF
.05 uF/200V (C13)	.047 uF/400V	Digi-Key Corp. EF4473-ND	Panasonic ECQ-E4473KF
.1 uF/400V (C1)	.1 uF/400V	Digi-Key Corp. EF4104-ND	Panasonic ECQ-E4104KF
.22 uF/200V-2% (C12)	Not replaced.		
.5 uF/400V (C4)	.47 uF/400V	Digi-Key Corp. EF4474-ND	Panasonic ECQ-E4474KF
4 uf/200V (C8)	3.9 uF/250V	Digi-Key Corp. EF2395-ND	Panasonic ECQ-E2395KF

Note 1: There appears to be a TT-1 schematic drafting error in that two capacitors are labeled as “C8" (one of the two 25 uF/25V electrolytic capacitors and the 4 uF/200V non-electrolytic capacitor).

Note 2: Replacement capacitors can be staked-down to the chassis or larger components as required using RTV (Permatex Part 66B silicone sealant or similar; available in many automotive supply stores).

I. SIGNAL OSCILLATOR TRANSFORMER (T2) ISSUES

Some TT-1 signal oscillator transformers have incorrectly color-coded wire leads. This is an important issue, and all readers should confirm that their signal oscillators transformers have correctly color-coded leads by verifying the winding resistance as per the table presented in Appendix B.

SECTION IV - TROUBLESHOOTING THE TT-1

A. OVERVIEW

Tube testers are not difficult to understand on a conceptual level and in fact are fundamentally low-tech instruments comprising little more than door-bell circuitry. Their complexity lies in the fact that their large number of switches, controls, and sockets make signal tracing and wiring verification difficult and tedious. The TT-1 is no exception to this unfortunate reality. As a result, troubleshooting the TT-1 requires patience and persistence in addition to a certain amount of technical skill and troubleshooting experience.

Since it is not possible to test, calibrate, and troubleshoot the TT-1 without the benefit of the Heathkit assembly and operational manuals, readers should not attempt these tasks without first obtaining this documentation. As per Section II-E, good quality repro manuals can be obtained from Don Petersen at Data Professionals.

B. INITIAL TESTS

If the TT-1 does not power-up or if components overheat or exhibit other signs of distress, the unit must be inspected very carefully for shorts, damaged components, and any other problems that might cause such symptoms. This is a tedious but necessary process. As part of this process, it is helpful to check the power transformer voltages using the transformer voltage chart near the end of the TT-1 operational manual.

Once the unit appears to power-up normally, conduct the preliminary verification tests and calibration procedures as per the assembly manual. Make note of any variances since these will guide subsequent troubleshooting. Note that some of the voltages may be off somewhat due to inherent design imprecisions (mostly associated with the use of non-regulated power supply voltages). This will require some technical judgment.

The verification test procedures can be found immediately prior to the TT-1 assembly manual roll-chart installation section. The calibration procedures can be found immediately following the roll-chart installation section. These procedures are not difficult to conduct but are involved and must be followed very carefully. (It may be helpful to repeat these procedures one or more times as required to achieve a complete understanding.)

If the above procedures cannot be successfully completed, begin troubleshooting based on the faulty readings. At this point it will be necessary to use the TT-1 schematic (even though this schematic is tedious to read as per the discussion below). All issues must be resolved if the TT-1 is to work properly.

C. TT-1 SCHEMATIC ISSUES

Although the TT-1 schematic is well-drafted, the complexity of this instrument is such that this schematic is difficult to read and follow. Unfortunately, the TT-1 manuals do not include extensive functional block diagrams and other aids that facilitate better understanding of the circuitry.

To help mitigate this formidable problem, I have drafted functional equivalent schematics that track the relevant TT-1 circuitry for the three calibration test procedures presented in the TT-1 assembly manual (see Figure 6) and also for the leakage and grid current tests (see Figure 7).

Figure 6A is the simplified functional equivalent schematic for the TT-1 when configured for the bias calibration procedure.

Figure 6B is the simplified functional equivalent schematic for the TT-1 when configured for the signal calibration procedure.

