Tektronix
The Round Corners

From Vacuum Tubes to Early Solid State

Giovanni Becattini

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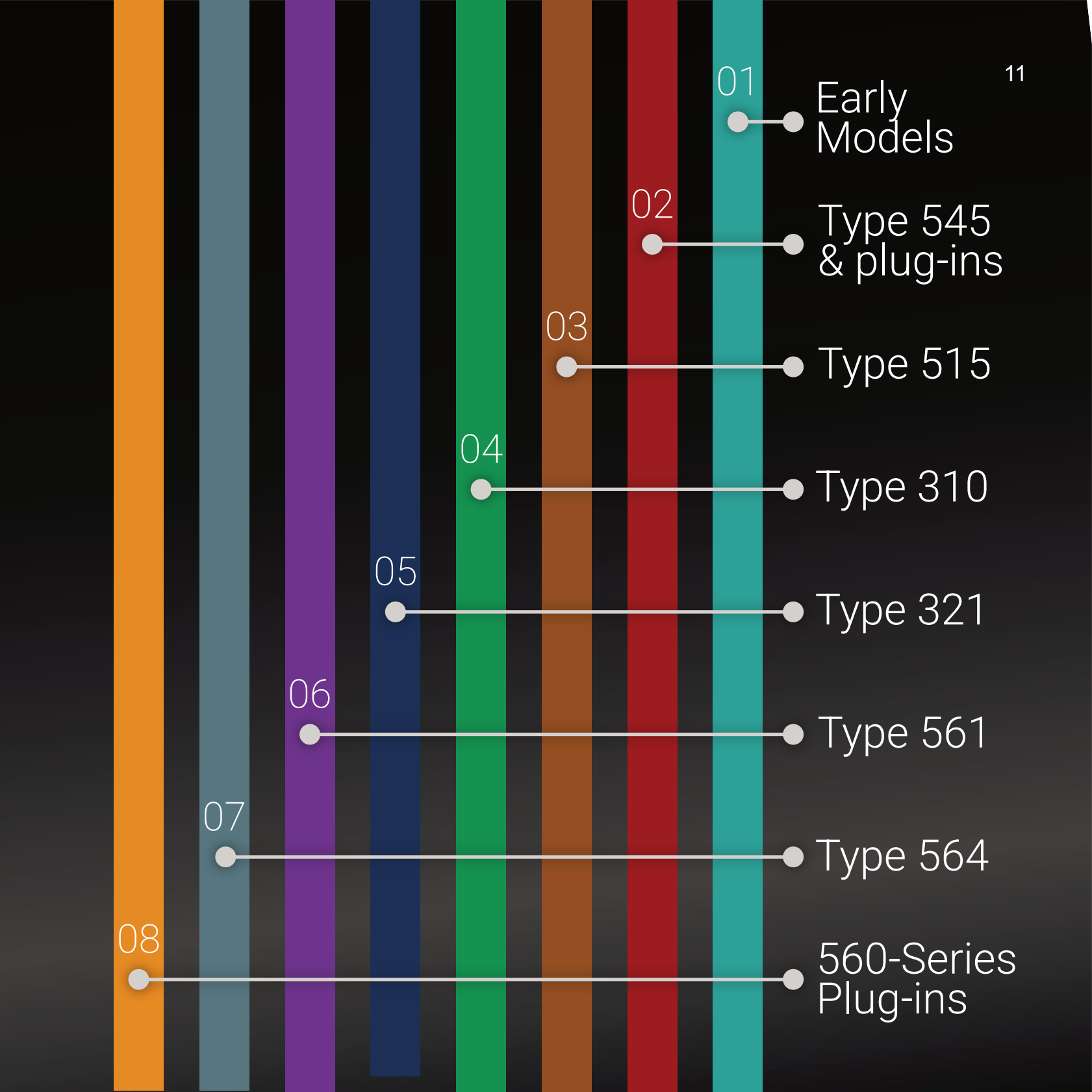
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- [DAB] Digital but Analog
- [TG7] When Machines Learned to Write
- [PDP-8] DEC PDP-8 – The Minicomputer That Anticipated Microprocessors
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- [TUB] The Tubes That Changed the World
- [TRC] Tektronix, The Round Corners – From Vacuum Tubes to Early Solid State
- [HEPS] Tektronix, 7000 Series Power Supplies – History, Design and Restoration

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From Zero to Convertibles

A Brief History from the Origins to the 531/535 Modular Oscilloscopes



TEKTRONIX



Calling it a bench oscilloscope almost understates the matter. The 517 consisted of a 76-pound indicator unit and a separate 72-pound power supply; when mounted on its 42-pound Scope-Mobile, the complete assembly weighed about 190 lb, or 86 kg. In 1953 it cost $3,500.

Tektronix engineer Frank Hood recollects:

> *"A lot of progress was made in 1949 and 1950. Work was well underway by Logan Belleville, Dick Rhiger and Howard on the high speed scope, the 517. This used some brand new circuitry, distributed (or chain) amplifiers, using 16 to 20 tubes in each stage to get the power needed to handle the high frequencies.*
>
> *Our best prediction at that time was that there were only about 30 to 50 people in the whole world who had need of a scope with 60 to 100 megacycle bandwidth. As it turned out, when we brought out a higher speed scope, people were able to design equipment of greater bandwidth and needed even faster measuring instruments. The cycle was regenerative. Having faster, more accurate measuring tools created a demand for even more measuring tools.*
>
> *We eventually sold several thousand of this instrument."*

(from TekWiki)

That recollection contains an idea worth remembering. Better measuring instruments did not merely satisfy an existing market; they helped create the technologies that would require still better instruments. Measurement capability and electronic development were beginning to drive one another.

Early 517s used the DuMont 5XP CRT. Later production changed to the Tektronix-made T517/T54 family, another sign of the company's growing determination to control one of the most critical components in the instrument.

Type 524-D — DC to 10 MHz

The Type 524-D, introduced in 1952, shows another direction in which Tektronix was expanding: specialization. Designed by Cliff Moulton for television waveform monitoring, it was derived in part from the 514 architecture but incorporated functions specifically intended for broadcast work, including specialized triggering and time-marker facilities related to television timing. Its vertical system extended to 10 MHz.

Left: the Type 524-D, introduced in 1952, was derived in part from the 514 architecture but incorporated functions specifically intended for broadcast work, including specialized triggering and time-marker facilities related to television timing. Its vertical system extended to 10 MHz.

eBay. How could I resist? I asked the editor for a little more patience, bought them, and decided not merely to add the 545 and 545B to the book, but to give them pole position.

There was another reason why I could not possibly leave the 545 out.

I do not remember exactly when I first began dreaming of owning a Tektronix oscilloscope, but I do know when I acquired my first monumental 545: 1976. I can reconstruct the date because I wrote an article about it that appeared in the December 1976 issue of CQ Elettronica, and even today I can remember the excitement that instrument gave me.

The Second Time Base

The second time base, absent from the Types 531 and 541, required no fewer than 13 additional tubes. One can imagine that, after considering various alternatives, the Tektronix designers finally resigned themselves to using a hinged chassis — a solution that turned out to offer several advantages at once:

- it made use of space that would otherwise have remained largely empty;
- it greatly improved service access, not only to the added time base itself but also to the circuitry beneath it;
- it could be added or omitted with relative ease, helping create the closely related 535/545 and 531/541 families.

We humble restorers from the future can only confirm that it was an excellent decision. In fact, working on this section is often even easier than servicing the rest of the instrument: the chassis simply swings out of the way and exposes both sides remarkably well.

There is only one small drawback to keep in mind. After decades of opening and closing, some of the interconnecting wires may have been repeatedly flexed or strained. Their solder joints therefore deserve careful inspection, and in some cases the wires themselves may need to be resoldered or replaced.

My own 545 provided a good example: several of these connections had suffered from years of movement and eventually required attention.



Competition — and Imitation

When the Type 545 appeared in 1955, Tektronix was certainly not alone in the oscilloscope business. DuMont, Cossor, Solartron and several other manufacturers offered serious laboratory instruments, and Hewlett-Packard was preparing to enter the field. Yet the comparison is revealing. DuMont's sophisticated Type 329, introduced the previous year, had a bandwidth of about 10 MHz and even offered an ingenious Notch Sweep facility for expanding a selected portion of the waveform. British instruments such as those from Cossor and Solartron were also highly regarded, but generally operated at still lower bandwidths. Hewlett-Packard entered the oscilloscope market in 1956 with the 150A, a modern instrument with plug-in vertical amplifiers and excellent triggering, but again with only about 10 MHz of bandwidth.

