A VACUUM TUBE CURVE TRACER ADAPTER FOR ALL TEKTRONIX SEMICONDUCTOR CURVE TRACERS

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*Front cover: Tektronix 577 Semiconductor Curve Tracer displaying the characteristic curves of a **TRIODE VACUUM TUBE**.*

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INTRODUCTION

By combining a Tektronix 575, 576, 577, 5CT1N, or 7CT1N Semiconductor Curve Tracer with a vacuum tube tester a universal curve tracer capable of testing semiconductors and vacuum tubes can be built for under $80[1]. A small adapter board is described in this paper that can be added to many vacuum tube testers to adapt them to display the characteristic curves of thousands of vacuum tubes on any Tektronix curve tracer. No modifications are necessary to the curve tracer.

John Kobbe designed the original Tektronix 570 Vacuum Tube Curve Tracer more than 60 years ago and a few years later he designed the 575 Semiconductor Curve Tracer. Both of these instruments set the standard for curve tracers for years to come. But the advent of semiconductors meant that many 570s were scrapped by the early 1970s. Today they are quite rare and highly prized instruments.

After 60 years most 575s have been replaced with newer curve tracers. Many have by now passed into the hands of hobbyists. Frequently, they are offered to anyone interested in owning one rather than see them scrapped. This means they can be commonly found at bargain prices. With the adapter described in this paper a 575 (or any of Tektronix' semiconductor curve tracer) becomes a universal curve tracer capable of testing semiconductors and vacuum tubes.

Custom built Vacuum Tube Curve Tracers were almost always inherently limited by the choice of tube sockets and filament voltages they provided. This meant they could often only test a few tube types from the same tube family". Until now nobody, to the best of my knowledge, has realized that the ***ideal*** way to make a Vacuum Tube Curve Tracer (VTCT) is to combine a Semiconductor Curve Tracer (SCT) with an ordinary vacuum tube tester. This has many significant advantages over designing and building your own custom vacuum tube curve tracer:

- The pre-wired test sockets of a tube tester allow the greatest variety of tubes to be tested.
- All of the standard filament voltages are provided by design in every tube tester. It would be impossible to find a transformer that has all these different secondary filament taps today.
- Most 575s are still fully functional since they were generally well cared for.
- If you don't already own a 575 SCT they can be found for less than $50. Since they are too heavy to justify shipping the best place to find them is Craig's List, or ham radio swap meets. You can place Want Ads in Craig's List for a 575 curve tracer.
- The 576 and the 577 (storage or non-storage versions) curve tracers are an excellent choice for testing vacuum tubes. They have a higher collector voltage capability that can come in handy when testing power tubes.
- The 5CT1N and 7CT1N were introduced as low cost, simpler, alternatives to full featured curve tracers. They can also be used (with lower total power capability) to test many vacuum tubes.

When combined with a vacuum tube tester, the VTCT adapter described in this paper will turn any Tektronix SCT (575, 576, 577, 5CT1N, or 7CT1N) into a universal SCT and VTCT. No changes are necessary to the SCT. It will still test all semiconductors exactly as before.

A working Tektronix 570 curve tracer sells at auction for $5,000 or more. And in many cases the original tube socket adapters are missing. By comparison used vacuum tube testers are readily available for almost nothing on Ebay, Craig's List, at local ham radio swap meets, and local antique radio swap meets. I paid $30 for mine. The VTCT adapter can be built for under $80.

[1] The adapter described in this paper was built entirely from parts available from Mouser (USA) and Farnell / Newark (Europe). A detailed parts list (with part numbers) is included at the end of this paper.

TEKTRONIX CURVE TRACER FEATURE COMPARISON

FEATURE / PRODUCT	570	575 Standard	575 MOD-122C	576 Standard	576 with 176	577 D1 or D2	5CT1N 7CT1N	EICO 667
HORIZONTAL VOLTS (MAX)	500V	200V	400V	1,500V	350V	1,600V	300V	N/A
MAX AMPS AT MAX VOLTS	1A peak	1A	0.5A	100mA	8A pulsed	40mA	6mA	N/A
VERTICAL AMP / DIV (MIN)	20uA	10uA	10uA	5nA	5nA	2nA	10uA	N/A
VERTICAL AMPS / DIV (MAX)	50mA	1.0A	1.0A	200mA	20A	2.0A	20mA	N/A
VOLTAGE STEPS (MIN)	100mV	10mV	10mV	5mV	5mV	50mV	1mV	N/A
VOLTAGE STEPS (MAX)	10V	200mV	200mV	2V	2V	2V	1V	N/A
NUMBER OF STEPS	4 to 12	4 to 12	4 to 12	1 to 10 or 10 to 100	1 to 10 or 10 to 100	1 to 10 or 10 to 100	0 to 10	N/A
STEP OFFSET MULTIPLIER	+8 steps	none	none	±10X step	±10X step	±10X step	±5X step	N/A
SCREEN VOLTAGE (DC)	10 to 300V	N/A	N/A	N/A	N/A	N/A	N/A	0 to 200V
HEATER VOLTS	1.25 to 117V	N/A	N/A	N/A	N/A	N/A	N/A	0.6 to 117V
STORAGE	NO	NO	NO	NO	NO	YES 577-D1	*	N/A
GRATICULE SIZE	10Div x 10Div	10Div x 10Div	10Div x 10Div	10cm x 10cm	10cm x 10cm	8cm x 10cm	*	N/A
ILLUMINATED GRATICULE?	YES	YES	YES	YES	YES	NO	YES	N/A

* Graticule size and storage capability are determined by the mainframe that the 7CT1N and 5CT1N are used in.

The 577 and the 576 are the most capable vacuum tube curve tracers due to their extensive feature set, their very high maximum plate voltage, and their wide range of available grid voltage steps. The 577 is capable of 2A of plate current but the 576 can only provide 0.2A.which is surprising since even the much earlier 575 was capable of 1A of plate current.

A useful feature that is present in the 577-D1 is CRT Storage. CRT Storage would be available for the 5CT1N if it was in a mainframe that has storage capability such as the 5111, 5113, 5115, or 5441 storage oscilloscopes. Likewise, CRT Storage would be available for the 7CT1N if it was in a 7000 mainframe that has storage capability such as the 7313, 7514, 7613, 7623, 7633, 7834, or 7934 storage oscilloscopes.

The 575 Mod 122C is capable of testing vacuum tubes with 400V at 1A. Its small maximum voltage step is remedied by the X10 and X100 voltage step amplifier of the VTCT Adapter. The 575 has the same capabilities as the 575 Mod 122C except the plate voltage is limited to 200V.

The 5CT1N and the 7CT1N are the least capable due to the limited front panel space, internal volume, and mainframe power limitations. Yes they are capable of 300V plate voltage. The most significant limitation is the plate current which is only 6mA at 300V.

The 575 is currently the least expensive curve tracer, and the most capable one given its low price and local availability. It is quite large and heavy however. It uses vacuum tubes. The 7CT1N is still a desirable plugin so its price tends to be well above the cost of a 575. The 5CT1N is similar in capability to the 7CT1N but fewer of them were made so they can be hard to find. Their scarcity also means the will cost more than a 575.

The 576 and 577 are both very flexible, feature rich, and highly desirable so they are the most expensive of the Tektronix semiconductor curve tracers.

TEKTRONIX CURVE TRACERS

Proceeding clockwise from the upper left on the next page is the original 570 Vacuum Tube Curve Tracer that made the Tektronix name synonymous with curve tracers, followed by the 575, 576, and 577. The 7CT1N in a 7603 mainframe is at the top left of the following page and a 5CT1N in a low cost 5111A storage oscilloscope is at the top right:

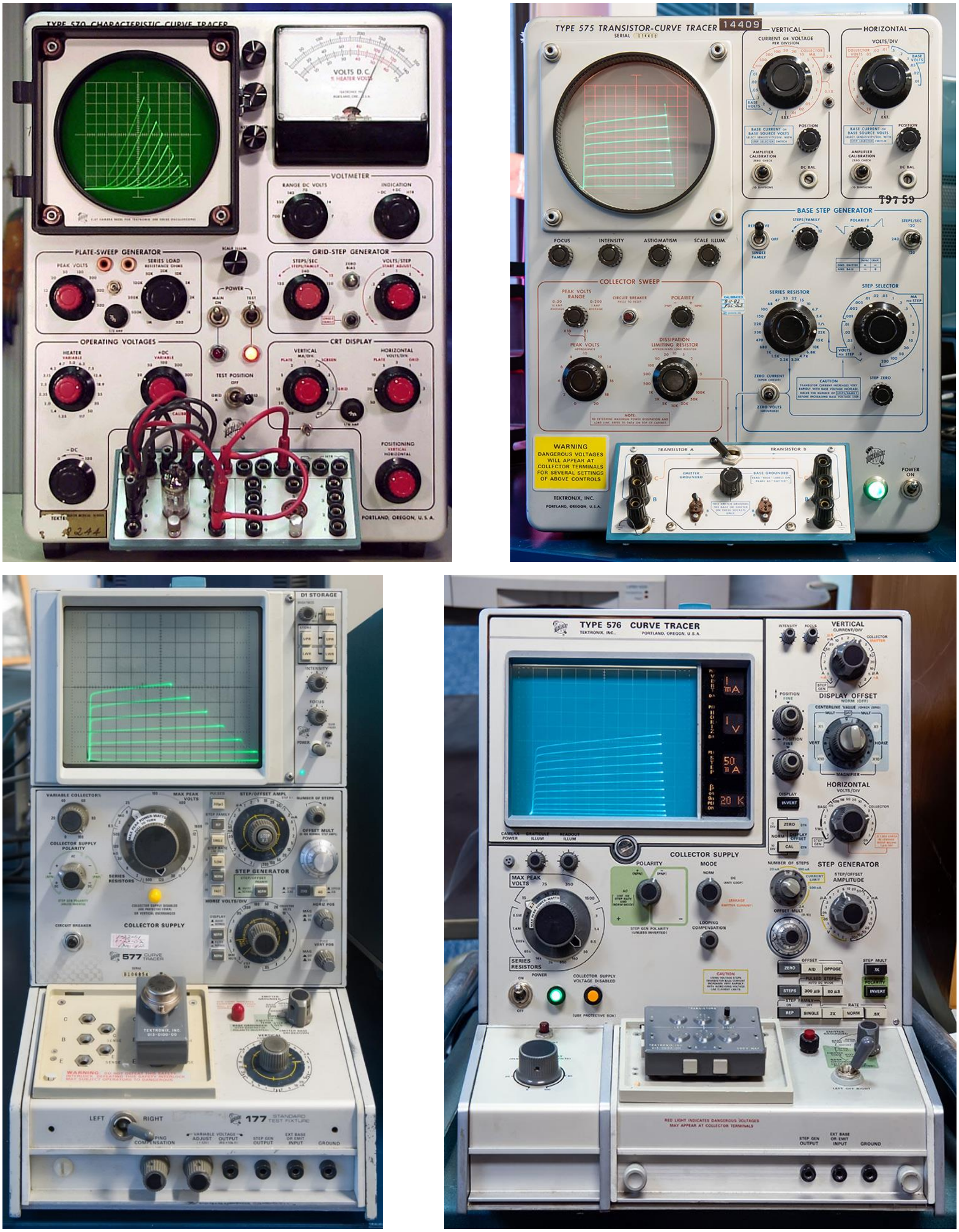
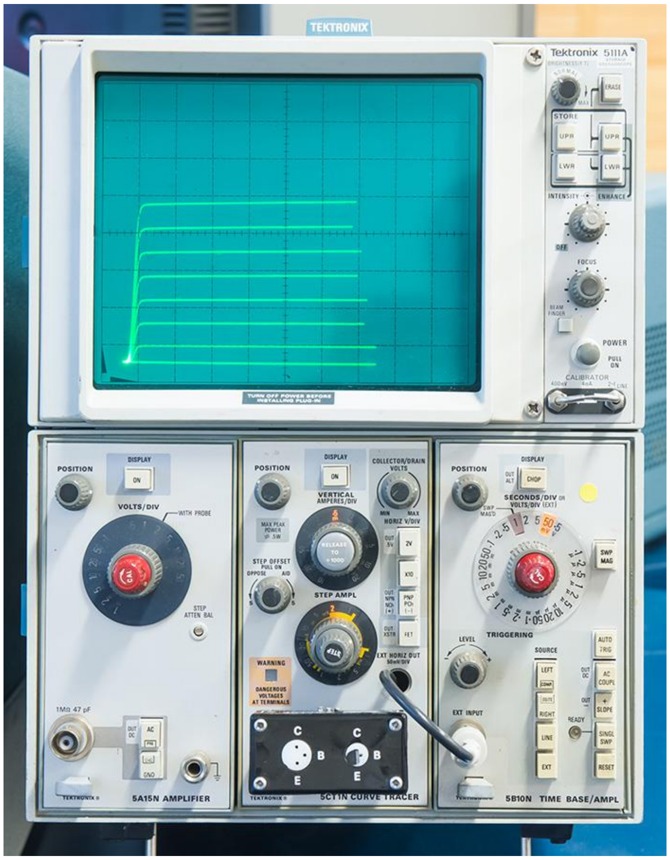


Figure 1 In 1955 Tektronix introduced their first curve tracer (clockwise from the upper left) the 570 Vacuum Tube Curve Tracer; followed by the 575 Transistor Curve Tracer in 1957; then the 576 in 1969; and the 577 in 1974. On the next page is a 5CT1N Curve Tracer plugin installed in a 5110 storage oscilloscope. On the back cover is a Dual 7CT1N Curve Tracer plugins are shown in a 7844 dual beam oscilloscope simultaneously displaying FET and pentode characteristic curves.



VACUUM TUBE TESTER FEATURE COMPARISON

Many tube tester models have been designed and sold. They fall into several distinct categories in order of increasing capability. They are: Filament Continuity Tester; Tube Checker; Emission Tester; Parametric Tester; and Mutual Conductance Tester[2]. All but the mutual (or dynamic) conductance testers are too simplistic to serve our purposes. Wikipedia defines a mutual conductance tube tester as:

> *"one that tests the tube dynamically by applying bias and an AC voltage to the control grid, and measuring the current obtained on the plate (anode), while maintaining the correct DC voltages on the plate and screen. This setup measures the transconductance of the tube, indicated in micromhos[3]".*

Connections to the vacuum tube's electrodes, in the most common tube tester design concept, are made via an array of switches. In the other common design concept the switches are minimized and replaced by many more individually wired tube sockets that achieve the same purpose.

The EICO 667 Dynamic Conductance Tube Tester which was used in this paper measures the dynamic conductance (plate conductance, mutual conductance, and emission) of diodes, triodes, tetrodes, and pentodes. The 667 is characterized by a small number of sockets—eight in this case—which are all that are needed to test thousands of different vacuum tubes. The advantages of fewer sockets, such as this tube tester uses (many others take this approach too) are simpler wiring, a smaller footprint, and lower manufacturing cost. The principal disadvantage is a switch matrix of 13 six-position lever switches is needed to connect each of the 13 possible tube pins to the correct heater, plate (anode), screen, and grid voltages. It takes time to configure these switches, and there is a risk of making errors.

