The Phantastron

Originated during World War II, a clever implementation of vacuum tube art.

TERAC presentation by

Philip Crosby W7PYX

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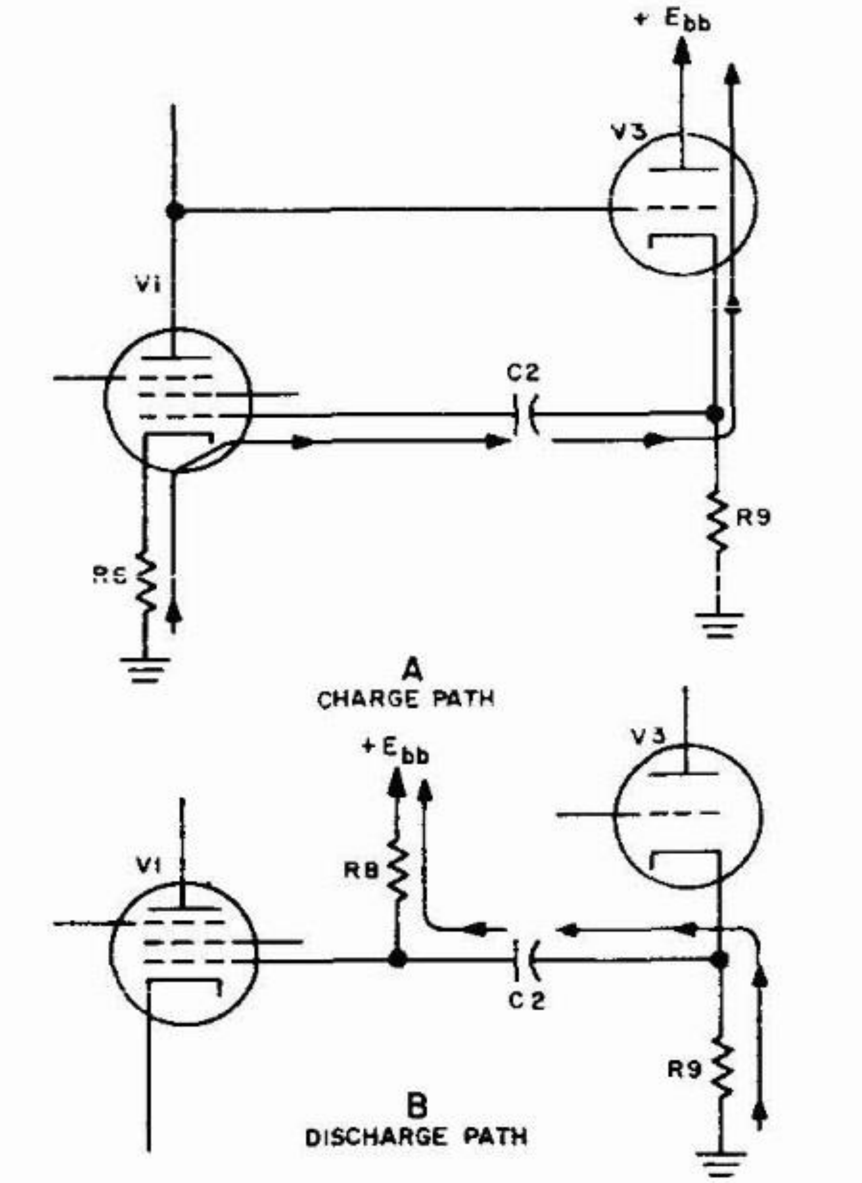
Terminology used

- The Navy, in their WW2 training manuals spoke of electron (rather than conventional current) flow because it was difficult to convince a farm kid who grew up fixing tractors that an element of current could flow from a spot on a CRT screen, navigate its way through a forest of potential lines, apertures, electric and magnetic fields to end up going through that one tiny hole in the grid cup and arrive precisely at the cathode.

  I will attempt to adopt that way of describing current.

- I wonder if the Navy still uses that convention. Anybody know?
- In any event, it is interesting to peruse the website at https://www.navy-radio.com/manuals/eimb_102/900000_102_20.pdf .
- Another excellent reference is at https://www.radartutorial.eu/17.bauteile/bt52.en.html

The way the Navy did it



Charge and discharge Paths for Capacitor C2

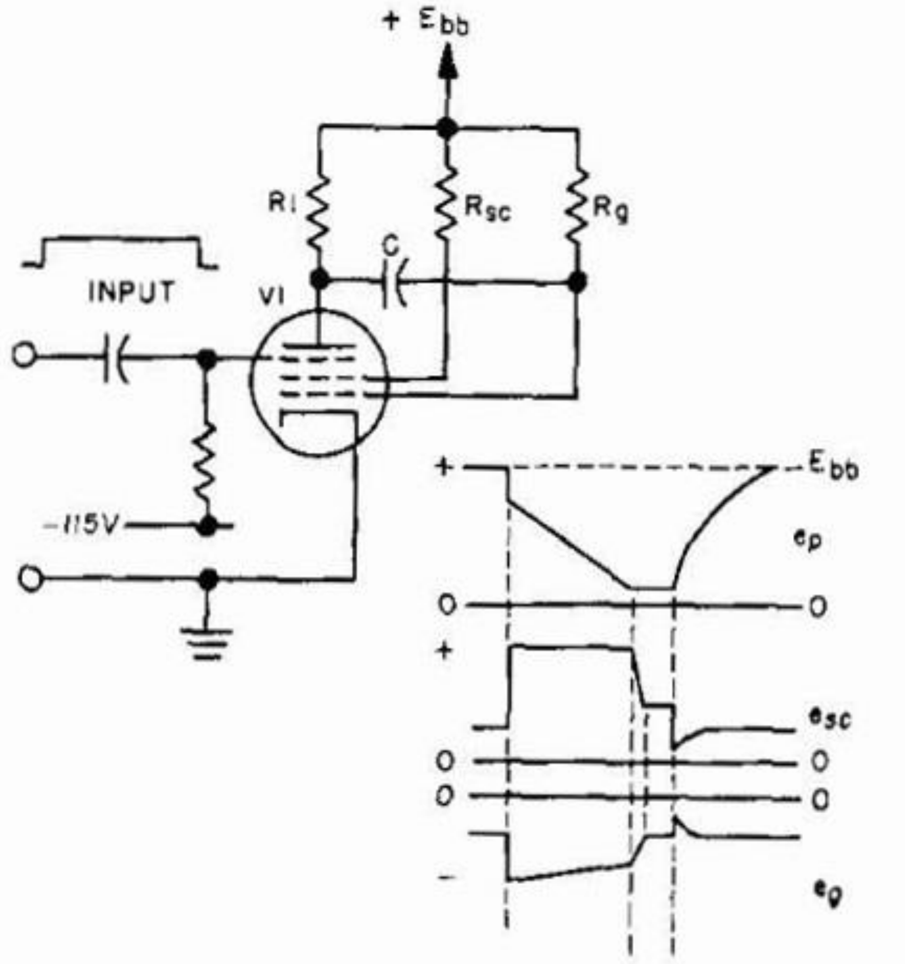
In this excerpt from the Navy training manual depicting a run-down Miller* sweep, the arrows indicate the direction of electron flow. The top schematic indicates how the capacitor is charged, the bottom schematic indicated how the timing resistor drains the charge out of the capacitor.

* see: https://en.wikipedia.org/wiki/Miller_effect

In all fairness, Benjamin Franklin didn’t know about the electron since it was discovered by J.J. Thompson 107 years after Ben’s death in 1790, but Ben would probably been happy to have revised his convention.

