The past few days have not gone well.

This week has not gone well…

- My car blew it’s head gasket
- I left the tube tester home so I drove back to Bellevue from Portland to get it
- I almost got ticketed in Seaside

Today is no exception.

- I have laryngitis
- My talk was cancelled (by someone else!)
- They gave my training room to someone else
- The overhead projector’s HDMI cable was busted
- They never got me a microphone to use so I could be heard whispering because of the laryngitis
- I’m afraid to think what else might happen if I go ahead with my talk, but here goes…

AN INEXPENSIVE VACUUM TUBE CURVE TRACER ADAPTER FOR ALL TEKTRONIX SEMICONDUCTOR CURVE TRACERS

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Tektronix Curve Tracers:

- 7CT1N and 5CT1N
- 575
- 575 Mod 122C
- 576
- 577 Non-Storage
- 577 Storage
- 570

Benefits

- Universal curve tracer which can test vacuum tubes, semiconductors, and any 2 or 3 wire electronic part
- Tests all tubes the tube tester is capable of testing
- 575s are cheap and common, local pickup only. Check Craigs List, Ham fests, or place a Craigs List Want Ad
- Tube testers are cheap and common. There are over 1,000 on Ebay at any moment. Not all will work.
- No changes are made to any Tek curve tracer
- Parts cost less than $75.00
- A working 570 usually sells for more than $5,000!

Drawbacks

- Only a *dynamic conductance* or *mutual conductance* tube tester will work
- Modification to the tube tester is required
- Dangerous voltages are present in tube testers
- Dangerous voltages come from the curve tracer

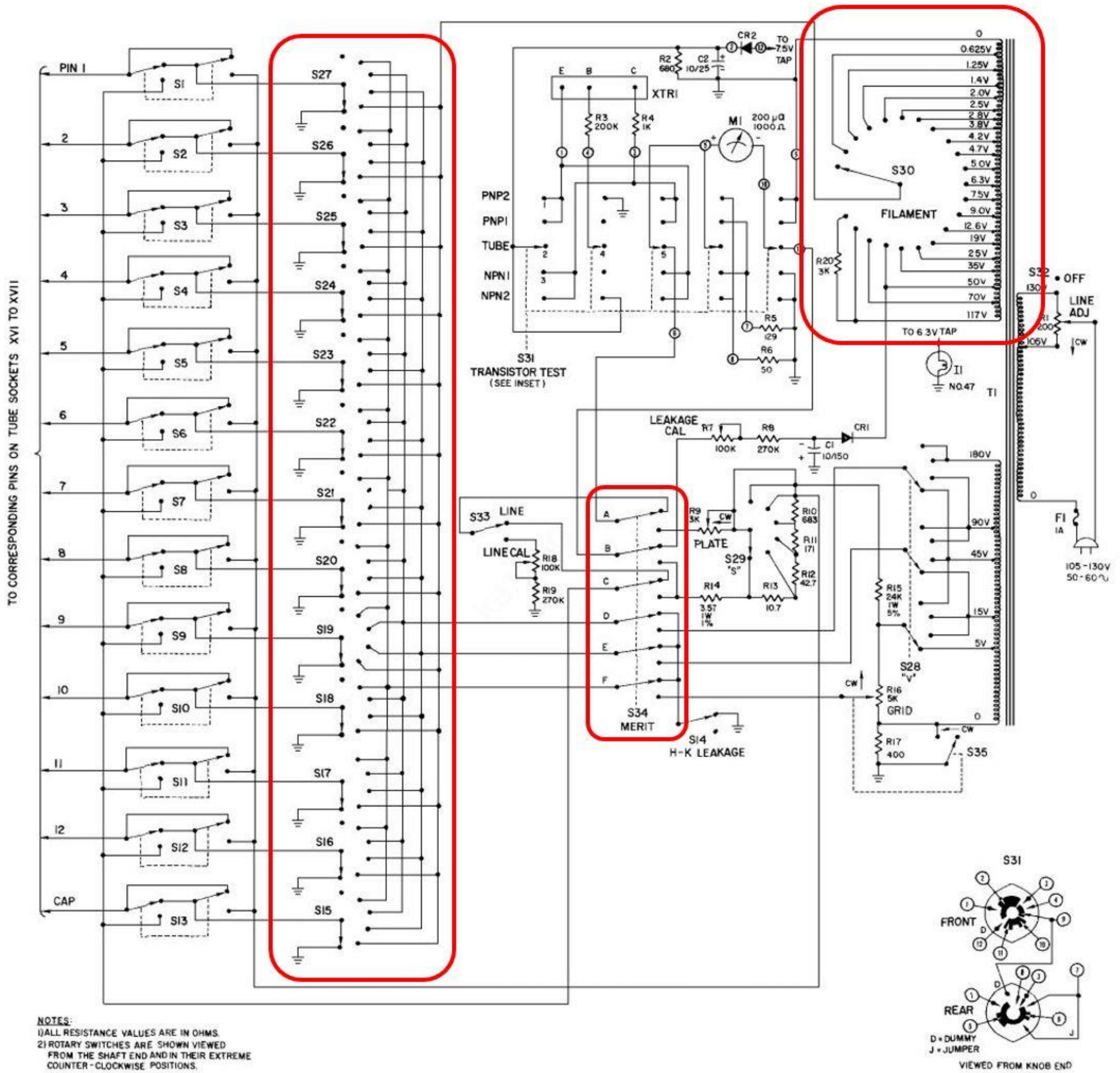
Tek Curve Tracer Pros and Cons

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

Tube Tester basics

- You can’t make a tube tester today — sockets and special transformers are unobtanium
- Find them here at the show or on Ebay
- Mutual conductance and dynamic conductance
- Switches versus sockets
- Internal voltages the adapter needs
- Primitive designs work fine to test tubes
- | Good | ? | Bad | meter reading can’t be trusted