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[2] Tube tester, Wikipedia: https://en.wikipedia.org/wiki/Tube_tester

[3] Ibid

The most common tube testers available today on the second-hand market use this minimal socket count approach. They are so common there isn't space to list them. An example of this approach is the EICO 667 used in this paper. This is what it looks like:

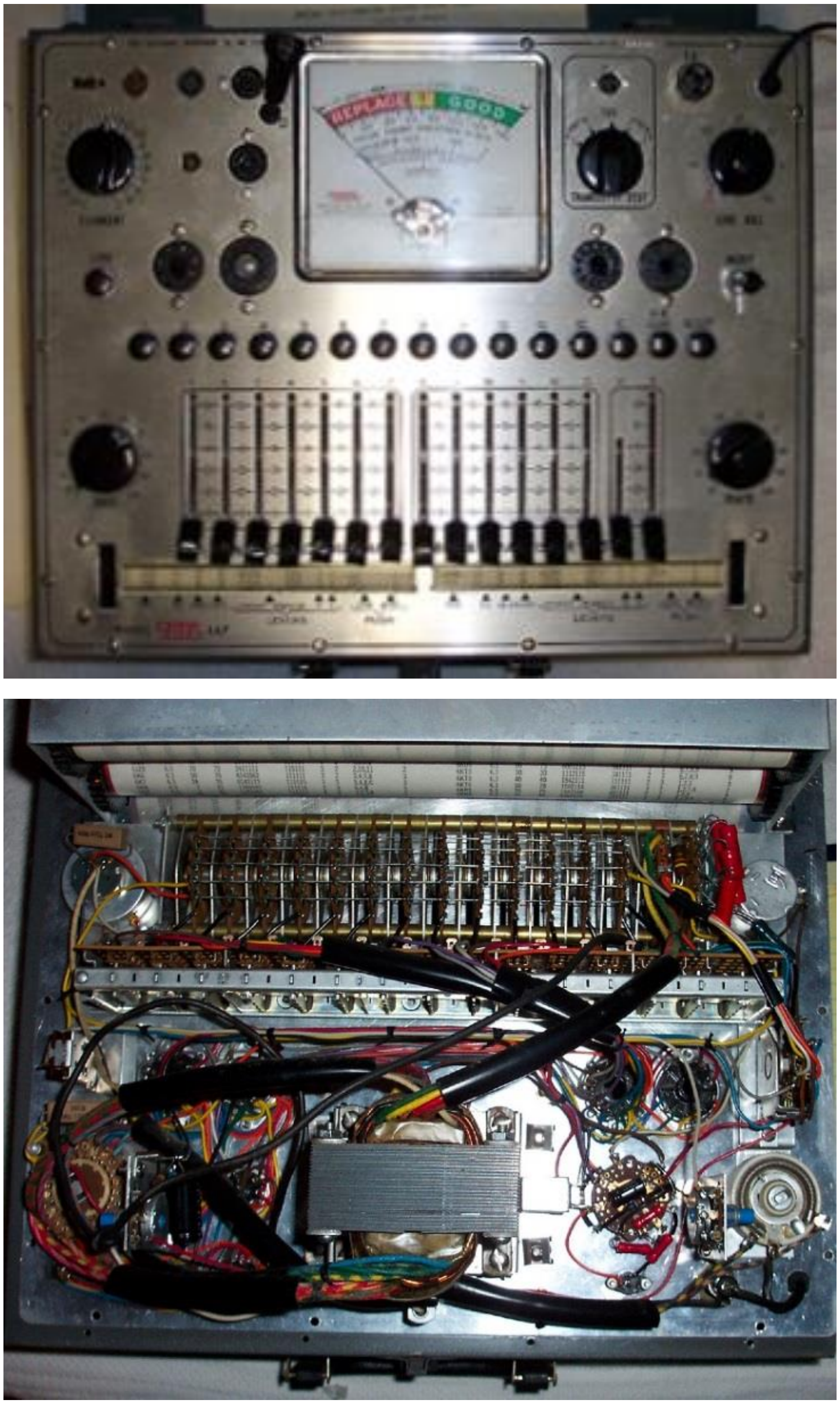

Figure 2 TOP: Exterior view of the EICO 667 Dynamic Conductance Tube and Transistor Tester. Note the array of 13 lever switches and the limited number of sockets which is characteristic of the switch-matrix design concept. BOTTOM: Interior view. Note the extensive wiring. This is common to all vacuum tube testers.

An alternative design approach is to have as many tube sockets as possible. The advantage to this approach is simpler setup once you locate the correct socket for your tube number which in many cases will share the socket's pin assignments with a "family" of tubes that have common pin-outs.

Examples of tube testers that take this approach are: B & K Dyna-Quik Model 700, shown in Figure 3, Century Fast Check, and Accurate Instrument Model 257. The disadvantage to this design concept is the higher assembly and wiring costs associated with all the sockets and the space they require. Testing is faster since setup is minimized with this design approach which is important when testing many tubes. This approach is not as popular as the previous one.

Figure 3 B&K DynaQuik Dynamic Mutual Conductance Tube and Transistor Tester. Note the large number of sockets which minimizes test setup time and setup errors.

It is easy to spot which approach the manufacturer took. The tube tester will either have a few sockets, many switches, and a few dials, like the EICO 667, or it will have numerous sockets, few switches, and a few dials like the B&K Dyna-Quik 700. Regardless of the design it will work when connected to an SCT provided it is a mutual (or dynamic) conductance tester. All of the sockets, voltages, and pin connections you need to turn your SCT into a VTCT are already present on a mutual (or dynamic) conductance vacuum tube tester. This means the tedious work has already been done for you.

Finding a suitable vacuum tube tester will be a little harder than finding an SCT because so many more models were made and documentation for each was not as well preserved. Search for the key word “conductance” in the tube tester’s name. SCTs present a simpler challenge because there are only five models to choose from, they all will work, and there is excellent documentation for each of them. Some models that should work are listed at the end of this paper.

From the schematic for the 667 it is apparent that the important connections to a diode are: the filament, the cathode, and the plate (anode). A triode adds a control grid to this. A tetrode adds the screen grid. Finally, a pentode adds a space-charge suppressor grid. To test a triode the 575 needs little more than a filament transformer and many quick and simple VTCTs have taken this approach. But generally speaking triodes require larger grid voltage steps than the 575 can provide. This requires amplification of the voltage steps of most Tektronix SCTs by a factor of 10X and, in some cases, even 100X. In addition the amplifier’s output steps must be able to cover a range between +5VDC and -50VDC. This is the first requirement the VTCT adapter must meet.

Tetrodes and pentodes require an additional variable screen grid supply that is capable of supplying at least 200VDC at up to 40mA of screen current each time the plate voltage drops below the screen voltage. This occurs 60 times per second on the 570 VTCT as well as on all Tektronix SCTs. This variable screen supply is the second requirement the VTCT adapter must meet.

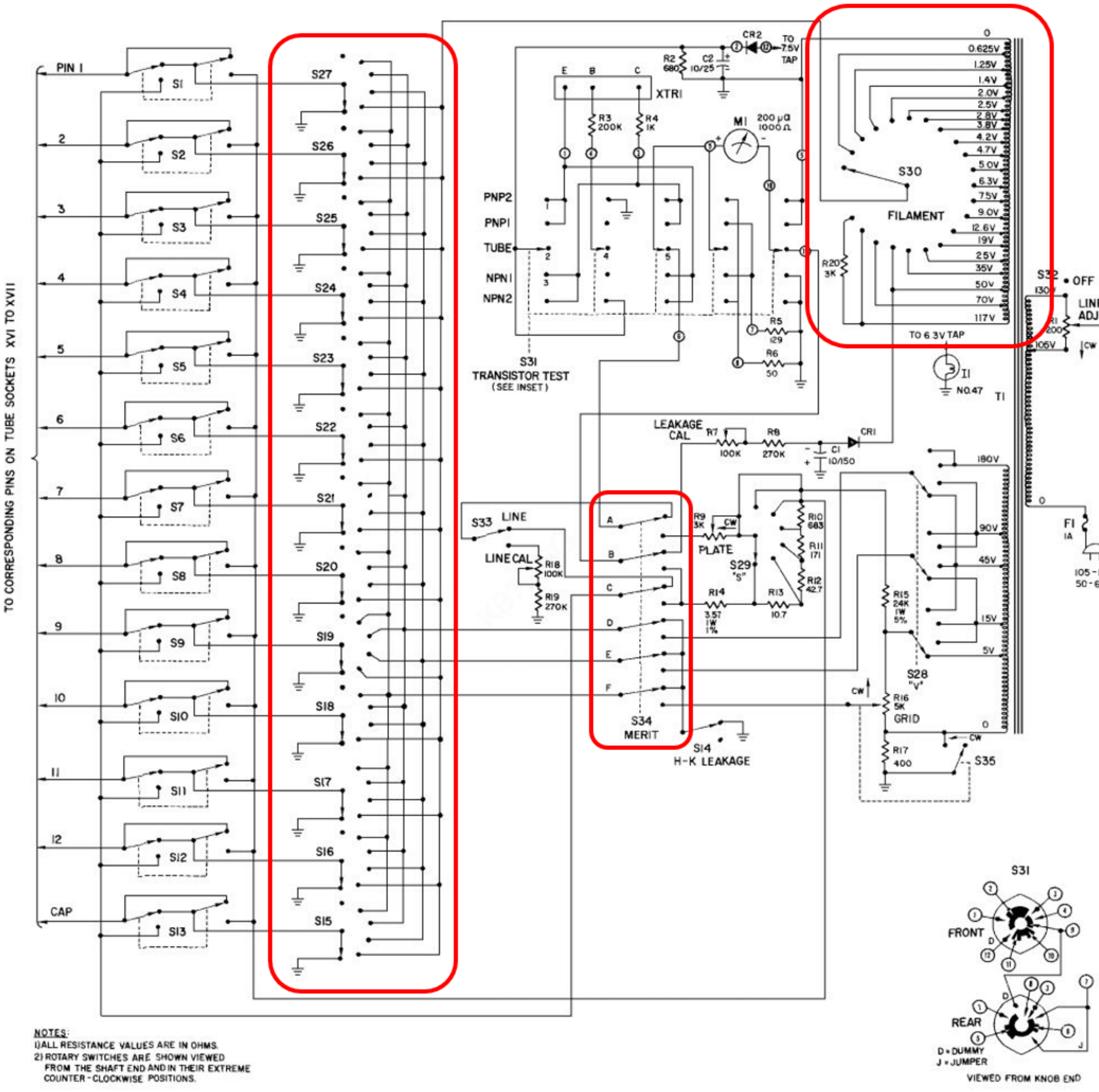

Figure 4 This is the schematic for the EICO 667 tube tester. Note the numerous transformer taps for filament voltages (upper right), the switch matrix towards (left side), and the MERIT switch (middle) which is where the adapter will be connect to the 667.

THEORY OF OPERATION

To see the complete schematic go to figure 25 on page 35 of this paper,.

There are two functions necessary for a semiconductor curve tracer to test any vacuum tube:

1) A stepped negative DC grid voltage which can go from +10V to -70V to test any tube.
2) A 0V to 300VDC Screen Grid supply capable of providing 4mA on average, and as much as 40mA peak, to test tetrodes and pentodes.

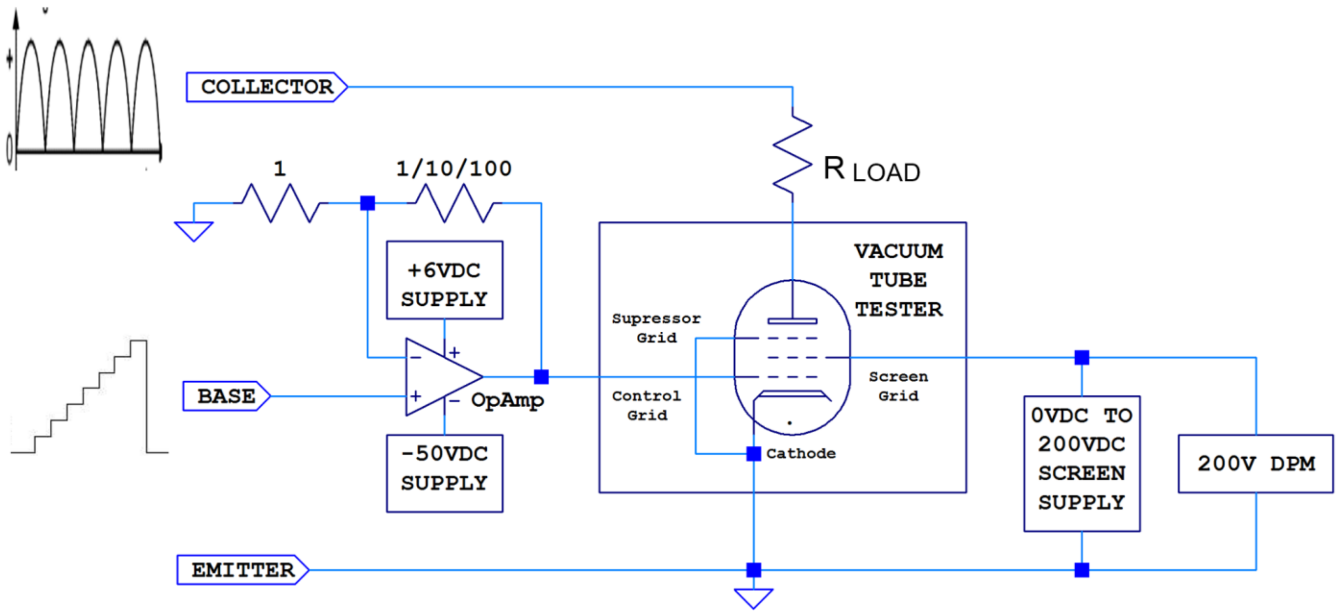

Figure 5 Block diagram of the VTCT adapter. See Figure 25 for the schematic.

Semiconductor curve tracers do not have voltage steps large enough to drive a low-mu triode from full conduction to cutoff. The VTCT adapter includes a Grid Voltage Step Amplifier that has gains of X1, X10 and X100 and an output range of +5VDC to -50VDC for this purpose.

SCTs do not have a screen grid supply for tetrodes and pentodes. The screen grid improves on the triode as follows according to the RCA Radiotron Designer's Handbook[4]:

> *"The function of the screen is to act as an electrostatic shield between the grid and the plate, reducing the grid-to-plate capacitance. The screen is connected to a positive potential (less than the plate) in order to counteract the blocking effect which it would otherwise have on the plate current. Owing to the comparatively large spaces between the wires in the screen, most of the electrons from the cathode pass through the screen to the plate. <u>So long as the plate voltage is higher than the screen voltage, the plate current depends primarily on the screen voltage and only to a slight extent on the plate voltage</u>[5]."*

> *"The plate voltage of pentodes having high plate resistance has only a very minor effect on the plate current, provided that it does not come below the screen voltage.[6]*

The VTCT adapter includes a 0 to 200VDC screen supply. The highest voltage tap in the EICO 667 vacuum tube tester powers this supply so it is currently limited to +200VDC. It must be capable of supplying 20 to 40mA each time during the 60Hz cycle that the collector voltage (which drives the plate) drops to zero. Ideally, the screen supply would be capable of providing +350VDC at 40mA.

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[4] *Radiotron Designer's Handbook*, 4th Ed, Radio Corporation of America, Electron Tube Division, Harrison, NJ, 1953
[5] Ibid, p. 7
[6] Ibid, p. 18

The +6VDC supply uses D11 as a half wave rectifier from the 9VAC filament tap of the EICO 667. This is filtered by a 220uF capacitor (C11) and regulated by VR1, a 78L06 integrated circuit. It would be desirable to increase the +6VDC to +12VDC to allow the grid to be driven to +10VDC for certain tubes. The OpAmp will have to be replaced with a higher voltage OPA454 before this change can be added.

The -50VDC supply uses D41 as a half wave rectifier from the 70VAC filament tap of the EICO 667. This is filtered by a 100uF capacitor (C41) and fed to the collector of Q41, a high gain ($40 < h_{FE} < 150$), high voltage (V_{CEO} = 300V), MJE5731 PNP TO-220 transistor, configured as a simple fixed voltage emitter follower. The base of Q41 is connected to a 51V 1N5369 Zener diode. Ideally it would be desirable to allow the grid to be driven to -70VDC for certain tubes. It will be necessary to replace the OpAmp with a higher voltage OPA454 before this change can be made.

The OpAmp is powered by asymmetric +6VDC and -50VDC power supplies. The combined voltage difference from the +6VDC supply and the -50VDC supply of +56VDC is below the 60VDC limit of the OPA551 High Voltage OpAmp. It is important not to exceed this 60V limit with the OPA551 OpAmp.

The OpAmp amplifies the base voltage steps from the semiconductor curve tracer, when necessary, by a factor of 10 or 100, or it leaves them unchanged if they are large enough as is to drive the control grid of the vacuum tube. The OpAmp is capable of providing up to -20V grid steps, but at present the maximum negative grid voltage swing is approximately -50VDC.

The 0VDC to +200VDC variable screen grid power supply uses D51 as a half wave rectifier from the 180VAC plate tap of the EICO 667. This is filtered by a 220uF capacitor (C51) and fed to the collector of Q51, a medium gain ($30 < h_{FE} < 150$), high voltage (V_{CEO} = 400V), TIP50 NPN TO-220 transistor configured as a simple emitter follower. The base voltage, which can be varied from 0 to 200VDC is provided by a 200V 1N5388 Zener diode which is connected to the top end of the Screen Voltage potentiometer. Varying the pot feeds the base of Q51 with a voltage that varies from 0VDC to 200VDC and the emitter follows this with a 0.7VDC drop. The 200V Digital Panel Meter displays the voltage applied to the screen grid of a pentode. When testing triodes the screen voltage can be set to 0V. A recent improvement (still being evaluated) involved replacing R53 with an E-562 Semitec 5.6mA Constant Current Diode. This compensates for the large positive temperature coefficient of the 1N5388 200V Zener diode improving its voltage stability to <1%.

All of the voltages necessary to power the adapter's amplifier, screen grid supply, and DPM come from selected transformer taps of the EICO 667.

EICO 667 MODIFICATIONS

To modify the tube tester to be driven by the signals coming from a Tektronix curve tracer it was necessary to determine where to break the connections going to the grid, the screen and the plate (anode) inside the EICO 667. The filament wiring did not need to change. The cathode is always grounded in this tube tester and it did not change either. So it was only necessary to trace out three voltage paths to break into. It is extremely valuable to have a schematic for your tube tester when you trace these signal paths. Tube testers may be simple in concept but they are all a maze of wires inside. Without a schematic you risk serious injury from dangerous voltages and currents.

In the EICO 667 there is a 6 pole momentary lever-switch called MERIT. The MERIT test is an emission reading for diodes and rectifiers, and a dynamic conductance (combined plate conductance, mutual conductance, and emission) reading for triodes, tetrodes, and pentodes. From the EICO 667 schematic it was apparent that the MERIT switch was the most important wiring point to connect to.

1. The control grid voltage goes through the MERIT lever-switch position F. This grid will be driven by the Base Step Generator of the Tek SCT. The base voltage steps from the SCT will need to be increased 10X or 100X to test triodes and 1X or 10X to test tetrodes and pentodes. Control grid voltage amplification will be provided by a high voltage OpAmp on the adapter PC Board.

