Tektronix 7000 Series Power Supplies

History, Design and Restoration

Giovanni Becattini

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- [7KS] Tektronix 7000 Series – Mainframes – Elektor Books
- [7KPI] Tektronix 7000 Series – Plug-ins
- [TREG] Tektronix Oscilloscopes Restoration Guide – Elektor Books – Sold Out
- [HP1] Hewlett-Packard and its Voltmeters and Oscilloscopes
- [HP2] Hewlett-Packard Signal Sources
- [HP3] Hewlett-Packard Counters and Spectrum Analyzers
- [HP4] Hewlett-Packard Calculators, Computers and HP-IB
- [VRE] Vintage Radio Equipment – Elektor Book
- [MAC] Apple Macintosh – History, Engineering, and Restoration – Elektor Books
- [QT602] The Good Giant – Tektronix DSA 602A Oscilloscope
- [QT11KP] The Last Plug-ins – Tektronix 11000-Series Plug-ins
- [SCLI] Strumentazione Vintage – Edizioni C&C
- [QTCOL] Collins Classics – KWM-2, 30L-1 and 51S-1: History, Engineering, and Restorat
- [QT324] Two Giants and a Shorty – Tektronix 323/324
- [QTBYOP] Become Your Own Publisher
- [DAB] Digital but Analog
- [TG7] When Machines Learned to Write
- [PDP-8] DEC PDP-8 – The Minicomputer That Anticipated Microprocessors
- [OTTO] Build Your Own Educational PDP-8 Clone Using an FPGA
- [TUB] The Tubes That Changed the World
- [TRC] Tektronix, The Round Corners – From Vacuum Tubes to Early Solid State
- [HEPS] Tektronix, 7000 Series Power Supplies – History, Design and Restoration

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Preface

This book began as an attempt to collect and organize the experience I had accumulated over years of working on Tektronix 7000-Series oscilloscopes, together with notes and documents I had previously written on the subject.

My original intention was simply to revise and expand that material. However, one question led to another, new investigations became necessary, and the project gradually grew into a book of its own.

Power supplies are rarely considered the most fascinating part of an oscilloscope. Yet, behind the apparent complexity of the Tektronix HEPS, and even the more conventional supplies, lie remarkable examples of engineering ingenuity.

My purpose is not to replace the original Tektronix service manuals, but to complement them with explanations, diagrams, measurements, and practical experience, hopefully making these circuits easier to understand and repair.

Along the way, I have made mistakes, followed misleading clues, and occasionally created new faults while trying to fix the original ones. Some of these adventures are included here, too.

If this book helps preserve a few more of these extraordinary instruments, while making their power supplies a little less intimidating, it will have achieved its purpose.

Giovanni Becattini

01 The High-Efficiency Power Supply

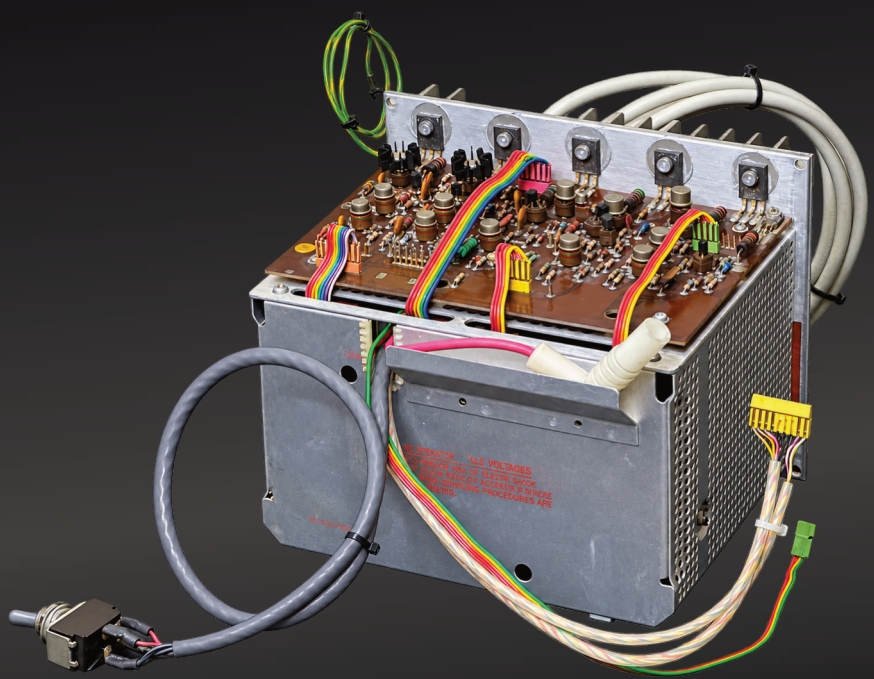
When the HEPS was introduced, energy efficiency was not yet a major design priority, and wasting a few watts was hardly considered a serious problem.

