Oscilloscope Development, 1943-57

Peter D. Hiscocks

Professor Emeritus, Electrical Engineering, Ryerson University

phiscock@ee.ryerson.ca

March 15, 2011

Contents

List of Figures

1 Introduction

The oscilloscope is a key instrument and enabling technology in Electrical Engineering. It has supported and benefited from the advancement of electronics over the past 60 year period. Here we examine the developments that lead up to modern oscilloscope technology.

This note compares the design of some early oscilloscopes in the USA between mid-1945 and mid-1950. During that period there was considerable innovation and advancement in oscilloscope design.

1.1 State of the Oscilloscope Art in 1943

By 1935, scopes were being made by General Radio, DuMont, General Electric and Radio Corporation of America...Before the surge occurred in CRT development for radar with the onset of World War II, GR dropped out of the scope business. [1]

Oscilloscope development had proceeded during WWII, especially to support radar and microwave circuit design. However, the capabilities of oscilloscopes were very limited. Oscilloscopes were used to view the shape of a waveform. Precise measurements of amplitude and frequency were performed with other instruments or by comparison with signals of known amplitude and frequency.

To give some perspective here are some of the obstacles faced by an oscilloscope designer of the mid 1940's:

- The cathode ray tube (CRT) was relatively new. Units were expensive and tended to be gassy. (One of Dumont's contributions was a hard-vacuum CRT.)
- No solid-stated devices existed, appart from point-contact diodes. Amplifying devices were vacuum tubes. Transistors come in two polarities - NPN and PNP - and this facilitates the design of many circuits. Vacuum tubes come in one polarity only. This makes it especially tricky to make a DC-coupled amplifier. The only rectifying devices were vacuum-tube diodes.
- Tubes operate at a high temperature, so they have warm-up drift during which time their characteristics change.
- Capacitors were physically large and some tended to fail after a period of time. This was particularly true inside the elevated temperature of tube equipment. There was significant tolerance on resistor values and the carbon-composition resistors of the day had excess noise.
- The power supply had to produce the B+ voltage for the vacuum tubes, which was typically 350 volts. In some designs, a similar negative voltage was required for level shifting. The CRT required a large negative voltage (eg, -1500 volts) at the cathode and an even large positive voltage (eg, 3500 volts) if the CRT included a post-deflection accelerator (PDA).

All of this inevitably contributed to an instrument that is large, heavy, power-hungry and expensive.

The instruments studied in this paper are summarized in the table of section 8 on page 33.

Early Terminology

- *oscillograph* for oscilloscope
- Capacitance in $\mu\mu$F (micro-micro-Farad) is now called *pF* (picoFarad)
- Frequency in cycles-per-second (cps) now called *Hz* (Hertz).

2 Dumont 224-A Oscillograph, 1943

DuMont had started company in late 1931 after leaving DeForest Radio Co. in Passaic, N. J., where he had been chief engineer and where he developed technology for manufacturing vacuum tubes and pursued television technology. DuMont's new company, in the basement of his home in Upper Montclair, N. J., began manufacturing cathode-ray tubes and later also made cathode-ray oscilloscopes. [1].

Dumont subsequently diverted energy from oscilloscope development into television receivers and a broadcasting network. *By 1937-38 the company was also becoming a major producer of TV receivers. It was first to introduce large-screen (14-inch) TVs and in 1939 had 14-inch sets at the New York World's Fair where others had 7-inch sets. Later, DuMont made a name in television transmitters and studio equipment and started a separate business, DuMont Broadcasting Corp., which operated television stations.* [1]

This oscilloscope is one of the earliest instruments available as a commercial device. The manual is dated 1943.

2.1 Dumont 224-A Features

Figure 1 shows the instrument. The input connections are by binding posts (this is pre-BNC connector) except for the probe connection, which is coaxial. The probe can be seen in the lid of the cover. From the schematic (figure 3), the probe divide ratio is about 3.7:1, compensated.

The screen is not yet divided into large and small divisions, as became usual practice later. The CRT is round, curved face and did not have PDA (post-deflection acceleration). This would limit the trace brightness at high sweep rates.

Some points of interest on the specifications:

- At 14 inches high, 15 inches deep and 8 inches wide, and 49 pounds this is a large, heavy unit.
- One vertical channel only, AC coupled only.
- Vertical channel frequency response, 20Hz to 2MHz. The frequency response is shown in figure 2.
- Power supply consumption is over 300 watts.

The retail cost of the Dumont 224A is not known, but we can make some educated guesses. In 1948 a Dumont oscillograph (oscilloscope) cost significantly less than the Tek 511, which was introduced at $700. Dumont felt that this was far too expensive. [1]. A price in the order of $200 in 1948 would be about $3000 in 2009 dollars (see section 11), much more than an individual could afford.

Pages 7 and 8 show the schematic. The nicely-drawn diagram is simple enough to fit on one-plus pages. Part values are given to support maintenance. In those days, components (such as tubes and capacitors) were unreliable and it was common for them to fail. It was expected that the owner would have to do maintenance on the instrument.

The vertical amplifier is a two-stage preamp followed by a push-pull stage to drive the CRT plates. Inductor peaking is evident. The peaking circuits are quite simple. The vertical channel gain is uncalibrated. The front panel controls indicate 0-100 rather than deflection factors.

As was common at this time, the timebase consists of a free-running oscillator which is 'synchronized' to the vertical signal. The vertical signal is coupled into the oscillator and with some tweaking of the oscillator controls the timebase could be made to sync to the vertical signal. Later timebases used a 'triggered' approach which is much more versatile and reliable.

Later oscilloscopes standardized on a CRT 5 inches in diameter. The CRT in the 224A is 3 inches diameter. A smaller CRT would be less expensive and easier to drive from the vertical amplifier.

The power supply transformer is a 60Hz line operated unit that produces about +400VDC for the vertical amplifier and timebase, and -1100VDC for the cathode ray tube. The transformer was probably a major component in the size and weight of the instrument. The power supply regulator (output voltage +190 volts) is quite sophisticated. Several of the supply output voltages are lethal. A warning in the manual states:

WARNING: It is inadviseable to operate this cathode-ray oscillograph with the case removed. There are potential differences as high as 1500 volts in this instrument, and it should be treated with proper caution.

No kidding.

