# Spectrum analyzers



Subsection

## Introduction

Enter the frequency domain

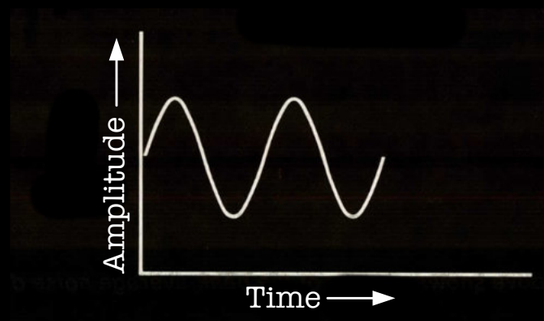
# Spectrum Analyzers

In Italian, “spettro” has also the meaning of “ghost” and that makes funny the name “Analizzatore di spettro” to laymen, who figure incredible witchcraft or ghost busting scenarios. Also among electronic technicians, the SA is however somewhat less common than an oscilloscope.

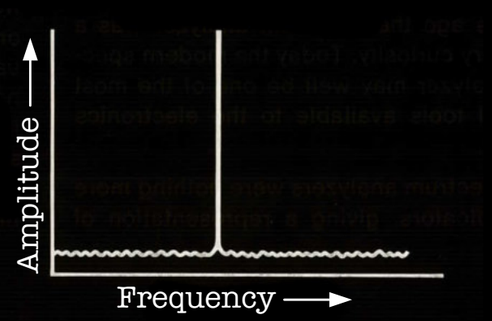
In my life, I also had no many opportunities to use them. I can remember a project for a modem at the end of the eighties and a deep study about contactless reader antennas for smart cards in 2011, where it played a major role (by the way: I discovered then that electronics quantities such as resistance, capacitance and inductance are not perfect as we should like to think, even at HF frequencies like that of the ISO 14443 smart card readers at 13,56 MHz). Apart from these projects, the SA are the every day typical instrument used in the EMC certification processes. This is the first opportunity I have to look at SAs with the interest of the enthusiast and not as a simple user.

A SA is exactly a “receiver” were the tuning frequency is controlled electronically, and that sweeps a certain frequency range in an automatic way. So, it is exactly like an oscilloscope, with the power of the signal on the y axis (instead of the voltage) and the frequency on the x axis (instead of the time).

SA are used in every field, such audio, telecommunications, standard compliance and even in mechanics with proper transducers, I suppose.

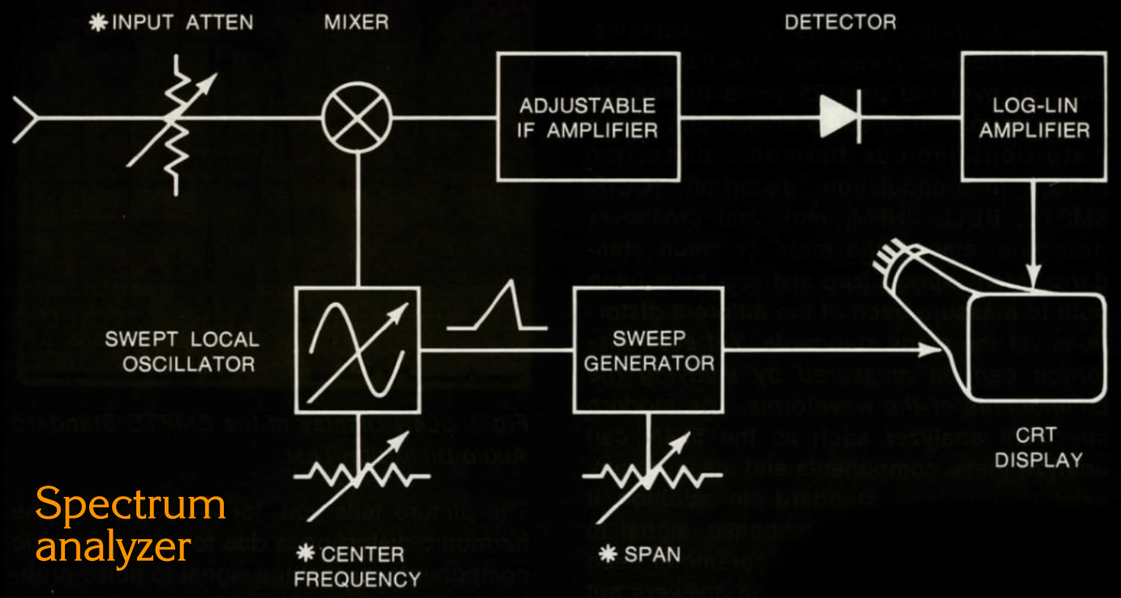



Oscilloscope graph



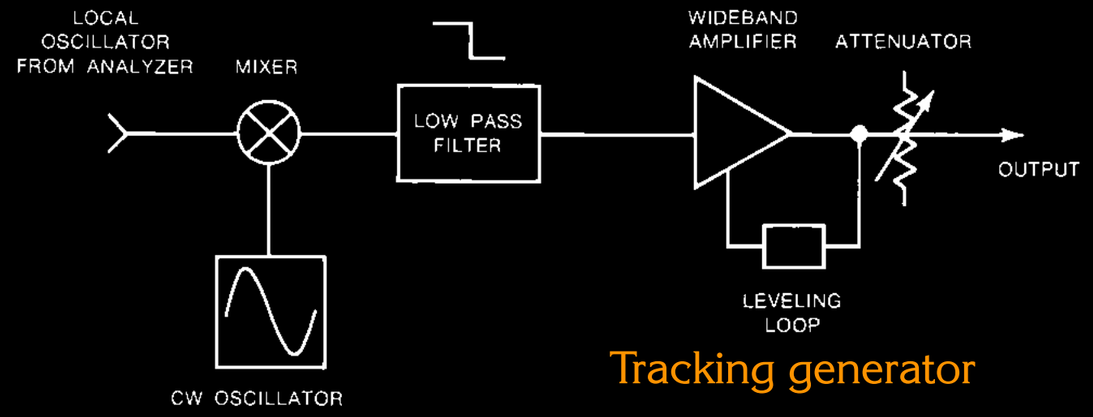

Spectrum analyzer graph






Spectrum analyzer

**Tracking Generator:** an optional accessory of the SA is the Tracking Generator, i.e., an instrument that gives a calibrated CW at the same frequency that the SA is produced at a certain time. It can be used to see the frequency behavior of a network when frequency change (i.e. an amplifier, an antenna, a filter…). Why is a special device for that? Why cannot I use the SA output for the TG? Simple, because the SA, like a receiver, has never a signal with the suitable frequency, which must therefore be rebuilt.




Tracking generator

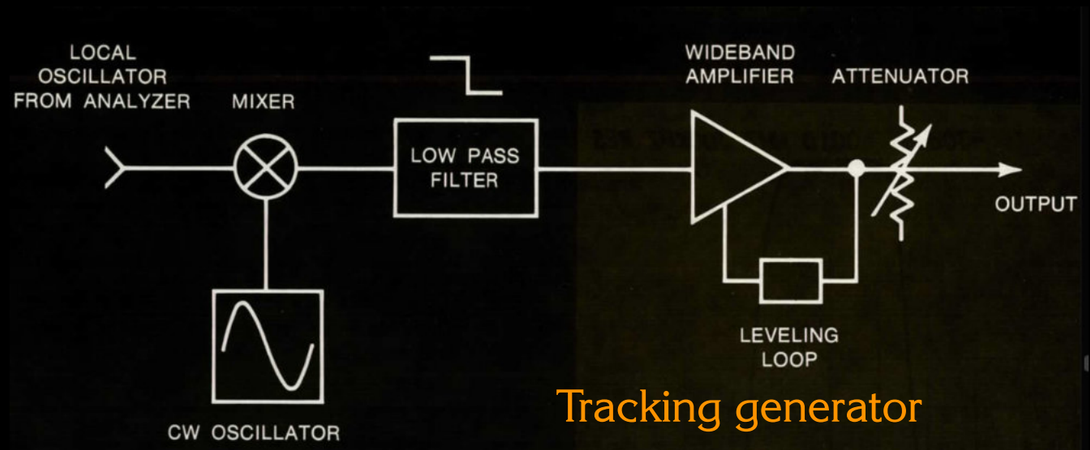
# Tracking Generators

An optional accessory of the SA is the Tracking Generator, i.e., an instrument that gives a calibrated CW at the same frequency that the SA produces on the screen at a certain time (today the TG is not anymore a separate instrument but is included in the Spectrum Analyzer).

