

The Tubes That Changed the World

From Edison Lamps to Vacuum Tube Testing

• TV-2/U • TV-7/U •

Giovanni Becattini



CONTENT

USE THE COLORED
PAGE EDGES TO
NAVIGATE THE BOOK
QUICKLY.

A TECHNICAL ART BOOK ON VACUUM TUBES AND TESTERS

This Book	13
-----------	----

Close Your Eyes and Look	15
Technological Habituation	15
Close Your Eyes	15

01

Building Blocks of Modernity 21

The Blackened Bulb	23
Year 1883	25
The Edison Effect	26
And the Lamps?	29
Ductile Tungsten	29
The Gas-Filled Lamp	30

Solving the Edison Effect	33
Electron, a Perfect Stranger	33
Joseph John Thomson	34
The Electron Theory	35
Another Revolution	35
Understanding Edison	36

Listening to the Atlantic	38
Then a Signal Emerged	38

Thermionic Emission	49
From Heat to Current	50
Owen Willans Richardson	50
The Price of Escape	51
A Cloud Around the Cathode	55
Emission Current and Plate Current	55
Saturation	56
A Useful Obstacle	59
Why This Matters to a Tube Tester	59
From Physics to a Device	60
Does the Cathode Run Out of Electrons?	60

The Electrical World Before the Valve	63
Without Steam?	63
The Battle of the Currents	66
Messages Through Wires	68
Into the Air	70
Making Waves with a Spark	71
The Search for a Continuous Wave	73
The Arc Transmitter	75

Radio by Mechanical Precision	76
Ready for the Leap	76
The Diode, the First "Valve"	81
How Does It Work?	83
Inside the First Valve	83
When the Plate Is Positive	84
When the Plate Is Negative	86
Not an Ideal One-Way Device	86
Symbolic Representation	87
From Alternating Current to Direct Current	88
Detecting a Radio Signal	91
What the Diode Could Not Do	94
From Detection to Control	96
Still Essential Since 1904	96
The Triode	99
The Invention Nobody Understood	99
Lee de Forest	100
The Long Road to the Third Electrode	104
Three Electrodes, but No Grid	107
The Grid Appears	108
An Audion, Not Yet a Triode	109
The Smallest Lever Ever Made	110
And Then, Almost Nothing Happened	111
One Audion After Another	112
The Invention on Trial	114
Two Judgments	116
The Men Who Understood	118
An Important Difference	121
From Detector to Repeater	122
Another Laboratory, the Same Problem	123
Years of Litigation	124
Refining the Gold	124
From a Bulb to a Continent	126
What the Grid Really Does	127
From the Diode to the Triode	127
Why the Grid Matters So Much	128
A Small Cause, a Large Effect	128
The Plate Helps, But the Grid Commands	129
Not a Barrier, but a Gate	129
Four Grid Conditions	130
<i>Grid Strongly Negative</i>	130
<i>Grid Moderately Negative</i>	131
<i>Grid Less Negative</i>	131
<i>Grid Positive</i>	131

Control Is Continuous	132
Why the Audion Was Confusing	132
The Defining Principle of Electronics	133
Reading the Curves	134
The Plate Characteristics	134
Reading One Curve	136
A Family of Curves	136
The Plate Still Has Influence	137
The Grid Voltage as a Third Dimension	137
The Transfer Characteristic	138
Plate Resistance and Transconductance	140
Plate Resistance	140
Dynamic Plate Resistance	142
Conductance	142
Transconductance	144
The Slope of the Transfer Characteristic	144
A Simple Example	146
Why the Name?	146
A Local Quantity	147
Why High Transconductance Matters	147
No Single Value Tells the Whole Story	149
Emission Is Not Transconductance	149
Why Tube Testers Measure It	150
The Smallest Lever, Measured	150
The Amplification Factor	151
The Triode Goes to Work	153
From Tube to Circuit	154
A Tube Alone Does Nothing	154
The Resting Condition	154
The Curves Describe; the Circuit Chooses	155
Why a Load Is Necessary	156
A First Audio Amplifier	158
Sound Becomes a Voltage	158
The Circuit at Rest	158
Adding the Signal	161
When the Grid Becomes Less Negative	161
When the Grid Becomes More Negative	161
The Signal Turns Upside Down	162
Where the Additional Energy Comes From	162
Two-Stage Amplifier	164
Not Yet a Loudspeaker Amplifier	164
Passing the Signal On	164
One Stage Hands the Signal to the Next	165

Each Stage Has Its Own Resting Point	166
Gain Becomes a Chain	168
Always Awake	168
Conducting Throughout the Cycle	168
Other Ways of Letting the Tube Work	169
<i>Preserving the Waveform</i>	169
<i>When the Original Waveform Need Not Be Preserved</i>	170
What the Triode Had Made Possible	170
Oscillators	171
Truly Understanding Oscillators	171
Oscillating Circuits	171
Damped Oscillations	173
Knocking the Bell	174
Recharging the Spring	174
Oscillators	177
Simple Triode Oscillator	177
Beyond the Triode	181
An Imaginary Dialogue	181
Why More Grids?	182
Was the Triode Not Enough?	182
The Problem with the Triode	182
Tetrodes	183
A New Approach to Research	183
Understanding the Screen Grid	185
Slope of the Plate Characteristics	186
Reading the Tetrode Curves	188
Pentodes	190
A New Problem: Secondary Emission	190
The Pentode	192
How Did We Get There?	194
Beam Tetrodes	196
Principle	196
Construction	196
The Virtual Cathode	199
Results	199
An Ideal Triode?	202
Comparisons With the Triode	204
Tubes With More Than Three Grids	204
Conclusions	205

