Digital Behavior in an Analog Era

Digital But Analog

When Technology Had to Go Beyond Its Limits

Giovanni Becattini

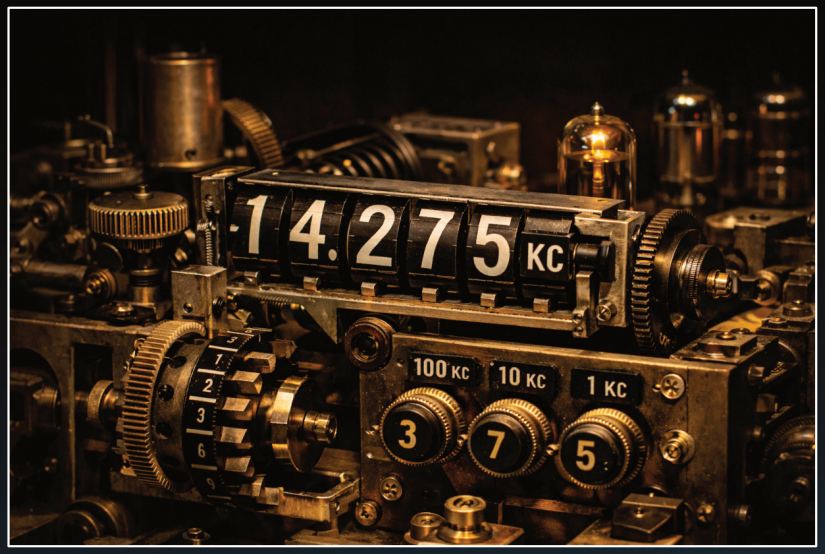
References

The following references are used in this book:

- [TEO] Tektronix Epic Oscilloscopes – Elektor Books
- [7KS] Tektronix 7000 Series – Elektor Books
- [TREG] Tektronix Oscilloscopes Restoration Guide – Elektor Books
- [TGHP] The Great Hewlett-Packard – 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
- [SCLI] 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
- [QTBYOP] Become Your Own Publisher – Quacktech
- [QTHPSS] Hewlett-Packard Signal Sources – Quacktech
- [DAB] Digital but Analog – Quacktech

Table of Content

Table of Content (cont'd)


14.275 KC
100 KC
10 KC
1 KC
3
7
5

Preface

The world around us is fundamentally analog. Yet in many situations—especially critical ones—we humans strongly wish it to behave digitally.

Long before the advent of digital electronics, the need for precise and unambiguous frequency indications was already essential, particularly in military and aeronautical applications. In such contexts, communications are vital, and even small uncertainties can have serious consequences. When setting the frequency of a radio, approximations such as "about 11.300 MHz" are simply not acceptable; what is required is the certainty of being exactly on 11.302 MHz.

This demand for precision, repeatability, and certainty imposed the development of new and often remarkably complex technological solutions at a time when such results might have seemed unattainable. Engineers were forced to achieve digital-like behavior using purely analog components, mechanical systems, and ingenious hybrid approaches—well before digital electronics became available.

This book explores a number of these solutions, implemented in a wide range of equipment developed from the early 1950s through the late 1960s, when the first digital circuits finally began to appear. It is a fascinating journey that reveals, once again, the extraordinary creativity of those designers who managed to go beyond the technological limits of their time. Often ingenious, often visionary, and too often forgotten, they succeeded in redefining what was thought to be possible.

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To my wife
and my family

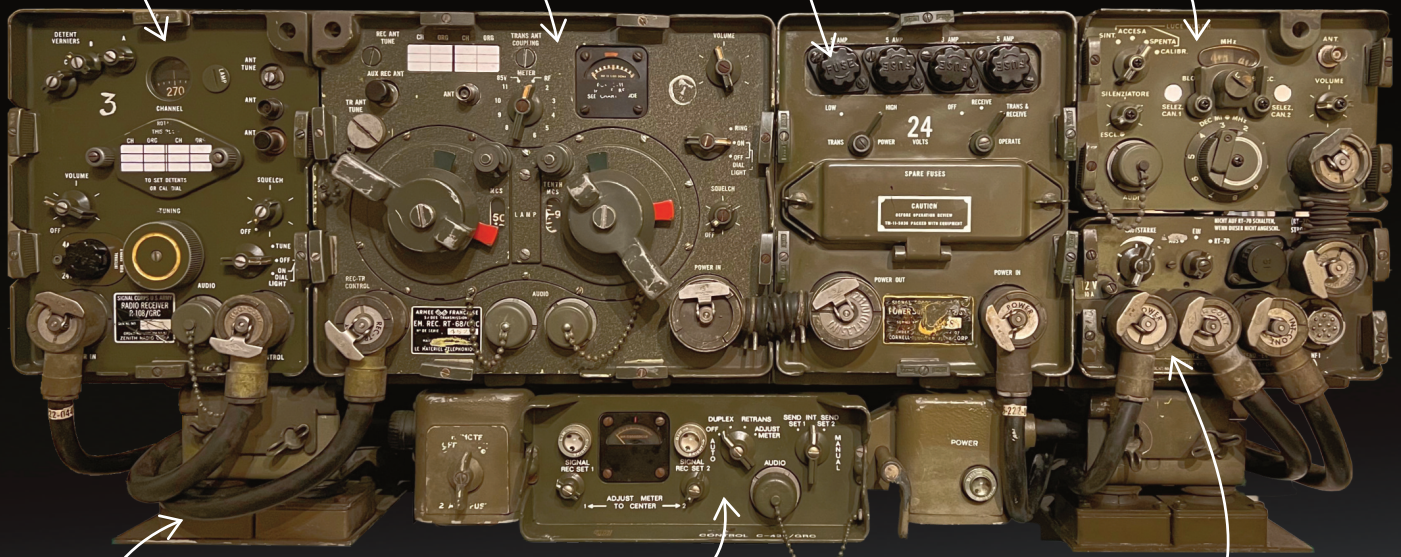

Introduction
R-390/URR Receiver
AN/GRC-19 Radio Set
RT-66, RT-67, RT-68/GRC Rx/Tx
Siemens E311 Receiver
AN/PRC-47 Radio Set
AN/PRC-74 Radio Set
Racal RA 1217 Receiver

R-108 (or 109 or 110)
Auxiliary Receiver

PP-112 (or PP-109)
Power Supply Unit

RT-66 (or 67 or 68)
Receiver/Transmitter

RT-70 Short Range
Receiver/Transmitter



AM-65 Intercom
Amplifier

MT-297 Vehicle
Mounting Base

C-435
Control Box

AN/GRC-7

Above: The AN/GRC-7, one of the many possible configurations that could be assembled using the nameless set of components I referred to as the "Modular Radio System" in [VRE].

If you are a purist, you may already have noticed a flaw: the auxiliary receiver should have the same frequency coverage as the transmitter-receiver. In this case, it ought to be an R-110. Too bad—but I can live with it…

Nomenclature Examples

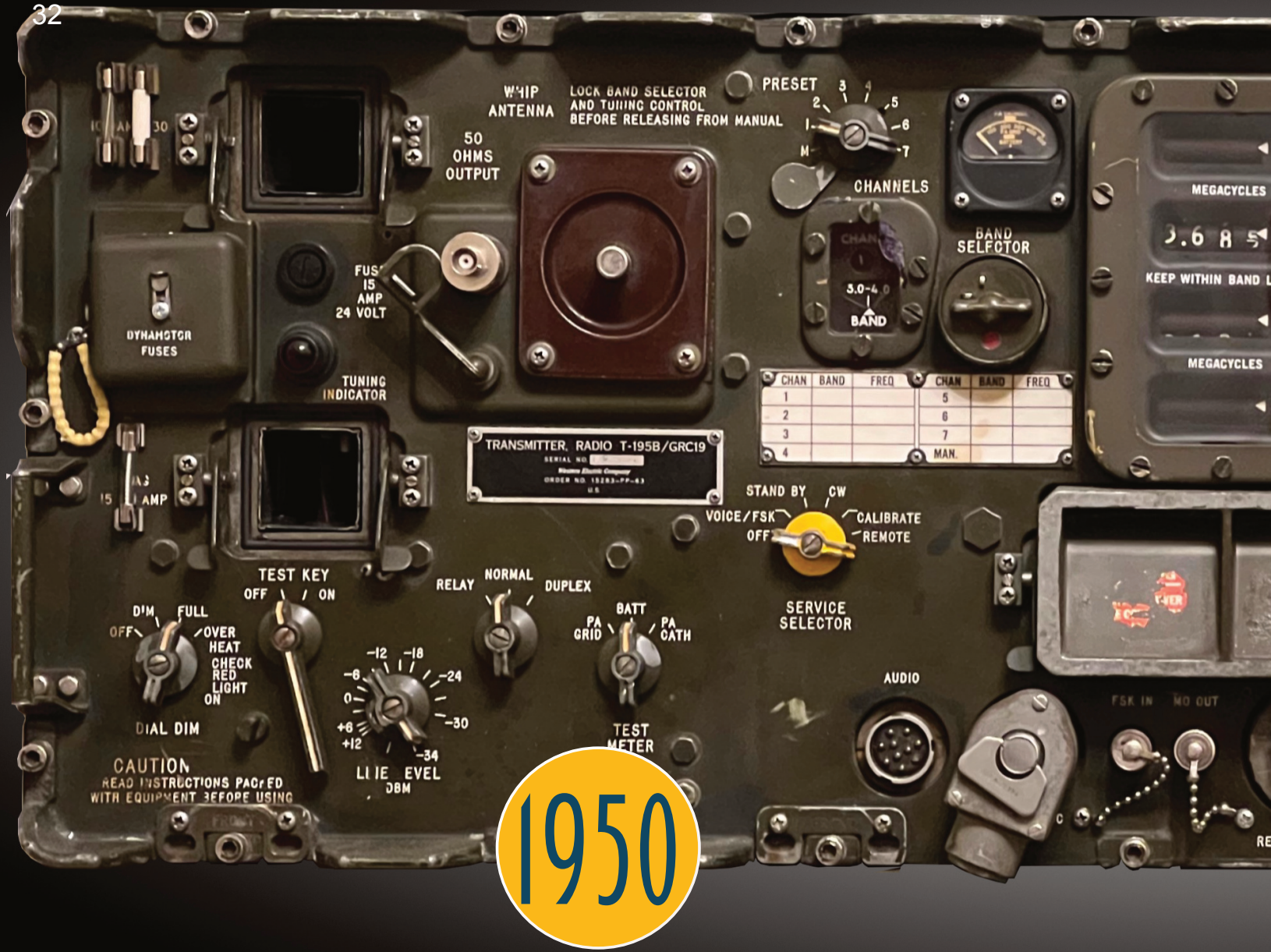
Before delving deeper into the discussion, let us briefly look at some of the equipment that will be discussed or mentioned throughout this book.

- **R-390/URR and R-392** – Utility Radio Receiver.
- **T-195** – Just "Transmitter".
- **GRC-7** family and related sets (≈ 1950) – This is a special case. A limited number of basic elements—such as the R-107/GRC (or R-109, R-110), the RT-66/GRC (or RT-67, RT-68), and the RT-70/GRC—were combined to create a large variety of complete radio sets (VRC, GRC, PRC, VRQ, and others; more than twenty configurations can be identified). All of these operated in the VHF band and used FM modulation exclusively.
- **RT-66/GRC** – A receiver transmitter included in a Ground / Radio / Communication set.
- **GRC-19 (1951)** – As explained in the nomenclature section, this designation identifies a ground communications set. In practice, however, the GRC-19 was very often installed in vehicles; its power-supply requirements (24–28 V DC) are in fact typical of vehicular installations. It is an HF-only station.
- **PRC-47 (1961)** – A typical manpack radio, although in practice the complete station often required two soldiers to transport it, hence the designation Portable. This set also operates exclusively in the HF band.
- **PRC-74 (1966)** – A more modern and lighter evolution of the PRC-47, the PRC-74 was genuinely portable and could be carried and operated by a single soldier. It is again an HF-only set.
- **PRC-70** (≈ late 1960s) – A more ambitious and complex unit, designed to operate in both the HF and VHF bands and supporting multiple emission modes (AM, FM, SSB, etc.). Its exact chronology is less clearly documented and will be discussed later in more detail.