Therefore, if you connect the TG output to the SA input, you can see a straight line, because the power is constant all over the sweep range. The level of this line depends on the TG output, that normally have an output attenuator.

If the connection between them is done by mean of a generic network, you will see on the screen the frequency behavior of that net. For example, you can test a filter, an amplifier, an antenna or something more complex. For its nature, with the SA+TG you can do without many other different instruments, that in the years have been designed mainly for cost reasons.

You could ask why you need a TG and not just an amplifier from the SA. The reason is simple: in the SA there is not an oscillator with the current sweep frequency, due to conversion stages, so the TG must “rebuild” that frequency value.




Tracking generator








An old spectrum analyzer (HP141T, composed by the mainframe, the 8553B RF section and the 8552B IF section), together with its 8443A tracking generator. In the modern equipment, they are normally contained in a single box.

# Spectrum analyzers

## Subsection
## 141T+8553B+8552B

This is, thanks to my friend Francesco Sartorello, that I will never thank enough, the first Spectrum Analyzer that is mine, and that determined a strong emotional personal involving, with tons of satisfactions, due also to its exceptional construction.

But this first “true” Spectrum Analyzer lacked a name, a big marketing mistake for HP. We will talk here mainly of the 8553B/8552B model, in the 141T mainframe.

# 141T+8553B+8552B

# “Frequency-domain oscilloscope”




1968

In 1968 Tektronix was leading the oscilloscope market, and Hewlett-Packard was only a follower (“Tektronix for the scopes, HP for all the rest”). The oscilloscope was however a mature product, logically not so different from today’s instruments, practical and easy to use.

Different was the situation on the RF’ side. These measurements had always been limited by the equipment available, much of which was special-purpose, complex, and hard to use. Manually tuned wave analyzers, distortion analyzers, receivers, and uncalibrated spectrum analyzers all had limitations which prevented designers from making rapid and meaningful use of the frequency domain, however recognized as one of the more powerful techniques available to engineers for characterizing circuits and systems.

In 1968 HP introduced a new family of instruments that aimed to change this situation for ever. They called them “Frequency-domain oscilloscopes” (FDO). With this term, they wanted to mean a new way of thinking about spectrum analyzers and a new way of using them. "To deserve the name 'frequency-domain oscilloscope’, a spectrum analyzer has to be fully calibrated, like an oscilloscope, and just as easy to use as an oscilloscope”.

Very interesting is to read which were the features that they highlighted at the moment, being their perception possibly different today.

## Immense areas of application

“These fully calibrated, easy-to-use instruments have an area of application that is, quite literally, immense. This application area is general circuit design - the same area in which the oscilloscope finds most of its applications. The spectrum analyzer is a basic measuring tool for designing oscillators, amplifiers, mixers, modulators, filters and so on.”

## Nameless?

Strangely, besides the well-guessed “Frequency-Domain Oscilloscope” name, this family had not a clear denomination; in my opinion, a lack in HP marketing strategies. Even in these few notes, I have difficulties referring to them. That was because the product was not a Spectrum Analyzer but an oscilloscope with spectrum analysis plug-ins, in this case a 140-Series mainframe with 855x plug-in.

## A new modular family

The new FDOs proposed by HP were probably the first Spectrum Analyzer, in the form that we mean today, and could be composed by an RF section, an IF section and a display unit, plus an optional Tracking Generator that we will discuss in the subsequent chapter.

Three RF sections were available, similar but with a different frequency range (see the table). Here we present the low frequency unit, from 1 kHz to 110 MHz.

Two IF sections were available for the 8555A, the 8552A, and the high resolution 8552B. The 8552B incorporates all the features of the 8552A and in addition offers a 2dB log expand display mode, manual scan, and better resolution because of better IF filter factors.

A choice of mainframes was also possible. Several displays were available, without or with CRT storage memory, when the scan rate must be slow enough for the bandwidth selected. The most modern mainframes (see next page) had the square display.

Prices are reported to show how valuable was this instrument. The 2023 conversion factors are 7.53 for 1971 and 8.31 for 1969. In this way, the complete unit we present here (8553B, 8552B, 141T and 8443A) had a 77,217$ price tag (referred to current date, 10,250 at the time). They knew they had created something special with its worth. Just to make a comparison, in the same 1971 year, a Tektronix 7704 with 2 x 7A12, a 7B70 and a 7B71, at the time the state of the art, costed “only” 5,845$, little more than half the price of the HP beast that you can see here.





Pages edited on June 27 2024




141S display unit

| Name | Type | Notes | Price USD | in year | Today USD |
|---|---|---|---|---|---|
| 8553B | RF section | 1 kHz ÷ 110 MHz | 2,200 | 1971 | 16,573 |
| 8554L | RF section | 500 kHz ÷ 1.25 GHz | 3,300 | 1970 | 24,860 |
| 8555A | RF section | 10 MHz÷18 GHz | 5,975 | 1971 | 45,012 |
| 8552A | IF section | Standard IF section | 2,150 | 1971 | 16,197 |
| 8552B | IF section | High resolution IF section | 2,850 | 1971 | 21,470 |
| 140S | Display unit | Normal persistence, round CRT | 725 | 1969 | 6,027 |
| 141S | Display unit | Variable persistence, round CRT | 1,525 | 1969 | 12,678 |
| 140T | Display unit | Normal persistence, square CRT | 875 | 1971 | 6,591 |
| 141T | Display unit | Variable persistence, square CRT | 1,700 | 1971 | 12,807 |
| 143S | Display unit | Large display | 1,500 | 1971 | 11,300 |
| 8443A | Tracking generator | With digital counter | 3,500 | 1971 | 26,367 |
| 8443B | Tracking generator | Without digital counter | 1,975 | 1971 | 14,878 |

# 140 Goes 180

Among the other, HP had two modular oscilloscope series:

- 140 Series - the “old one” The first oscilloscope of the 140 series was the HP 140A mainframe, which appeared in the 1963 catalog. The choice of the Mainframe-Drawer solution probably came from the competitive challenge with Tektronix. None of the many drawers developed for general purpose oscilloscopic measurements would be a significant technology advance compared to the oscilloscope market of the time. But HP quickly included many new products in the 140 series counting on their technology leadership (from hpmemoryproject.org).
- 180 Series - the “new one” (in 1966). They were presented for the first time at the Hewlett-Packard WESCON, Hollywood Park, in August 1966. They are described in this book in the oscilloscope section.

Both the 140 and the 180 mainframes could become spectrum analyzers with the proper plug-ins.

It is however interesting to see that the 141T mainframe, here described, is really a 181A transformed to accept 140-Series plug-ins, as it is evident by comparing the pictures in these pages. it's like saying that from a certain point on, all mainframes were 180s, with a different plug-in interface.