2. The screen grid voltage goes through the MERIT lever-switch position E. There is no equivalent connection to the Tektronix SCT. Screen current is normally about 4mA, but it rises sharply if the screen becomes more positive than the plate. This happens for a large part of every collector sweep cycle for all Tektronix SCTs. The screen grid will be powered by a variable 200VDC power supply on the adapter PC Board, capable of supplying up to 40mA for the times when the plate voltage drops below the screen voltage.

   Pentodes are almost unaffected by changes in supply voltage, and the plate current changes little as plate voltage varies. Plate current in a pentode is controlled by the screen grid so this voltage is specified when testing a pentode. A 0 to 200VDC Digital Panel Meter (DPM) is an essential part of the design of this adapter to set and monitor the screen grid voltage specified in the datasheets of pentodes and tetrodes.
3. The plate (anode) voltage goes through the MERIT lever-switch position D. The plate will be driven directly by the Collector Sweep Generator of the SCT.
4. The cathode will be connected directly to the Emitter contact of the curve tracer which is grounded (a Common Emitter configuration). All of the cathodes in the EICO 667 are grounded.

There was little room on the front panel of the 667 for the new controls needed for these modifications. Fortunately the 667 had a transistor tester feature on the front panel that could be appropriated for the new controls. Anyone who owns an SCT will not need the primitive transistor testing capabilities of a tube tester like the EICO 667. So the transistor tester switches and sockets were sacrificed to make room for the new controls on the front panel. This also freed up enough room inside the tube tester for the adapter's PC Board. The PC Board occupies an absolute minimum amount of space to insure it will fit into any tube tester. It measures 2" W x 2.8" L x 1.32" H (5,1cm x 7,1cm x 3,3cm).

In case the native tube testing capabilities of the EICO 667 turned out to be useful later on a 3 pole double throw (ON—ON) "Transfer" toggle switch was added to permit quick selection of the new VTCT capabilities or the old Dynamic Tube Tester capabilities with the flick of a switch.

WHAT CAN I EXPECT WITH THE CURVE TRACER I MAY ALREADY OWN?

Anyone with a Tek SCT probably has the skills and parts needed to add the VTCT adapter to a tube tester and turn their SCT into a universal curve tracer. If you don't already have an SCT then the most obvious curve tracer to look for is the 575. Since thousands were made they are still abundant, and almost free at this point. The 575's 200V collector supply is perfectly usable, but the 400V 575 MOD 122C is better. The 576 and 577 are ideal. The 5CT1N and the 7CT1N have limitations which may or may not be a consideration for your intended application. Their most significant limitations are a 0.5W maximum power; 4 peak voltages (7.5V, 30V, 75V, and 300V), and a short circuit current of 6mA on the 300V range or 24mA on the 75V range.

More importantly, you must accommodate the different front panel wiring of the 5CT1N and the 7CT1N. The base and the collector leads of the adapter must be reversed to work with these two curve tracer plugins to test FETs and tubes. The easiest way to do that is to reverse the wires coming from the tube tester at the triple banana plug that will plug into the E/S, B/D, and C/G banana jacks of the 5CT1N and 7CT1N. If you notice Tek has warned you in advance of the necessary change. Ordinarily the Base would be paired with the Gate (B/G) and the Collector would be paired with the Drain (C/D). If this change is not made the high collector voltages from the SCT will, at the very least, damage the OpAmp on the adapter board.

WHAT YOU WILL NEED TO MAKE THIS VTCT

You need a mutual conductance or dynamic conductance tube tester with a schematic and operating instructions. Each tube tester is different and has different directions but most important is the schematic. There are hundreds (thousands actually) of tube testers on Ebay at any one time but they should also be available on Craig's List (USA), at flea markets, at ham fairs, and at antique radio swap meets. Only buy one if it has documentation and a schematic or you can get them on the internet. $30 is a reasonable price to pay for one. They are quite simple in design but they have so many wires it may take a while until you understand where to connect the adapter and mount the new controls.

Dangerous voltages and power levels are present in every vacuum tube tester. Observe caution.

To be compatible with the VTCT adapter the vacuum tube tester must have a transformer winding of approximately 160VAC (and no more than 180VAC) for the adapter's screen grid power supply. The rectified voltage from this winding should not exceed 260VDC at TP1. If it does, bad things can happen.

There must also be a transformer winding of approximately 60VAC to 70VAC. The rectified voltage from this winding should not exceed 120VDC at TP4 or bad things may happen. 70VAC is a common filament voltage so all tube tester transformers will have a tap for this.

Finally, there must be a transformer winding of 8 to 11VAC. The rectified voltage from this winding should not exceed 14VDC at TP6. If it does that could be bad. 9.0VAC is a common filament voltage so all tube tester transformers will have this tap. Either one can be used.

Simple machine shop / metal working skills are necessary to make ¼" holes for the Tube Tester / Curve Tracer transfer toggle switch, for the Screen Grid Voltage pot, and for the Step Voltage Gain rotary switch. In addition you will need to make a rectangular hole for the Screen Grid Voltage DPM.

A gold plated printed circuit board, which uses thru-hole component mounting, is available from the author to making building it simple. Anyone with moderate electronic construction experience should be able to assemble the PC board in less than 2 hours. All of the parts, including the PC Board, can be bought for less than $80.00. The Mouser and the Farnell / Newark part numbers are included in the parts list to facilitate ordering. In a few cases I indicated where a Mouser / Farnell / Newark part cost as much as 3 times what you would pay for a similar part bought elsewhere on the internet.

There are three sets of connections on the board. They are all located along one edge and they each have a different number of wires to insure that connectors, if they were used, could not be accidentally inserted on the wrong header pins. Eight troubleshooting test points are brought out along another edge. Five mounting holes are available along a third edge for securing the PC Board to the chassis inside the vacuum tube tester.

TWO CHARACTERISTIC CURVES THIS ADAPTER CAN'T DISPLAY (THE 570 CAN)

The original 570 vacuum tube curve tracer was designed specifically for displaying the characteristic curves of vacuum tubes. Because semiconductors behave differently from vacuum tubes, SCTs do not need to display some of the curves that VTCTs must display. The Operating Instructions section of the 570 Instruction Manual[7] show these additional vacuum tube displays that are unique to the 570:

1. Screen Current vs. Plate Voltage (Pentode): None of the SCTs can display this set of curves.
2. Screen Current vs. Grid Voltage (Pentode): None of the SCTs can display this set of curves.
3. Plate Current vs. Grid Voltage: Each curve tracer has different capabilities for this set of curves:
   - The 576 and 577 can display this by switching the HORIZ VOLTS/DIV knob to BASE VOLTS or STEP GEN.
   - The 575 can display this by switching the HORIZONTAL VOLTS/DIV knob to BASE SOURCE VOLTS.
   - The 5CT1N and 7CT1N cannot display this.

It would be useful to measure a vacuum tube's screen current and grid current on an SCT like the 570 does but it would be too complicated and / or too costly to do this.

[7] *Tektronix 570 Oscilloscope Instruction Manual*, Tektronix, Inc. Beaverton, OR, 1963, pp.2-7 – 2-11

MATCHING TUBES WITH THE VACUUM TUBE CURVE TRACER

With a simple adapter (or set of adapters) the Vacuum Tube Curve Tracer can be used to match tubes or to confirm the match between separate halves of dual triodes. Figure 20 shows a prototype adapter displaying a pair of 6AU6A pentode curves in a variety of display formats on a 577-D1 Curve Tracer. The storage capability of the 577-D1 makes it easy to display the characteristic curves of two tubes several different ways. NOTE: These adapters must be wired to be compatible with "families" of tubes that share the same pin assignments. Their simple design makes it practical to create adapter variations that will work with other "families" that have different pin outs or that use different sockets.

7-PIN MINIATURE PENTODE MATCHING ADAPTER

A 7-pin miniature tube plug was wired to two 7-pin sockets to demonstrate the ability of the VTCT to match two 6AU6 pentodes. Pins 2, 3, 4, and 7 of the tube plug were connected to the same pins of both 7-pin sockets. The three wires coming from the tube plug that corresponded to the 6AU6's control grid (pin 1), screen grid (pin 6), and plate (pin 5) were connected to the 3 center contacts of a 3-Pole Double Throw (3PDT ON-OFF-ON) switch. The 3 left contacts of the switch were connected to pins 1, 6, and 5 of the right 7-pin socket and the 3 right contacts of the switch were connected to pins 1, 6, and 5 of the left 7-pin socket. Toggle the 3PDT switch left or right to display the curves of the right or left.

A prototype I made to demonstrate the simplicity of these "matching tube adapters" and how well the characteristic curves of two pentodes compare can be seen in figure 20 on page 32 of this paper.

The complete list for every receiving tube base can be found in the *Terminal Diagrams Designations* section of any RCA Receiving Tube Manual.[8] The list for all the tubes that are pin compatible with the 6AU6 pentode is listed under tube base 7BK (JEDEC No. E7-1), a Small-Button Miniature 7-Pin tube base: It includes the 3AU6, 3BA6, 4AU6, 6AH6, 6AH6WA, 6AK6, 6AU6A, 6AU6WB, 6BA6, 6BD6, 6HR6, 6HS6, 12AC6, 12AF6, 12AU6, 12BA6, 12BD6, 12BL6, 12CX6, 12DZ6, 12EA6, 12EK6, 18GD6A, 19HR6, 19HS6, 19MR9, 26A6, 5749, 6660, 7543, BA6, EF93, EF94, HF93, HF94, M8108, PM04, W727, and XF94.

9-PIN MINIATURE DUAL TRIODE MATCHING ADAPTER

A 9-pin adapter can be made for confirming that the two halves of popular 9-pin miniature tube base (9A or Noval base) dual triode tubes such as the 6AU7, 12AE7, 12AT7, 12AU7, 12AX7, 12BH7, 12DW7, and ECC83 are matched to name a few. To check that the separate halves are matched the heater pins (pins 4, 5, and 9) are connected to a 9-pin socket from the 9-pin plug. The cathodes on pin 3 and pin 8 are wired together. Pin 7 of the tube plug (the section 1 triode's grid pin coming from the tube tester) is wired to one center contact of a Double Pole Double Throw (DPDT ON-OFF-ON) toggle switch and pin 6 of the tube plug (the section 1 triode's plate pin coming from the tube tester) is wired to the other center contact. The two left switch contacts go to pins 7 and 6 respectively of the 9-pin socket. The two right switch contacts go to pins 2 and 1 respectively of the 9-pin socket. To test both halves of the tube set the tube tester up to test the first section of the dual triode. By toggling the switch to the left or right the characteristic curves of each half of the dual triode are displayed on the curve tracer.

OCTAL DUAL TRIODE MATCHING ADAPTER

In similar fashion octal dual triodes such as these members of a pin compatible family consisting of the 6AS7, 6BL7GT, 6BX7, 6SL7GT, and 6SN7GT can be matched using a single octal socket.

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[8] *RCA Receiving Tube Manual RC-30*, 8 / 1975, RCA, Distributor and Special Products Division, Cherry Hill Offices, Camden, N. J. 08101, p. 597

IMPRESSIVE RESULTS

The VTCT adapter combines these three elements into a flexible, accurate and repeatable instrument:

- The accuracy of the Tektronix Semiconductor Curve Tracers.
- The ability of a tube tester to test any tube.
- Large grid voltage steps and a variable screen supply.

The resulting curves displayed by the VTCT and adapter are identical to the ones in the manufacturer's data sheets. The displayed curves are more than accurate enough to be used to make measurements of the three most important parameters[9] of a tube and to identify when a pair of tubes have matching parameters. The most important vacuum tube parameters are:

μ	$\left(\frac{\partial v_p}{\partial v_G}\right)_{i_P} \equiv \mu$	**Amplification Factor:** The ratio of change in plate voltage to the change in grid voltage for a constant plate current.
r_p	$\left(\frac{\partial v_p}{\partial i_p}\right)_{v_G} \equiv r_p$	**Plate Resistance**: The quantity which expresses the ratio of an increment of plate potential to the corresponding increment of plate current when the grid potential is kept constant.
g_m	$\left(\frac{\partial i_p}{\partial v_G}\right)_{v_P} \equiv g_m$	**Mutual Conductance (Transconductance)**: The quantity which gives the ratio of an increment of plate current to the corresponding increment in grid potential for constant plate potential. It has the units of μSiemens (new 1971 SI unit) or alternatively the old unit, μmhos.

These three parameters are determined by the tube's internal construction.[10] The three parameters are interrelated by this formula:

$$\boldsymbol{\mu = r_p\, g_m}$$

Screen photos showing how to calculate μ, r_p and g_m for a 12B4A triode and for a 6AU6A pentode from the tube's characteristic curves are at the end of this paper.

The usual orders of magnitudes of the tubes parameters for conventional triodes are approximately:

$\boldsymbol{\mu}$: 2.5 to 100 (no units)

$\boldsymbol{r_p}$: 0.5Ω to 100,000Ω

$\boldsymbol{g_m}$: 500 to 10,000μA / V, or μSiemens (new 1971 SI unit) or, the old unit, μmhos.

The plate resistance $\boldsymbol{r_p}$, plate-grid transconductance $\boldsymbol{g_m}$, and amplification factor $\boldsymbol{\mu}$ of a pentode are defined exactly as for a triode (but with the suppressor and screen grid held constant)[11].

Measurements were performed on several of the screen photographs confirming the ability of the VTCT to display accurate values for $\boldsymbol{\mu}$, $\boldsymbol{r_p}$, and $\boldsymbol{g_m}$ that are in agreement with the published values for these parameters from the tubes datasheet(s).

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[9] J. Millman and C. Halkias, *Electronic Circuits and Devices*, New York City, NY, McGraw-Hill, 1967, pp. 163-164

[10] F. Rosebury, *Handbook of Electron Tube and Vacuum Techniques*, New York City, NY, American Institute of Physics, 1993, p. 132

[11] Millman and Halkias, p. 171

ADDITIONAL CONSTRUCTION DETAILS

VIEW FROM THE OUTSIDE OF THE EICO 667

Figure 7 Adapter Front Panel.

The front panel for the new controls was made using AlumaJet printable aluminum. The graphic image of the front panel is printed on the AlumaJet using an inkjet printer. More information can be found at [https://alumajet.com/.](https://alumajet.com/)

MetalPhoto photo-sensitive anodized aluminum is a similar product. It also works on an ink jet printer. More information can be found at [https://metalphoto.com/.](https://metalphoto.com/)

VIEW FROM THE INSIDE OF THE EICO 667

The VTCT adapter PC Board is mounted in the EICO 667 front panel along with the screen grid voltage DPM and control pot, the Tube Tester / Curve Tracer Transfer switch and the X1 / X10 / X100 Step Voltage Gain switch for amplifying the base steps of the SCT.

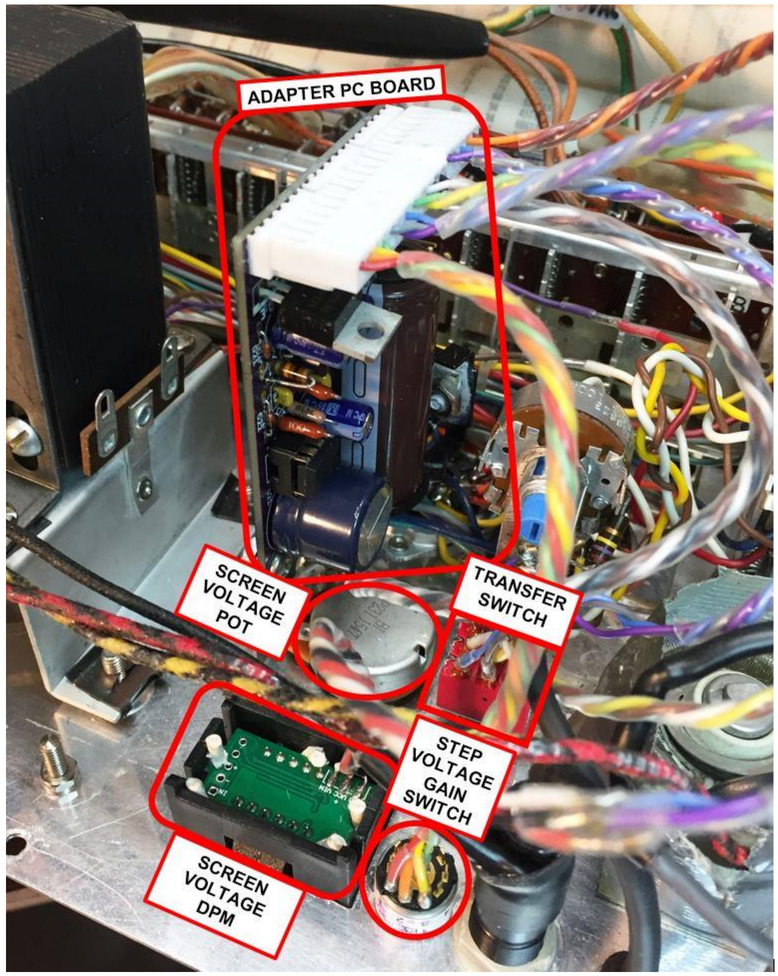
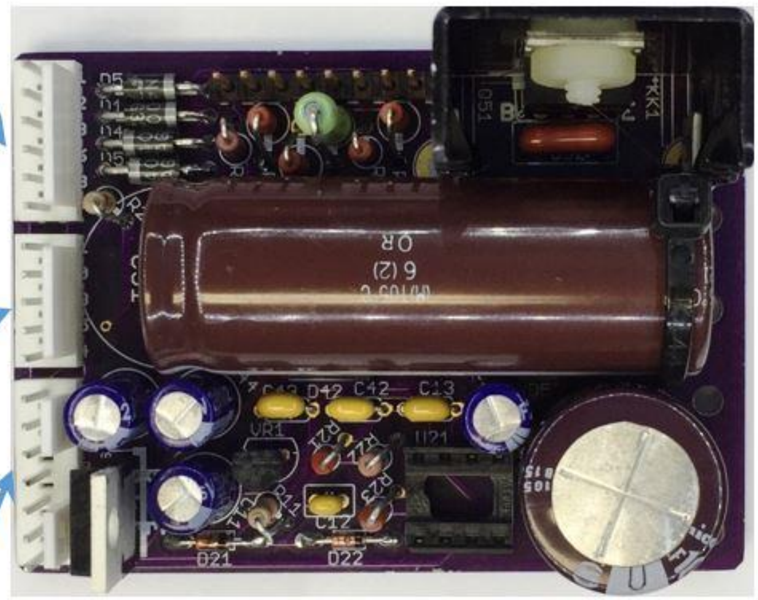


Figure 6 Internal view of the VTCT Adapter PC Board, controls, and DPM.