Right: Too digital to fully belong in this book, the Telefunken E724 is nevertheless another example of a dual-scope receiver. It was essentially an HF E863 to which the tactical bands (up to 80 MHz) and FM reception were later added. The result was a technically interesting but not entirely homogeneous design: outstanding in HF performance, yet less harmonious in the integration of the extended VHF coverage.

Below: the R-390A/URR, the final and most widely produced version of the R-390/URR, featuring the addition of mechanical filters and a generally improved technical implementation. At the time of its introduction, it represented the very best available and clearly marked an era. Among its many innovative features, the digital frequency indicator was undoubtedly the most striking.

At first glance, one might think this is the same photograph shown on the previous page—but it is not. The earlier image depicts my own R-390A/URR, built by Electronics Assistance Corporation (EAC). This one, instead, belongs to my friend Jacques Fortin and was manufactured by Collins Radio Company itself, under the very first production contract. For this reason, it carries a significantly greater historical value—a subtle difference to the eye, but a substantial one to history.



1950

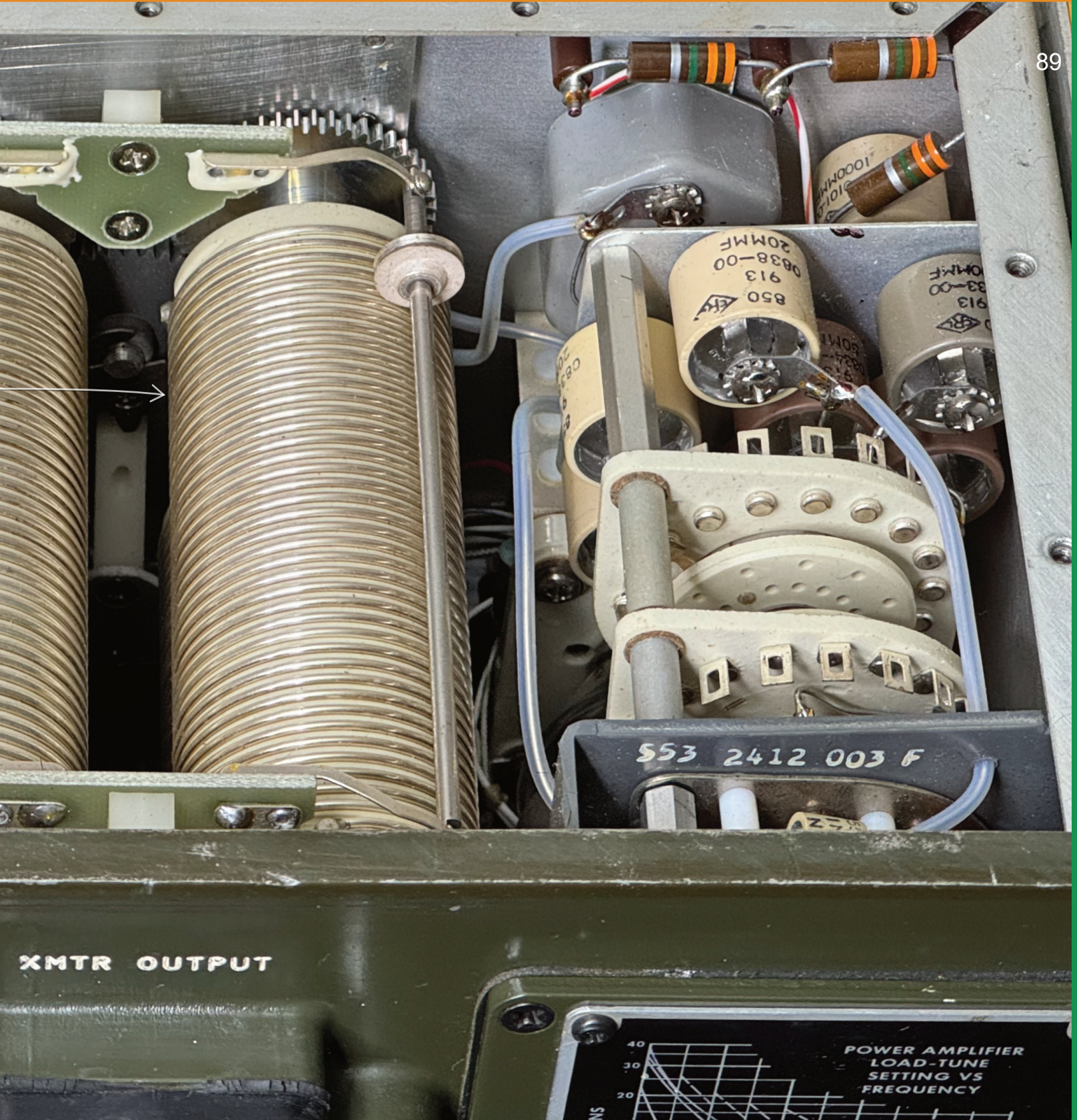
New Equipment Required

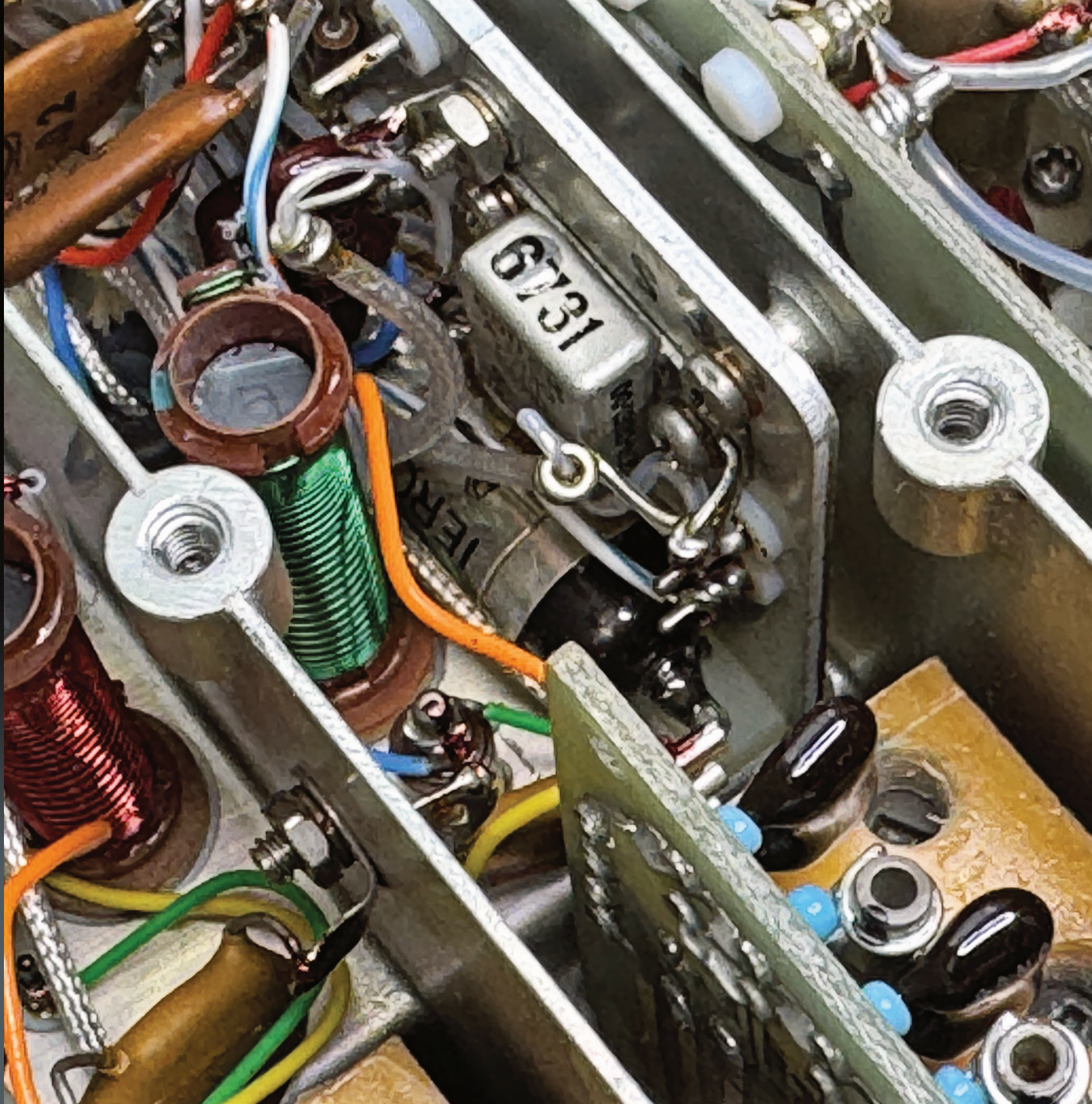

C-1M
C-1L

In Short

The **Radio Set AN/PRC-47** was a high-frequency radio communications system introduced in the early 1960s. It primarily provided approximately 10,000 preset channels for upper sideband (USB) voice transmission and reception, continuous-wave (CW) telegraphy, and frequency-shift keying (FSK) teletype operation over the 2.000–11.999 MHz frequency range.

The radio set could be operated directly from its own control panel or remotely controlled by a power control unit—such as the Control Group AN/GRA-6—over distances of up to approximately 2 miles.


XMTR OUTPUT
POWER AMPLIFIER
LOAD-TUNE
SETTING VS
FREQUENCY
40
30
20
S53 2412 003 F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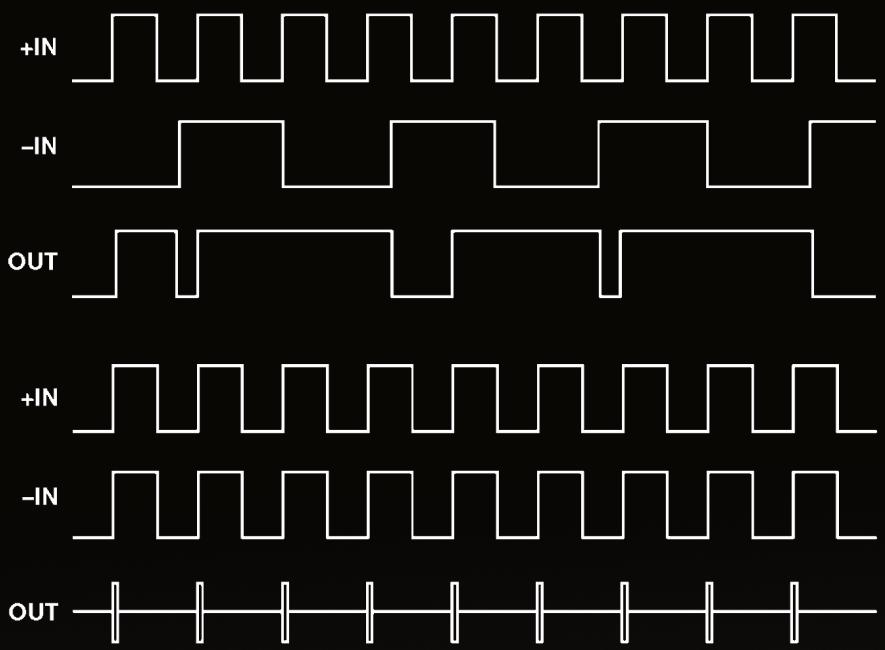


Left: PLL signals: the upper traces show the unlocked condition, the lower traces the locked condition. Note that a small phase correction is continuously applied even when the loop is locked.

For example, if a divide-by-2 stage is added, the VCO will operate at 200 kHz while the phase detector still compares 100 kHz signals. By replacing the fixed divider with a programmable divider, it becomes possible to generate a wide range of output frequencies, all inheriting the stability of the reference oscillator despite being produced by a relatively unstable VCO.