However, with some EE profs I’ve known, I’m not so sure.

Navy Description of a Miller Sweep Generator



Miller Linear Sweep Generator

CIRCUIT ANALYSIS.

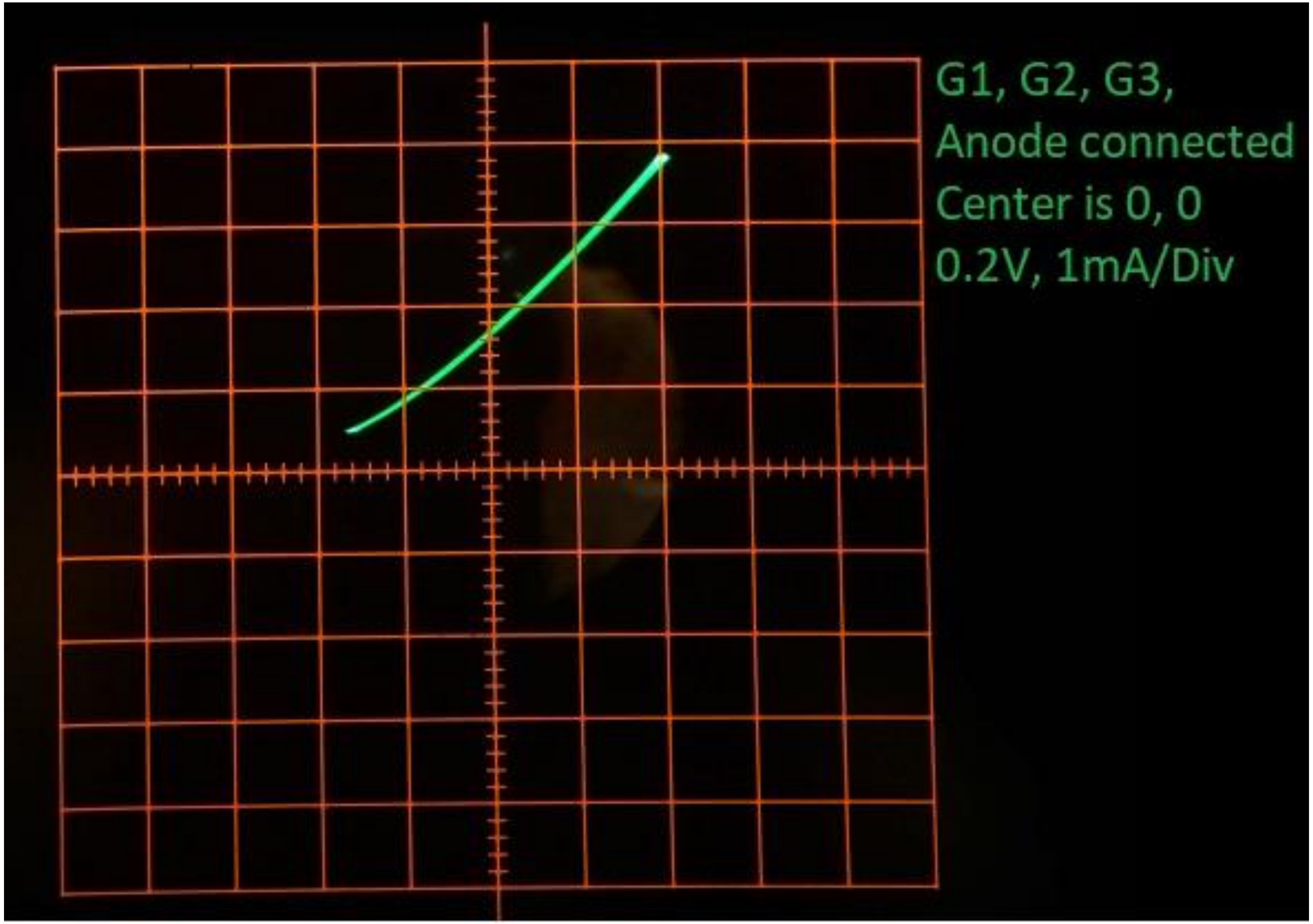
General. The operation of the phantastron circuit is based on the use of a Miller-type linear sweep generator which uses a suppressor-gated pentode. In the Miller linear sweep generator, the suppressor grid is normally biased (negative) to prevent plate current flow, while the screen conducts heavily. The grid is returned to B+ through a resistor so that it is effectively at zero potential, and the cathode is grounded. When a positive gate is applied to the suppressor, plate current flows and produces a voltage drop across the plate load resistor. This negative-swinging plate voltage is fed back through a small capacitor to the grid, and quickly drives the grid negative; thus, it maintains the plate current at a small value, and also greatly reduces the screen current. Reduction of the heavy screen current produces a large positive swing on the screen, and the tube essentially remains in this condition, producing a positive screen gate. Meanwhile the plate current flows under control of the feedback voltage applied to the grid until no further feedback is produced. During this time the plate-current increase is linear, and the plate voltage continues to drop. (The normal discharge of C through R_g would cause the current through the tube to increase in an exponential manner, thereby causing the plate voltage to drop exponentially. However, any exponential change is fed back to the grid 180 degrees out of phase with the normal discharge of C, thereby causing a linear increase in plate current.) At a point about 2 volts above ground, however, no further plate swing is possible, and the screen again conducts heavily, returning almost to the initial operating point. When the suppressor gate ends, the plate current is cut off, the screen returns to its initial operating point, and the cycle is ready to be resumed under control of the next gate. The following schematic shows the basic Miller circuit. Observe that the screen is not coupled, that a separate bias source is used for the suppressor, and that an external sweep gate is necessary. These are the main ways in which it differs from the phantastron.

This excerpt shows how circuits are described in the Navy manuals. It also depicts a Miller sweep generator using an external gating pulse. This is how oscilloscope sweep generators worked in the old days. A monostable pulse generator (one shot) would determine the duration of the sweep signal and an appropriate ramp rate would have to be selected in response. Two things to deal with. Messy.

The Phantastron - invented by Alan Blumlein

- **Alan Dower Blumlein** (29 June 1903 – 7 June 1942) was an English electronics engineer, notable for his many inventions in telecommunications, sound recording, stereophonic sound, the ultra-linear amplifier, television, and radar. He received 128 patents and was considered one of the most significant engineers and inventors of his time. (Blumlein Street in the Tek Industrial Park is named after him).
- Tragically, he died during World War II at age 38 on 7 June 1942 during the secret trial of an H2S airborne radar system then under development, when all on board the Halifax bomber in which he was flying were killed when it crashed in Wales due to an improperly tightened rocker arm locknut.
- https://en.wikipedia.org/wiki/Alan_Blumlein

6AS6 As a diode



The following photos are the work of a Tek 570 curve tracer (more on that later). Unfortunately, the camera position and alignment were a bit difficult to maintain, but I think you get the idea.

The 570 was mostly the brainchild of John Kobbe, a very bright early Tek employee.