Figure 6C is the simplified functional equivalent schematic for the TT-1 when configured for the meter circuit calibration procedure.

Figure 7A is the simplified functional equivalent schematic for the TT-1 when configured for the leakage test procedure.

Figure 7B is the simplified functional equivalent schematic for the TT-1 when configured for the grid current test.

Although these functional schematics are simplified, they accurately illustrate the signal path through all the essential components (including the switches, potentiometers, and the meter). As a result, they greatly facilitate signal tracing and troubleshooting. If any of the calibration procedures cannot be successfully completed, use the associated functional equivalent schematic to help trace the signal until the problem is found.

There appears to be a TT-1 schematic drafting error in that two capacitors are labeled as “C8" (one of the two 25 uF/25V electrolytic capacitors and the 4 uF/200V non-electrolytic capacitor). Another issue is that the wire connection carry-over arrows in the schematic upper left (“To SP-2", “To SO-2", and “To SR-2") are not matched by corresponding connection indications at these three switches in the schematic lower right. To avoid confusion, SP-2, SO-2, and SR-2 should be hand-annotated to indicate these connection carry-overs.

Finally, the rotary switches can be difficult interpret, especially to younger readers who are less familiar with customized switches. (In modern electronic circuitry, simpler standard switches are mostly used in conjunction with microprocessor firmware to implement complicated switch decoding when necessary.) In contrast, 1960s circuitry did not have the benefit of microprocessors and thus placed a heavier reliance on complex custom switches.

D. <u>FULL WIRING INSPECTION AND VERIFICATION</u>

If the troubleshooting steps suggested above are unsuccessful, the troubleshooting step of last resort is to conduct a full TT-1 wiring inspection and verification. Although such a procedure is very tedious and time-consuming (it will require that some of the switches be temporarily removed so that their wiring is more visible), it does not require much technical skill. Also, this wiring is superbly documented in the TT-1 assembly manual.