02 Tube Testers 207

From Emission to Mutual Conductance 209

Is This Tube Still Good? 210

An Essential Question 212

First Tube Testers 212

Making It Practical 213

Hickok 214

The Evolution 214

A Brief Reminder: Mutual Conductance 215

How These Instruments Work 215

What the Tester Must Do 215

Differential Amplifiers 217

A Balanced Bridge 217

An Electromechanical Differential Amplifier 218

Adding the Tube 218

Emission Testers 220

Why Did They Exist? 223

Answering the Initial Question 224

TV-2/U Mutual Conductance 227

Wonderfully Complex 228

Meeting the TV-2 228

TV-2/U Description 230

What Is The TV-2? 230

A Generation of TV Testers 230

Specifications 231

Test Ranges 232

Functions 232

Documentation 234

Block Diagram 237

The Power Supplies 237

The Test Circuits 238

Press to Test 239

The Electrode Selectors 239

One Instrument, Several Questions 240

Advantages 240

A Few Considerations 243

A Little Disappointing? 243

An Irresistible Combination 245

03

Hands-On Experience	246
Out of the Box	246
First Switch-On	249
Learning to Use It	251
Setting the G.M. CENTERING Knob	251
Understanding the Grid Circuit	252
The Mysterious Disturbance	255
An Extra Gift: Measuring Triode Plate Current	260
Actual Measurement	261

TV-7/U Small & Light	263
---------------------------------	------------

Destined for a Greater Success	265
---------------------------------------	------------

Description	265
The TV-7: Military-Grade Tube Testing	265
Specifications	267
Functions	268
Documentation	269
A Market Favorite	269
Using—and Comparing—it	271
<i>Other Practical Differences</i>	272
TV-7 Block Diagram	274

Performing Calibration	278
-------------------------------	------------

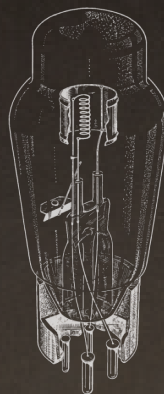
Out of the Box	278
Calibration	278
A Bit More Complex Than It Seems	280
Required Instrumentation	280
Splitting the Problem	282
Real Voltages	282
What Does a DC Voltmeter Measure?	286
Comparing Theory with the Manual	286
Practical Measurements	288
Not Yet Finished	290
Instrument to Use	290
Calibration Table	291
Calibration Tips	291
<i>Preparation</i>	291
<i>R130 Adjustments</i>	292
<i>Start with the Line-Adjust Circuit</i>	292
<i>Do Not Rely Blindly on the Panel Meter</i>	292

The Problem of the FUSE Lamp	295
-------------------------------------	------------

What Should We Expect?	296
------------------------	-----

04

Some Comparative Tests	296
What Is the Actual Mutual Conductance?	298
gm on the TV-2	298
gm on the TV-7	299
Conclusion	300
Measured Values	301
Gassy Tubes	302
How Can We Detect Gas?	303
Analyzing the Results	304
<i>Gas Test on the TV-2/U</i>	304
<i>Gas Test on the TV-7/U</i>	307
Two Similar Circuits, Two Different Philosophies	308
Conclusion	310



References

The following references are used in this book:

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

- All rights reserved. No part of this publication may be reproduced or stored in any form or by any means, electronic or mechanical, without the prior written permission of the Author.
- The Author has made every reasonable effort to ensure the accuracy of the information contained herein but assumes no responsibility for errors or omissions, or for any loss or damage resulting from the use of this material.
- Most photographs were taken by the Author; others derive from commercially licensed or Creative Commons sources, clearly indicated where applicable.
- AI-assisted content disclosure – This book contains AI-assisted content used for language revision and for the creation of original illustrative material. All ideas, technical content, structure, and final editorial decisions remain entirely the Author's own.
- Some illustrations in this book were generated with the assistance of artificial intelligence tools, using original prompts and concepts developed by the Author. These images serve a purely illustrative and metaphorical purpose and are not intended to depict or reference any existing copyrighted characters, brands, or proprietary visual styles.
- Apple, Hewlett-Packard, Tektronix, Teletype, and all other trademarks or logos mentioned in this book are acknowledged and remain the property of their respective owners.
- © 2025, 2026 Giovanni Becattini, Florence, Italy.

Close Your Eyes and Look

Technological Habituation

We are all familiar with the phenomenon of **habituation**. When we are exposed to the same stimulus for long enough, we gradually notice it less and less, even though its intensity has not changed.

We now live in a state of technological habituation. Everything seems natural to us: hearing a voice from the other side of the world, watching events unfold live thousands of miles away, gaining access in a few moments to an almost unlimited amount of information. Every day we use devices that would have seemed miraculous only a few generations ago, yet very few technological advances are still capable of genuinely astonishing us.

Close Your Eyes

So let us pause for a moment. Close your eyes, set aside everything we take for granted today, and try to return to **1880** with minds temporarily cleansed of our technological addictions.

Technology has already transformed the world profoundly. **Steam engines** power factories and ships; **railways** cross continents; the **telegraph** carries messages at speeds that

long, thin and flexible wire. This greatly simplified lamp construction and rapidly made the earlier sintered filaments obsolete.

The Gas-Filled Lamp

Irving Langmuir, also working at GE, then studied the evaporation of tungsten from the hot filament. By filling the bulb with nitrogen and winding the tungsten wire into a compact coil, he slowed the loss of material and allowed the filament to operate at a higher temperature. By 1913, GE was marketing the resulting gas-filled, coiled-tungsten lamp as the Mazda C. The process did not completely eliminate blackening, but it reduced it substantially while producing a brighter and much more efficient lamp.

By 1913, the combination of ductile tungsten, coiled filaments and inert gas had largely brought the old problem under control. The blackening that had troubled Edison was no longer an unavoidable limitation of the incandescent lamp.

Yet the strange current he had observed thirty years earlier had taken on a life of its own. The failed attempt to improve a lamp had revealed that electricity could cross an empty space—and other scientists were beginning to understand how that apparently useless effect might be put to work.