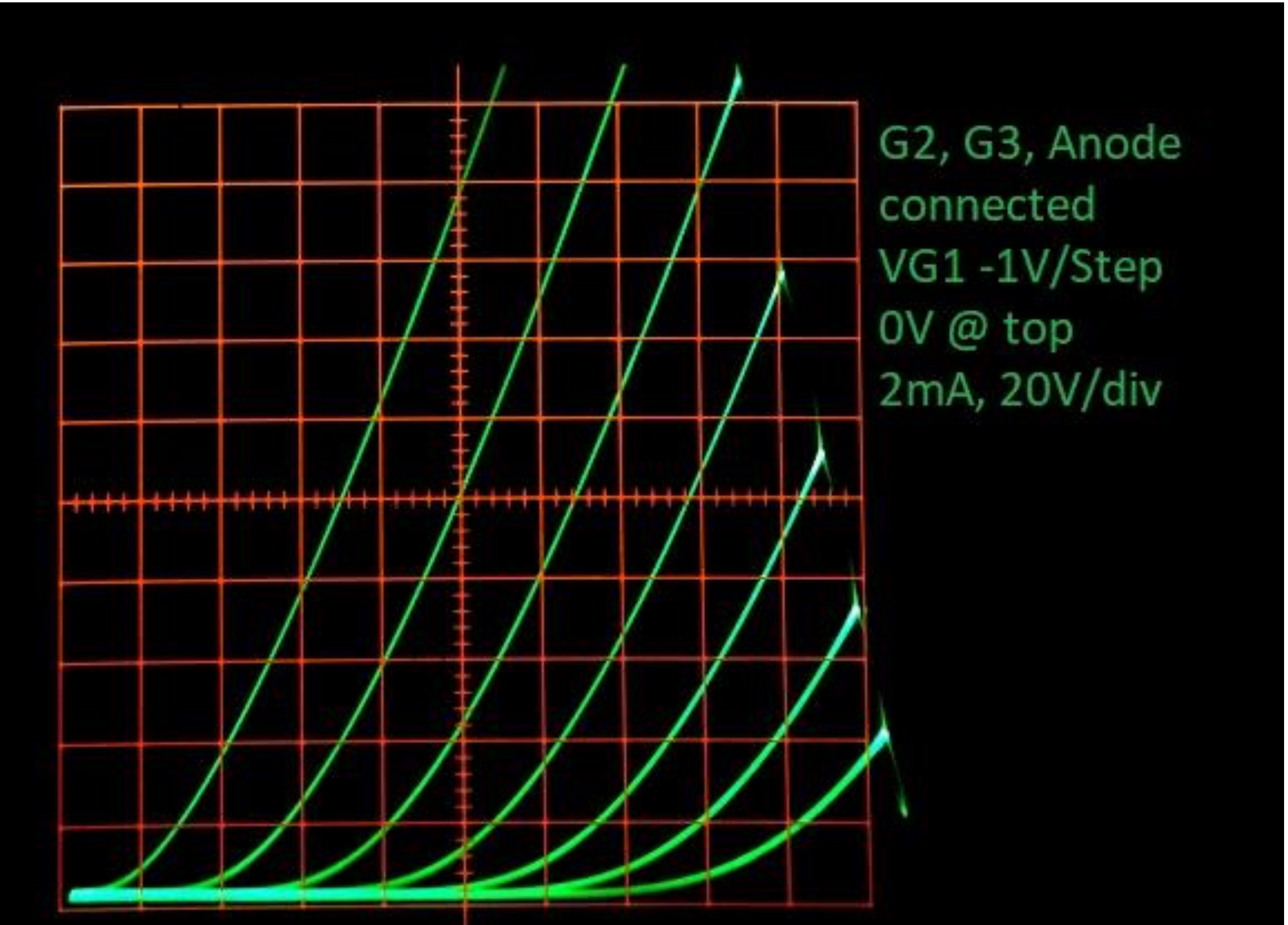
Not a lot to say here, except that thermionically emitted electrons have energy.

That could conceivably be used with radioactive heat sources for deep-space power. Thermoelectric sources are more efficient, but they need a radiator.

As an aside, Bruce Baur recently discovered that microampish levels of current flow between heater and cathode showing characteristics of a temperature-limited diode.

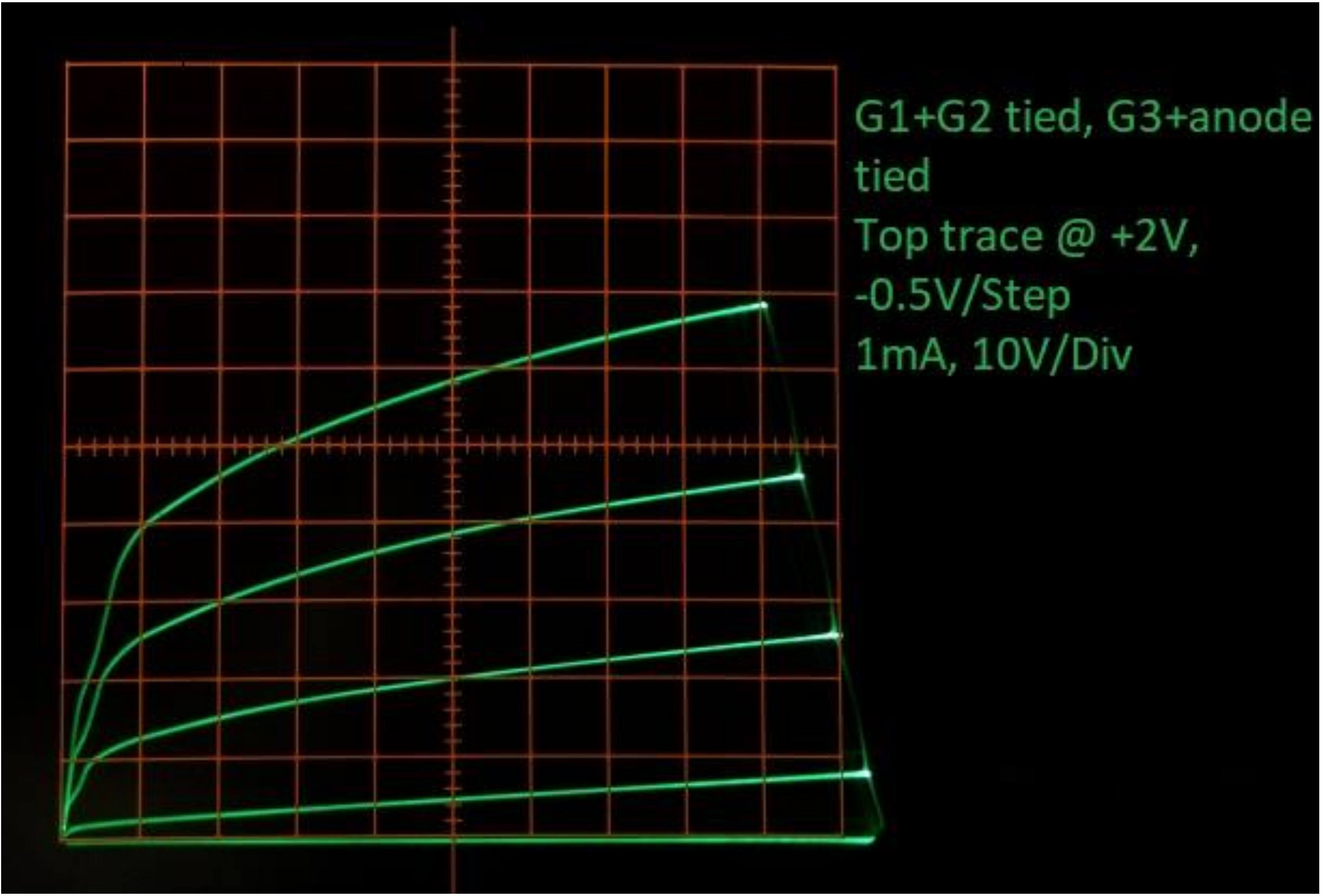
Vacuum tubes still have the power to surprise.