## Warning, Save Your CRT!

Thanks to David from Groups.IO, I discovered that HP storage CRTs are not so robust as Tektronix ones, and that they must be mandatory used prudently to avoid their damaging.

Read the instructions for their correct use in the Oscilloscope Section of this book, in the Hewlett-Packard Type 181A chapter.

Pages added on June 27 2024




❶ Plug-ins removal (green arrow). The two modules can be then separated by pressing the button pointed by the red arrow. ❷ The button and how to rotate the module to separate it from the other.

## Modularity

The various modules are integrated rather well. It is easy to extract the drawer composed by the RF and IF section (green triangle in the photo ❶). Also separating them is easy, when you know that you have to press the button pointed by the red triangle and rotate, as shown in photo ❷.

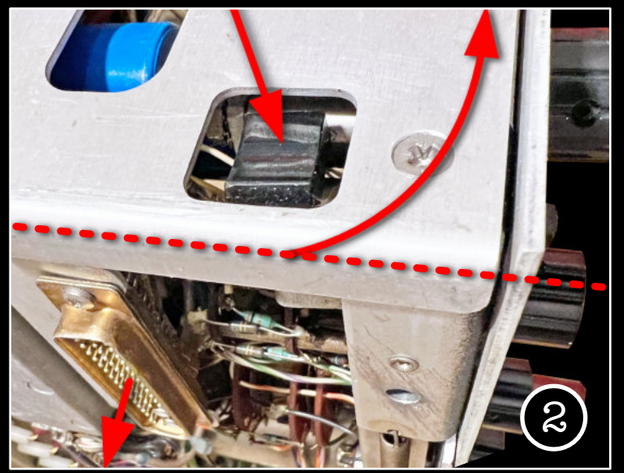
Surely, the modules are easy to manage and interchangeable among the various models, but they did not claim the modularity. Probably, interchanging the RF or IF section would have required the instrument recalibration; it was not a simple plug-in interchange, like in the Tektronix 7000-Series, I suppose.

## The first time

According HP Journal 8/1968, for the first time, a spectrum analyzer has absolute amplitude calibration combined with broad sweep capabilities, high sensitivity, low distortion, wide dynamic range, and flat frequency response. The new Spectrum Analyzer was designed to be a general-purpose measurement tool, to make the frequency domain as scope-accessible as the time domain.

## Easy to use and interpret

It was a central aim of the design to devise the controls and the display so they would be easy to use and interpret. Automatic frequency stabilization occurs during normal use of the instrument without preliminary adjustments. The display is free of clutter because a low-pass input filter prevents out-of-band signals from overloading the analyzer or causing confusing spurious responses. A red panel lamp warns the operator when the display becomes uncalibrated because the scan rate is too fast for



the bandwidth selected.

## The 8553B/8552B pair

This new spectrum analyzer was developed in the HP microwave laboratory for use in many electronic fields, especially those concerned with circuit design in communication systems. Its frequency range, 1 kHz to 110 MHz, is a span that includes audio, video, and IF amplifiers, navigational aids, telemetry, and most multiplex basebands, as well as commercial AM, FM, TV, and land mobile communications. The new analyzer could be used for evaluating oscillators, frequency converters, amplifiers, filters, and numerous other system components. Important design parameters that could be readily derived from its display were such things as modulation index, harmonic and intermodulation distortion, noise levels, spectral purity, residual FM, and frequency response.

## Which were the most appealing features?

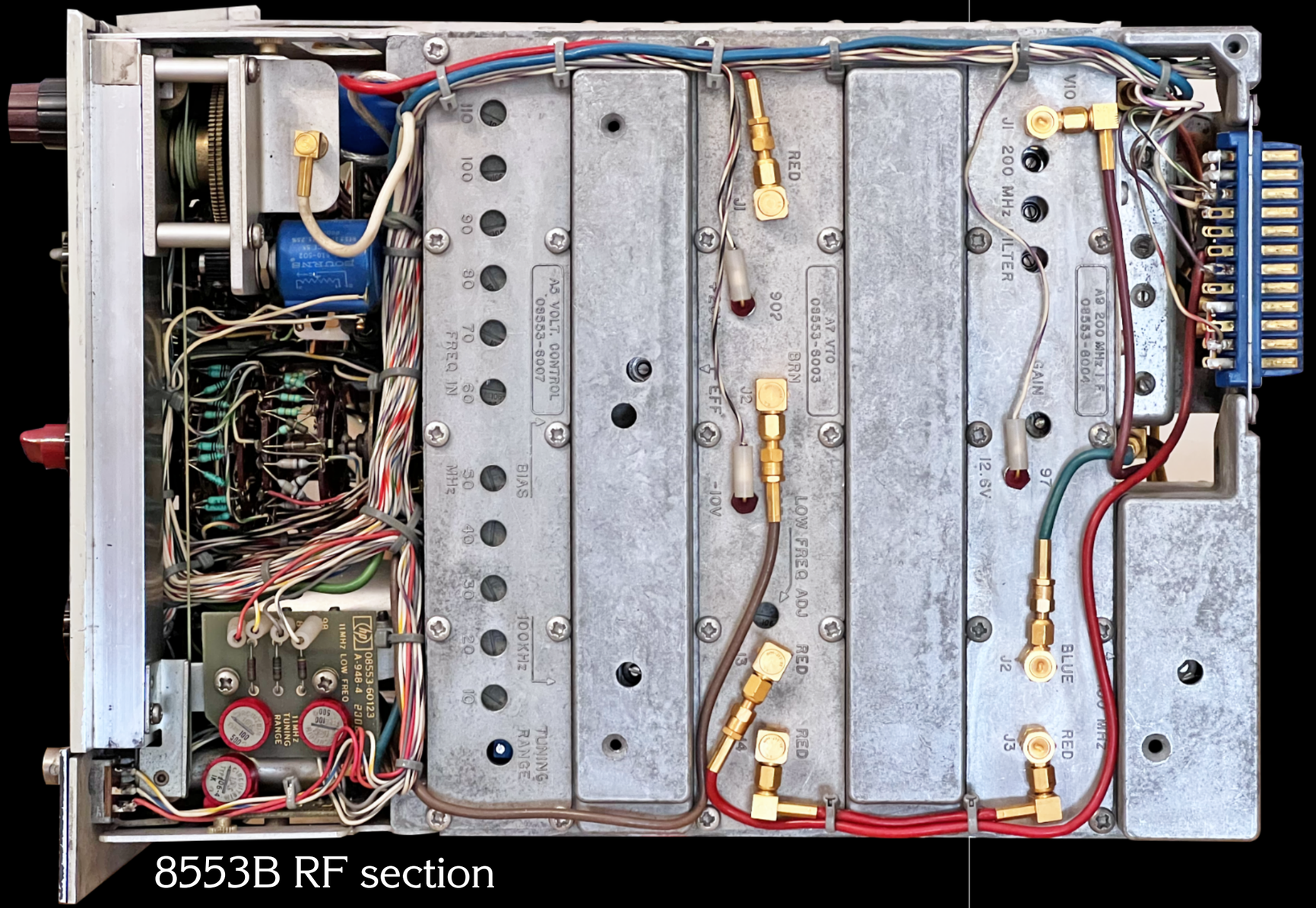
- Broad frequency range and wide-scan capability.
  Frequency range is 1 kHz to 110 MHz. The 8553B/8552B has the capability to scan as wide as 100 MHz or as narrow as 2 kHz (200 Hz/div). This single system allows wide band measurements of such phenomena as harmonic distortion or out-of-band emissions with the capability to "zoom-in" on a particular signal for modulation measurements or in-band distortion analysis.
- Flat frequency response. Response is flat within ±0.5 dB over the entire frequency range.
- High Resolution: The 8553B/8552B features 10 Hz equal signal resolution throughout the frequency range. More significant, such phenomena as line related sidebands may be resolved even when they are 60 dB or more below the carrier level. IF bandwidths as narrow as 10 Hz with 60 dB/3 dB shape factors less than 11:1 allow this high resolution capability.
- High Stability: Accurate high resolution analysis requires an extremely stable measurement system. With residual FM less than 1 Hz, the 8553B/8552B becomes the stable reference necessary for full use of narrow bandwidth operation.
- Absolute Amplitude Calibration: The spectrum analyzer has absolute amplitude calibration in addition to a fully calibrated display. Absolute signal levels in either dBm or voltage may be read directly from the CRT. External calibration signals are not required to obtain accurate amplitude information.