INTERCONNECTING CABLING

The VTCT adapter has three sets of connections along one side (the left side in this photograph). In this photo montage you can see that standard 0.1" (2.54mm) center Molex connectors were used to make the three cables removable.

There is a row of 8 pins along the top edge in this photograph. These are test points to assist in troubleshooting.



The Molex connectors and the row of 8 pins are a convenience not a requirement.

If you do use the Molex connectors note that each of the three has a different number of pins (6, 5, and 7 pins). This was done to insure the Molex connectors could not be accidentally interchanged.

From top to bottom the 3 cables are:

6 Wire: Three wires in this cable are connected to the tube tester's 180VAC, 70VAC and 8VAC transformer windings. The other three wires plus the wire from the curve tracer Collector go to the cathode, grid, screen, and plate connections of each of the lever switches.

5 Wire: Three wires go to the screen voltage adjustment pot. The remaining 2 wires go to the wire from the Curve Tracer Base and its shield.

7 Wire: Three wires go to the Screen Voltage 200V DPM. The remaining 4 wires go to the Grid Voltage Step Gain rotary switch.

Figure 8 Makeup and location of the VTCT interconnecting cables.

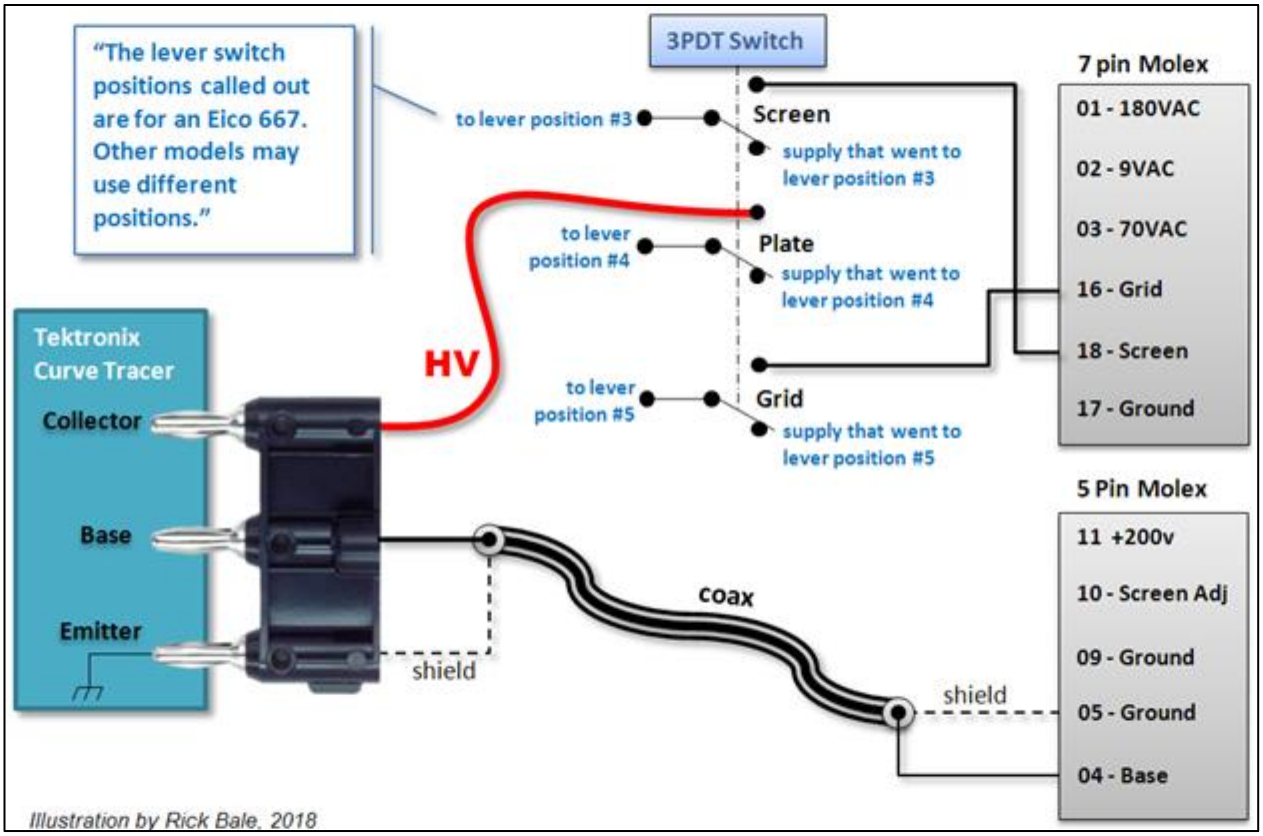


Figure 9 Wiring the VTCT Adapter's Molex connectors to a Tektronix Curve Tracer.

FUTURE DIRECTIONS

It would be desirable to increase the range of the voltage step amplifier from the present limits of +5VDC to -50VDC to at least +10VDC to -100VDC. This would allow the VTCT to drive nearly every low-mu triode from saturation to cutoff. The present voltage limitation is due a lack of high voltage OpAmps in DIP packages (which make assembly easy). The current OpAmp, although limited to a 60V output swing has one very important capability – it can operating from asymmetric +6V and -50V power supplies. An OPA454, which is only available in a SO-PowerPAD surface mount package, would be able to provide the desirable +10V / -100V grid voltage range. It will be necessary to evaluate the OPA454 to see if it can handle the +15V / -105V asymmetric power supply voltages this would require.

It would also be desirable to increase the adjustable screen voltage to at least 400V. This represents a greater challenge because there are usually no transformer windings in a vacuum tube tester that can generate that much voltage. A voltage doubler might work in some cases but not in others. For the cases where an appropriate voltage tap is not available for a voltage doubler the only solution may be to add a separate 400V transformer. The 115V winding for the grid voltage step amplifier OpAmp will not be a problem because good vacuum tube testers have a transformer winding for 115V filaments.

At the present time low cost off-the-shelf Chinese DPMs only go to 200VDC. In time the Chinese may start making DPMs for higher voltages.

MAKE AND MODEL TUBE TESTERS TO LOOK FOR

This list of tube testers will continue to change over time. One thing is almost certain however, mutual conductance or dynamic conductance tube testers are the ones to look for. Emission testers are too simplistic inside. As a result they are unacceptable. The following lists can be used as a guide in searching for a suitable tube tester. Here is what the categories mean:

- ***TESTED*** means just that. They work with the VTCT adapter.
- ***SHOULD WORK JUST FINE***: These are mutual conductance or dynamic conductance type tube testers and they should work with the VTCT adapter. Their manuals and/or their schematics contain the proper circuitry. There may be some variation in available voltages that may not be obvious without further examination.
- ***UNACCEPTABLE***: These tube testers will not work based on an examination of the manual and/or schematics. Don't waste any time on them.
- ***POSSIBLY GOOD***: These look promising but there was not enough information to determine if they will work.
- ***MOST LIKELY UNACCEPTABLE***: The available information was discouraging but incomplete so no definitive conclusion was possible.
- ***NO INFORMATION***: There is such a make and model but there is no information on it.

TESTED

EICO 667 Dynamic Conductance T.T.

EICO 665 Dynamic Conductance T.T.

SHOULD WORK JUST FINE

B&K 707 Dynamic Mutual Conductance T.T.

Marconi MU-101 Mutual Conductance T.T.

Mercury Model 1000 Mutual Conductance T.T.

Mercury Model 2000 Mutual Conductance T.T.

Precise 111 GM and EM T.T.

Precise 116 GM and EM T.T.

Stark 9-66 Micromho Dynamic Mutual Conductance T.T.

Stark 121-22 / 12-22A Dynamic Mutual Conductance T.T.

Supreme Model 45 Mutual Conductance Tube Checker

Supreme I-177B Military T.T. (Mutual Conductance)

Triplett Model 3423 Mutual Conductance T.T.

POSSIBLY GOOD

Mercury 990

Stark 8-77

Sylvania 139

MOST LIKELY UNACCEPTABLE

RCA 156

UNACCEPTABLE

EICO 625 T.T.

Jewell 209, WD-209, 214, 533, 534, 538, 540

Mercury Model 1101

PACO T-60

Precision 612, 614

Radio City Products (RCP) 314, 803

Sencore TC130 Mighty Mite, TC162 Mighty Mite

Simpson Models 325 & 333, 220 & 222

Stark Model 9-11 and 9-55, 9-54T, 9-56, 9-99

Triplett 1210 and 1260

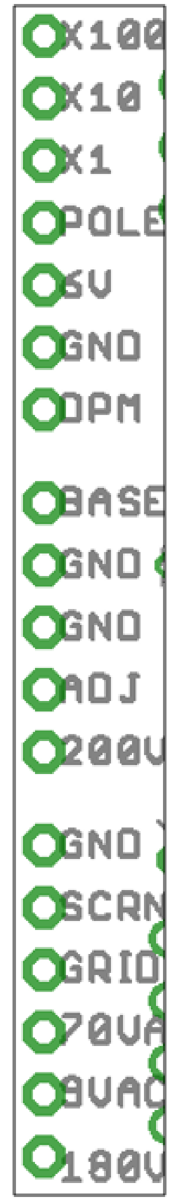
NO INFORMATION

Sencore TC114 and TC136

VTCT ADAPTER PC BOARD EXTERNAL WIRING

PC BOARD SIGNAL DESCRIPTION	SIGNAL NAME
X100 gain position of the Grid Step Rotary Switch	X100 GAIN
X10 gain position of the Grid Step Rotary Switch	X10 GAIN
Unity gain position of the Grid Step Rotary Switch	X1 GAIN
Center lug of the Three Position Grid Step Rotary Switch	POLE
+6VDC Power to the Screen Voltage Digital Panel Meter	+6VDC
Ground for the Screen Voltage Digital Panel Meter	GROUND
Digital Panel Meter Input from Screen Voltage	D.P.M.
Connects to the Base Banana Jack of the Tektronix Curve Tracer	BASE
Connects to the Emitter Jack of the Tektronix Curve Tracer	GROUND
Connects to the ground side of the Screen Voltage Potentiometer	GROUND
Connects to the wiper of the Screen Voltage Potentiometer	SCREEN ADJ
Connects to the high side of the Screen Voltage Potentiometer	+200VDC
To Screen, Grid , and Cathode connections common to each path	GROUND
Connects to the Screen connection (to all tube sockets)	SCREEN
Connects to the Grid connection (to all tube sockets)	GRID
70VAC from the 70V tap of the tube tester filament voltage selector	70VAC
9VAC from the 9V tap of the tube tester filament voltage selector	9.0VAC
180VAC from the plate supply of the tube tester	180VAC

PC BOARD



TESTING YOUR ASSEMBLED VTCT ADAPTER

There are eight test points on one side of the PC Board. They are there to make it simple to test your work before placing the adapter in a tube tester.

Start by removing the OPA551 OpAmp if you installed it already. This is to protect it until we have confirmed the power supplies are working.

+200VDC REGULATED SUPPLY

1. Connect the ground lead of a DC voltmeter to *TP0 (GND*).
2. Connect a 100K Screen Voltage Control pot to *connections 09 (GND)*, *10 (ADJ)*, and *11 (200V)*.
3. Apply +250VDC to *connection 01* (*180VAC*).
4. Verify that +250VDC appears at *TP1* and at *TP2*.
5. Turn the Screen Voltage Control pot and verify the voltage at *TP3* and at *connection 18* (*SCRN*) goes from 0V to +200VDC.
6. Repeat steps 3 through 5 with +220VDC applied to *connection 01 (180VAC).*
7. Repeat steps 3 through 5 with +280VDC applied to *connection 01 (180VAC).*
8. Verify the heatsink of Q1 has no voltage on it. It should be isolated from Q1's collector tab.

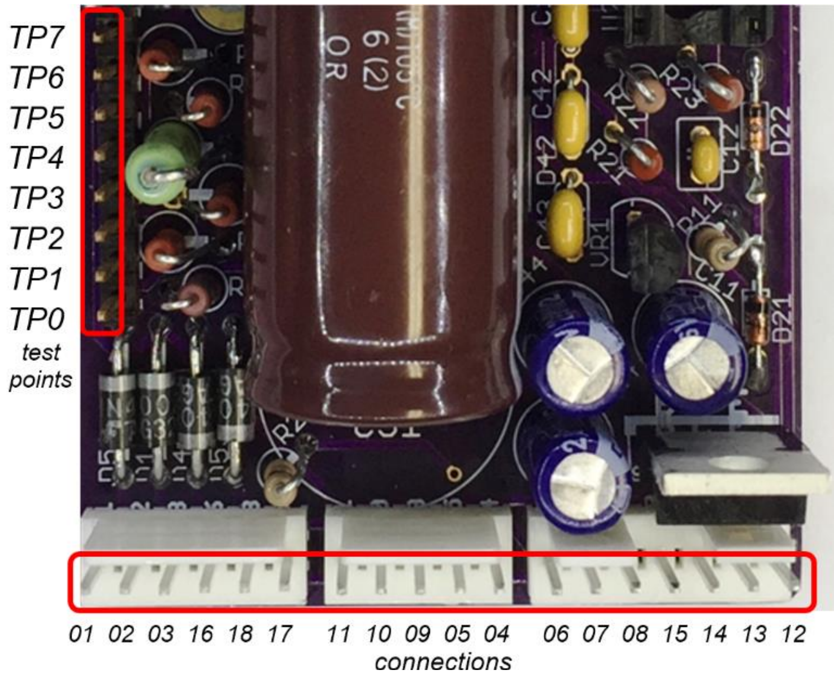


Figure 10 Location of Test Points and Connections.

-50VDC REGULATED SUPPLY

1. Connect the ground lead of a DC voltmeter to *TP0 (GND*).
2. Apply -70VDC to *connection 03 (70VAC).*
3. Verify that -70VDC appears at *TP4*.
4. Verify that -50VDC appears at *TP5* and *U21 pin 4*.
5. Repeat steps 2 through 4 with -85VDC applied to *connection 03 (70VAC)*.
6. Repeat steps 2 through 4 with -65VDC applied to *connection 03 (70VAC)*.

+6VDC REGULATED SUPPLY

1. Connect the ground lead of a DC voltmeter to *TP0 (GND*).
2. Apply +9.0VDC to *connection 02 (9VAC)*.
3. Verify that +9.0VDC appears at TP6.
4. Verify that +6.0VDC appears at *TP7* and *U21 pin 7*.
5. Repeat steps 2 through 4 with +11.0VDC applied to *connection 02 (9VAC)*.
6. Repeat steps 2 through 4 with +8.6VDC applied to *connection 02 (9VAC)*.

GRID STEP VOLTAGE AMPLIFIER

1. Connect the single pole three way rotary switch to connections *12 (X100)*, *13 (X10)*, *14 (X1)* and *15 (POL.)*.
2. Insert U21, the OPA551P OpAmp into its 8 pin socket.
3. Apply -70VDC and +9VDC to the adapter board.

4. Apply a 0.1Vp-p signal to *connection 04 (BASE)*, turn the Grid Step Voltage Amplifier to *X1* and confirm that the signal on *connection 16 (GRID)* is like the input signal and 0.1Vp-p in amplitude.
5. With the Grid Step Voltage Amplifier set to *X10* confirm that the signal on *connection 16 (GRID)* is like the input signal and 1Vp-p in amplitude.
6. With the Grid Step Voltage Amplifier set to *X100* confirm that the signal on *connection 16 (GRID)* is like the input signal and 10Vp-p in amplitude.

0V to 200VDC DIGITAL PANEL METER

1. Connect the DPM to *connections 06 (DPM)*, *07 (GND)*, and *08 (6V)*.
2. Verify that it has +6VDC applied to it from the +6V regulator, and a variable 0 to 200VDC voltage applied to it from the Screen Supply.