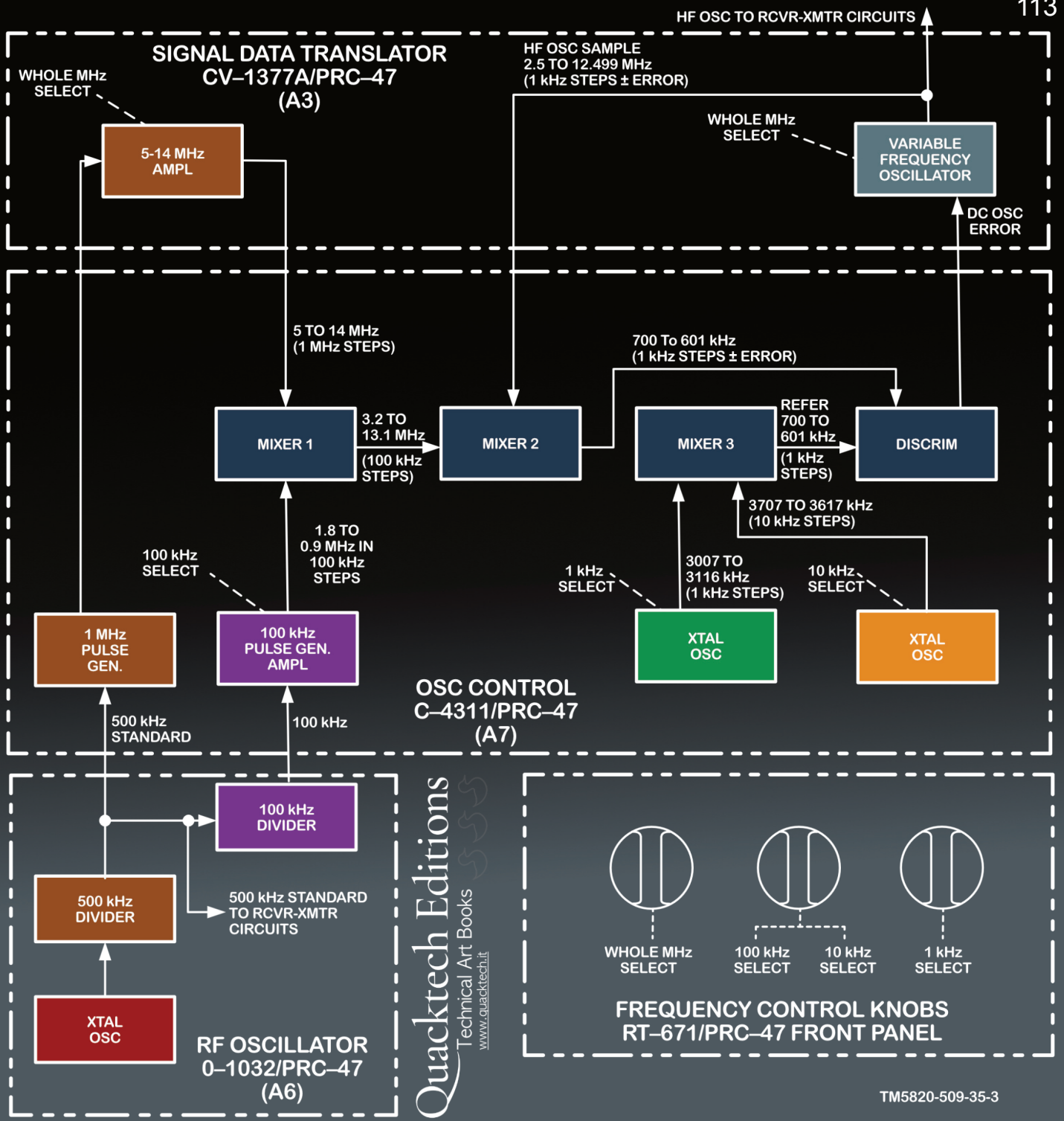
This scheme, in which the division ratio is an integer number N, is known as an Integer-N PLL. More advanced variants, such as the Fractional-N PLL, exist and allow finer frequency resolution, but these lie outside the scope of the present discussion (a detailed example can be found in [HPTGA] in the discussion of the HP 3325A).

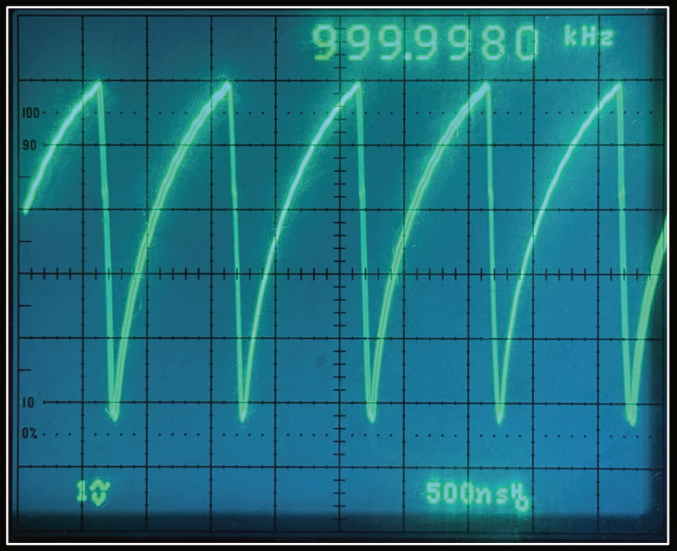
Fully Analog Implementations

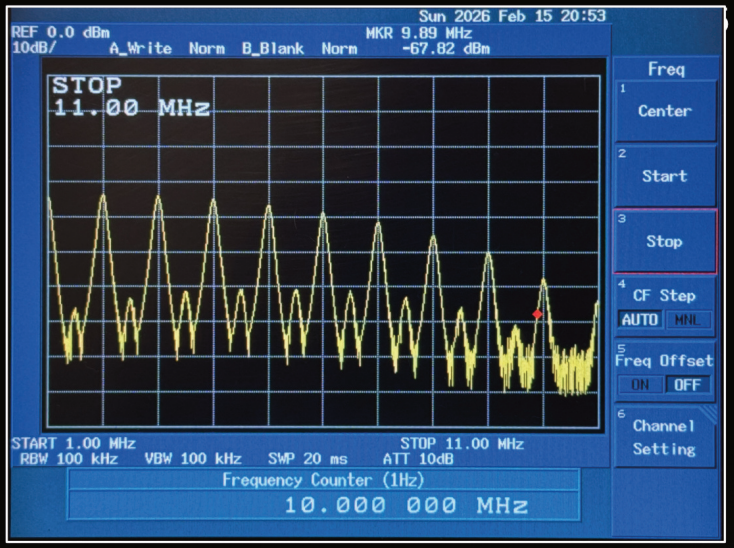
As one might expect, by the end of the 1950s phase detectors could be implemented without difficulty using discrete components, but programmable digital dividers were either unavailable or impractical—certainly so for a compact, portable military radio such as the PRC-47. The designers therefore had to devise a solution using only the analog building blocks at their disposal.

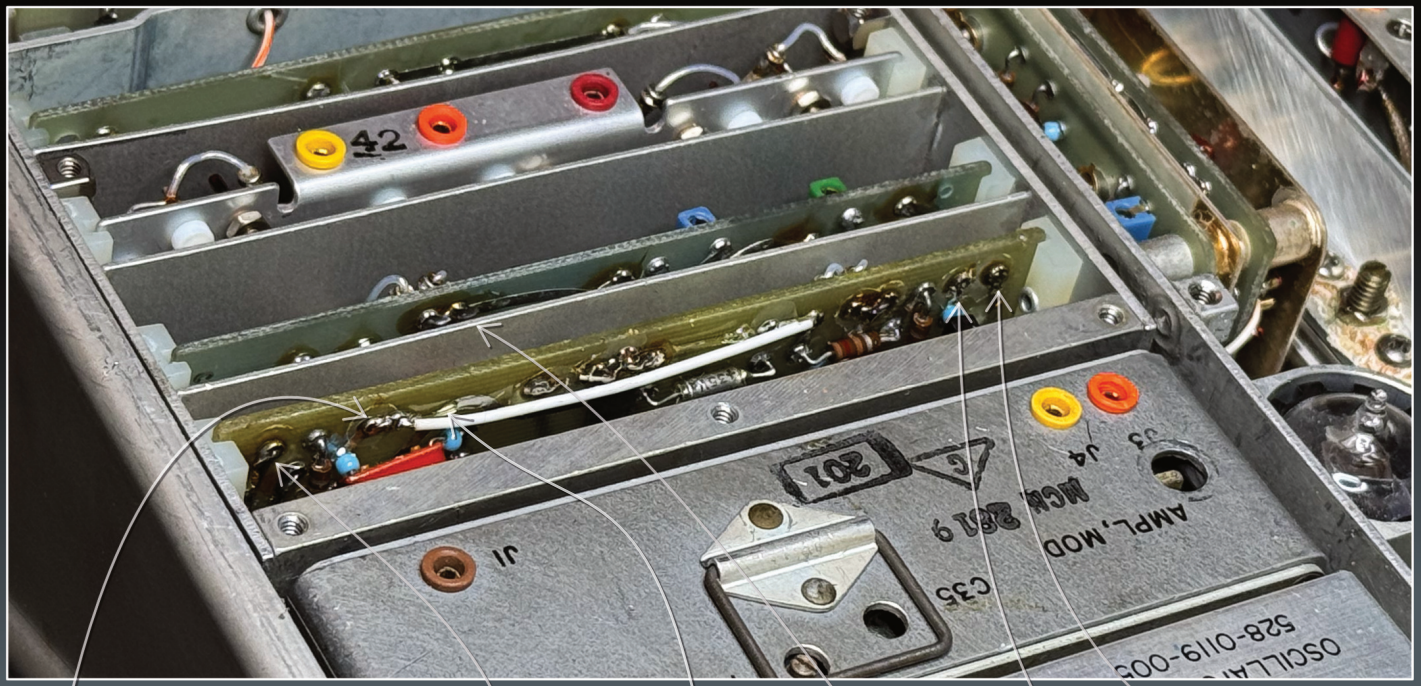
RF Oscillator 0–1032/PRC–47 (A6)

Above: the 0–1032/PRC–47 RF Oscillator (A6), which serves as the reference generator for the PRC-47 PLL. The overall frequency accuracy and stability of the set are determined by this oscillator. Collins devoted particular care to its design and achieved excellent results without any form of thermal regulation. Remarkably, it remains so stable and accurate that broadcast stations can be tuned at zero beat, even though the PRC-47 was not designed for AM reception. Note also here the components layout on the metal cover.