6AS6 as a triode



When all of the electrons passing through G1 are collected, the 6AS6 doesn't look too bad. It shows a mu of about 30 and four to six thousand micromhos, however, one should be careful not to overheat elements that are used in an unexpected manner.
I may have done that because one 6AS6 didn't recover.

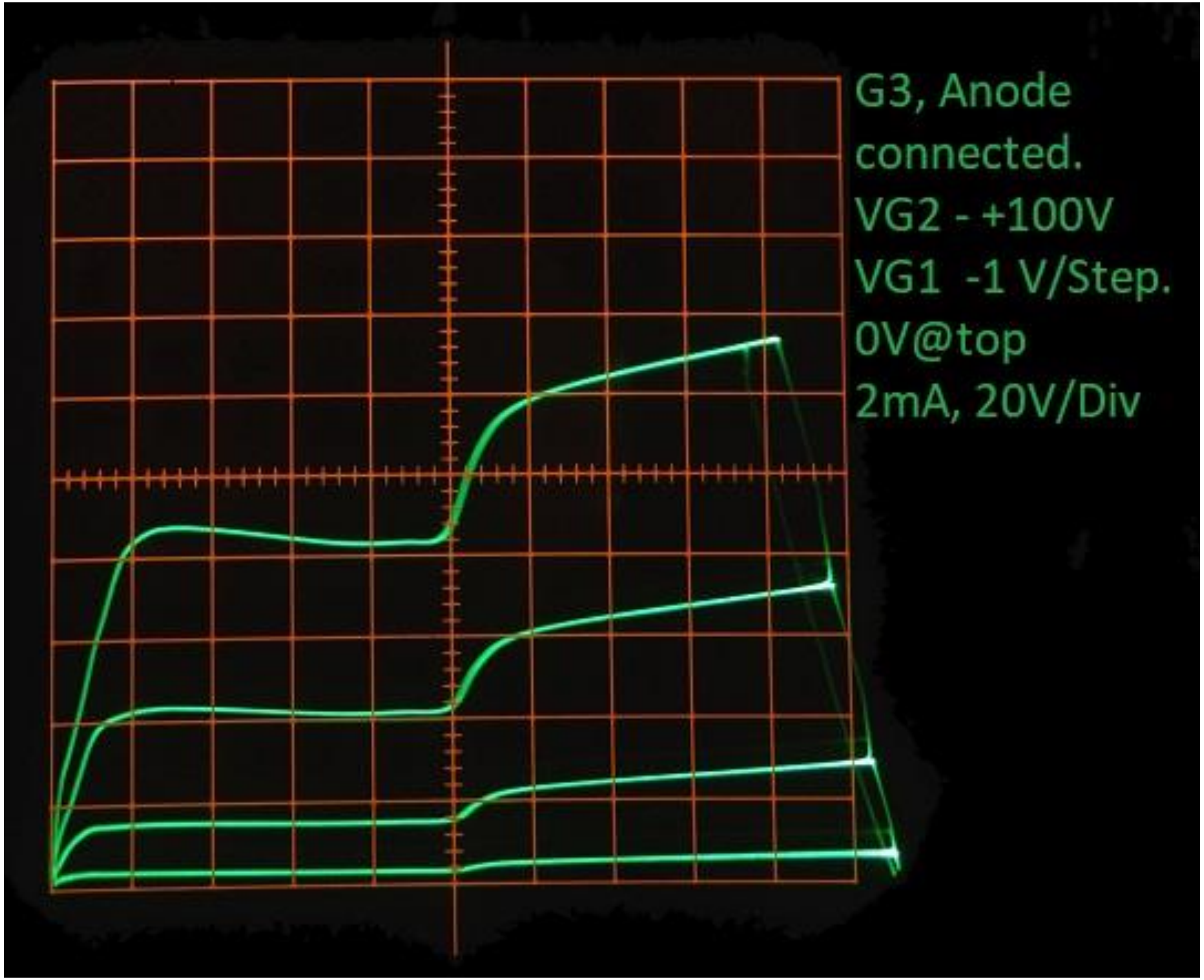
A different kind of triode



Here G1 and G2 are tied together, with G3 tied to the anode. I'm including this because this is how I visualized transistors after becoming aware of them.

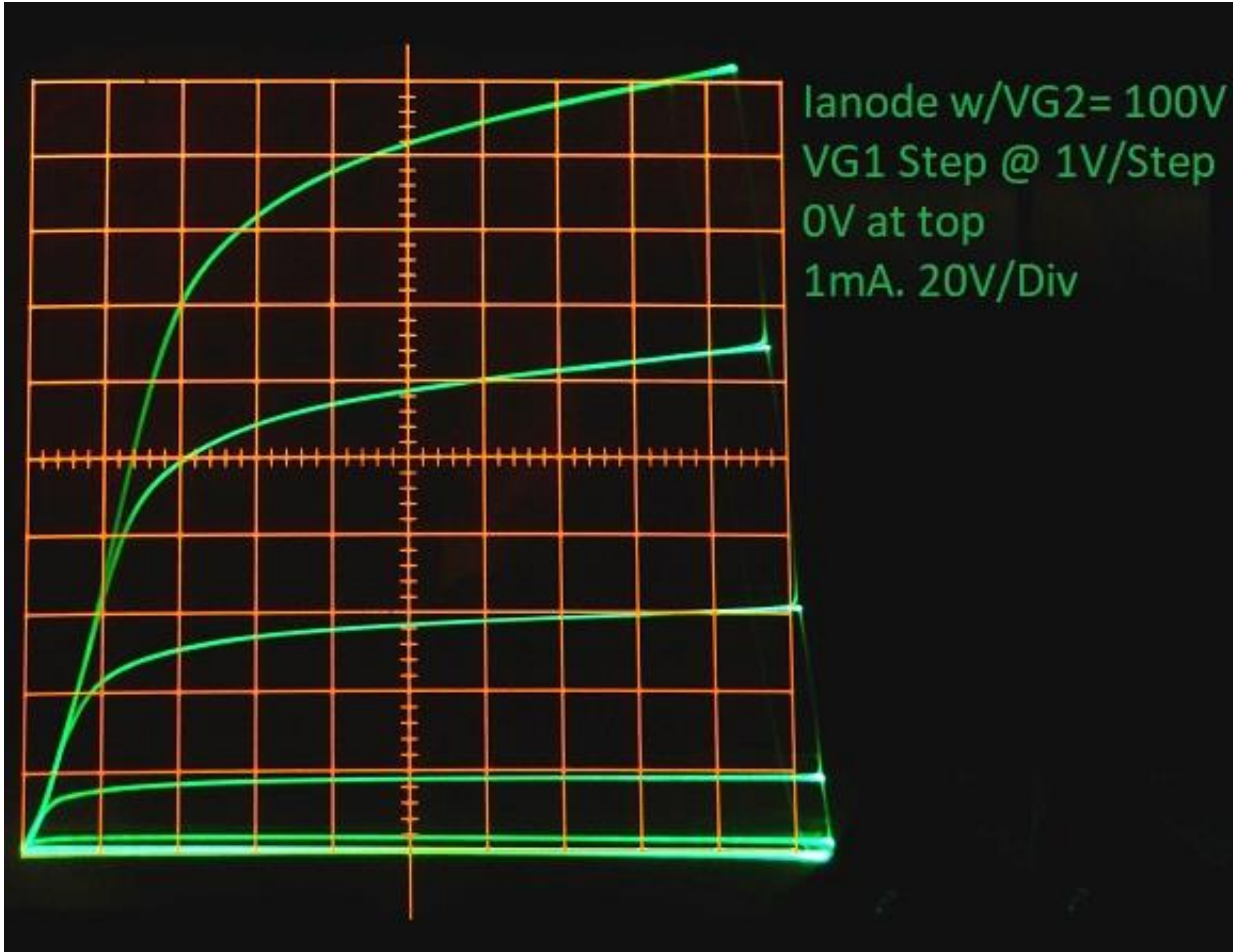
Having concentric control elements somewhat isolates the stuff going on around the emitting surface from anode potential variations, providing potentially higher voltage gain. Note the resemblance to an NPN transistor. This feature was in the output triode of the 6B5 vacuum tube integrated circuit. Although it is called a dual triode, the input triode has a cathode resistor, the second "triode" has two concentric grids, allowing the input cathode follower to be biased at zero volts with no negative supply. The B+ went to the anode of the input C.F. and the second anode drove the output transformer. Sweet!