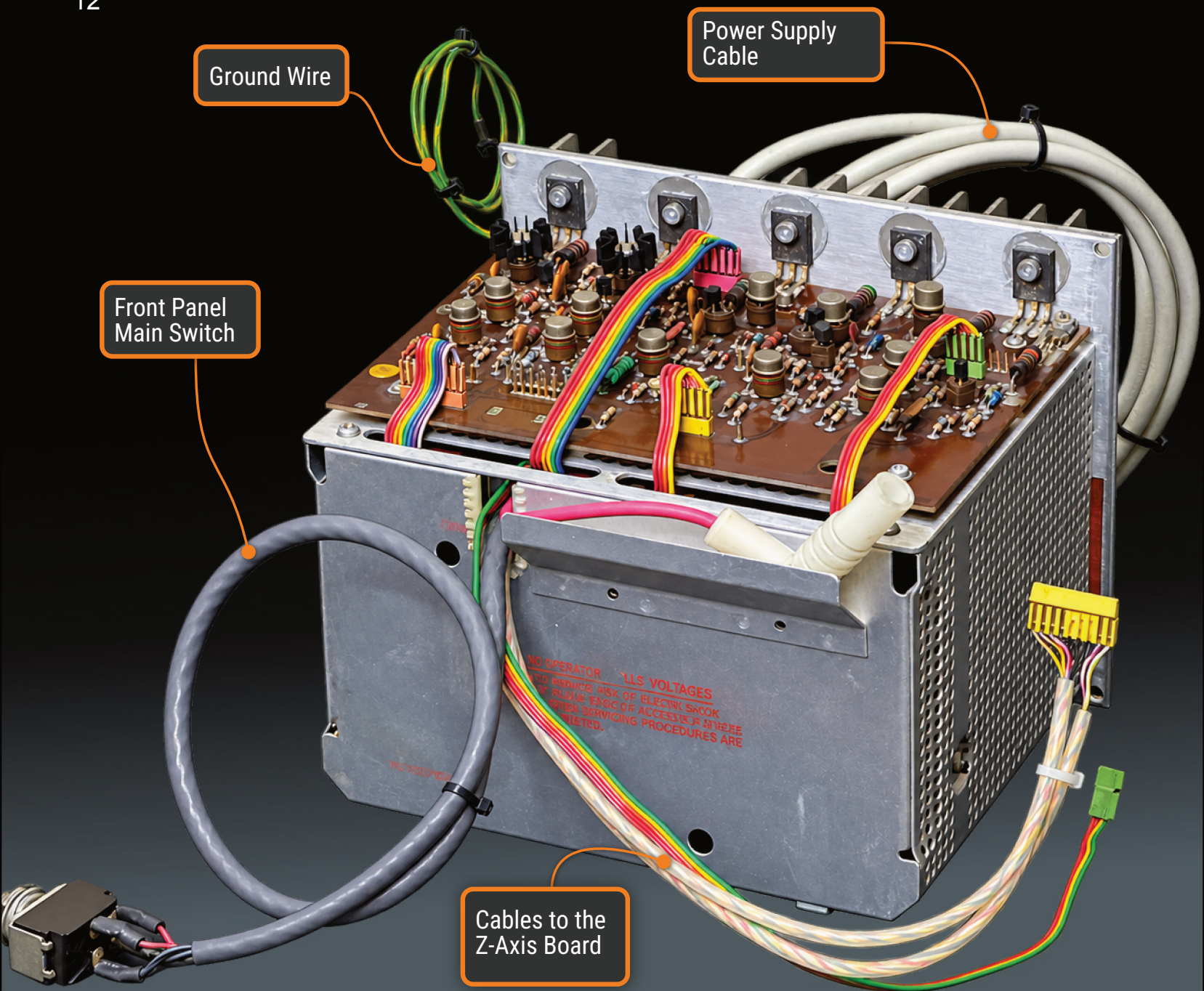
Weight, however, was another matter. And so was the noise of a cooling fan. Both were enemies worth fighting.

The HEPS was undoubtedly one of the most innovative power-supply designs of its time. In various forms, it powered Tektronix's top-of-the-range oscilloscopes for more than two decades, and its design philosophy influenced many subsequent generations of instruments.

The High-Efficiency Power Supply

An Innovative, Monolithic Assembly Powering Tektronix's Top-of-the-Range Oscilloscopes of the 1970s and 1980s





The HEPS Power Supply (7904)

Operating at such frequencies allows the transformer to be considerably smaller and lighter than a conventional 50/60 Hz unit, contributing to the compact size and high overall efficiency of the supply. The result is a remarkably compact power supply weighing only about 3.4 kg.

However, the HEPS should not be confused with a modern switching-mode power supply. The inverter provides preregulation, but the low-voltage outputs still rely on conventional linear regulators for their final stabilization. It is therefore an interesting hybrid of switching and linear power-supply techniques.

Complex

The HEPS is a true engineering masterpiece, achieving impressive performance with a limited number of components. It is also remarkably robust, and many units have operated for decades with relatively few failures. Nevertheless, it is definitely complex.

It is anything but simple to understand, and the Tektronix documentation itself requires some effort to digest. They say that the Holy Bible continuously reveals hidden meanings the more you study it; the HEPS seems to work the other way around: the more you study it, the more hidden details you discover, and you never seem to finish documenting it.

This book started simply as a collection of information gathered during several repair projects, but in many places it eventually became something close to a reverse-engineering exercise. Hopefully, it will make the work of future HEPS restorers both safer and easier.

Perhaps Tektronix itself eventually wondered whether such complexity was always justified. In the three-bay mainframes, such as the 7603, the company returned to a more conventional linear power supply built around a standard 50/60 Hz mains transformer.

However, the basic HEPS philosophy did not disappear. Many later instruments, including the 2400 Series, adopted a broadly similar architecture, combining a switching pre-regulator with conventional linear regulators for final stabilization.

The HEPS is mechanically complex as well. In the 7904, the high-voltage section is incorporated into the same assembly, resulting in a remarkably dense construction. We will partly analyze some of its evolutions, seeing that in later instruments, such as the 7834 and the 7854, the high-voltage circuitry was moved out of the HEPS and placed on a separate board.

Connection Groups

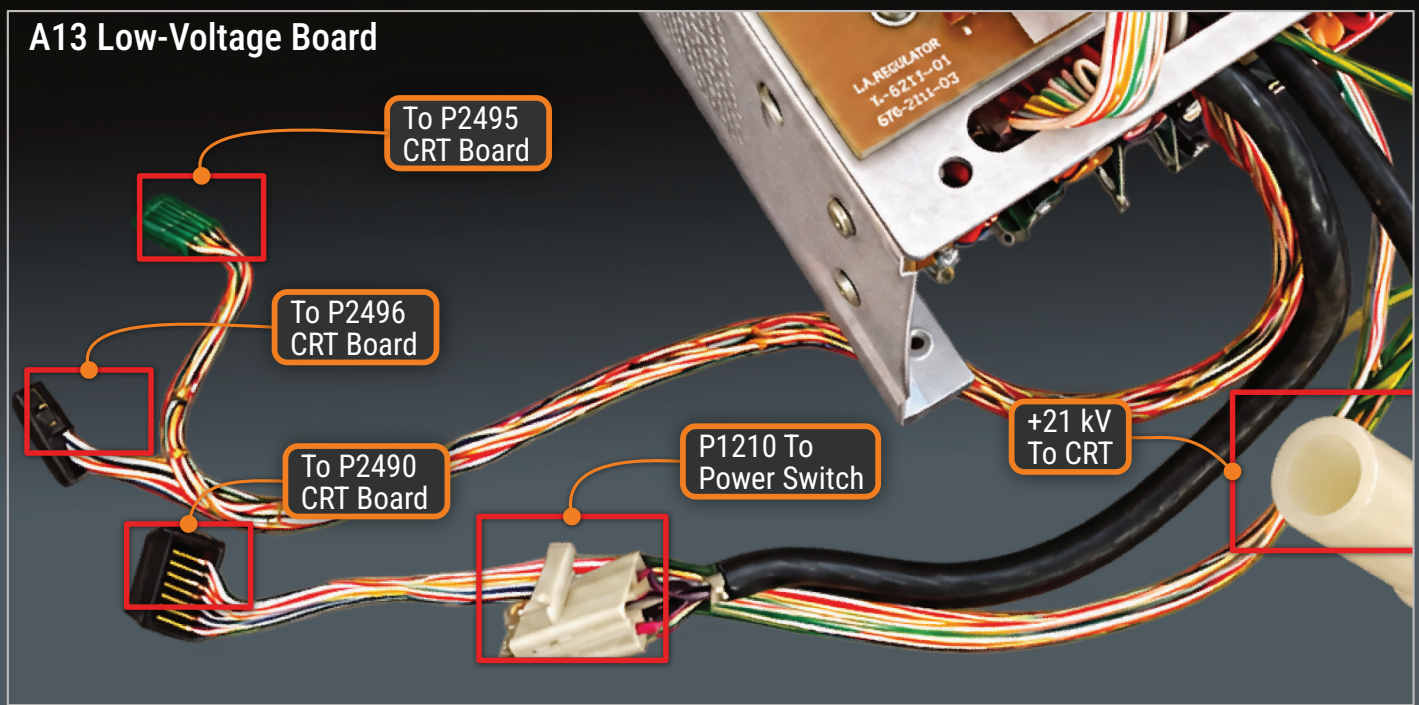
The complexity becomes considerably more manageable if we group the connections according to their function, as done below.