From the Cat's Whisker to Germanium

This is not merely a story I learned from old books. As unlikely as it may seem, I used a galena detector myself when I was a boy.

My grandfather was the person who first encouraged my interest in radio. He gave me a galena detector and one of those distinctive coils wound in a honeycomb pattern, and with them I built my first receiver.

For the radio enthusiasts of the 1920s, building and operating a receiver often meant becoming at least a little bit of a technician. Tuning was not simply a matter of turning a knob. The circuit had to be assembled, the antenna and ground arranged, and the delicate cat's-whisker contact patiently moved across the crystal until a sensitive point was found.

My grandfather also gave me two radio books from the 1920s, one by Montù and the other by Banfi. I still own them today. They were, in effect, my first electronics textbooks.

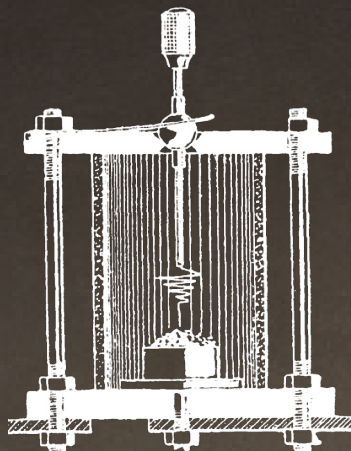
Then, one day, my grandfather told me: "You know, they have invented a little device called a germanium diode. It does the same job, but no longer needs the cat's whisker."

He gave me the money to buy one. As far as I remember, it was an OA70—my first semiconductor device.

The difference seemed almost miraculous. The tiny diode replaced the crystal, its uncertain sensitive spots and the fragile wire contact with a component that simply worked. I could not know it then, but in that modest receiver I had crossed, in miniature, one of the great boundaries in the history of electronics: from the empirical detectors of the pioneering age to the solid-state world in which I would later spend most of my professional life.

Here, on the right: the galena detector, one of the earliest semiconductor diodes. It consisted of two main elements: a crystal of galena, a naturally occurring mineral composed of lead sulfide, and the cat's whisker, a very fine, springy metal wire that the operator gently moved across the surface of the crystal until a sensitive "sweet spot" was found. This point contact behaved as a primitive diode, allowing current to flow more readily in one direction than in the other and thus rectifying the radio signal.

Beside it: Alessandro Banfi's book, an essential guide for early radio enthusiasts and one of my very first electronics textbooks.



A valve may possess adequate cathode emission and still perform poorly because of weak grid control, low transconductance, gas, leakage, electrode distortion or other faults. Conversely, a measurement made under strongly space-charge-limited conditions may reveal more about the test circuit than about the cathode's true maximum emission.

This is why an **emission test** and a **mutual-conductance** test do not answer the same question.

Much later in this book, when a tester marks a valve simply GOOD or BAD, we shall have to ask exactly which of these phenomena it is really measuring.

From Physics to a Device

Richardson had shown how temperature governed the supply of electrons. The study of space charge then explained why the current collected by a second electrode depended also upon voltage and geometry. Child investigated the limiting effect mathematically in 1911, and Langmuir developed an extensive treatment of thermionic currents and space charge in high vacuum in 1913.

The pieces were now in place:

- a hot cathode could release electrons;
- a positive plate could collect them;
- the intervening space charge could regulate their flow;
- reversing the plate voltage would repel rather than attract them.

The Edison Effect was no longer merely a curious current inside an experimental lamp. It had become the physical basis of a device that could conduct electricity predominantly in one direction.

John Ambrose Fleming would turn that principle into the first practical thermionic valve.

Does the Cathode Run Out of Electrons?

At this point, another rather natural question may arise. If a hot cathode continuously releases electrons, does it eventually run out of them?

Fortunately, it does not. Electrons are not a special substance stored inside the cathode and gradually consumed during operation. They are ordinary constituents of the metal, and the external circuit continuously replaces those that leave its surface.

The Arc Transmitter

The second approach used an electric arc. An arc was already familiar as an intense and persistent electrical discharge between two electrodes. Under suitable conditions, however, it could do more than produce heat and light. Connected to a tuned electrical circuit, it could supply energy continuously to an oscillation.

The best-known development of this principle was the Poulsen arc transmitter. Its glowing arc operated inside a specially constructed chamber and was subjected to a magnetic field. Around it stood heavy coils, capacitors, cooling arrangements and a powerful direct-current supply.