MISCELLANEOUS

1. Verify the collector lead from the Tektronix curve tracer connects to the plate connection of the tube tester
2. Verify the screen supply from *connection 18 (SCRN)* of the VTCT adapter connects to the screen connection of the tube tester.
3. Verify the amplified grid voltage amplifier output on *connection 16 (GRID)* connects to the grid connection of the tube tester.

SCHEMATIC, PARTS LIST, PCB ARTWORK AND ASSEMBLED ADAPTER

The engineering drawings and parts list at the end of this paper should expedite construction of the VTCT adapter. A high quality double sided gold plated printed circuit board is available from the author.

ON-LINE RESOURCES

There are many on-line sites with vacuum tube data sheets and electronic copies of manufacturer's tube manuals such as:

- List of vacuum tubes: https://en.wikipedia.org/wiki/List_of_vacuum_tubes
- Tube Manual Listing from NJ7P: http://www.nj7p.org/Manuals/Tube_Manuals.php
- Comprehensive List of Tube Data: http://www.shinjo.info/frank/sheets0.html
- Frank's Electron Tube Pages: http://www.tubedata.org/
- The National Valve Museum: http://www.r-type.org/

These sites have many Vacuum Tube Tester Manuals and Schematics. You will need a schematic for your tube tester to be able to wire the adapter into it. A manual is helpful as well. These are the sites:

- Articles about tubes and tube testers: http://alltubetesters.com/articles.htm
- Tube Tester and Test Equipment Manuals: http://pacifictv.ca/wanted.htm#testequip

These sites provide vacuum tube parts:

- https://www.tubesandmore.com/products/tube_accessories?sort=sku
- http://pacifictv.ca/socket.htm
- https://www.tubesandmore.com/
- http://www.parts-express.com/cat/vacuum-tubes-amp-parts/78
- https://www.aliexpress.com/price/9-pin-vacuum-tube_price.html

PHOTO ALBUM

The photographs at the end of this paper illustrate the many different combinations of characteristic curves it is now possible to display with each of the Tektronix Semiconductor Curve Tracers and a vacuum tube tester that has this VTCT adapter in it. Each of the Tektronix SCTs is shown under the same conditions except where indicated. The test setup for tetrodes would have been the same as for pentodes. The test results for a 576 SCT would have been identical to the results for the 577 SCT since they are interchangeable in terms of their capabilities.

SPECIAL THANKS TO …

George Lydeck built several elegant and simple tube tester designs that were the source of much envy on my part. These inspired me to build my own, and when I was given a 575 my first thought was to base my design on his. George and his co-workers were kind enough to double check my results and to scan this paper for technical errors, omissions, or confusing explanations. During the development of my tube tester, George offered many helpful suggestions. He confirmed some of my results on a 570 curve tracer he has access to where he works. For more information about the very elegant tube tester fixtures George has built, see:

http://glydeck.blogspot.mx/search?updated-min=2012-01-01T00:00:00-08:00&updated-max=2013-01-01T00:00:00-08:00&max-results=8

Scroll halfway down the page to February 21, 2012 to see George's pentode test fixture. Scroll to the end at January 6, 2012 where he shows his triode test fixture

Dr. Aris Silzars, My collaborator on so many fascinating projects, kindly loaned me the tubes I used as my unwilling test subjects during the development of the Vacuum Tube Curve Tracer. Most of the tubes are none the worse for wear. A few pentodes and triodes changed to diodes during my testing much to my surprise! The virtual Aris maintains a presence at:

http://www.worldviewofglobalwarming.org/html/about.html

Charles Osborne once told me something that has stuck in my head ever since:

"Man's creativity is limited by the capacity of his water heater".

I think of that every time I am in the shower. It was during one of my more "creative" showers that I was struggling with the problem of how to add more filament voltages to George Lydeck's design and still fit it on the 575 front porch that I had the inspiration to combine a 575 curve tracer and a tube tester into the best of both worlds. Thank you, Charles.

Charles maintains a wonderful site devoted to the RCA Selectron tube, a Selective Electrostatic Storage Tube used as a 4096 bit digital memory in 1940s era computing. This interesting site can be viewed here:

http://rcaselectron.com/index1.html

The TekScopes Forum:

In 2017 the TekScopes Forum moved from Yahoo to Groups.io. In the past 17 years I have made many friends at the TekScopes Forum. I can ask just about any question I don't know the answer to and someone somewhere around the world will respond with an answer. It is easy to join. Just go to

https://groups.io/g/TekScopes

On the left side near the top it says "Subscription" click on that link, answer a few questions, and then introduce yourself to the group and tell us a little about your interest in Tektronix in your first post to the group. That is all that's needed.

Figure 11 Clockwise from upper left: displaying the 6AU6A characteristic curves on a 575, a 577, a 5CT1N plugin, and a 7CT1N plugin. The 6mA current limit and fixed load resistors of the 7CT1N / 5CT1N mean the plate voltage can only swing part way across the CRT for the 0V to -2V grid steps.

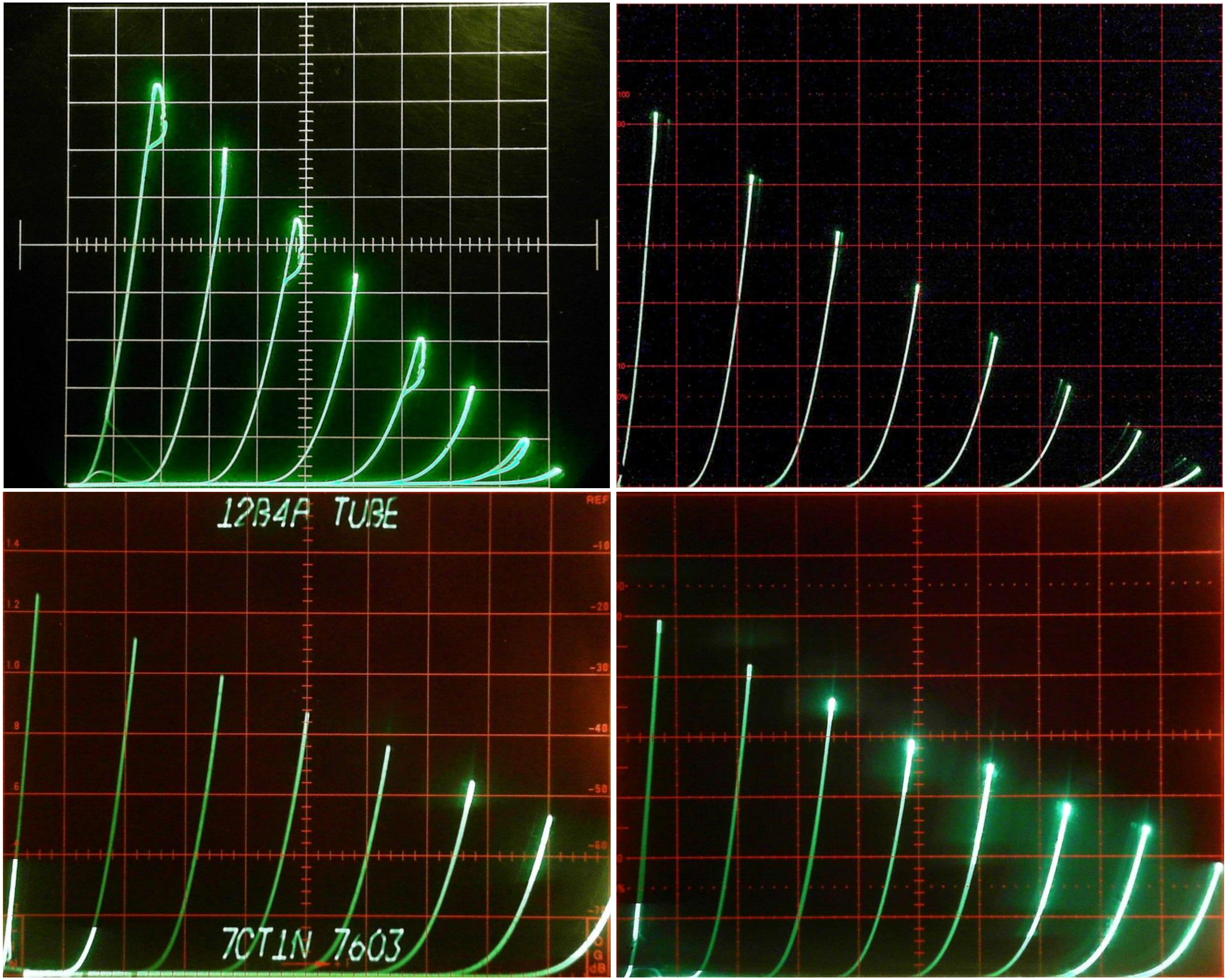


Figure 12 Clockwise from upper left: displaying the 12B4A Low Mu Triode characteristic curves on a 575, a 577, a 5CT1N plugin, and a 7CT1N plugin. Each curve tracer has the same settings. Horizontal: 20V / Div., Vertical: 1mA / Div., Grid Steps: -5V each. Next page: early prototype photos match the manufacturer's data sheets.

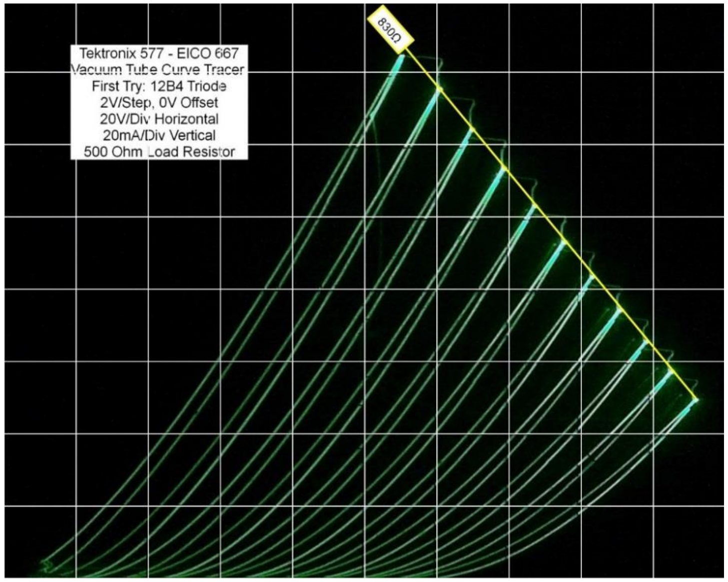


Figure 15 This is the first photo from the VTCT. The plate resistance, rp, of the 12B4 (the yellow line) is 830Ω. The loops are due to the Miller effect between the collector and base of the prototype.

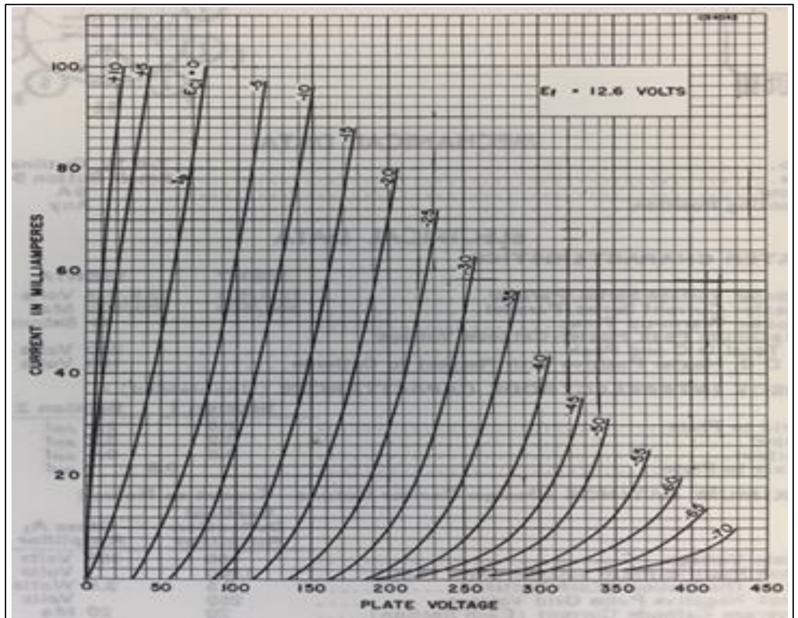


Figure 16 These are the 12B4 curves from the Sylvania Technical Manual.

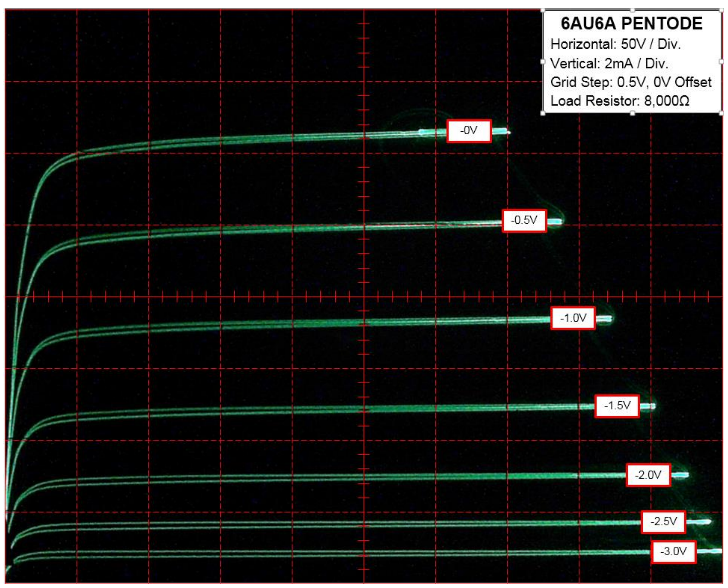


Figure 14 The 6AU6A pentode's characteristic curves match the set in the RCA Receiving Tube Manual, shown at right, perfectly.

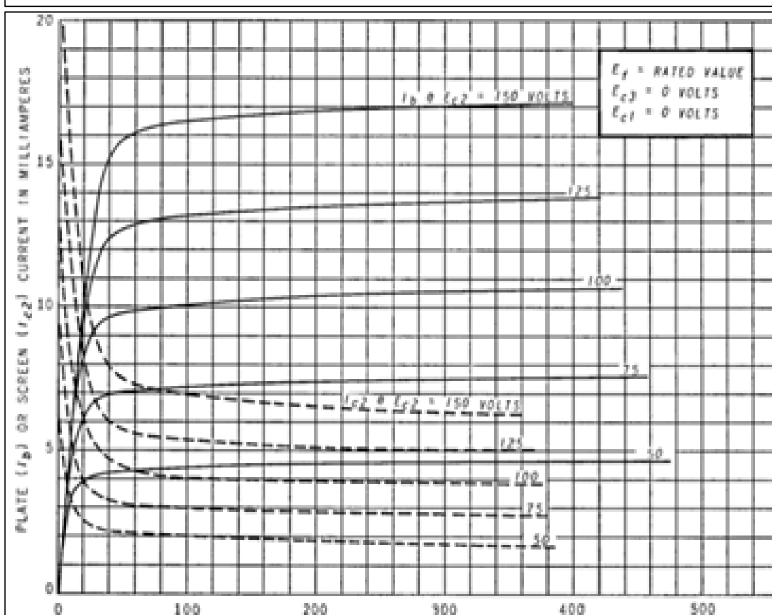


Figure 13 6AU6A characteristic curves. The dotted line labeled IC2 is the Screen current. As the plate voltage drops below the screen voltage the screen captures all of the plate current.

TRIODE TEST RESULTS

The annotated photographs in the next three pages are the first ones I made. They are based on the curves I made from the 12B4 triode results on the Tektronix 577 / EICO 667 VTCT. Note: the loops in each curve are due to Miller Effect capacitance between the base and collector lead of the cable connecting the curve tracer to the tube tester. By shielding the base lead from the collector lead the loops were eliminated in later photographs.

The Sylvania Technical Manual gives the following description for the 12B4:

> *The 12B4 is a miniature, low mu, high perveance triode amplifier designed for service as a Class A amplifier or vertical deflection amplifier in television sync circuits. The center tapped heater permits operation from a 6.3 or 12.6 volt source.*

Here are how my results compared with the typical results from the Sylvania Technical Manual. NOTE: theory says $\mu = r_P * g_m$.

Source	μ	g_m	r_P	$\mu = r_P * g_m$	Comments
Sylvania	6.5	6,300µmhos	1,030Ω	6.5 = 1,030 * 6,300 = 6.48	these results are mutually consistent.
Dennis (#1)	7.5	11,875µmhos	850Ω	7.5 = 850 * 11,875 = 10.0	these results were not very accurate.
Dennis (#2)	6.625	8,125µmhos	750Ω	6.625 = 750 * 8,125 = 6.09	these results were very good.

The Sylvania Technical Manual[15] values came from measurements taken at a plate voltage of 150V, a grid voltage of -17.5V, and a plate current of 34mA.

I took two readings of each parameter to get a better idea of what a typical value might be. The first set of readings were taken at, or close to, 0V grid bias. The 2nd set of readings were made on the curves where the grid bias was more negative as a rule.

The EICO 667 Dynamic Conductance Tube Tester determined that this particular tube was exactly in the middle of the questionable range between Replace and Good. The curves I captured do not seem to support that conclusion. The tube seems to be within the typical range for the three most important parameters - r_P (plate Resistance), μ (Amplification Factor), and g_m (Transconductance). The values I measured for these (see above) are consistent with the values provided in the Sylvania Technical Manual.