Individual competitors could therefore match particular features of the 545, and some introduced clever solutions of their own. What I have not found is a contemporary general-purpose instrument combining, in one package, the 545's 30-MHz DC bandwidth, interchangeable vertical plug-ins, calibrated dual time bases, delayed sweep and sophisticated triggering system. This was perhaps the real strength of the 545. It was not simply faster than most of its competitors; it brought together a collection of advanced ideas into a coherent measurement system.

An unusual confirmation of this technological lead came only a few years later. By the end of the 1950s the U.S. military, which was using large numbers of Tektronix oscilloscopes, wanted alternative suppliers rather than depending upon a single manufacturer. Companies including Hickok, Jetronic and Lavoie Laboratories were consequently asked to provide instruments equivalent to the Tektronix 535 and 545. What followed went considerably beyond normal competitive inspiration. The Hickok 1805 family and the Lavoie LA-265A reproduced Tektronix circuitry so closely that a long patent dispute followed. In one particularly extraordinary episode documented during the litigation, Hickok even submitted a Tektronix-built oscilloscope fitted with a Hickok faceplate as a sample of the instrument it proposed to manufacture.

The affair became a matter of principle for Tektronix. The company pursued the case for years, despite the considerable expense and the obvious risk involved in challenging one of its most important customers. Alan Scott Douglas later wrote that Howard Vollum was determined to continue largely on principle, even though Tektronix ultimately spent more on the litigation than it recovered. Whether every detail of Vollum's personal motivation can still be documented, the outcome cannot: Tektronix persisted and eventually prevailed on the central patent-infringement issues.

There is a certain irony in the whole story. When genuine competitors tried to challenge the 545, they generally offered lower bandwidth or fewer of its advanced features. And when the U.S. military later demanded a true second source for an instrument of the same class, some suppliers found the simplest solution was not to invent a fundamentally different oscilloscope. They tried to clone Tektronix.

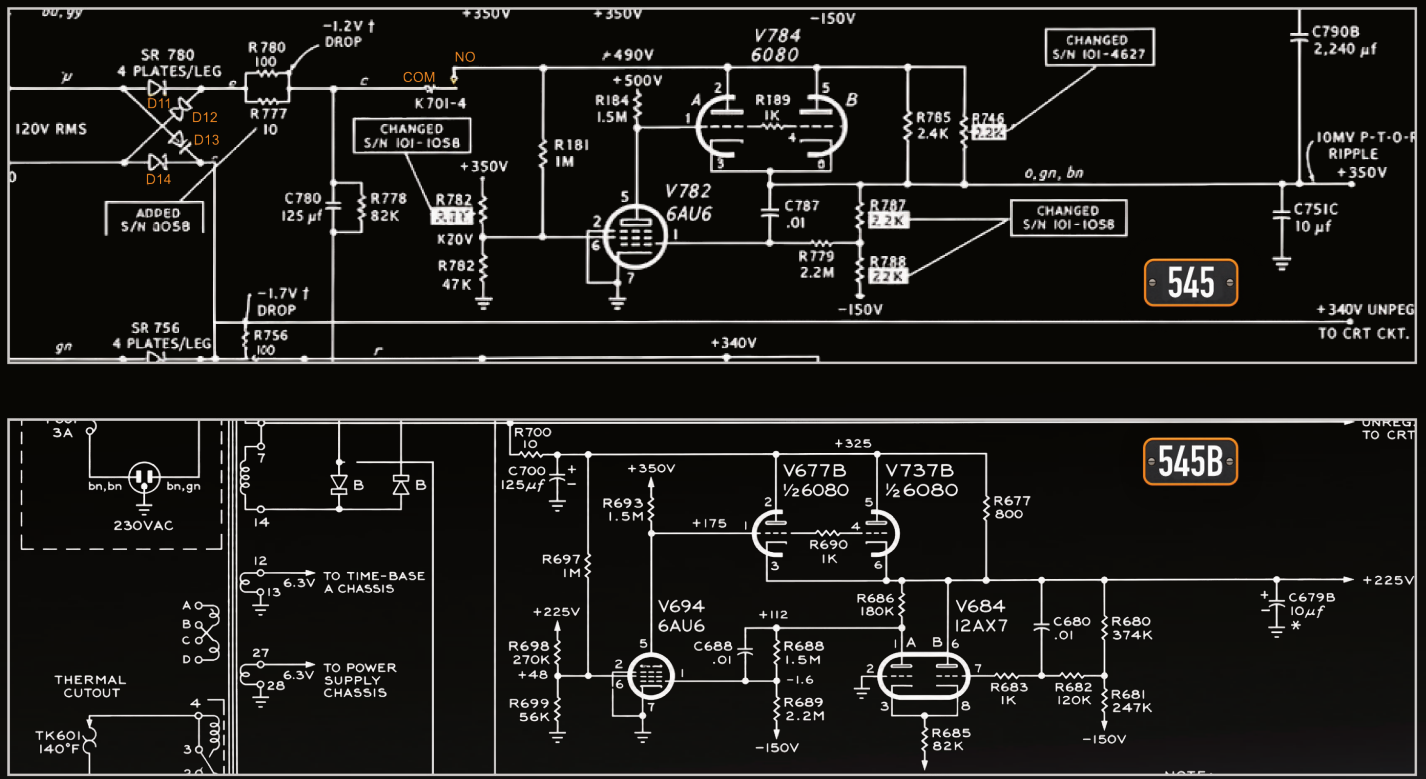
Power Supply Unit

The power supply unit (PSU) generates the several voltages required for the oscilloscope to operate. The 545 and 545B use rather different circuits in some areas, but their power supplies are based on essentially similar principles. Where significant differences exist, we shall point them out; once the basic operating concepts are understood, they are generally quite easy to follow.

The most important step is therefore to understand the principle behind the basic voltage regulator. The various regulated outputs differ in detail, but not fundamentally in the way they work.

The circuits we are going to examine are not particularly complicated. Nevertheless, I found that they require a little thought before their operation becomes completely intuitive. The Tektronix manuals provide accurate and detailed circuit descriptions, and there would be little point in reproducing them here. Instead, we shall try to provide something slightly different: an overall explanation of why the circuits work as they do, connecting the individual components into a picture that is sometimes less evident from the manuals alone.

Tektronix has always provided remarkably good and comprehensive service manuals. In the company's earliest years, however, these manuals did not normally include component layouts — that is, drawings showing the physical location of each component and its reference designator. The component layouts reproduced on these pages cover the power-supply section of the Type 545. Since no equivalent maps were available in the original documentation, I reconstructed them myself from the instrument, identifying and locating the individual components one by one.



immediately reapplied, but remain disconnected for approximately another 25 seconds while the tubes warm up again.

Relay K701 performs the actual switching of several power-supply connections. The original schematic does not identify its individual contacts particularly clearly, so I have added the usual designations COM (common), NC (normally closed) and NO (normally open) to make their operation easier to follow.