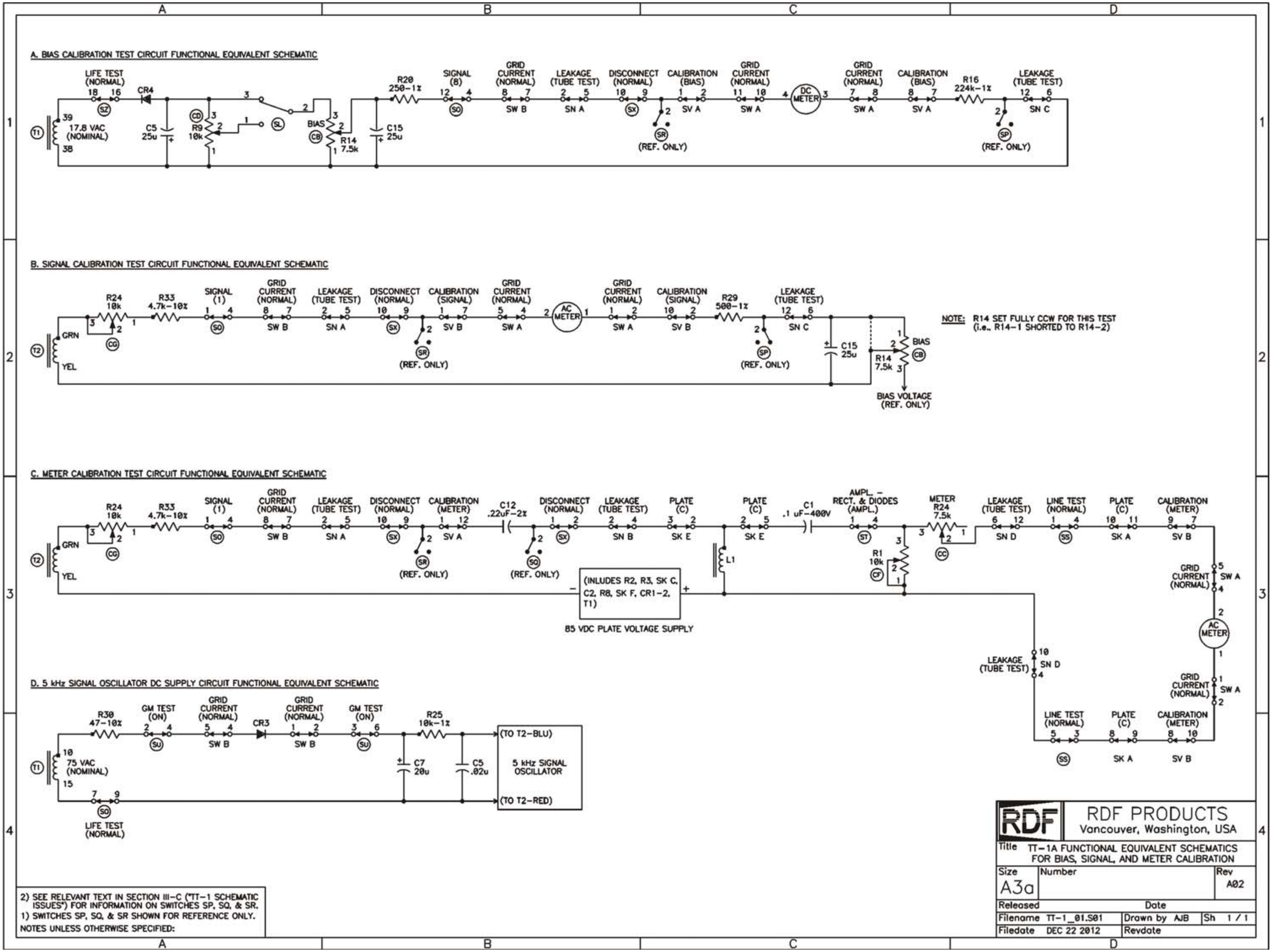


Figure 6 - TT-1 Functional Equivalent Schematics for Bias, Signal, and Meter Calibration