Power Input Connection

AC mains power enters the HEPS through the permanently attached rear power cord, a solution I have never particularly liked. In later instruments it was finally replaced by a detachable connector—not a moment too soon.

Inverter Connections

The main AC power connections between the HEPS sections are made through transformer T1310, located at the center of the assembly as described earlier. These connections are therefore galvanically isolated and don't use separate wires.



After a time Tb, determined by U1275, the switch moves from B to C. Q1241 now conducts and CR1234 becomes reverse-biased. The resonant current itself cannot change instantaneously, but its path does: I3 falls to zero as the current commutates into Q1241 and becomes I4. The negative half-cycle can then develop in essentially the same way as the preceding positive one.

U1275 Inverter Control

The 155-0067 custom integrated circuit was designed by **Joe Burger** and **Gene Andrews** for the control of DC-to-DC inverter power supplies. Tektronix describes it as providing the circuitry required for regulation and protection of the inverter system. On the facing page, its electrical schematic diagram and pinout.

The original Tektronix data sheet lists its use in the 434, 485, 4851, 4852, P7001, 7704A, A7704, 7844, 7903, 7904, 7904A, and 7912. Its use in the 7104 can also be verified directly from that instrument's schematic diagrams.

Unfortunately, no complete original functional description of all sixteen pins seems to be readily available. What follows is therefore a reconstruction based on the surviving Tektronix documentation, the internal schematic of the 155-0067, the service manuals of the instruments in which it was used, and practical measurements made during repair work.

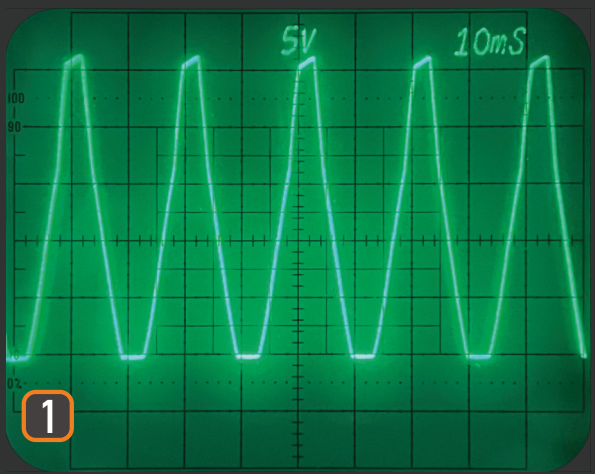
The functions explicitly documented by Tektronix include:

- sensing and controlling secondary faults through a bidirectional, ground-referenced node on pin 2;
- sensing and limiting maximum inverter current on pin 13;
- sensing the line voltage through pin 3;
- sensing inverter-current phase through pins 10 and 11;
- controlling the inverter base-drive circuitry through outputs 8 and 9.

The available pin information can therefore be summarized as follows; we will discuss each of these functions in more detail:

- **Pin 1** — FAULT HOLD-OFF TIME; Over Voltage Timing Input
- **Pin 2** — BAL SENSE; Voltage Sensing Null Input. Used for sensing and controlling secondary-voltage faults through a bidirectional, ground-referenced node.
- **Pin 3** — LINE STOP TIMER; associated with line-voltage sensing and stop timing.
- **Pin 4** — LINE STOP SENSE; Line Sensing Input
- **Pin 5** — GROUND – to be externally connected to pin 16;
- **Pin 6** — +7.5 V SUPPLY, Vcc. Requires a current-source supply; internally regulated at 7.5 V.

Beautiful Waves

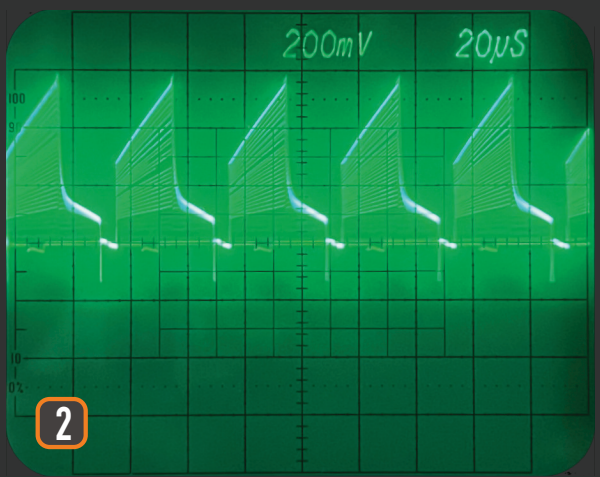


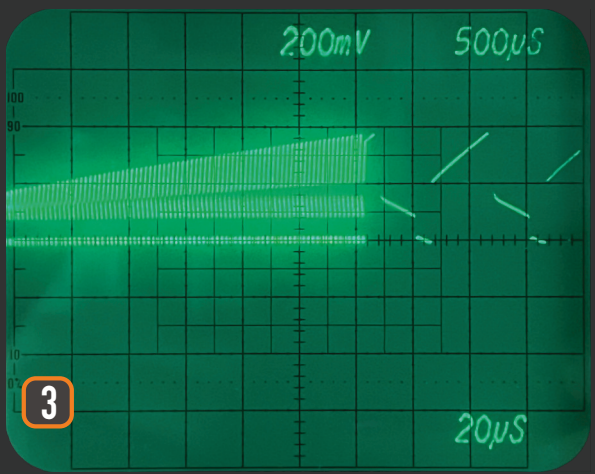
The action of the kickstarter is rather violent and should obviously not be repeated at every cycle. What prevents this from happening?

The mechanism is quite simple. Once the inverter is running, the recurrent waveform at the collector of Q1241 acts through CR1242 and repeatedly pulls the voltage on C1242 back down, preventing it from again reaching the firing voltage of CR1238.