The next 3 pages show how the μ, g_m, and r_p of a triode are calculated from the characteristic plate curves.

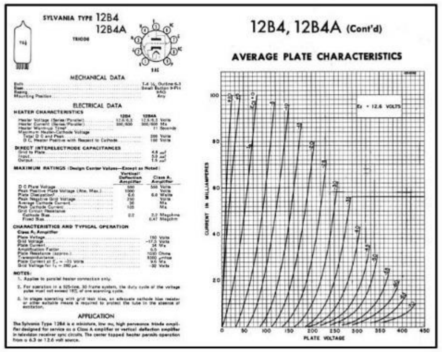
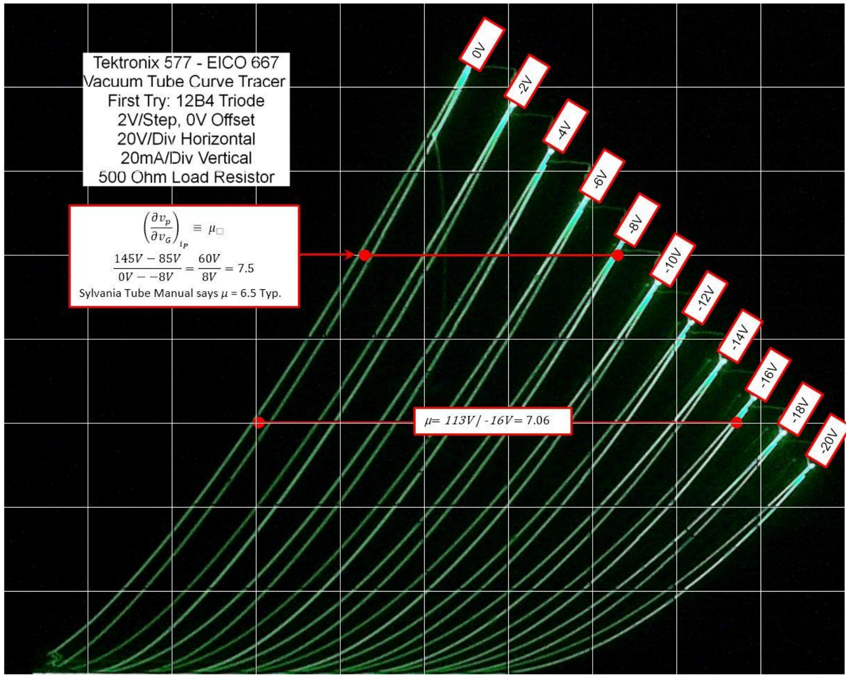
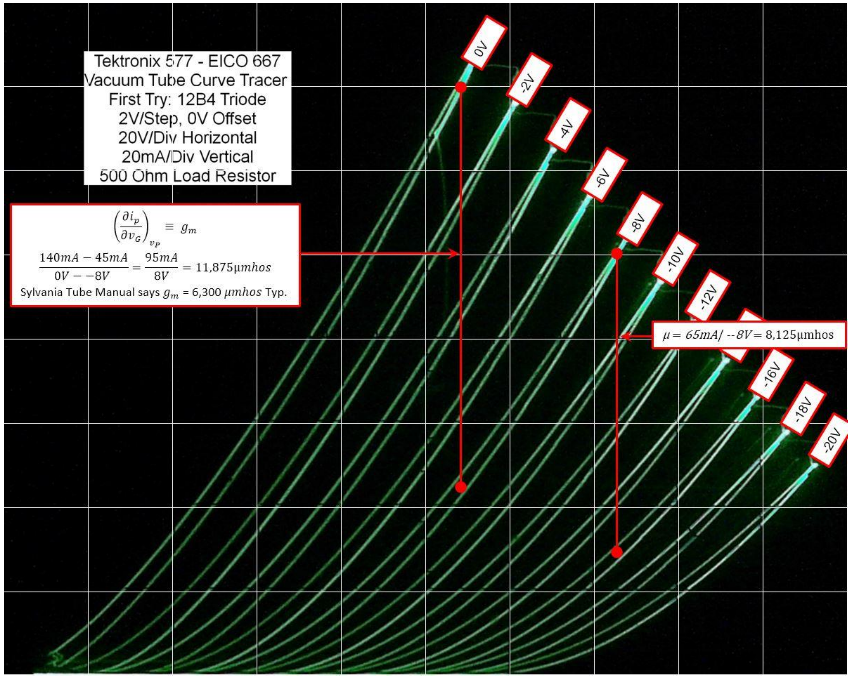


Figure 29 12B4 Triode tube data.

[15] *Sylvania Technical Manual*, Sylvania Electric Products Inc., Sylvania Electronic Products, New York, NY 1959





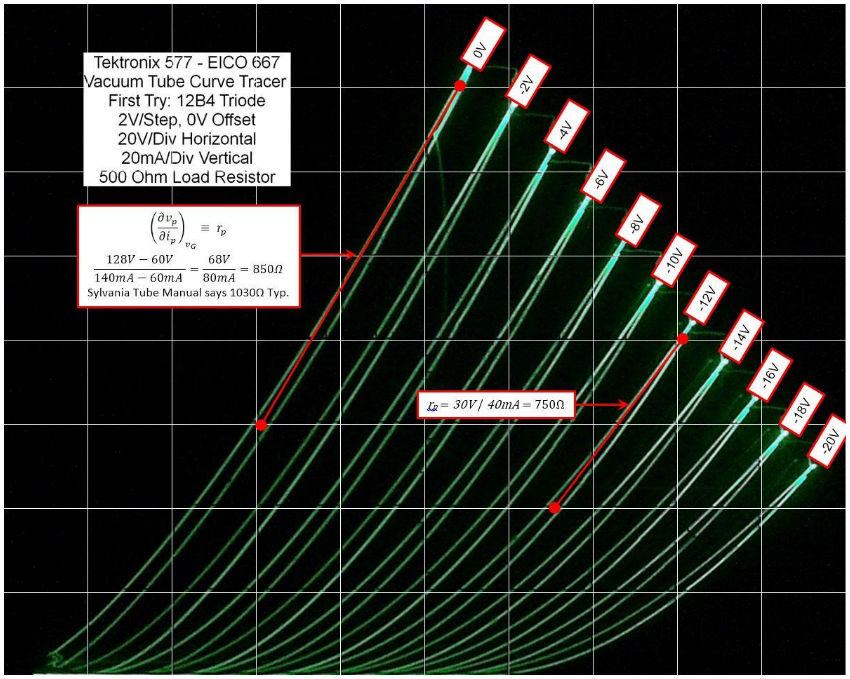


Figure 17 These are the first measurements made with the VTCT adapter prototype of a triode's characteristic curves. They confirmed the adapter could make accurate measurements of the triode's parameters from the characteristic curves. Loops in the curves are due to Miller Effect capacitance. Shielding the base lead fixed this.

PENTODE TEST RESULTS

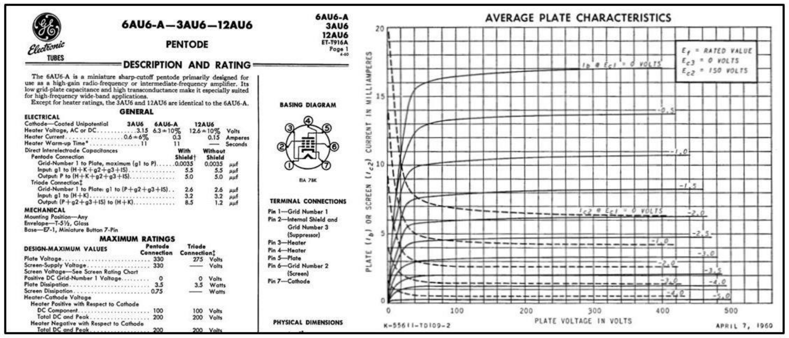
The 6AU6A is a common, well documented, pentode. The photographs on the next three pages are based on curves I captured on the 575 and 577 curve tracers. The 577 is an 8 X 10 aspect ratio CRT and the aspect ratio of the 575 is 10 X 10 so it is easy to tell which curve tracer is which from the photographs. I used the 575 to demonstrate its usefulness as a curve tracer. I set the 575 up to generate the small 0.1V grid steps necessary for me to calculate the amplification factor (μ) of the pentode. A pentode's gain is so large that the only way to measure it is with very small grid steps. The Sylvania Technical Manual gives the following description for the 6AU6A:

The 6AU6A is a miniature sharp cutoff pentode, r f amplifier capable of operation up to 400 mc.

Here are my results compared with the typical results from the Sylvania Technical Manual. NOTE: In theory $\mu = r_p * g_m$.

Source	μ	g_m	r_p	$\mu = r_p * g_m$	Comments
Sylvania	none	4,500μmhos	1.50Ω	1,500,000 * 0.00450 = 6,750	This μ falls half way between my results.
Dennis (min)	1100	3,730μmhos	0.77MΩ	770,000 * 0.00373 = 2,872	Plausible, but low μ result for a pentode.
Dennis (max)	1400	4.930μmhos	2.62Ω	2,620,000 * 0.00493 = 12,916	Too big. This is 9 times the μ I measured.

Here are the specifications for the 6AU6 from the Sylvania Technical Manual. This set of plate characteristics is for the screen set to 150V.

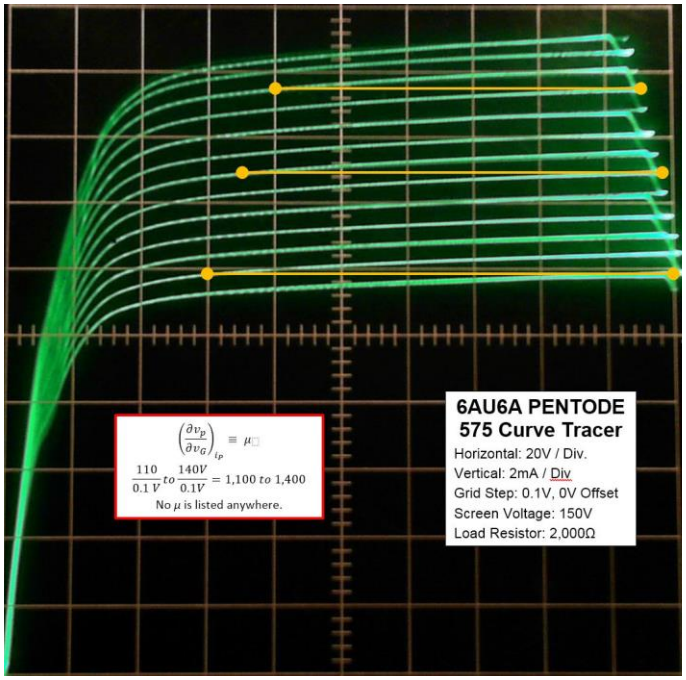

6AU6-A—3AU6—12AU6

PENTODE

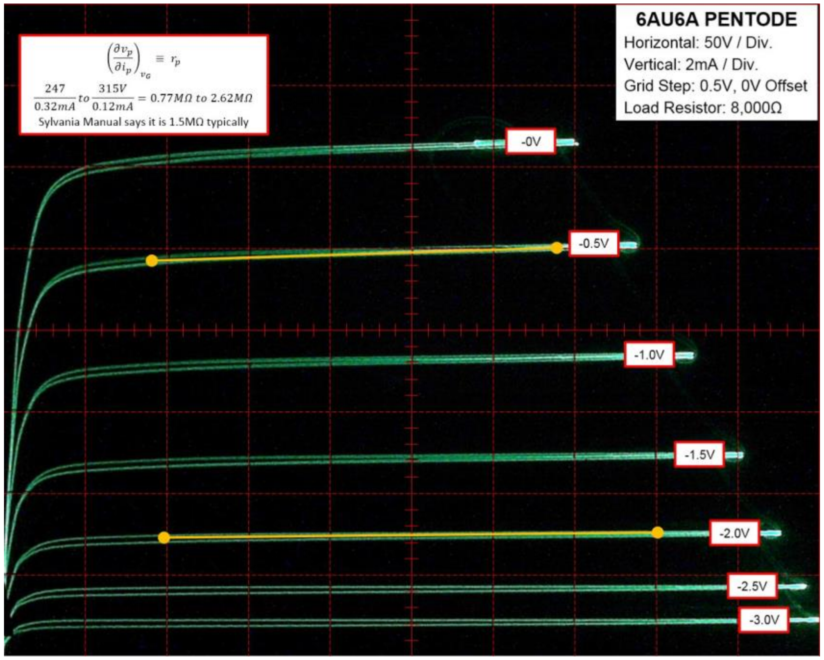
DESCRIPTION AND RATING

AVERAGE PLATE CHARACTERISTICS

Figure 30 6AU6A Pentode tube data.



The next 4 pages show how the μ, g_m, and r_p of a pentode are calculated from the characteristic plate curves. Also, on page 4 is an example of how g_m can be calculated from the I_a / V_g transfer characteristics.



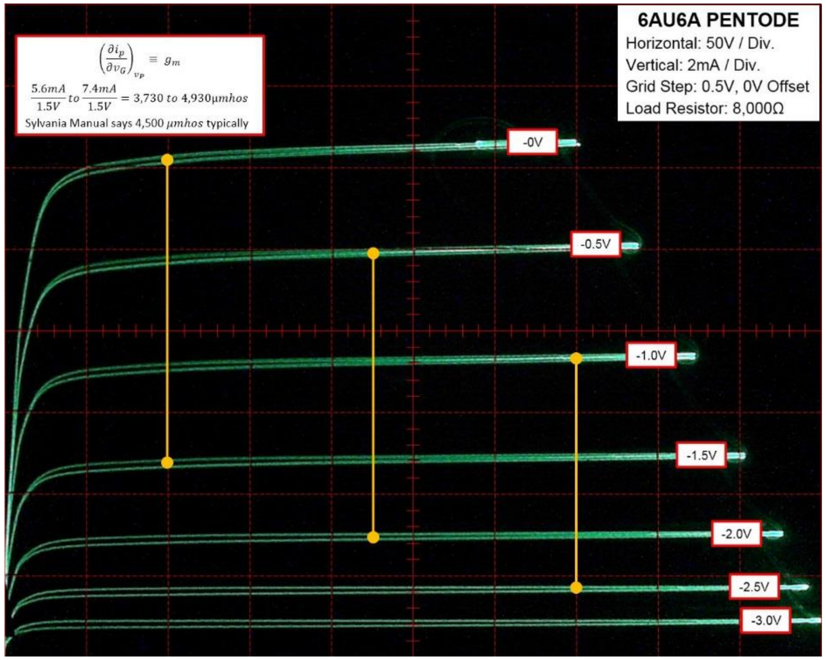


Figure 18 These are the first measurements made with the VTCT adapter prototype of a pentode. This demonstrated to me the ability of the adapter to make accurate measurements of the pentode's parameters directly from the characteristic curves of the tube.

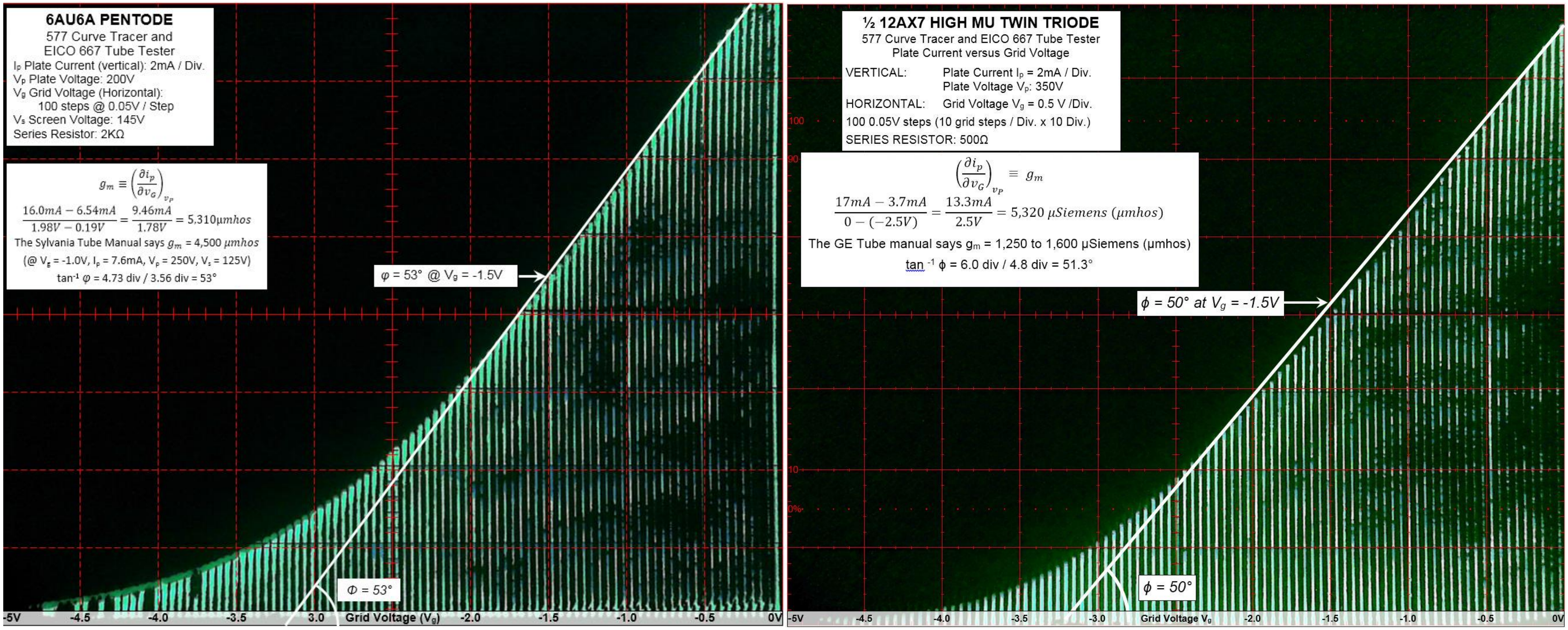


Figure 19 *This is the I_a / V_g transfer characteristic of a pentode (Left) and a triode (Right). The tangent of the angle ϕ indicates the transconductance (g_m) of the tube at that point[12]. Where the resulting currents follow a straight line the transfer curve of the tube is linear. Displaying 100 steps requires the curve tracer to take 10 times longer to display. The capability of the 577-D1 to store the slow sweeping trace makes it possible to display these curves. The non-storage 575, 576, or 577-D2 require a camera to take this photo. A 5CT1N or a 7CT1N placed in a 7000 series storage mainframe would be able to conveniently display these curves as well.*

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12 J. Deketh, *Fundamentals of Radio-Valve Technique*, N.V. Philips' Gloeilampenfabrieken, Technical and Scientific Literature Department, Eindhoven, Netherlands, 1949, p 128.