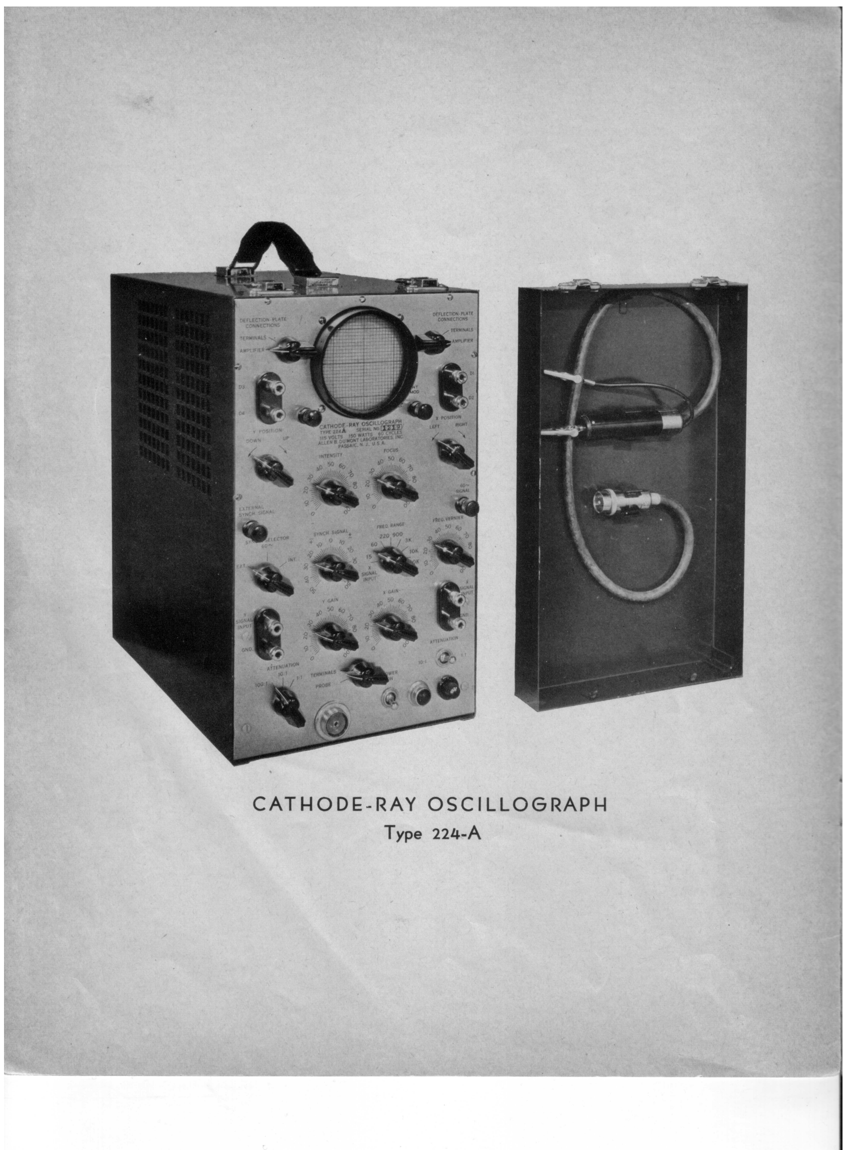


Figure 1: Instrument Picture

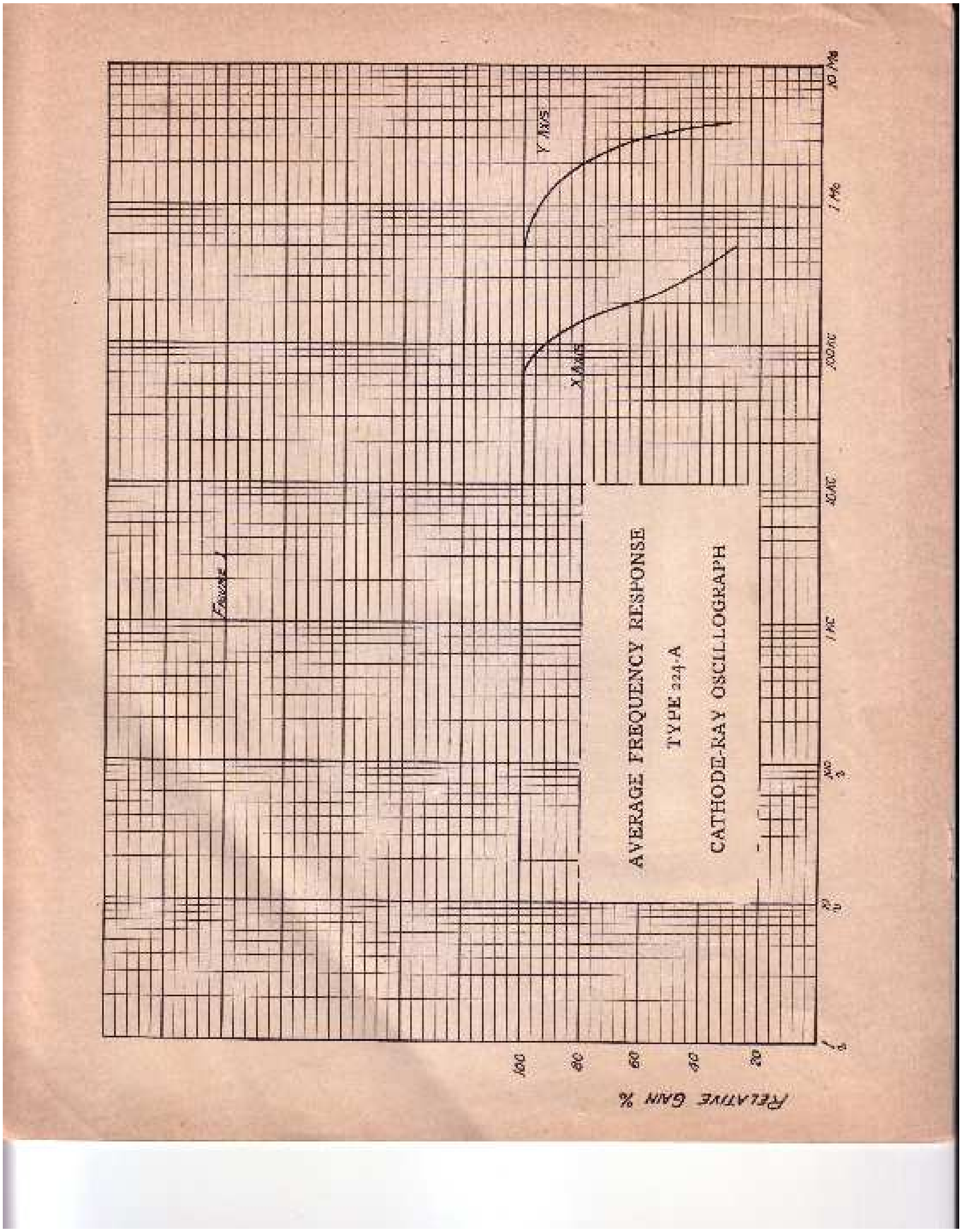
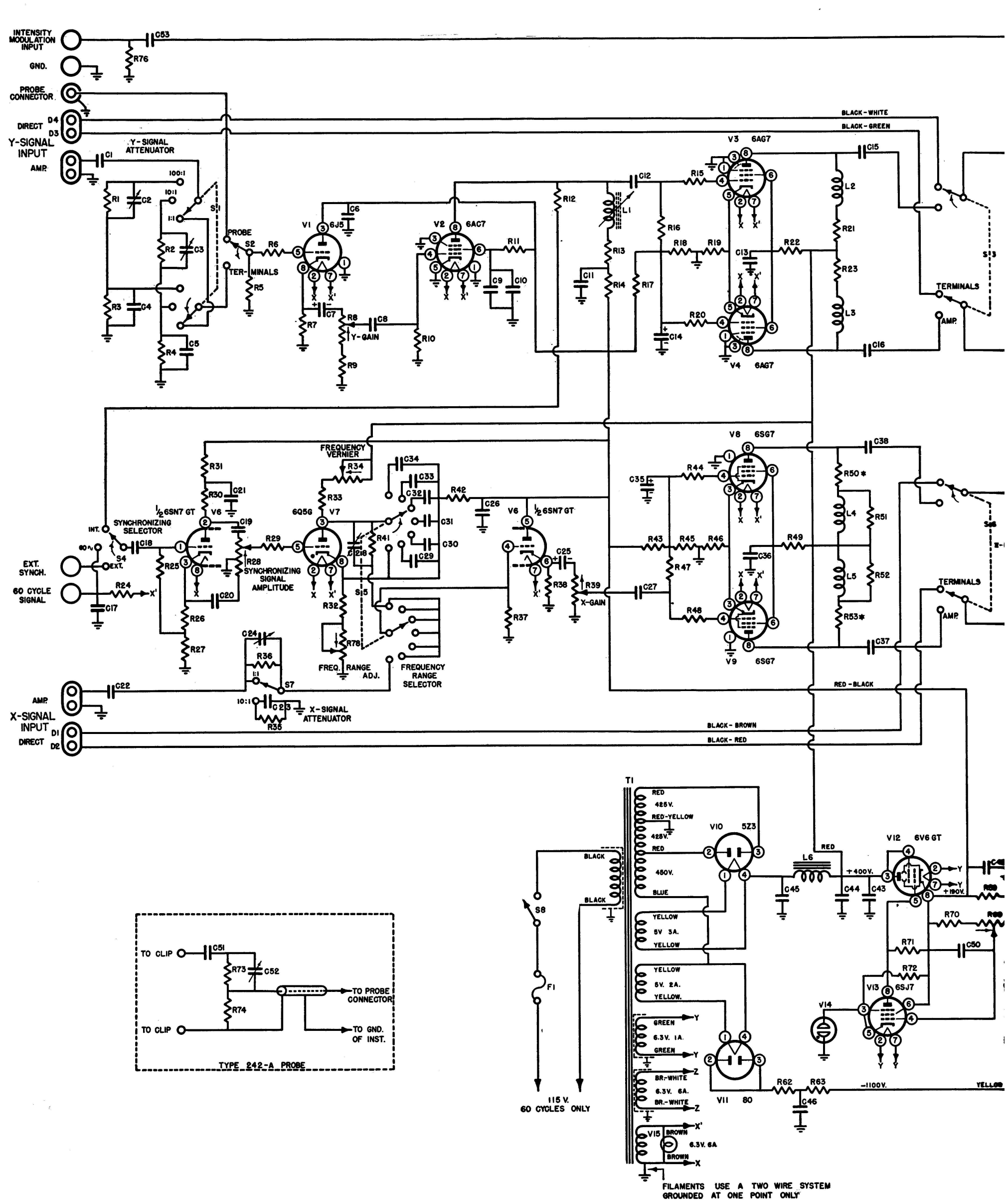


Figure 2: Frequency Response



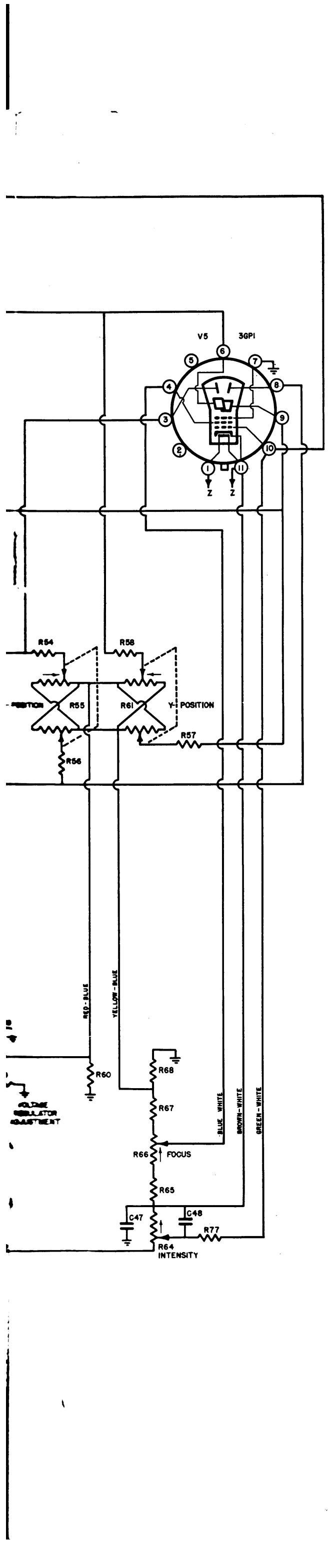
SCHEMATIC OF CIRCUIT

TYPE 224-A

CATHODE-RAY OSCILLOGRAPH

DD-840-D-2

Figure 3: Schematic, Left Side



COMPONENT PARTS LIST

C1	0.2 μf. 400V.
C2	3-12 μμf. 500V.
C3	3-12 μμf. 500V.
C4	.001 μf. 500V.
C5	70 μμf. 500V.
C6	0.2 μf. 400V.
C7	100 μf. 50V. elec.
C8	0.1 μf. 1000V.
C9	0.5 μf. 600V.
C10	0.5 μf. 600V.
C11	4 μf. 600V.
C12	0.5 μf. 200V.
C13	0.5 μf. 600V.
C14	25 μf. 50V. elec.
C15	0.1 μf. 1000V.
C16	0.1 μf. 1000V.
C17	0.25 μf. 400V.
C18	.05 μf. 400V.
C19	0.1 μf. 1000V.
C20	0.1 μf. 1000V.
C21	0.5 μf. 600V.
C22	0.25 μf. 400V.
C23	70 μμf. 500V.
C24	3-12 μμf. 500V.
C25	100 μf. 50V. elec.
C26	0.2 μf. 400V.
C27	0.5 μf. 600V.
C28	3-12 μμf. 500V.
C29	0.15 μf. 400V.
C30	.04 μf. 400V.
C31	.01 μf. 400V.
C32	2500 μμf. 500V.
C33	600 μμf. 500V.
C34	150 μμf. 500V.
C35	25 μf. 50V. elec.
C36	0.5 μf. 600V.
C37	0.1 μf. 1000V.
C38	0.1 μf. 1000V.
C39	Deleted
C40	Deleted
C41	Deleted
C42	Deleted
C43	4 μf. 600V.
C44	4 μf. 600V.
C45	4 μf. 600V.
C46	0.5 μf. 1500V.
C47	0.5 μf. 1500V.
C48	0.5 μf. 600V.
C49	0.5 μf. 600V.
C50	0.5 μf. 600V.
C51	.05 μf. 400V.
C52	4-30 μμf. 500V.
C53	.05 μf. 1600V.
F1	3 amp. fuse
L1	70-250 μh.
L2	170 μh.
L3	170 μh.

L4	8.5 mh.
L5	8.5 mh.
L6	19 h. 150 ma.
R1	2 meg. ½W.±5%
R2	2 meg. ½W.±5%
R3	20 K ½W.±5%
R4	250 K ½W.±5%
R5	2 meg. ½W.
R6	50 ohm ½W.
R7	1 K ½W.
R8	1 K pot.
R9	110 ohm ½W.
R10	25 meg. 1W.
R11	75 K 1W.
R12	100 K ½W.
R13	2.5 K 1W.
R14	10 K 3W.
R15	50 ohm ½W.
R16	75 K ½W.
R17	100 K 1W.
R18	15 K ½W.
R19	500 ohm 3W.
R20	50 ohm ½W.
R21	3.5 K 10W. non ind.
R22	15 K 10W.
R23	3.5 K 10W. non ind.
R24	35 K ½W.
R25	500 K ½W.
R26	1.5 K ½W.
R27	8 K ½W.
R28	200 K C.T. pot.
R29	20 K ½W.
R30	10 K 1W.
R31	10 K 1W.
R32	1 K ½W.
R33	500 K 1W.
R34	4 meg. pot.
R35	250 K ½W.±5%
R36	2 meg. ½W.±5%
R37	2 meg. ½W.
R38	10 K ½W.
R39	10 K pot.
R40	Deleted
R41	3 meg. ½W.
R42	75 K 3W.
R43	100 K 1W.
R44	50 ohm ½W.
R45	15 K ½W.
R46	2 K 1W.
R47	2 meg. ½W.
R48	50 ohm. ½W.
R49	75 K 3W.
*R50	37.5 K 2W.
R51	20 K ½W.
R52	20 K ½W.
*R53	37.5 K 2W.
R54	5 meg. ½W.

R55	4 meg. dual pot.
R56	5 meg. ½W.
R57	5 meg. ½W.
R58	5 meg. ½W.
R59	100 K 1W.
R60	100 K 1W.
R61	4 meg. dual pot.
R62	10 K 1W.
R63	100 K. 1W.
R64	100 K pot.
R65	150 K 1W.
R66	500 K pot.
R67	750 K 1W.
R68	200 K 1W.
R69	500 K pot.
R70	500 K 1W.
R71	500 K 1W.
R72	100 K 1W.
R73	680 K ½W.±5%
R74	250 K ½W.±5%
R75	Deleted
R76	1 meg. 1W.
R77	500 K 1W.
R78	1 K pot.
S1	D.P. 3.T.
S2	S.P. D.T.
S3	D.P. D.T.
S4	S.P. 3.T.
S5	D.P. 7.T.
S6	D.P. D.T.
S7	S.P. D.T.
S8	S.P. S.T.
T1	Power Transformer Part No. 20-177
V1	6J5
V2	6AC7
V3	6AG7
V4	6AG7
V5	3GP1
V6	6SN7GT
V7	6Q5G
V8	6SG7
V9	6SG7
V10	5Z3
V11	80
V12	6V6GT
V13	6SJ7
V14	¼ W. neon
V15	6.3 V. .15 amp.

*2 75 K 1W. in parallel

K = ohms × 1000 (example 15K = 15000 ohms)

Figure 4: Schematic, Right Side

3 Dumont 248 Oscillograph, 1945

The 248 is larger, heavier and more sophisticated than the 224a. It has a larger vertical bandwidth (5MHz vs 2MHz), includes a vertical channel delay (for the observation of the leading edge of pulses) and a triggered timebase.

The 5 inch CRT includes a selectable 2000 volt/4000 volt post deflection accelerator, which increases trace intensity at fast sweeps and low repetition rates[1].

The vertical channel is still AC coupled. The vertical calibration is limited to three gain steps: $\times 1$, $\times 10$ and $\times 10$, with a variable gain control. The manual advises that the vertical sensitivity is halved at the higher acceleration voltage. This further limits the ability to make accurate voltage measurements.

The triggered timebase has four sweep durations: 5, 25, 100 and 1000 μSec. (The 1:2:5 sequence, for vertical or horizontal settings, had not yet been invented.)

As usual for the day, the vertical and horizontal deflection plates can be accessed from front panel terminals. Direct access removes the frequency limitations of the vertical and horizontal amplifiers. This allows the scope to display a Lissajous figure for the precise determination of a radio frequency.

The power supply (page 11) is entirely line operated (no high frequency oscillators), with 4 power transformers, a 19 henry inductor and a 7 henry inductor for filtering. As shown on the schematic of page 14, the 425V B+ line of the vertical amplifier is regulated. This regulator uses a total of 7 tubes: three triodes as the series-pass element, a pentode as the error amplifier, a gas-discharge tube as the reference element and two diode rectifiers. A delay relay alows time for the filaments to reach temperature before applying the B+ voltage.

The Dumont 248 must be one of the largest, heaviest oscilloscopes ever made. It's divided into two units: a display and the power supply. Together, they total a volume of 5 cubic feet. Some indication of the size can be obtained from the picture on page 10, recognizing that the CRT is 5 inches in diameter.

The total weight of the unit is 170 pounds: 60 pounds for the display (the *indicator unit*), 110 pounds for the power supply. Notice in the photograph page 10 that the display unit has one carrying handle. The power supply has two[2].

The *Someone Stole My Scope!* situation (as a co-worker makes off with one's test equipment) is familiar to anyone who has worked in an electronics shop. This would not be a problem with the Dumont 248: the would-be thief would need a fork lift truck or several accomplices.