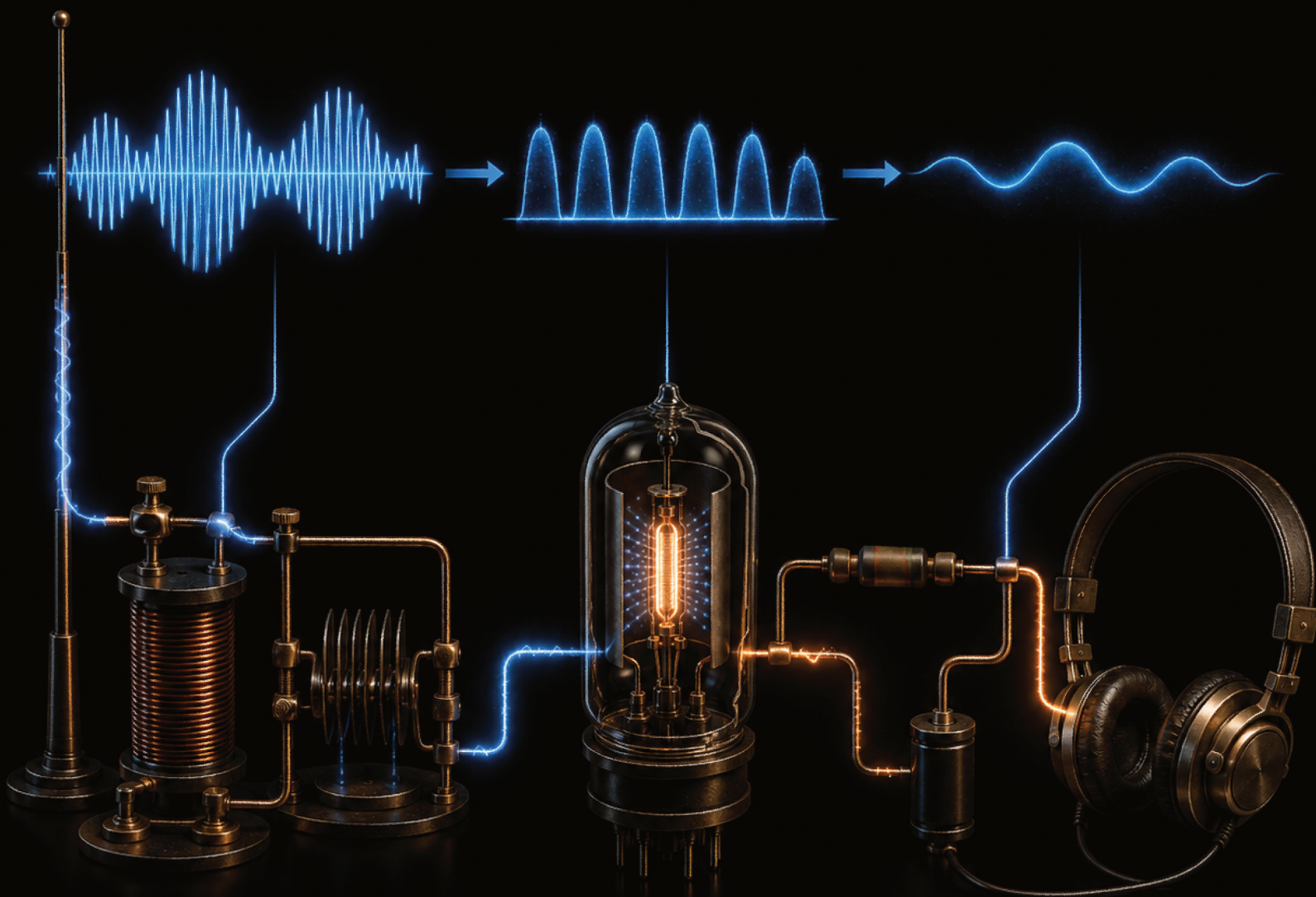
Unlike a spark gap, the Poulsen arc did not repeatedly ignite and extinguish. It formed a continuous conducting discharge supplied with direct current. Because the arc exhibited negative differential resistance, it could continuously replenish the energy lost in the tuned LC circuit, sustaining a radio-frequency oscillation rather than producing a succession of damped wave trains.

Poulsen's achievement grew out of William Duddell's "singing arc," which had shown that an electric arc could sustain oscillations at audio frequencies. Poulsen extended the principle into the radio range by enclosing the discharge in hydrogen or hydrocarbon vapor, cooling the electrodes and applying a transverse magnetic field. These measures allowed the arc to respond rapidly enough to feed a high-frequency tuned circuit. The resulting continuous wave occupied a much narrower band than a spark signal and could therefore be tuned more selectively. It also provided a carrier suitable for modulation, making the arc transmitter one of the first practical routes toward radiotelephony as well as long-distance wireless telegraphy.

Yet the apparatus was far from simple. The arc had to remain stable; its electrodes deteriorated; heat had to be removed; and large installations required considerable electrical and mechanical equipment.

The transmitter contained no electronic valve, but it was hardly a delicate instrument. It was more like an electrical furnace persuaded to sing at radio frequency.

Left: A more advanced spark transmitter using two coupled tuned circuits. The Ruhmkorff coil charges the Leyden jars to a high voltage. When the spark gap fires, the capacitor and the primary winding form a damped oscillatory circuit. These radio-frequency oscillations are then transferred by inductive coupling to the secondary circuit connected to the antenna and ground, which radiates the Hertzian waves.



From Radio Waves to Sound

The diode rectifies the radio-frequency signal, producing unidirectional pulses whose amplitude still follows the modulation envelope. A suitable load circuit suppresses most of the RF component, leaving the slower audio signal for the headphones.

In the account he presented to the **American Institute of Electrical Engineers** in October 1906, De Forest traced the origin of the Audion back to experiments he had performed six years earlier. Working at night in his room, he operated a small induction coil from a distance by pulling a string. Above his table burned a gas lamp fitted with a Welsbach mantle. The setting seems almost too picturesque to be true, but it reveals the intellectual world from which the Audion emerged: flames, ionized gases, sparks and Hertizian waves rather than clean streams of electrons moving through a perfect vacuum.

De Forest became interested in the possibility that an incoming radio signal **might alter the conductivity of a gas**. If the gas formed part of a circuit supplied by a local battery, a very weak signal arriving at the antenna might produce a much larger and therefore more easily detectable variation in that circuit.

This was already, in a broad sense, an **amplifying idea**. The received signal would not have to provide all the energy heard in the telephone receiver. It would merely disturb or control energy supplied locally.

Yet the imagined mechanism was still far removed from that of the modern triode. De Forest thought principally in terms of **ions** and **changes** in the conductive state of a **gaseous** medium. The hot filament was useful because it rendered the gas electrically active; the partial vacuum provided suitable conditions for ionization. The tube was not yet understood as an evacuated space in which electrons traveled almost freely from cathode to plate.

During 1905 and 1906, he investigated numerous forms of sealed detector containing heated and unheated electrodes. These devices were not successive textbook stages—first diode, then triode—but members of a rather disorderly experimental family. Their geometry, gas pressure, electrode materials and electrical connections varied as De Forest searched for the most sensitive arrangement.