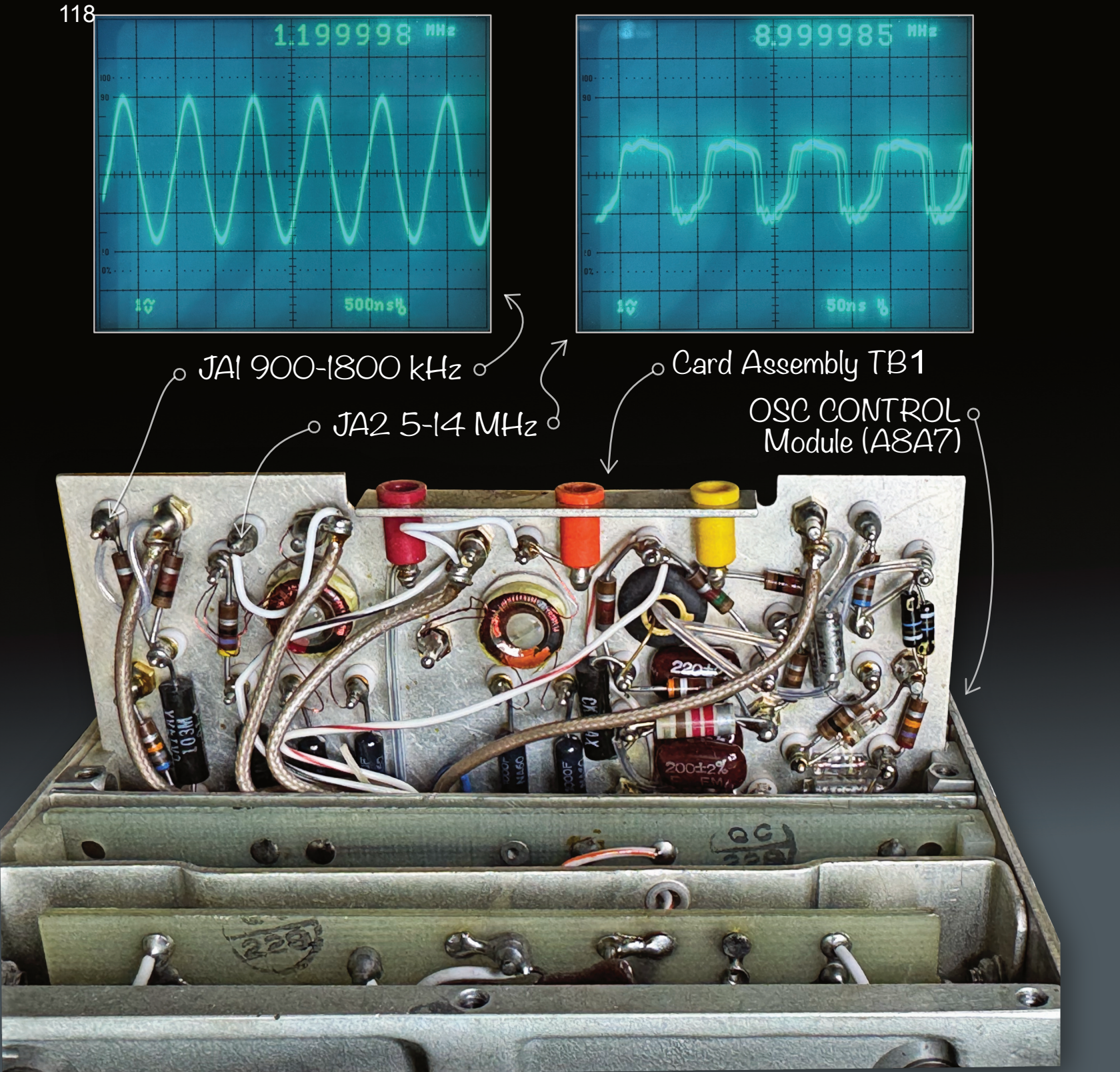


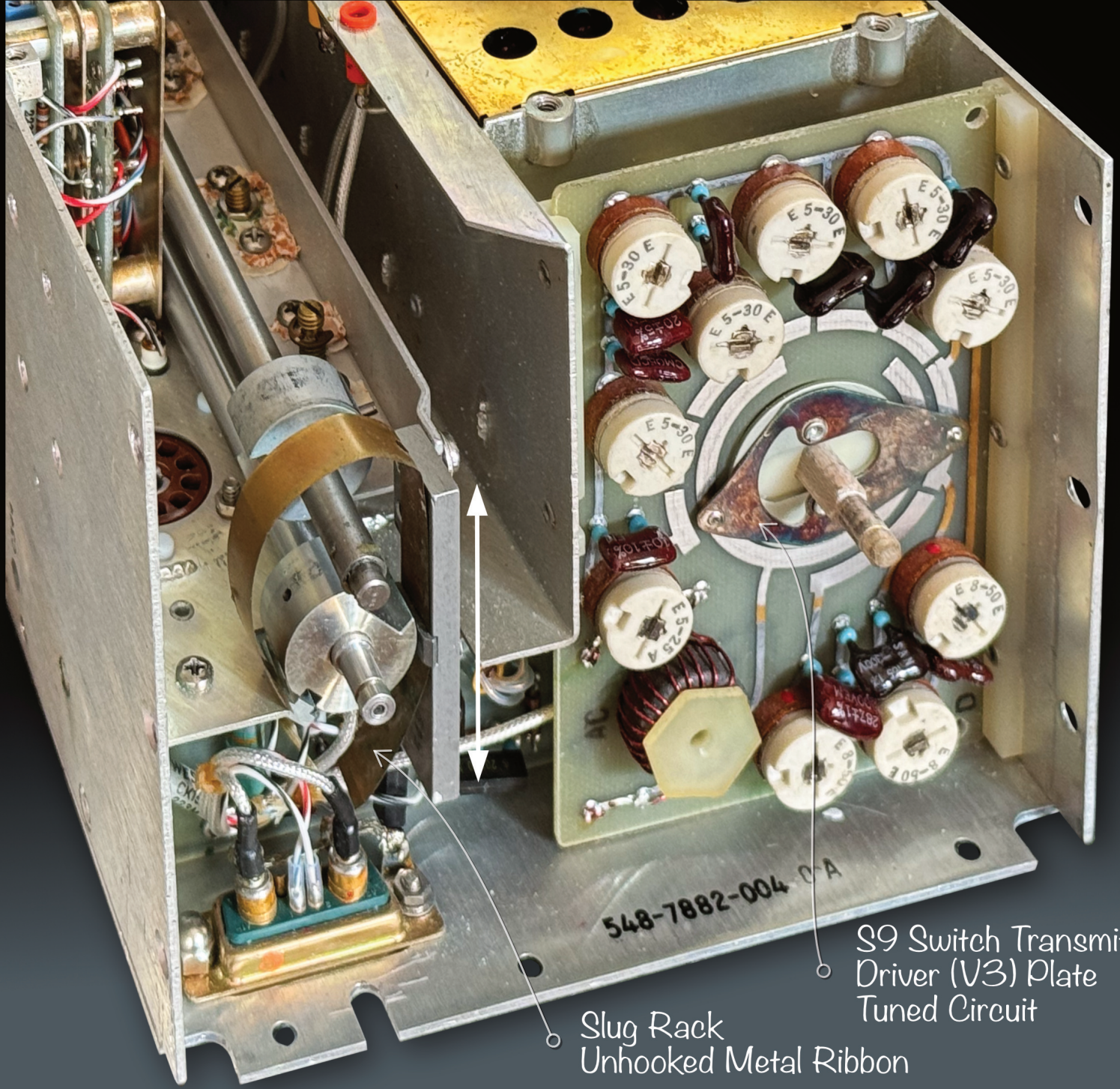




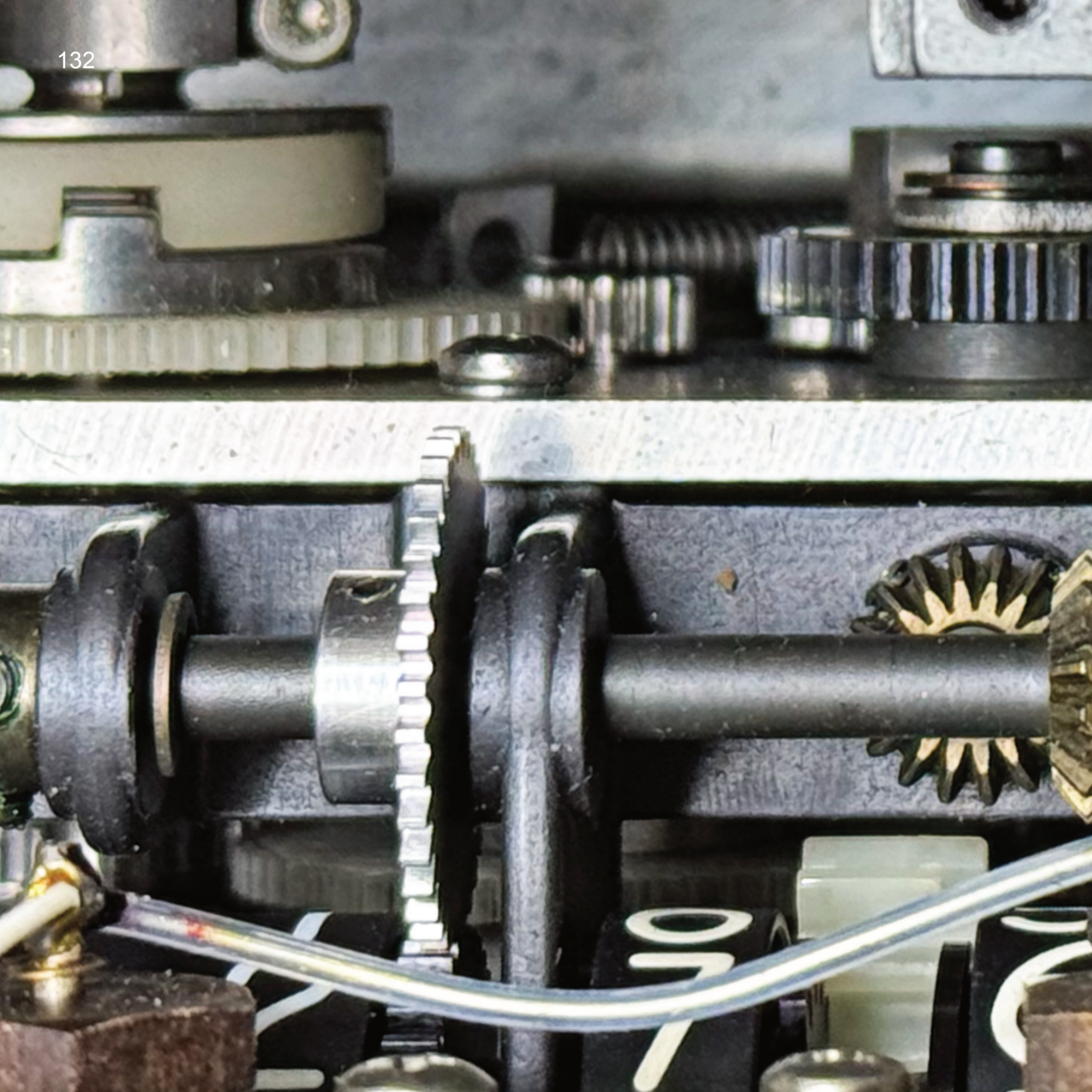


Above: 1 MHz pulse signal on the OSC CONTROL module C-4311/PRC-47 (A8A7) (left) and corresponding spectral content (right), illustrating the wide harmonic distribution of the waveform (see manual, p. 3-72).


1.199998 MHz
500ns
8.999985 MHz
50ns
JA1 900-1800 kHz
JA2 5-14 MHz
Card Assembly TB1
OSC CONTROL
Module (A8A7)



This photo lets you understand how the slug rack works: the pulleys, turning, wrap up or down the ribbon which moves the rack (note the white arrow).



Antenna tuning

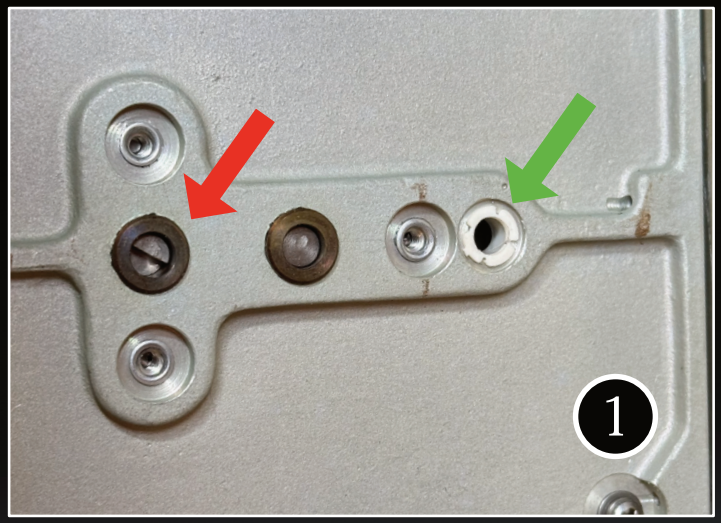
The output circuit of the power amplifier is connected to the antenna system when T/R relay K101 is energized. This output stage is tuned to the operating frequency indicated on the KILOCYCLES display and matched to the antenna system by adjustment of the POWER AMPLIFIER TUNE and POWER AMPLIFIER LOAD controls on the front panel of the RT-671/PRC-47.

Optimum adjustment is indicated by maximum deflection of the XMTR OUTPUT meter M101, corresponding to maximum RF power delivered to the load.