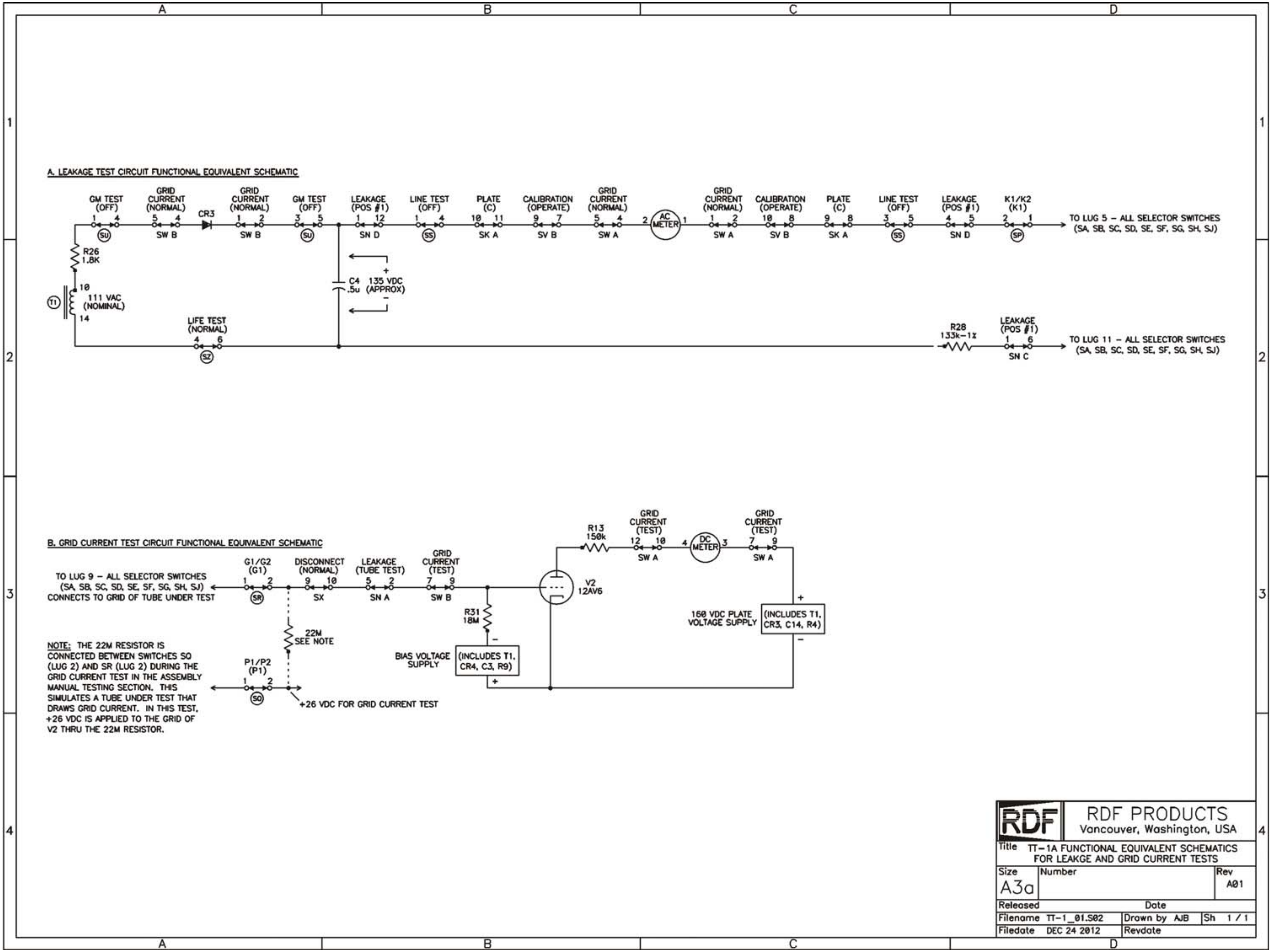


Figure 7 - TT-1 Functional Equivalent Schematics for Leakage and Grid Current Tests

SECTION V - CLOSING COMMENTS

Although I was ultimately successful in my efforts to recondition and troubleshoot both my “primo” and “junker” TT-1As so that they successfully passed the test and calibration procedures presented in the assembly manual, I was a little disappointed that these units gave substantially different transconductance readings for the same tube. More specifically, the transconductance readings for the same 6AU6 were over 25% apart.

I probably should not have been too surprised, however, since Kent Nickerson cautioned me that he believed that the Gm measurement accuracy could be as far out as 30%. This being the case, the disparity between my two units seems more reasonable.

Even so, it still seems to me that such an elaborately designed and well implemented instrument should be expected to have better accuracy. Initially I thought that this discrepancy meant that one or both of the instruments still had a wiring error or other problem. However, both units passed the testing and calibration procedures and I was unable to find any wiring or other errors (over and beyond the ones I had already found and corrected).

After considerable thought and additional testing, I came to the following preliminary conclusions:

1. The plate choke (L1) used for the tube under test appears to have an ill-defined impedance. I noticed that when I swapped out the chokes between my two TT-1As and redid the calibration procedure, I obtained significantly different Gm readings.

2. Although it would seem reasonable that the calibration procedure should compensate for any variations in plate choke impedance, it is possible that this choke behaves differently when driven by a low impedance source (i.e., the calibration circuitry where no tube is present) versus a high impedance source (i.e., the impedance presented to the choke by the high plate resistance of the tube under test).

3. The plate choke might exhibit different (and variable) impedance when DC current is passing through it due to iron core saturation effects.

4. I noticed that the 5 kHz signal oscillator output was non-sinusoidal, meaning that the waveform was harmonic-rich. With such a substantial amount of signal power in these harmonics, the choke impedance is different at these harmonic frequencies as compared to the 5 kHz fundamental frequency. Since my two TT-1A signal oscillators have markedly different waveforms (with correspondingly different harmonic spectral output), it is reasonable to expect different results.