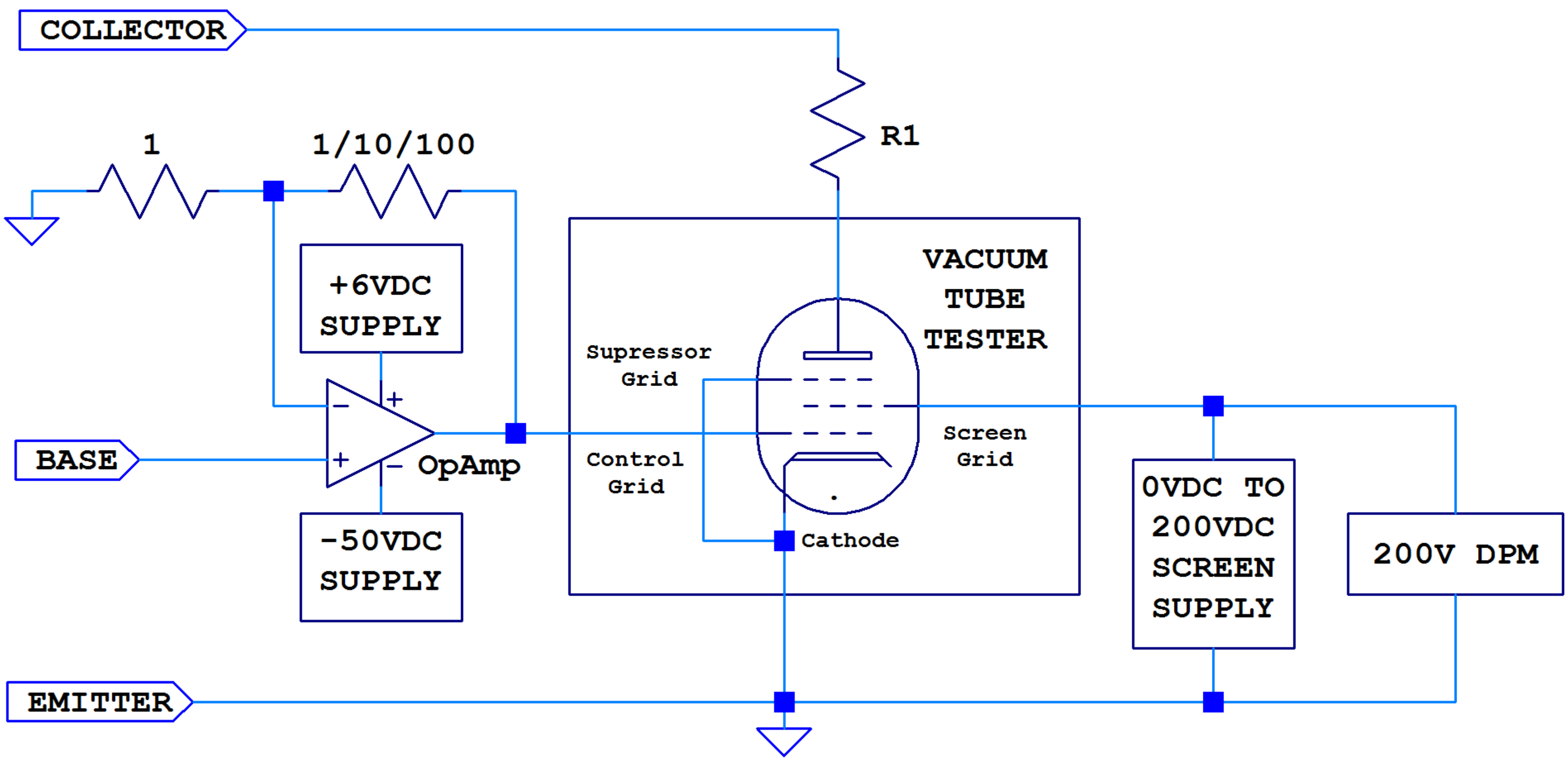
EICO 667 Tube Tester Schematic



Issues to consider

- Triodes need a wide range of grid voltage steps
  - Tek curve tracer's base voltage is limited to 20V total
  - Some triodes require -20V for <u>each</u> grid step
  - Some triodes are tested with +10V to -150V grid swing
- Pentodes and Tetrodes need a DC screen supply
  - The screen determines the operating point, not the grid
  - 0 to 200V screen supply, 40mA sinking capability
  - The screen must be lower than the plate or else…
  - If the plate voltage drops below the screen voltage the screen robs plate current. The amount of current depends, so it is specified on every datasheet.

Theory of Operation



What **YOU** need to make a VTCT

- A dynamic conductance or mutual conductance tube tester
- A tube tester schematic (often easy to get on internet)
- A 60 to 70V winding from the transformer (that is a standard filament tap) for the -50V regulated supply for the OpAmp
- A 160V to 180V winding for the 0 to 200V regulated screen supply
- An 8V to 11V winding for the +5V regulated supply.
- My little 2” x 2.8” gold plated PC Board for $15.00. 85 sold so far. Will I make 100?
- The parts listed in the parts list at the back of my paper. The total cost for all parts is about $75 ($60 if you already have a PC Board).

