

The CRT-Based Oscilloscope

The Basic Mysteries

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Knowledge to be Covered

- What the Oscilloscope Does For You
- Introduction to the CRT
- CRT Components
 - The Electron Gun
 - Electrostatic Deflection Plates
 - Post-Deflection Accelerator
- Operating a CRT
- Considerations
- Example CRT – the 5ADP1
- Creation of Operating Potentials
- Simple Oscilloscope Practical Block Diagram
- Sweep Circuits
- Amplifiers
- Chop / Alternate Sweep
- Probes
- Measuring High Voltages
- Safety
- Repair Tips for Scopes
- Time Permitting:
 - References
 - Hands-on Q&A
 - Free Stuff
- LCD based digital scopes will not be discussed.

What the Oscilloscope Does For You

- The Oscilloscope draws an accurate picture of the variations of a voltage and plots it:
 - Against time.
 - Against another static or varying voltage.
- Accessories enable it to plot electrical current or trace curves of tubes or transistors.
- Shows you things about a signal that the finest meter can not.

Introduction to the CRT

- The CRT the Heart of the Oscilloscope
 - The rest of the instrument is dedicated to support the CRT.
 - Alone, the CRT is only a high tech ornament.
 - Understanding the CRT is the first step to knowing how the 'scope works, how to use it, and how to repair it.
- The CRT is a Linear Accelerator

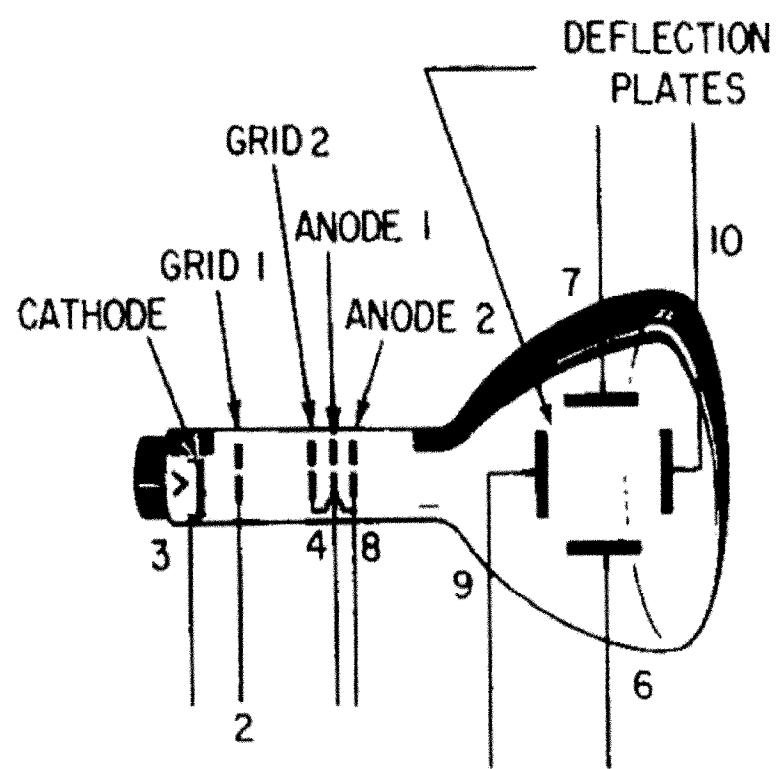
| +KV | Km/S | %C (Newtonian) |
|------------|-------------|-----------------------|
| 0.6 | 14,527 | 5 |
| 1 | 18,754 | 6 |
| 2 | 26,523 | 9 |
| 6 | 45,939 | 15 |
| 10 | 59,307 | 19 |
| 20 | 83,873 | 27 |
| 50 | 102,720 | 44 |

CRT Components

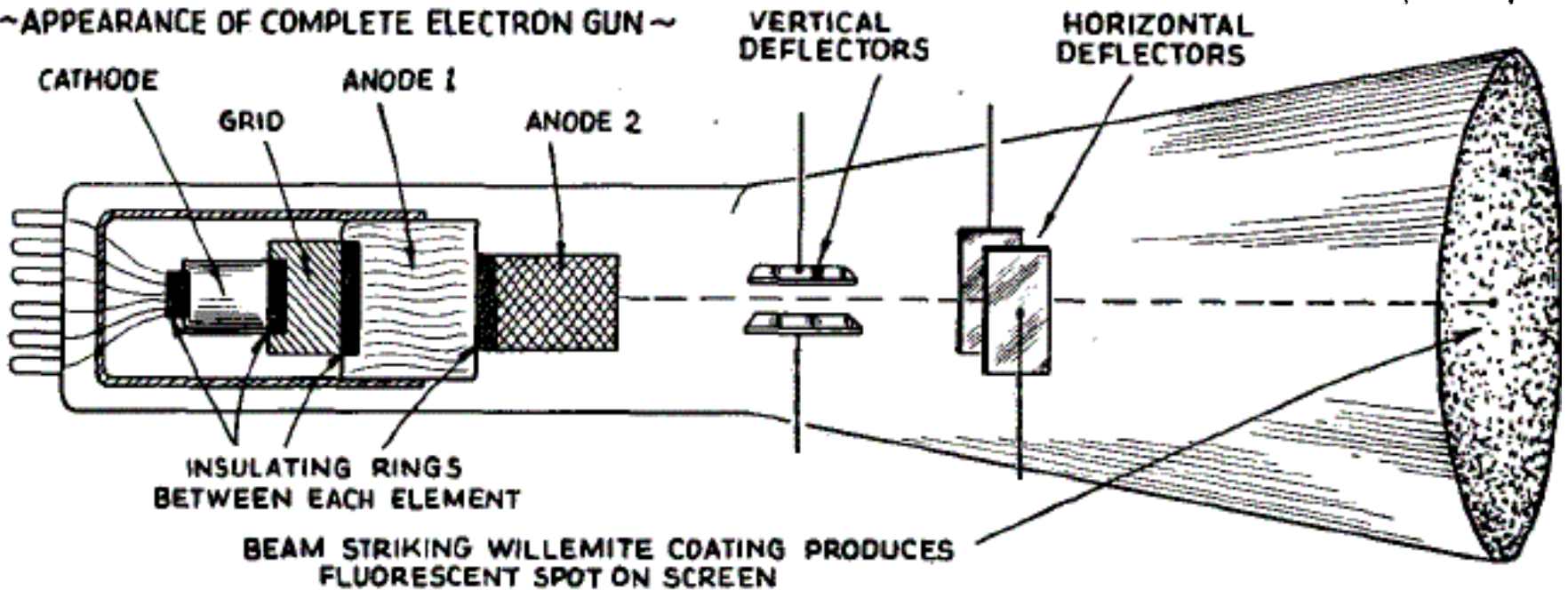
- Electron Gun
 - Heater-Cathode
 - Grid
 - Accelerating Anode (A1)
 - Focus Anode (A2)
- Electrostatic Deflection Plates
- PDA / Ultor Anode / A3 (*some CRTs*)

The Electron Gun

- Heater-Cathode
- Control Grid
- Accelerating and Focus Anodes comprise the "Electrostatic Lens"



~APPEARANCE OF COMPLETE ELECTRON GUN ~



The Electron Gun

(in simplest CRTs)

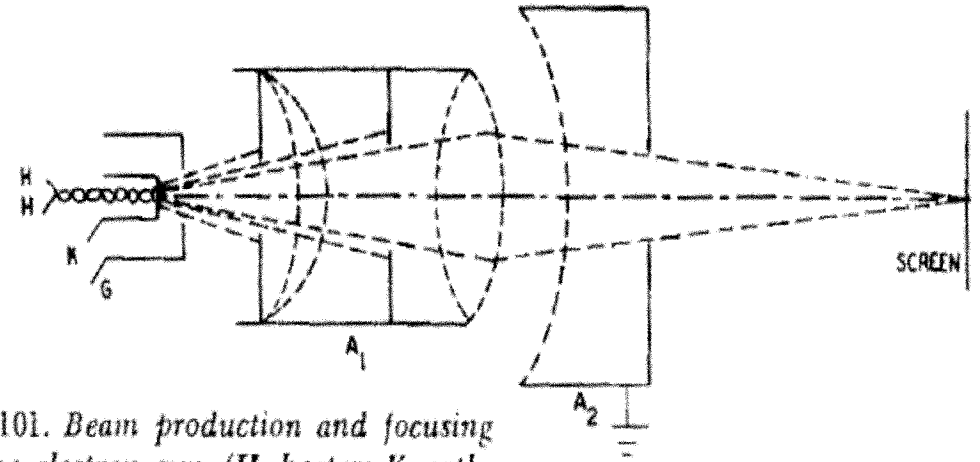
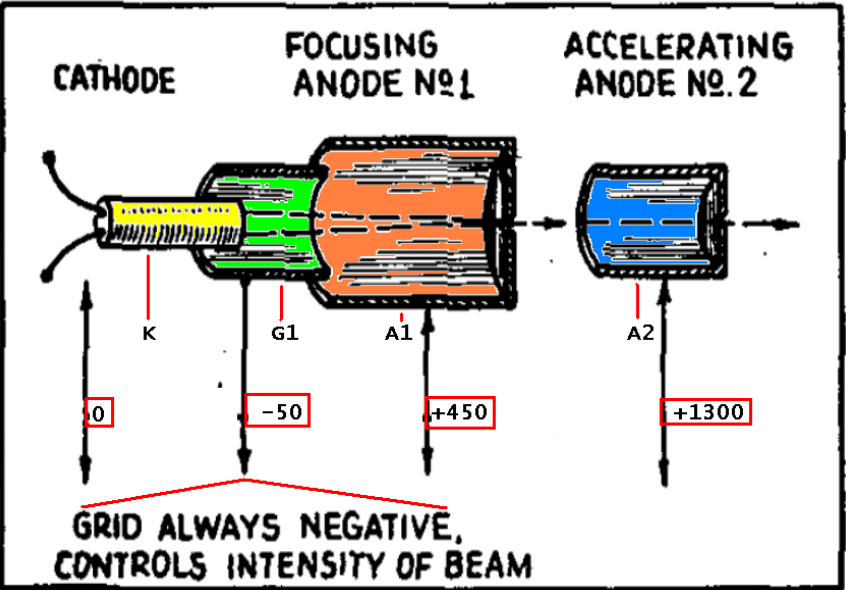
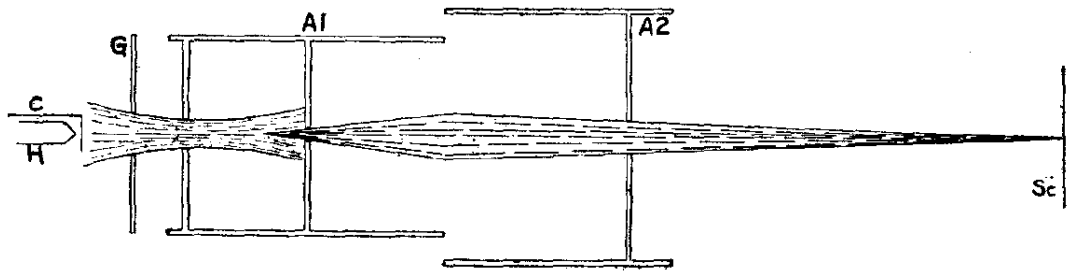
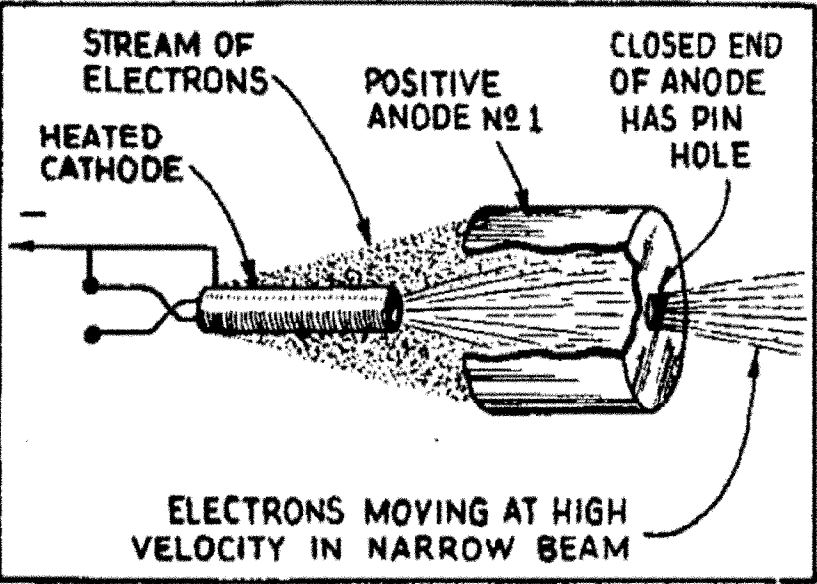
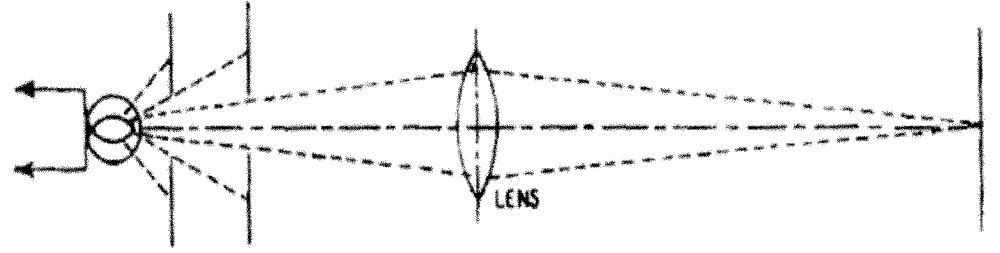


Fig. 101. Beam production and focusing by the electron gun. (H, heater; K, cathode; G, control grid.) An optical analogue is shown below.