8553B
RF section



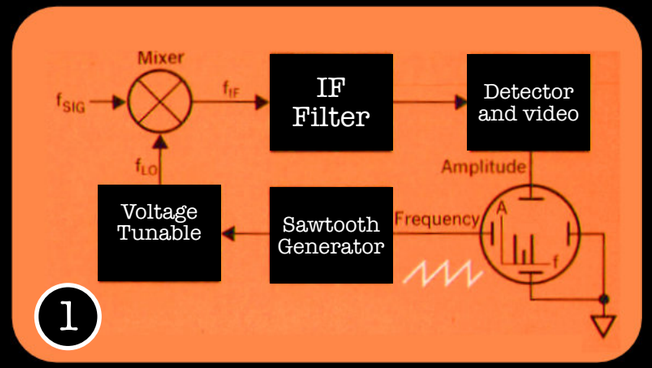

8553B RF section

Excellent ±0.5 dB flatness across the full frequency range makes direct measurements accurate and simple.

- 70 dB Display: A dynamic display range of 70 dB, free from spurious and image responses, allows meaningful measurements over a wide amplitude range. Three display modes are provided on the spectrum analyzer: 10 dB per division logarithmic; 2 dB per division logarithmic; and linear display with selectable scale factors from 0.1 V per division to 100 mV per division.
- High Sensitivity: Low level signals may be accurately characterized with ease due to the -140 dBm (25 nV) sensitivity of the spectrum analyzer. A wide measurement range from -140 dBm to + 10 dBm provides great flexibility for a variety of measurements.
- Variable Persistence Display: High resolution analysis requires slow scanning rates. These slow rates are made practical through the use of the 141T Variable Persistence Display Section which provides a flicker-free display at even the slowest scan rates. With normal persistence, the trace would appear merely as a slowly moving dot on the CRT. Trace storage is also provided on the 141T Display Section for side-by-side comparison of spectra.

**We will talk later of the construction techniques of these splendid instruments. The 8553B follows the general scheme but has the boards alternately reversed (one is accessible from the top, the next from the bottom. It uses furthermore a die cast aluminum frame instead of the less expensive extrusion of the subsequent models.**

## Block diagram




Picture ❶ reports the simplified overall block diagram of the 8552B/8553B Spectrum Analyzer.

The SA is essentially a triple conversion receiver calibrated in frequency and amplitude. Its tuning frequency can be controlled by a DC ramp (or by a constant value) and the output is not in a loudspeaker but on CRT, where the frequency is on the x axis and the signal amplitude on the y axis.

With reference to the more detailed block diagram ❷ on the front page:

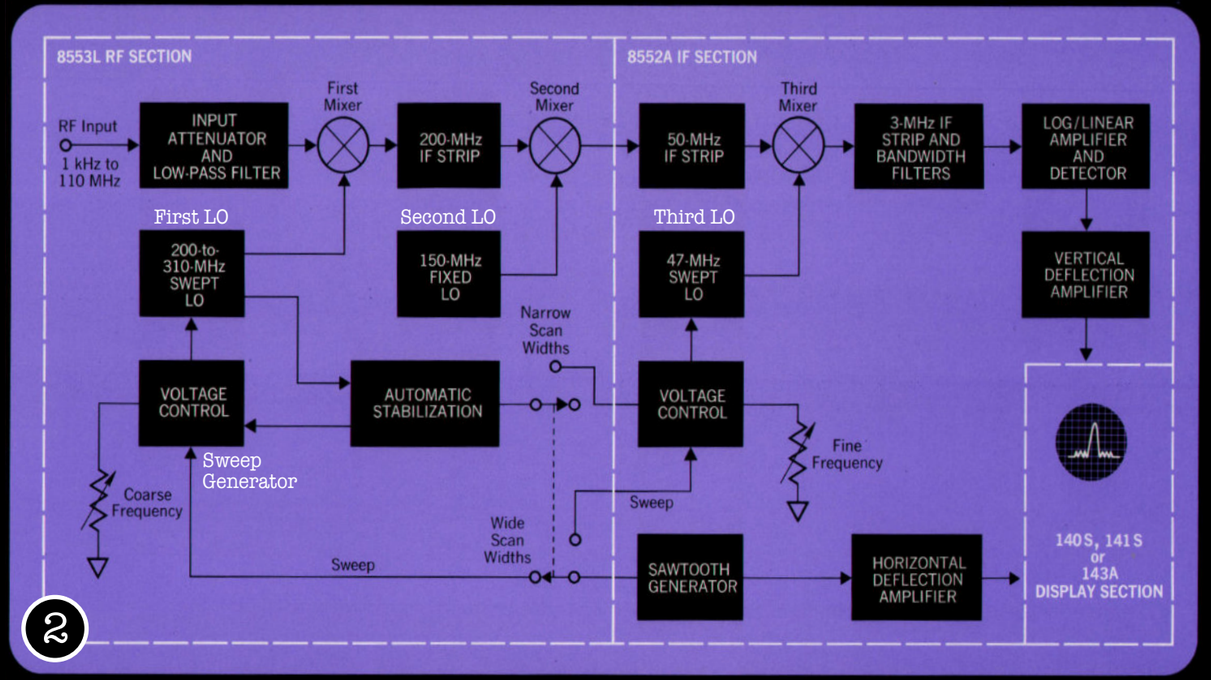
- at the input, a low-pass filter and an attenuator are provided;
- the input signal is mixed with the 1st Local Oscillator (LO) (200÷310 MHz), producing the signal for the 200 MHz IF amplifier/filter;
- the 1st LO is controlled by a Varactor which allows to scan the whole the 200÷310 MHz by means of a DC voltage control;
- the Voltage Control (Sweep Generator) produces the ramp that controls the 1st LO to sweep the entire operational range or selected portions of it. In narrow scan modes or in ZERO scan mode the first local oscillator is phase locked to the 100 kHz reference signal and the 3rd LO is swept;
- the crystal-controlled 150 MHz 2nd LO down-converts the signal to 50 MHz for the second IF.
- the 50-MHz signal is then mixed with the 47-MHz 3rd LO to produce the 3 MHz signal;
- this 3-MHz signal passes through the bandpass filters and the logarithmic amplifier in the third IF to the detector, and the output of the detector is displayed on the CRT;
- the 3-MHz bandpass filters determine the receiver bandwidth; they are selected by a front panel control.

## Multiple conversion superheterodyne

As noted, a spectrum analyzer like this is substantially a superheterodyne radio receiver, and thus it is subject to spurious responses ("image frequencies"). For this reason, multiple conversions are used, because there is a tradeoff between low image response and selectivity.