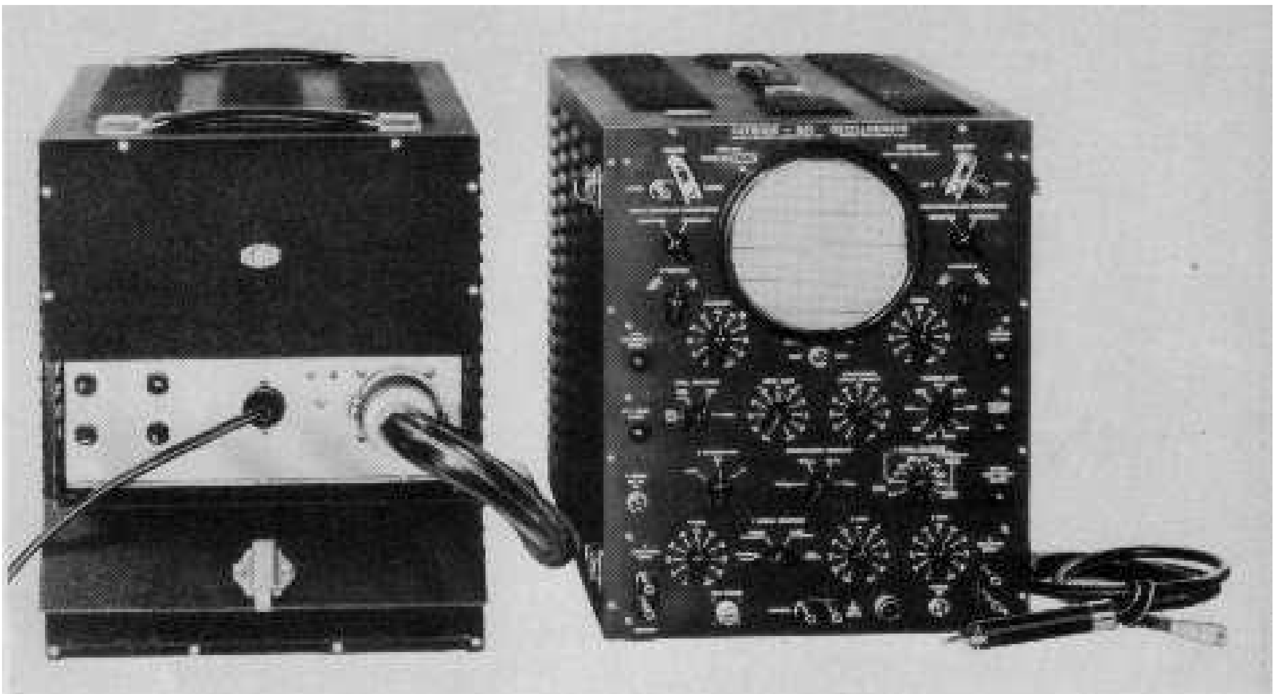
Photographs and schematics of the Dumont 248 are shown on pages 10 to 14.

It's interesting to compare the timebase of the Dumont 248 (page 13) with that of the Tektronix 511 (page 19). The Tek circuit abandons the earlier *synchronized oscillator* approach and focusses entirely on a triggered sweep.

[1] It is possible to obtain the same result by making the cathode voltage more negative. However, this reduces the deflection sensitivity of the CRT, which places more demand on the vertical and horizontal amplifiers. The PDA has less effect on deflection sensitivity, so it is the preferred approach to increase intensity.

Even with a high accelerator voltage, the trace was dim at low repetition rates. A so-called *fishmask* accessory was available to help with this. It was a rubber tube, cutout for the observers face at one end and to be placed over the CRT face at the other. This device blocked ambient light. An engineer who used one of these things for an entire day would return home with a bizarre red mark around the face. To simulate this experience, place your face in the opening of a rubber boot.

[2] Tektronix also produced at least one model in which the display and power supply were in separate units, which the author recalls using in the 1960's. The two units were more-or-less permanently installed on a Tektronix scope dolly.



Du Mont Type 248 Cathode-Ray Oscillograph

Figure 5: Instrument Picture

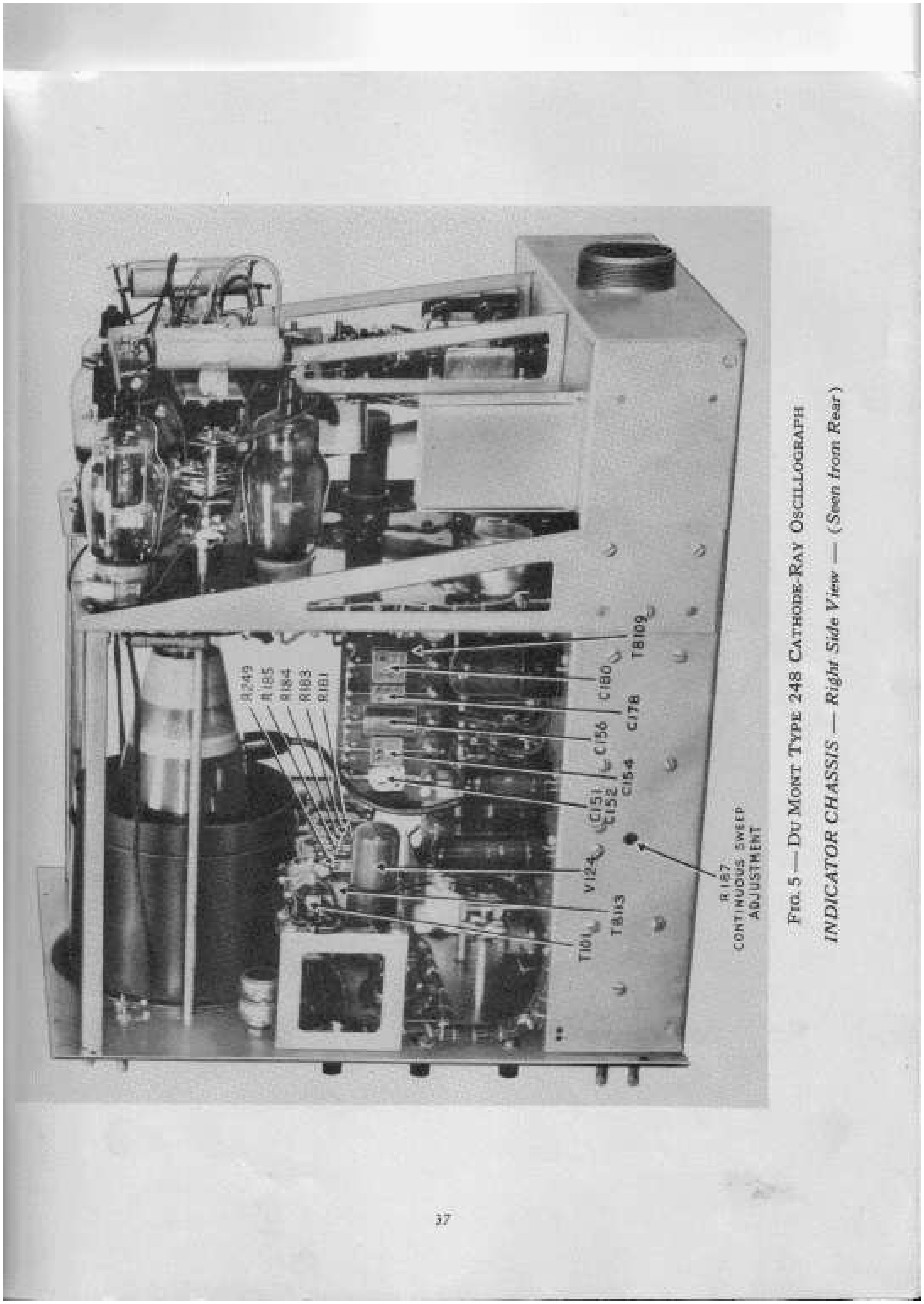


Figure 6: Display Unit Internals

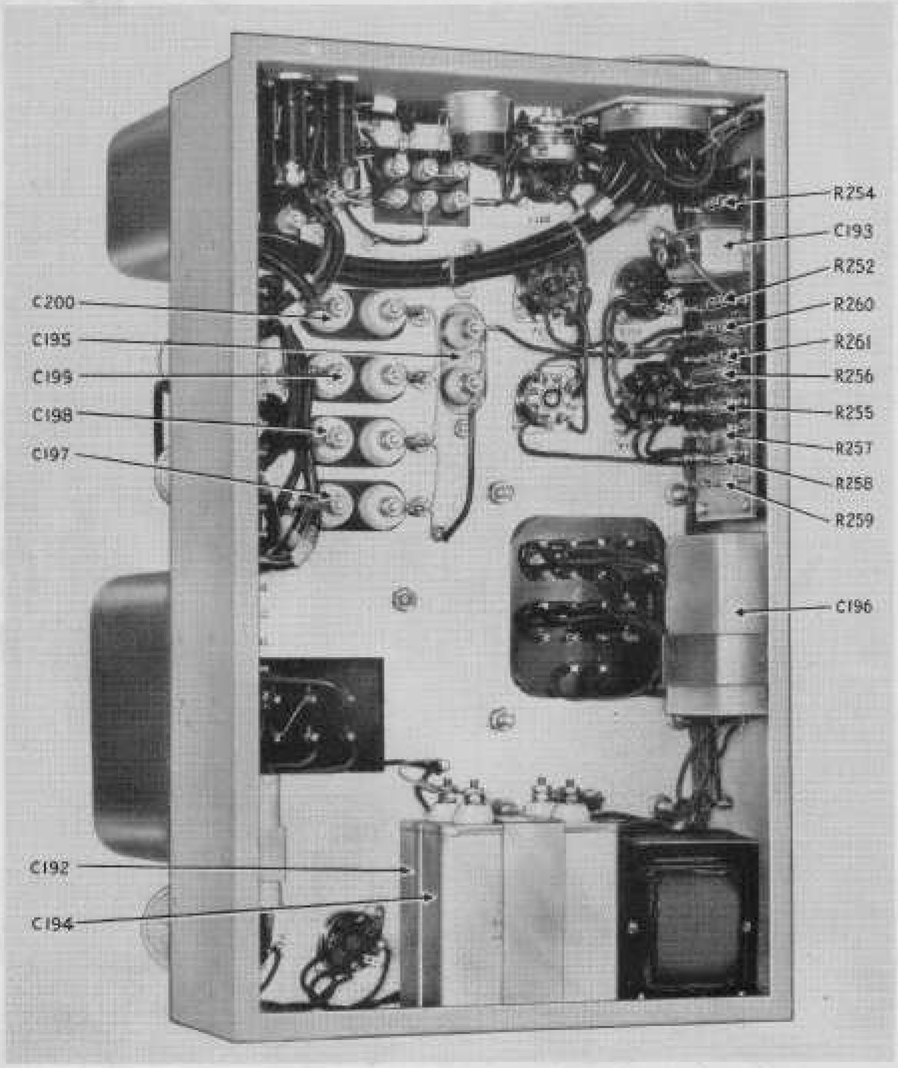
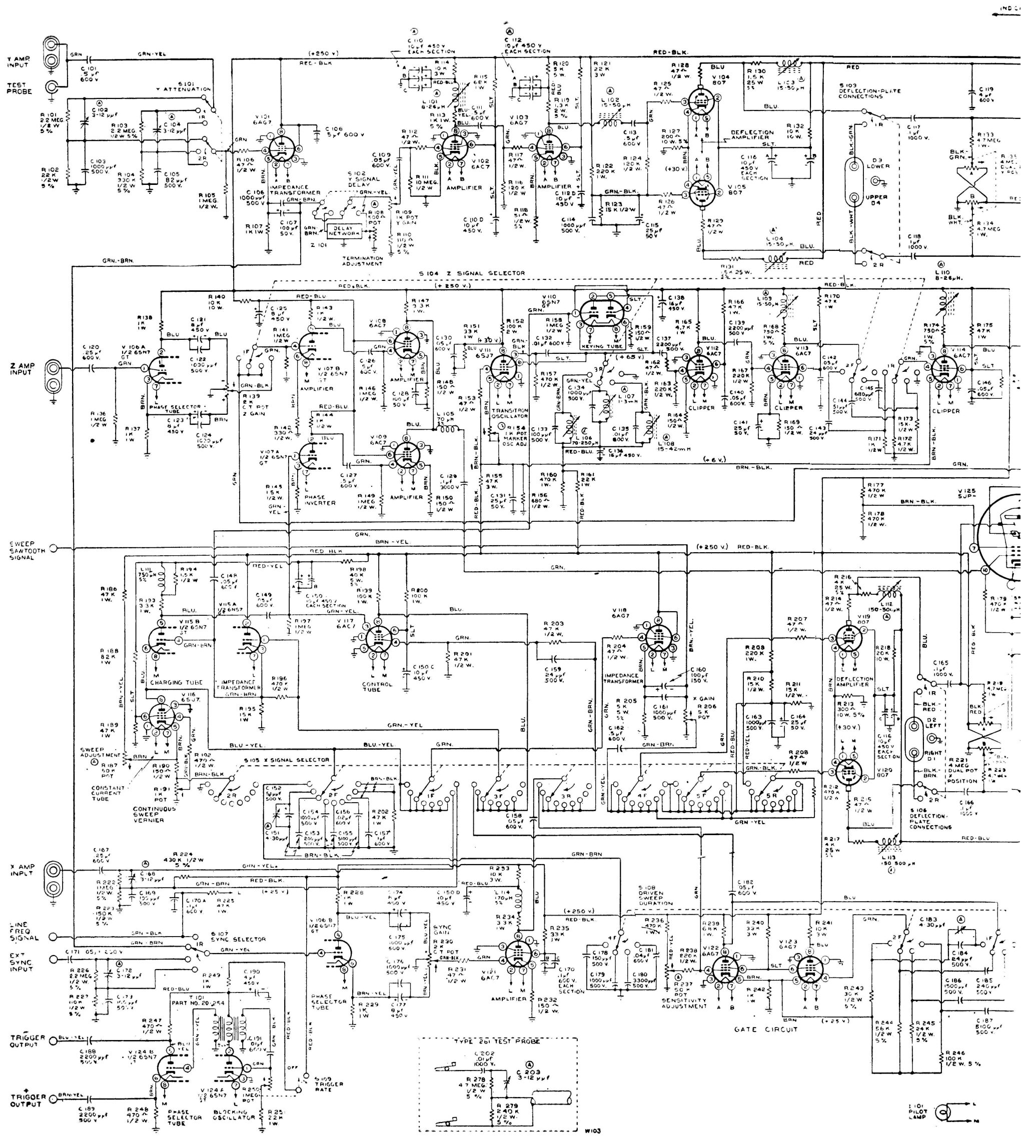