Two very different time scales are therefore superimposed: the slow mains-derived charging waveform, with a half-cycle of about 10 ms, and the much faster inverter action, occurring on a scale of only a few tens of microseconds.

C1242 does not simply follow the mains-derived waveform. Through the high-value starting network, it continuously tends to charge toward the instantaneous voltage imposed by the line. After each discharge through CR1242, it immediately starts charging again toward that level. This remains true even while the mains envelope itself is falling: the target voltage may be slowly decreasing, but it is still well above zero, so each individual recharge ramp rises again from the discharged level.





This explains the peculiar appearance of photo 2, where many sweeps overlap and produce the characteristic “fan” of ramps. Photo 3 finally reveals what is happening by using a dual-speed sweep: the first portion is displayed at 500 µs/div, the second at 20 µs/div.



Anatomy of a Click

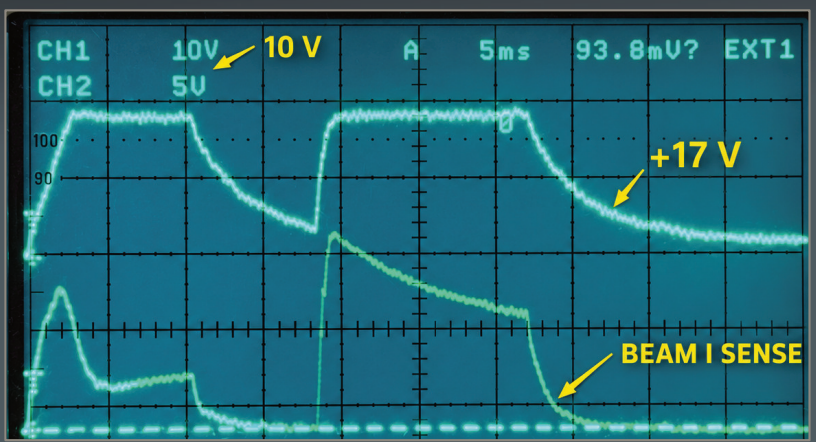
Four signals recorded simultaneously during two consecutive startup interruptions.

Notice how BEAM I SENSE (blue) decreases while BAL SENSE (orange) rises towards its positive threshold.

When BAL SENSE reaches approximately +200 mV, the controller activates STOP (green), shutting down the inverter.

HV I SENSE (purple) shows no corresponding positive excursion that could explain the shutdown.

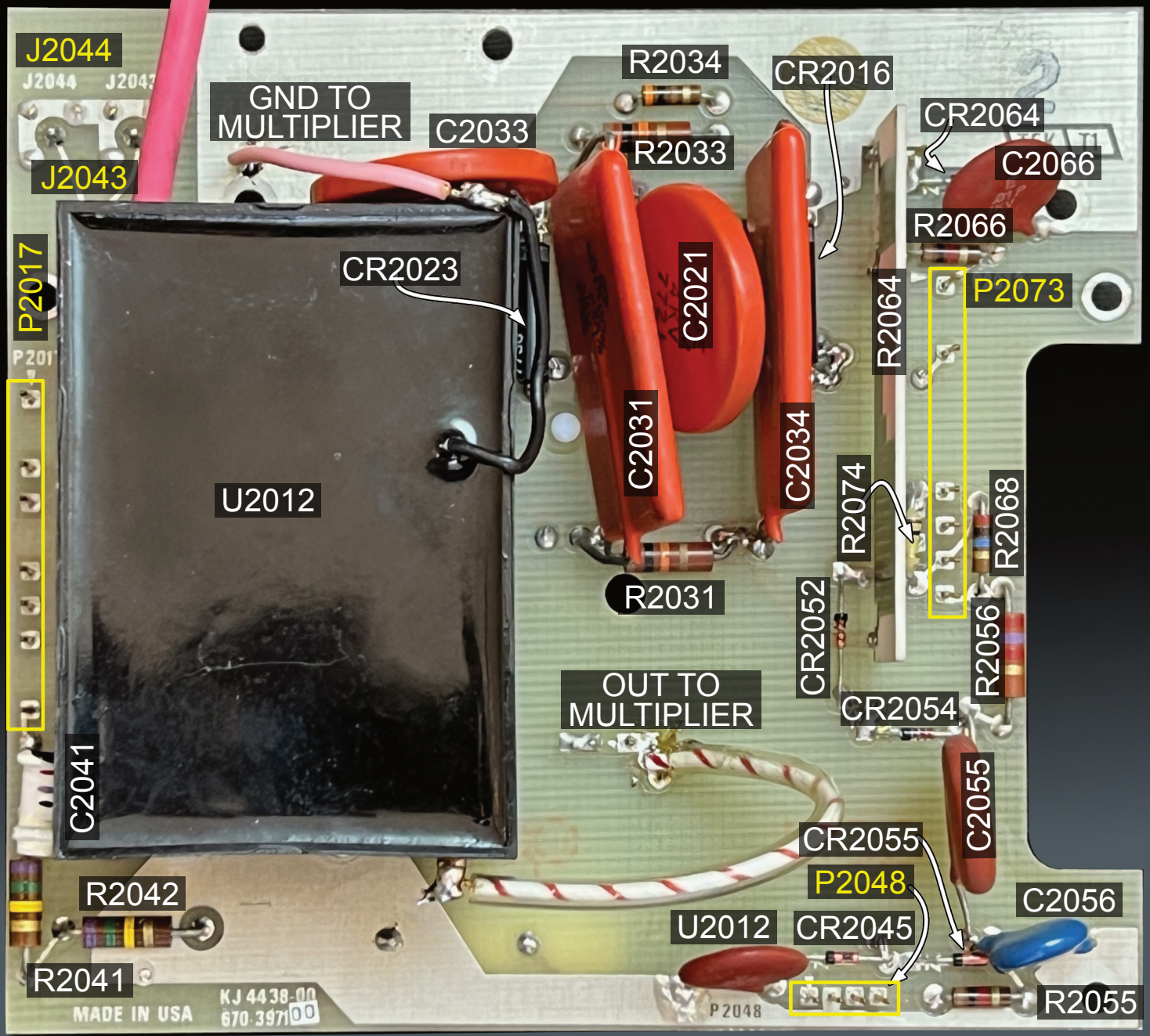
These measurements suggest that BEAM I SENSE is responsible for triggering the observed protection events.