He gave them a new name: **Audions**.

The name itself provoked **discussion**. At the meeting in October 1906, the distinguished physicist **Michael Pupin** complained that electrical science would soon become a maze if every detector received a new name. He also objected that Audion was an ungainly mixture of Latin and Greek. De Forest replied, with characteristic confidence, that whatever its linguistic ancestry, the name was brief and expressive—and that an instrument used a hundred times a day required a short name.

The exchange tells us something **about the man**, but also about the **device**. The Audion was being introduced to the electrical world primarily as another wireless **detector**. It was not yet presented as the

De Forest looked at him.

"The Audion depends upon the gas."

"Are you certain?"

"I invented it."

"That tells me who placed the electrodes inside the bulb. It does not necessarily tell us what is passing between them."

Stone intervened before the silence became uncomfortable.

"Dr de Forest has already found that better exhaustion allows the tube to operate at a higher plate voltage."

Arnold turned back toward the apparatus.

"How much higher?"

"Considerably," De Forest said. "If the gas pressure is too great, a blue glow appears and the Audion becomes paralyzed."

"Then why leave any gas at all?"

"Because an Audion with too little gas may lose its sensitivity."

"Or perhaps," Arnold said slowly, "because the tubes have not yet been constructed to operate without it."

De Forest folded his arms.

"You believe the grid can control the current in a complete vacuum?"

"Not a complete vacuum. We shall never obtain that. But a vacuum high enough to prevent appreciable ionization."

"What would carry the current?"

"Electrons from the hot filament."

"The gas is the conducting medium."

"The gas may be concealing the real conductor."

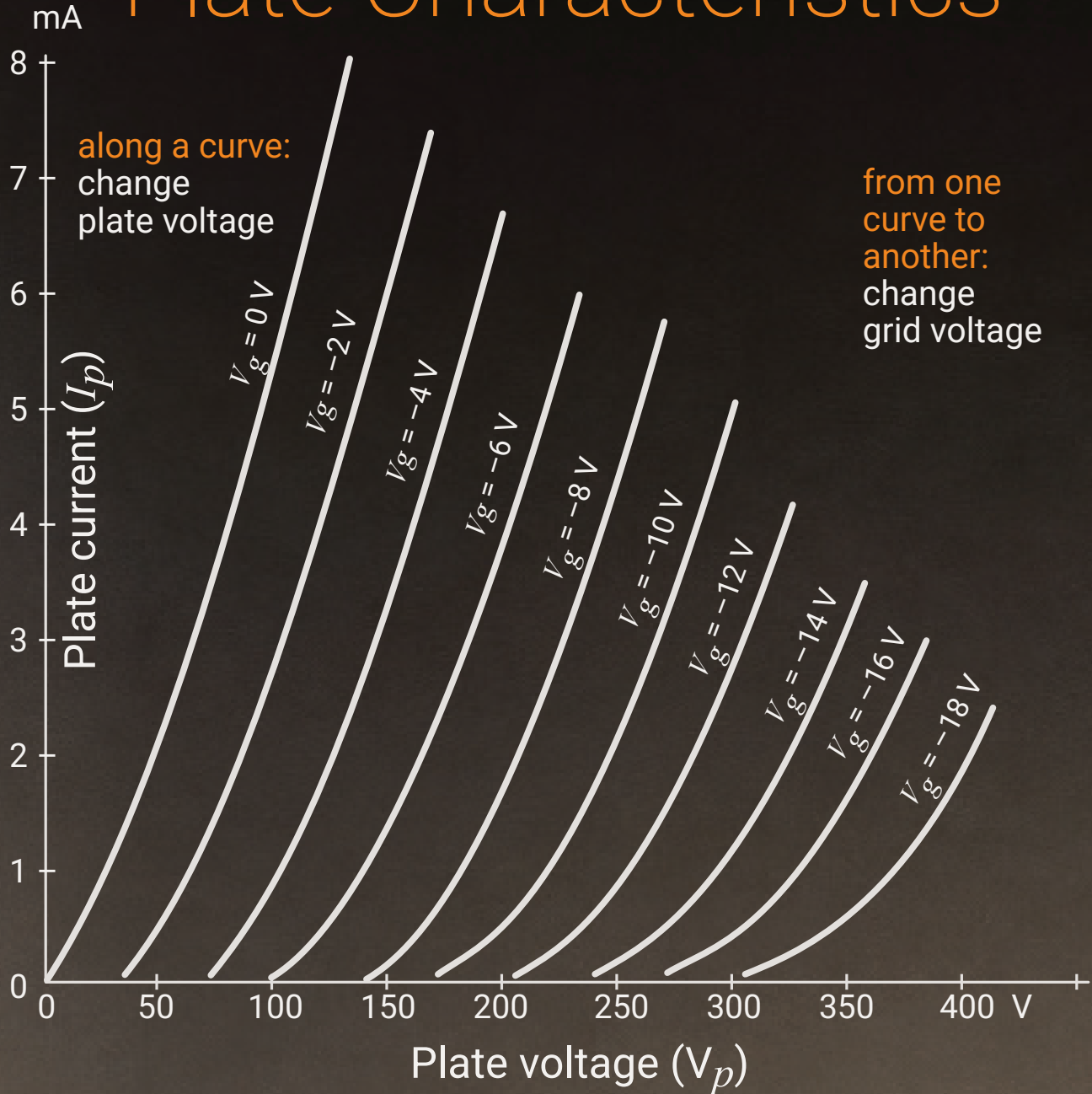
Arnold traced the circuit with one finger. The grid received the weak signal. The plate circuit contained the local battery and the telephone receiver.

"The signal does not need to supply the output energy," he said. "It needs only to control the electron current drawn from this battery."