What this **CAN'T DO** that a 570 can

- Pentode Screen Current vs. Plate Voltage. None of the Semiconductor Curve Tracers can display these curves.
- Pentode Screen Current vs. Grid Voltage. None of the Semiconductor Curve Tracers can display these curves.
- Plate Current vs. Grid Voltage: Each Semiconductor Curve Tracer has different capabilities for these 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.

What this **CAN DO** that a 570 can't

- The 570 can't match tubes. The ability to match tubes is a very big deal to audiophiles and to many others.
- It is absurdly simple to do pentode matching; triode matching; dual triode matching; rectifier matching, etc.
- All it requires is one or two tube sockets, a plug and a DPDT or 3PDT switch.
- A simple fixture needs to be made for each "tube family" that share the same pinouts.
- 1,500 Plate Voltage (576 and 577) versus 500V (570)

Measuring tube parameters: g_m, μ, $r_{p.}$

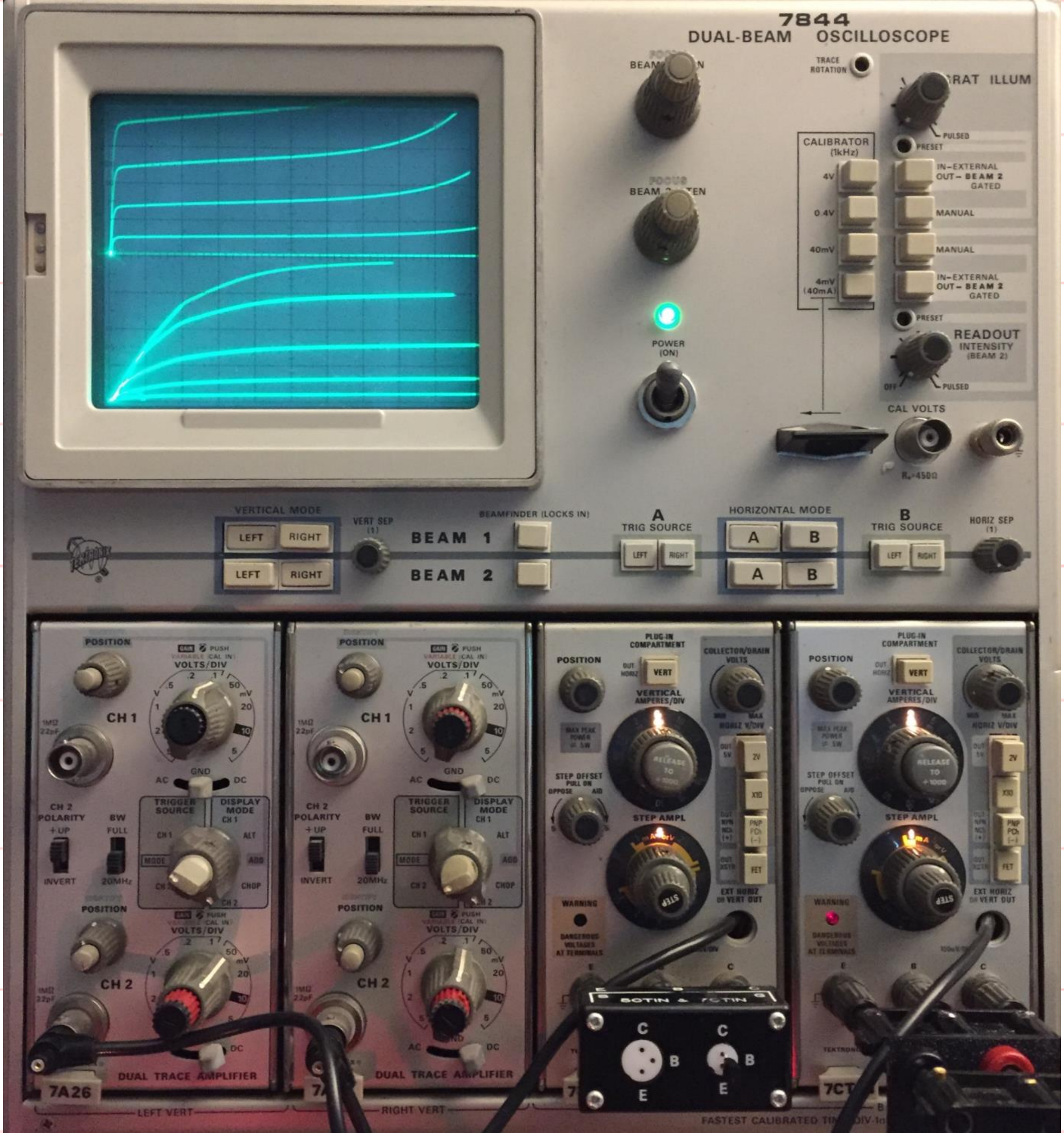
$\left(\frac{\partial v_p}{\partial v_G}\right)_{i_P} \equiv \mu$	**Amplification Factor:** The ratio of change in plate voltage to the change in grid voltage for a constant plate current.
$\left(\frac{\partial v_p}{\partial i_p}\right)_{v_G} \equiv r_p$	**Plate Resistance**: The quantity which expresses the ratio of an increment of plate potential to the corresponding increment of plate current when the grid potential is kept constant.
$\left(\frac{\partial i_p}{\partial v_G}\right)_{v_P} \equiv g_m$	**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.