Fault #1, 545

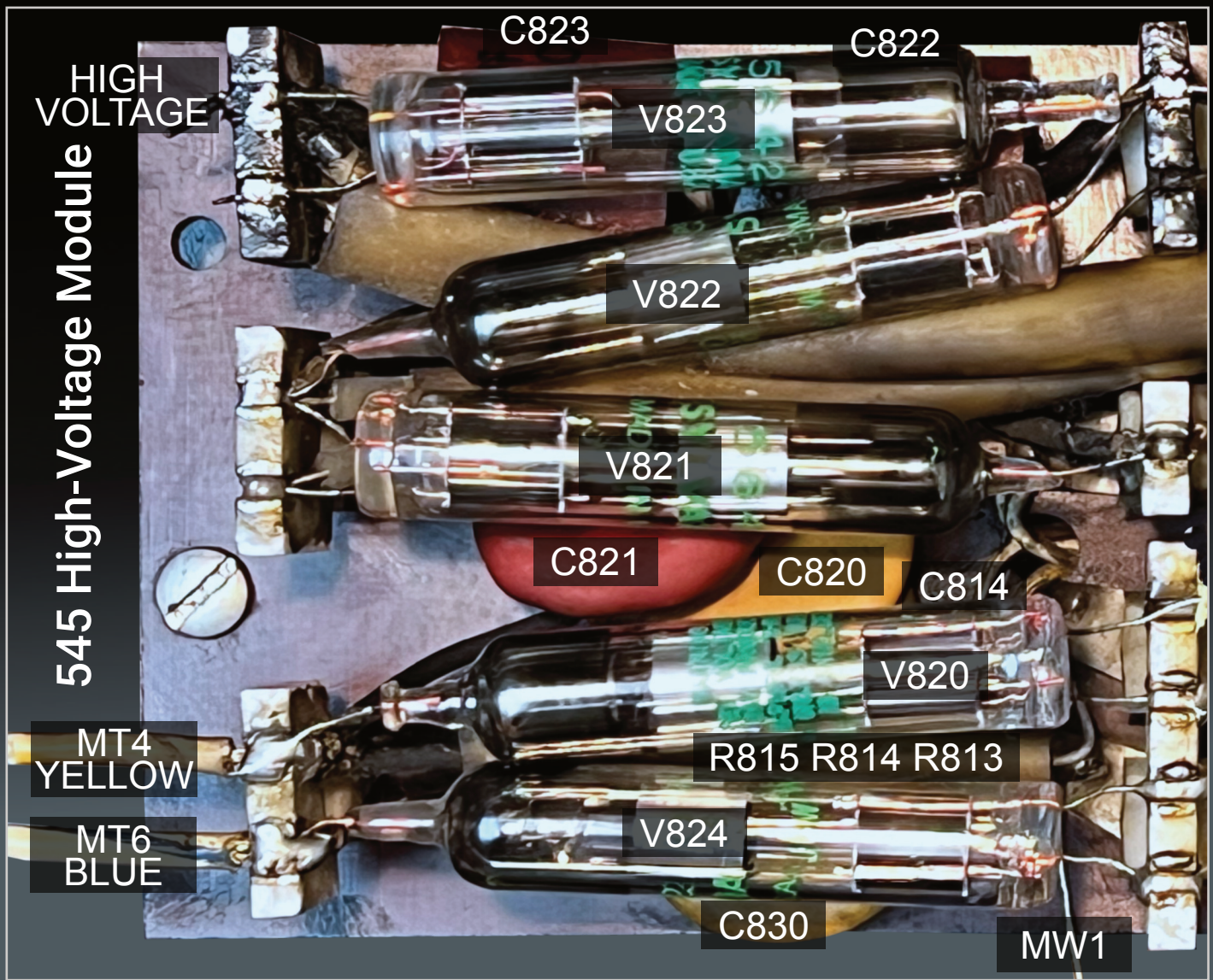
With instruments this old, you soon learn not to take anything for granted. A fault can change its behavior while you are investigating it, apparently disappear, and then return in a completely different form.

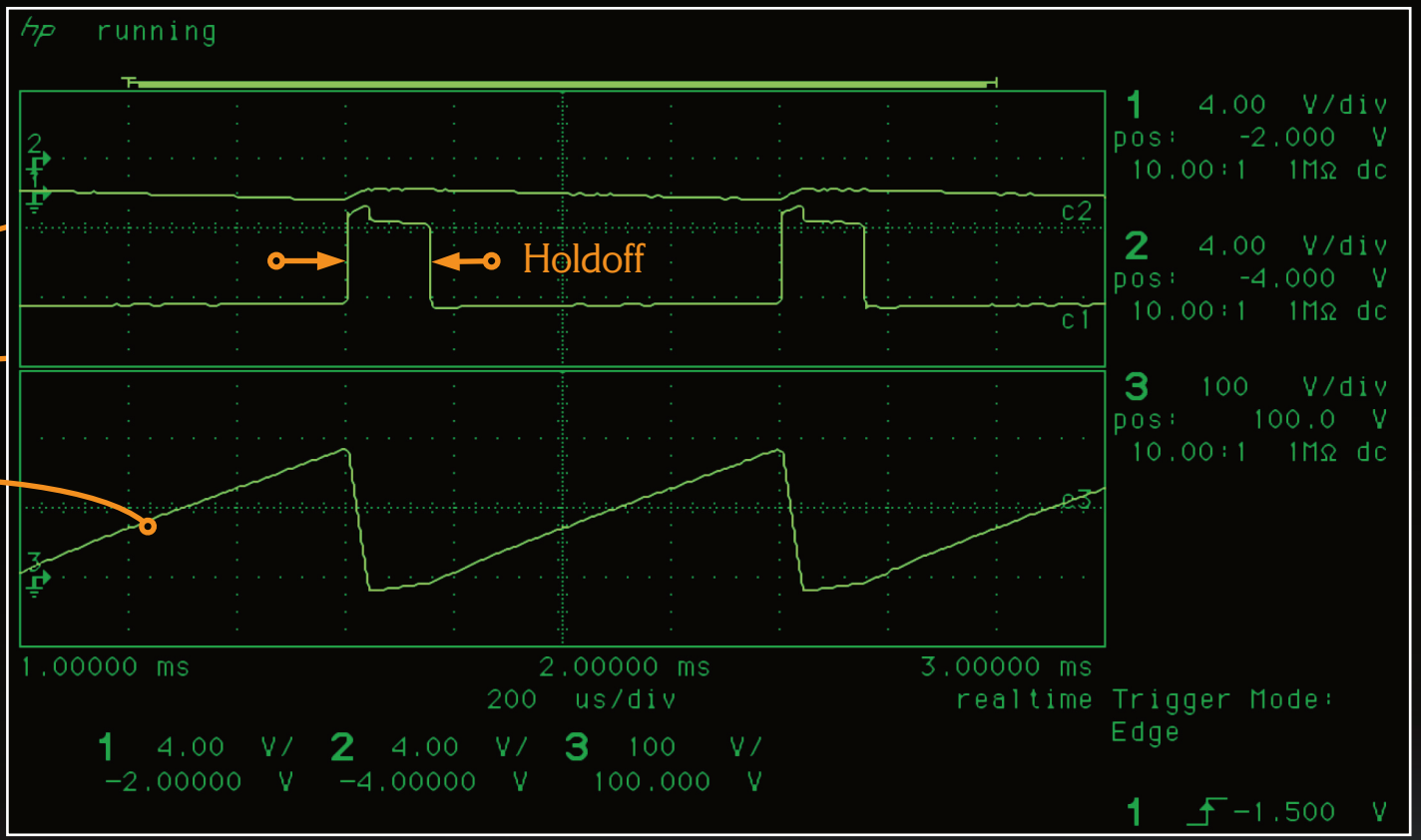
At one point I suddenly found a very large ripple on the +350 V line, although it had not been there during my previous checks. Tracing it backward, I soon discovered that it was already present on the +100 V supply, from which the +350 V circuitry ultimately derives part of its reference.

Unblanking

The intensity of the CRT beam must not remain constant under all conditions. It has to be modulated for several reasons:

- to blank the beam during sweep retrace;
- to produce the intensified portion of the trace when the delayed time base is used;
- to permit external blanking through the corresponding input.





Above: Waveforms recorded at different points in the sweep generator, including the output sawtooth. The holdoff interval is clearly visible: during this period the sweep circuitry resets and the trace returns to its leftmost starting position before the next sweep can begin.

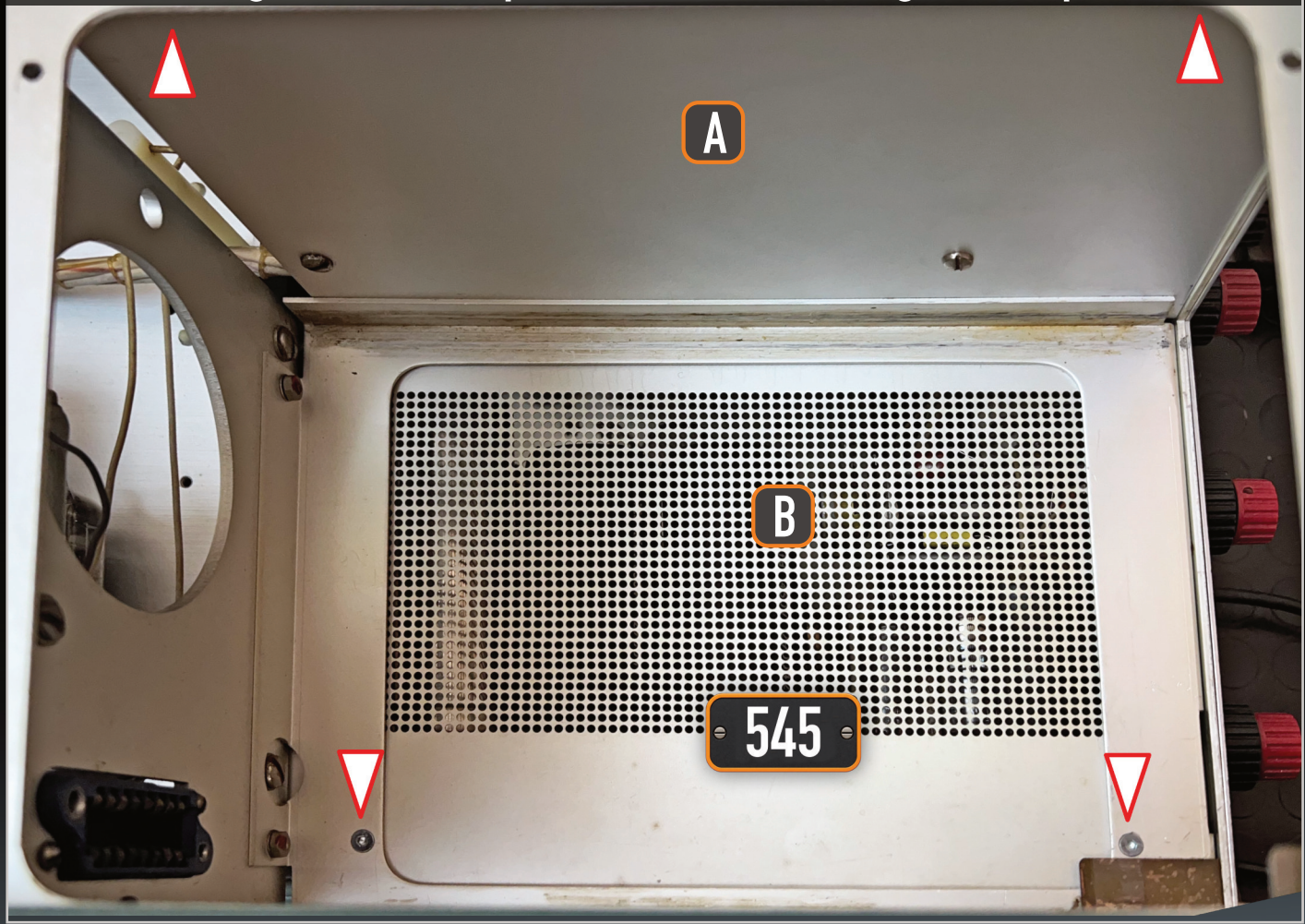
V150B therefore reproduces the Miller ramp at its cathode with low output impedance. This buffered sawtooth can then be sent to the horizontal-display circuitry without significantly loading the integrator itself.