"That," De Forest replied, "is what I have been telling people."

"Yes. But you have been trying to make the gas perform the control."

Plate Characteristics



A transconductance test asks:

How much does the plate current change when the grid voltage changes by a known small amount?

The second question is much closer to the actual function of an amplifying tube.

Why Tube Testers Measure It

A mutual-conductance tube tester applies controlled operating voltages to the tube and introduces a small alternating signal at the grid.

This signal produces a corresponding alternating component in the plate current.

By measuring the magnitude of that current variation, the tester estimates the tube's transconductance.

The instrument is therefore not merely asking whether electrons can leave the cathode. It is testing whether the grid still possesses its intended control over them.

This is why mutual-conductance testers occupy a more significant position than simple emission testers. They attempt to determine not merely whether the tube conducts, but whether it still behaves as an amplifying device.

The Smallest Lever, Measured

Earlier, we described the grid as perhaps the smallest lever ever made.

Transconductance tells us the effectiveness of that invisible lever.

It connects three stages of our story:

- the physical action of the grid inside the tube;
- the slope of the transfer characteristic;
- the reading eventually displayed by a mutual-conductance tube tester.

What began as a bent piece of wire between cathode and plate has now become a measurable number.

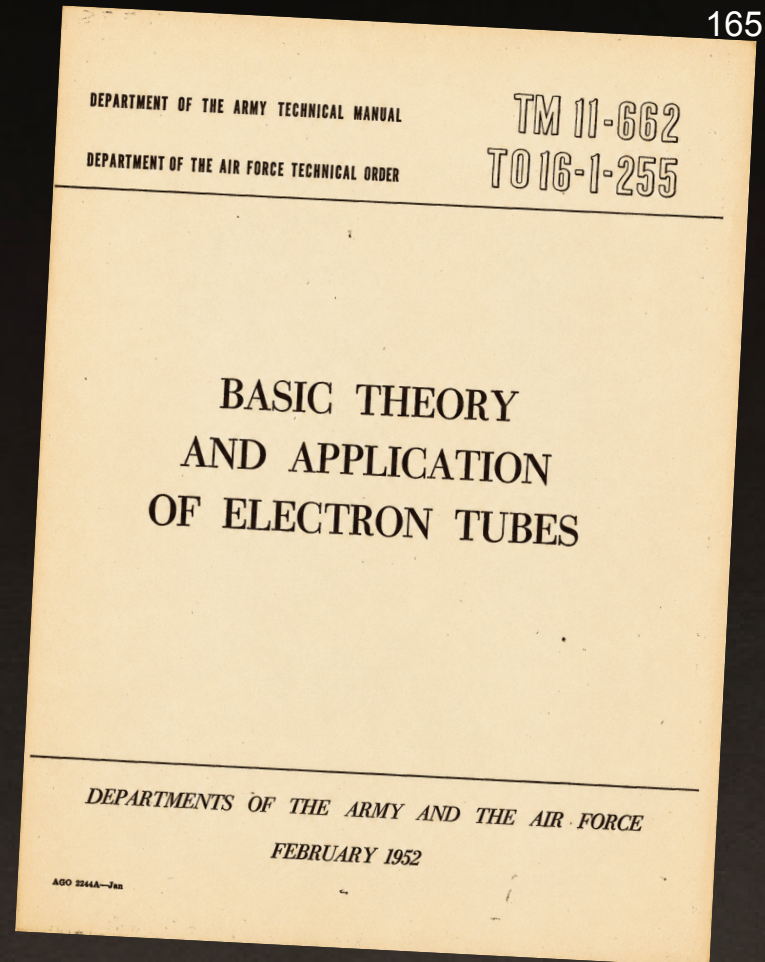
The Sacred Book

One source has accompanied us so faithfully through these pages that it deserves a brief acknowledgment of its own. It is the 1952 U.S. Army and U.S. Air Force manual Basic Theory and Application of Electron Tubes, a book written for instruction, clarity, and practical understanding.

Its drawings belong to another age, and so do its symbols, notations, and typographic habits. Yet precisely for that reason, it offers something especially valuable: not only technical information, but a direct glimpse into the way vacuum tubes were once explained to students, technicians, and servicemen.

Whenever possible, we have preserved its figures with minimal alteration, treating them not merely as illustrations but as historical documents. If, at times, it has seemed to speak with the authority of scripture, that is because few books combine so much pedagogical sobriety with such quiet charm.

For these reasons, it has earned, in these pages, the affectionate title of our sacred book.



The signal can therefore continue to the next stage without disturbing its operating point.

This arrangement, known as resistance-capacitance coupling, became one of the most familiar building blocks of vacuum-tube audio amplifiers. The manual illustrates it with two triode stages connected through a coupling capacitor and grid resistor.

One Stage Hands the Signal to the Next

The circuit we have just examined can amplify the small voltage produced by a microphone, but there is a limit to how much useful amplification we can ask of a single stage.

If we attempt to obtain too large an output from one triode, the operating point moves too far into the curved regions of the tube characteristics. The positive and negative halves of the waveform are then no longer treated in the same way, and the output begins to lose the shape of the input.



The Claims of Lady Plate

Sometimes an imaginary argument between Lady Plate and the Control Grid can make the tetrode easier to understand than a page full of formulas.

The idea was patented by Philips and quickly became an important part of vacuum-tube development. It preserved the principal advantages of the tetrode—high gain, high plate resistance, and low grid-to-plate capacitance—while largely eliminating the characteristic kink caused by secondary emission.

The pentode is therefore a particularly clear example of engineering evolution. The triode solved the problem of controlling an electron stream. The tetrode reduced the unwanted influence of the plate. The pentode then corrected the new problem introduced by the tetrode itself.

It was not a completely new principle, but rather a carefully targeted refinement—and an extremely successful one.