Adapter placement

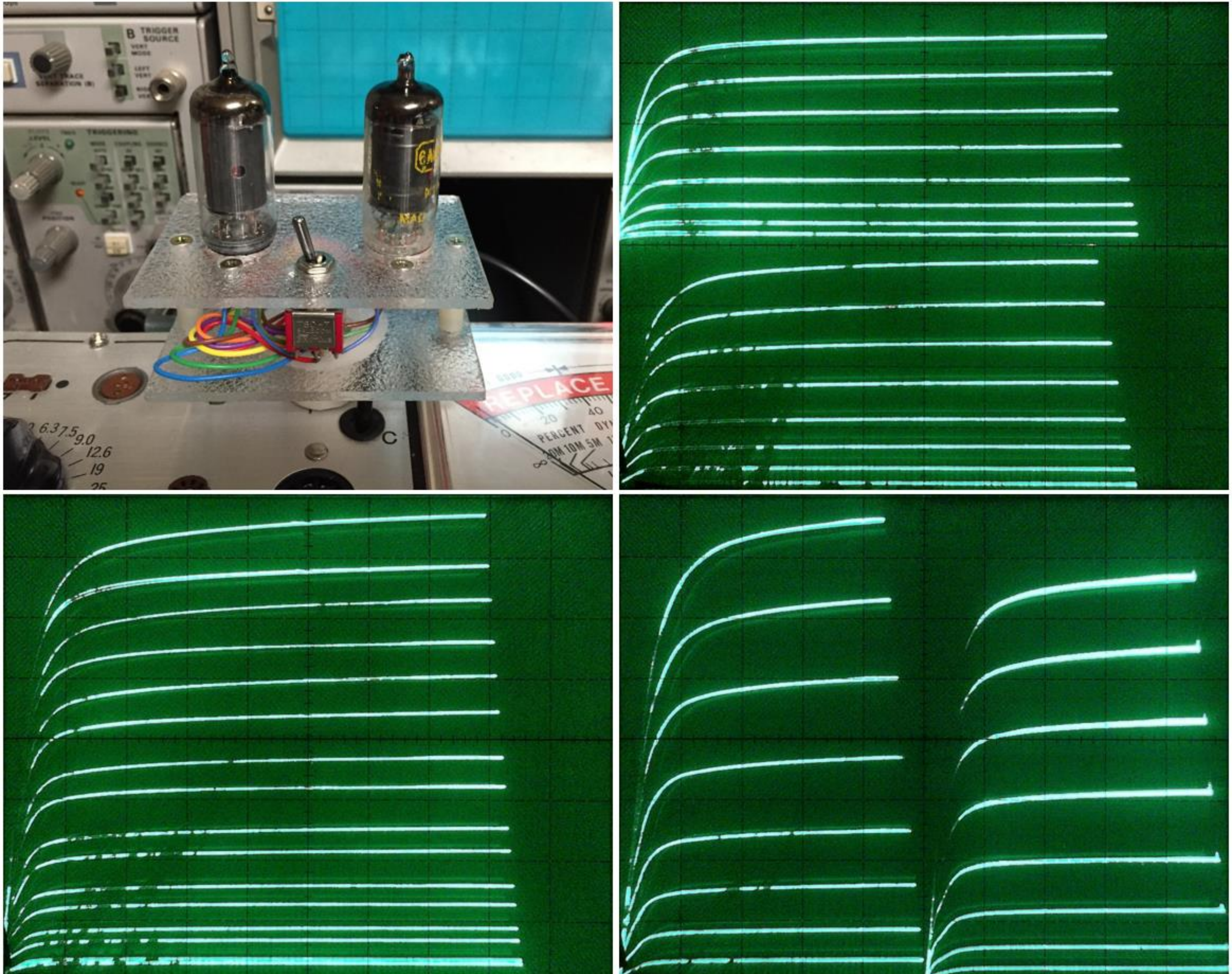
- Inside if there is sufficient room and there is space on the front panel for a DPM, 2 knobs, and a switch.
- Outside in a box
- MetalPhoto and AlumaJet for the nameplate
- Mounting holes on the PC Board.
- After the talk we can look inside the tube tester

Pictures

- Picture #1: PN2222 Bipolar NPN transistor and a 6AU6A Sharp Cutoff Pentode simultaneously sharing the CRT of a 7844 (back cover of my paper).
- Picture #2: Pentode matching on a 577 Storage curve tracer
- Picture #3: Pentode characteristics and measuring g_m, μ, and r_p
- Picture #4: Triode characteristics and measuring g_m, μ, and r_p
- Picture #5: 12B4A Triode curves displayed on four different curve tracers to show the curves are the same
- Picture #6: I_a vs. V_g transfer characteristics of a pentode and a triode using 100 grid voltage steps