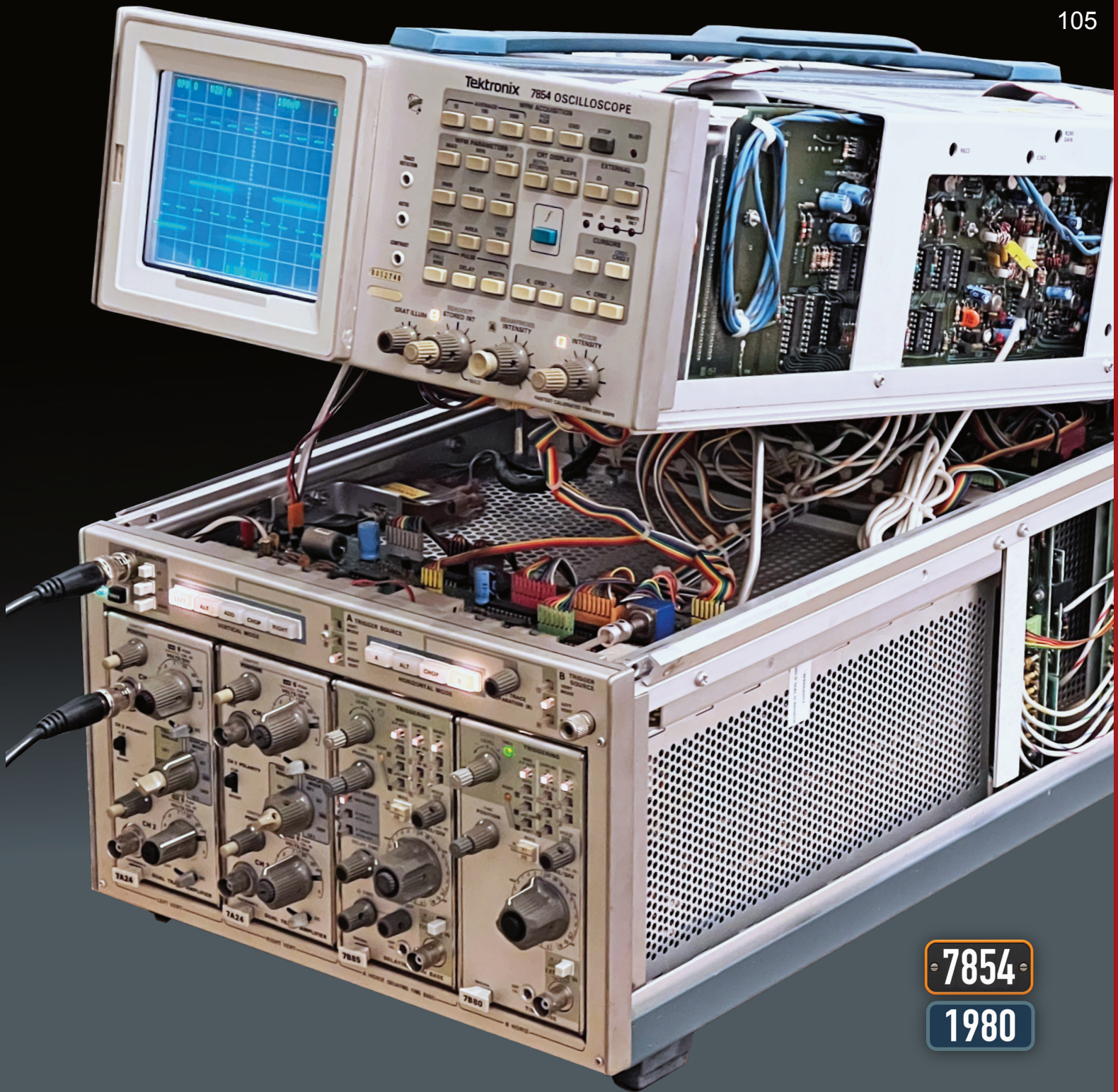


Comparing BEAM I SENSE with the +17 V supply during startup.

The supply remains relatively stable while BEAM I SENSE exhibits a substantial transient.

7834 High-Voltage Board - Front Side





7854

1980

Actual Modifications

Besides the wiring, I observed only a few differences, that are easy to fix:

- the resistors in series with the 25 kHz 1.5 kV square wave must be changed (see below);
- capacitor C2402 (0.001 μF) is missing; nevertheless, I did not add it.

The modifications for using the 7844 HEPS in the 7904 are minimal: remove R2320, R2321, R2322, R2323, R2343, and replace the following resistors to adjust the 7904:

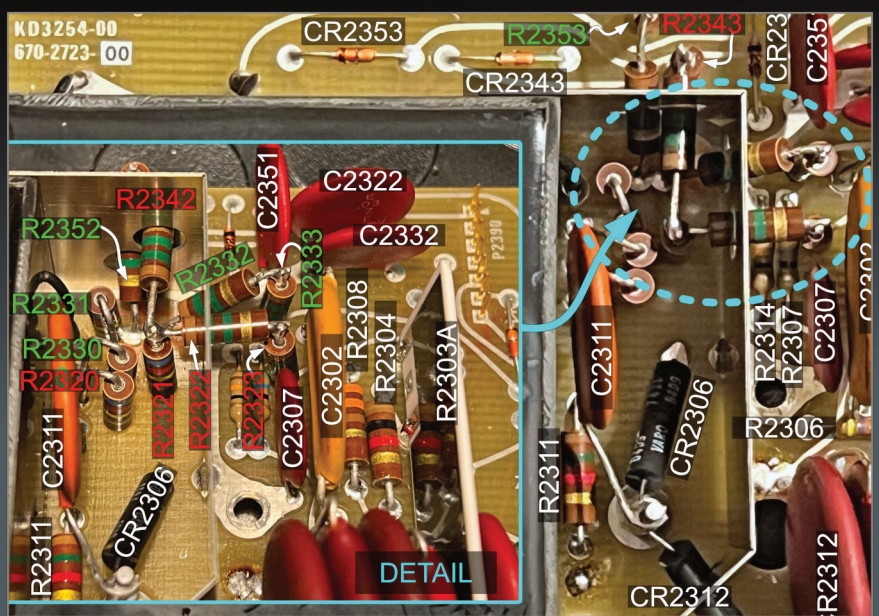
- R2330 (620K) + R2331 (620K) in series with BM1 Intensity and BM2 Focus [1.3M + 1.3M]: \2,586
- Beam 1 Intensity: it has in series R2332 (1.5M) + R2333 (1.5M) [3.0M + 3.0M]; about 6,050
- Beam 2 Focus: it has in series R2352 (1.5M) + R2353 (1.5M) [2.2M + 2.2M].