Why we have a G3. the suppressor.



Sorry for that digression, but I do love cute things.
Of course, we all learned about tetrodes long ago, but it's nice to see it this way.
A lot of the electrons making it through G1 race merrily to the anode but when the anode voltage is less than the G2 voltage, many electrons choose to go to G2.
RCA had the idea of the beam tetrode, where the G2 wires were in the shadow of the G1 wires (or maybe they stole the idea, I don't know), but a lot of tubes were built with a third grid to control the hinky things that could happen when the anode voltage got lower that the G2 voltage.

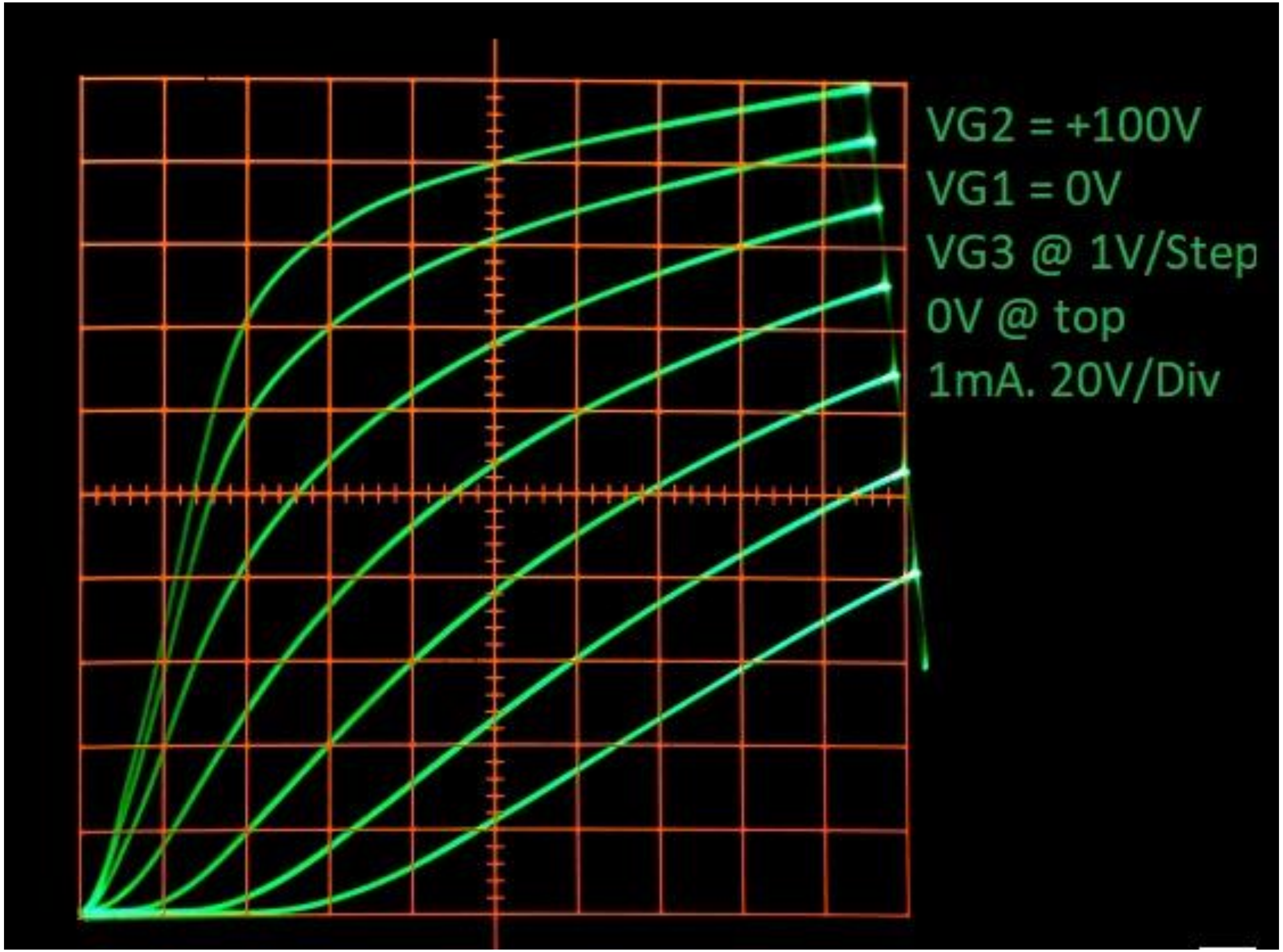
6AS6 Pentode Characteristic



The suppressor grid, G3, is generally used to repel secondary electrons emitted by G2 and to keep G2 from hogging the electrons that made it through G1, but by increasing the G3 pitch, suppressor Gm can increase to accomplish interesting first-quadrant multiplicative behavior.

Cathode current flow is governed primarily by G1 voltage with respect to the cathode. But that current (electrons, remember?) can flow to G1, G2, G3, or the anode, so there are many possibilities.