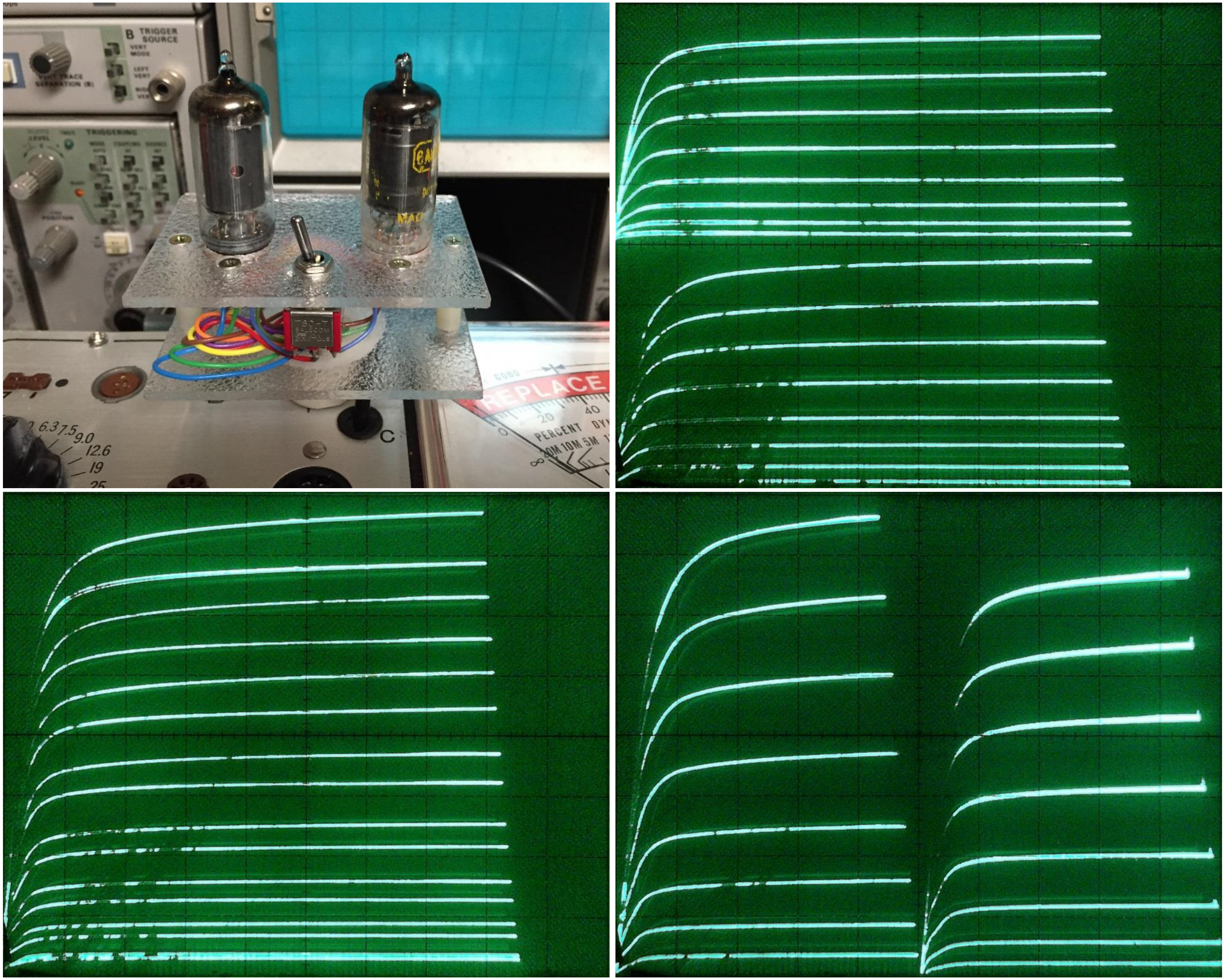


Figure 20 Clockwise from top left: Prototype Tube Matching Adapter; 6AU6A pentode curves displayed in the upper and lower storage halves of the 577 –D1 Storage Curve Tracer; same curves displayed side by side; same curves displayed full screen superimposed on each other. Settings: Horizontal: 50V / Div.; Grid: 1 V / Step; Screen: 200V, Vertical: 10mA / Div. upper right photo, 5 mA / Div. lower left and lower right photos.

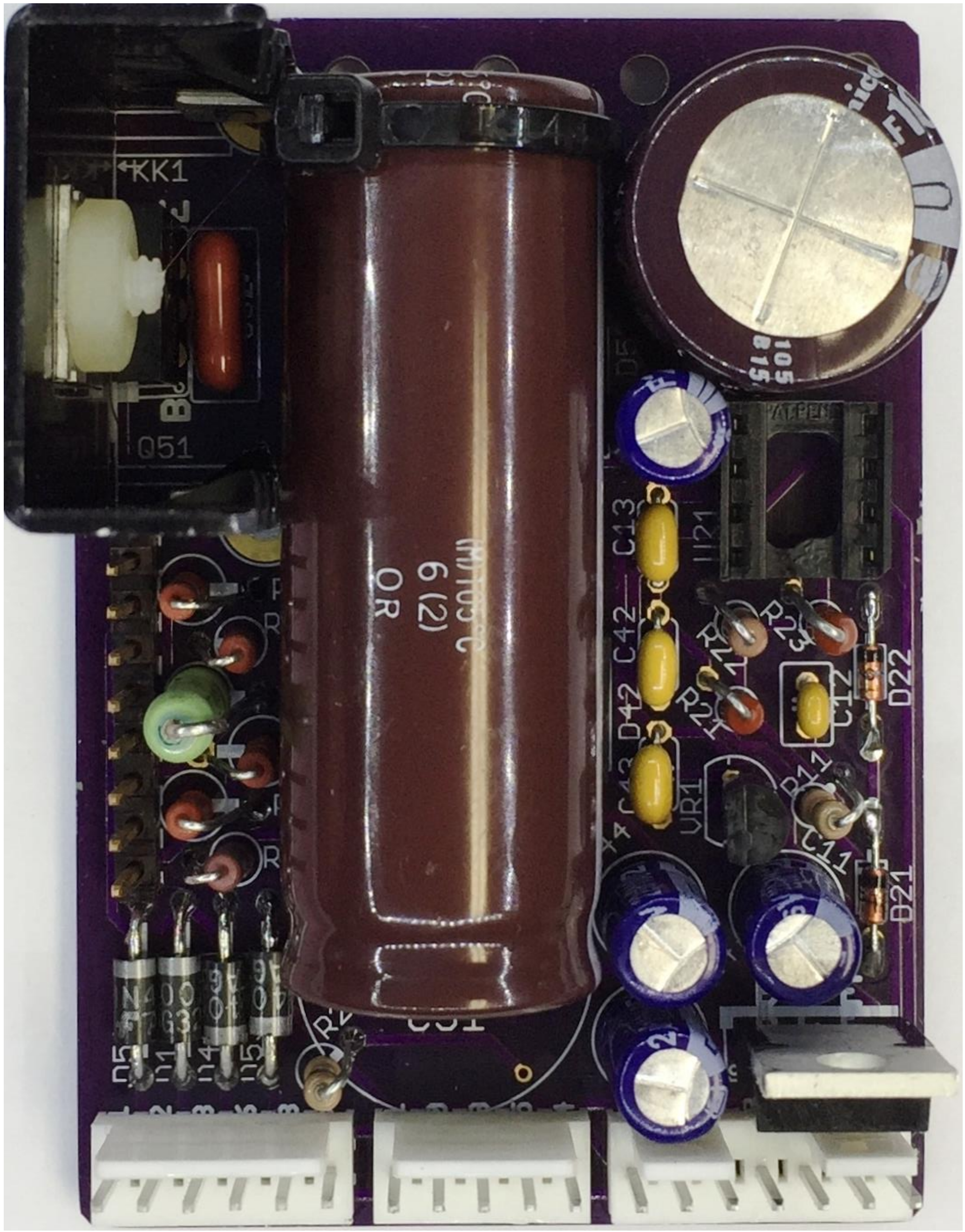


Figure 23 Completed VTCT Adapter Board.

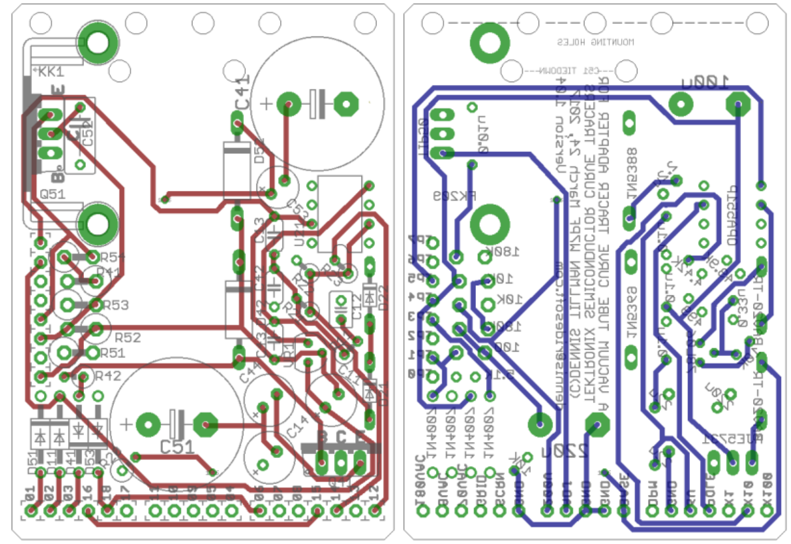


Figure 22 VTCT Adapter version 1.04 PC Board Artwork.
Left: Component Side; Right: Solder Side..

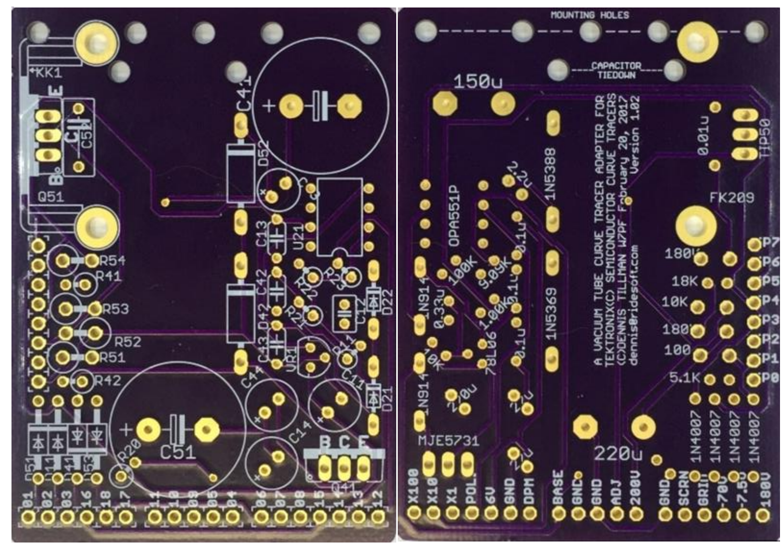


Figure 21 Gold plated VTCT Adapter PC Board.
Left: Component Side; Right: Solder Side.
NOTE: The photograph on the right shows version 1.02 of the PC Board. The changes between v1.02 and v1.04 are cosmetic.

#	VTCT ADAPTER PARTS LIST	EAGLE VALUE	EAGLE DEVICE / PACKAGE	DESCRIPTION	MOUSER PART #	US $	FARNELL / NEWARK
1	C11	220u/16V	CPOL1 / E2,5-7	Electrolytic capacitor	667-ECA-1CM221B	$0.25	FARNELL: 2282200
2	C12	0.33u/50V	C-US025-030X050	Capacitor	80-C320C334K5R9170-R	$0.82	FARNELL: 2673123
3	C13, C42, C43	0.1u/200V	C050-024X044	Capacitor	80-C330C104K2R	$1.62	FARNELL: 1702665
4	C14, C44	22u/100V	CPOL1 / E2,5-7	Electrolytic capacitor	667-ECA-2AM220	$0.54	FARNELL: 9693920
5	C41	220u/160V	CPOL-USE7.5-18	Polarized Capacitor	661-EKXG161ELL221ML2	$1.87	FARNELL: 1691087
6	C51	220u/400V	CPOL-USE10-30	Polarized Capacitor	661-EKXJ401ELL221MM5	$4.97	FARNELL: 2504583
7	C52	0.01u/400V	C-US075-042X103 (C-US)	Capacitor	667-ECQ-E4103KF	$0.36	FARNELL: 2281808
8	C53	2.2u/250V	CPOL-USE2.5-6 (CPOL-US)	Polarized Capacitor	667-ECA-2EM2R2	$0.33	FARNELL: 9693998
9	D11, D41, D51, D53	1N4007	DO34-7 1000V, 1A RECTIFIER	DIODE	512-1N4007	$0.64	FARNELL: 1467514
10	D21, D22	1N459A	DO35 SMALL SIGNAL DIODE	200V 500mA DIODE	512-1N459	$0.27	FARNELL: 9804765
11	D42	1N5369BG	DO34Z7 ZENER DIODE	51V, 5W Zener DIODE	863-1N5369BG	$0.47	FARNELL: 9558268
12	D52	1N5388	DO34Z7 ZENER DIODE	200V, 5W Zener DIODE	863-1N5388BG	$0.47	FARNELL: 9558403
13	DPM * See note below	200V, 27 x 14 x 5mm	DIGITAL PANEL METER	0.36" 200VDC DPM	* See note below	$2.00	* See note below
14	J1	POMONA 2970-0 or 2970-2	TRIPLE BANANA PLUG	Triple Banana Plug	565-2970-0 or 565-2970-2	$6.24	NEWARK: 35F1065
15	KK1	265-118ABHE-22	Wakefield-Vette FK-209	TO-220 Heat Sink	567-265-118ABHE-22	$0.71	NEWARK: 78R1848
16	Q41	MJE5731G	O220AV HIGH BETA, HV POWER	PNP TRANSISTOR	863-MJE5731G	$1.18	FARNELL: 2627982
17	Q51	TIP50	HIGH BETA, HV POWER	NPN TRANSISTOR	512-TIP50	$0.57	FARNELL: 1695917
18	R11, R20	10K 1/4W 5%	R-US_0207/2V	RESISTOR	603-CFR-25JR-5210K	$0.20	Any brand will work
19	R21	499 1/8W 1%	R-US_0207/2V	RN55C RESISTOR	71-RN55C-F-499	$0.14	Any brand will work
20	R22	4.42K 1/8W 1%	R-US_0207/2V	RN55C RESISTOR	71-RN55C4421F/R	$0.12	Any brand will work
21	R23	49.9K 1/8W 1%	R-US_0207/2V	RN55C RESISTOR	71-RN55C-F-49.9K	$0.10	Any brand will work
22	R41	10K 2W 5%	R-US_0309/V	RESISTOR	594-5083NW10K00J	$0.34	FARNELL: 4603114
23	R42	5.1K 1/2W 5%	R-US_0309/V	RESISTOR	594-SFR25H0005101JR5	$0.10	Any brand will work
24	R51	100 1W 5%	R-US_0411/3V	RESISTOR	594-5073NW100R0JA100	$0.18	FARNELL: 2614497
25	R53	10K 1W 5%	R-US_0411/3V	RESISTOR	594-5073NW10K00JA100	$0.19	FARNELL: 2614499
26	R52, R54	180K 1W 5%	R-US_0411/3V	RESISTOR	594-5073NW180K0J	$0.36	FARNELL: 1755137
27	RP51	100K 1/2W POT	Linear Taper	POTENTIOMETER	858-P231QC20BR100K	$1.55	FARNELL: 1684830
28	SW1	1 POLE 3 POSITION	NKK MRB14B Mini Rotary Switch	X1/X10/X100 GRID STEP	633-MRB14B	$10.20	NEWARK: 10X5232
29	SW1 Knob (optional)	n/a	n/a	Knob BLK for NKK-MRB14	633-AT433	$0.54	NEWARK: 09X7650
30	SW2 ** See note below (optional)	3PDT ON-ON	Miniature Toggle Switch	MTA306D	506-MTA306D	$21.51	NEWARK: 61F1250
31	U21	OPA551	DIL08	High Voltage OpAmp	595-OPA551PA	$5.12	FARNELL: 4427191
32	VR1	78L06	78L06	+6V Voltage Regulator	512-MC78L06ACP	$0.35	FARNELL: 2394005
33	P1 (optional)	Molex 22-27-2071	Thru Hole (PCB) Header	7 Position, Male	538-22-23-2071	$0.50	FARNELL: 2112410
34	P2 (optional)	Molex 22-27-2051	Thru Hole (PCB) Header	5 Position, Male	538-22-23-2051	$0.30	FARNELL: 9731679
35	P3 (optional)	Molex 22-27-2061	Thru Hole (PCB) Header	6 Position, Male	538-22-23-2061	$0.34	FARNELL: 1462922
36	J1 (optional)	Molex 22-01-2071	Connector Housing	7 Position, Female	538-22-01-2071	$0.33	NEWARK: 25M1706
37	J2 (optional)	Molex 22-01-2051	Connector Housing	5 Position, Female	538-22-01-2051	$0.22	NEWARK: 55H8904
38	J3 (optional)	Molex 22-01-2061	Connector Housing	6 Position, Female	538-22-01-2061	$0.25	FARNELL: 4234170
39	20 Crimp Terminals (optional)	Molex 08-50-0114	n/a	Crimp Terminal 22-30 TIN	538-08-50-0114	$2.18	NEWARK: 59M7685
40	PC Board, Version 1.04	Available from the author	Double sided, gold plated, 2.00" x 2.80"		Available from the author	$15.00	Available from the author
	MISCELLANEOUS: 2' of thin flexible coax - any kind; 2' of rubberized 1500V High Voltage wire, Insulator kit and thermal grease for Q51 heatsink					***$83.43***	***TOTAL FOR ALL PARTS***
	* Available on Ebay. Search for 0-200V DC Digital Panel Meter and/or Part Number: TOOL071-011-0-200V, 27 x 14 x 5mm (small size is desirable) approximate Ebay price with shipping: <$2.00.						
	** Any 3PDT ON-ON Miniature Toggle Switch found on the internet is almost certainly acceptable. Prices start at $4.00 (a savings of more than $16 over the MTA306D listed here)						