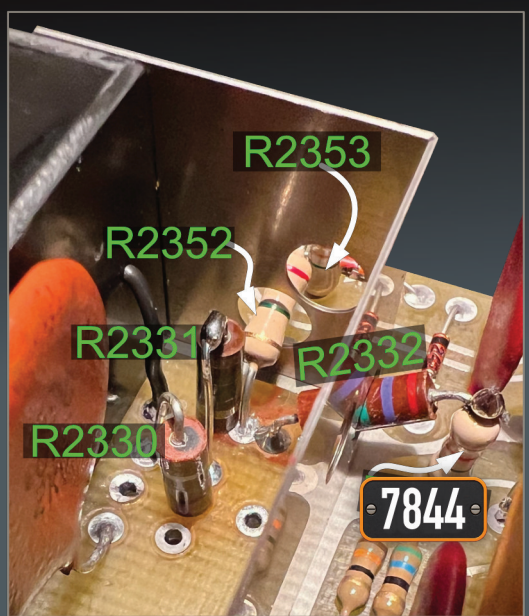
The Tek's choice of using two resistors in series is probably due to voltage requirements; in this way the voltage at the resistor's terminals is halved. I obtained the required values by selecting appropriate resistors, even if they are not equal to each other (respectively 1+1.5, 2.7+3.3, 2.2+2.2).

Below: Modifications to the 7844 HEPS High-Voltage Board, as described in the text, to make it compatible with the 7904.

Right, above: The 7904/7844 Low-Voltage Board, showing the reference designators of the pin-header connectors and the colors of their mating cable connectors. The enlarged detail circled in red shows the voltage test points.

Right, below: My book Tektronix Oscilloscopes Restoration Guide, published by Elektor Books International, is now sold out. If you are considering a similar HEPS transplant, feel free to contact me. I will gladly send you the relevant pages, containing all the technical details and instructions, free of charge.





The clamper circuit is extremely simple, consisting essentially of a diode, a capacitor, and a discharge resistance.

Its operating principle is equally simple. During the appropriate half-cycle, the diode conducts and charges the capacitor to the voltage required to place the corresponding signal peak at the reference voltage (Vbias), neglecting the diode forward drop. During the remainder of the cycle, the diode is reverse-biased and the capacitor retains approximately the same charge, effectively adding a DC voltage to the input signal.

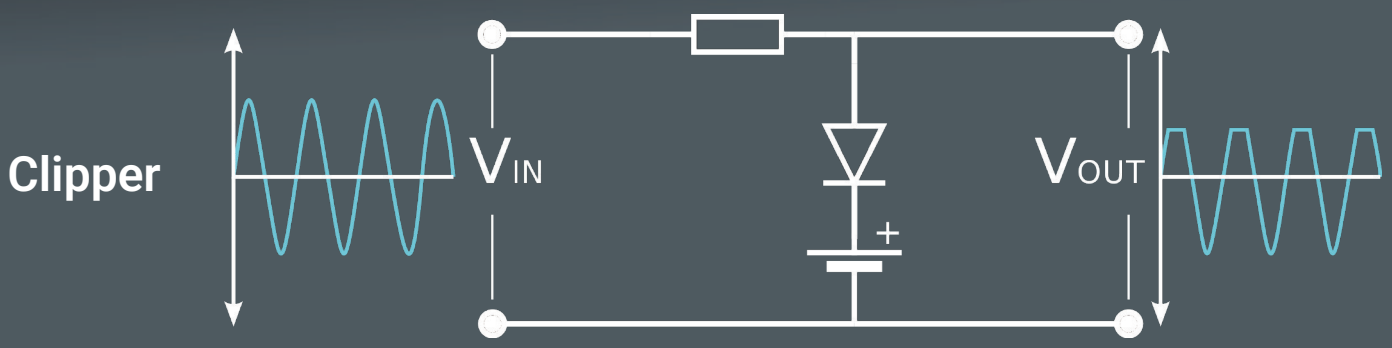
For this approximation to hold, the RC time constant must be sufficiently long compared with the period of the input signal, so that the capacitor discharges only slightly between successive conduction intervals.

A clamper can therefore be regarded as a kind of voltage translator: ideally, it does not alter the shape or peak-to-peak amplitude of the waveform, but simply moves it to a different DC level.

The Clipper Circuit

The figure on the right shows the clipper circuit, apparently similar to the clamper, but with the capacitor replaced by a resistor and with a completely different effect. A clipper prevents the signal from exceeding a defined voltage level: instead of shifting the entire waveform up or down, as the clamper does, it removes—or clips—the portion of the waveform that would extend beyond that level.

In the configuration shown, the circuit clips the positive excursions of the signal at approximately the battery voltage, neglecting the forward voltage drop of the diode. To clip the negative excursions instead, the polarities of both the diode and the battery are reversed.







(6) Carefully slice the original insulating material horizontally with a cutter, removing it little by little and taking great care not to damage the cable, the soldered joint, or the underlying CRT surface. (7) The probable killer's footprint: a dark brown stain extending from the high-voltage terminal toward the area beneath the metallic band wrapped around the front portion of the CRT. The band overlaps the grounded external metallization, separated only by a very thin adhesive layer, and can therefore be regarded as being effectively at ground potential for the purposes of the electric field.

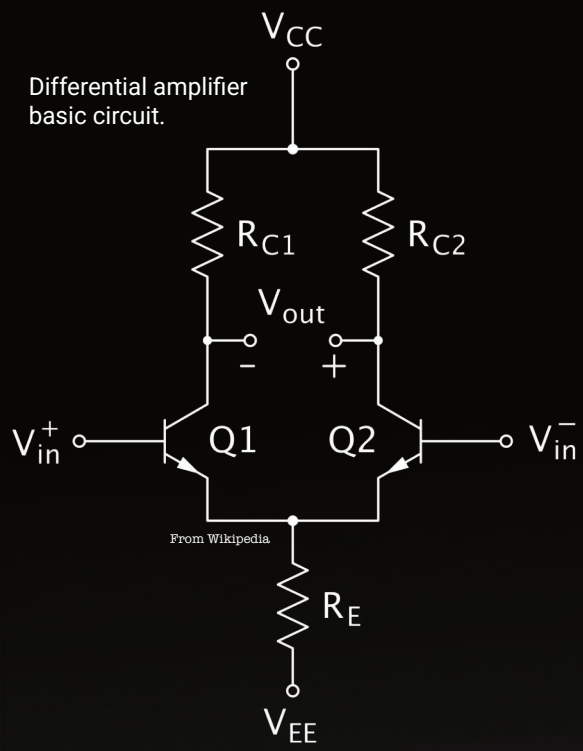
An Old Warning

Looking back through my earlier notes, I found an episode that I had almost forgotten. It happened shortly after this 7904 first arrived. But then...