When a Defect Becomes Useful

The characteristic kink of the tetrode was normally an undesirable feature. In part of that region, however, the tube exhibits negative differential resistance: as plate voltage increases, plate current can actually decrease.

This apparently abnormal behavior was deliberately exploited in the dynatron oscillator.

If the tetrode is biased so that it operates within the negative-resistance region and is connected to a resonant LC circuit, the tube can compensate for the losses of the tuned circuit. Under the right conditions, oscillations are then sustained without the usual regenerative-feedback arrangement.

The principle was investigated by Albert W. Hull at General Electric and became known as the dynatron effect. Dynatron oscillators found some use in early radio and laboratory equipment, although they were never as widely adopted as more conventional oscillator circuits.

Their main weakness was the same phenomenon that made them possible: secondary emission. Its magnitude varied considerably from tube to tube and with operating conditions, making the negative-resistance region less predictable than designers would have liked.

The dynatron is therefore a nice historical reminder that, in electronics, even an undesirable characteristic can sometimes become useful if the circuit is designed around it.

This was not merely a laboratory curiosity. The 1931 Crosley Model 122 “Super Buddy Boy,” a seven-tube superheterodyne receiver, used a dynatron circuit as its local oscillator. In other words, the very secondary-emission effect that designers were trying to eliminate from the tetrode was deliberately exploited in a commercial radio receiver.



Is This Tube Still Good?

Cleveland, Ohio – 1934

Historical reconstruction

The owner of the radio shop was annoyed. Another customer had just come back to complain about a replacement tube he had bought for his radio. It had been sold as used, but perfectly good.

“And yet I had it tested...” he muttered.

Then he looked toward the workbench.

“Hey, Job! What are you doing over there? Are you testing these tubes or not?”

“I’m sorry, sir. I’m doing what I can...”

“What do you mean, what you can?”

“I mean we don’t have the right instrument to test them properly. All we can really check here is emission...”

“This again! I’ve already told you we certainly can’t afford a Sterling, at what those things cost. I’d have to cut your salary in half!”

Job R. Barnhart decided that perhaps it was better not to insist, but kept thinking. Was it really impossible to find a way to measure the mutual conductance of a tube without spending a small fortune?

longer emit enough electrons. Or emission may still appear satisfactory while the control grid has lost some of its effectiveness, reducing the tube's transconductance.

And not every tube should be judged by transconductance at all. Rectifiers, voltage regulators, thyatrons, indicator tubes, and other special devices perform different functions and therefore require different tests.

A mature tube tester consequently became much more than a single measuring instrument. It became a collection of carefully chosen tests, each asking the tube a different question.

There is also an important limitation to remember. A tube tester cannot reproduce every circuit in which a tube might eventually be used. Instead, it places the tube under a selected set of operating conditions and examines a limited number of parameters considered significant for its intended service.

This was especially important in military equipment. The technician did not need a complete laboratory analysis of every tube. He needed a repeatable answer to a practical question:

Can this tube be trusted, or should it be replaced?

By the early 1950s, decades of experience had brought all these ideas together into increasingly sophisticated instruments capable of examining a tube from several different points of view.

One of the most elaborate of them was about to appear, and it was called the TV-2/U.

These switches are one of the keys to the versatility of the instrument. The TV-2 does not depend on a fixed socket wiring for each tube type. Instead, the operator effectively constructs the required connection between the tester and the tube by setting the electrode selectors according to the roll-chart data.

The same physical socket can therefore accommodate many different tube pinouts.

One Instrument, Several Questions

Seen in this way, the apparently complicated TV-2 becomes much easier to understand.

The left side of the diagram **creates the electrical environment** in which the tube is to operate.

The right side **connects that environment to the correct tube electrodes**.

The center section then asks one of several possible questions:

- Is the filament intact?
- Are any electrodes shorted or leaking?
- Does the cathode still emit enough current?
- Is there excessive gas?
- Does a regulator tube maintain its voltage?*

Or, for an amplifying tube:

- How effectively does the grid still control the plate current?

That last question is answered by the transconductance circuit and displayed on the PERCENT QUALITY meter.

Seen from the block diagram, the TV-2 is therefore not one tube tester but, in a sense, several different testers sharing the same power supplies, meters, switches, sockets, and wiring.

Advantages

The TV-2/U follows a logic of its own, and this approach offers several advantages:

- within limits, its measurements do not depend directly on the supply voltage;
- it does not rely on a conventional line-adjustment procedure to establish the test conditions: the relevant voltages and signal level are checked directly during setup.

The reference connection is not shown in this simplified diagram; to find it, we must look at the complete schematic. I partially restored and colored the relevant section to make the connection easier to follow.

In the lower part of the drawing, the signal-generator loop is highlighted in red. Following the yellow line, we find that one point of this floating circuit is connected to the wiper of the R29 BIAS potentiometer. In this way, the entire signal generator rides on the DC bias voltage, which establishes its reference with respect to ground.

The voltage applied to the grid is therefore the sum of two components:

- the DC bias set by R29;
- the AC signal selected by the GM-SIGNAL RANGE switch.

At least, that is what should happen.

The Mysterious Disturbance

During verification of the TV-2/U transconductance circuit, a small but significant anomaly appeared. According to the procedure given in the manual, the SIGNAL generator should provide 0.25 V in positions A, B, and C, 0.5 V in D, and 2.5 V in E, exactly as expected from the circuit described above.

At the tube grid pin, however, the measured values were **too high**, especially on the lower ranges, and I spent most of a day trying to understand why.

We expected the grid voltage to contain A + B: the DC bias plus the intended AC signal. Instead, there was also an unexpected C component.

When measured directly across the resistor chain R50-R49-R47, the signal voltages were essentially correct. The problem therefore did not appear to be in the signal generator itself.