A Complete Sweep Cycle

The entire process can therefore be summarized quite simply. A valid trigger passes through the V140 comparator. The V155 multivibrator changes state, causing the disconnect diodes V180A and V180B to stop conducting. The Miller integrator is released and generates a linear ramp, which is buffered by V150B and sent to the horizontal system.

At the end of the sweep, the multivibrator returns to its quiescent state. The disconnect diodes conduct again, the timing circuit is reset, and the holdoff circuitry prevents retriggering until the generator has fully recovered. Only then is V140 ready to accept the next trigger.

Accessing the C54x Capacitors from the Plug-in Compartment



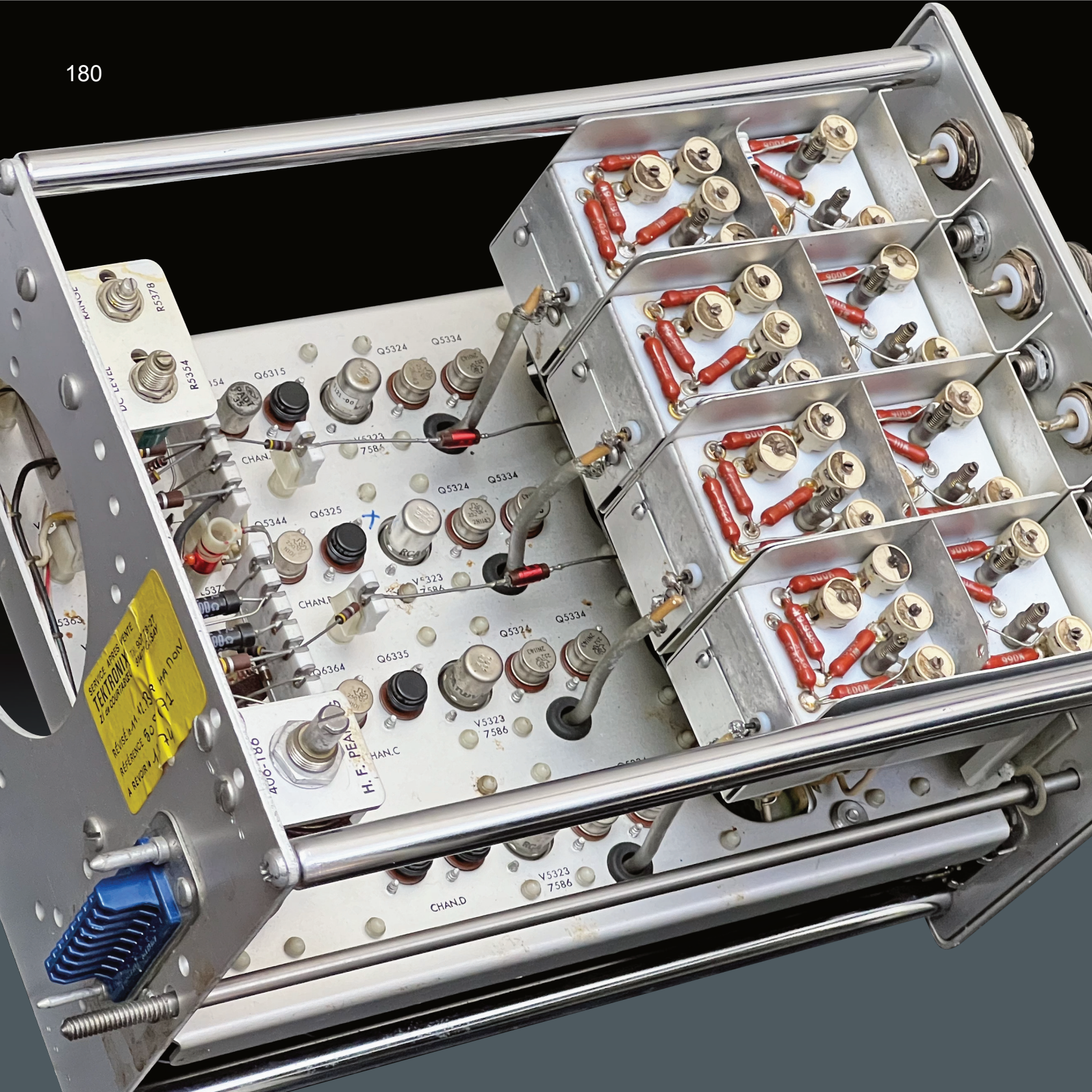
Above: Some of the Bumblebee capacitors can be reached only from the plug-in compartment, after removing the metal divider panels. To remove panel A, it is advisable to rotate it approximately 90° counterclockwise before withdrawing it.

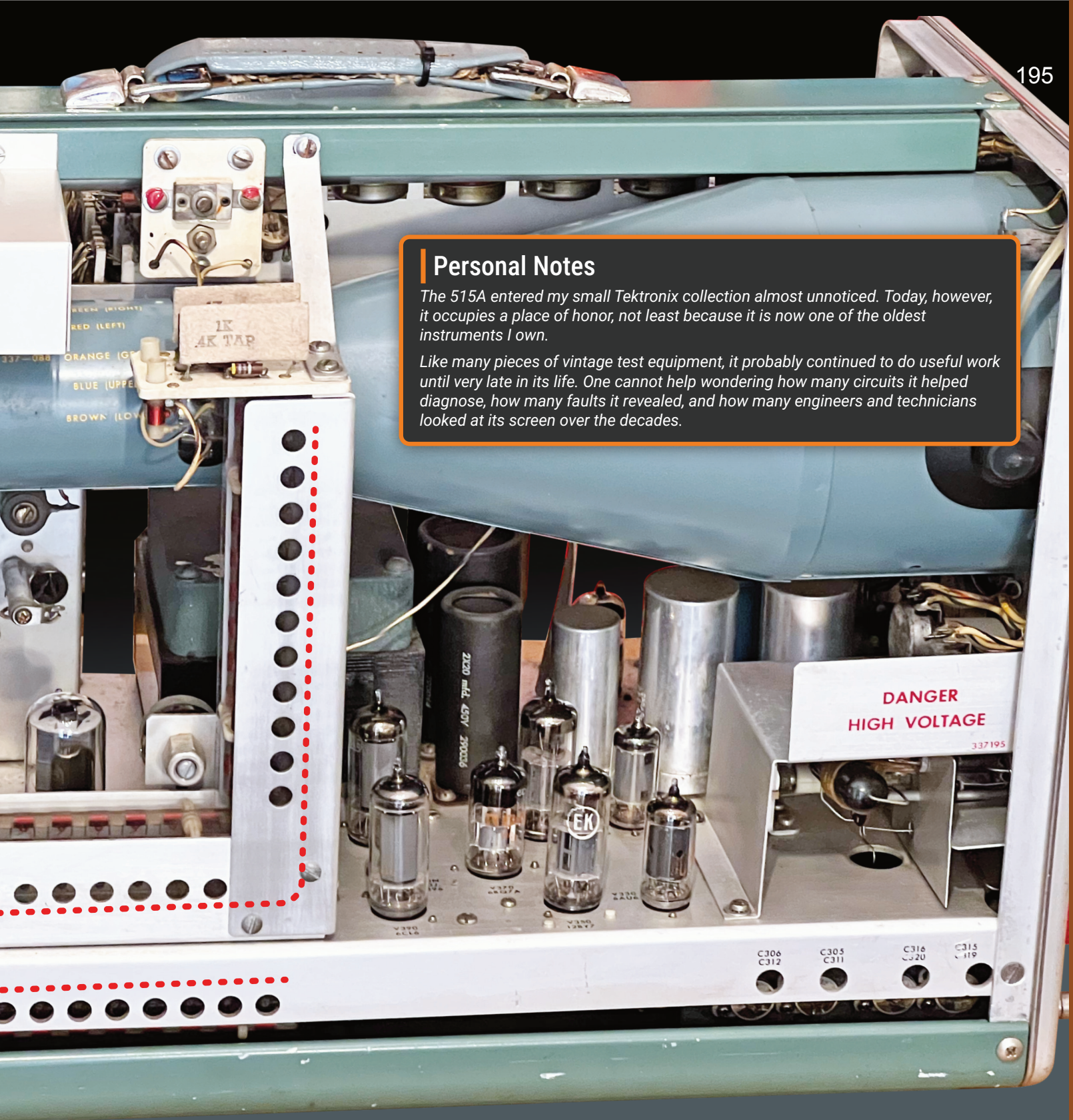
The photograph was taken from the left-hand side of the oscilloscope, with the instrument in its normal upright position.