> *...Hours later, the cleaning was finished. I switched the instrument on again and... Noooo! A terrible noise came from the CRT area. Panic. Surely I had used up my last miracle. I must have done something wrong.*
>
> *After some frantic checking, I found the cause: high voltage was discharging somewhere in the CRT area, while the metal CRT shield acted almost like an amplifying trumpet. Perhaps a small amount of water used during cleaning had found its way into exactly the wrong place.*
>
> *I took a hair dryer, carefully dried the whole area and tried again.*
>
> *The third miracle occurred: the 7904 worked again.*

At the time I regarded this simply as an accident caused by residual moisture. In the light of what was discovered much later, however, the episode becomes more interesting. It does not prove that the present fault had already developed, but it does show that the CRT high-voltage region had once been capable of sustaining a surface discharge under unfavorable conditions.

Anyway, this story doesn't change the present.



Differential amplifier basic circuit.

There is another interesting refinement. Rather than measuring the voltage directly at the regulator output, Tektronix uses a separate feedback connection, known as the **SENSE** line, to monitor the voltage at the point where power is delivered to the mainframe (Fig. 3).

This arrangement compensates for voltage drops along the supply wiring, allowing the regulator to maintain the correct voltage at the destination rather than merely at its own output terminals.

Note, however, that this remote-sensing arrangement extends only as far as the Main Interface Board. The other boards are supplied through the mainframe's distribution system and therefore benefit from this compensation only indirectly. Voltage drops in their individual connections are not directly compensated.

Differential Amplifiers

Differential amplifiers are widely used in Tektronix circuits, particularly in the Low-Voltage Boards, where they form the heart of the voltage regulation system.

The basic circuit, shown in the figure, consists of two transistors, Q1 and Q2, sharing a common emitter resistor RE. This resistor establishes the total emitter current, which is divided between the two transistors according to the difference between their base voltages.

When both inputs are at the same voltage, and the transistors are identical, the current is shared equally. If the voltage at the base of Q1 increases relative to Q2, Q1 conducts more and Q2 less. Consequently, the voltage at Q1's collector decreases, while that at Q2's collector increases.

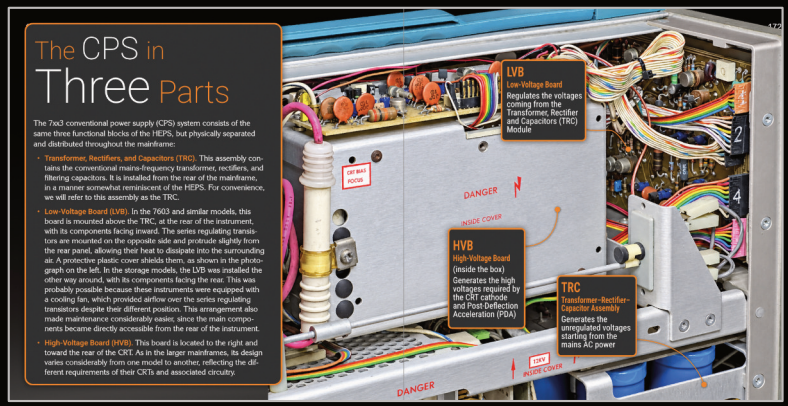
The interesting feature is that even a very small voltage difference between the inputs can produce a substantial change in the collector currents and voltages.

The output can be taken between the two collectors, as shown, or from just one of them, as is often done in Tektronix regulators.

CPS Anatomy

The Conventional Power Supply used in three-bay models such as our 7603 is structurally quite different from the HEPS.

The latter was an almost monolithic assembly, with most of its components housed in a single enclosure, including the Low-Voltage Board (LVB) and, in some models, even the High-Voltage Board (HVB).



The 7xx3 CPS performs the same three basic functions, but its components are physically separated and distributed throughout the mainframe:

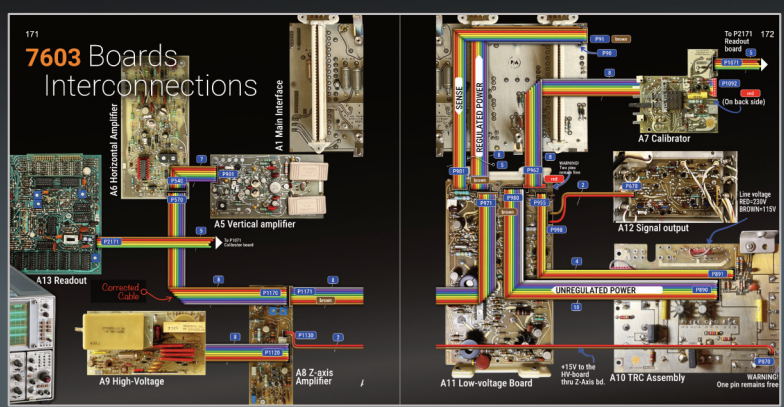
- Transformer, Rectifiers, and Capacitors (TRC) assembly;
- Low-Voltage Board (LVB), mounted above the TRC, at the rear of the instrument;
- High-Voltage Board (HVB), located to the right and toward the rear of the CRT.

Another illustrated spread, “The CPS in Three Parts,” shows this arrangement in detail.