FIG. 10 — DU MONT TYPE 248 CATHODE-RAY OSCILLOGRAPH

POWER SUPPLY UNIT — Bottom, View A

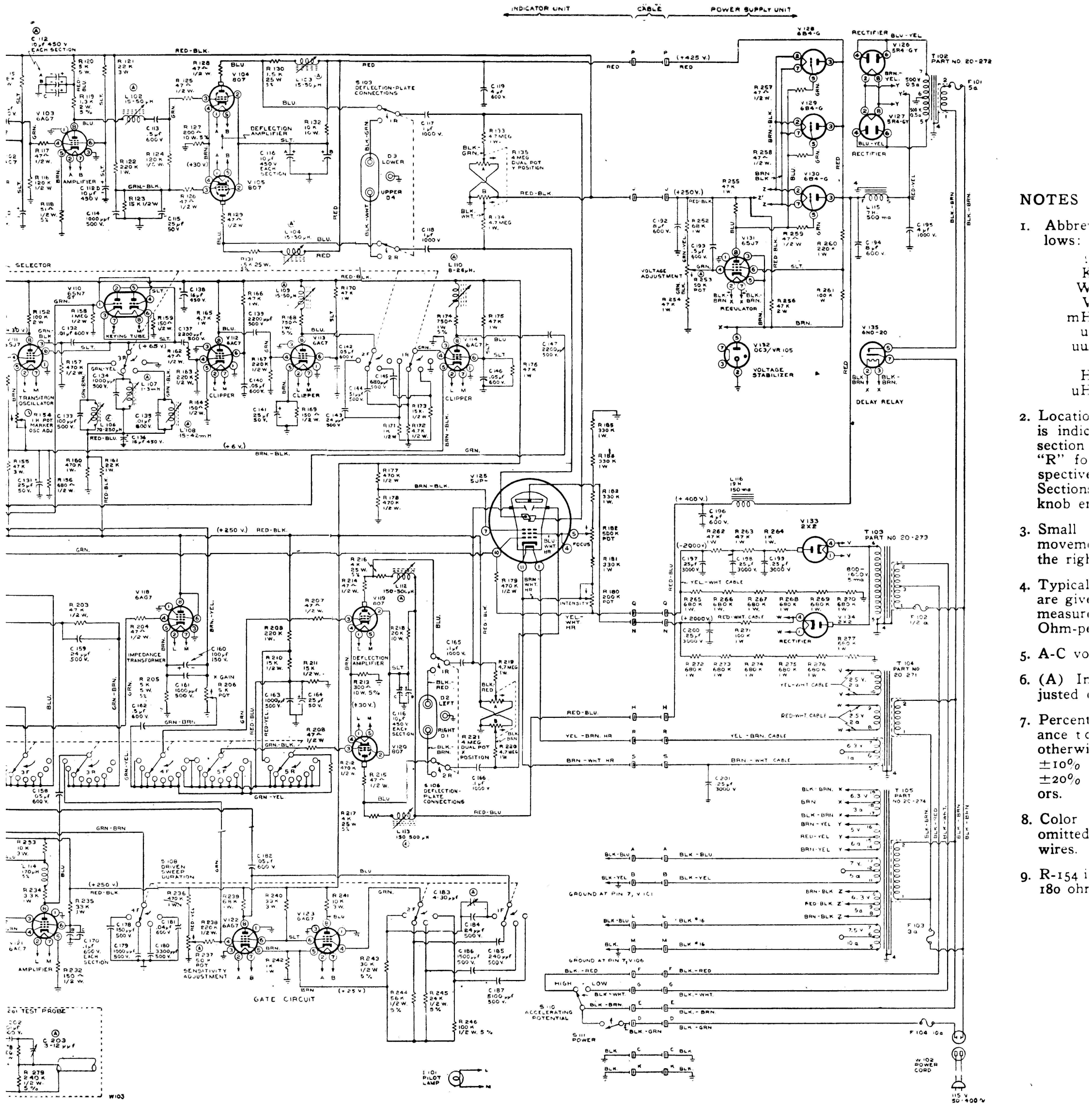
42

Figure 7: Power Supply Underside



DU MONT TYPE 248 CATHODE-RAY OS
SCHEMATIC OF CIRCUIT
Ref.: DD-4363-E-4

Figure 8: Schematic LHS



DU MONT TYPE 248 CATHODE-RAY OSCILLOGRAPH
SCHEMATIC OF CIRCUIT
Ref.: DD-4363-E-4

Figure 9: Schematic RHS

4 The Tektronix 511, 1948

The Tektronix company traces its roots to the electronics revolution that immediately followed World War II [2]. The company was founded by C. Howard Vollum and Melvin J. "Jack" Murdock in 1946.[3].

Vollum decided to build an oscilloscope from spare electronics parts being stockpiled by his partners from post-war government surplus sales. At the time, the Du Mont Company was the leading manufacturer of oscilloscopes, which were indispensable to the rapidly growing electronics industry. Vollum later told Forbes that Du Mont "wanted to fool around with big-time television. They were complacent about their scope." [3].

In contrast to Dumont and other oscilloscope companies such as RCA and General Electric, Tektronix remained almost totally focussed on oscilloscope design and development.

The first Tektronix scope was shown at the annual IRE (Institute of Radio Engineers) convention, 1948 [1]. An image of the Tektronix 511 from [5] is shown on page 17.

4.1 Specifications

The Tek 511 was a transitional product between the previous generation of oscilloscopes, represented here by the Dumont 224A and 248, and oscilloscopes that we would recognize as full-featured. The Tek unit still uses AC coupling in the vertical amplifier, and there is still only one vertical channel. However, there is clearly a movement toward calibrated amplitude and time measurements.

- A three-step adjustable calibration voltage is available for the vertical channel. The gain settings are still not calibrated, but a signal amplitude can be compared with a known voltage from the calibrator to determine amplitude.
- Sweep speeds are adjustable in units of time/cm (rather than CPS, cycles per second, as in previous units). Sweep speed is adjustable in stepped (not continuous) controls of SWEEP RANGE and SWEEP SPEED MULTIPLIER. A continuously variable SWEEP MAGNIFIER control can be disabled.
- As in the Dumont 248, the timebase can be *triggered*. Consequently this scope can display single-shot events that occur at random intervals, which is not possible with a synchronized timebase.
- Again, as in the Dumont 248, there is a delay line (optional at no doubt additional cost) for the vertical channel[4].
- Dumont oscilloscopes used a power-line operated transformer to generate the CRT high voltage. The Tek 511 uses a high-frequency oscillator to drive a much smaller, lighter step-up transformer. Total weight of the 511 was a reasonable 50 lbs.

4.2 Vertical Amplifier

The Tek 511 vertical amplifier is shown on page 18.

The preamp is a selectable one or two stage circuit, with a tradeoff of gain versus bandwidth. The amplifier is capacitively coupled, even between the output amplifier and the CRT vertical deflection plates.

The input attenuators are quite sophisticated. They can be compensated for pulse response and to present a constant capacitance to the input circuit.

[3]The current Wikipedia entry says *The companyâĂŹs founders C. Howard Vollum and Melvin J. "Jack" Murdock invented the worldâĂŹs first triggered oscilloscope in 1946, a significant technological breakthrough.* The Dumont 248 circuit description clearly refers to triggered operation, so this is a questionable claim.

[4]Delay lines later became standard in vertical amplifiers. It is a major design challenge to create an delay line – and the circuitry to drive it – that does not degrade pulse shape or bandwidth. As a consequence, delay lines added significantly to the cost of an oscilloscope. Modern digital oscilloscopes do not require a delay line and can locate the trigger point anywhere on the display.

Inductor-capacitor peaking circuits show up in the preamp first stage and in the output stage. These are more sophisticated that the Dumont 224.

The cathode ray tube has post-deflection acceleration (+1800V) which would improve the trace brightness for high sweep rates and infrequent repetitions. Overall, the vertical amplifier is a relatively simple affair. This would change in the future.

4.3 Timebase

The timebase is shown on page 19.

This circuit is quite modern in concept. There is significant circuitry but it can be broken into functional blocks, each of which can be optimized.

The trigger amplifier is AC coupled only but can selectable the slope of the trigger waveform. This drives a multivibrator, which functions as a primitive state machine to determine when the sweep waits, runs or resets. The sweep generator then produces the timebase ramp. This architecture continues to be used in analog oscilloscopes to this day.

The DC output voltage of the sweep amplifier is positive. Applying that directly to the horizontal deflection plates would attract the CRT electrons. Consequently the sweep amplifier (a differential amplifier) is direct coupled to the CRT plates via neon lamps, each of which provide a constant-voltage drop of about 90V, biased by the -800V supply. (Today we would use zener diodes.) This has the effect of moving the average output voltage of the amplifier to a negative voltage, which is more acceptable to the CRT.

4.4 Power Supply

The power supply (page 20) contains 13 tubes, three more than the Dumont 548. However, it contains only two transformers (one of which is a small, light high frequency unit) and no inductors. Moreover, there are two voltage regulators: one for the amplifier 450V B+ supply, a second for the high voltage oscillator.

Much attention is given to the circuit designs of oscilloscope vertical amplifier and timebase sections. However, the power supply is critical. In this case, the Tek 511 power supply is clearly superior to the Dumont 248: it's smaller, lighter and cost far less to manufacture.