Figure 24 All Vacuum Tube Curve Tracer adapter parts are shown in this list. The total cost for the parts listed here comes to ~$84.00 but $70.00 is a more realistic figure.

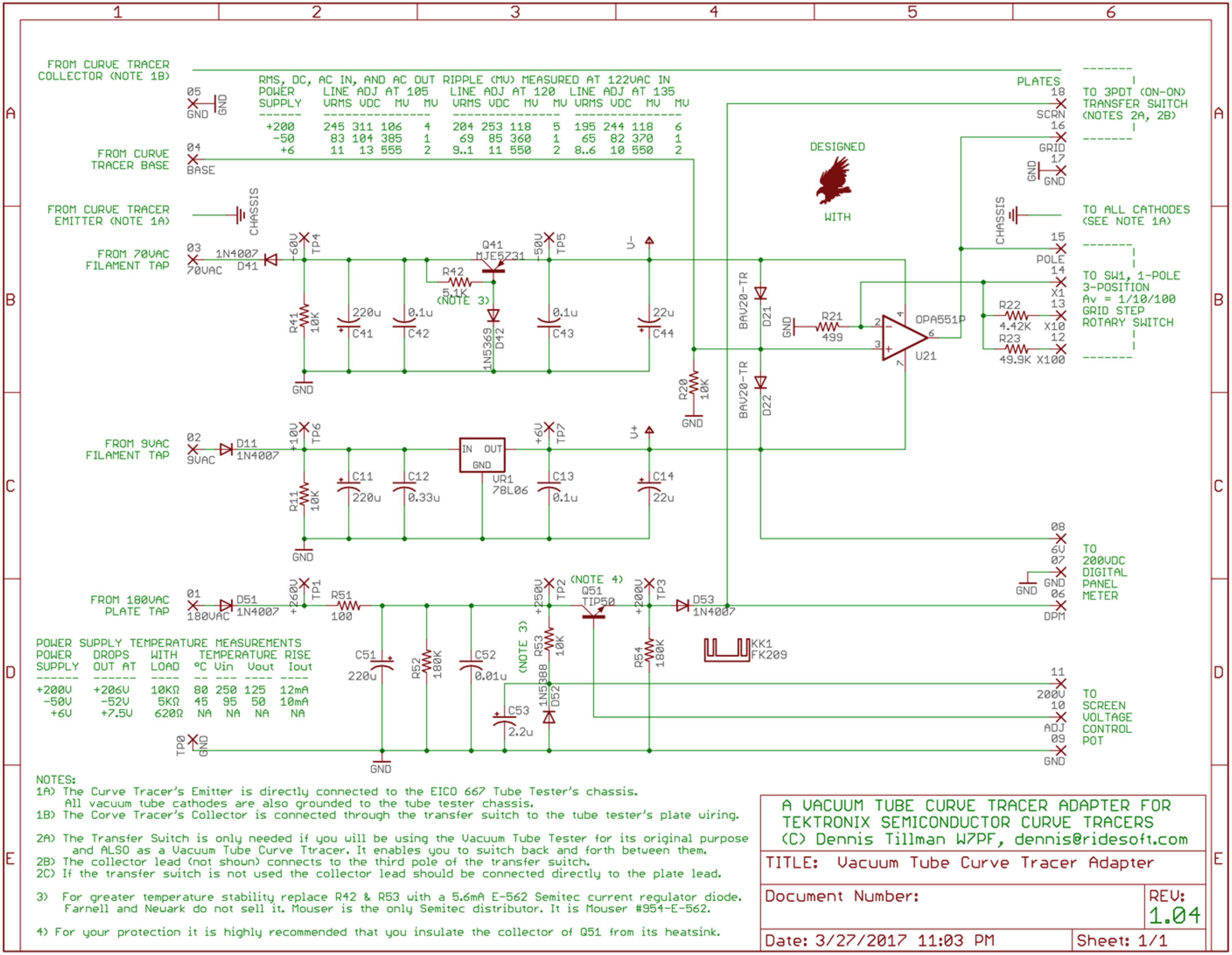


Figure 25 Complete schematic (Version 1.04) of the Vacuum Tube Curve Tracer adapter circuitry.

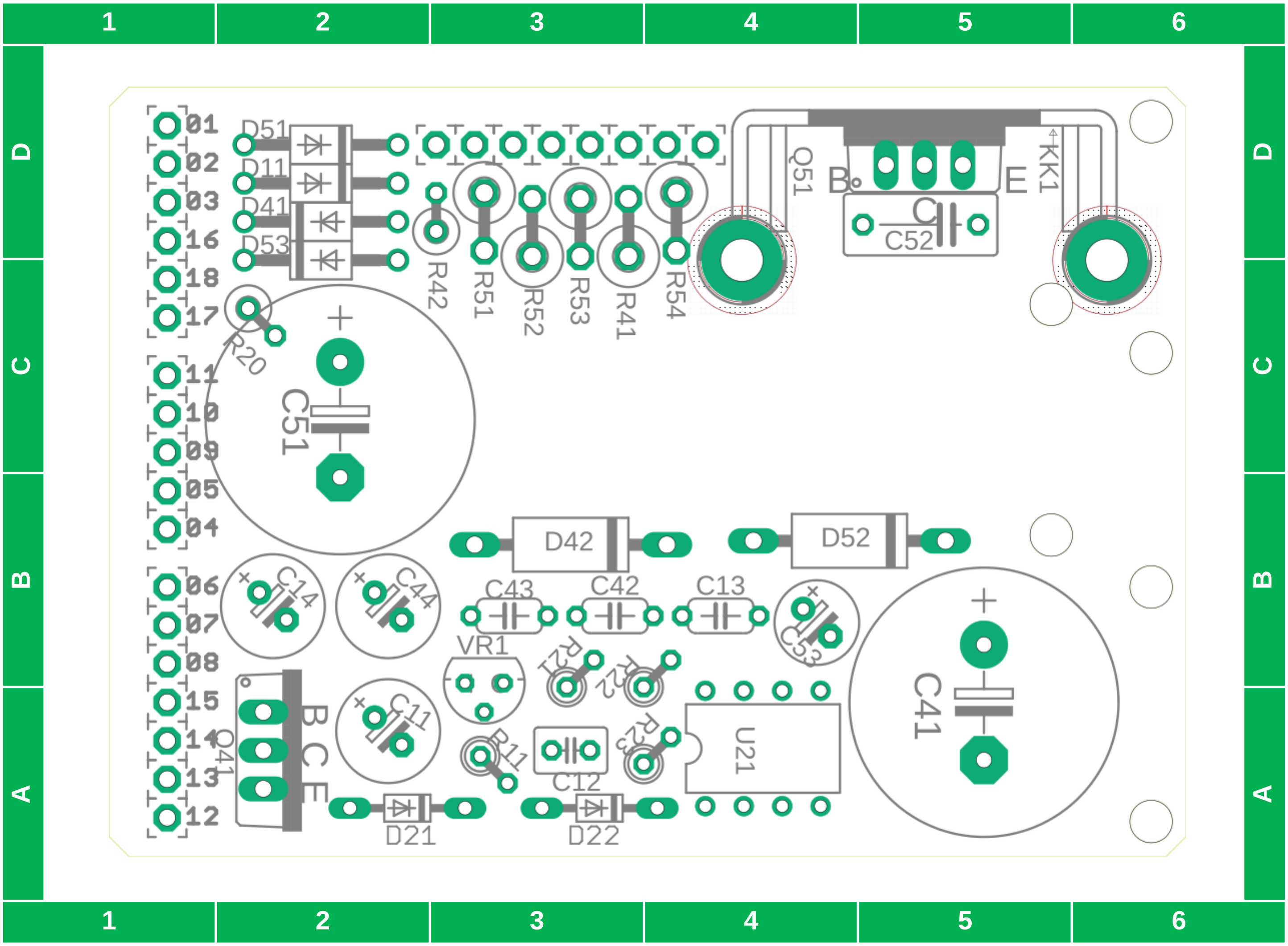
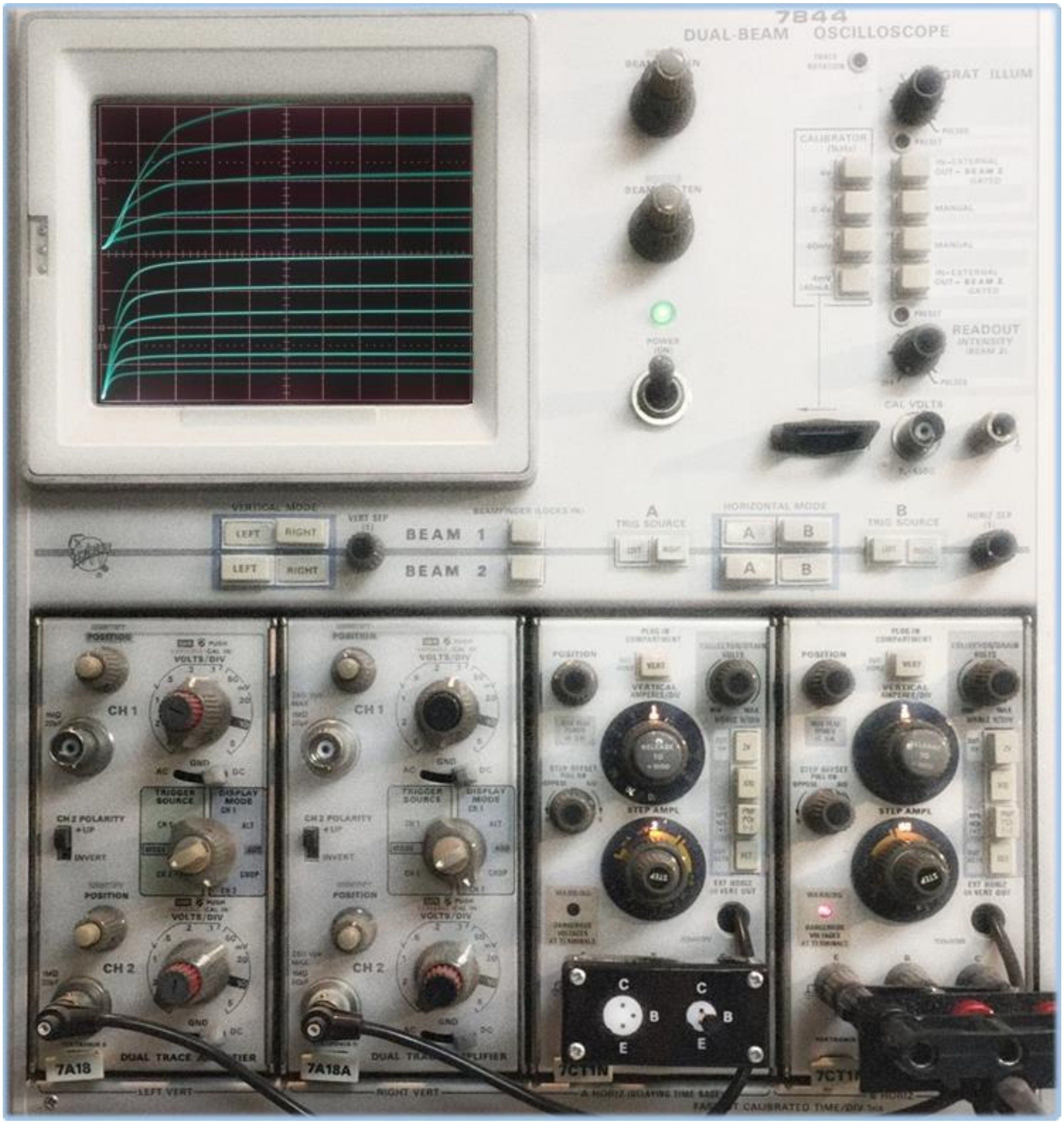


Figure 27 *Printed Circuit Board (Version 1.04) parts layout.*

PART NUMBER	SCHEMATIC LOCATION	BOARD LOCATION	PART NUMBER	SCHEMATIC LOCATION	BOARD LOCATION	PART NUMBER	SCHEMATIC LOCATION	BOARD LOCATION
01	1D	1D	C13	3C	4B	R20	4B	2C
02	1C	1D	C14	4C	2B	R21	5B	3A/3B
03	1B	1D	C41	2B	5A/5B	R22	6B	3A/3B/4A/4B
04	1A	1B	C42	2B	3B	R23	6B	3A/3B
05	1A	1B	C43	3B	3B	R41	2B	3C/3D
06	6D	1B	C44	4B	2B	R42	3B	3D
07	1C	1B	C51	2D	2C	R51	2D	3D
08	1C	1B	C52	3D	5D	R52	3D	3C/3D
09	6D	1C	C53	3D	4B	R53	3D	3D
10	6D	1C	D11	2C	2D	R54	4D	4D
11	6D	1C	D21	4B	2A	TP0	1D	3D
12	6B	1A	D22	4B	3A	TP2	3D	3D
13	6B	1A	D41	2B	2D	TP3	4D	3D
14	6B	1A	D42	3B	3B	TP4	2B	3D
15	6B	1A	D51	2D	2D	TP5	3B	3D
16	6A	1D	D52	3D	4B/4C	TP6	2C	4D
17	6A	1C	D53	4D	2C/2D	TP7	3C	4D
18	6A	1C	Q41	3B	2A	U21	5B	4A
C11	2C	2A	Q51	3D	5D	VR1	3C	3A/3B
C12	2C	3A	R11	2C	3A			

Figure 26 *Red locations are on the schematic. Green locations are on the PC Board.*

Back cover: Tektronix 7844 Dual Beam Oscilloscope simultaneously displaying the characteristic curves of an N-Channel Field Effect Transistor and a Pentode vacuum tube.



This Tektronix 7844 Dual Beam Oscilloscope***** is **displaying the characteristic curves of a 2N5484 N-Channel FET** in the bottom half of the CRT using Beam 1, and **the characteristic curves of a 6AU6A sharp cutoff pentode** in the top half of the CRT on Beam 2 using the VTCT adapter described in this paper. Both sets of curves are displayed using 7CT1N Curve Tracer plugins <u>simultaneously</u> to illustrate the similarity between FETs and pentodes.

The measured g_m of the 2N5484 FET is 2.8mA / 0.8V = 3.5mSiemens (3,500µmhos).
The specification is 3.5mSiemens minimum.

The measured g_m of the 6AU6A Pentode is 6.0mA / 1.5V = 4.0mSiemens (4,000µmhos).
The specification is 3.9mSiemens minimum.

** Note: The simultaneous display and measurement of transistor and vacuum tube parameters can only be performed on a Tektronix 7844 Dual Beam Oscilloscope.*