Reassembly Notes

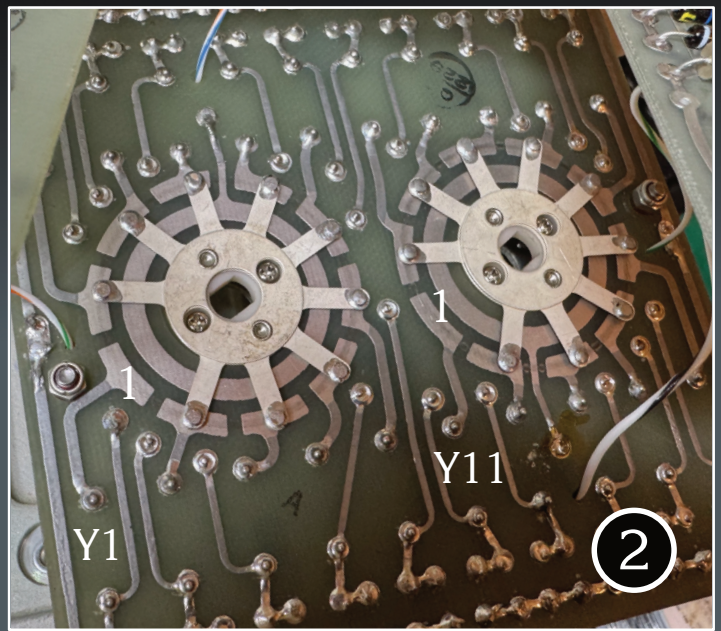
Coming to Reassembly

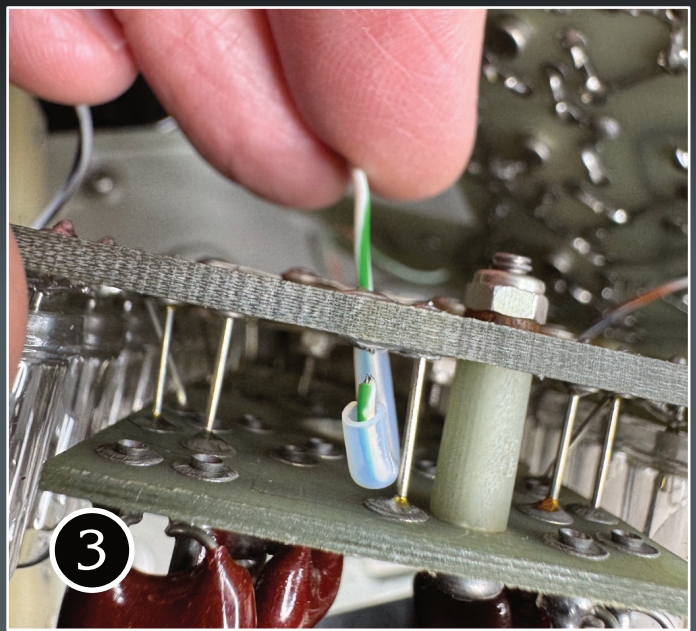
When it comes time to reassemble what was so happily disassembled, things inevitably become a bit more complex, so a few notes are mandatory. First of all, make sure not to lose the plastic washer indicated by the green arrow in photo 1, and before reassembly rotate the shaft marked by the red arrow fully counterclockwise.

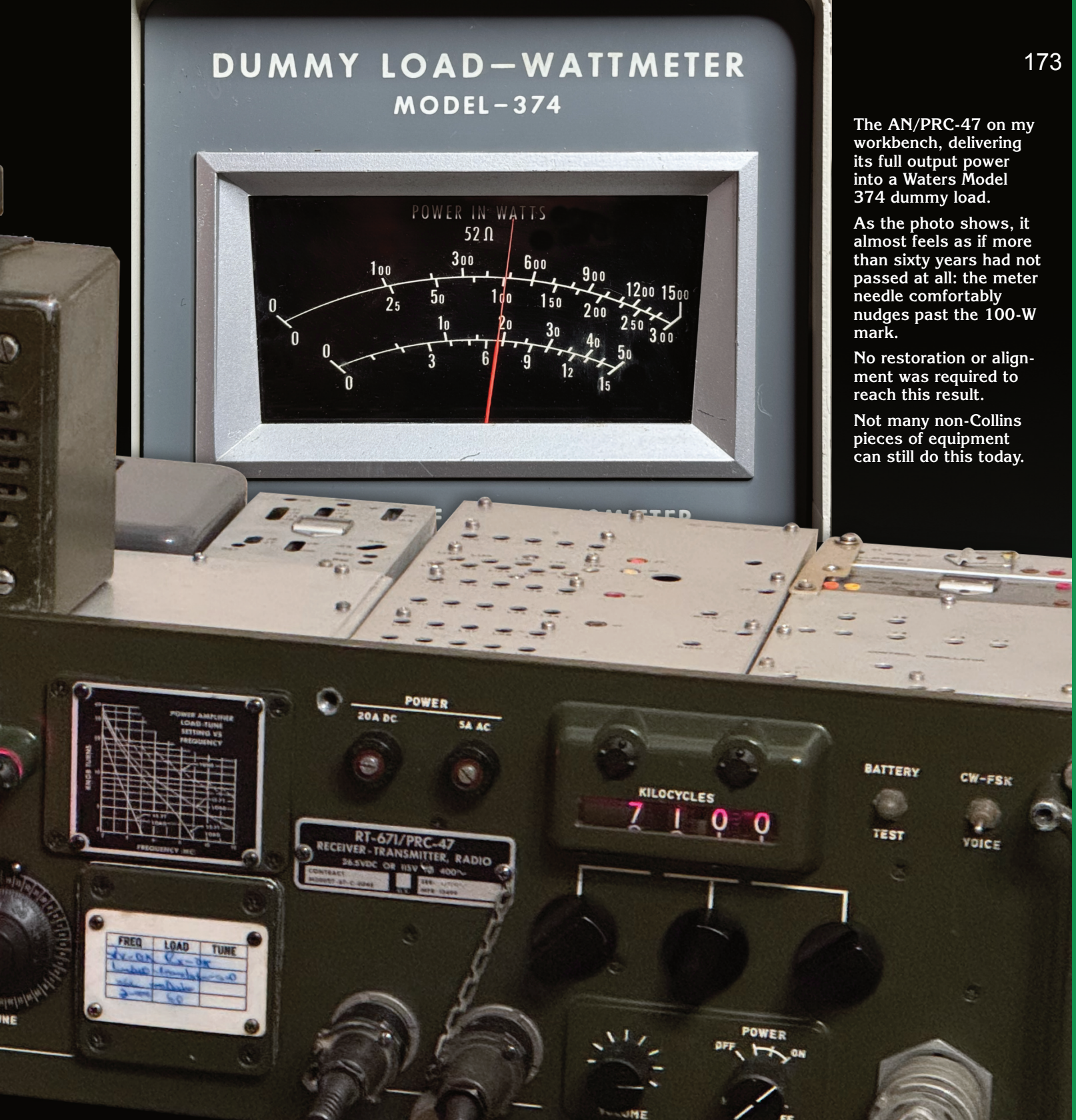


Next, set switches S1 and S2 on the A7 board to position 1, and do the same for switch S3 on the E5 board. The manual provides a figure only for the latter (and our photo of the E5 board above also shows position 1). For S1 and S2, no figure could be found in the manual, so their correct position has been reconstructed here (photo 2).

Finally, carefully check all the wiring. Since the boards are permanently interconnected, it is quite easy to damage or break a wire during reassembly (photo 3).







The AN/PRC-47 on my workbench, delivering its full output power into a Waters Model 374 dummy load.

As the photo shows, it almost feels as if more than sixty years had not passed at all: the meter needle comfortably nudges past the 100-W mark.

No restoration or alignment was required to reach this result.

Not many non-Collins pieces of equipment can still do this today.


KILOCYCLES
7100

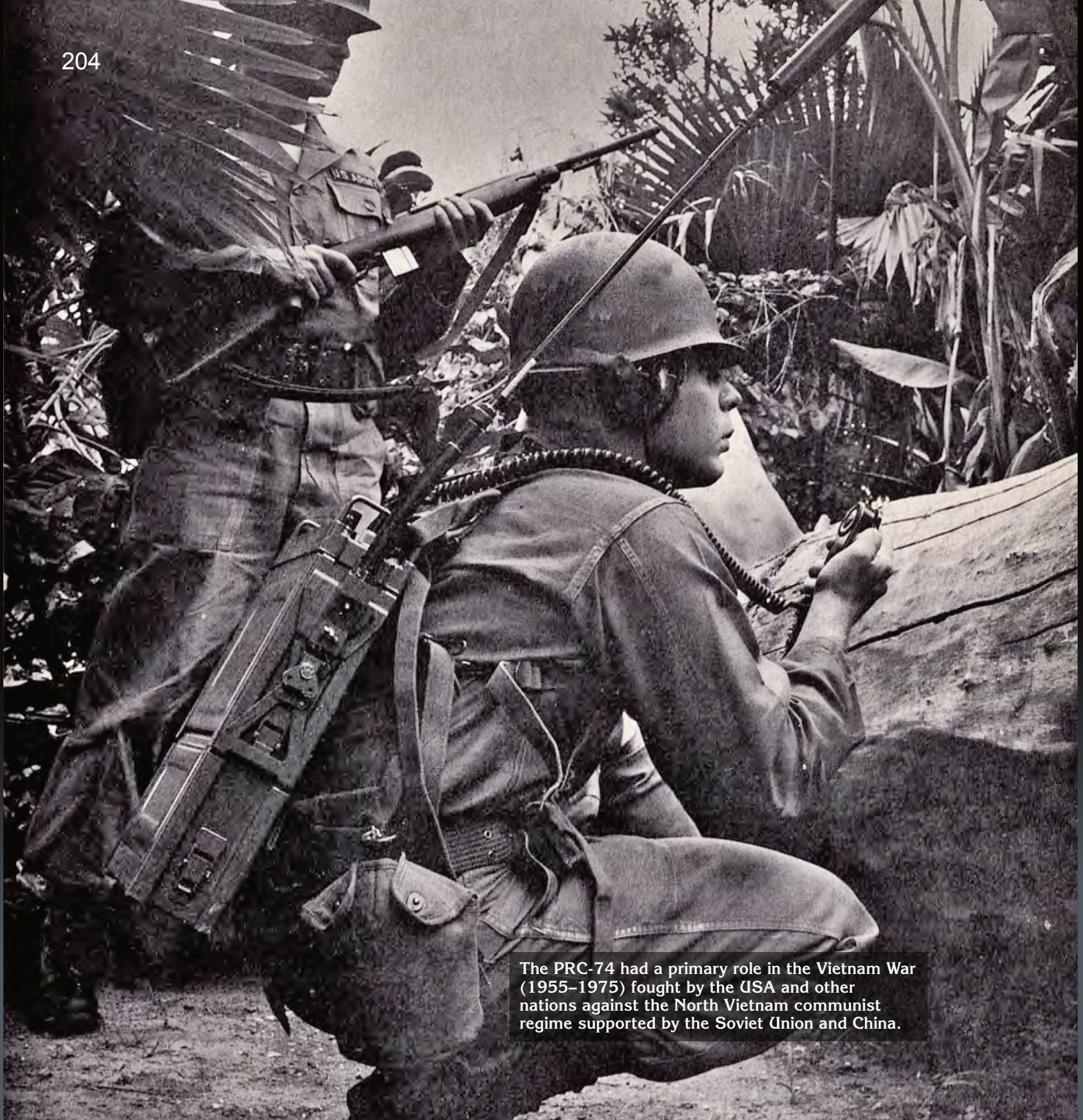
Case CY-3700/PRC-47 Lower Tray

(W) Shoulder Strap Assembly

(U) Rucksack Frame

(W) Backstrap


ANT
ANT TUNE
OFF
ON
TUNE
CAUTION
DO NOT ATTACH ANTENNA TO THIS UNIT IF HIGH POWER TRANSMITTERS IN THE RANGE 2-12MC ARE BEING OPERATED WITHIN 200 FEET.
C
100 KC
10 KC
1KC
ANT IND
ANT LOAD
PEAK NOISE
R.F. GAIN
AUDIO
CLARIFY
PUSH TO CALIBRATE
GND