Figure 10: The Tek 511

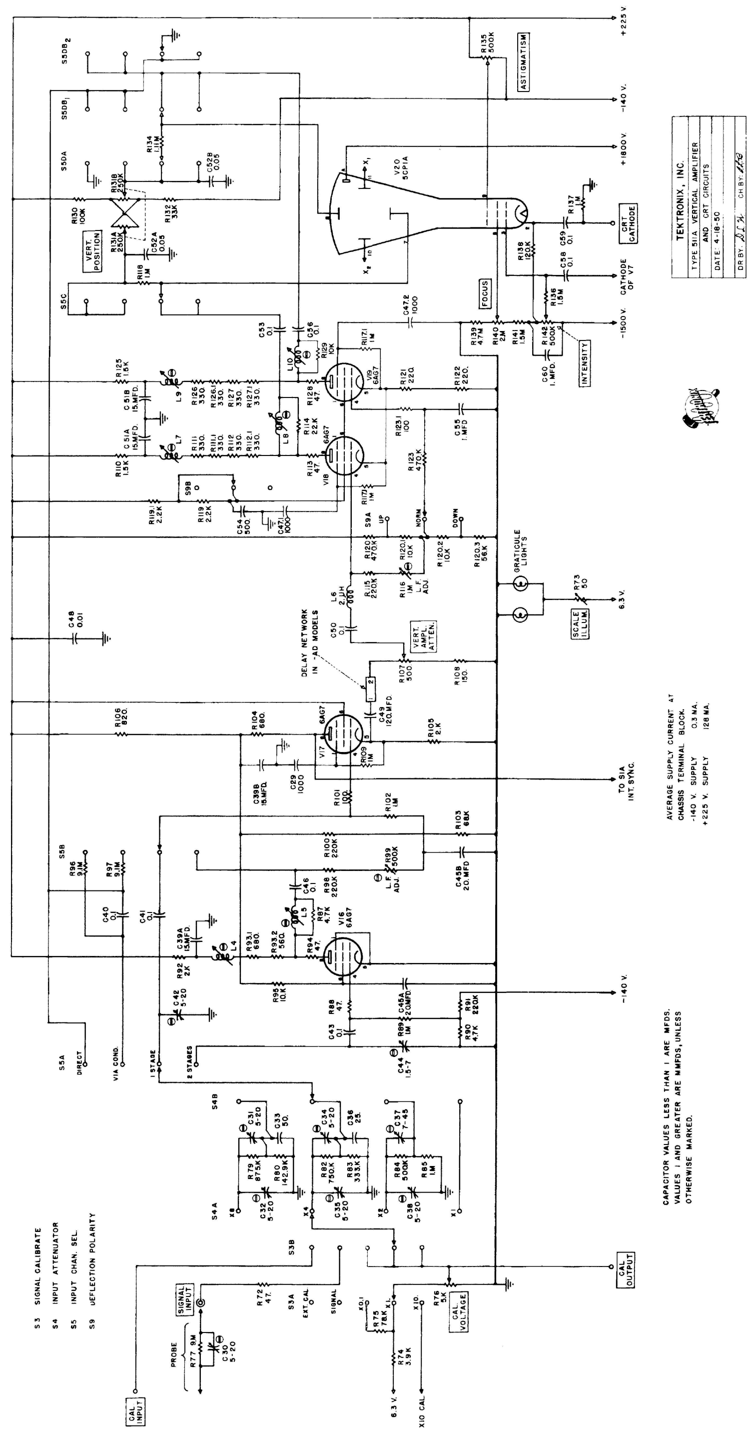


Figure 11: Tek 511 Vertical Amplifier

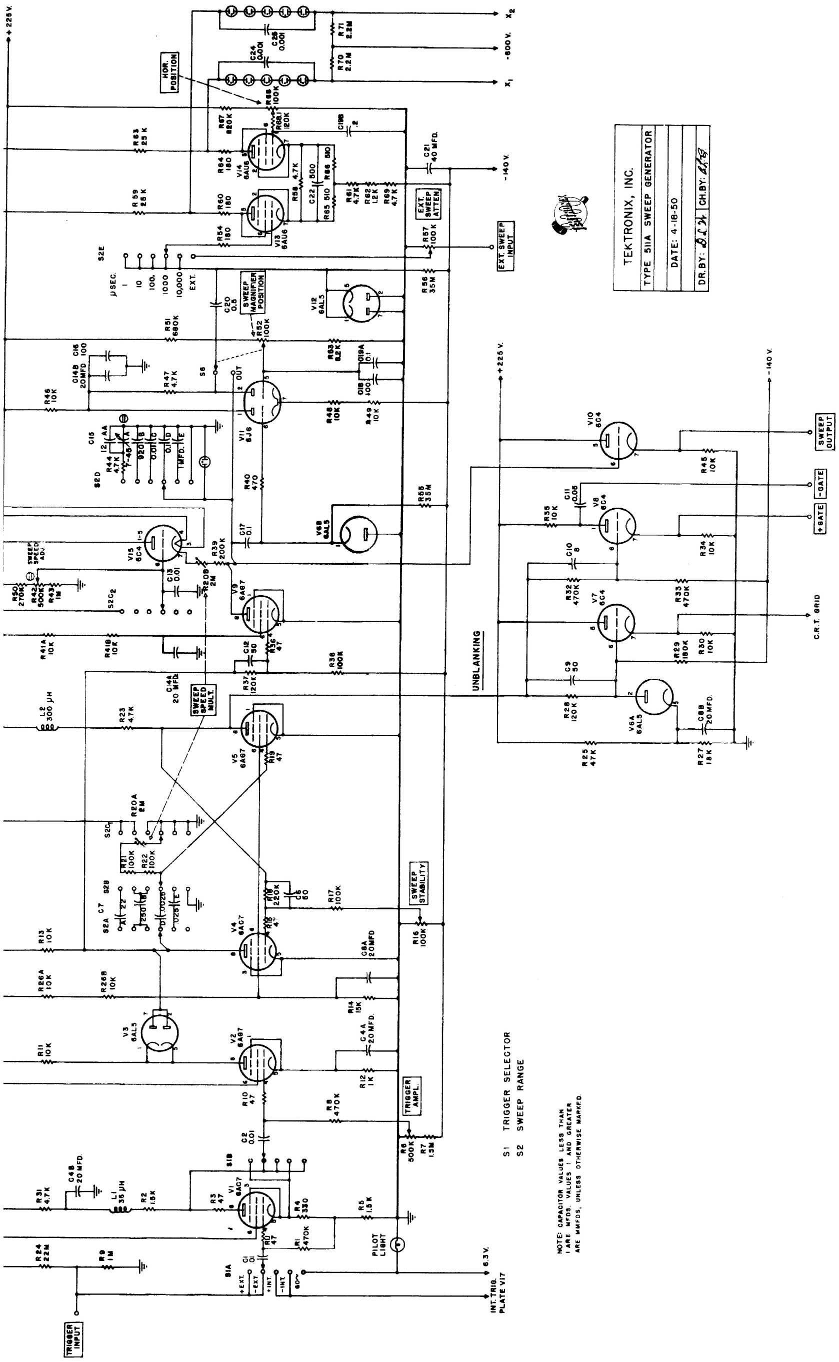


Figure 12: Tek 511 Timebase

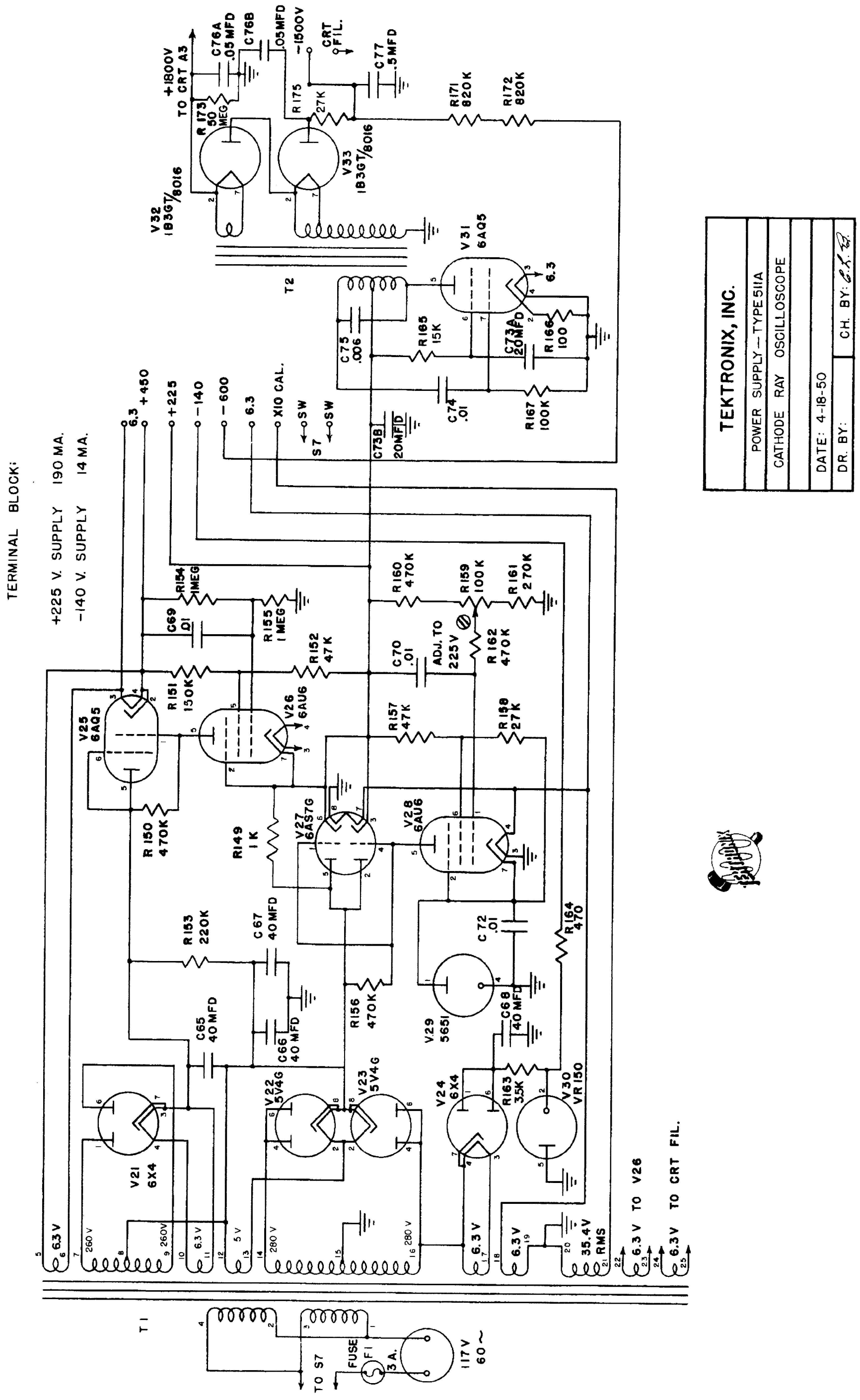


Figure 13: Tek 511 Power Supply

5 Dumont 304-A, 1953

The Dumont 304-A is the only Dumont oscilloscope to show up in the BAMA archive [8], which suggests that it was produced in large numbers and was relatively popular. Released some 8 years after the 248, shows an interesting change in emphasis.

An overall view of the instrument is on page 22. The CRT appears to be flat faced and the internal view shows that the CRT has a magnetic shield. The binding posts and knobs are relatively modern[5]. The weight is not given, but it must have been substantially lighter than its predecessor, the Dumont 248. (Note the single handle on the top cover). Appart from the gas-discharge tube used in the sweep circuit, the tubes are miniature type.

The schematic of the vertical amplifier is on page 23. The vertical amplifier (still only one) is direct coupled. It's fully differential, so in some circumstances it could be used to reject common mode signals (an example is given in the manual). However, the vertical attenuator is only available for one input to the differential amplifier, limiting its usefulness.

The vertical bandwidth is only 100kHz[6]. There is been surprisingly little attempt to extend the bandwidth with peaking networks: just one inductor in the CRT vertical plate driver stage[7].

The vertical gain has 4 steps 0.1:1:10:100 *Y Axis Full Scale* along with a *Multiplier* control which is labelled *Adjust with Calibrator*. Not as convenient as current practice, but approaching it.

The timebase can be triggered. It uses a gas-discharge tube to act as a relaxation oscillator, in which the grid establishes the discharge threshold. The sweep speed cannot have been very accurate, the continuously variable vernier control is labelled *10 to 100*. The sweep speed steps are in the sequence 2:10:50:250:1250:6k:30k rather than a strict 1:2:5 sequence.

The power supply is relatively simple. The only regulated supply is B+ for the vertical amplifier, and that is done with a single gas-discharge tube. The differential amplifier configuration, used in the vertical and horizontal amplifiers, inherently rejects power supply noise and drift – that may have allowed the supply to be largely unregulated. The transformer must be a relatively modest size: it is not visible in the internal photograph.

[5] Either that, or one can say that binding post design has not changed over the intervening years.

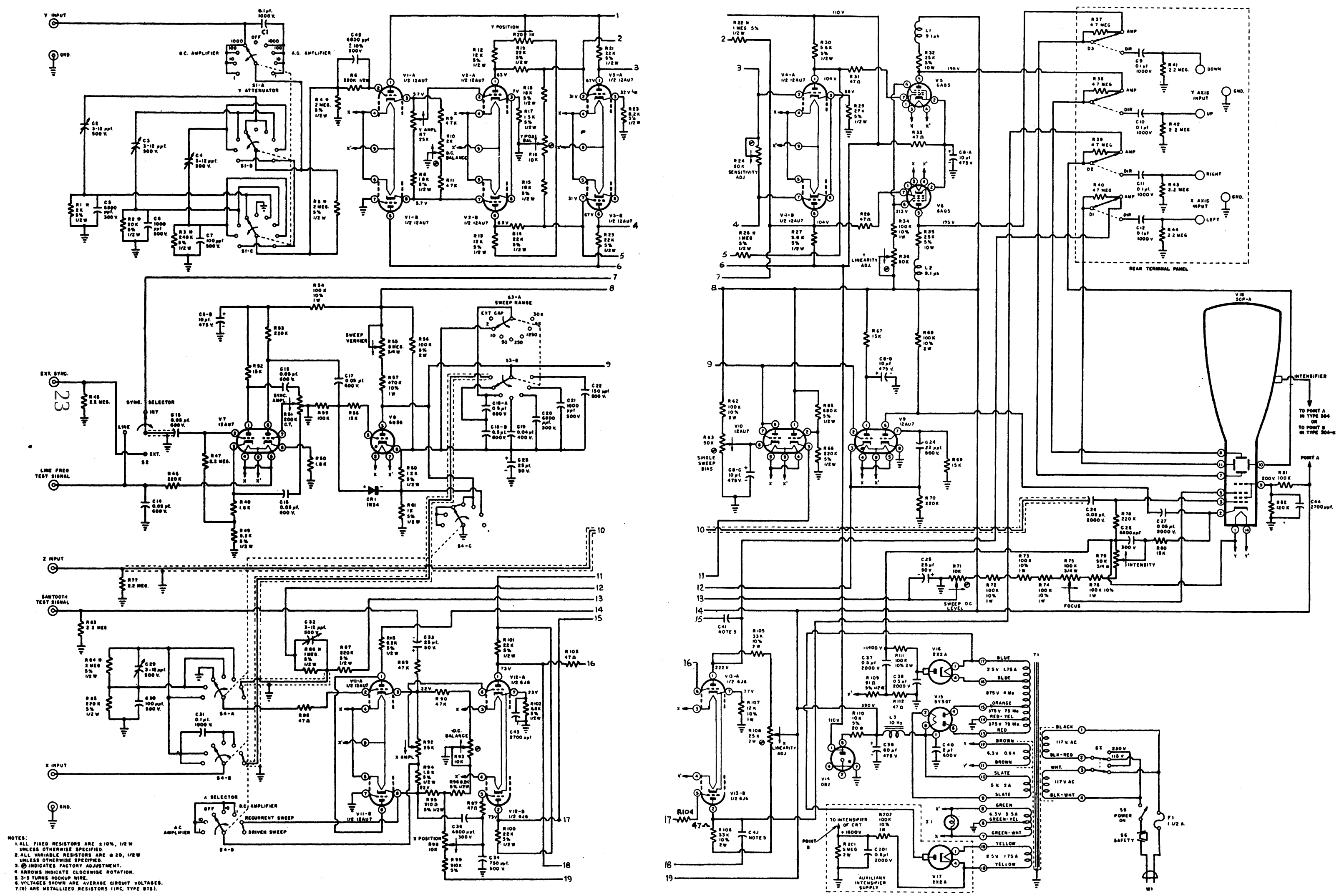
[6] Response is given as down 10% at 100kHz, which means the 3db bandwidth (approximately 30% down) would have been somewhat higher.