7844
DUAL-BEAM OSCILLOSCOPE
TRACE ROTATION
GRAT ILLUM
PULSED
PRESET
CALIBRATOR (1kHz)
4V
0.4V
40mV
4mV (40mA)
IN-EXTERNAL
OUT- BEAM 2 GATED
MANUAL
MANUAL
IN-EXTERNAL
OUT- BEAM 2 GATED
PRESET
READOUT
INTENSITY (BEAM 2)
OFF
PULSED
POWER (ON)
CAL VOLTS
VERTICAL MODE
LEFT
RIGHT
LEFT
RIGHT
VERT SEP
BEAMFINDER (LOCKS IN)
BEAM 1
BEAM 2
A
TRIG SOURCE
LEFT
RIGHT
HORIZONTAL MODE
A
B
A
B
B
TRIG SOURCE
LEFT
RIGHT
HORIZ SEP
POSITION
VOLTS/DIV
CH 1
GND
AC
DC
CH 2 POLARITY
+UP
INVERT
BW
FULL
20MHz
TRIGGER SOURCE
DISPLAY MODE
ALT
ADD
CHOP
MODE
CH 2
DUAL TRACE AMPLIFIER
7A26
LEFT VERT
RIGHT VERT
PLUG-IN COMPARTMENT
VERT
COLLECTOR/DRAIN VOLTS
VERTICAL AMPERES/DIV
HORIZ V/DIV
STEP OFFSET
STEP AMPL
STEP
WARNING
DANGEROUS VOLTAGES AT TERMINALS
EXT HORIZ OR VERT OUT
E
B
C
C
B
E
C
B
E
FASTEST CALIBRATED TIME/DIV



Clockwise from top left: Prototype Tube Matching Adapter on an EICO 667 Tube Tester; 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 and 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.

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.

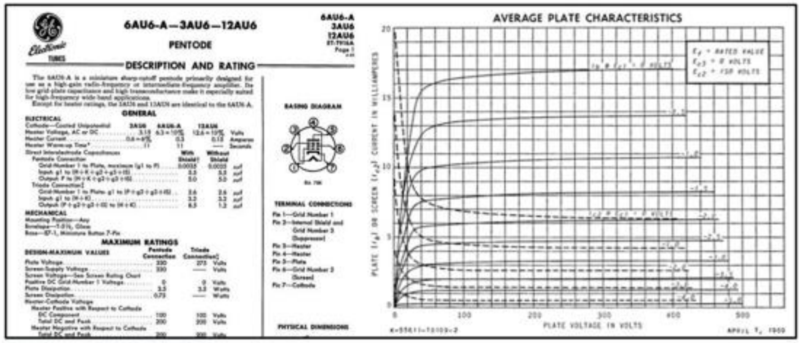
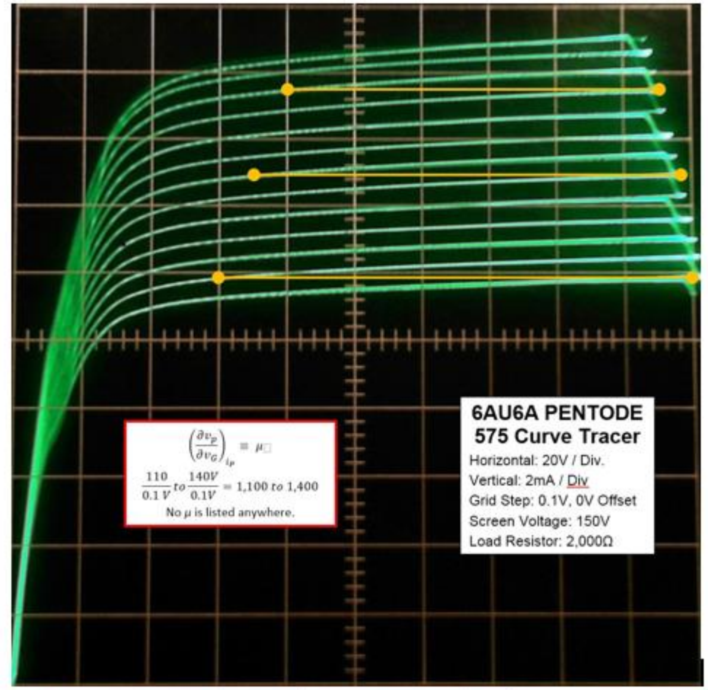
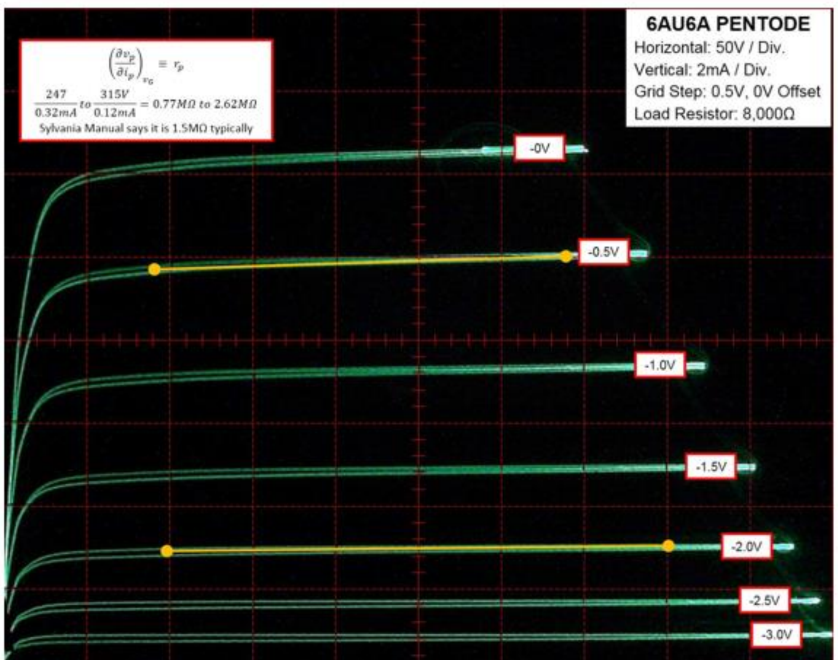
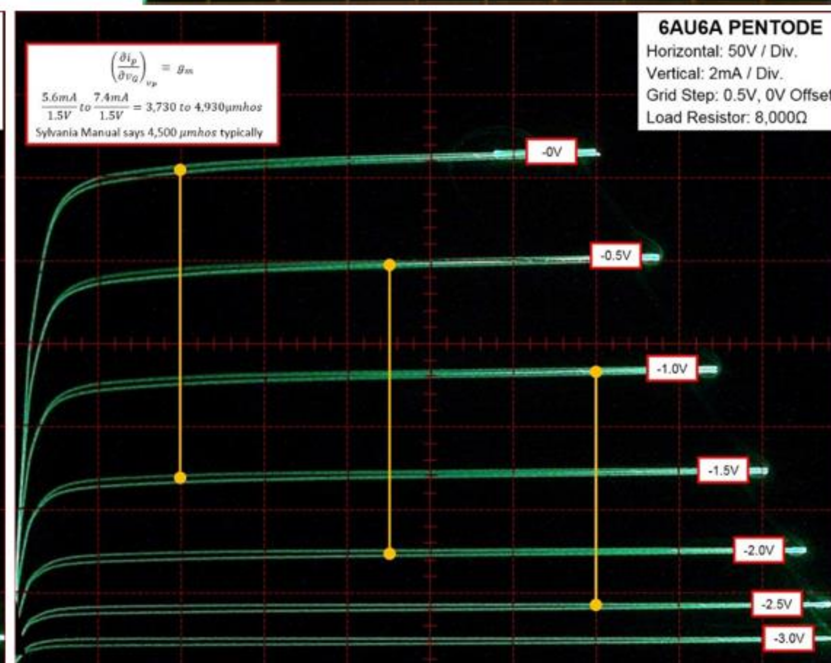