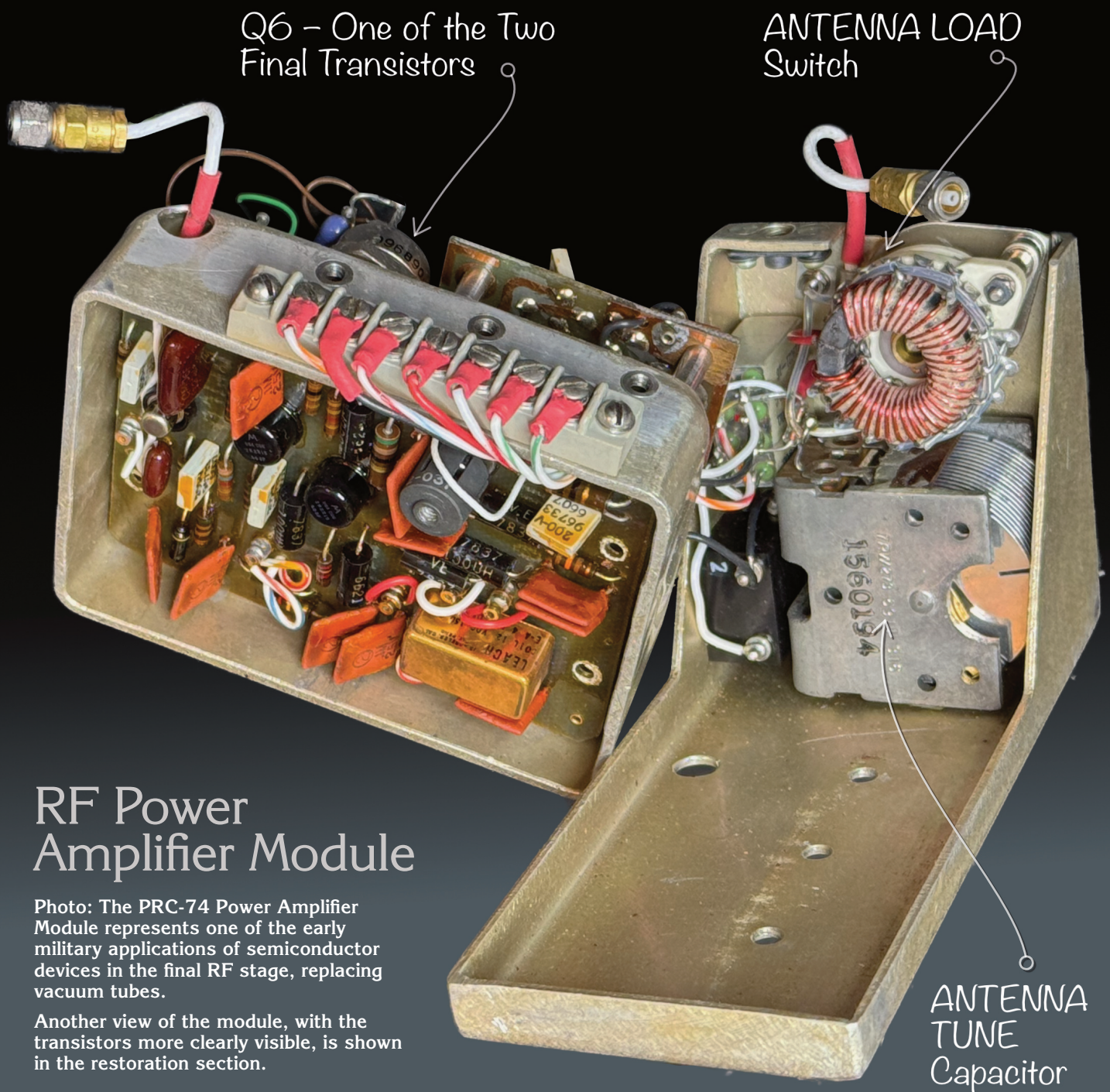
The PRC-74 had a primary role in the Vietnam War (1955–1975) fought by the USA and other nations against the North Vietnam communist regime supported by the Soviet Union and China.

PRC-74 Successors

By the end of the 1970s, the PRC-74 began to be phased out. Officially, it was replaced by the long-delayed PRC-70, which nevertheless saw limited deployment and suffered from persistent reliability issues. In practical terms, the true successor was the **AN/PRC-104**, a more modern HF manpack introduced in the early 1980s. The PRC-104 offered full 2–30 MHz coverage, SSB and CW operation (including LSB—at last), and significantly improved efficiency.

Even so, the PRC-74 did not disappear quickly. U.S. arsenal records show PRC-74B units undergoing overhaul as late as 1987, a clear indication of their enduring value and continued utility. Today, the PRC-74 is a sought-after item among collectors—myself included—thanks in no small part to my friend Francesco, to whom I owe both inspiration and valuable resources for this chapter.

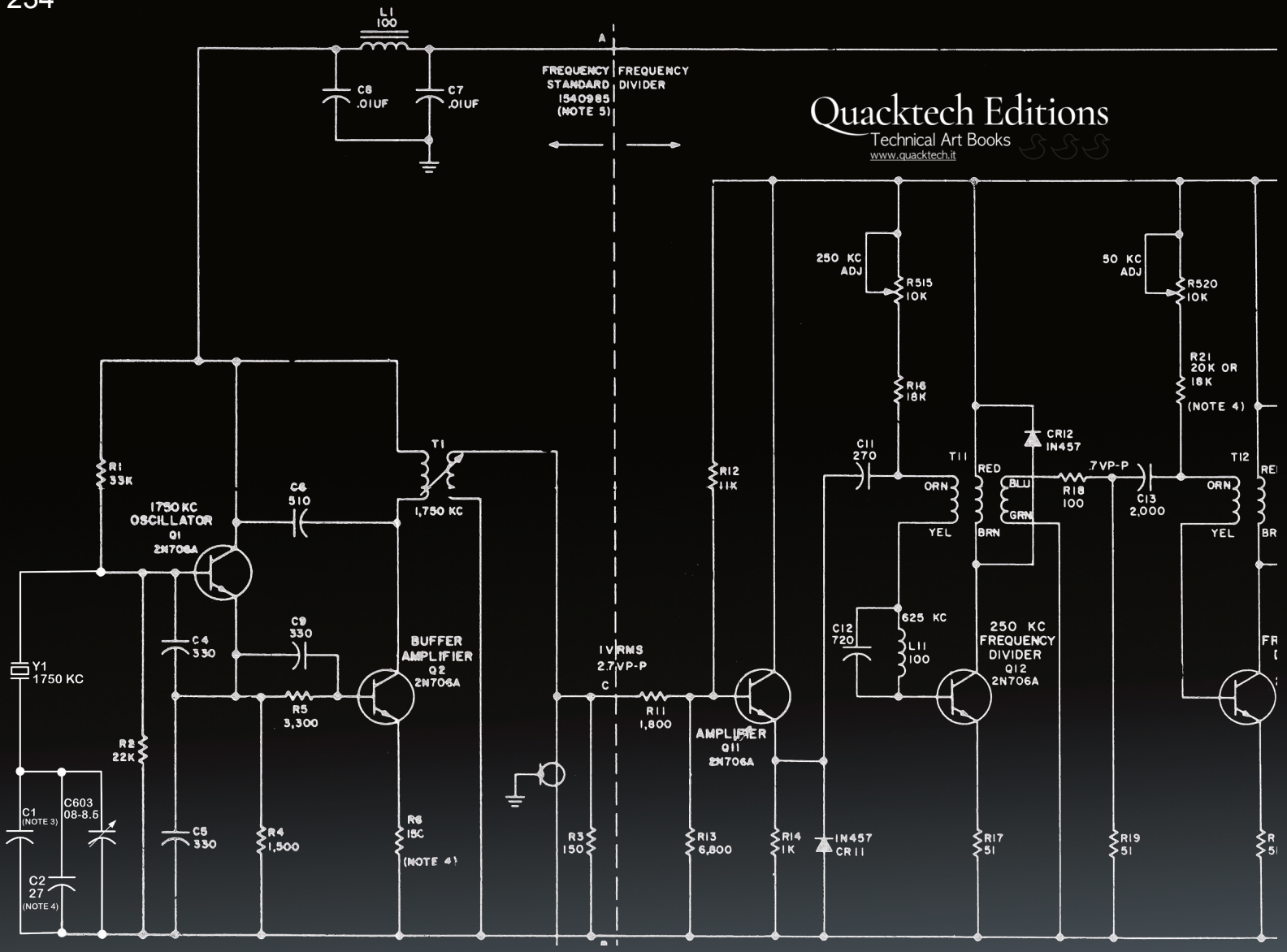
| *Note: Much of the information above is drawn from n6cc.com and greenradio.de.*



RF Power Amplifier Module

Photo: The PRC-74 Power Amplifier Module represents one of the early military applications of semiconductor devices in the final RF stage, replacing vacuum tubes.

Another view of the module, with the transistors more clearly visible, is shown in the restoration section.

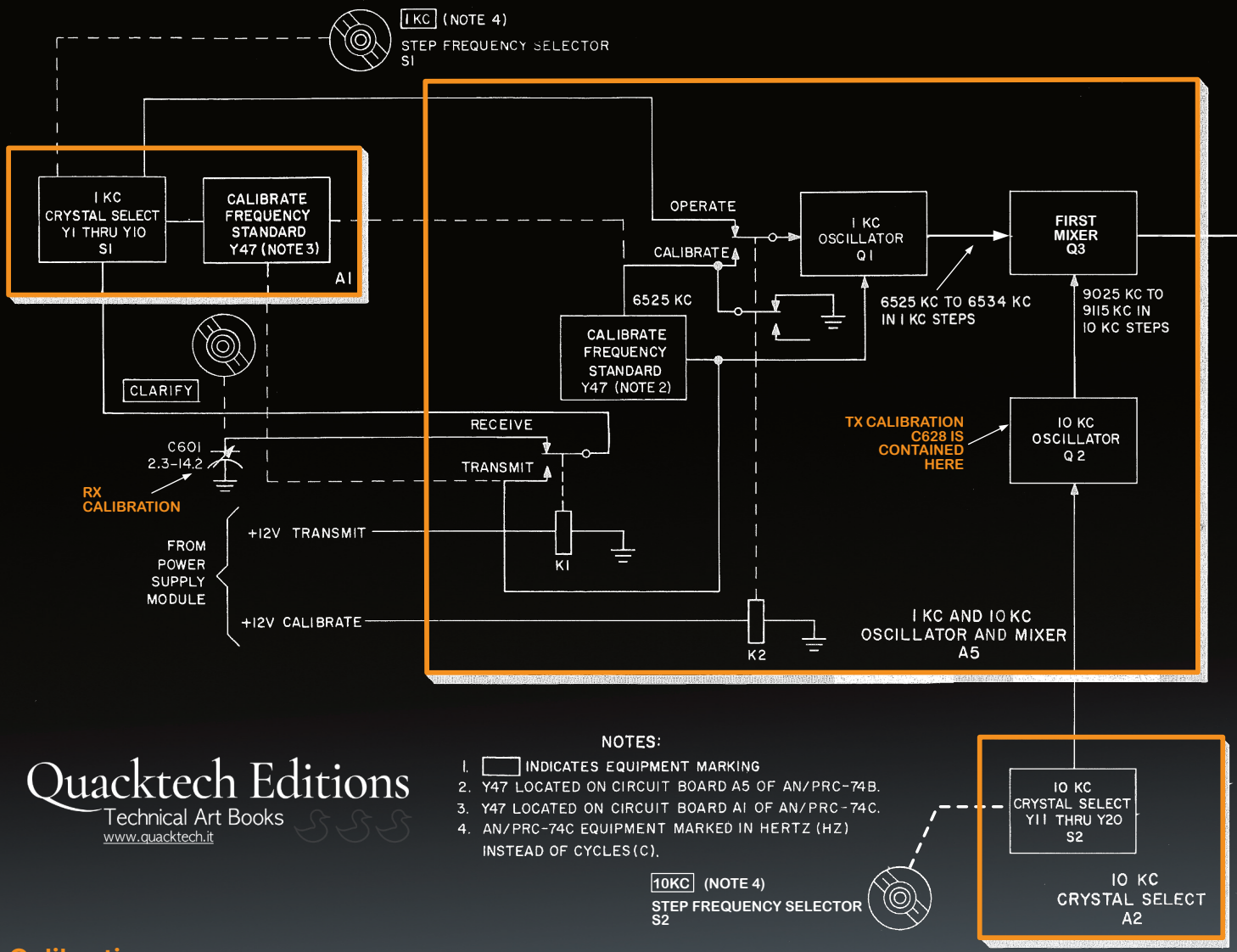


Above: Partial schematic diagram of the Reference Generator Module.