Why multiple conversion? The separation between the received frequency and the image frequency is equal to twice the IF frequency, so the higher the IF, the easier it is to design an RF filter to remove the image frequency from the input and achieve low image response. However, the higher the IF, the more difficult it is






to achieve high selectivity in the IF filter. At shortwave frequencies and above, the difficulty in obtaining sufficient selectivity in the tuning with the high IFs needed for low image response impacts performance. To solve this problem two IF frequencies can be used, first converting the input frequency to a high IF to achieve low image response, and then converting this frequency to a low IF to achieve good selectivity in the second IF filter. To improve tuning, a third IF can be used [from Wikipedia].

## Residual responses.

Incrementing the number of conversions, we create however other problems, like the residual responses, which appear as false indications when no signal is present at the input of the SA. Residual responses result when the higher harmonics of internal oscillators mix together to produce signals at one of the intermediate frequencies.

**❶ S8552B/8552B Spectrum Analyzer simplified block diagram. ❷ A more detailed block diagram.**

8553L-8552A
RESIDUAL SPURIOUS RESPONSES

FIRST MIXER

| 1ST LO | 2ND LO | 1ST LO MHZ | 2ND LO MHZ | SPUR MHZ |
|---|---|---|---|---|
| 1 | 3 | 250 | 450 | 50 |
| 2 | 2 | 500 | 300 | 50 |
| 2 | 4 | 400 | 600 | 0 |
| 2 | 5 | 550 | 750 | 75 |
| 3 | 3 | 650 | 450 | 16.6667 |
| 3 | 4 | 800. | 600 | 66.6667 |
| 3 | 6 | 700 | 900 | 33.3333 |
| 3 | 7 | 850. | 1050 | 83.3333 |

In a broadband receiver the residual problem is compounded by the number of different local oscillators and intermediate frequencies. It is possible for each mixer to have high output levels through the tenth harmonic of each oscillator. In a triple conversion spectrum analyzer all of the harmonics of the three LO's can mix with each other to produce any of the three intermediate frequencies.

Computer Aided Design. Today is normal to use some software to predict the behavior of a circuit, but in 1968 it was a relevant novelty, and, to help identifying residual responses and locate their sources, a dedicated computer program had been written. The program applied the general mixing equation to each converter and calculated the frequencies where spurious responses will occur. The harmonic numbers and frequencies involved were also printed, so that filter requirements could be determined. The computer printout for the interaction of the first and second local oscillators is shown in ❶. Those who are no longer young will be moved by recognizing in this printout the typical font of the ASR-33 teletypewriter.

Spurious responses are printed out in the order of ascending harmonic numbers of the LO's. This corresponds approximately to the order of importance of the responses, since higher harmonic conversions are generally at lower levels. The first line in the table indicates that a residual response



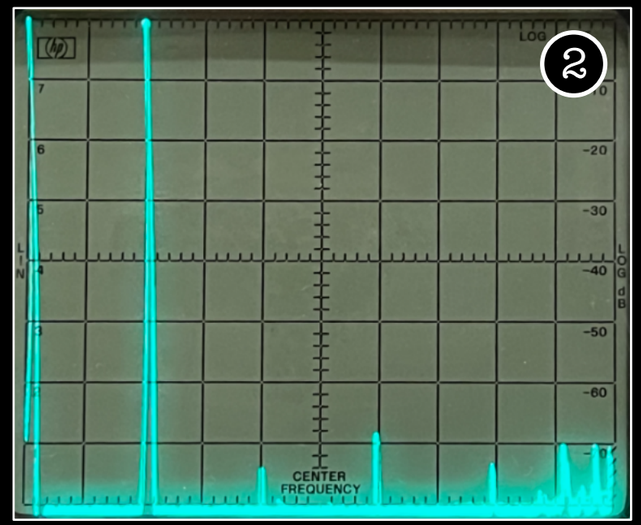
(SPUR) will occur at 50 MHz on the spectrum-analyzer frequency dial if the first and second LO frequencies of 250 MHz and 450 MHz are allowed to mix. These frequencies correspond to the fundamental and third harmonic of the first and second LO's, respectively. These signals are suppressed in the analyzer through careful filter and mixer design.

As a result of this computer-aided design technique, the new spectrum analyzer had virtually no residual responses. The responses are typically much less than -110 dBm. This is one reason for the analyzer's 70-dB clutter-free display range.

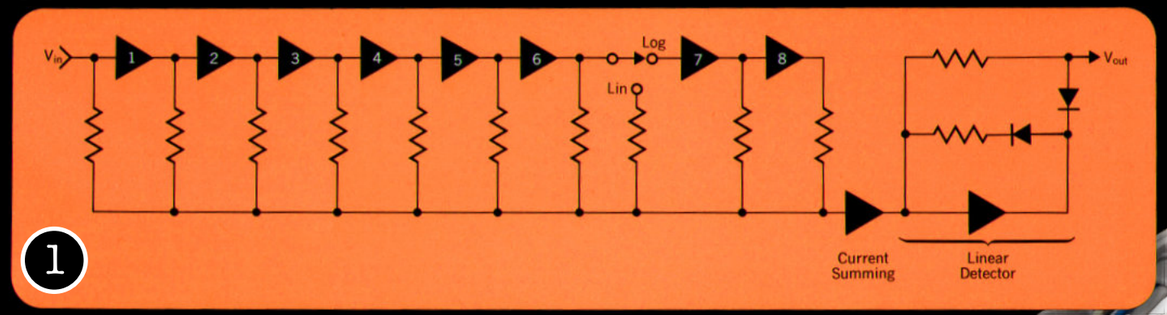
## 70-dB log amplifier

Another theme that I found very intriguing is the logarithmic amplifier, which allows to clearly see on the same CRT signals has high as 0 dBm (for example) and as low as -70 dBm. If you are used to oscilloscopes, with their linear screen, this is something you must get acquainted with. Normally, you set the reference level on the top of the graticule and each division is 10 dB (unless you set the switch to 2 dB LOG or LINEAR). Look, for example, at the screenshot ❷ on the right. You can see the 20 MHz carrier from an 8640B signal generator at the reference level (-10 dBm) and, at on the extreme right, the FM broadcast stations. They seems to be about one tenth of the 8640B but really they are 90 dB lower, i.e., one billion times less powerful (E-9).

The logarithmic amplifier (❶ above) uses a successive limiting technique to achieve wide bandwidth and a 70-dB dynamic range. This amplifier has eight amplifier/limiter stages, each of which has 9 dB of gain. The logarithmic characteristic is obtained by summing the outputs of the individual stages.




To understand the operation of the log amplifier, first consider a weak signal, one just strong enough so that the eighth stage begins to limit. The output voltage of each stage is limited to approximately three volts. When the eighth stage begins to limit, the output of the log amplifier is a voltage proportional to the




1

output of the eighth stage, plus a voltage proportional to the sum of the outputs of the first seven stages, which have not yet limited. Thus the output is $K(3 + S_{1\text{-}7})$ volts, where K is a constant gain factor and $S_{1\text{-}7}$ is the sum of the outputs of the first six stages. If the input signal increases by 9 dB, the seventh stage begins to limit, and the output is a voltage proportional to the sum of the outputs of two limiting stages, plus a voltage proportional to the sum of the outputs of six non-limiting stages. Thus the output is $K(6 + S_{1\text{-}6})$. If the input increases another 9 dB, the output is $K(9 + S_{1\text{-}5})$, and so on.