The anomaly became much clearer with the GM-SIGNAL RANGE switch set to F, where the test signal is removed. Even in this position, almost 0.1 V AC remained at the grid pin.

The same unwanted voltage was found at the wiper of R29, the BIAS adjustment potentiometer. This was particularly puzzling because the upper end of R29 showed only the normal 100 Hz ripple produced by the V2 6X4 rectifier and its filter capacitor, while the wiper carried a much larger 50 Hz component.

For anyone restoring or maintaining tube-based audio equipment, a properly calibrated tube tester can be an extremely useful tool, and the TV-7 has become one of the most desirable choices.

The same renewed enthusiasm has also affected the tube market itself. Types commonly used in audio equipment, such as the ECC82 and 811, can now command prices that would once have seemed surprising. But progress—and fashion—always have their victims.

TV-7D/U

Front View





The Hewlett-Packard 3403C True RMS voltmeter and a modern digital multimeter used to compare readings on the pulsating DC waveform. Different instruments may display different values because they process non-sinusoidal waveforms in different ways.

Meter reading	Corresponding value in micromhos			
	Range B	Range C	Range D	Range E
0	0	0	0	0
10	250	500	1250	2500
20	500	1000	2500	5000
30	750	1500	3750	7500
40	1000	2000	5000	10000
50	1250	2500	6250	12500
60	1500	3000	7500	15000
70	1750	3500	8750	17500
80	2000	4000	10000	20000
90	2250	4500	11250	22500
100	2500	5000	12500	25000
110	2750	5500	13750	27500
120	3000	6000	15000	30000

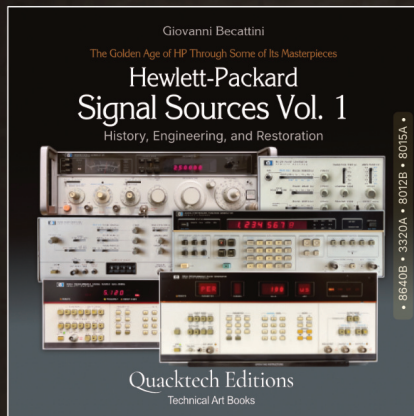
Table from the TV-7 manual showing the conversion from meter readings to mutual conductance values in micromhos for the different test ranges.

The problem is the opposite of the one encountered with the TV-2. The TV-7 gives us a numerical g_m , but it does not directly tell us the actual operating conditions of the tube during the test. Without knowing the effective plate voltage, grid bias, signal amplitude, and waveform, we cannot compare that number rigorously with a datasheet value either.

So once again, the reading is meaningful primarily within the standardized test method of the instrument created by the manufacturer.

Conclusion

The comparison leads to a rather simple conclusion. The TV-2 gives us a percentage, but not an unambiguous absolute value of g_m . The TV-7 gives us a value that can be converted into micromhos, but does not tell us enough about the operating point to verify it directly against the datasheet.

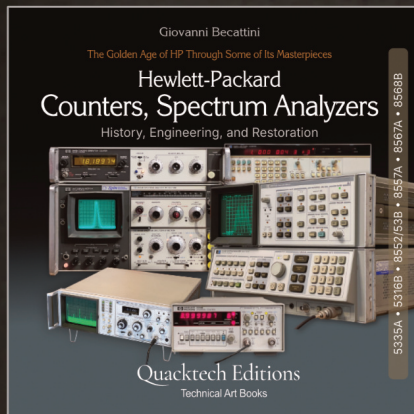


HP Signal Sources Vol.1

History, Engineering, and Restoration

8640B, 3320A, 8012B, 8015A

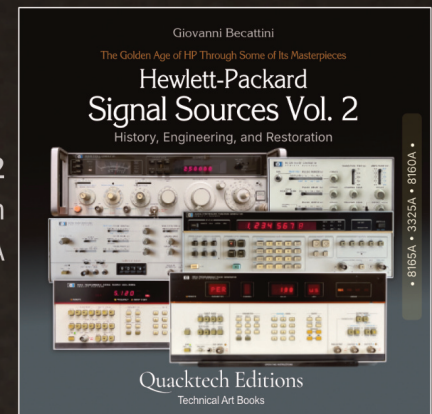
Hewlett-Packard



HP Counters, Spectrum Analyzers

History, Engineering, and Restoration

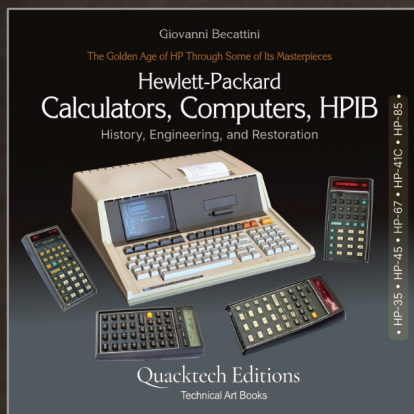
5335A, 5316B, 8552/53B, 8557A, 8568B



HP Signal Sources Vol.2

History, Engineering, and Restoration

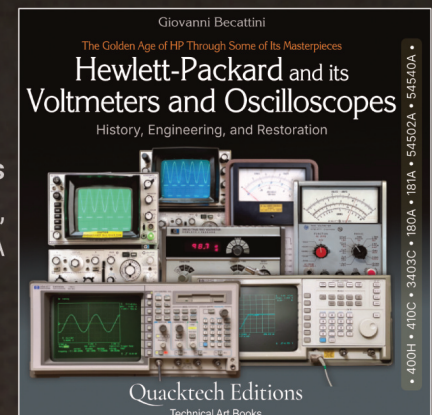
8165A, 3325A, 8160A



HP Calculators, Computers, and HPIB

History, Engineering, and Restoration

HP-35, HP-45, HP-67, HP-41C, HP-85



HP Voltmeters and Oscilloscopes

400H, 410C, 3403C, 180A, 181A,

54502A, 54540A