The leftmost portion has been restored, as the component values of the oscillator were unreadable in the original document.

In this section, the same frequency divider “brick” previously studied in the PRC-47 is employed.

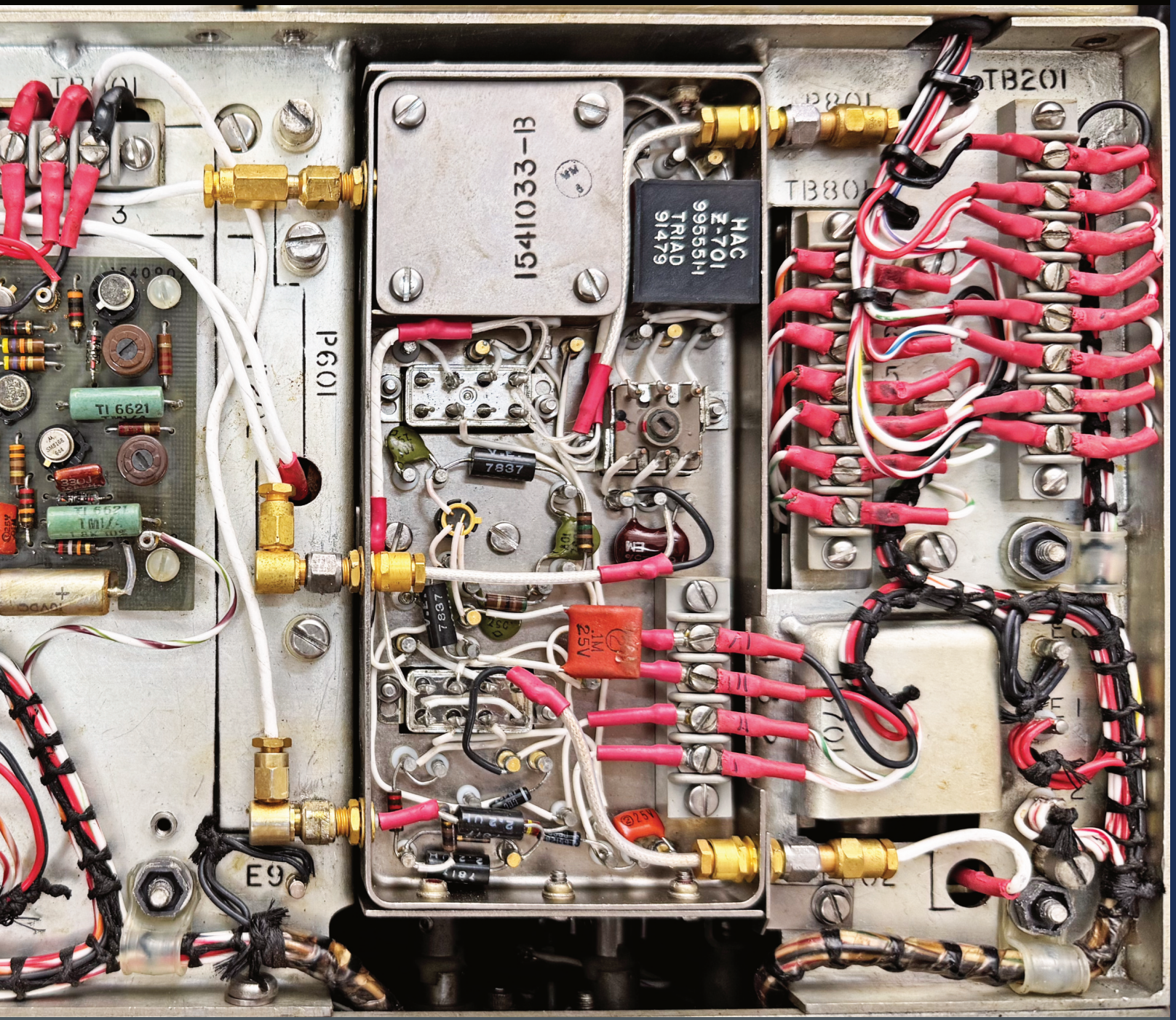
The schematic is shown only partially in order to keep the text readable; the subsequent divider stages are conceptually similar.

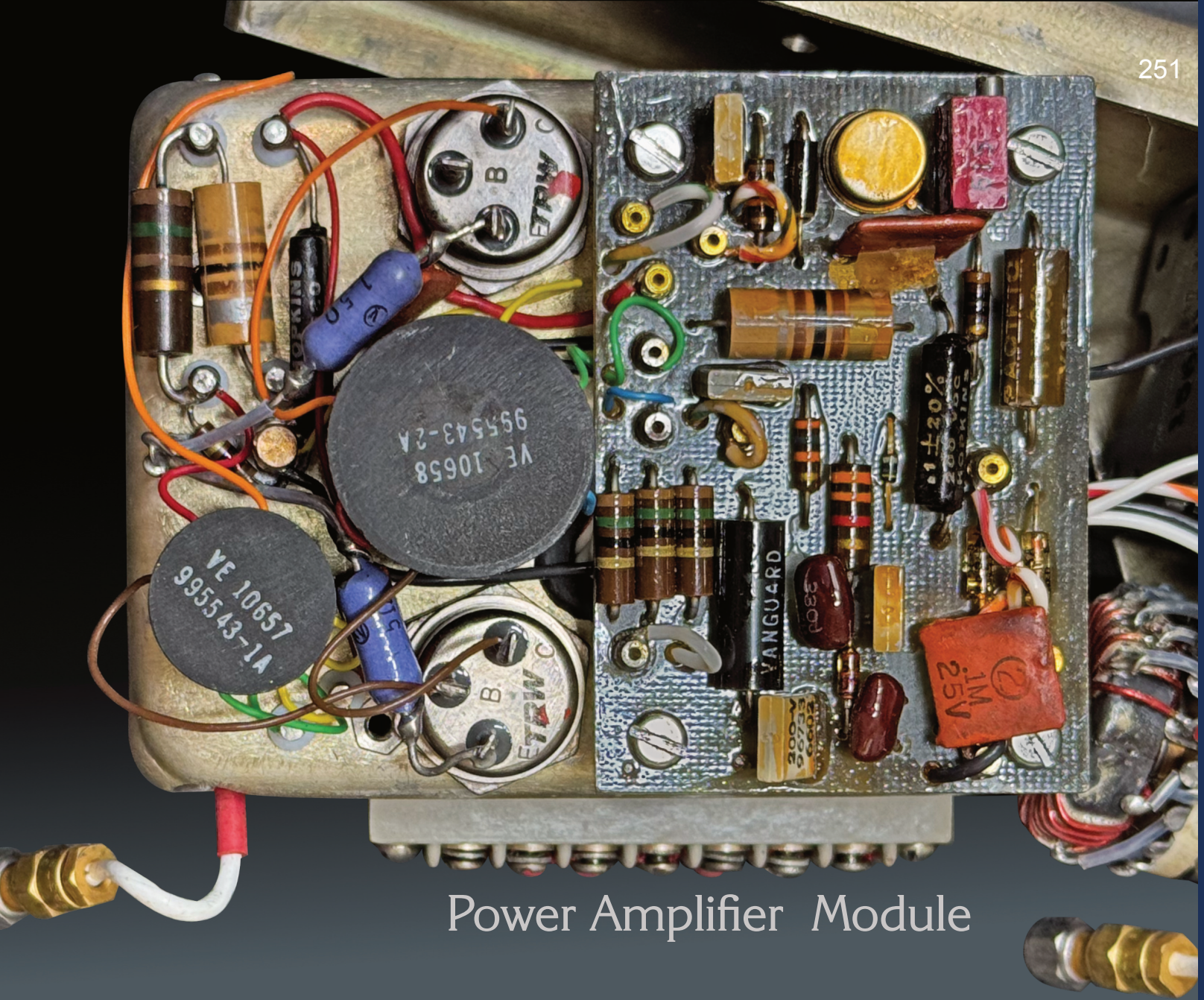


Calibration

Calibration is the process that we jokingly referred to earlier as a “manual PLL.” Given that the crystal oscillators already provide a good level of intrinsic accuracy, the PRC-74 greatly simplifies frequency control by assigning the final locking step to the operator, who effectively replaces the phase detector—using their ears as the comparison element.

With reference to the block diagram above, two distinct calibration procedures are provided: one for transmit and one for receive.


TB201
TB801
1541033-B
HAC
Z-701
995551-1
TRIAD
91479
TI 6621
7837
.1M
25V
P601
E9



Power Amplifier Module

Another view of the interior of the Power Amplifier Module.

The two large transistors marked TRW belong to the final RF stage. Their type is Hughes 723075, also identified as TRW 996890-1, and they are believed to be similar to the TRW 2N2887.

At the time of writing (27 May 2025), these devices can still be found on the surplus market—for example, used pairs are available on eBay at around USD 40.

Repairs

As I mentioned earlier, both PRC-74 units given to me by Francesco were in good physical condition but showed functional issues. One unit transmitted only on certain bands. Fortunately, I had a spare RF module, and swapping it in resolved the issue. The remaining problems were all due to improper module seating—a surprisingly common fault. Once corrected, the radio came back to life. Extracting the internal modules is neither easy nor intuitive, but it's also not excessively difficult if you carefully follow the instructions provided in the manual. Patience is the key.

Alignment

Since the PRC-74 cannot be aligned as a complete unit—each module would require a dedicated test fixture—I didn't dare attempt full calibration. Both units now deliver around 12 W output, slightly below the 15 W specification, but I chose to accept this performance level.

Information from the Internet

Many PRC-74s sold as surplus were non-functional or have been tampered with, requiring extensive repairs. The synthesizer and RF amplifier circuits are particularly complex, and the use of vintage germanium transistors can lead to failure. Some hobbyists have documented full restorations: for example, operator N6CC describes a PRC-74B received as a "Frankenradio" composed of mismatched modules, likely discarded for unserviceable repairs. He replaced faulty transistors and realigned the RF and synthesizer sections to restore proper sensitivity ($<1\ \mu V$). Another restoration case on RadioNerds involved an audio section hack attempt that was corrected by transplanting a complete front wiring harness from a donor PRC-74B.