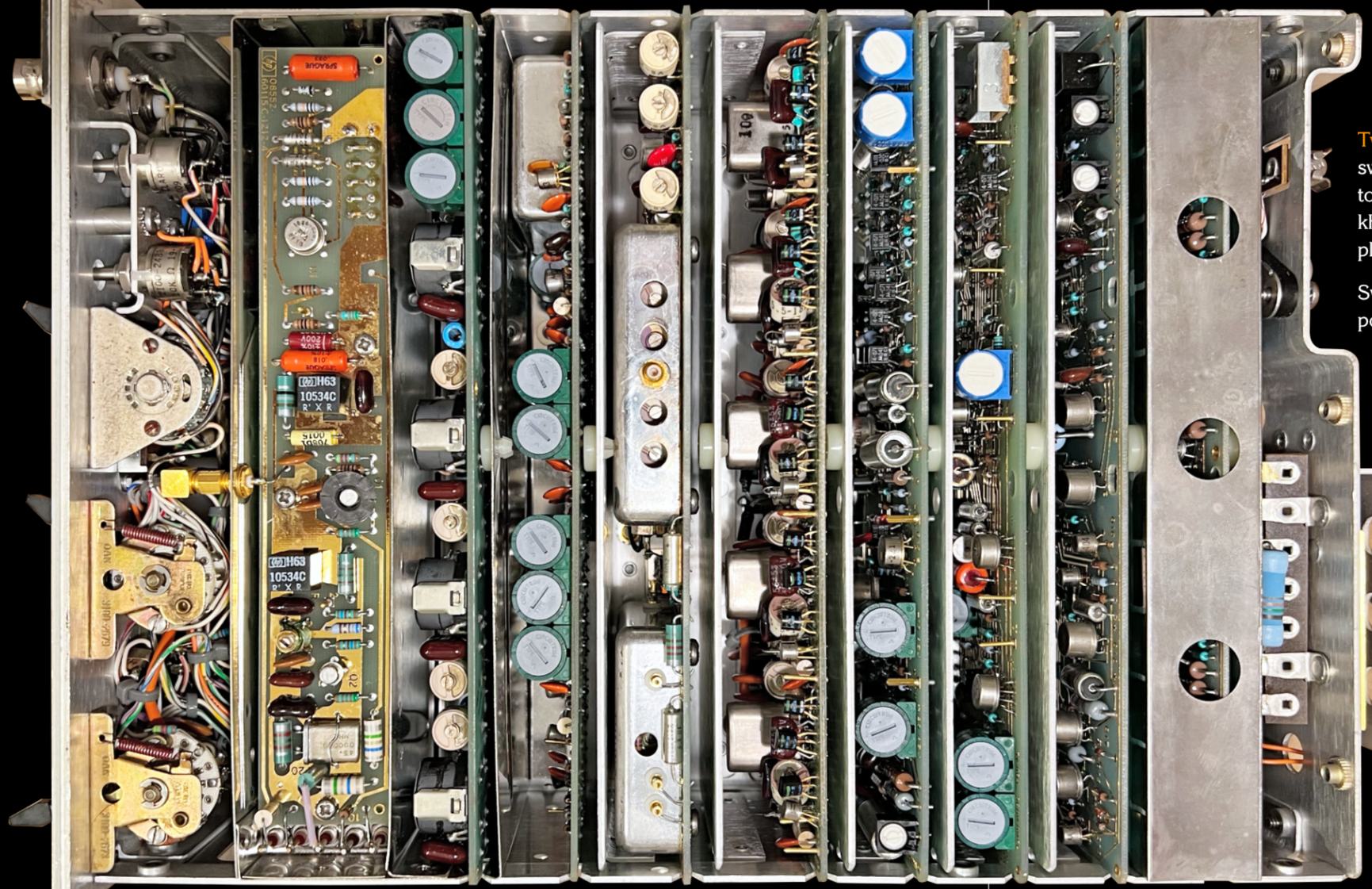
In other words, the output is the sum of the input signal itself and from the eight amplifiers. If no stage limits, the output is linear, but the last stages, receiving the amplified signal from the preceding ones, start soon to limit, reducing the global amplification. The dynamic range is then 8 x 9dB = about 70 dB.

For a linear display, the amplifier is made to operate in a linear mode by increasing the weighting of the output of the sixth stage so that none of the stages limit, even when the output reaches its maximum value. The last two stages are switched out in the linear mode; this maintains the same output signal-to-noise ratio in the linear mode as in the log mode.





8552B IF section



8552B IF section

## Frequency stability issues

High stability and ease of operation were the principal design requirements for the frequency-scan system.

Two sweepable oscillators. There are two local oscillators that can be swept. For scan widths between 10 MHz/div and 50 kHz/div, the 200-to-310-MHz first local oscillator is swept. For scan widths between 20 kHz/div and 0.2 kHz/div, the 47-MHz third local oscillator in the IF plug-in is swept.

Sweeping the 47-MHz third LO for narrow scan widths makes it possible to get better stability by phase-locking the first LO to a very stable fixed-frequency reference.The 200-to-310-MHz first local oscillator (VTO) is a voltage-variable-capacitor-tuned IC oscillator which has good stability and low phase noise (see Fig. 3). It consists of a pi tank circuit, a two-transistor oscillator which has a phase shift of 180° (01 and Q2), and a grounded-base buffer amplifier (Q3). Good stability is achieved by using high-Q elements in the tank circuit and by keeping the loading of the tank circuit to a minimum. Power output is limited by the de collector current in Q2, which serves both as an amplifier and as a limiter.

To take full advantage of the VTO's inherent good stability, noise and drift on the control voltage had to be minimized. This was done by using low-noise operational amplifiers for summing and shaping the control voltage.

The shaping amplifier uses twelve straight-line segments to generate its nonlinear transfer characteristic and gives a voltage-to-frequency characteristic that is typically linear within + 5% or better, even for the narrowest scan widths.

The good stability and low phase noise of the 200-to-310-MHz first local oscillator system makes it possible to use IF bandwidths as narrow as 1 kHz without stabilizing or phase-locking the first LO. After warmup, drift is typically less than 10 kHz in 10 minutes and residual FM is less than 300 Hz peak-to-peak.

Narrow bandwidths. When the IF bandwidth becomes narrower than 1 kHz, the instability of the 200-to-310-MHz first local oscillator becomes apparent. An improvement in the analyzer's stability of better than an order of magnitude can be obtained by phase-locking the first LO to a harmonic of the 100-kHz reference. Phase-locking is accomplished simply by throwing a front panel switch from UNSTABILIZED to STABILIZED. No pre-stabilization adjustment or trace re-centering is necessary.

When the analyzer is switched to STABILIZED, the APC line (Fig. 4) is disconnected from ground, allowing the APC loop to operate. The search network sweeps the VTO until the VTO's frequency reaches some harmonic of 100 kHz. At this point the VTO locks onto the harmonic of the 100-kHz reference and the APC loop becomes stable, disabling the search signal. An error voltage, Ve, which is proportional to how far the VTO frequency had to shift to reach a harmonic of the 100-kH, reference, is established on the APC line. This error voltage is applied to the 47-MHz LO in the IF plug-in. The 47-MHz LO then shifts its frequency the same amount that the VTO shifted to reach a phase-lock point. As a result, there is essentially no change in the location of a trace on the analyzer's screen when the analyzer is switched from UNSTABILIZED to STABILIZED.






The stabilization system operates only for narrow scan widths, when the 47-MHz local oscillator is swept so that the first local oscillator can become a fixed-tuned signal source. For scan widths wider than 20 kHz/div, that is, when the first local oscillator is swept, an override on the scan-width switch prevents any attempted phase-lock of the first LO, regardless of the tuning-stabilizer switch setting. Thus the stabilizer can be left on all the time, and the first local oscillator will automatically go into stabilization when the scan width is switched to 20 kHz/div or narrower. In this sense the stabilization system is fully automatic. The only caution an operator must observe is not to use the first local oscillator's coarse tune for scan widths narrower than 20 kHz/div with the stabilizer on and the first LO phase-locked. If this is done the first LO may jump its lock point to the next higher or next lower harmonic of 100 kHz. Tuning should be done instead with the fine-tune control, which tunes the 47-MHz local oscillator.