Electrostatic Deflection Plates

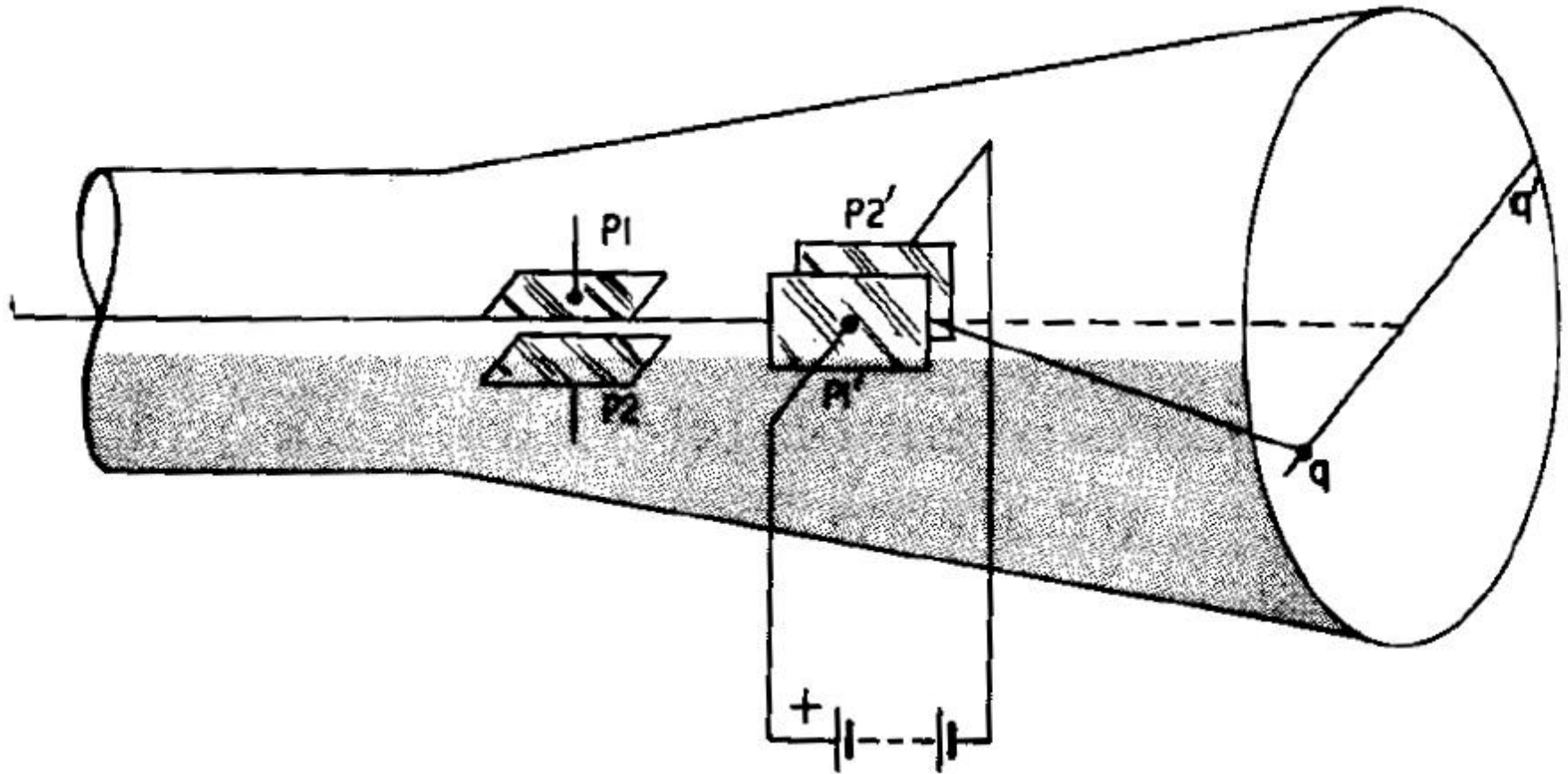
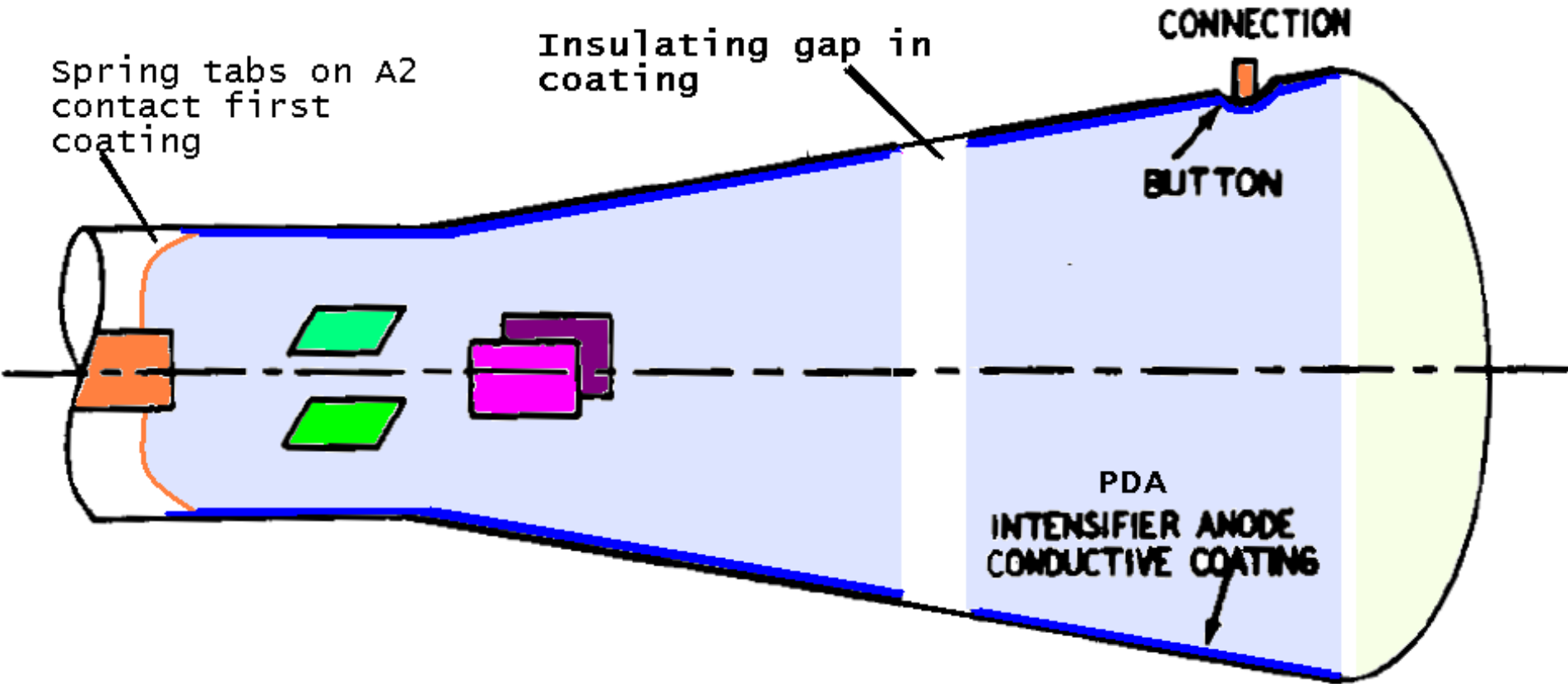


Fig. 104. *P1* and *P2* represent the vertical deflection plates. *P1'* and *P2'* are the horizontal deflection plates. By means of these plates (positioned at right angles) the spot can be moved vertically and horizontally.

Post-Deflection Accelerator



Operating a CRT

- **Brightness Control** – varying the voltage on G1 relative to K.
 - G1 negative → lower brightness
- **Focus Control** – varying the voltage on A1 relative to A2.
 - A2 is usually two separate cylinders in modern CRTs, one before A1 and one after A1.
 - Creates the “Focus Lens”.
 - A2 is responsible for beam acceleration through the deflection plate area.
- The **ultimate brightness** is determined by the final accelerating potential, often that of A2 on smaller CRTs. This can be up to about 2,000V relative to K.
 - Limited by socket insulation
- It is maintaining the correct **relationships** between the operating voltages that creates a quality electron beam and a well-focused, round spot on the screen.

Operating Considerations

- **Consideration:** The deflection plates must often be +/-300V relative to chassis GND for circuit design reasons, therefore K is often 600V to 2000V negative relative to GND.
- **Consideration:** The deflection plates are physically close to A2, A2 is often within +/-300V of the deflection plate average voltage.
 - to prevent arcing
 - prevent distortion of the focused electron beam
 - excessive electrostatic field gradient (parasitic lensing).
- A3, the **Third Anode**, is an optional element made of an internal conductive coating and carries the highest potential. It has a terminal on the side of the CRT bell because the socket cannot usually withstand 4000 to 10,000 Volts.
 - Also called the PDA or Ultor
 - Scope CRT can usually function without a much higher voltage on this, but at reduced brilliance.

Example CRT - The 5ADP1

MAXIMUM RATINGS (Absolute Maximum Values)

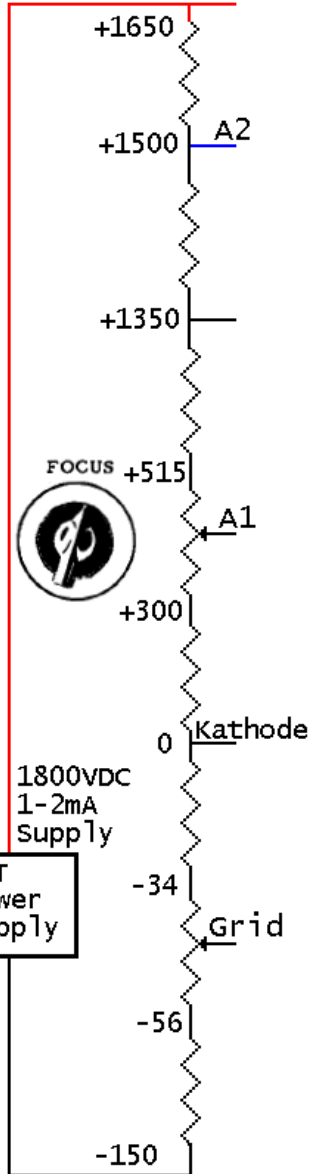
| | |
|---|----------------|
| Anode No. 3 Voltage..... | 6600 Volts d c |
| Anode No. 2 Voltage ² | 2860 Volts d c |
| Ratio of Anode No. 3 Voltage to Anode No. 2 Voltage..... | 2.3 : 1 |
| Anode No. 1 Voltage..... | 1100 Volts d c |
| Grid No. 1 Voltage | |
| Negative Bias Value..... | 220 Volts d c |
| Positive Bias Value..... | 0 Volts d c |
| Positive Peak Value..... | 2 Volts |
| Peak Heater-Cathode Voltage | |
| Heater Negative with Respect to Cathode..... | 200 Volts d c |
| Heater Positive with Respect to Cathode..... | 200 Volts d c |
| Peak Voltage Between Anode No. 2 and Any Deflection Plate..... | 550 Volts |

TYPICAL OPERATING CONDITIONS

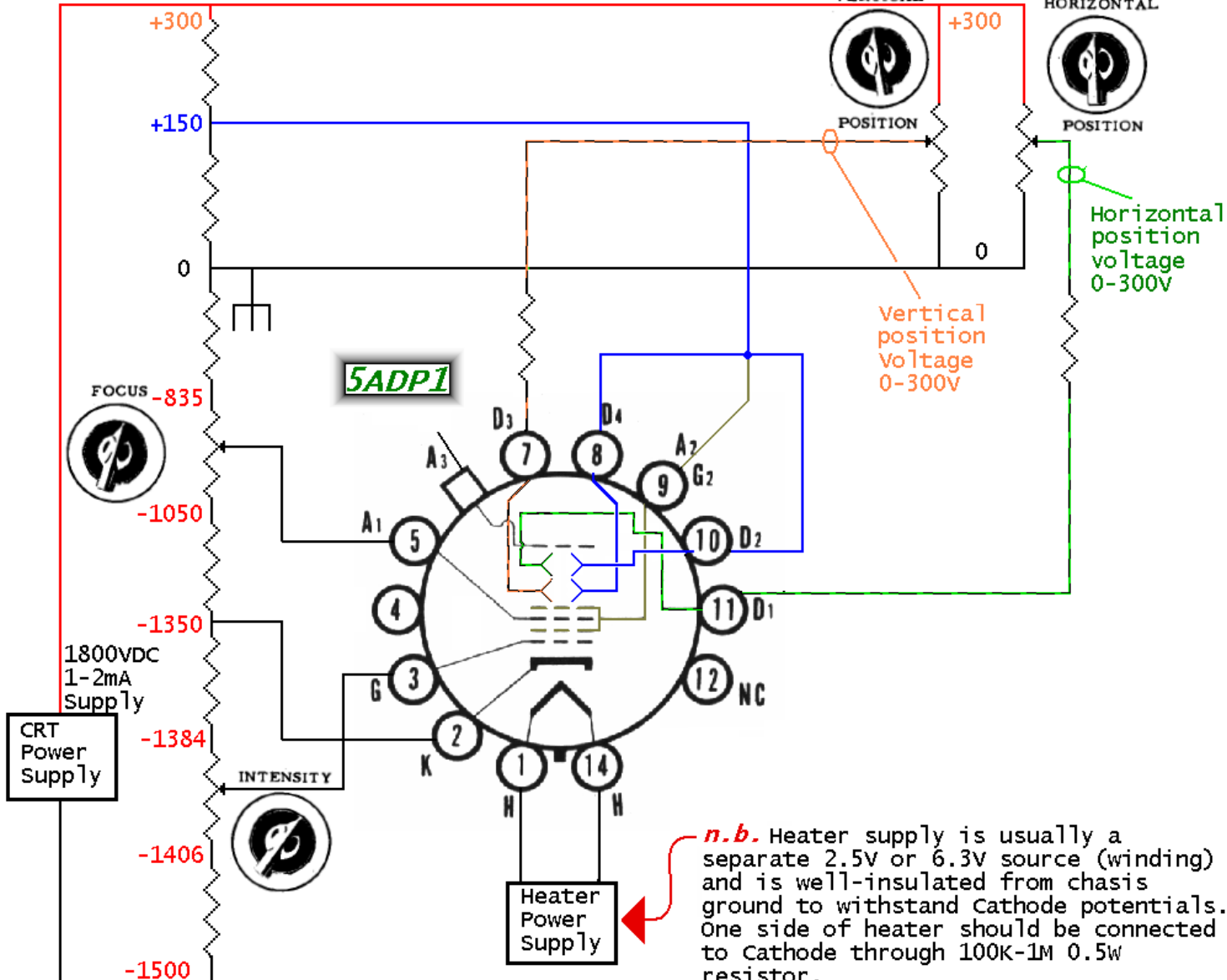
| | |
|---|-----------------------------|
| Anode No. 3 Voltage..... | 3000 Volts |
| Anode No. 2 Voltage..... | 1500 Volts |
| Anode No. 1 Voltage for Focus..... | 300 to 515 Volts |
| Grid No. 1 Voltage Required for Cutoff ³ | -34 to -56 Volts |
| Deflection Factor | |
| Deflecting Plates 1-2 ⁴ | 40 to 50 Volts d c/Inch |
| Deflecting Plates 3-4 ⁵ | 30.5 to 37.5 Volts d c/Inch |