6AS6 G3 Characteristic

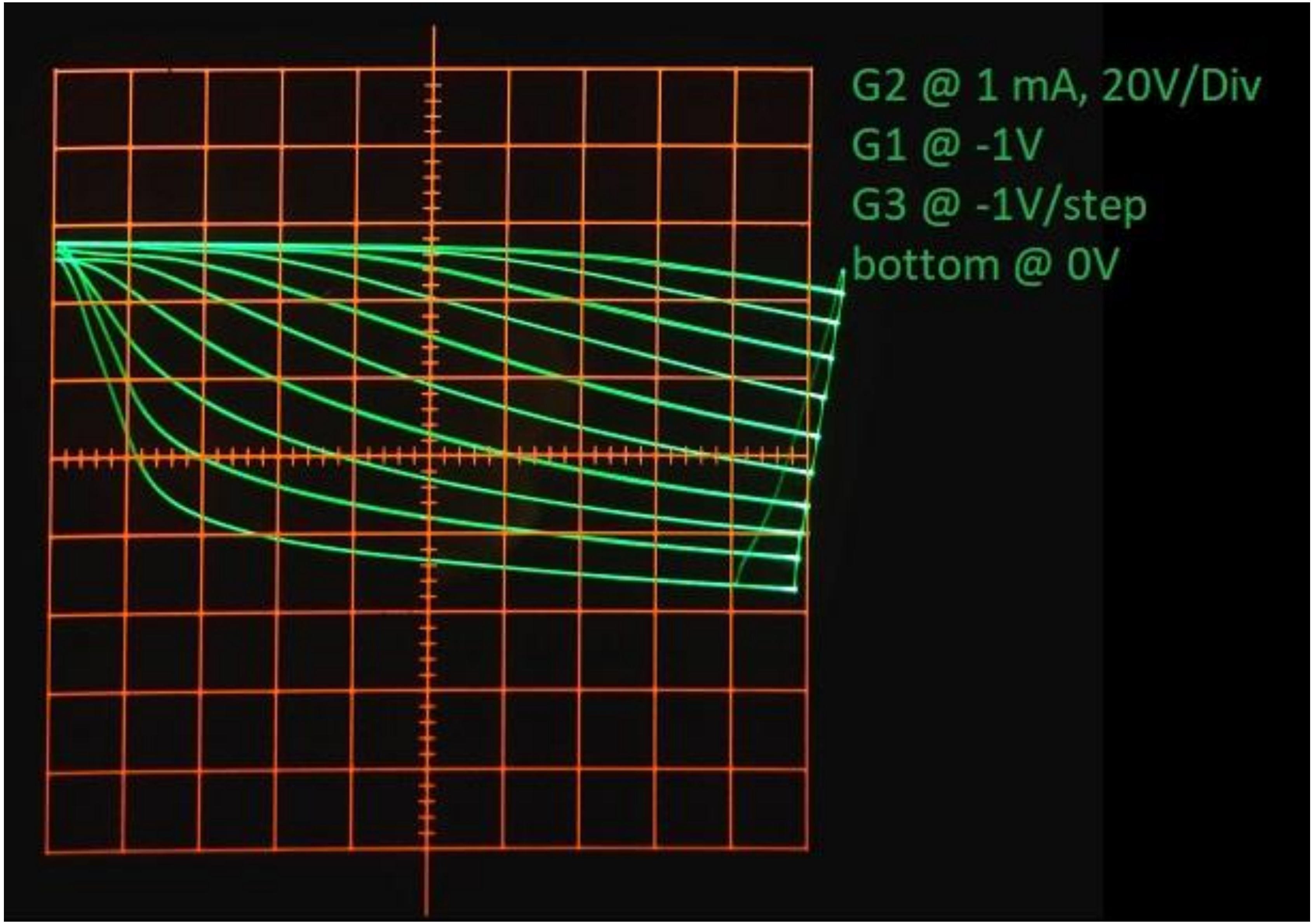


Here we see the 6AS6 with G1 = 0V, G2 = +100V, and G3 stepping from 0V to -7V in 1V steps. This shows us that electrons that are not flowing to the anode must be flowing to G2.

With a resistive load on G2, G2 voltage will **decrease** with decreasing voltage on G3, allowing positive feedback to perform switching behavior.

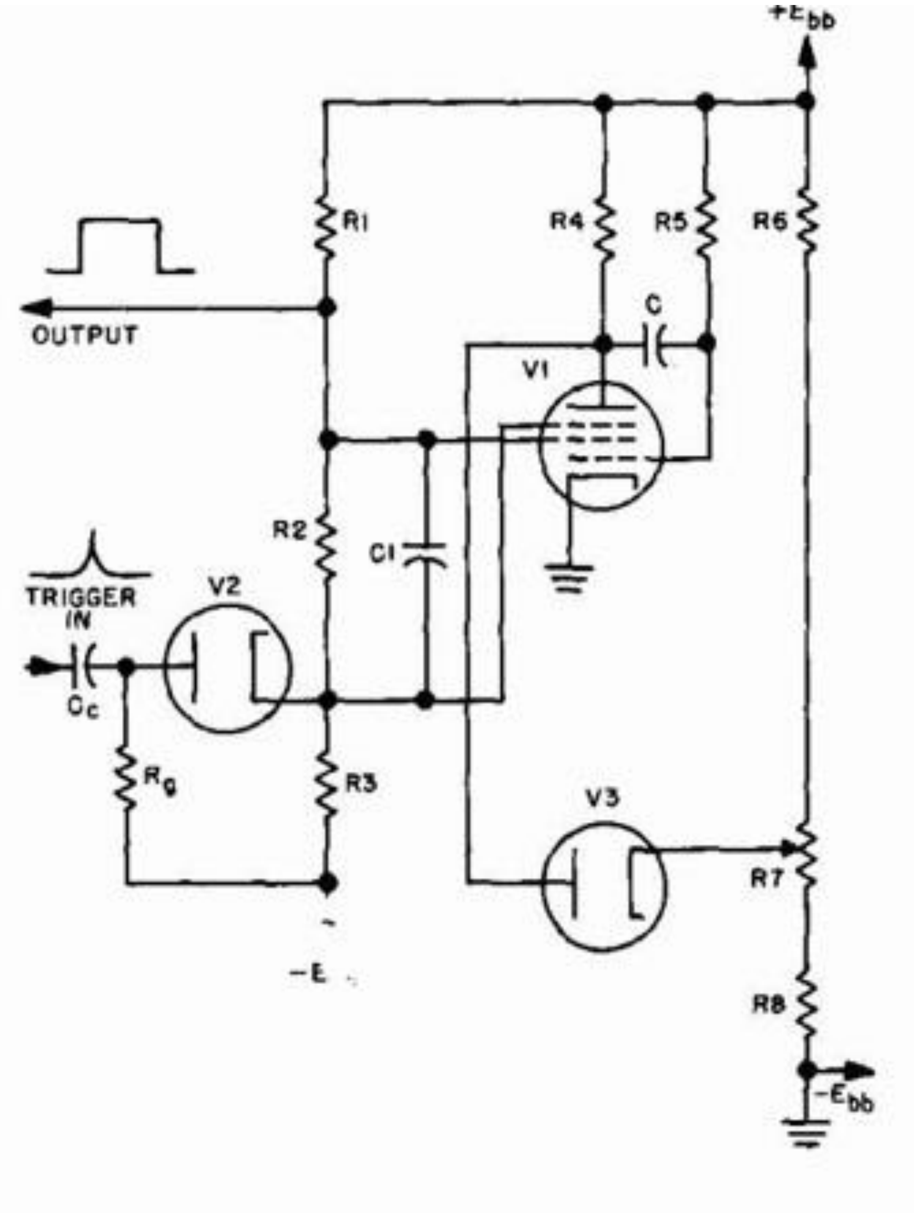
Note that, as G3 gets more negative the anode V-I characteristic looks more like that of a triode. That’s because the electrons in the G2-G3 region have a choice and they can vote with their feet, so to speak.

G2 Current w/G3 stepping



Here we can see how we can get a positive feedback loop going. The bottom trace is the G2 current when G3 = 0V. The G2 current increases as G3 goes negative because G3 repels electrons that would otherwise have been attracted to the anode, so a connection between a resistively loaded G2 and G3 was used to make oscillators. One such design, invented by Cledo Brunetti in 1939 was called the transitron oscillator.
Another oscillator, was the dynatron. It depended on secondary emission behavior which was not well understood (e.g., hinky).