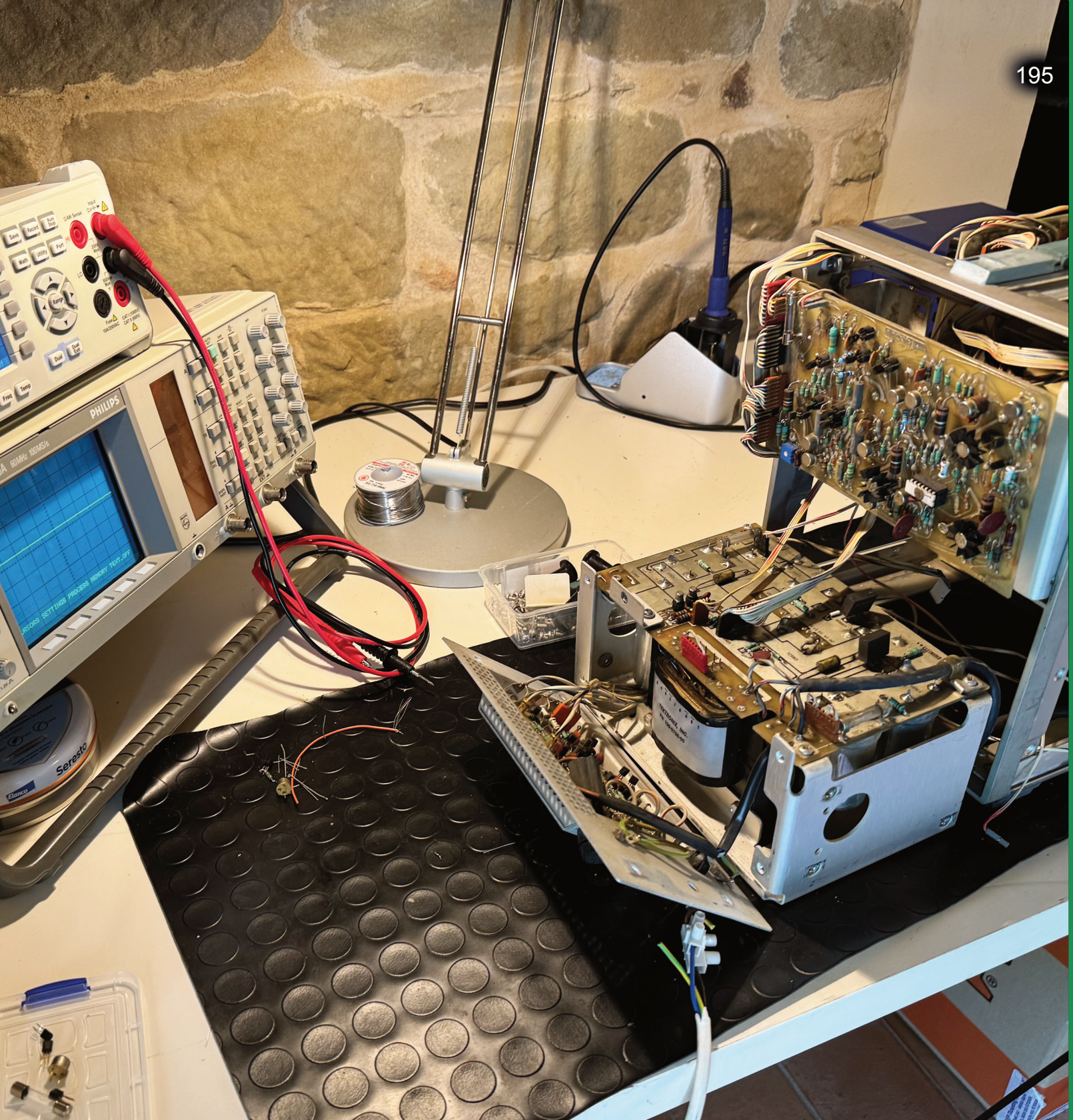
Connections

The distributed architecture of the CPS, with its three major assemblies located in different parts of the mainframe, made an already complex network of interconnections even more intricate.

To help you find your way through this maze of cables and connectors, we begin with the general Board Interconnection Diagram, presented here in a revised and updated version, with several errors corrected.



Even this detailed diagram, however, cannot tell the whole story. We have therefore prepared three additional illustrated spreads, filled with photographs, connector locations, and practical notes to help


PHILIPS
Seresto
Elanco

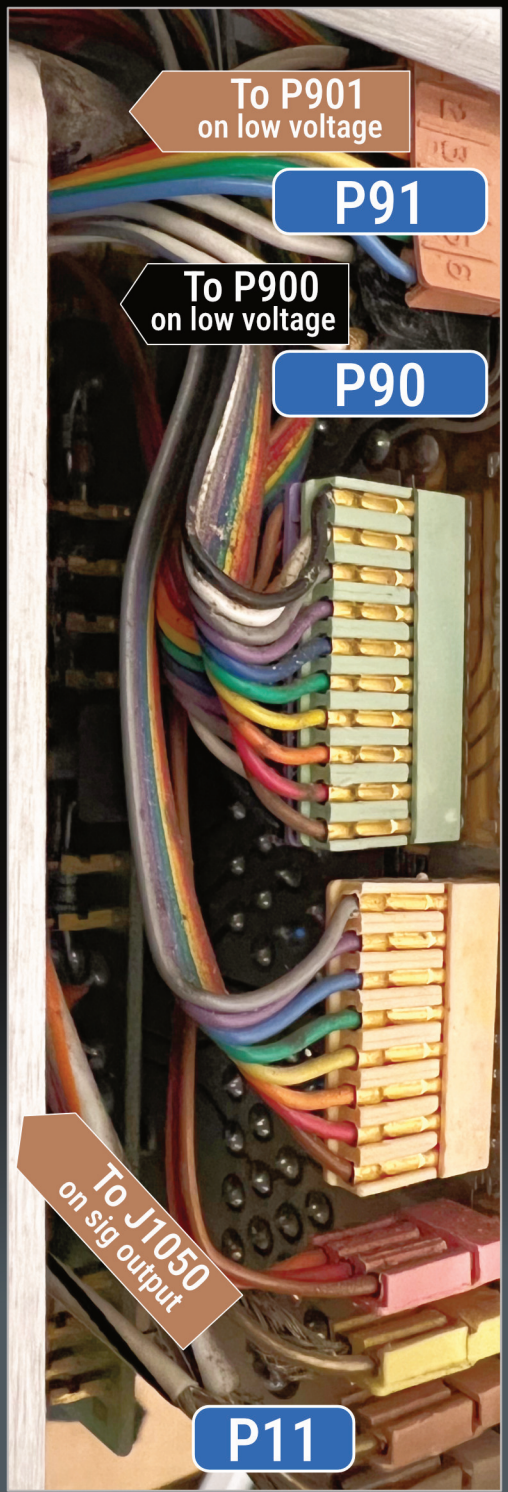
Power Connectors

in 7xx3 Mainframes

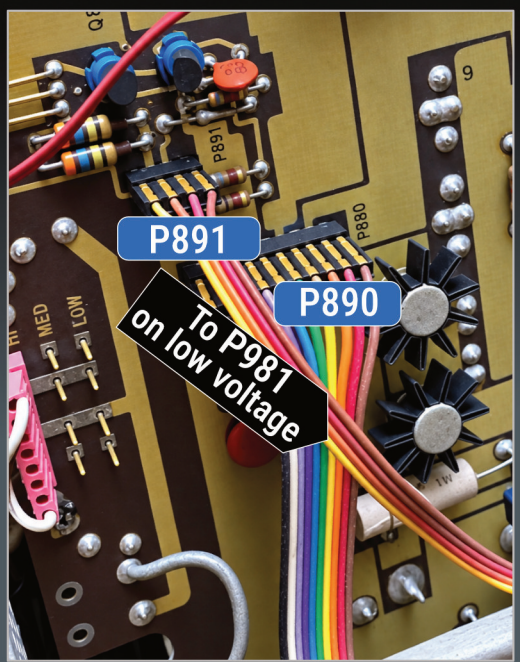
(1) Power-related connectors located on the right side of the Main Interface Board, viewed from the front of the instrument.

(2) and (3) Connectors on the Rectifier Boards. Note the unused pin on P870.

(4) Connectors on the Low-Voltage Board (LVB). Pay particular attention to P962, which has two unused pins, as shown in the enlarged detail.







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