Creation of Operating Potentials

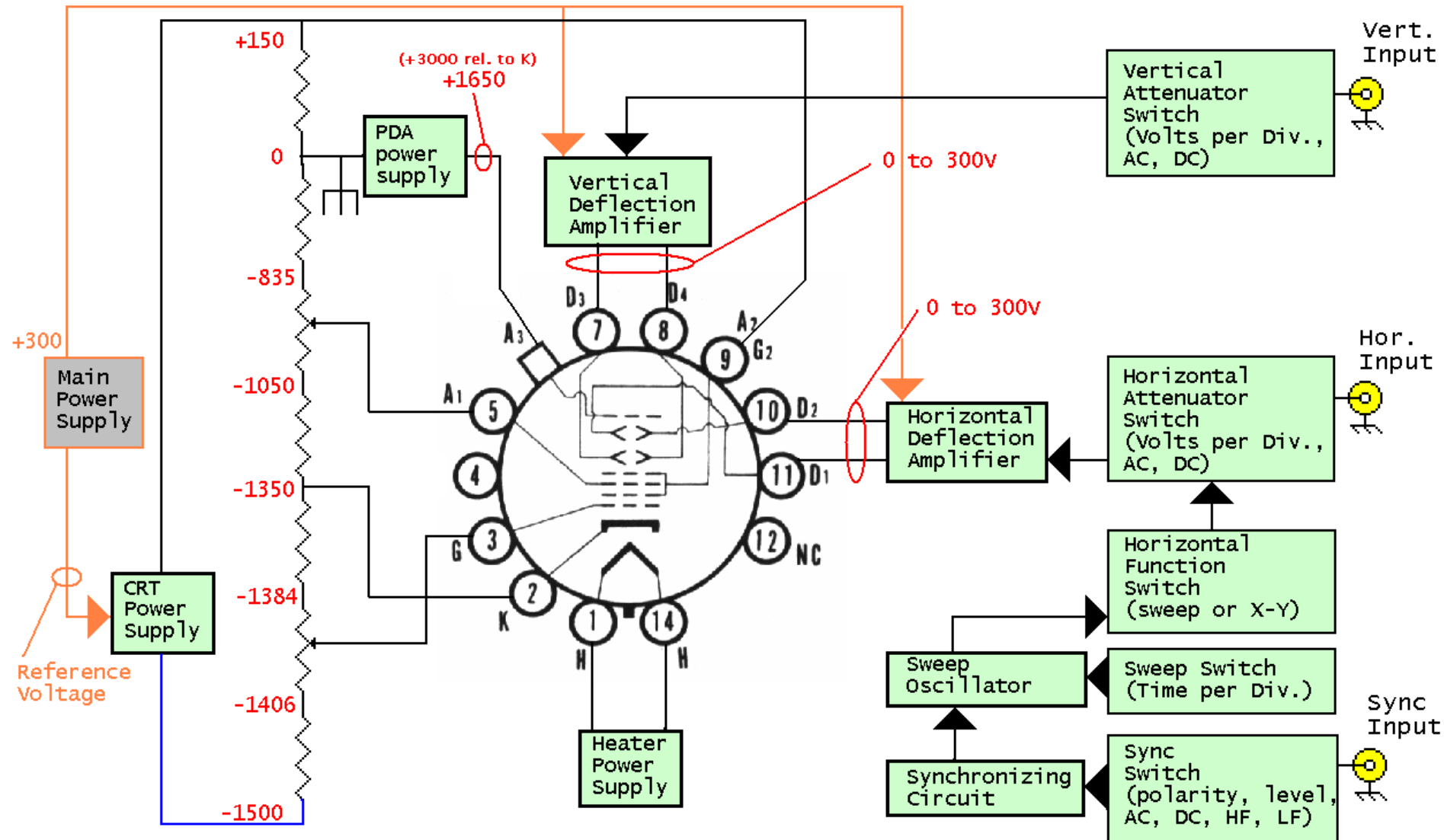
Tube Manual Figures



Practical Figures



Practical Oscilloscope Block Diagram



[Return to AC Amplifier](#)

Sweep Circuits

- The “clock” of the oscilloscope
- Generates sawtooth signal for horizontal deflection axis
- Provides calibrated and variable time standard against which to display and measure waveforms
- Generates blanking signals to turn off beam when not drawing the waveform
- Can run without trigger, trigger while running, wait for trigger, be manually triggered (one-shot)
- Can be triggered by AC line, input signal, external signal

Sweep Time Constants

- Generating a sawtooth waveform the easy way:
 - 1. Charge a capacitor through a resistor
 - 2. Quickly discharge the capacitor
- RC charge curve is nonlinear but the scope needs a linear sweep.

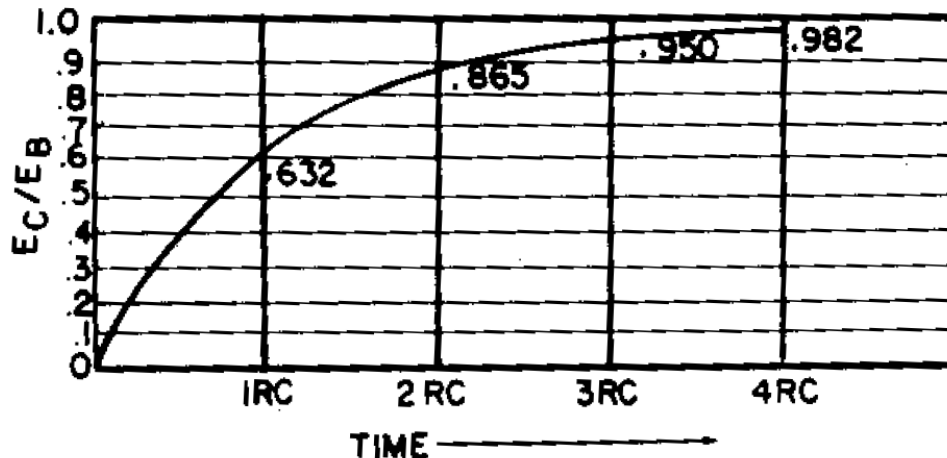


Fig. 3-3. Graph showing the rise in voltage as a capacitor is charged through a resistance.

Sweep Time Constants

- Using only a small portion of the charging waveform results in an acceptably linear increase of voltage with time.

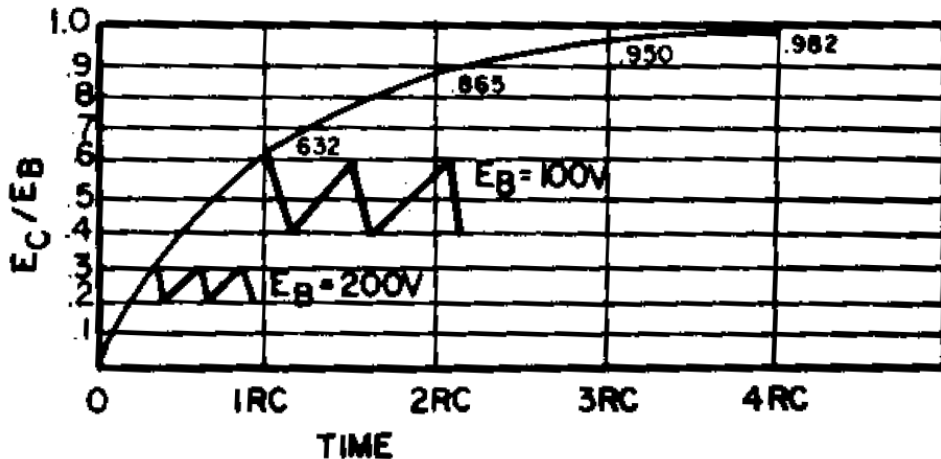
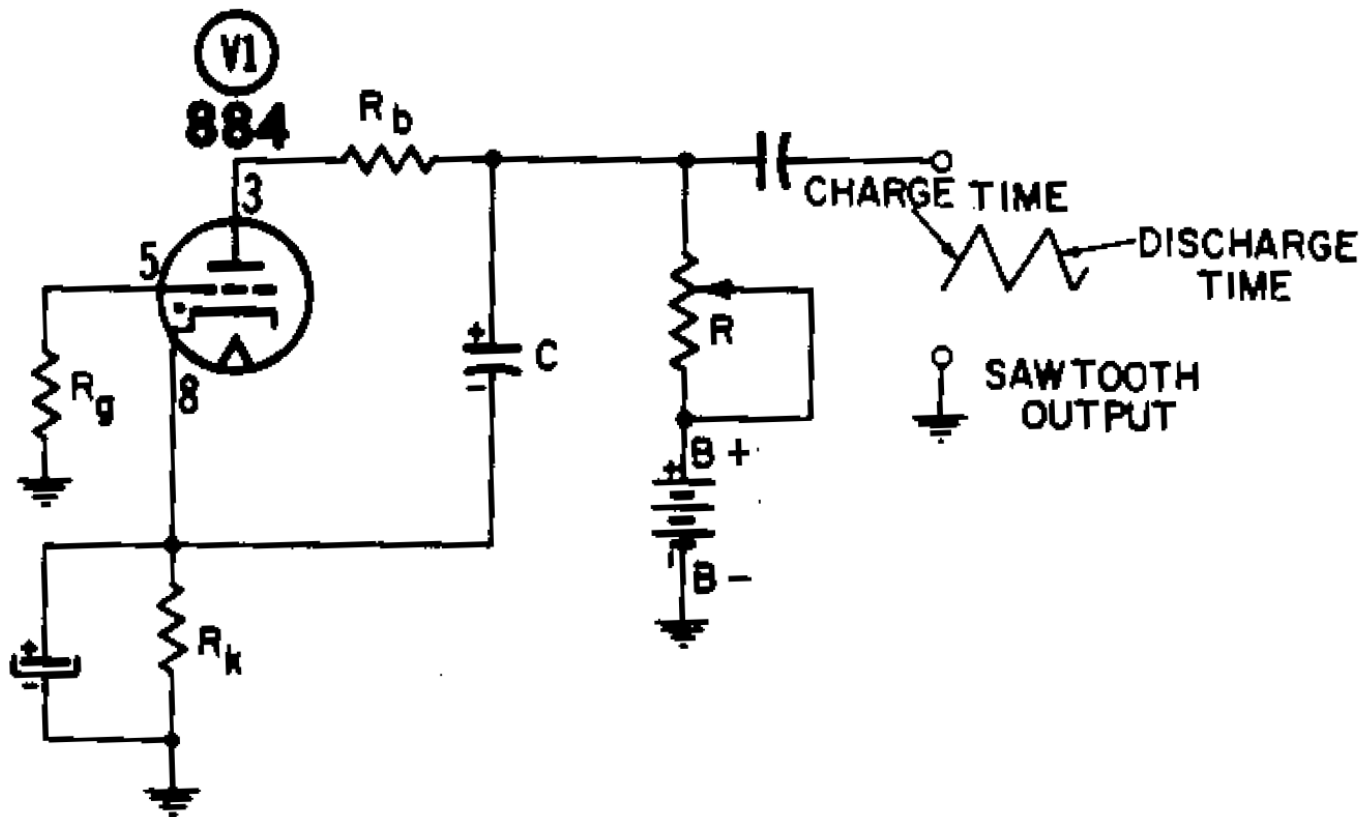


Fig. 3-6. Graph showing the effect of different values of E_B applied to a thyatron sawtooth oscillator.

Sweep Oscillator -Thyratron

- A thyratron such as the 884 can discharge the capacitor almost instantly depending on circuit constants.
- In this diagram, current limiting resistor R_b is large and the discharge time is too long for scope use.
- The 884 has been used in 1-2MHz scopes with H sweep rates up to about 50KHz.



Sweep Oscillator-Thyratron

- Several sweep frequency ranges are made available by selecting different timing capacitors C.
- 2M resistor R adjusts the frequency continuously within each range.