## The optional Tracking Generator

Besides its qualities, these instruments offered the possible addition of the ultra-modern 8443A Tracking Generator/Counter, capable to digitally indicate the frequency of any signal that may be displayed on the Spectrum Analyzer CRT; to select a signal the operator simply positions an intensified marker on the desired signal using the marker position control, and the counter displays the marker frequency.

Furthermore, the Tracking Generator and Spectrum Analyzer together formed a swept measurement system since the Tracking Generator output signal exactly tracks the input tuning of the Spectrum Analyzer. In essence it is a sweeper which tracks a receiver. The system could then display the amplitude response of any device placed between the Tracking Generator output and Spectrum Analyzer input. But we will see this 8443B in the next chapter.

# Spectrum analyzers

## Subsection
## 8443A Tracking generator

The ideal complement of the 8553B/8552B Spectrum Analyzer was the Tracking Generator. This has been one of the most hi-tech innovation in those years.

# 8443A tracking generator

The 8443B Tracking Generator and 8443A Tracking Generator/Counter appeared in 1971 in the HP catalog and added a new dimension to the spectrum analyzer making it an extremely versatile, precision, frequency domain measurement system.

By the way: a SA with a Tracking Generator is a wonderful toy, that can help you wasting your time in many way. I will give you some suggestions later in this chapter for this purpose.

## The 8443B (without counter)

The 8443B was a swept signal source whose output frequency tracks the input frequency of the spectrum analyzer. With a swept source, the analyzer could make swept frequency response and return loss measurements on filters, amplifiers, antennas, etc. The combination of a tracking source and selective detector eliminated harmonic and spurious responses from the display allowing a measurement range of more than 120 dB. An



additional result of the analyzer's selectivity is the ability to make swept frequency response measurements in the presence of high level signals or noise.

Because the tracking generator's output was derived by mixing a crystal oscillator with the spectrum analyzer's local oscillators, the 8443 shared the analyzer's stability and flatness, at the time considered excellent. These qualities allowed quick and accurate characterization of high Q devices. In addition to exceptional stability and flatness, absolutely calibrated, continuously variable output made the 8443B useful also as a precision signal generator.

## The 8443A (with counter)

In the 8443A, frequency counter and variable marker capabilities were combined with the sweeper/signal generator capability of the 8443B. Besides all that above, the 8443A had a digital display, something at the time on the top of technology by itself.



The Tracking Generator/Counter provides a marker which can be placed anywhere on the analyzer's display and measures the frequency of that point to seven digits. Making use of the spectrum analyzer's sensitivity and selectivity, the counter can measure the frequency of extremely low level signals even in close proximity to much larger signals. With the 8443A Tracking Generator/ Counter, precision frequency measurement with 10 Hz resolution is brought to spectrum analysis and spectrum surveillance as well as swept frequency response measurements.

The frequency counter and variable marker section could be added to the 8443B Tracking Generator with an easy to install modification kit, the 11663A.

## The Nixies

Nixies have a magic flavor for me and probably for most of you. A Nixie tube or cold cathode display, were among the first electronic devices used for displaying numerals or other information using glow discharge.

The glass tube contains a wire-mesh anode and multiple cathodes, shaped like numerals or other symbols. Applying power to one cathode surrounds it with an orange glow discharge. The tube is filled with a gas at low pressure, usually mostly neon and a small amount of argon, in a Penning mixture. In later Nixies, in order to extend the usable life of the device, a tiny amount of mercury was added to reduce cathode poisoning and sputtering.

Although it resembles a vacuum tube in appearance, its operation does not depend on thermionic emission of electrons from a heated cathode. It is hence a cold-cathode tube (a form of gas-filled tube), and is a variant of the neon lamp. Such tubes rarely exceed 40 °C (104 °F) even under the most severe of operating conditions in a room at ambient temperature. Vacuum fluorescent displays from the same era use completely different technology—they have a heated cathode together with a control grid and shaped phosphor anodes; Nixies have no heater or control grid, typically a single anode (in the form of a wire mesh, not to be confused with a control grid), and shaped bare metal cathodes.

[From Wikipedia - the photo was edited by me from By ScAvenger - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=3159609]

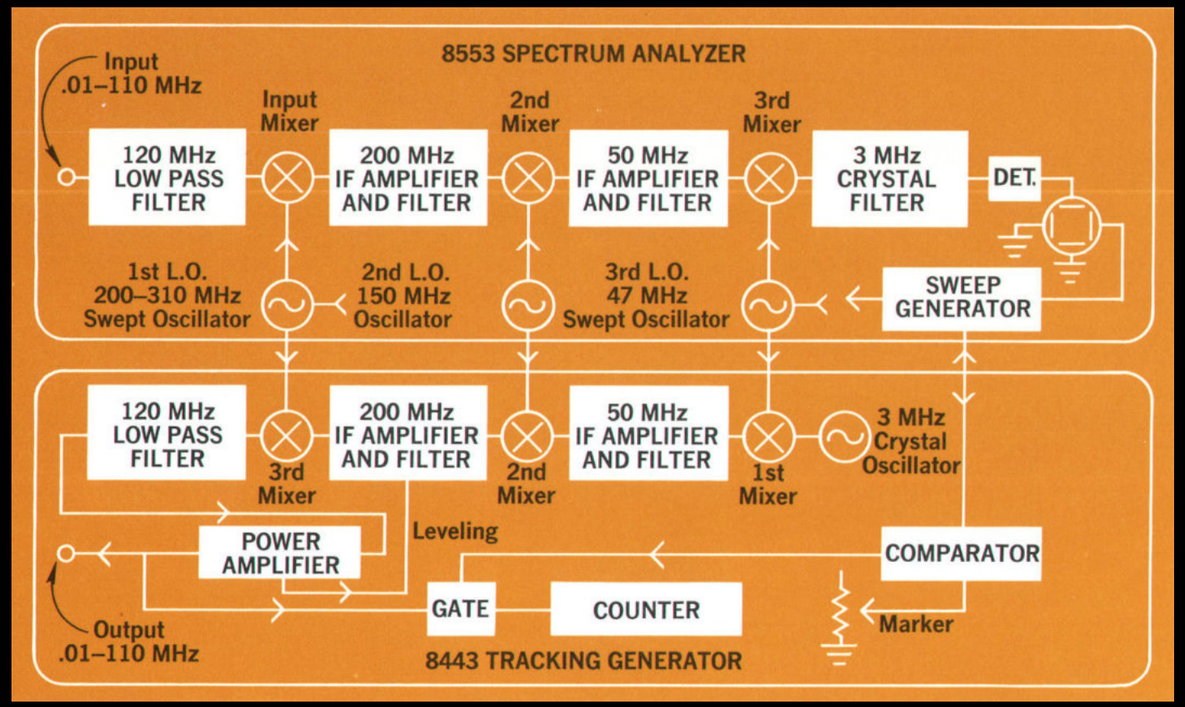
## How does it do?

The counter section of the 8443A measures the frequency of the tracking signal by stopping the Spectrum Analyzer scan at some predetermined point in the scan, counting the frequency, then resuming the scan. When the scan is stopped, an intensified marker appears on the CRT where the scan stopped. The marker can be positioned with the MARKER POSITION control. In this way, the counter is able to measure the frequency of any signal appearing on the Spectrum Analyzer CRT. The MARKER POSITION control can be turned into a manual sweep control, by placing the counter in the SCAN HOLD mode.