These examples illustrate the robust modular engineering of the PRC-74 (facilitating parts-swapping) but also the technical skill required for successful restoration. Fortunately, the availability of technical manuals and a supportive online community can assist today's restorers in reviving these historic sets.


rf tune
MHz
rf range
agc
sh
med
lg
man
cal
check bfo
ae att
dimmer
phones
min
MHz
2nd vfo
ext
int
rf level
af level
cal fine tune
kHz
det – bfo mode
ssb
usb
lsb
am
+6
+3
0
-3
-6
bfo tune kHz
if bw kHz
af level
af gain
rf gain
MHz lock
kHz lock

The Fox And The Grapes

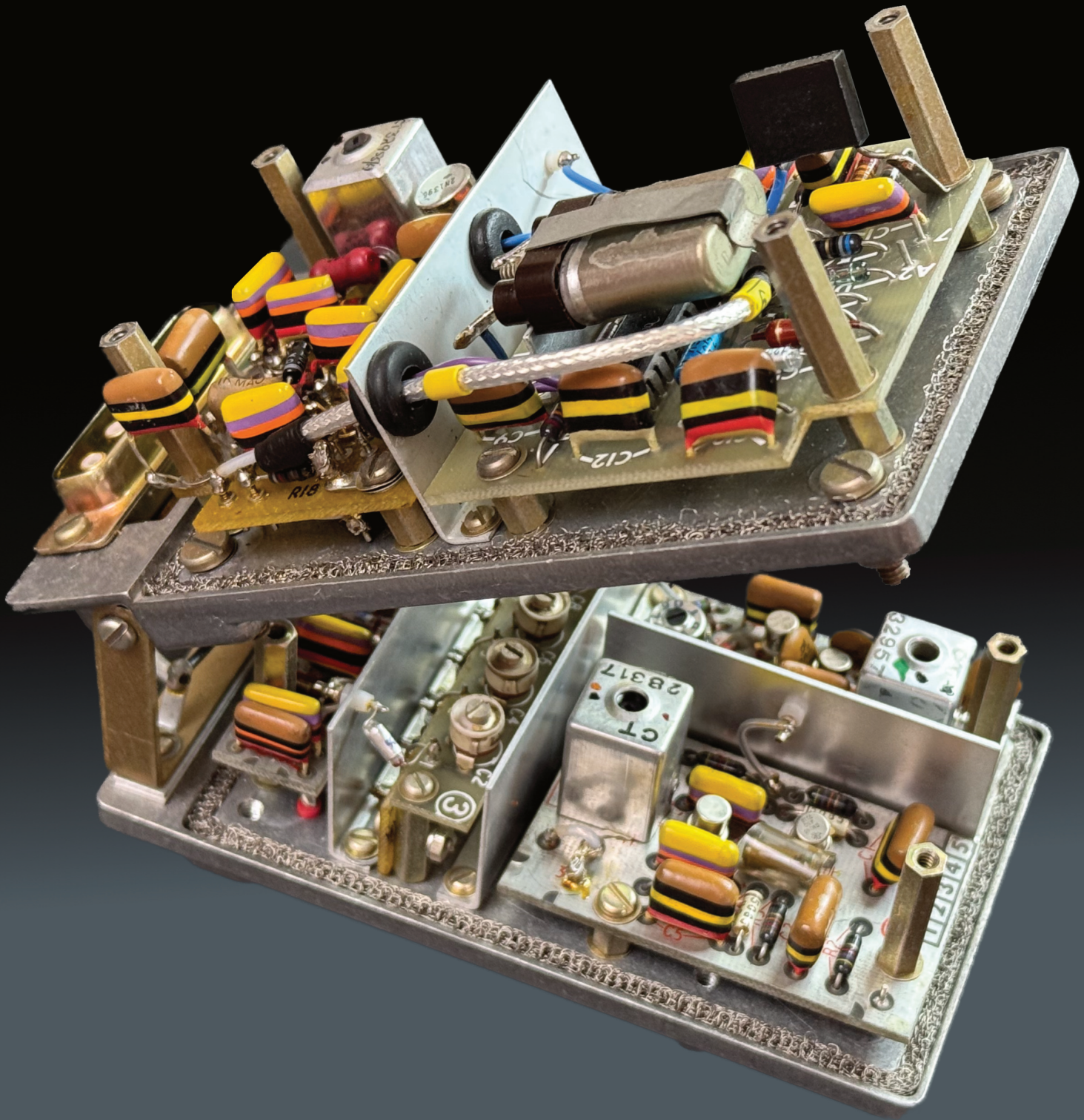
Finally!

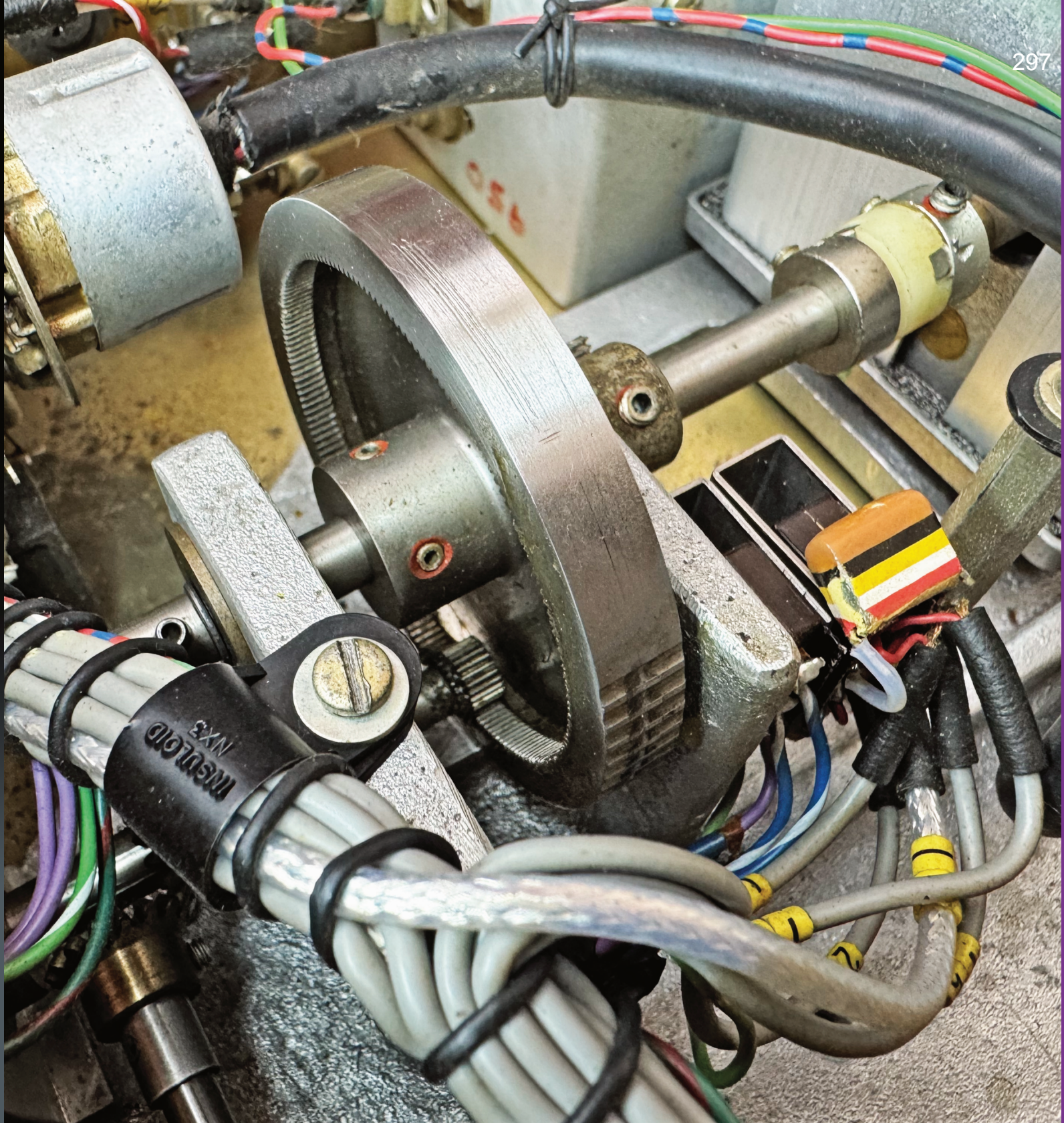
This is the opportunity I have been waiting for to prove to you that I am not that frivolous guy who falls in love with every piece of equipment he meets on his way. We are talking about a wonderful piece of equipment, the **RA.1217**, the first transistorized edition of the famous vacuum-tube RA.17 (which, on the contrary, I was in love with...).

Like in the Fable

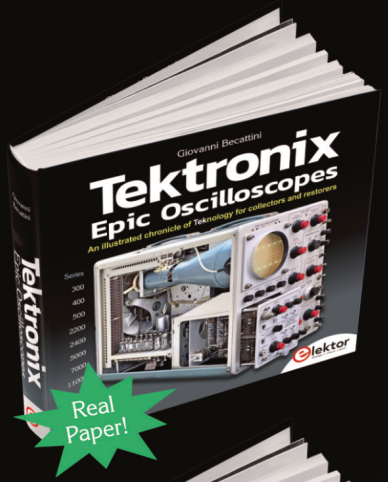
"The Fox and the Grapes" is a fable by Aesop, an ancient Greek storyteller (6th century BC). It tells the story of a hungry fox who, unable to reach a high hanging bunch of grapes, walks away muttering, *"Nondum matura"* (it's not ripe yet), belittling what she could not reach (*"she" because, in Italian, the fox (la volpe) is feminine, and it could not be different, I suppose...*)

I think that in this coldness of mine there is certainly the component of the rejected lover. As we will see, no matter how hard I tried, I was unable to produce a decent restoration.


R18
C12
CT
2831T
R295
3


MUSCLOID
NX3

Library of Vintage Electronics



Tektronix Epic Oscilloscopes

A 600-page hard cover, real paper book about Tektronix and their most classical oscilloscopes.
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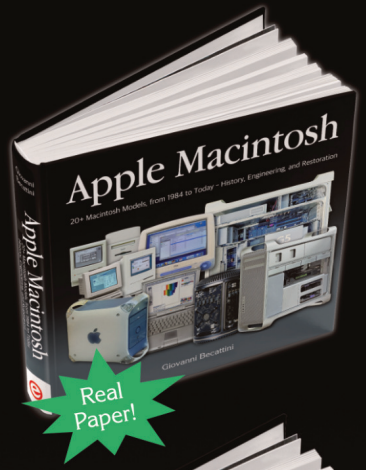

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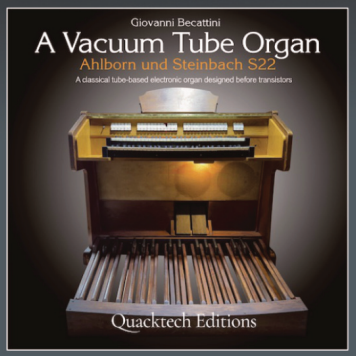

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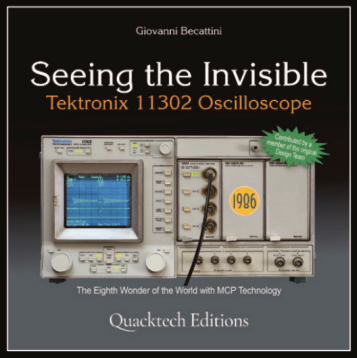

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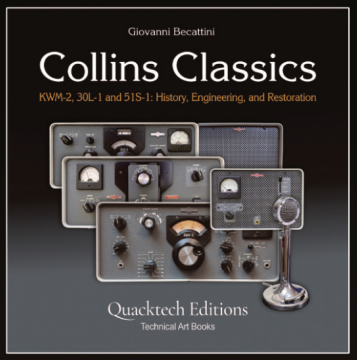

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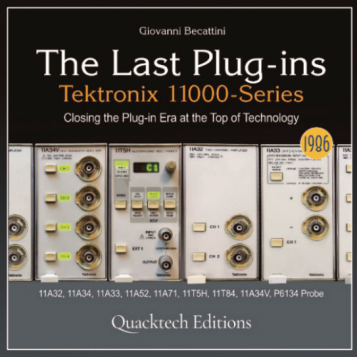

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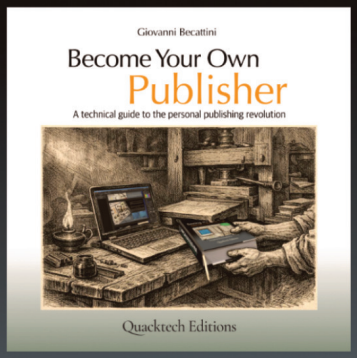

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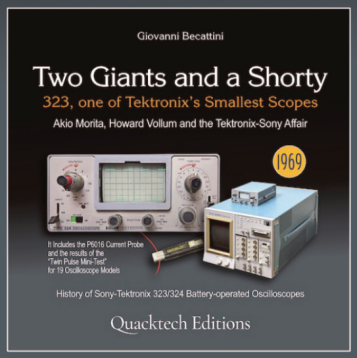

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Acknowledgments

These books would not have been possible without the invaluable support, generosity, and inspiration of several people, organizations, and communities I deeply admire. My heartfelt thanks go to Francesco Sartorello, Elektor Books International, TekWiki and Kurt Rosenfeld, the VintageTek Museum, Wikipedia, and ChatGPT.

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