The best access is from the plug-in compartment. Remove the two bulkheads marked A and B by taking out the four screws indicated by arrows in the photograph above. The operation itself is not particularly difficult and improves access enormously. It does not, unfortunately, eliminate the need for patience.



Poster Showing 36 Different Plug-In Faces (vintageTEK Museum)


DC LEVEL
R5354
Q6315
Q5324
Q5334
CHAN.
V5323
7586
Q5344
Q6325
Q6364
Q6335
CHAN.C
CHAN.D
H.F. PEAK
TEKTRONIX

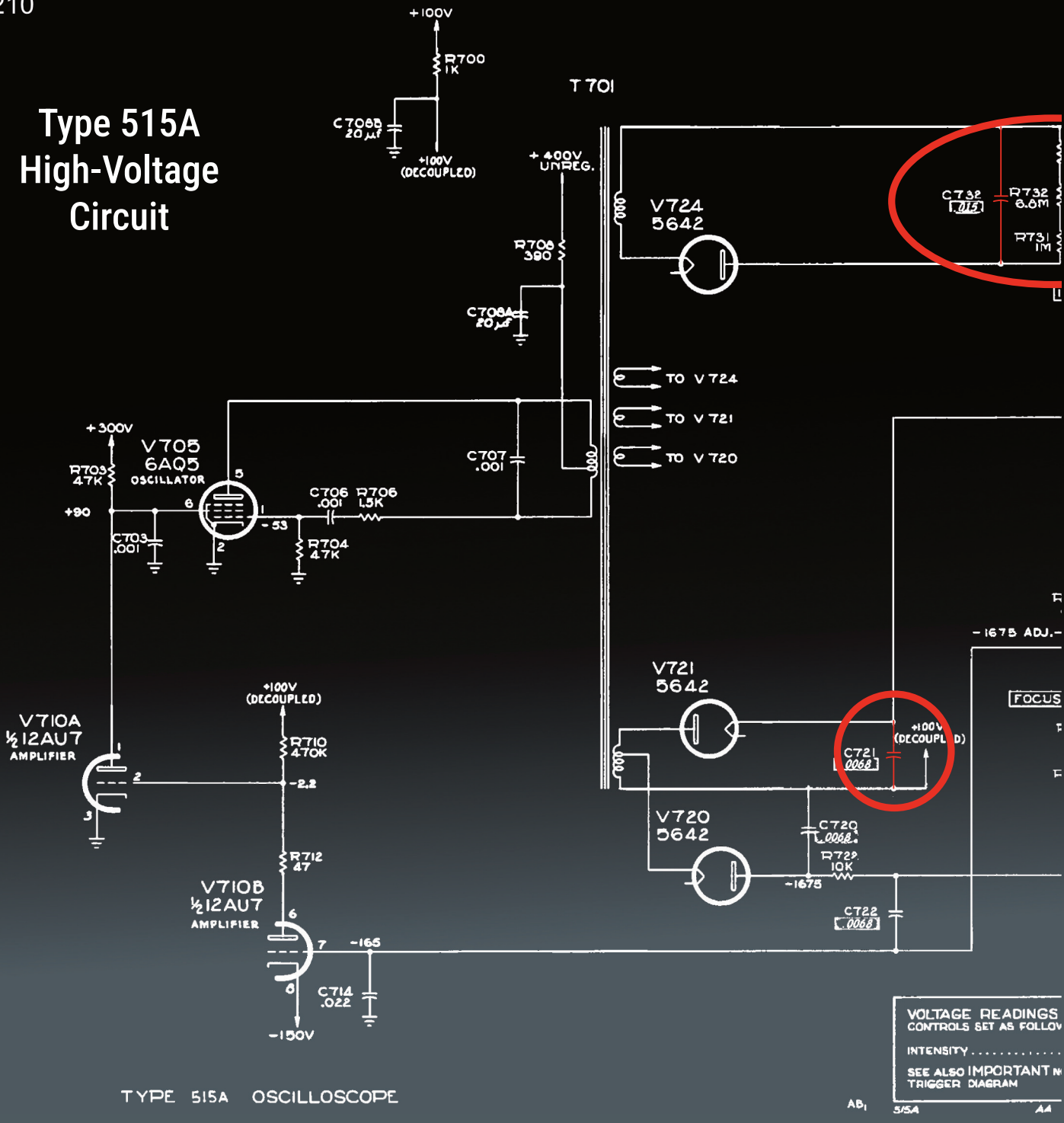


Personal Notes

The 515A entered my small Tektronix collection almost unnoticed. Today, however, it occupies a place of honor, not least because it is now one of the oldest instruments I own.

Like many pieces of vintage test equipment, it probably continued to do useful work until very late in its life. One cannot help wondering how many circuits it helped diagnose, how many faults it revealed, and how many engineers and technicians looked at its screen over the decades.

Type 515A High-Voltage Circuit



Born for IBM

The origin of the 310 is unusually well documented. **IBM** had asked Tektronix for a high-performance, lightweight portable oscilloscope suitable for servicing its computers. Frank Hood proposed several ideas and was assigned as project engineer for the new instrument.

By 1954 the engineering model had met IBM's approval and production began. Even more interestingly, Hood recalled that the instrument was manufactured under both the Tektronix and IBM names.

Tektronix apparently regarded the project as relatively specialized and did not initially expect large sales, but once again, the market had other ideas. Hood later recalled that tens of thousands of 310 and 310A oscilloscopes were sold. What had begun as an instrument largely intended for computer servicing had revealed a much broader demand for a small oscilloscope offering serious laboratory performance.

The 1955 Tektronix catalog described the idea very clearly: the Tektronix Type 310 is fully capable of performing much of your **laboratory work**, yet has the physical characteristics desirable for work away from your bench. It emphasized field maintenance, small size, low weight and, at the same time, calibrated measurements and complete accessibility to components.

Those apparently contradictory requirements explain much of the remarkable construction of the 310.