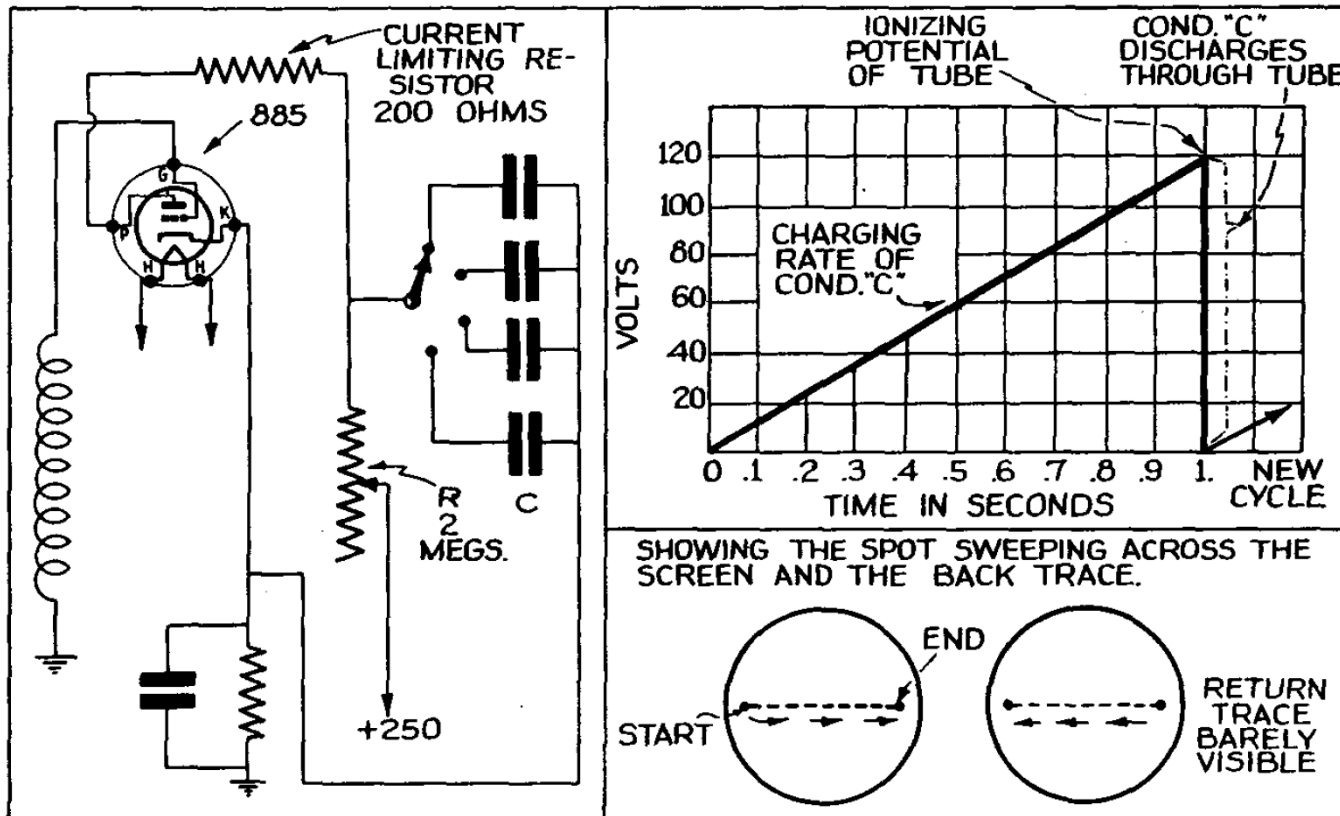


Fig. 24A

B—Above

C—Below

Sweep Oscillator – Multivibrator

- Multivibrators can run much faster than thyratrons and careful design is necessary to achieve a fast discharge.

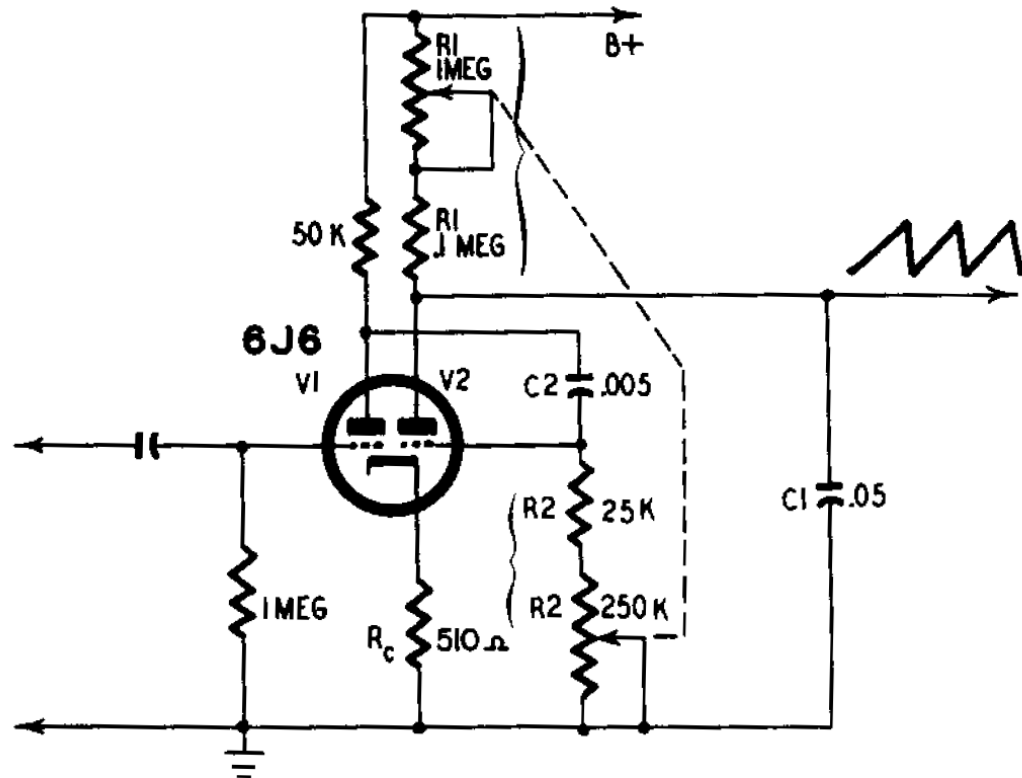


Fig. 240. Typical multivibrator type time-base generator.

Sweep Oscillator – Multivibrator

- Showing interconnections to H DEFL amplifier, blanking circuit, and trigger circuit
- Switch selects capacitors from banks C1 and C2.
- C1 is retrace. C2 is trace.

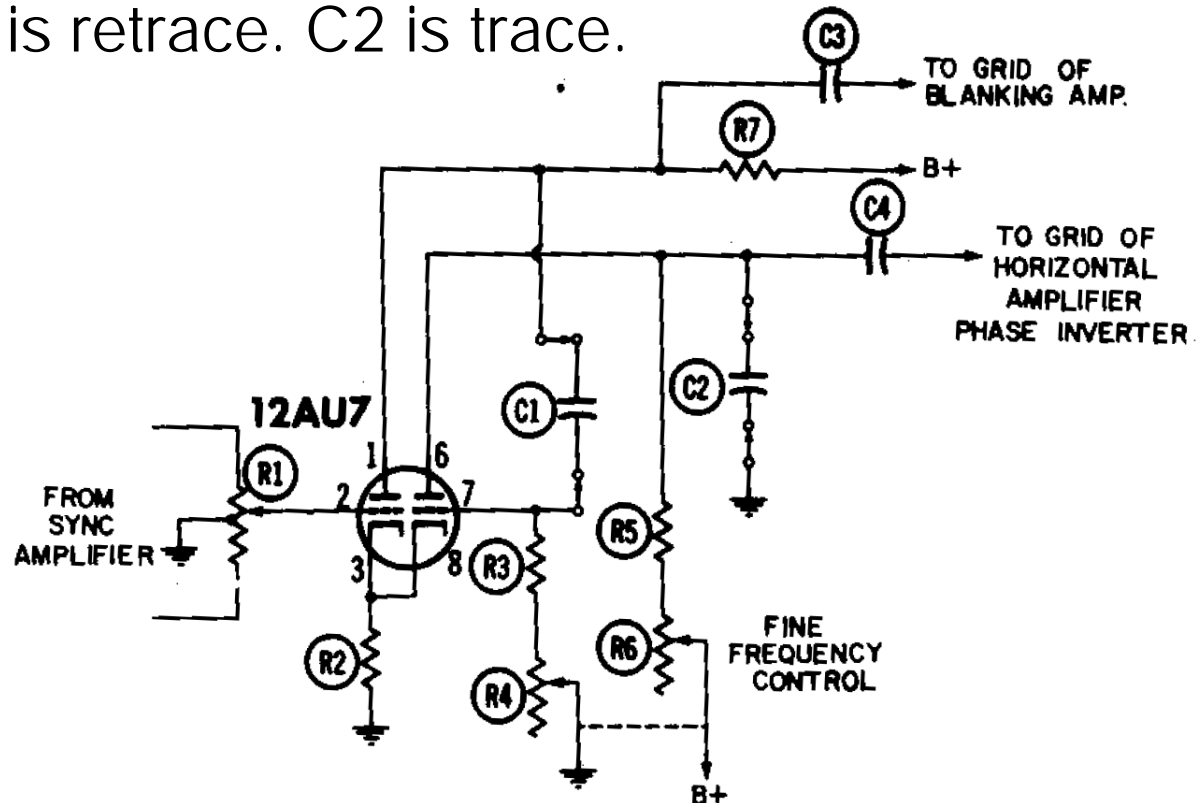
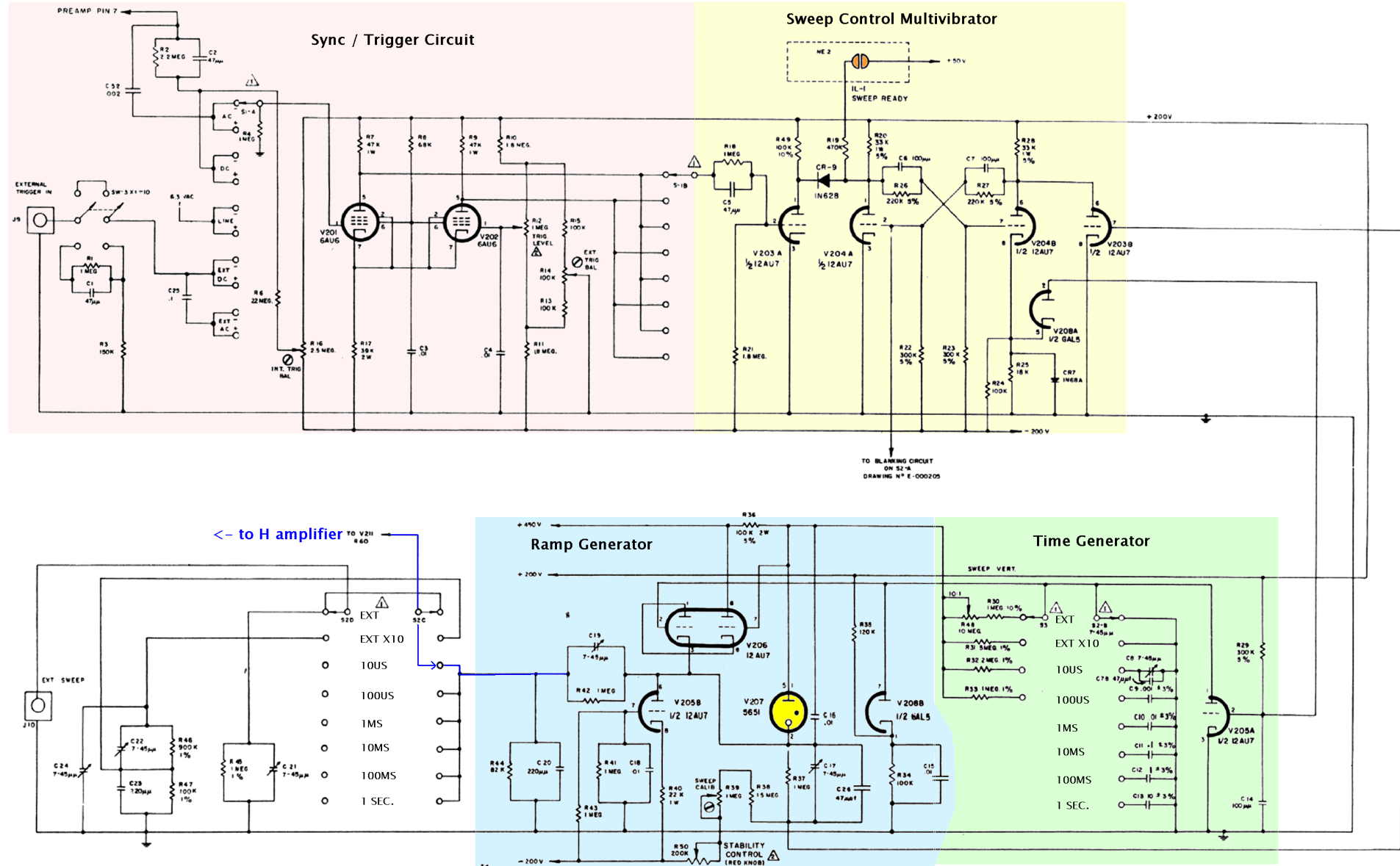
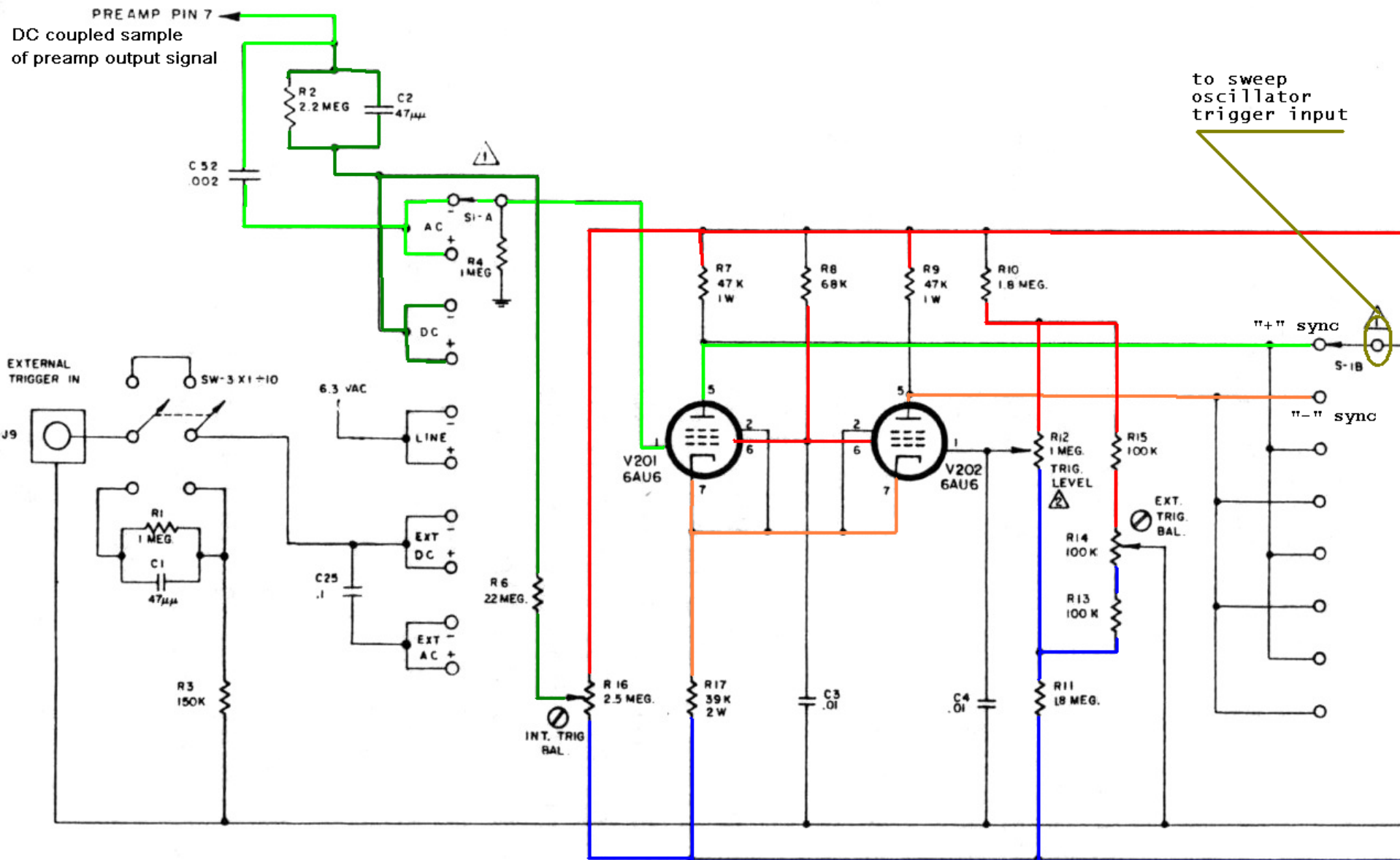