Fortunately, there are practical technical solutions that can remedy all of these issues. These solutions will be presented in detail in the follow-on paper VR-005 (“Upgrading the Heathkit Model TT-1/TT-1A Tube Tester to the TT-1B”) along with other instrument refinements and enhancements. This paper will also address the all-important matter of independently measuring transconductance to provide a true standard for instrument calibration.

APPENDIX A - TT-1A CHASSIS PHOTOS

TT-1A chassis photos are presented below to help readers identify the substituted components and their locations.

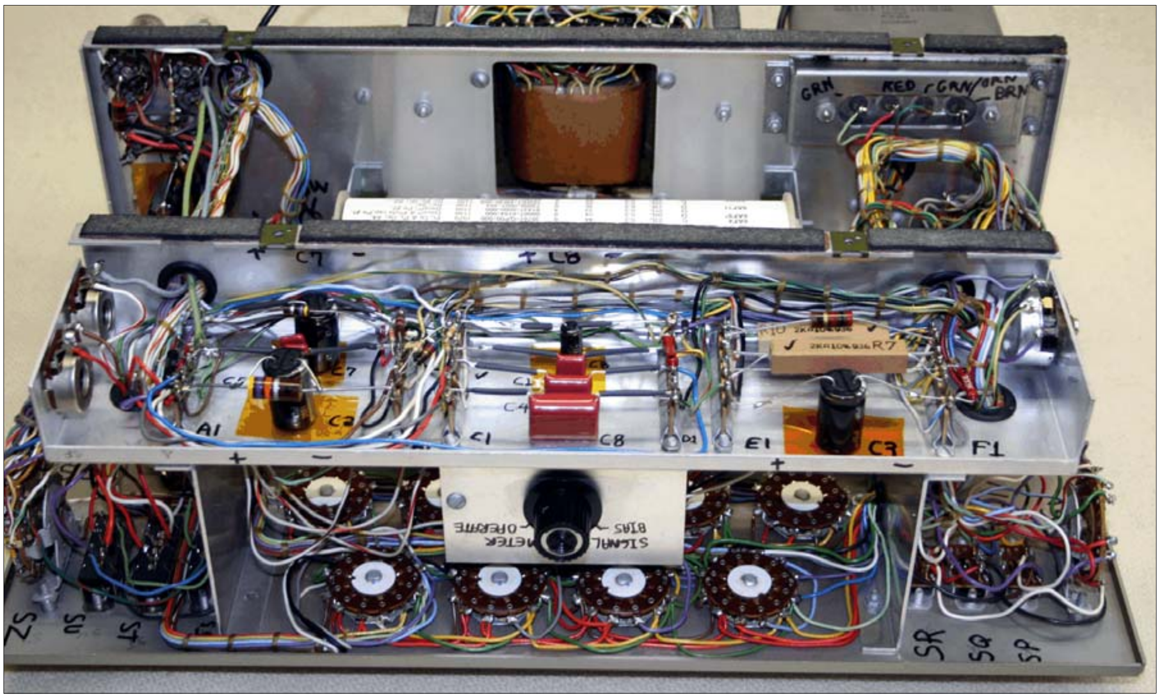