Figure 30 6AU6A Pentode tube data

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.







These are the first measurements made with the Vacuum Tube Curve Tracer 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.

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.

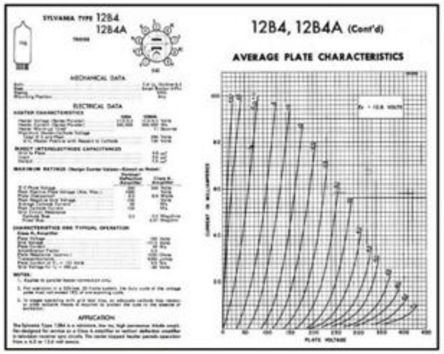
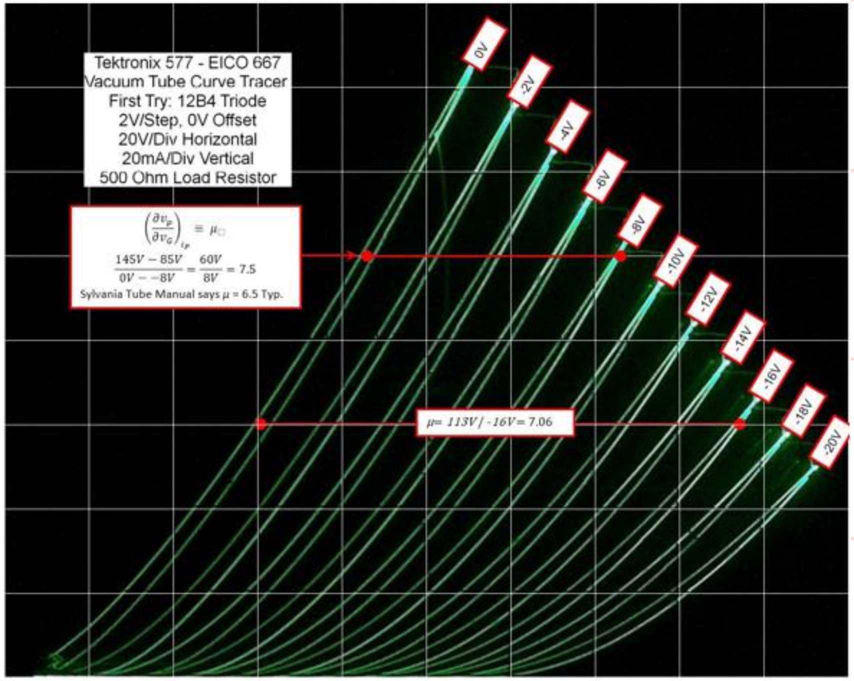
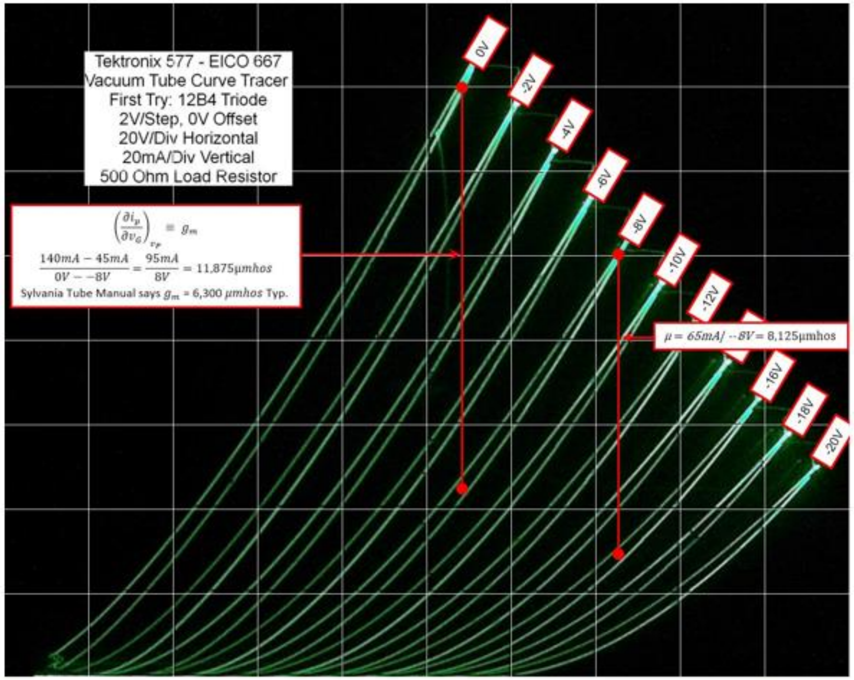
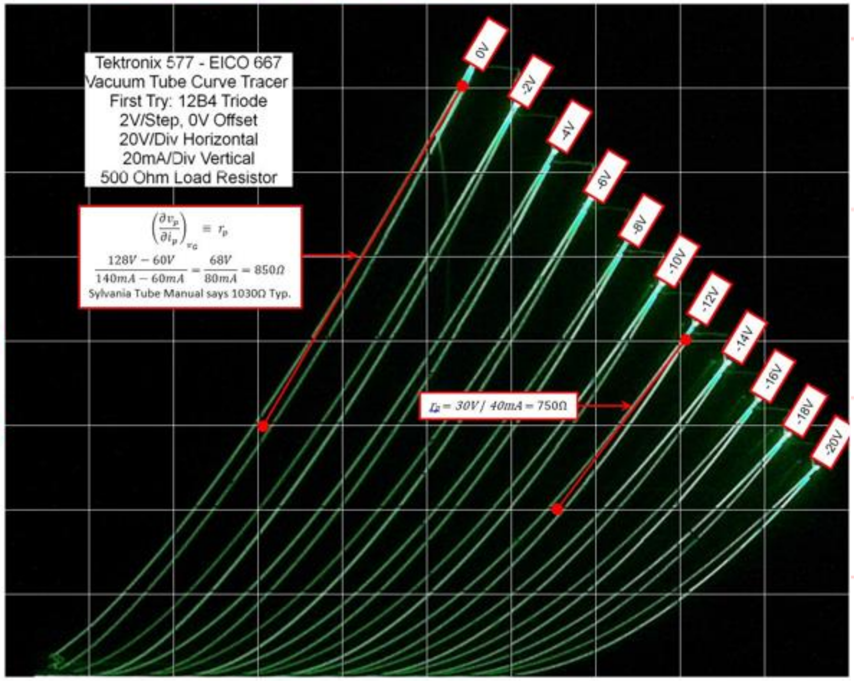