[7] Tektronix developed peaking networks to a high art. These doubled the vertical amplifier bandwidth and for many years they were a trade secret [11].

FIGURE 2-1a - FRONT PANEL VIEW OF TYPE 304-A

8

Figure 14: Dumont 304a



Schematic of Du Mont Models 304 and 304-H.

Courtesy Du Mont Labs.

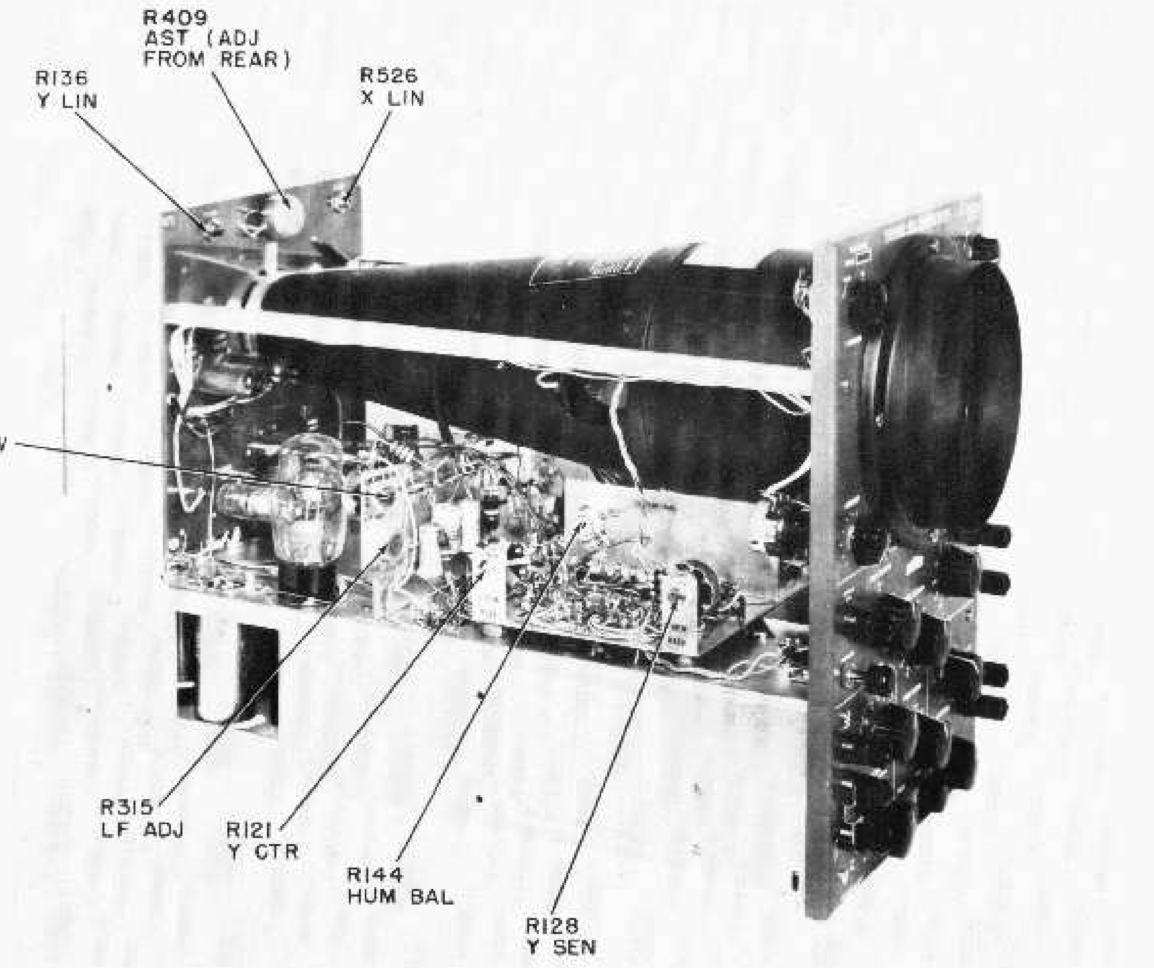


FIGURE 4-1a - IDENTIFICATION OF BACK-OF-PANEL CONTROLS, LEFT SIDE, TYPE 304-A

Figure 16: Interior

6 Heathkit O-11, 1957

It has been said that *an engineer is someone who can do for one dollar what any idiot can do for a hundred dollars* [9]. It takes real engineering skill to produce a low-cost product that fills a market niche. Heathkit were successful at doing so. They produced hundreds of products, ranging from an analog computer to a colour television set, among which were 18 different model oscilloscopes over the period from 1947 until 1990 [7]. Not only were these instruments cost effective, they were sold as kits that could be assembled without specialist skills in electronics. All of this must be kept in mind when comparing the specifications to other oscilloscopes of the day.

The O-11 oscilloscope is shown on page 26. It is relatively small and light compared to other units described in this paper, using aluminum rather than steel in the chassis and cover. The entire circuit uses 15 tube functions in 10 physical tubes, which is a very economical use of circuitry. As a consequence – and because there is no post-deflection accelerator supply – the 60Hz power transformer is relatively small. The transformer is visible in the chassis underside view on page 27. The bandwidth is a respectable 4MHz at a sensitivity of 10mV/cm.

In other respects, the scope is limited. It has one vertical channel, which is AC coupled. There is no calibrator. The vertical and horizontal channels are essentially uncalibrated. The timebase uses a synchronized oscillator, rather than a triggered multivibrator. The CRT does not have a post-deflection accelerator.

6.1 Vertical Channel

As an example of a design tradeoff, consider the vertical channel input attenuator. The Tektronix 511 attenuator system (page 18) uses three independent selectable attenuator circuits. Each one has two variable capacitors: one to optimize the step response and one to adjust the input capacitance so that all gain settings present the same capacitance at the input terminals.

The Heathkit schematic of page 28 also shows a three-position attenuator, but it is one single voltage divider with two adjustable capacitors. The Heathkit version has far fewer parts and probably worked well enough in its application domain. The Tektronix version is much more expensive to manufacture but would have been easier to adjust and optimize.

6.2 Line Voltage Compensation

Referring to the schematic of page 28, the Heathkit power supply is essentially unregulated.

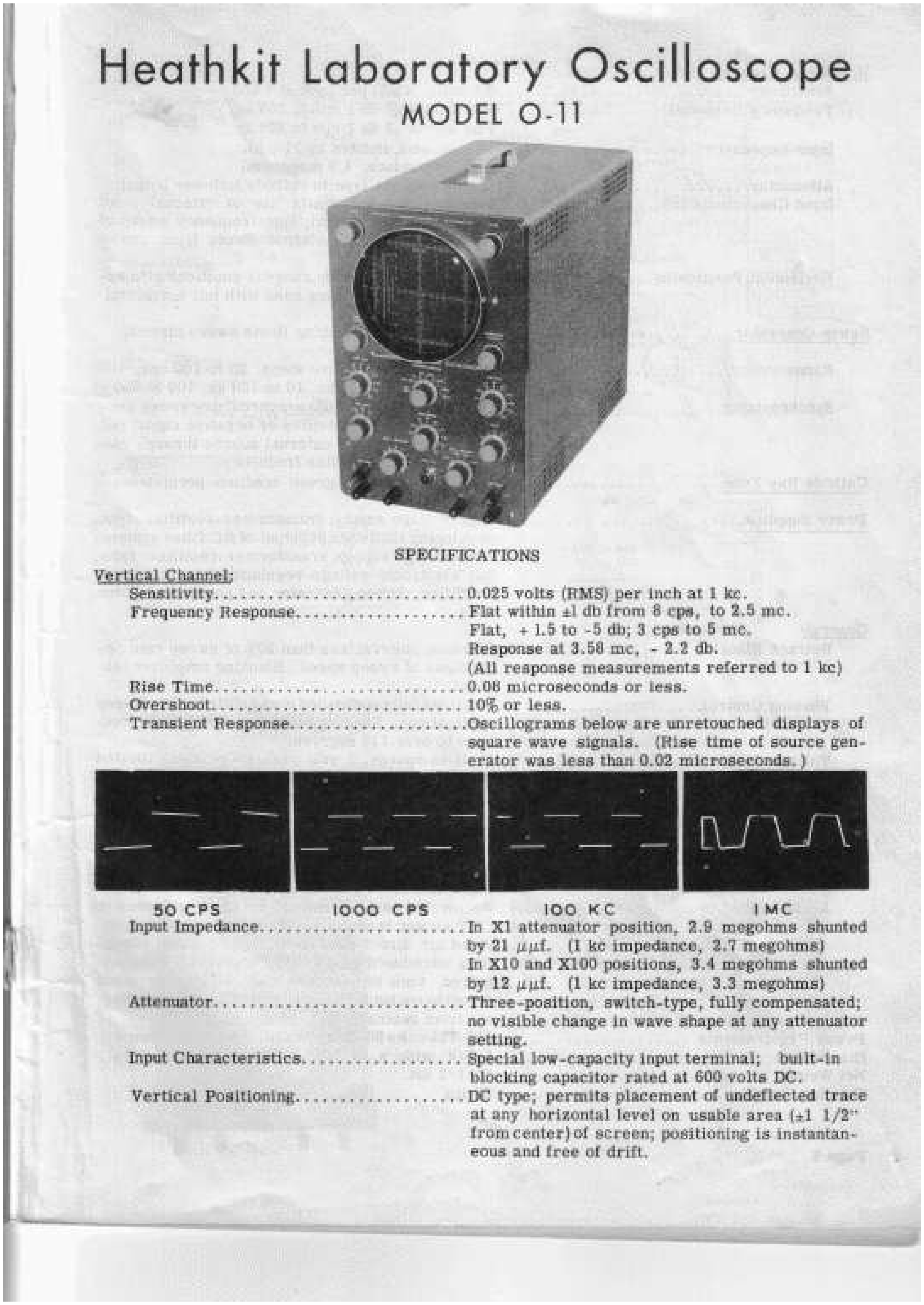
The function of V10 was a mystery until John Addis provided an explanation. He pointed out in correspondence that V10 increases the amplifier supply voltages as the CRT voltage increases. To quote John: *As the line voltage goes up, the hv supplies go up, decreasing the sensitivity of the CRT in both axes because the electrons travel through the deflection plates more quickly. V10 increases the amplifier power supplies voltages, increasing their gain, keeping the deflection relatively unscathed by line voltage changes. And it takes only one tube!*.

While the V10 regulator provides line regulation (compensation for changes in line voltage), there is nothing to provide load regulation (changes in load current).

6.3 Summary

In many ways, the O-11 is a ten-year old design, upgraded with modern parts. For example, minature type tubes replace the octal-base units that are found in a Dumont design of the mid 40’s.

Notwithstanding the limitations, it was affordable by hobbyists and technicians, and the performance was sufficient for the applications and the expectations of the day.



Heathkit Laboratory Oscilloscope

MODEL O-11

SPECIFICATIONS

Vertical Channel:

Sensitivity	0.025 volts (RMS) per inch at 1 kc.
Frequency Response	Flat within ±1 db from 8 cps, to 2.5 mc. Flat, + 1.5 to -5 db; 3 cps to 5 mc. Response at 3.58 mc, - 2.2 db. (All response measurements referred to 1 kc)
Rise Time	0.08 microseconds or less.
Overshoot	10% or less.
Transient Response	Oscillograms below are unretouched displays of square wave signals. (Rise time of source generator was less than 0.02 microseconds.)