Figure 8 - TT-1A Chassis Photo

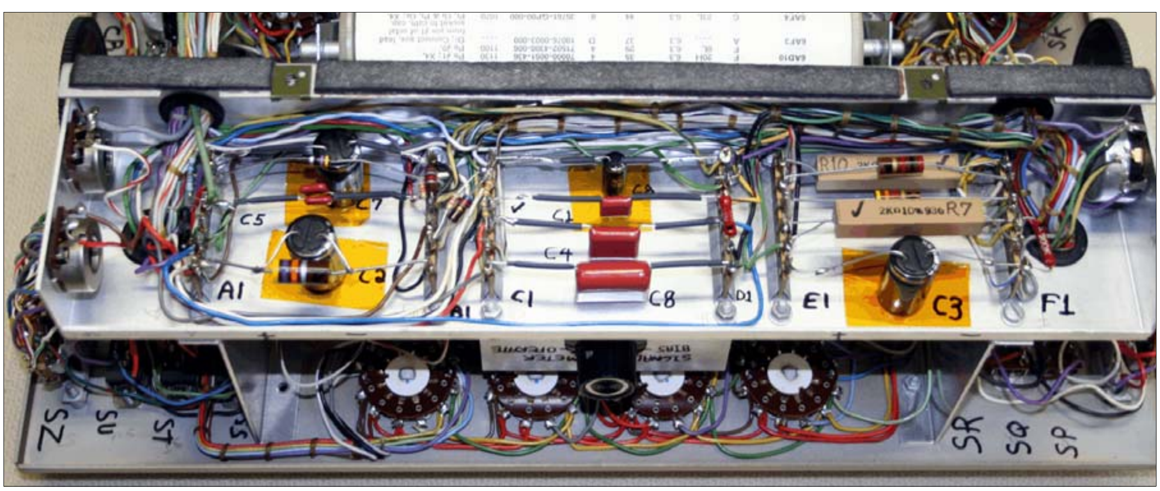


Figure 9 - TT-1A Chassis Photo

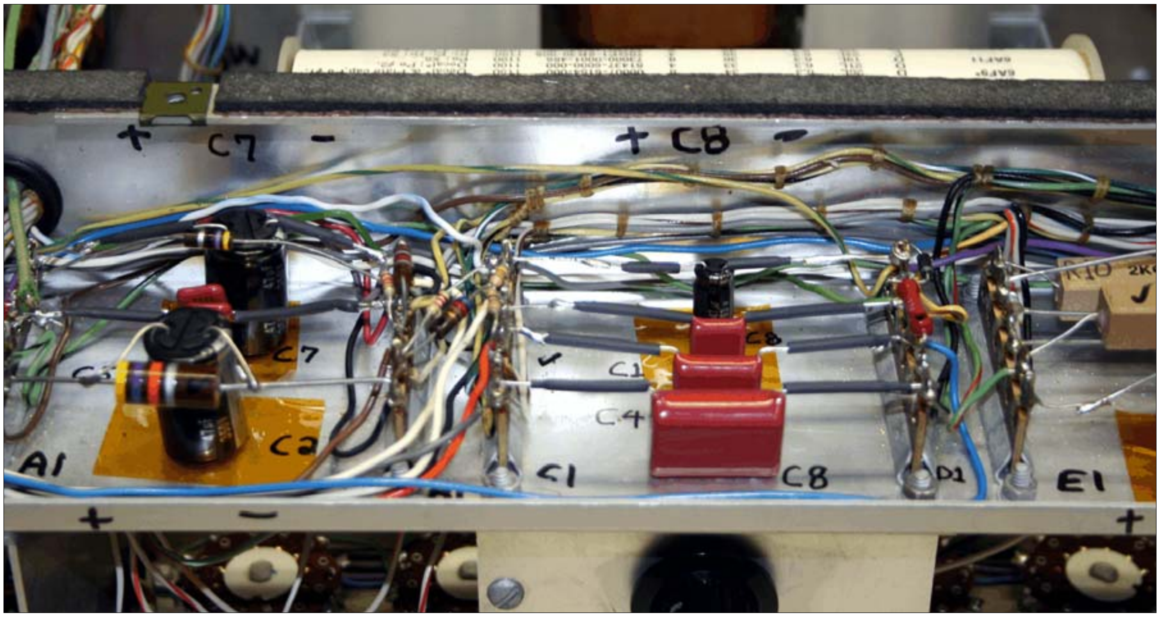


Figure 10 - **TT-1A Chassis Photo**

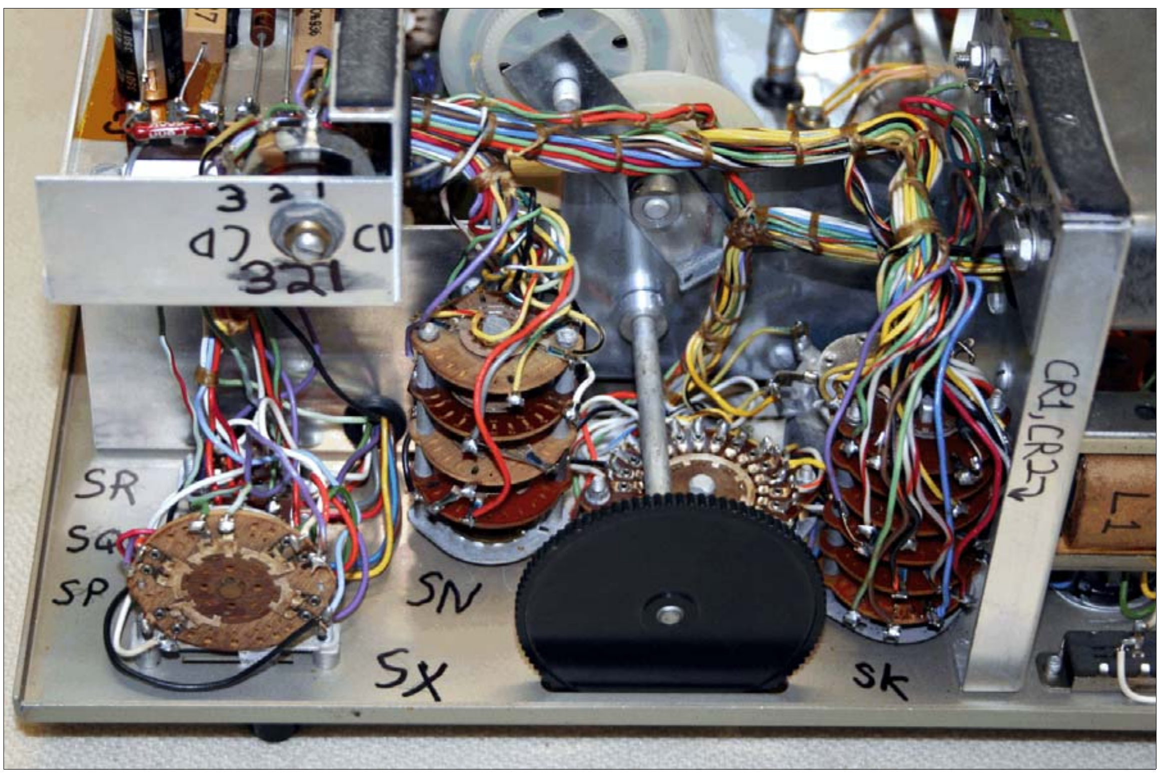
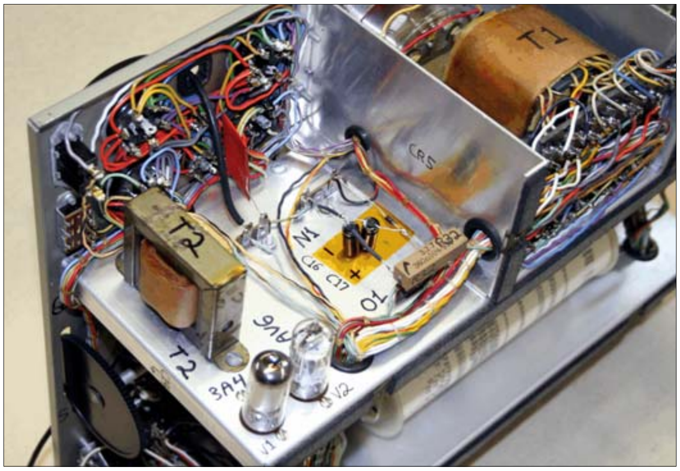
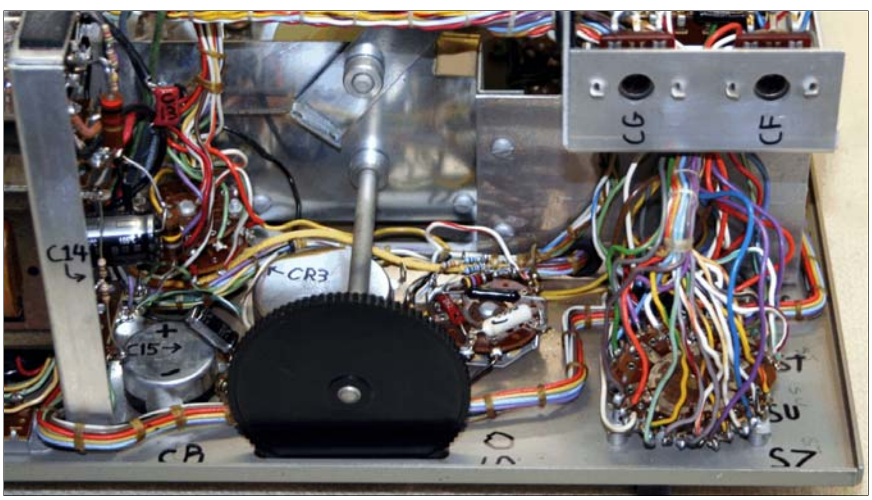