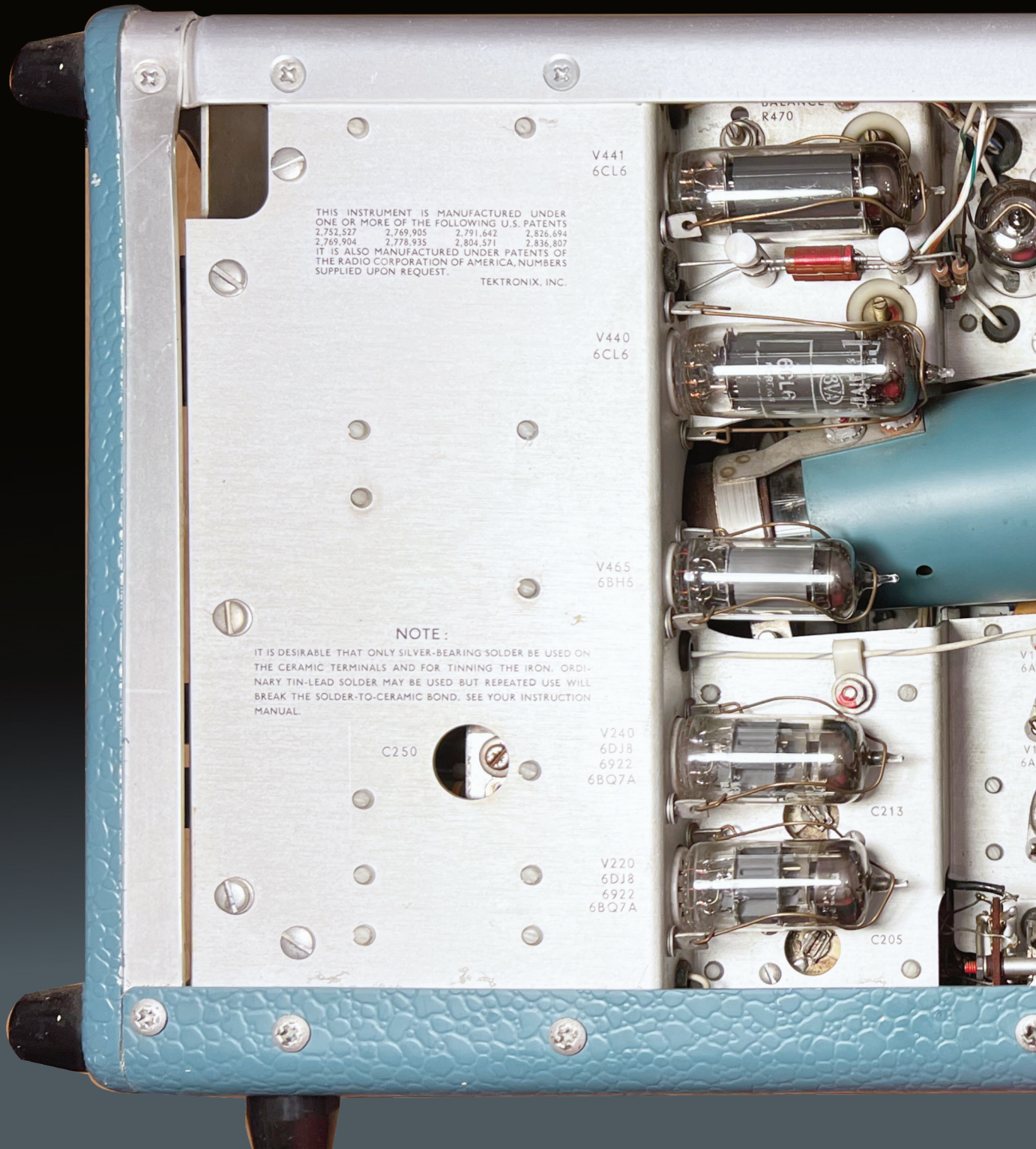
Not the First Portable

The idea of a compact field oscilloscope was certainly not new, however. In fact, we encountered one of its ancestors almost at the beginning of this book.

The military **OS-34/USM-32**, closely related to the commercial **DuMont Type 301-A**, had originated from a U.S. Navy requirement several years earlier. As we saw, the first Navy contract was awarded to DuMont in 1951, while the commercial 301-A appeared publicly around 1953.

The 301-A was already remarkably compact. It used a 3-inch CRT, offered approximately 4 MHz vertical bandwidth, weighed about 21 lb (9.5 kg), and sold for $935. So the Tektronix 310 did not invent the portable oscilloscope.

The Portable 310A



CIRCLE 22 ON READER SERVICE CARD

NEW TRANSISTORIZED PORTABLE OSCILLOSCOPE

Operates from { Internal Battery, External DC and AC Line



TYPE 321

TRULY PORTABLE

Battery Powered.
Weighs only 13½ lbs. without batteries.
Batteries weigh 2 to 4 lbs.
Size only 5½" x 8½" x 16".

HIGH PERFORMANCE

Vertical Response: DC to 5 MC, 0.07 μsec risetime.
Calibrated Sensitivity: 0.01 v/div to 20 v/div in 11 calibrated steps.
Continuously adjustable from 0.01 v/div to 50 v/div.
Calibrated Sweeps: 0.5 μsec/div to 0.5 sec/div in 19 calibrated steps.
Accurate 5x magnifier extends calibrated range to 0.1 μsec/div.
Continuously adjustable from 0.1 μsec/div to 1 sec/div.
Simplified Triggering: Fully automatic, or amplitude-level selection with preset stability control.
4-kV Accelerating Potential on 3" crt.
6-div by 10-div Display Area.
Amplitude Calibrator.

NO POWER SOURCE PROBLEMS

Operates from:
1. Ten size D Flashlight cells, ½ hour continuous, more with intermittent, operation.
2. Ten rechrageable cells, 2.5AH—3 hours continuous operation. Ten rechrageable cells, 4.3AH—5 hours continuous operation.
3. 11 to 35 v dc (aircraft, auto, boat, etc.).
4. 105 to 125 v ac or 210 to 250 v ac, 50 to 800 cps.

Price **$775.00**
Built-in Battery Charger **35.00**
Complete Set of 2.5AH Batteries **36.50**
f.o.b. factory

It's so easy to take the Type 321 wherever an oscilloscope is useful. It's a convenient solution to many difficult situations, too . . . for example: Where power cords are apt to be a nuisance—where isolation from ground is desirable—where power-line fluctuations are troublesome—where hum pick-up is a problem. The Type 321 is sure to satisfy your portable oscilloscope needs.

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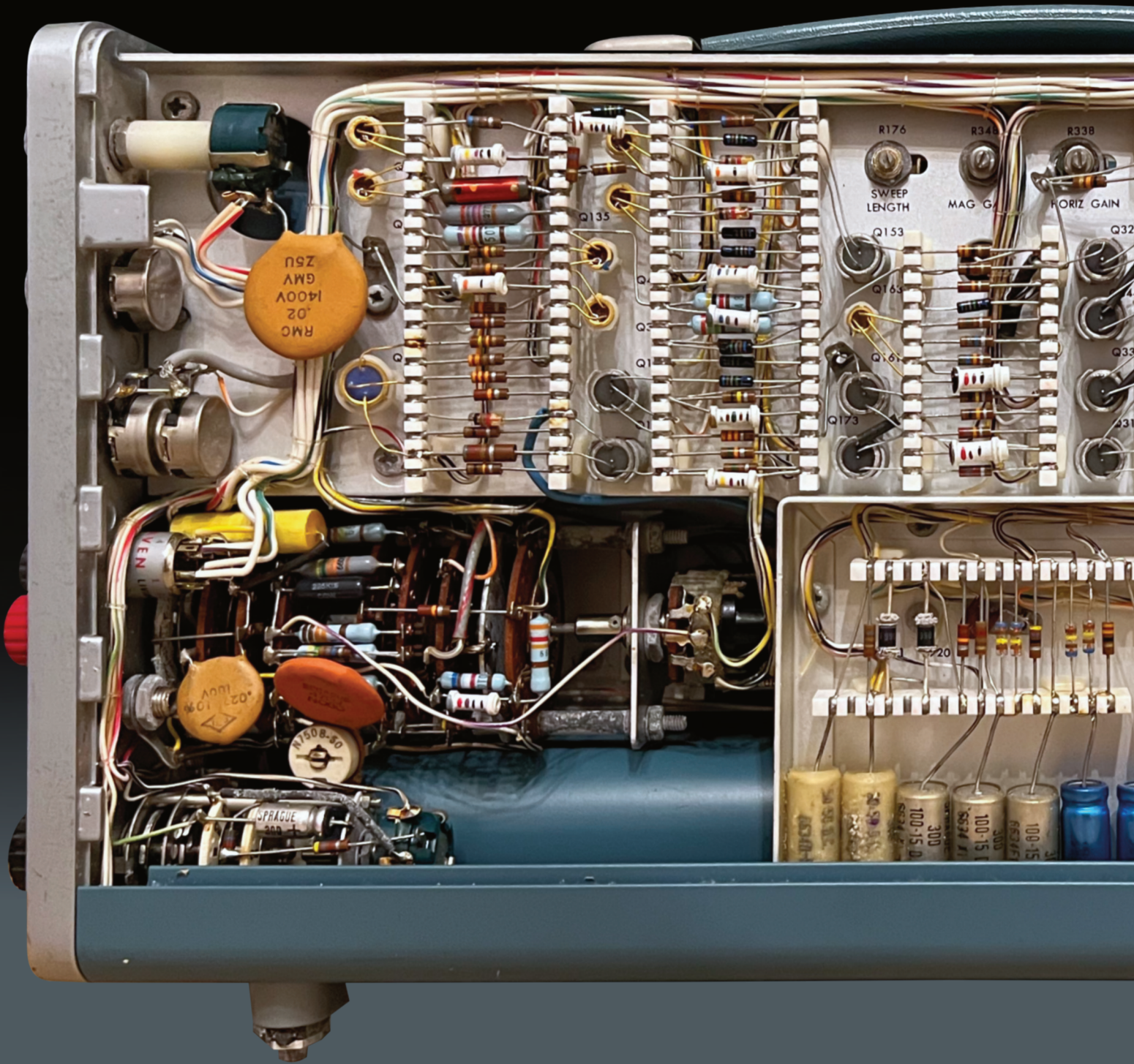
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ENGINEERS—Interested in furthering the advancement of the oscilloscope? We have openings for men with creative ability in circuit and instrument design, cathode-ray tube design, and semiconductor research. Please write Richard Rougeaquet, V.-P., Eng.