Fig. 3-12. Multivibrator sweep generator used in Simpson Model 466 HANDISCOPE.

Refined Sweep Circuit



Sync / Trigger Circuits



Deflection Amplifiers

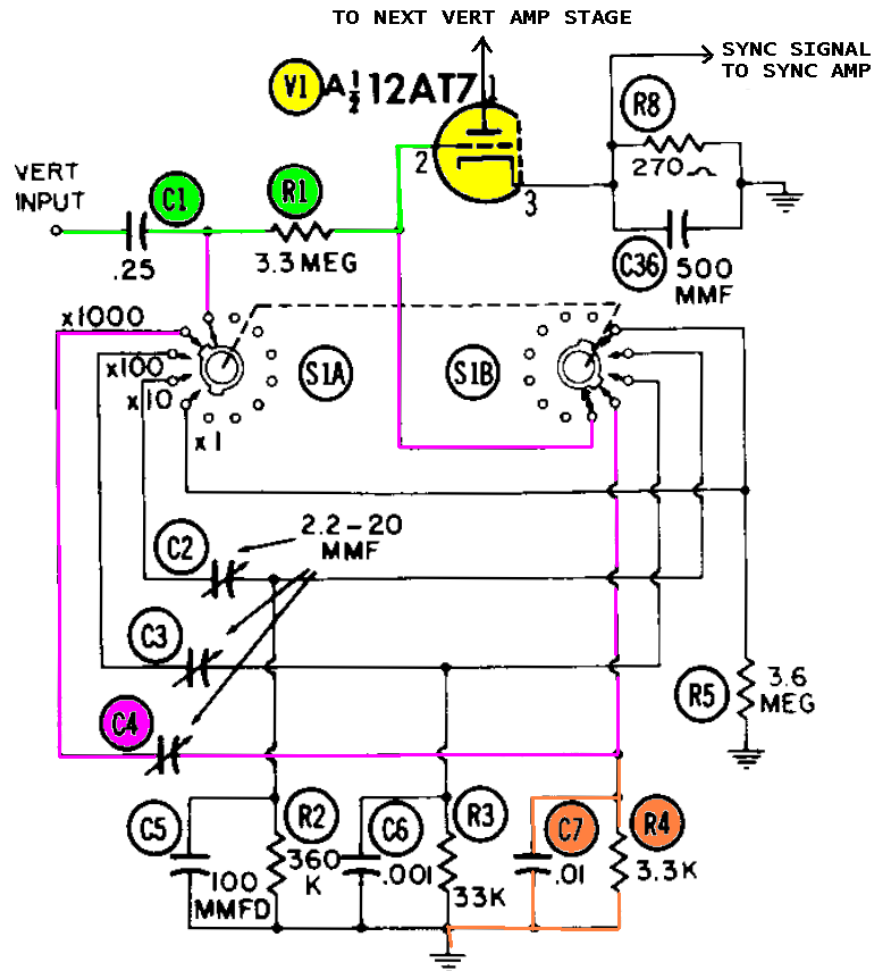
AC Coupled Amplifiers

- Simple design
- Low parts count
- Ease of alignment
- Ease of repair
- Cannot amplify a DC voltage
- Distortion increases at frequencies $<100\text{Hz}$

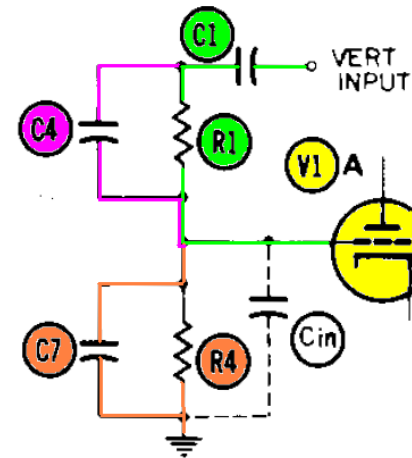
DC Coupled Amplifiers

- Handle AC, DC and mixed signals accurately
- No distortion at low frequencies
- Special measurements possible
- Complex balanced design
- 2x-3x the parts count
- Harder to align and repair

AC Coupled Input Attenuator



(A) Schematic diagram.

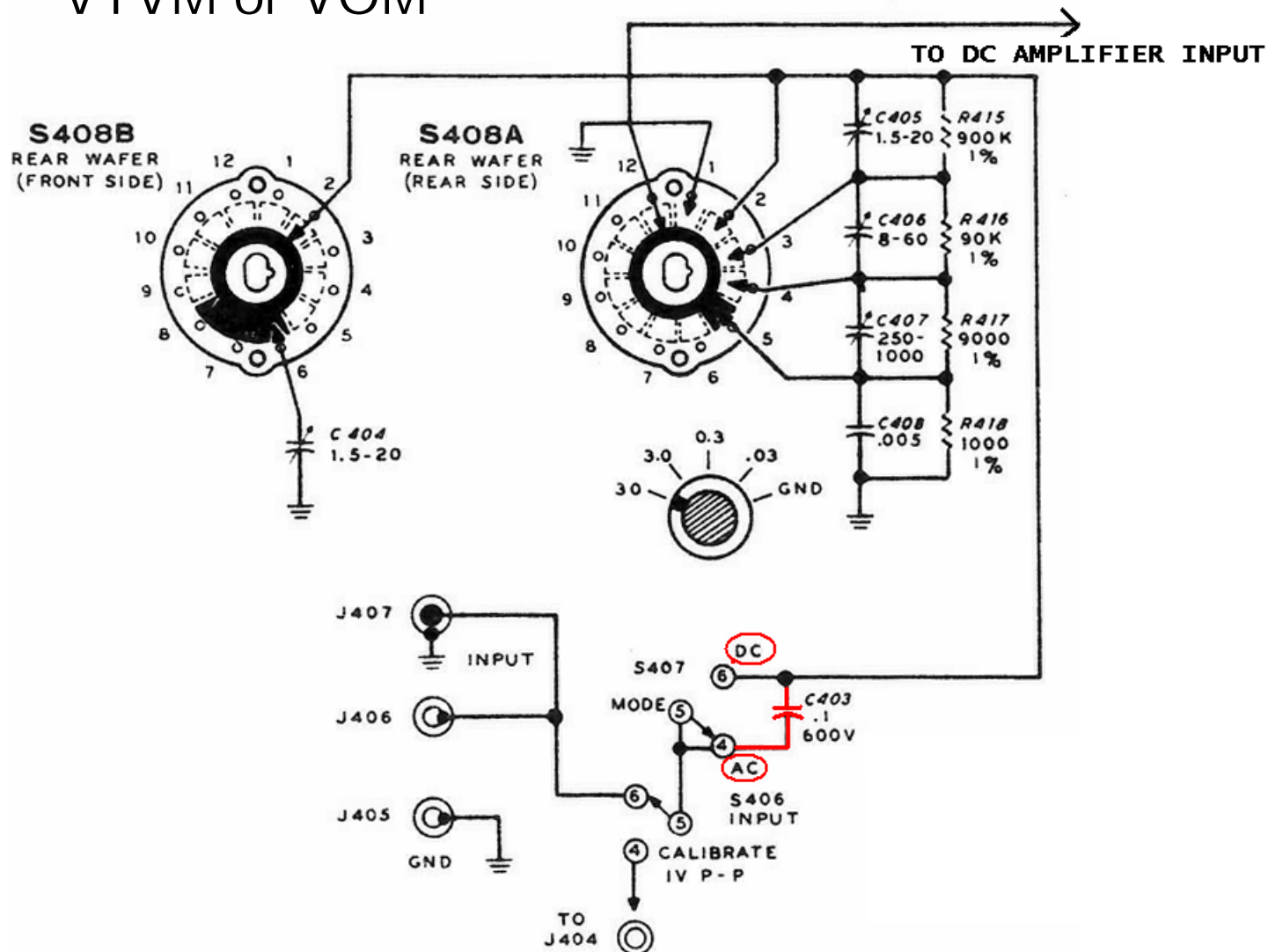


(B) Simplified diagram.

Fig. 5-4. The frequency-compensated vertical attenuator of the Simpson Model 458 Colorscope.