Figure 11 - **TT-1A Chassis Photo**

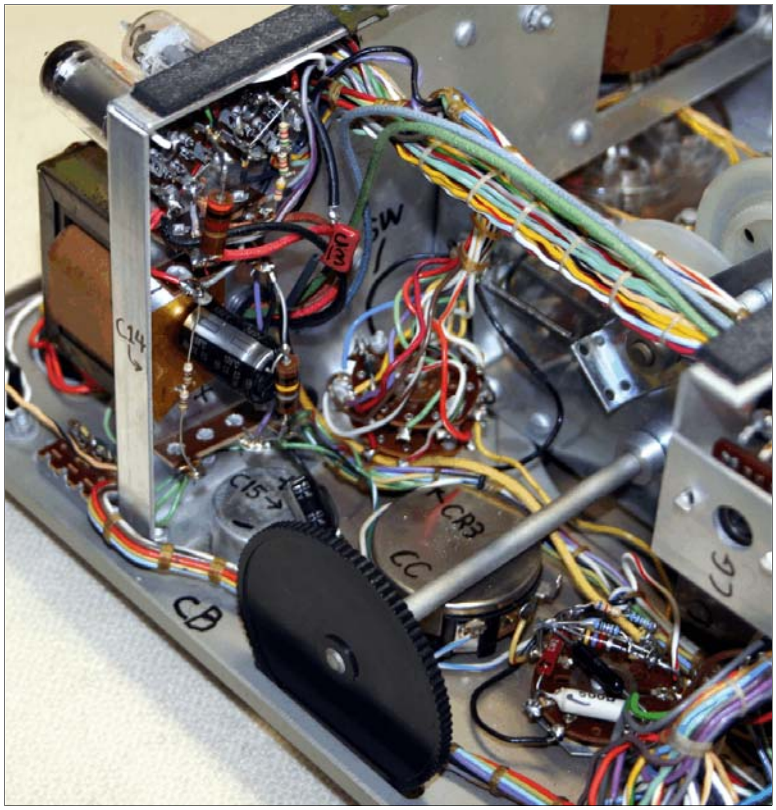


<u>Figure 12</u> - TT-1A Chassis Photo

<u>Figure 13</u> - TT-1A Chassis Photo



<u>Figure 14</u> - TT-1A Chassis Photo



<u>Figure 15</u> - TT-1A Chassis Photo

APPENDIX B - SIGNAL OSCILLATOR TRANSFORMER WIRE COLOR-CODE ISSUES

One of my two TT-1As (the "primo" unit) did not function primarily because of a manufacturing error in the signal oscillator transformer (T2). More specifically, this transformer had incorrectly color-coded wire leads. Although I don't know how widespread this problem was, the reader can verify transformer wire color-coding with an ohmmeter using the following table:

Correct Winding Color Codes	Winding Function	Nominal Winding Resistance
RED/BLK	Oscillator grid	65 ohms
BLU/BRN	Oscillator feedback	37 ohms
YEL/GRN	Oscillator output	20 ohms

Also refer to the TT-1 schematic.