If you missed the Type 321 at WESCON, see it at NEC, booth 193-194.

CIRCLE 23 ON READER SERVICE CARD →


R176
SWEEP LENGTH
HORIZ GAIN
Q153
Q135
Q173
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Taking the Plug-In Idea One Step Further

The plug-in concept itself was certainly not new to Tektronix. It had been one of the keys to the extraordinary success of the 530 and 540 Series. Howard Vollum had strongly supported the idea from the beginning, believing that no manufacturer could anticipate every possible use of an oscilloscope. A versatile instrument, adaptable to different tasks, made more sense to him than a collection of highly specialized instruments.

This philosophy had not originally been universally accepted. **Logan Belleville**, one of Tektronix's most respected early engineers, argued for almost the opposite approach: the best instrument for a particular job should be designed specifically for that job. **Vollum** instead favored versatility. The market eventually settled the argument rather decisively: within a year of their introduction, the 531 and 535 accounted for almost half of Tektronix oscilloscope production.

The 560 Series carried Vollum's modular philosophy considerably further. In the 530 and 540 Series, the vertical amplifier was interchangeable, but much of the oscilloscope—including the horizontal system—remained permanently installed in the mainframe. In the 560, both vertical amplifier and time base became plug-ins.

The mainframe was therefore reduced almost to its essentials: CRT, power supplies, calibrator and the mechanical structure necessary to hold the two modules.

Straight to the Plates

Tektronix promoted direct connection to the CRT deflection plates as an advantage. There was no additional amplifier between the plug-in and the CRT to restrict bandwidth or distort the signal. In electrical terms, it was an extremely clean solution.

But this approach also had **disadvantages**. The deflection sensitivity of individual CRTs varied appreciably, and because the mainframe contained no standardized output amplifier to absorb these differences, gain and sweep calibration depended on the particular combination of mainframe and plug-in. Changing a module could therefore require recalibration if accurate measurements were expected.

There was also an economic consequence that is less obvious at first sight. Moving the final vertical and horizontal amplifiers into the plug-ins made the mainframe simpler and cheaper—but every plug-in now had to contain circuitry capable of driving the CRT plates directly. A laboratory owning several

I immediately suspected C822, and I was right. After replacing it, the voltage rose at once to 4.9 kV. Victory? Unfortunately not. This turned out to be only an incidental failure. C822 was rated at 5,000 V, but after so many years it may simply have been unable to withstand almost 4,900 V and finally gave up.

I therefore reconnected R849, but the original fault was still there. I continued disconnecting everything that was not essential, progressively reducing the circuit to the smallest possible area.

During this phase I also checked the inverter waveform with another oscilloscope. This is easily done at V800, pin 9. A 2 kV ×100 probe is required—I used an inexpensive one from China—because the plate sits at approximately 400 V DC, while the oscillator waveform is about 600 V peak-to-peak. Its positive peak can therefore exceed 700 V with respect to ground, far too much for an ordinary oscilloscope probe.

Below: The TV-7D/U Tube Tester was, and still is, one of the most highly regarded instruments of its class. Unlike the myriad of simple emission testers, it measures tube transconductance, which provides a much more meaningful indication of tube condition (see the [TUBES] book).



564 Specifications

The Tektronix Type 564 used two interchangeable 2- and 3-Series plug-ins, allowing the vertical amplifier and time-base functions to be adapted to a wide range of applications. Its most distinctive feature, compared with the other members of the family, was clearly its storage capability.

The 564 employed a Tektronix-manufactured bistable storage CRT whose screen was divided into two independent 4 × 10 cm storage areas.

Either half of the screen could be stored or erased separately, making it possible to retain one waveform for comparison with a subsequent one. The instrument could also be operated as a conventional non-storage oscilloscope.

Stored traces could remain visible for up to about one hour, a particularly valuable capability when observing single-shot events, very slow phenomena, or when photographic recording was required.

The 564 was a vacuum-tube instrument and was later replaced by the solid-state 564B in 1969. Its effective bandwidth depended largely on the plug-ins installed and, with suitable 3-Series sampling units, the system could also be used for measurements extending into the microwave region.

Model Numbering and 564B

As we have seen, Tektronix products were generally identified by a type number. When a model underwent a significant revision, a letter was often added to the original designation, most commonly “A” or “B”.

During the 1950s and 1960s, these revisions sometimes reflected substantial changes in circuit technology, including the gradual transition from vacuum tubes to semiconductors. We have already encountered examples in the evolution of the 530/540 Series and, within the 560 family itself, in the 561.

The 564 followed a slightly unusual path, however, as there was never a production 564A: the original 564 was followed directly by the 564B.

Introduced around 1969, the 564B was a fully solid-state redesign, appearing at approximately the same time as the similarly redesigned 561B. It therefore seems plausible that Tektronix chose the “B” suffix to keep the two closely related mainframes aligned, although I have found no contemporary Tektronix documentation explicitly confirming this explanation.

instead, allowing the electrons to reach the phosphor and keep those portions of the screen illuminated.

The original electrical signal may have vanished long ago, but its charge pattern remains on the storage target. The flood guns continually convert this invisible electrostatic pattern back into visible light.

What is stored, therefore, is not the light itself and certainly not a digital representation of the waveform. It is an electrostatic image of the trace; the screen is not displaying a memory and the screen itself is the memory.

The Coffee-Cup Problem

For a long time, one aspect of this mechanism puzzled me. If the writing beam removes electrons from the storage surface and the flood guns continuously supply new ones, why do the incoming electrons not simply fill the “holes” and destroy the stored charge?

A very ordinary cup of coffee finally gave me a useful mental picture.

Imagine water continuously entering a cup while an equal amount flows out. Individual water molecules are constantly being replaced, but the level in the cup remains essentially unchanged.

Something similar happens on the storage target. The flood electrons do not simply accumulate until the stored charge disappears. Under the correct electrical conditions, incoming and outgoing electrons establish a stable equilibrium. The charge pattern remains, and with it the stored image.

It is certainly not a rigorous physical model, but it finally made the phenomenon intuitive for me—and sometimes that is more useful than another page of equations.