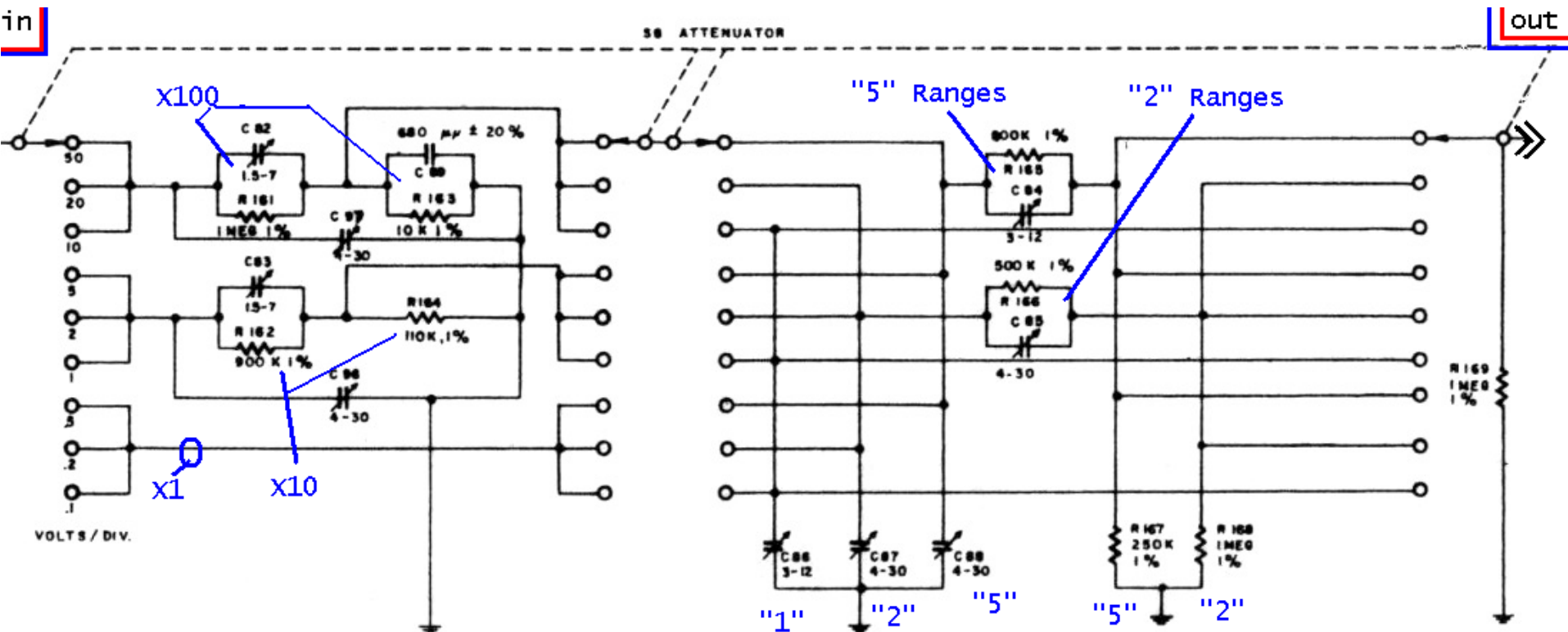
DC Coupled Input Attenuator

- Simple compensated attenuator is much like that in a VTVM or VOM

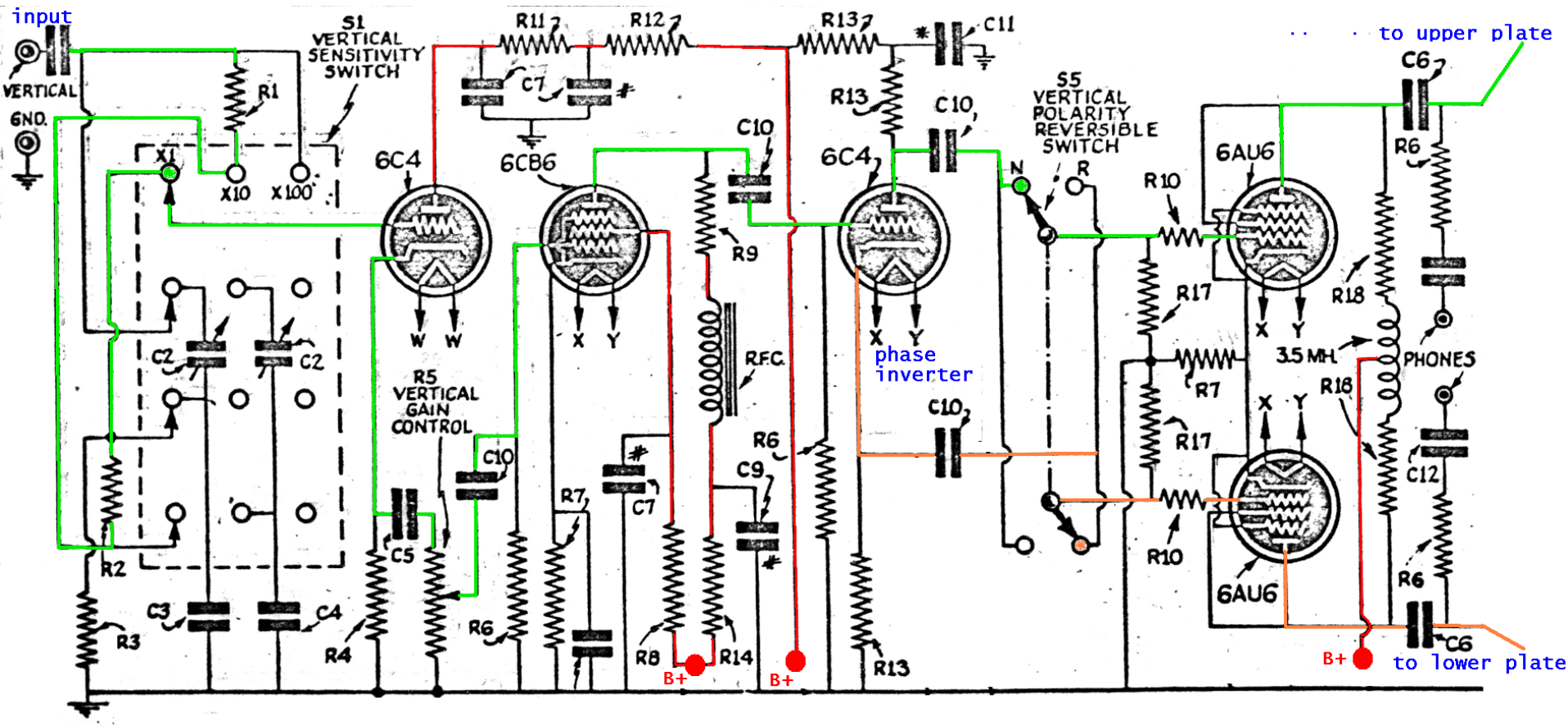


DC Coupled Input Attenuator

- High accuracy attenuator uses separate compensation for decade (0.1-1-10) and integer (1-2-5) ranges



AC Amplifier (balanced deflection)



AC Amplifier Beam Positioning

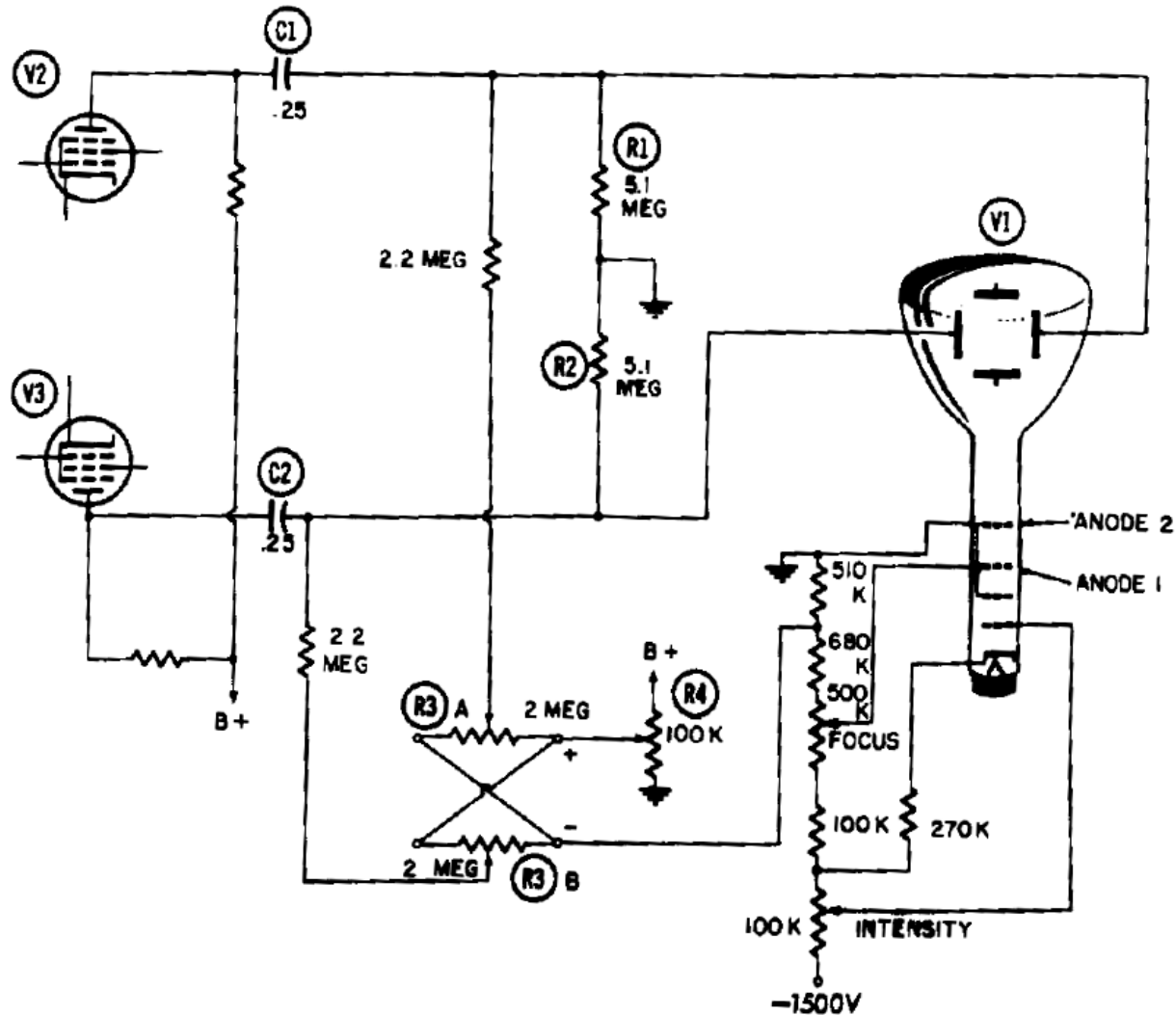
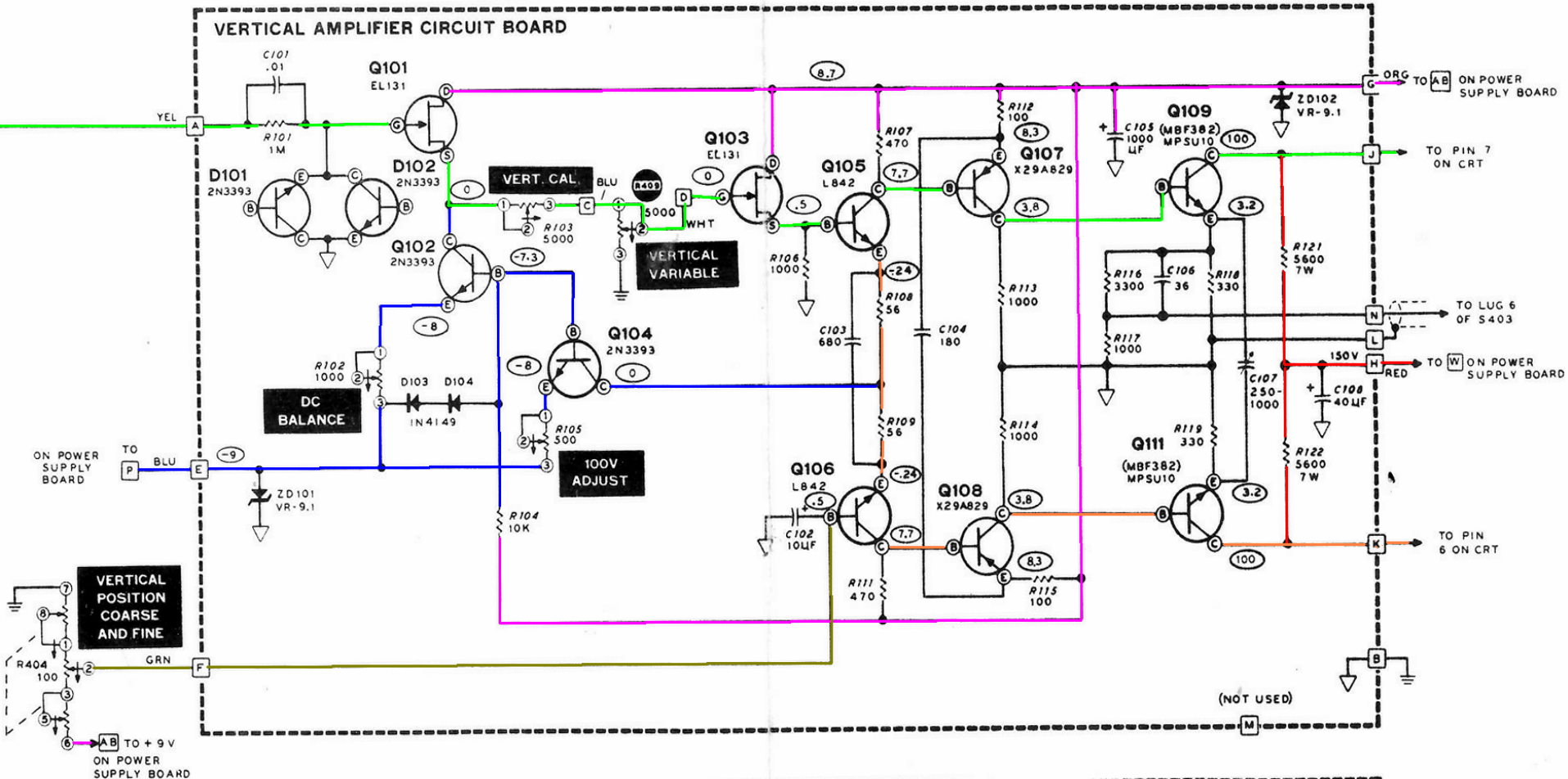
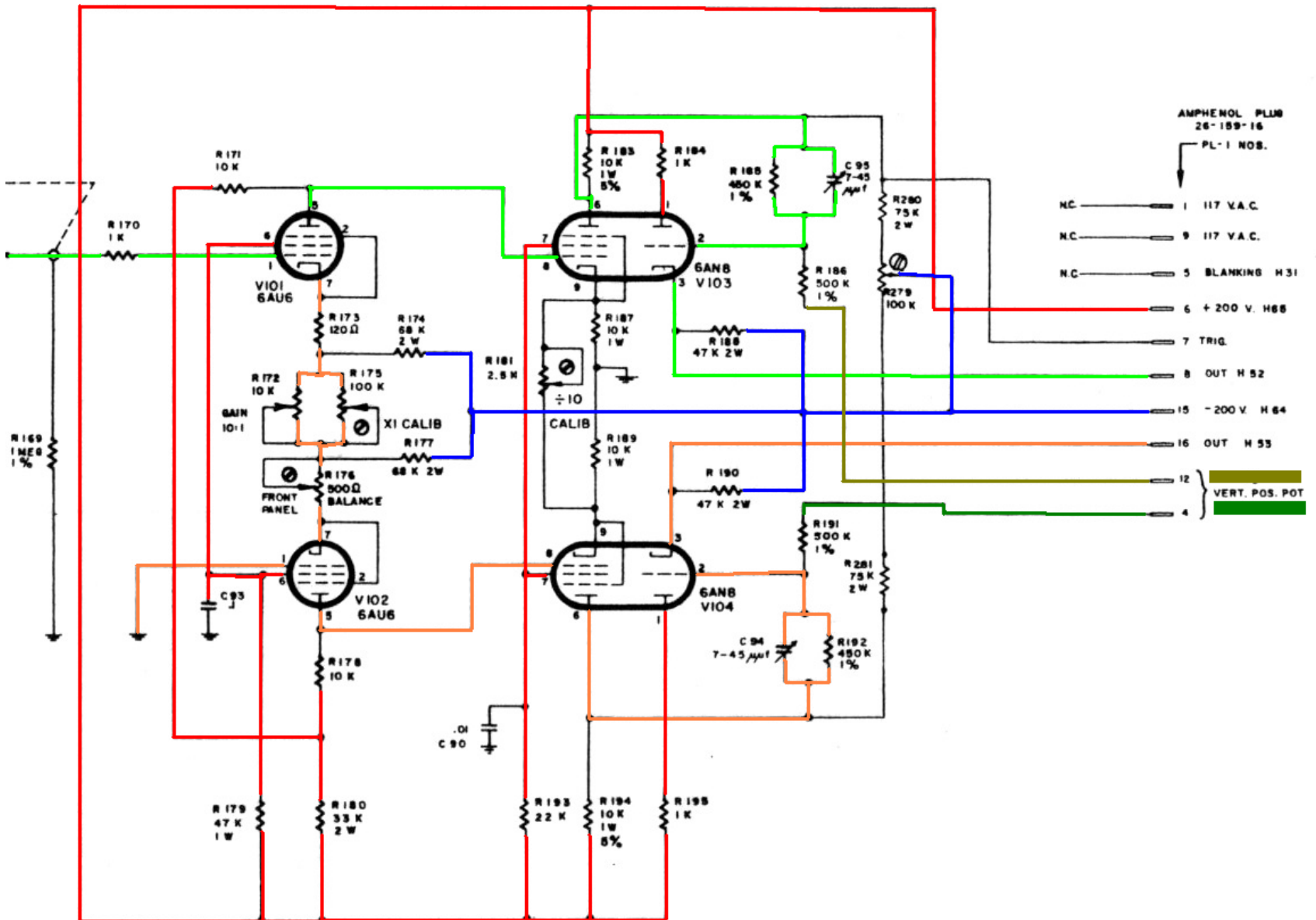


Fig. 2-5. Partial schematic diagram showing the positioning control and high-voltage divider network of an oscilloscope (Triplet Model 3441).