Figure 29 12B4 Triode tube data

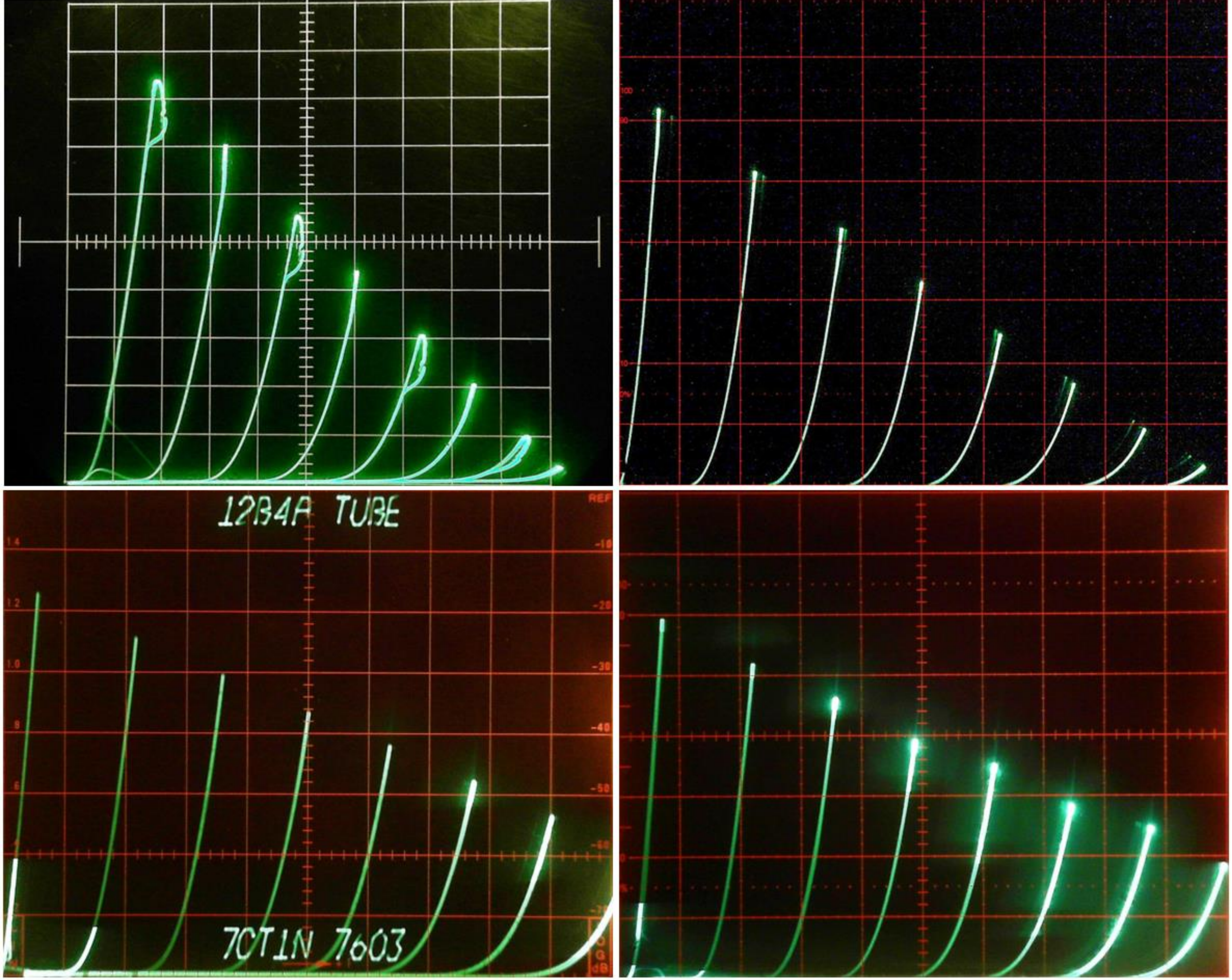
[15] *Sylvania Technical Manual*, Sylvania Electric Products Inc., Sylvania Electronic Products, New York, NY 1959