50 CPS 1000 CPS 100 KC 1 MC

Input Impedance	In X1 attenuator position, 2.9 megohms shunted by 21 $\mu\mu$f. (1 kc impedance, 2.7 megohms) In X10 and X100 positions, 3.4 megohms shunted by 12 $\mu\mu$f. (1 kc impedance, 3.3 megohms)
Attenuator	Three-position, switch-type, fully compensated; no visible change in wave shape at any attenuator setting.
Input Characteristics	Special low-capacity input terminal; built-in blocking capacitor rated at 600 volts DC.
Vertical Positioning	DC type; permits placement of undeflected trace at any horizontal level on usable area (±1 1/2" from center) of screen; positioning is instantaneous and free of drift.

Figure 17: Heathkit O-11

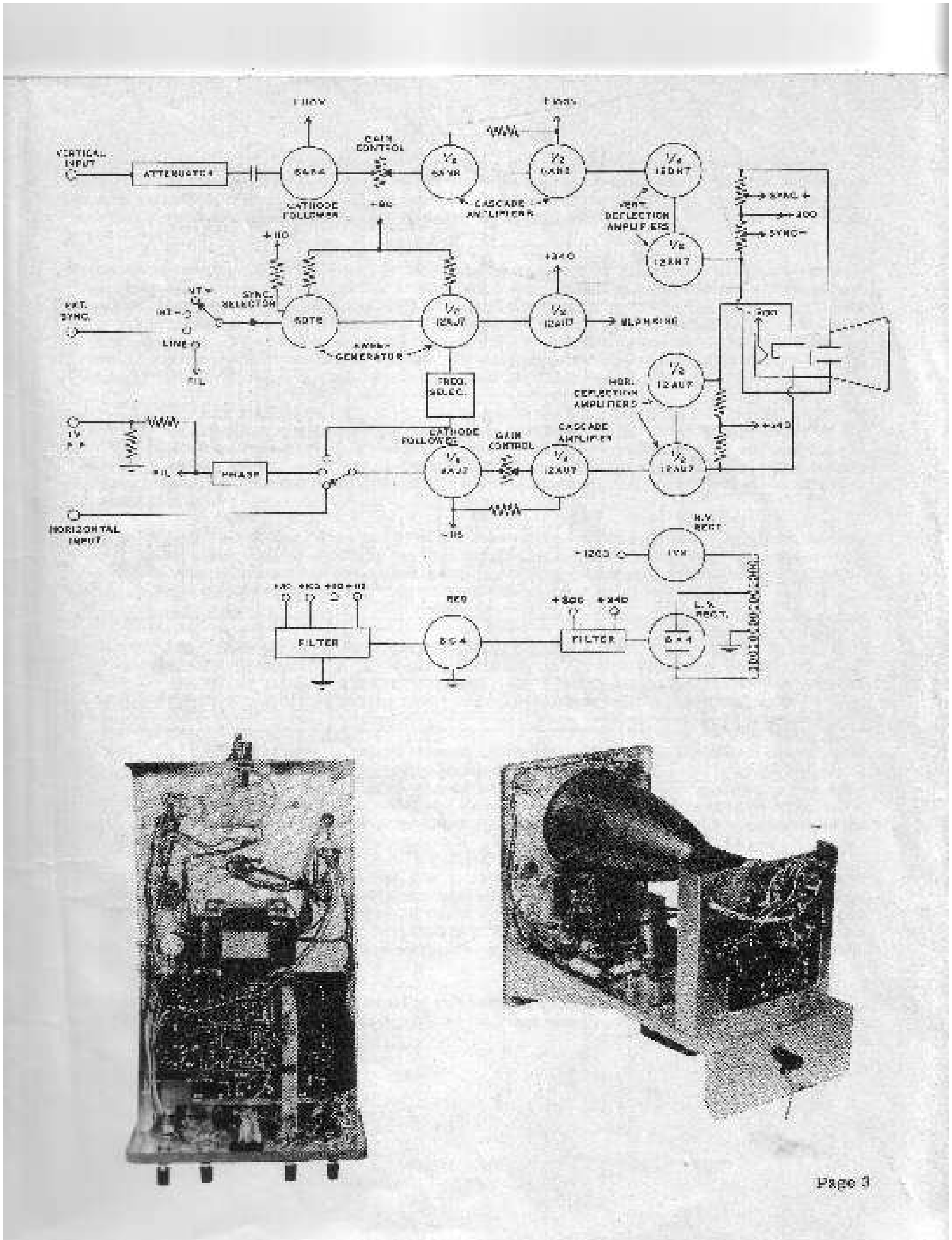


Figure 18: Heathkit O-11 Block Diagram

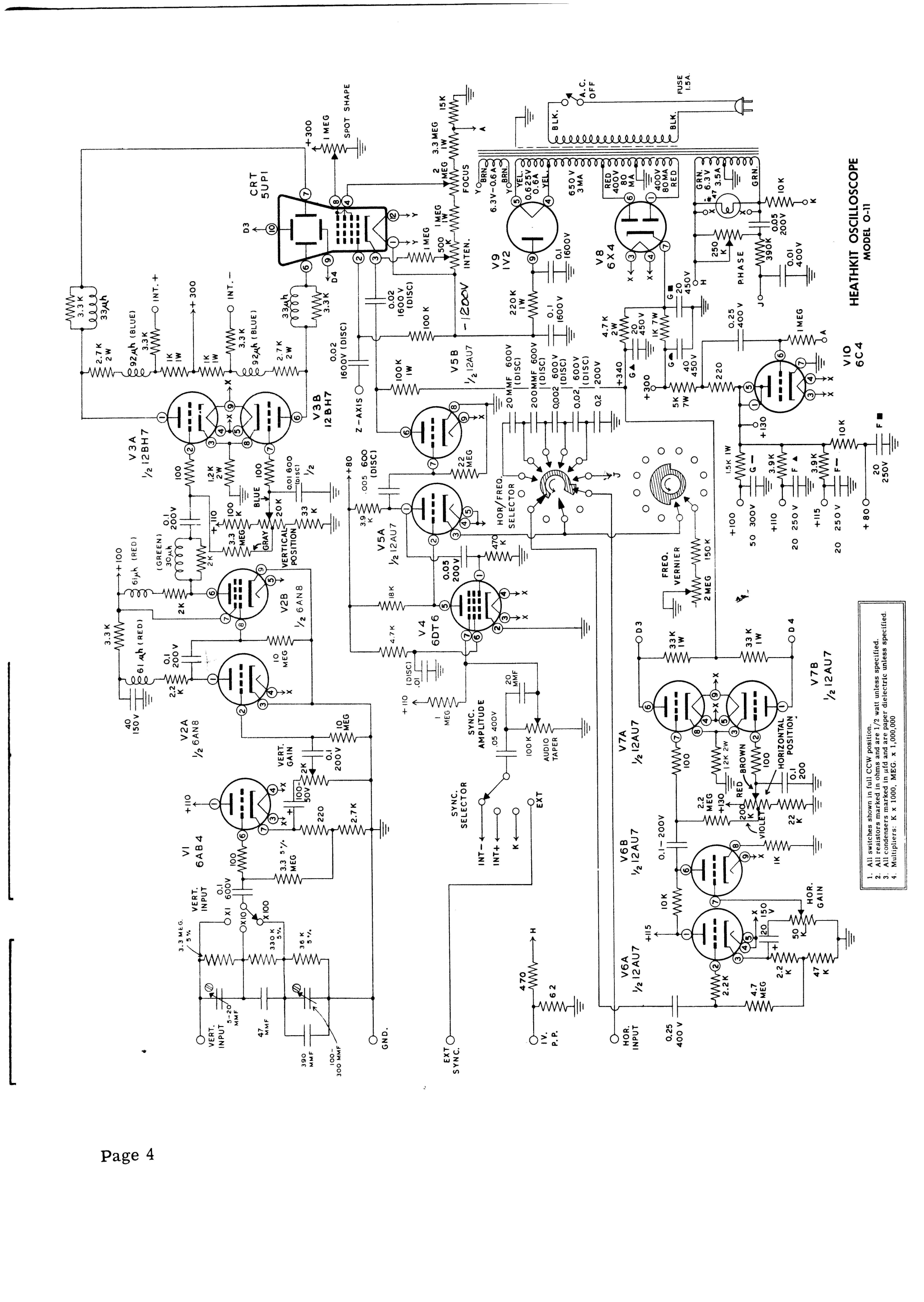


Figure 19: Heathkit O-11 Schematic

7 Tektronix 545 Mainframe with CA (53/54C) Vertical Amp, 1956

The Tek 545 (page 30) indisputably represents modern practice in oscilloscope technology. Appart from its size and power consumption (both massive by the standards of 2009), the 545 with 53/54C plug-in would be instantly recognizeable and useable in a modern engineering lab. Ten years after the the Tek 511, the 545 adds the following features:

- The oscilloscope mainframe provides for various vertical plug-ins, a concept that has carried through to the present day. A Tek 53/54D manual of 1957 shows 8 different vertical amplifiers. including various low-level amplifiers, general purpose amplifiers, and a wideband unit.
- The vertical channel is now DC or AC coupled.
- There are *two* vertical channels, with *chopped*, *alternate* and *algebraic add* modes.
- The vertical bandwidth is 24MHz.
- Vertical and horizontal settings are calibrated and selectable in a 1:2:5 sequence.
- The horizontal timebase ranges from 500nSec/div to 5Sec/div in 24 steps
- A *main* and *delayed* timebase are available.
- Some earlier scopes provided direct access to the deflection plates of the CRT in order to bypass the bandwidth limitations of the amplifiers. That feature is absent in this unit, probably because the scope has sufficient bandwidth for many applications.
- The total CRT accelerating voltage is about 10kV and the sweep can be shortened to increase intensity, both features to make it useable for viewing high-frequency transients.
- Four neon-lamp indicators indicate the position of the CRT beam, which is helpful in finding the beam at setup.

The signal connections use UHF type connectors, rather than the BNC type that came later.

The 545A used an enormous number of vaccum tubes: something like 102 in total, with 14 in the power supply regulator [10] and 20 in the mainframe vertical amplifier. The rear panel has a large diameter fan to move air past the circuitry. Tek manuals were full of warnings about the dire consequences of restricting the air flow.

The price was a breathtaking $1725, equivalent to $17,000 in 2009. This is an engineering instrument, not for hobbyists or repair technicians.

7.1 Vertical Amplifier

The mainframe vertical amplifier, with a bandwidth of 24MHz[8], was a remarkable achievement at the time. The circuit (page 31) used a *distributed amplifier* [12] to drive the CRT plates. In this design, a series of gain devices (tubes in this case) contribute to the signal as it propagates down a transmission line. A distributed amplifier is capable of very high bandwidth because the stray capacitances of the tube become part of the transmission line and therefore do not roll off the gain at high frequencies. However, the gain is additive, so a large number of tubes are required. This is a brute-force bandwidth-at-any-cost approach.

In 1964, the upgraded 545B replaced the distributed amplifier with a lumped delay line, hybrid amplifier using 4 tubes and 8 transistors, and sophisticated peaking circuits.

[8]Achieved with the type CA vertical plugin, up to 30MHz with a type K plug-in.

7.2 Power Supply

The power supply circuit is on page 32. There are 5 regulator circuits, each consisting of one or more triode series-pass elements and a pentode error amplifier. A single gas-discharge tube V609 provides a reference for the most negative supply. This supply then acts as a reference for the other regulators. Later Tek scopes translated this design directly to transistor circuitry.