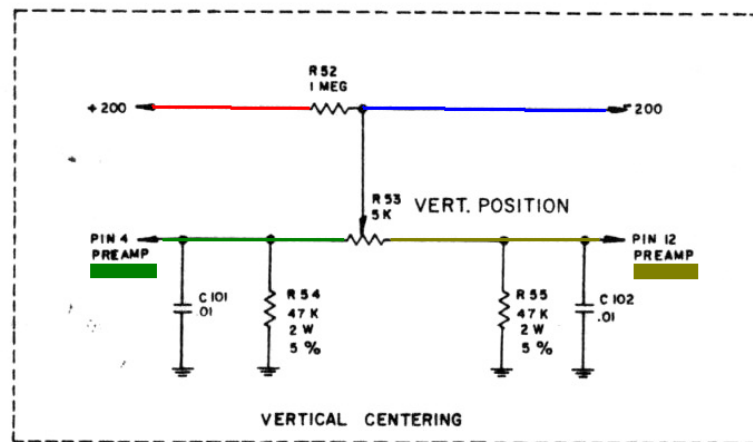
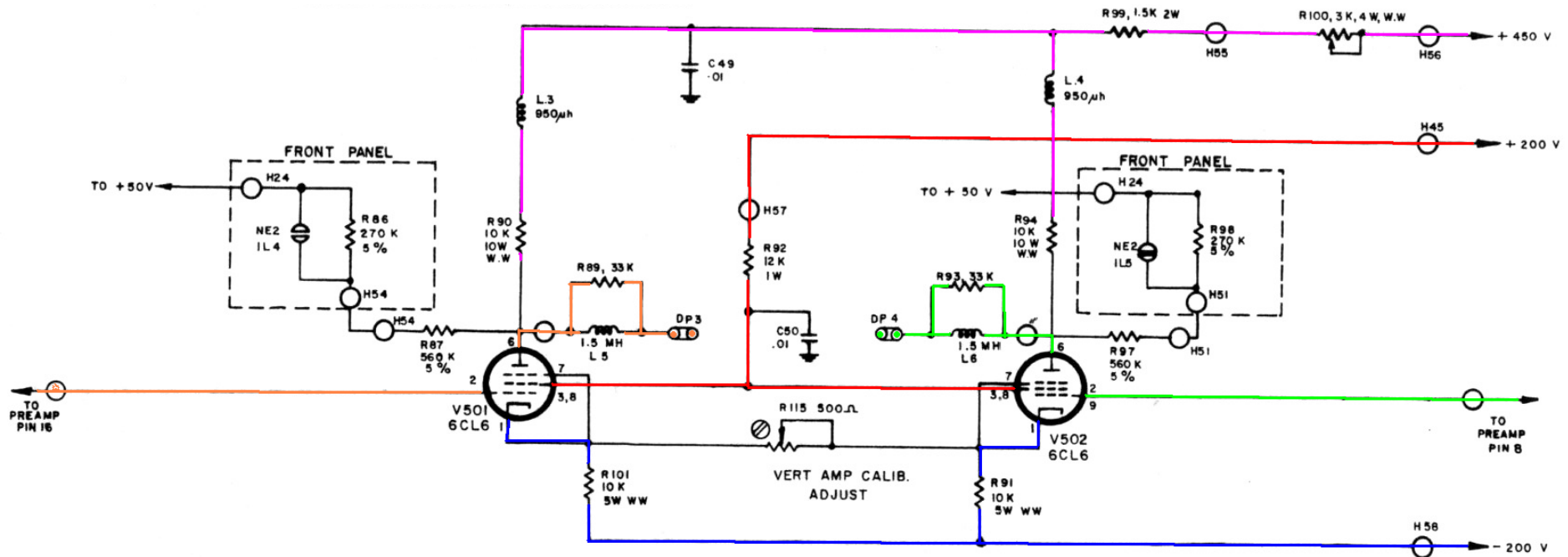
DC Amplifier (solid state)



DC Amplifier (tube preamp section)



DC Amplifier (tube output section)



NOTE:

1. UNLESS OTHERWISE SPECIFIED ALL RESISTORS ARE 1/2 WATT $\pm 10\%$ AND ALL CAPACITORS ARE IN MICROFARADS.

Chop/Alternate function

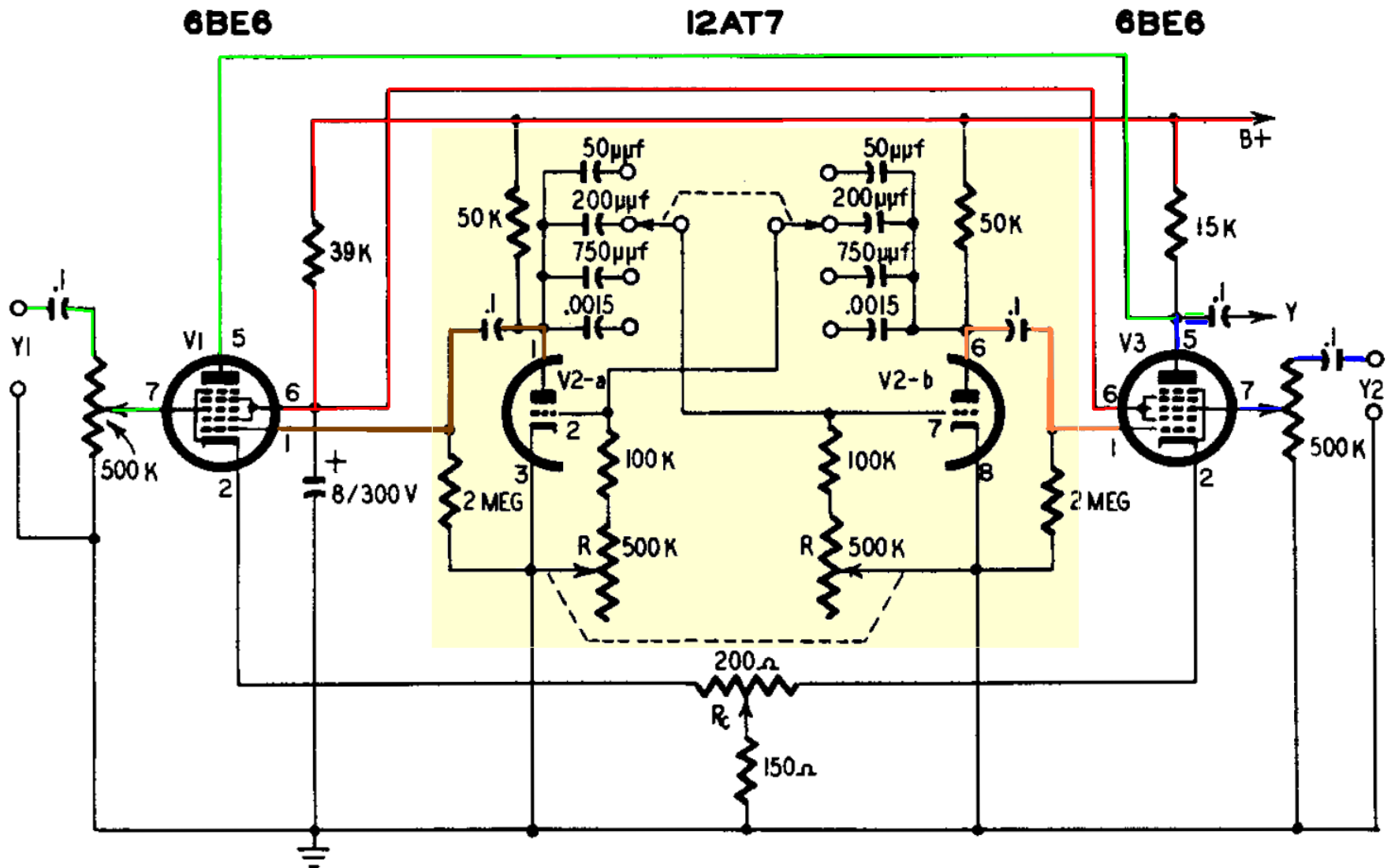


Fig. 302. Electronic switch of the multivibrator type.

Synchronized Trace Alternation

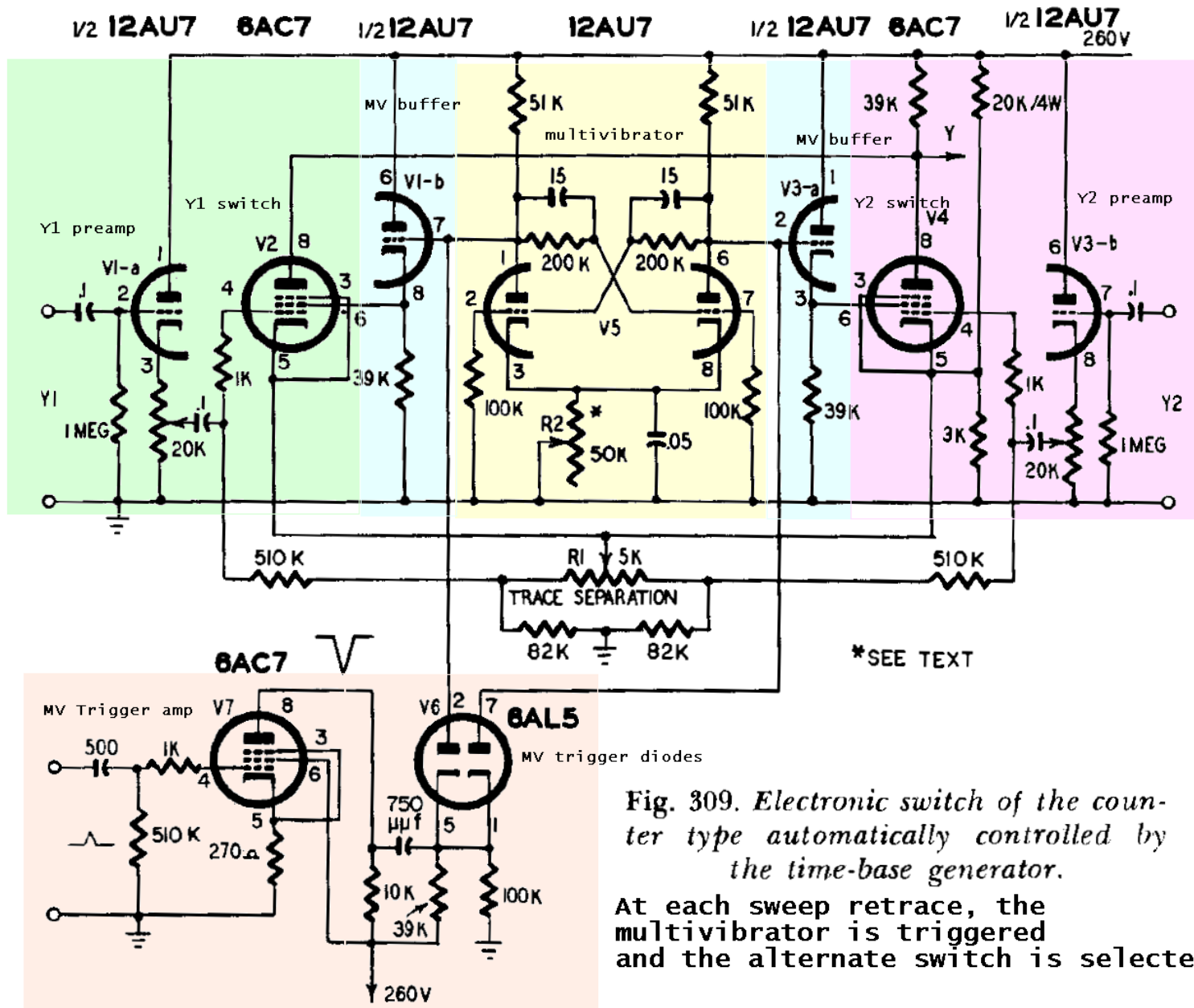


Fig. 309. Electronic switch of the counter type automatically controlled by the time-base generator.