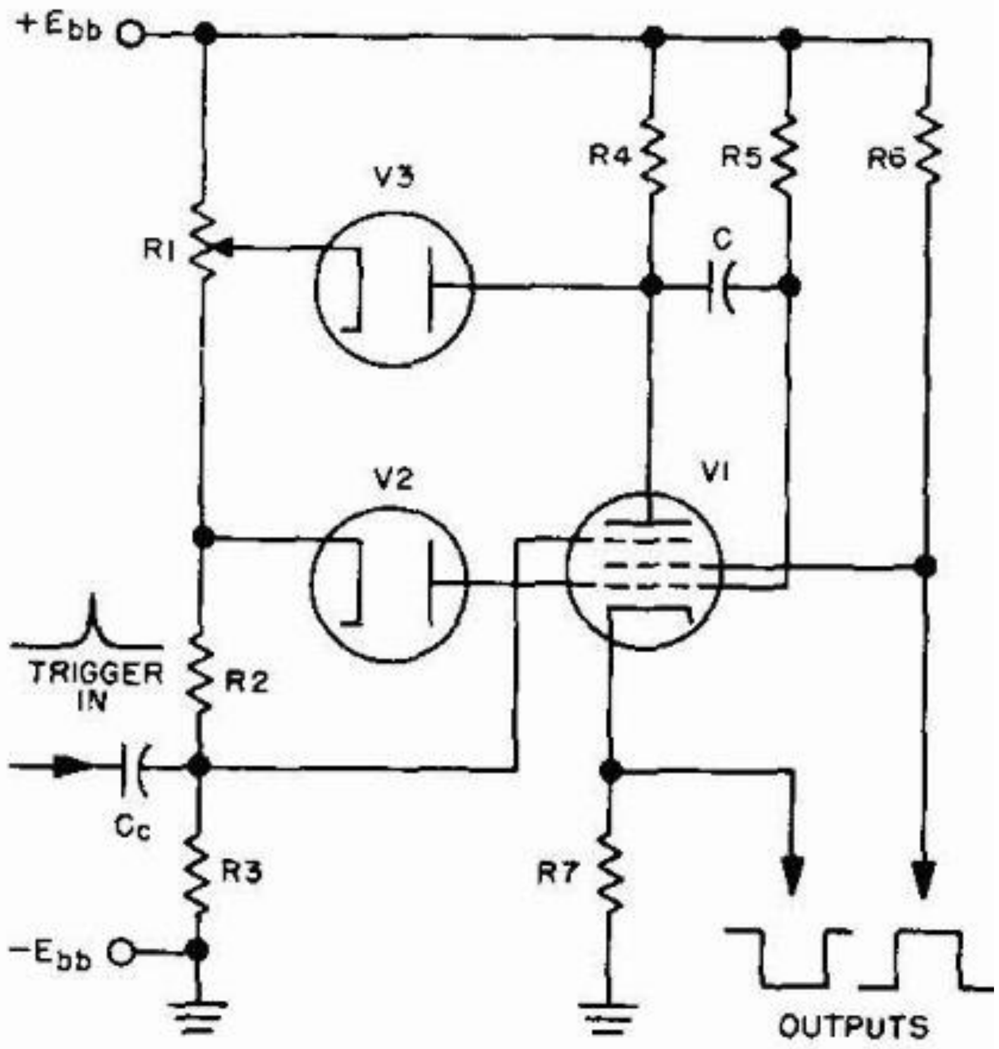
Phantastron as a delay generator (One Shot)



Basic Screen-Coupled Phantastron

Looking at the source of these schematics, we can understand that the generation of relatively precise delays was essential for radar and calibration of instrumentation used for maintaining those systems.
Initial condition is that the control grid of V1 is supplying electrons to timing resistor R5 and nearly all of the electrons that don’t go to G1 go to the screen, pulling it low. With the suppressor pulled below cutoff, no electrons can flow to the anode. This is a stable state.
A trigger pulse sufficient to allow some of the cathode current to pass through G3 to the anode, depresses its voltage and that of G1, reducing the current to G2. As the voltage at G2 and G3 rises more anode current flows, establishing the negative feedback loop that sets the negative-going ramp rate across capacitor C.
Once the ramp has been triggered, the delay interval approximates a linear function of the start voltage. A more robust clamping function could (and probably did in many instances) involve replacing V3 with a cathode-coupled pair having a cathode follower whose grid is driven by the tap of R7 and a diode-connected triode clamping the anode of V1.
Note that this circuit requires a negative voltage supply.

Another interesting phantastron delay circuit



Also from the Navy manual, this is called the cathode-coupled phantastron. I think the name is a bit misleading, but the circuit is quite clever. The phantastron, I think, can be defined as a Miller-type timing circuit whose initial condition has V2 conducting the timing current that flows through R5 with G3 cutting off the anode current, due to the cathode current flowing through R7.

Here, catch diode V3 sets the quiescent anode voltage and catch diode V2 sets the initial grid voltage of V1. A positive pulse applied to G3 sufficient to cause anode current to flow activates the negative feedback loop that produces the timing ramp. The ramp terminates when the anode can no longer attract enough electrons to supply the voltage drop across R4 and R5.

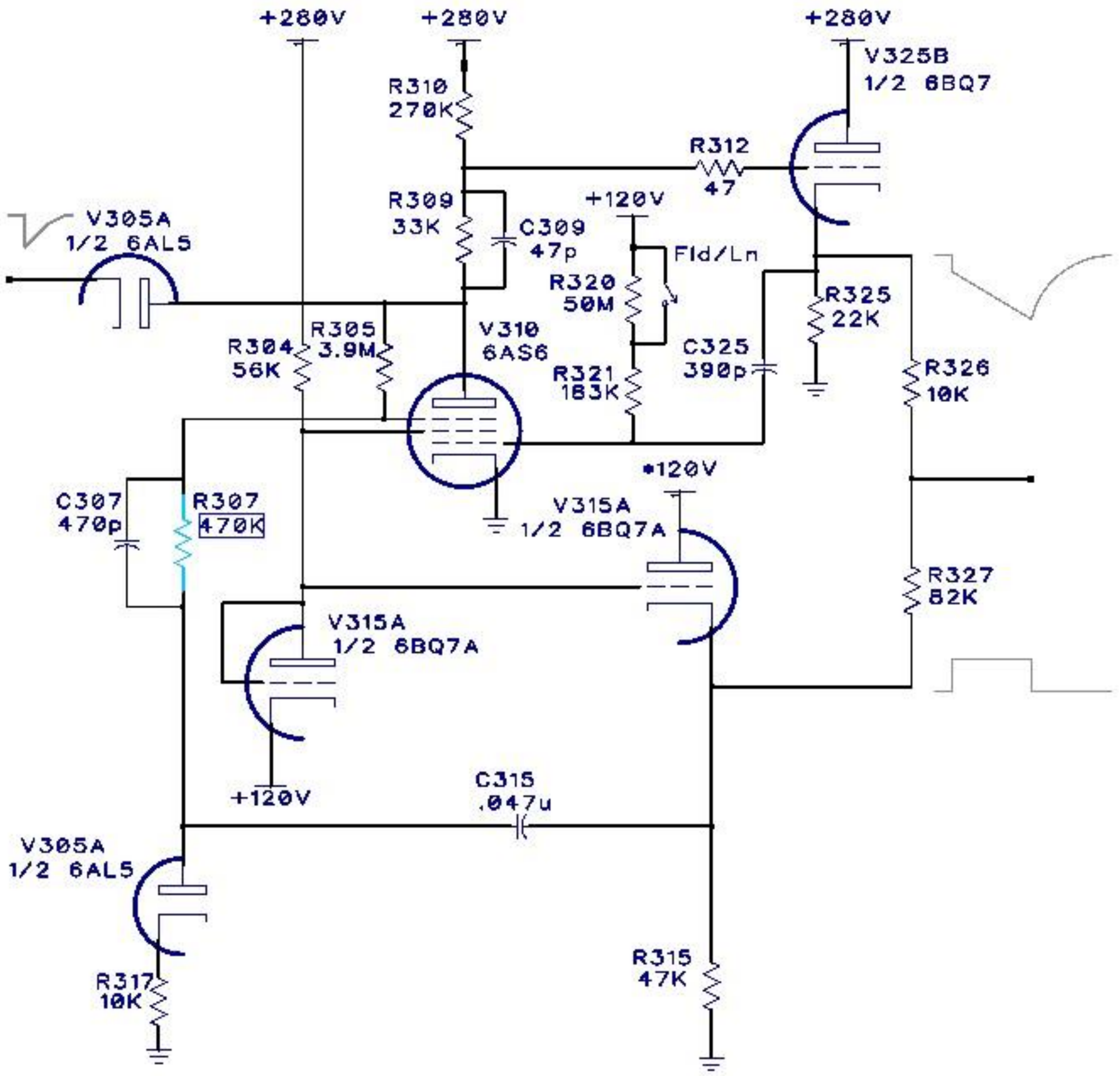
Here, either pulse polarity can be selected and no negative power supply is needed.