Bistable Storage

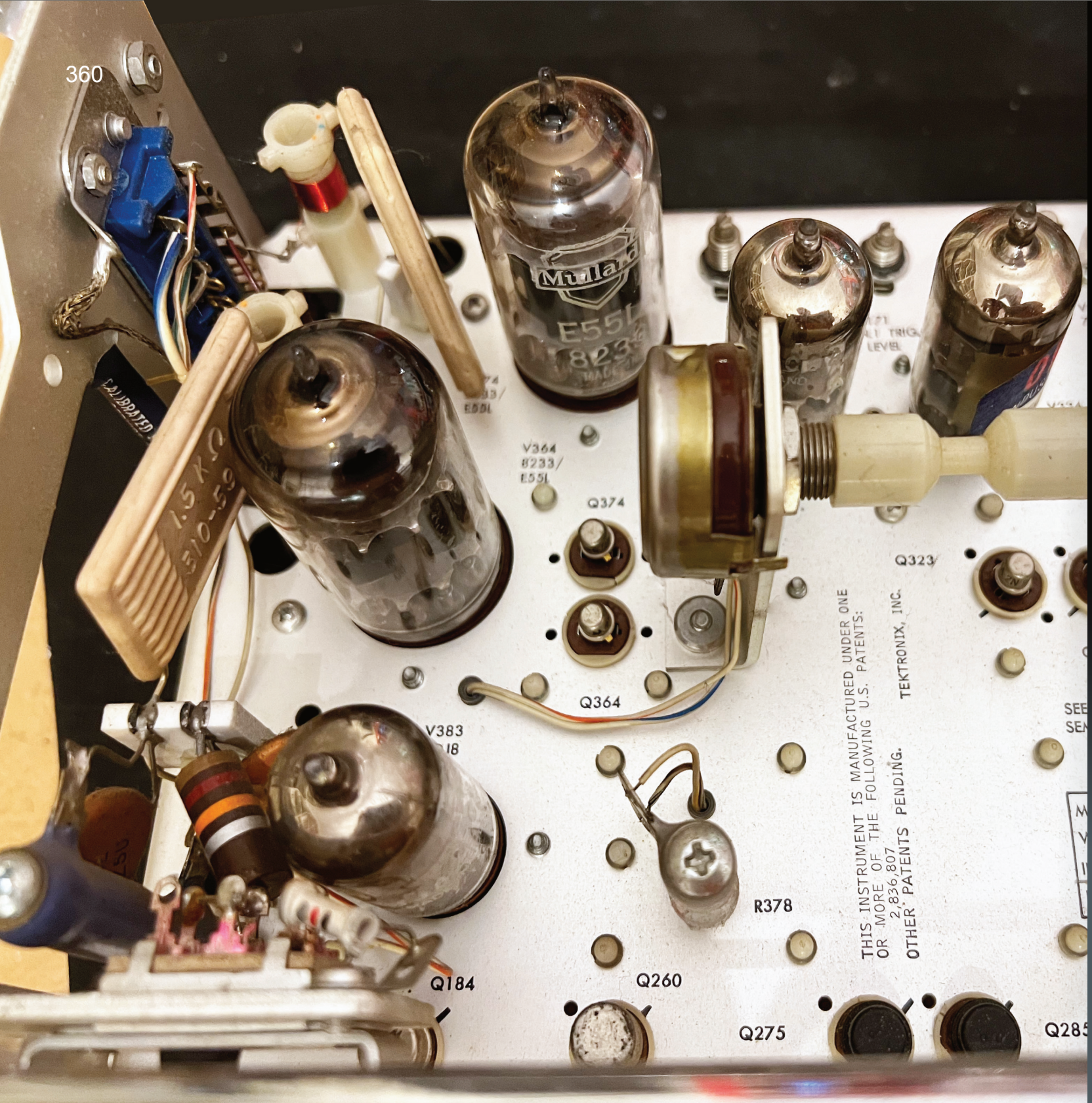
The 564 belongs to the early generation of bistable storage oscilloscopes.

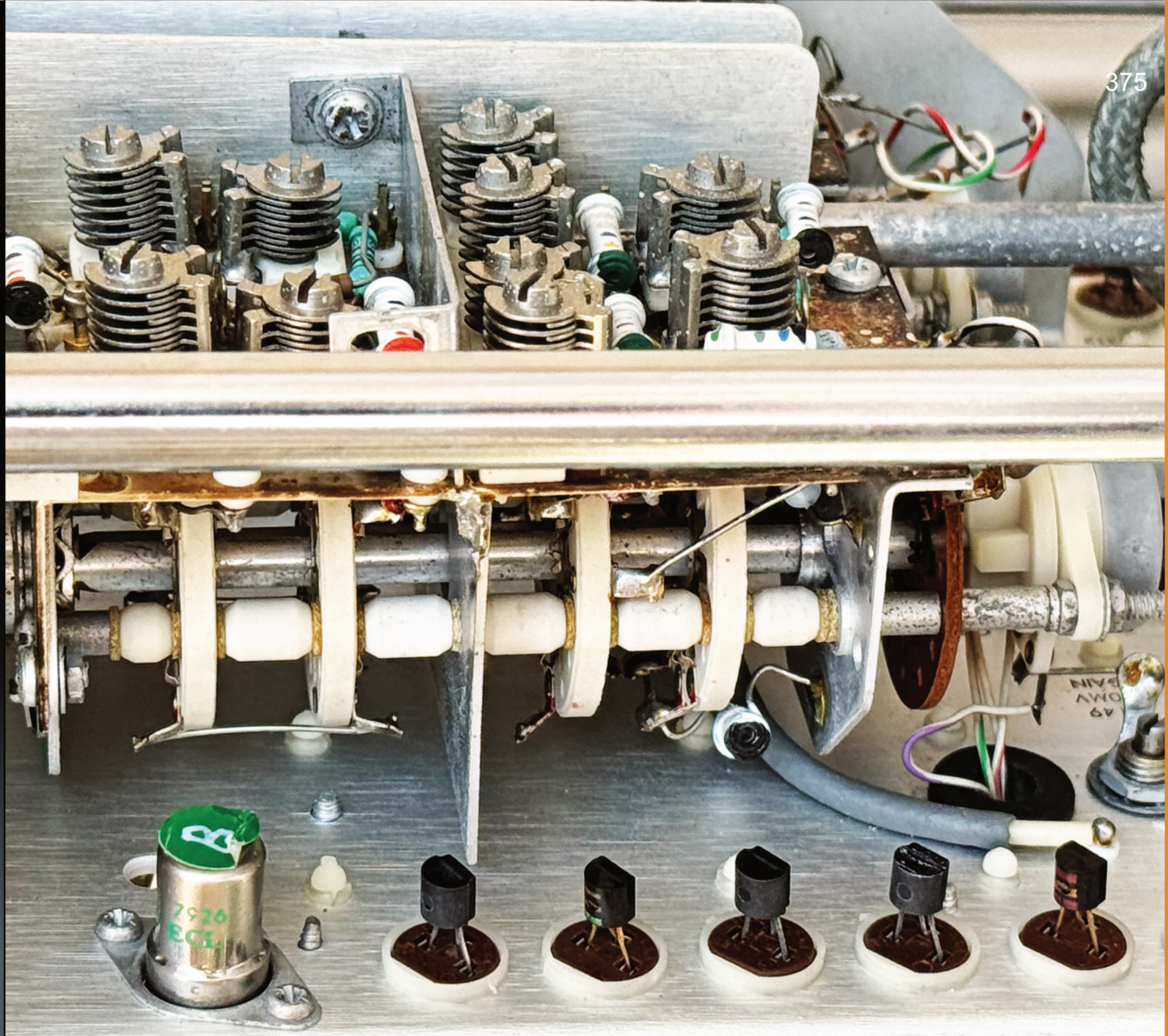
The name is quite descriptive. The storage surface essentially operates between two stable states: written and unwritten. Once a region has been driven into the written state, the flood electrons maintain the visible image until the screen is deliberately erased. The great advantage is long storage time, the disadvantage is speed.

3Bx Plug-ins

A rich range of models for the successful line of Tektronix 56x oscilloscopes




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V364
8233/
E55L
Q374
Q364
Q323
V383
R378
Q184
Q260
Q275
THIS INSTRUMENT IS MANUFACTURED UNDER ONE OR MORE OF THE FOLLOWING U.S. PATENTS:
2,836,807
OTHER PATENTS PENDING.
TEKTRONIX, INC.



By simply removing four screws, the panel can be taken off to reveal the beautifully made ceramic attenuator switch used in the 3A1 and 3A6 vertical amplifiers. These are high-quality components and, after a thorough cleaning with WD-40C—a contact cleaner and deoxidizer intended for electrical applications—they usually return to perfect working order.

How Can It Do That?

I squeezed my brain trying to understand what Tektronix meant when it said that D415 “switches to its low state” and makes the base of Q424 more positive, but initially with rather modest results.

The important point is that the tunnel diode is not acting like a tiny battery. The circuit biases it so that the change in comparator current forces D415 abruptly from one stable branch of its characteristic to the other. Because the voltage across the diode changes suddenly during this transition, the voltage at the base of Q424 also jumps.

In other words, the unusual negative-resistance characteristic allows a relatively slow change from the tube comparator to be converted into a very fast electrical transition.

That is the real trick.

Looking Inside

On the facing page, the oscilloscope photograph shows three relevant waveforms:

- the main-sweep ramp;
- the plate voltage of V414B, the right-hand side of the comparator;
- the plate voltage of V414A, the left-hand side.

When the sweep ramp reaches the threshold selected by the DELAY TIME control, the comparator changes state: V414A turns on and V414B turns off.

The abrupt change in current forces D415 to switch between its two stable states. This produces the sharp voltage transition applied to Q424; after inversion and differentiation, the resulting pulse becomes the command that starts the delayed sweep.

What initially looked like a rather mysterious extra spike is therefore not voltage somehow “created” by the tunnel diode. It is the visible consequence of an extremely rapid transition between two operating states—a clever way of obtaining a clean timing pulse from an otherwise relatively slow tube comparator.

Very simple and effective, I begin to like tunnel diodes now!