Figure 20: Tektronix 545A, image courtesy of [10]

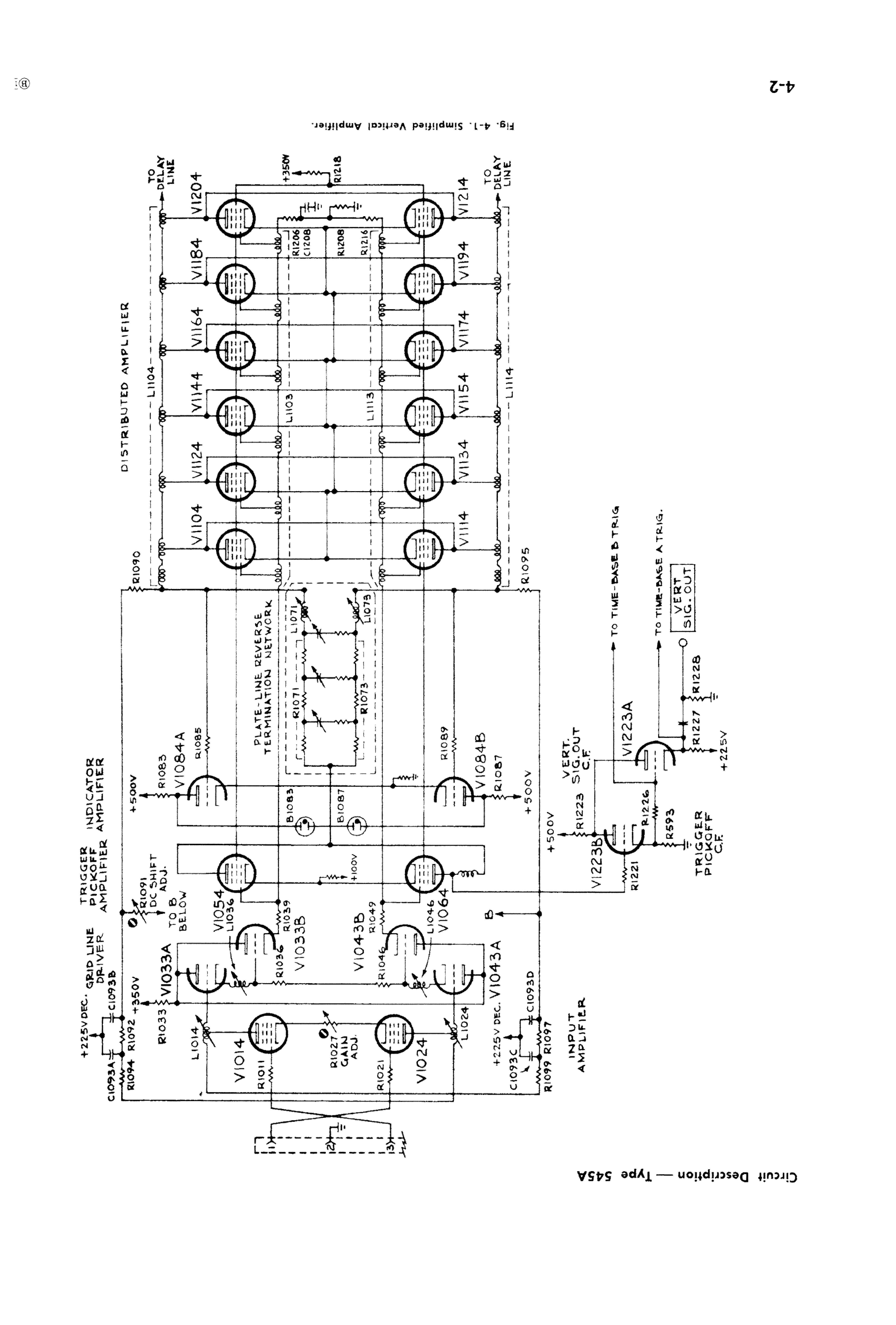


Figure 21: Main Frame Vertical Amplifier

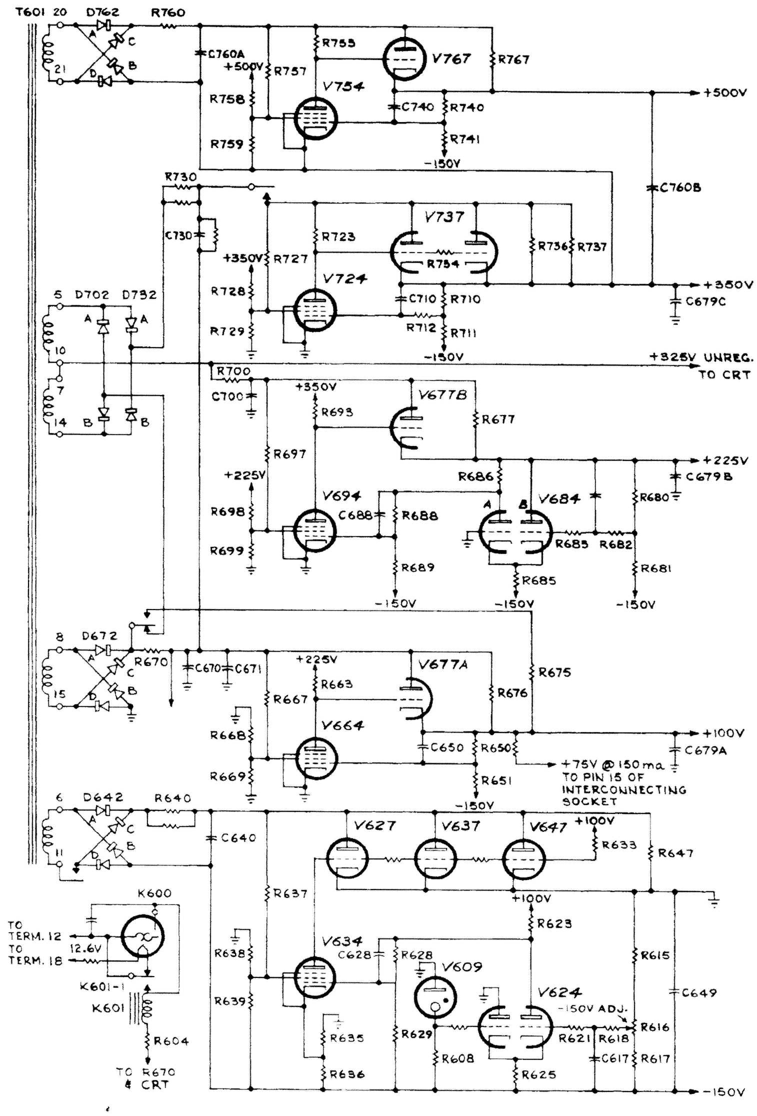


Fig. 4-8. Simplified Low-Voltage Power Supply.

Figure 22: Power Supply

8 Summary and Comparison

Model	**Dumont 224a**	**Dumont 248**	**Tek 511**	**Dumont 304a**	**Heathkit O-11**	**Tek 545 + 53/54C**
Year	1943	1945	1946	1953	1957	1956
Size, ft^3	0.97	5	2.4	1.4	1.12	3.1
Weight, lb	49	170	50	?	21	65
Power,watts	150	550	230	110	80	500
Manual Pages	16	44	73	57	16 (1)	165
Triggering	Sync	Sync, Trig	Trig	Sync, Trig	Sync	Trig
Vert Channels	1	1	1	1	1	2
Vert Coupling	AC	AC	AC	AC,DC	AC	AC,DC
Vertical BW, MHz	2	5	8 (3)	0.1	4 (2)	24
Vertical Cal	No	No	Yes (4)	Yes	No	Yes
Vertical Sens, mV/cm	55	55	270	10	10	50
Vertical delay? (7)	No	0.7μsec	0.25μsec	No	No	Yes
Horiz Cal (5)	No	Yes	Yes	No	No	Yes
Price (at time)	$150 (8)		$700		$65	$1725
Price (2009)	$2740		$11,700		$641	$17,780

(1) Excludes construction material.
(2) Estimated
(3) With 2 stage preamp. 10MHz with one-stage preamp.
(4) By comparison with calibration voltage
(5) No: Controlled by frequency. Yes: Rudimentary calibration in time/division
(6) Source: [6]
(7) A vertical delay is required to observe the leading edge of pulses. The Dumont 248 required 0.1μsec for the timebase to start, so 0.7μsec is more than adequate. In the Tek 711, vertical delay line is an option.
(8) Estimated from the following: a used Dumont type 208B was evaluated in 1961 as worth approximately $150. We assume that was half the new price and extrapolate back to 1943. Incidentally, a 3 inch CRT sold for $15 in 1948, equivalent to $219 in 2009.

9 Observations

One comes away from an examination of these instruments with a tremendous respect for what the designers accomplished and how they advanced oscilloscope technology.

There is a certain mythology around the first Tektronix oscilloscope, the 511. The Tek 511 introduced in 1948 was only a marginal advance over existing Dumont scopes. There is one vertical channel, and that is AC coupled. The timebase is triggered, but so was the Dumont 248. (The Tek timebase circuit may have been a better design: we don't know.)

However, by 1956 the situation had changed dramatically. The Dumont 304A is something of an improvement over its predecessors, and it was purchased in large numbers by educational institutions. But the Tek 545 is a huge advance over Dumont scopes. Tektronix had packed enormous advancements into that decade: sophisticated circuit design, better user interface, calibrated operation, meticulous construction, greater bandwidth and large range of products. The engineering community bought these oscilloscopes in large numbers, regardless of the premium price.

The Heathkit oscilloscope is clearly aimed at a different market. Tube-type televisions were being bought in huge numbers by the public, and these required significant maintenance. Television repair shops provided this service. Every small town had its TV repair shop. The Heathkit scope was good enough for these applications and much more affordable than the Dumont or Tektronix units. The number of different models produced by Heathkit reflects the success of this product.

Tektronix and Heathkit were successful because they had a very clear vision of the end user and were focussed on developing products to suit. Dumont was on the decline and eventually gave up the oscilloscope business entirely.

10 Acknowledgements

These notes were inspired by manuals that were declared surplus when the Ryerson University Department of Electrical Engineering moved from 87 Gerrard Street East to it's current location on Church Street. They would have been used when Ryerson was a Ryerson Polytechnic Institute, training veterans of WWII.

Special thanks to Ryerson Electrical Engineering Support Staff, Dave Spaulding and Jim Koch for their careful stewardship of these and other technical manuals over the years.

We greatly appreciate having access to BAMA, the Boat Anchor Manual Archive, the other primary source for this material.

Instrument pictures have been obtained from web sites, as noted in the text. These sites are hugely valuable in documenting past examples of the engineering art.

11 Appendix: Rate of Inflation

The average annual inflation rate for the past 50 years has been 4.5% [13]. This gives us a method of calculating equivalent price over a period of years. For example, the price ratio 1945 to 2009 is $1.045^{65} = 17.48$ In earning power, $1 in 1945 would be equivalent to $17 in 2009.

12 Appendix: Document Notes

The document was created using a text editor and the LaTeXtypesetting program on a Linux Suse system. Latex can incorporate images in postscript or encapsulated postscript format, so images needed to be scanned and converted to that format. Scanned documents showed two problems:

- Photographs from the original manuals are *screened*, that is, they consist of tiny dots. The scanning process beats visually (a form of signal aliasing), producing light and dark bands on the scanned image.
- Scanned schematics had terrible resolution.

Here's what was done to correct these problems.

12.1 Scanning Photographs

Photographs were scanned from their manuals[9] using Canon LIDE30 scanner attached to a computer running Windows XP operating system.

The *ArcSoft PhotoStudio* software provided with the Canon scanner has an advanced mode where colour, resolution and other modes can be selected[10].

Photographs were scanned using **grayscale** mode, **descreening** and whatever resolution gave the least banding effect. The scanned photograph was then saved in jpg format.

[9] Some photographs were downloaded directly from web pages, as noted on the figures.
[10] The *Canoscan program* also supplied with the scanner does not provide the necessary controls.

12.2 Scanning Schematics

Some schematics were scanned directly from their manual.

In the case of a manual obtained from BAMA (eg, [8]) the schematic was downloaded and displayed using *Acroread* (pdf format) or *Evince* (djvu format). The schematic was then printed on a laser printer and the printed copy scanned. Scanning from a printed copy sounds like a recipe for generation loss, but in fact it works very well.

The scanner modes were **Black and White** colour and **600 dpi** output resolution.

The scanned schematic was then saved in jpg format.

12.3 Processing Document to Postscript

The jpg format documents were moved to the Linux machine.

Various methods were used to convert the jpg formatted document to postscript. Some gave terrible results. The most successful was the **convert** routine that is part of the ImageMagick suite of processing routines [14].

The command `convert myfile.jpg myfile.ps` does the conversion.

The image is then incorporated into the document using the Latex `includegraphics` command, which can scale and rotate the image to suit.

Incidentally, if you are using the xdvi image viewer, the image quality there is *not* an indicator of final quality. You need to convert document to .pdf format and and view the final document with `Acroread`.

Using this sequence, the tiniest typeface visible on the original is clearly reproduced on the final document, even though the final document is a different scale.

References

[1] *Scopes' story: fits and starts*
http://www.eetimes.com/anniversary/designclassics/scopes.html
If the URL does not work, type the title into Google.

[2] *Tektronix*
http://en.wikipedia.org/wiki/Tektronix#History

[3] *Tektronix Company History*
http://www.fundinguniverse.com/company-histories/Tektronix-Inc-Company-History.html

[4] *Tektronix 511A 511AD Cathode Ray Oscilloscope Technical Manual*
http://bama.edebris.com/manuals/tek
http://bama.sbc.edu/
BAMA is the Boat Anchor Manual Archive, a repository for the technical manuals of electronic equipment.

[5] *Tektronix 511 Oscilloscope*
Tektronix Museum,
http://www.geocities.com/r_corriveau/500/511.html#tline

[6] Keith Rowland
Older Heath Test Equipment-The Scopes
http://lists.tempe.gov/admin/WA.EXE?A2=ind9711&L=heath&T=0&F=P&P=12410

[7] Dale Wentz
Heathkit Test Equipment Matrix
http://www.nostalgickitscentral.com/heath/products/heathkit_test.html

[8] *Dumont 304-A Schematic and Manual*
http://bama.edebris.com/manuals/dumont/304
Archived by Kent Kershaw, Chuck McGregor

[9] *Cost capping Q&A with FIA President Max Mosley*
http://www.formula1.com/news/interviews/2009/3/9026.html

[10] *The Valve Page, Tektronix 545A*
http://www.thevalvepage.com/testeq/tek/545a/545a.htm
A number of photographs of antique oscilloscopes

[11] *Good Engineering and Fast Vertical Amplifiers*
John Addis
in
Analog Circuit Design
Editor, Jim Williams
Butterworth Heinemann, 1991

[12] *Distributed Amplifier*
http://en.wikipedia.org/wiki/Distributed_Amplifier

[13] *Rate of Inflation*
http://www.mhinvest.com/newsbi/inflation.html

[14] ImageMagick
http://www.imagemagick.org/script/index.php