In this radar application, the end of the delay interval could be set by intensifying the trace to coincide with the echo and the range could then be read off a scale connected to the knob on potentiometer R1.

What determines the ramp?

- $It = \frac{Vs - Vbias}{Rt}$
- *dV/dT*= - It/C
- Defining *Vi* and *Vf* as the initial and final ramp voltages,
- *T = (Vi – Vf) / (dV/dT)*
  But what is Vf?
  It is the point where enough cathode current shifts from the anode to G2 grid to produce enough positive feedback via the suppressor g_m to override the negative Miller feedback. That can be only a few volts.
- Defining a as the fraction of Vs as the start, a first-order approximation of the delay is $a * RtC$, which is substantially supply voltage independent, depending mostly on R, C and a!

525 Sweep Generator (slightly simplified)



This design was done by Cliff Moulton, who designed the first Tek TV-specific products.

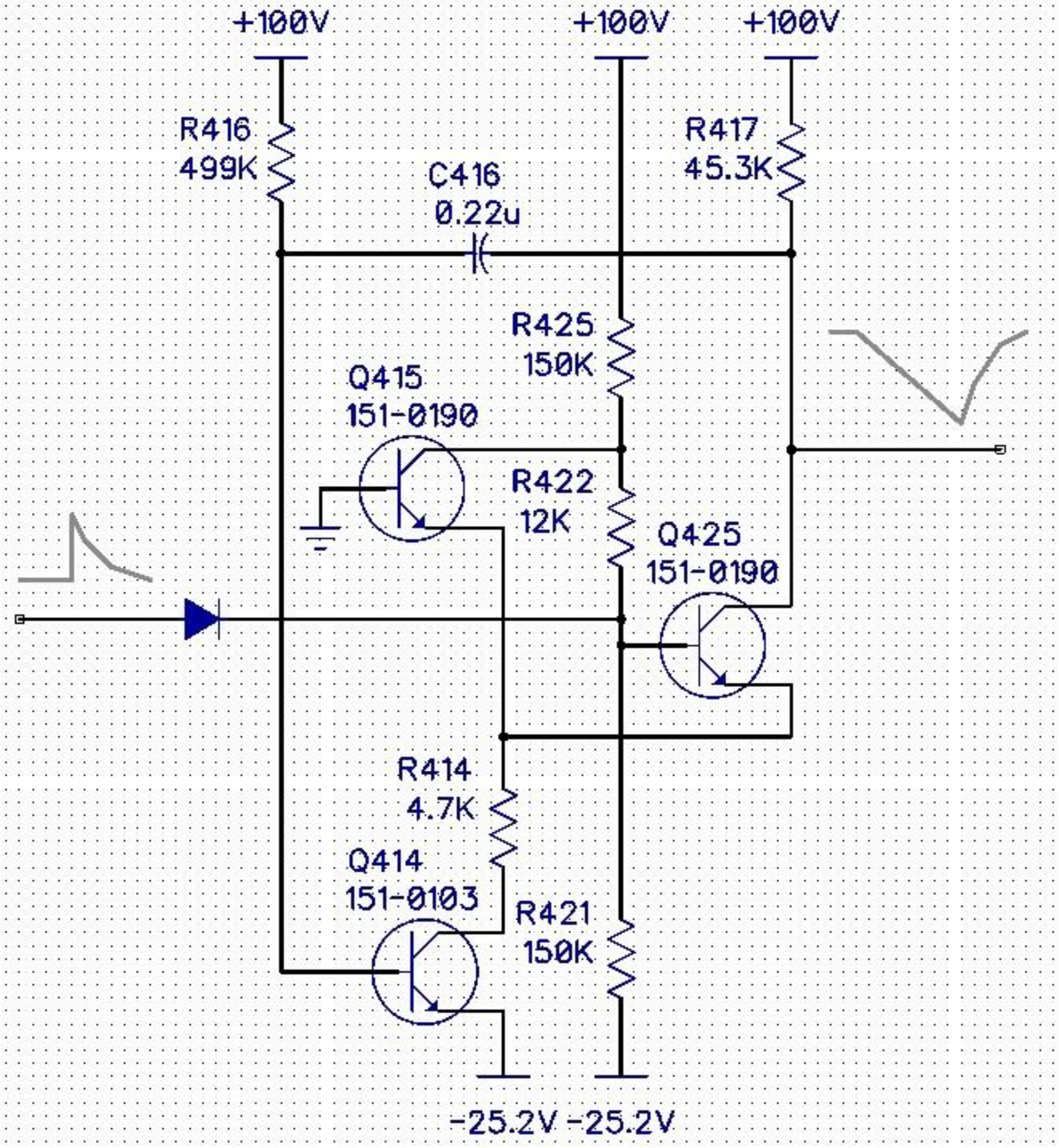
The 525 was Tek's first video waveform monitor, designed specifically for inspection of NTSC monochrome and color video signal quality. Since only a few sweep rates were required, the sweep generator didn't need to be very complex and with a known trigger rep rate, no holdoff circuit was needed.

A negative pulse applied to the anode momentarily cuts off the cathode current, allowing the screen and suppressor voltage to increase, causing anode current to flow, which closes the feedback loop through the 390pF timing capacitor, C325, used for both line and field rate displays.

There are other subtle features, such as the ability to continue providing sweep and unblanking signals in the absence of a trigger signal. This is done by having positive (regenerating) AC feedback, but negative overall DC feedback, which wins in the end.

R317 allows the cathode of V315A to rise quickly because the 525 also needs an unblank pulse.

And then, transistors



In this rather obvious manifestation of the phantastron principle, the function of the cathode and grid of the pentode is replaced by the emitter and base of Q414.
A Schmitt multivibrator-connected pair of transistors, Q415 and Q425 play the roles of G2 and the anode, respectively in controlling the flow of current-limiting resistor R414. As the negative-going ramp approaches its limit, the saturation of Q425 causes enough current to flow through Q415 to give it the gain to be a positive feedback element, taking over the current through R414.
I used this circuit in the 529 waveform monitor to accomplish its line selection feature.
It seemed only appropriate.
Thanks, guys, I'm in your debt.

A thank you to Bill DeVey and the 570

Long time Tek employee Bill DeVey had a love affair with vacuum tubes for many years and willed his near-pristine 570 Characteristic Curve Tracer to the VintageTEK museum.
It has been a genuine pleasure to go back six and even seven decades with this wonderful instrument and all its accessories.
It has also been good to remember the practical-mindedness of designers of that era and the dedication of those who, like Alan Blumlein, made such near-magical contributions to the art of engineering at a time of such peril to our civilization.

A belated thank you also to Warren Collier and Bob Sadilek, who ran the test training class that I attended in 1957 in the basement of the shopping center across Sunset Highway from bldg. 81.
That class gave me valuable insights into the designs of those instruments that were a part of Tek's early evolution and into the thinking of those who designed them.