At each sweep retrace, the multivibrator is triggered and the alternate switch is selected

Common Probes

- 1:1 “straight” probe
 - 100V at probe is carried directly to scope input
- 10:1 probe with compensator
 - 100V at probe is reduced by series resistor to 10V at scope
- RF detector probe
 - Simple, has built in RF diode detector and network
 - Usually for low RF voltages <50V peak AC
 - Usually good for DC to 400-600V (capacitor isolated)
 - Often good to 500MHz
 - Detected envelope (e.g. audio) is delivered to scope
 - Not always calibrated for amplitude
- Always use the GND.



Measuring Voltages to 600V

- Be certain of scope input voltage limits
 - Usually stated as peak or DC on front panel near input connector
 - Some are 600V, some are 50V, some special are even 5V
 - If not stated, 250-400V is usually OK on older tube units.
 - Trigger inputs may have different ratings.
 - What is the voltage rating of the probe?
 - Read the manual.
- Always use the GND.



Measuring High Voltages

- Special Considerations
 - Would you trust the probe in your hand when you touch it to these test points?
 - 5000V pulse in the tube color TV set?
 - 700V DC+AC in a filter choke input?
 - Anything over 600V peak should never be measured with a standard probe.
 - Arc at the tip.
 - Arc through the probe body
 - Over 600V should only be measured with a probe built or designed for higher voltages.
- Always use the GND.

Measuring High Voltages

- HV Series Multiplier Probes
 - If scope has 1M input resistance, adding a 9M resistance in series increases resistance to 10M and allows 10X the voltage rating.
 - Commercial series-probes and probe tip adapters are out there. Be aware that if the scope is not grounded to the work, and the tip or probe is not plugged into the scope, arcing may occur.
 - For DIY - Always observe voltage ratings of series resistors.
 - Most resistors are 200-600V, some are less.
 - Use nine 1M resistors in series for example.
 - Or buy a special HV resistor
 - Caddock, OhmCraft, Victoreen, Vishay
 - Remember - no compensation with resistors only.
- Always use the GND.

Measuring High Voltages

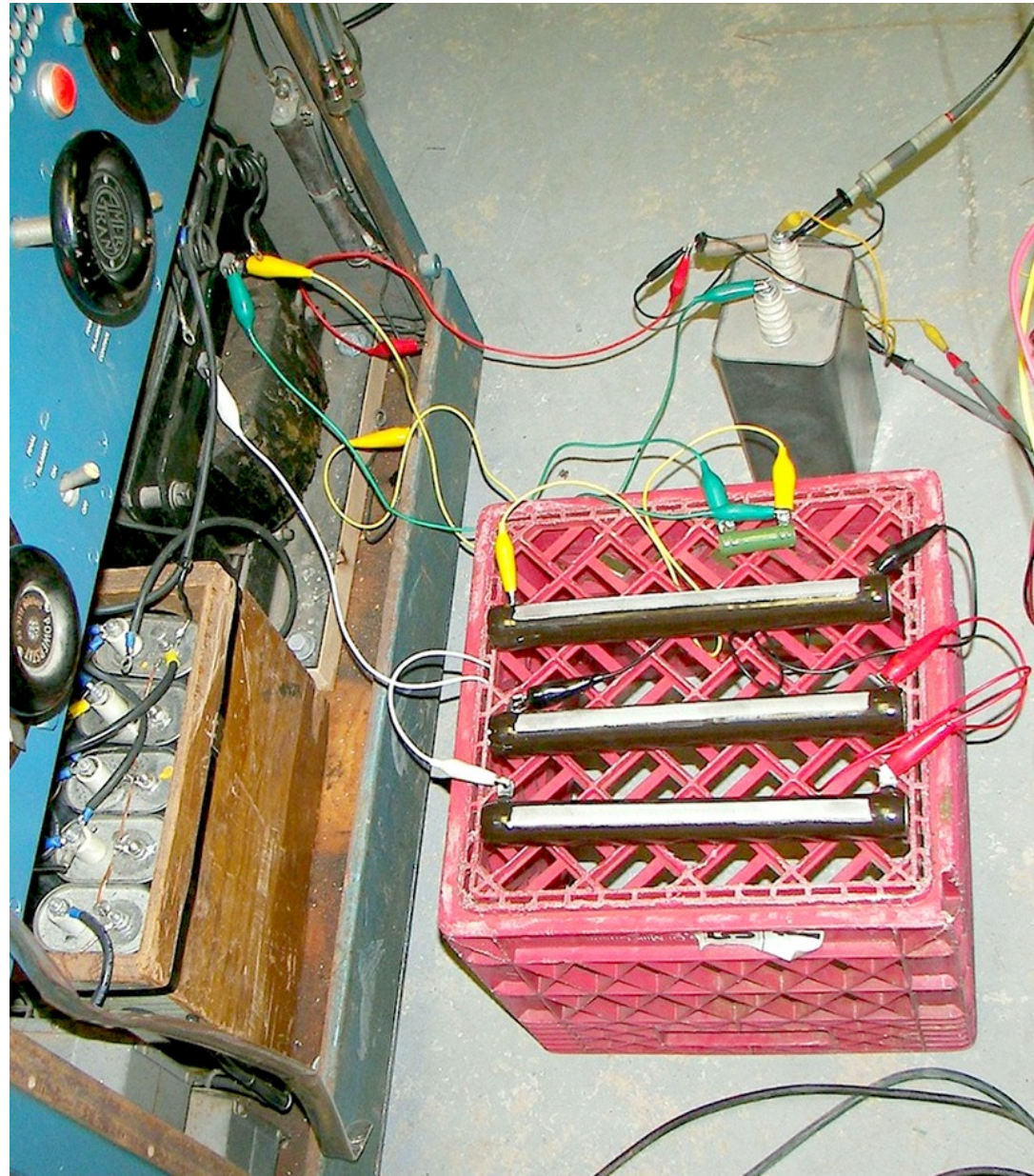
- DIY HV Series Multiplier Probes
 - Use nine 1M resistors in series for example.
 - Slip into a glass tube with a tip at the end.
 - Slip the glass tube inside a (brass) metal tube leaving 1" exposed at the tip ('hot') end.
 - Run coaxial cable from scope plug to housing.
 - Center to 'cold' end of resistor string
 - Shield to tube (housing) and a GND lead
 - Brass tube probe body becomes a metal grounded shield between the high voltage resistor and the operator.
 - ALWAYS have probe attached to scope before probing.
 - Otherwise, HV may arc at loose scope end of cable and back to operator.
- Always use the GND.

Measuring High Voltages

- DIY High Voltage Divider Probes
 - Same body construction as series probe
 - Increased safety ; integral ground.
 - Assume scope input=1M
 - Use nine 1M resistors in series plus a 500K and a 1M
 - Tip –1-1-1-1-1-1-1-1-1-0.5-tap-1-GND_lead
 - The scope is tapped to the top of the last 1M resistor.
 - Multiplication is 20:1; 2KV at tip makes 100V at scope.
- Always use the GND.

Measuring Power at Very High Voltages

- The 7575 Ohm “dummy load” attached to the modulator has a 7306V p-p audio signal across it, and is also at 3500VDC above ground. - 101:1 divider
- Tip-2500-2500-2500-Tap-75-GND.
- Power of 890W RMS measured using scope to see clipping level and VOM to read volts.
- Can Do – *with care*.
 - Use external divider and temporarily install to equipment, then attach to tap and GND
 - Space and insulate divider and cables from objects to prevent arcing.
 - Respect wattage and voltage ratings.
- **Always use the GND.**
- **Hands-Off measurement**
- **Kill-Switch on AC Input**
- **Stand well back**
- **Observe from distance**
- *Light fuse and get away.*



Safety

- Isolation and Grounding
 - Scope should always be grounded using AC grounding plug.
 - Some scopes do not have a grounding cord. Connect proper ground wire between the scope and workbench power ground.
 - Your workbench must have an AC power ground.
 - Use isolation transformer on equipment under test.
 - If not appropriate to isolate gear, check for AC leakage from gear and if OK proceed.
 - Noise from bad grounds and ground loops can obscure weak signals. Not a safety issue but an annoyance.
- Point? Bad things happen to hands, scopes, and signal purity when lots of current flows through the probe ground.

Safety

- High Power Stuff Inside the Scope
 - Bipolar power supplies, +/- 200 to 500VDC
 - Cathodes as well as anodes in DC amplifiers
 - Deflection amplifiers (solid state units as well)
 - Large tube scopes like the Tektronix 545 can deliver 1amp at 600VDC for a few seconds before blowing a fuse.
 - Any CRT connection (Cathode -2KV)
 - Especially the PDA +1.5KV to +20KV

Safety

- CRT Implosion
 - Violent breakage of glass; “explosion”.
 - Drives fragments toward each other, smashing and scattering in all directions.
 - Eye protection against flying glass.
 - Gloves and apron protect against cuts.
 - 3500 lbs of atmospheric pressure on a 5” CRT bulb.
 - Cleanup? Fairly harmless, just get all the glass.
 - No mercury, lead, or poison gas
 - Phosphors are basic mineral compounds, just don’t eat.
 - Trash OK. Wash hands.
 - Don’t break it in the first place.

Scope Repair

- Same problems as radios
 - Caps leaky
 - Resistors out of tolerance
 - Bad tubes
 - Mechanical damage
 - These need not be discussed
- Special problems
 - Arcing
 - Ozone and corona damage
 - Problems of HV insulators and couplings
 - CRT issues
 - HV supply issues
 - DC amplifier issues

Scope Repair

- Arcing
 - May be seen and heard and snapping white sparks
 - Diagnose quickly, don't let it go on.
 - Clean up area or spots on wire
 - Possibly apply 3M self bonding tape, corona dope, or silicon glue
 - Replace badly burned wire with 5KV or better "test lead" wire.
 - In some cases wire may need to be 10KV or 20KV rated.

Scope Repair

- Ozone and Corona Damage
 - @ 2KV to 20KV points
 - Ozone “fresh air” odor.
 - Faint or very faint hissing sound.
 - Do not stick your ear near it. The hiss is a warning. It will arc.
 - Tiny violet discharge into air, seen in dark.
 - Clean and repair.
 - Remove sharp edges from object.
 - Or cover with insulating compound
 - Insulate with corona dope or silicon glue.

Scope Repair

- Problems of insulators and shaft couplings
 - HV standoffs and enclosures
 - Insulated non-conductive shafts
 - Insulating shaft couplers, u-joints
 - Shafting and couplers often found on intensity and focus pots.
 - Any control that is >500V to GND
 - Dirt is the real enemy
 - Cleaning Scrubbing Wiping with non-residue solvent.
 - Remove carbon tracks if burn has occurred.
 - Cover damaged area.

Scope Repair

- Problems of CRTs
 - Replace it for
 - Internal shorts
 - Dynamic shorts with HV applied
 - Loose internal parts
 - Burn marks on screen
 - Can you live with it?
 - Search for replacement.
 - Heater does not light
 - Neck warm?
 - Check heater voltage
 - Check solder on pins
 - Low emission, poor focus, low brightness
 - Check all operating voltages against instrument manual or CRT manual
 - Standard CRT rejuvenation techniques as last resort

Scope Repair

- HV Supply Issues
 - Check manual for correct potentials
 - Is supply oscillator-driven?
 - Rectifier or voltage multiplier
 - Some have 2 or 3 tubes
 - Open or burned resistors
 - Also check CRT circuit voltage dividers
 - Short on intensity or focus pot?
 - Shorted capacitor
 - Leaky PCB capacitor – clean up, bag, dispose in trash
OK; EPA definition “small PCB capacitor”

Scope Repair

- DC Coupled Amplifier Issues
 - Can cause beam to be held off the screen to the side, making it look like the CRT is faulty.
 - Tip: connect all 4 deflection plates together momentarily. Spot should appear on screen.
 - Transistorized units – check potentials at each device. Work as if it were an audio power amplifier.
 - Tube units - check all potentials on each tube using the cathode voltage as the (-) VOM lead/reference point.
 - Find missing/wrong voltages
 - Use tube manual as guide if instrument manual is not available.
 - Start at front end and work towards deflection plates.
 - The usual suspects
 - Tubes, Resistors, Capacitors
 - DC amplifier grid and plate voltages change when the position or centering controls are moved. An audio generator is also useful.
 - Using a scope to troubleshoot a scope is a plus.

References:

Most of the pictures in this presentation were taken from the materials listed here. We owe the authors of these documents a debt for their contributions. It is advisable to study these materials in order to increase one's knowledge of CRT-based oscilloscope technology, use, and maintenance. These documents are available freely on the WWW.

- **THE CATHODE RAY TUBE AT WORK, John Rider**
- **Hughes Memo-Scope 104D Instruction Manual, Hughes Aircraft Company**
- **Know Your Oscilloscope, Paul C. Smith**
- **Troubleshooting With the Oscilloscope, Robert G Middleton**
- **Oscilloscope Techniques, Alfred Haas**
- **The Cathode-Ray Oscilloscope, Charles Sicuranza**
- **Cathode Ray Tube Displays, Louis N Ridenour, MIT Radiation Series V22**
- **Radio and TV Test Instruments, Hugo Gernsback**
- **Sylvania 1959 Tube Manual, Sylvania**
- **Tektronix 545 Oscilloscope Manual, Tektronix**
- **Precision Electronics ES-500 Oscilloscope Manual, Precision Electronics**
- **Bell and Howell 9560-1 / Heathkit 100-203-31 5" Oscilloscope Manual**

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Errata

- Page 13: Grid voltage should be 0 to -220V per tube manual and in the practical example should be -1350 to -1570V . The power supply design voltage could be adjusted to compensate for any difference.
- Page 14: same corrections as page 13.

Questions?

Thanks!

Free stuff:

- DVD with reference materials