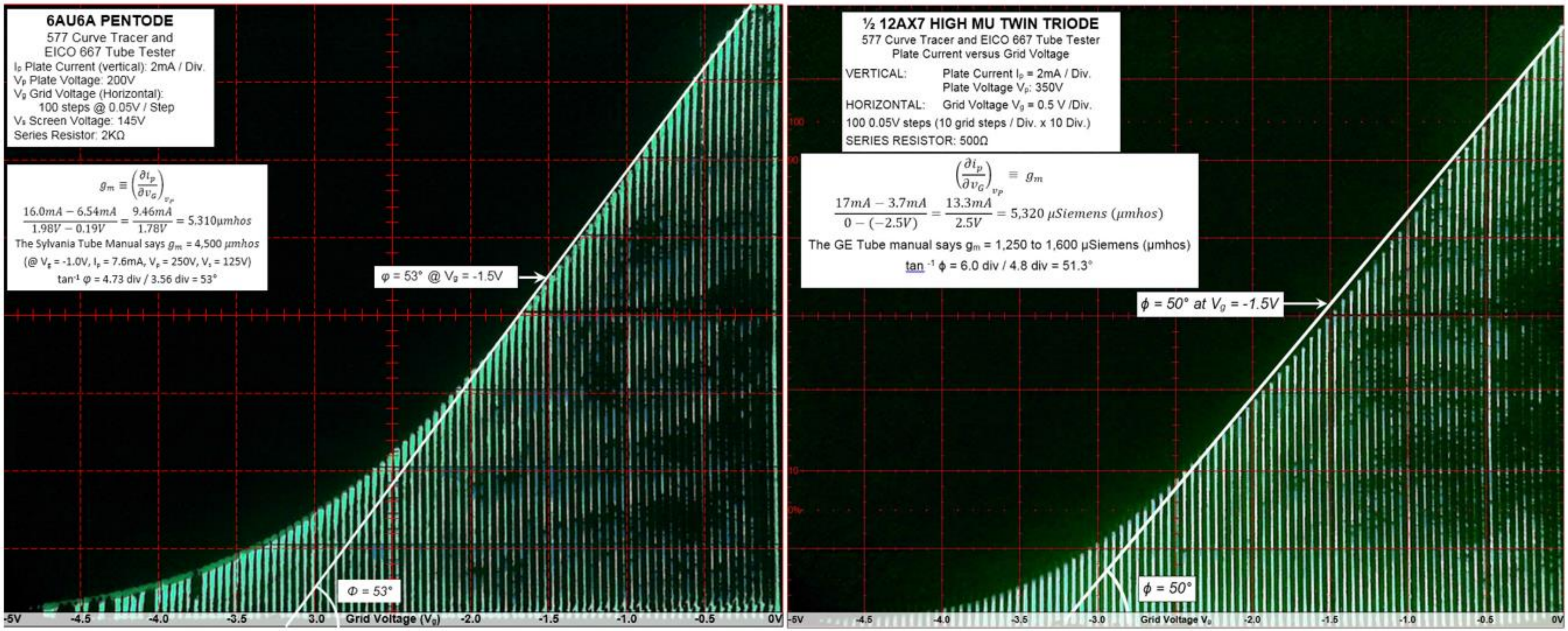




First measurements made with the VTCT adapter prototype of a triode. This confirmed the ability of the adapter to make accurate measurements of the triode's parameters from the characteristic curves. Loops in the curves are from Miller Effect capacitance. Shielding the base lead fixed it.



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: the Horizontal is set to 20V / Div., the Vertical is set to 1mA / Div., and the Grid Steps are -5V each.



This is the I_g / 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 valve 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 them. The capability of the 577-D1 to store the slow sweeping trace makes it much more convenient to display the curves than a 575, 576, or 577-D2 which do not have storage. A 5CT1N or a 7CT1N placed in a 7000 series storage mainframe would be able to conveniently display these curves as well.

Demonstrations (time permitting)

- Triode
- Pentode
- Triode matching
- Pentode matching
- View inside the tube tester

Questions?