## Block diagram

The TG recombines the signals from the SA to produce an output signal which exactly tracks the tuned frequency of the SA. Refer to the block diagram in the picture. We have already described the SA section in the previous chapter, so, with reference to the diagram on next page, we limit here to the TG part:

I own a second 8443A, clearly more recent, where a seven-segment display took the place of Nixies. As you can imagine, I love both but the Nixies… ehm!




- a 3-MHz signal from a crystal oscillator in the TG is mixed with the 47 MHz 3rd LO signal from the SA to produce 50 MHz;
- this 50-MHz signal in turn is up-converted to 200 MHz using the SA 150-MHz 2nd LO signal;
- this 200-MHz signal in turn is mixed with the 200-310 MHz 1st LO to produce the tracking signal;
- the tracking signal is amplified to a level of +10 dBm; that signal is made flat within ±0.5 dB over the frequency range by an automatic level control (ALC) circuit. Various output signal levels can be selected with the output attenuators.

## Output levelling

The Tracking Generator output signal is kept at a constant level by an ALC circuit. Automatic leveling requires either an amplifier with a variable gain or a variable attenuator to adjust the RF level in response to the output detector. Such gain adjustments are simplest at a single frequency, but it is also desirable to have the input signal levels to the mixers remain constant to minimize spurious signals. Therefore, the 200-MHz IF amplifier was designed to have a voltage variable gain, since it operates at essentially a single frequency and it is the last element before the broadband third mixer. The gain is adjusted by placing a voltage tunable notch or trap between amplifier stages. As the ALC feedback voltage is increased, the center frequency of the notch moves closer to 200 MHz, increasing the attenuation of the signal. This type of gain-adjusting element gives a range of more than 30 dB with a minimum of components.





## Thin-film microcircuit

A Thin-film microcircuit technology met the need for flat, high-gain output amplifiers. A high-gain amplifier is required to give a high, level output, since the output of the third mixer is made low in level to minimize spurious signals. Flat frequency response is easier to achieve with a thin-film circuit because of its relative freedom from parasitic inductive and capacitive effects. Placing the detector on the thin-film circuit very close to the 500 thin-film output resistor promotes the achievement of good VSWR characteristics in the leveled output. Microcircuit techniques are also advantageous because of the excellent heat sinking that is obtained by putting the active device directly on the sapphire substrate.

## Counter Section

The 8443A marker control circuit stops the scan ramp generator in the 8552 IF Section during a part of each sweep cycle and counts the 8443A output frequency during the period when the scan is stopped and the frequency is fixed.

Because the scan is stopped at the same point on each sweep, the CRT beam is directed at the same point on the CRT for a large percentage of the scan time, causing an intensified spot at that point. This spot is an easily recognizable marker, and its position corresponds precisely to the frequency measured by the counter. By use of a continuously variable MARKER POSITION control, the operator can locate the marker on any point of the swept frequency display.

# Ex uno discere omnes

In Italy, when I was a boy, it was mandatory to study Latin, and that was the most important subject in the school. The above statement, that if I correctly remember was from Virgilio, means “from one, learn to know all the others”. That is also true for the 8443.

## A scheme widely used by HP

In fact, the 8443 follows ideas and general construction schemes, that we find in other HP RF instruments as well. So we take this opportunity to analyze them more in details.

## Design goals

Like for the other instruments, the primary objectives of the product design of the 8443A were:

- to build an instrument that can be efficiently manufactured;
- to shield it effectively against RF leakage;
- to make it easy to test, troubleshoot and repair.

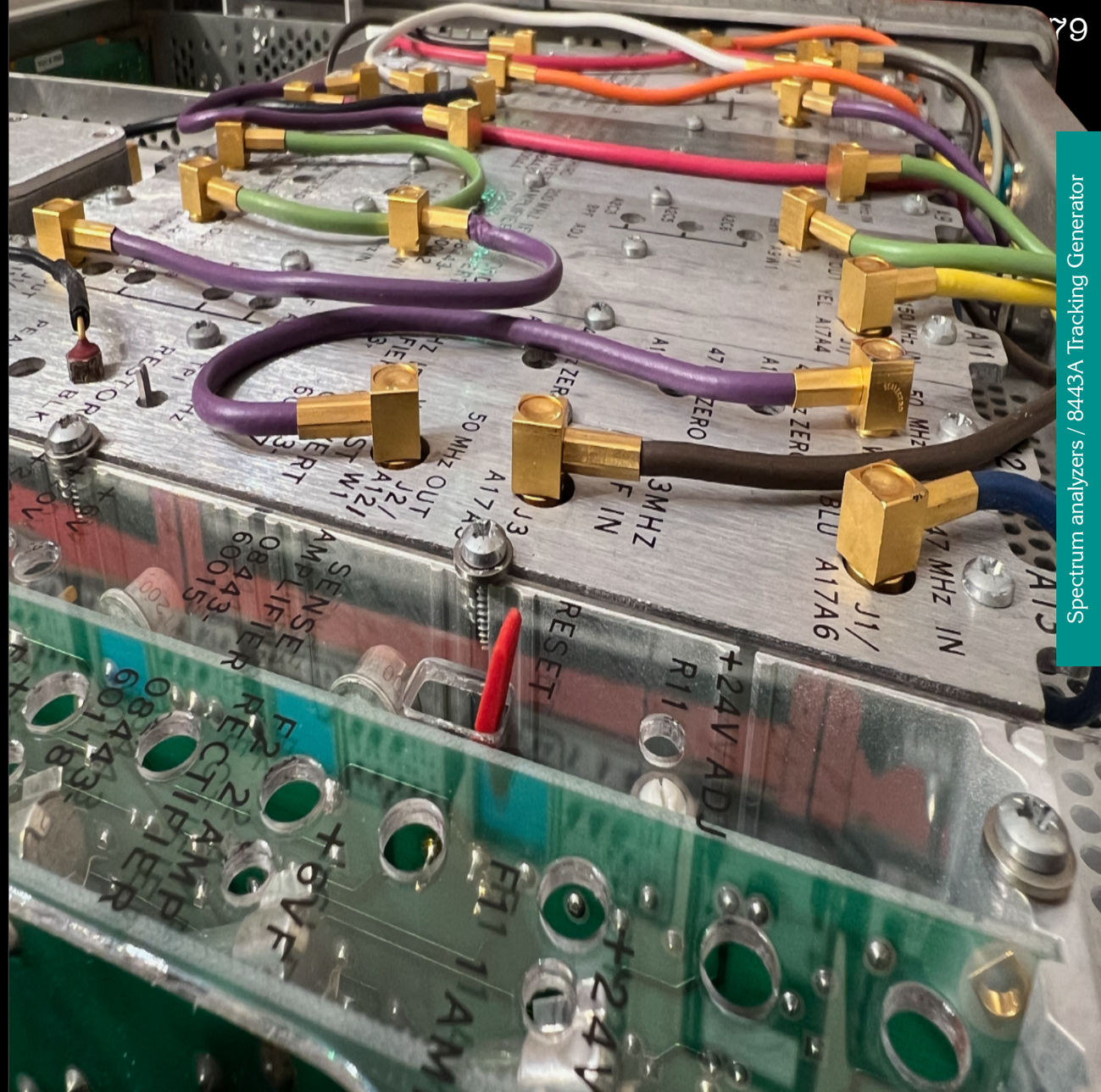
Furthermore, the 8443 was supposed to be aesthetically compatible with the 8552/8553 Spectrum Analyzer.

## Modularity

Most of the requirements could eventually be translated in the word “modularity”.

As we are going to see, modules are interconnected by means of a motherboard for the “cold” signals (like the power supply) and shielded cables terminated by SMA or SMB connectors (see about them later in this document).





# The mother board

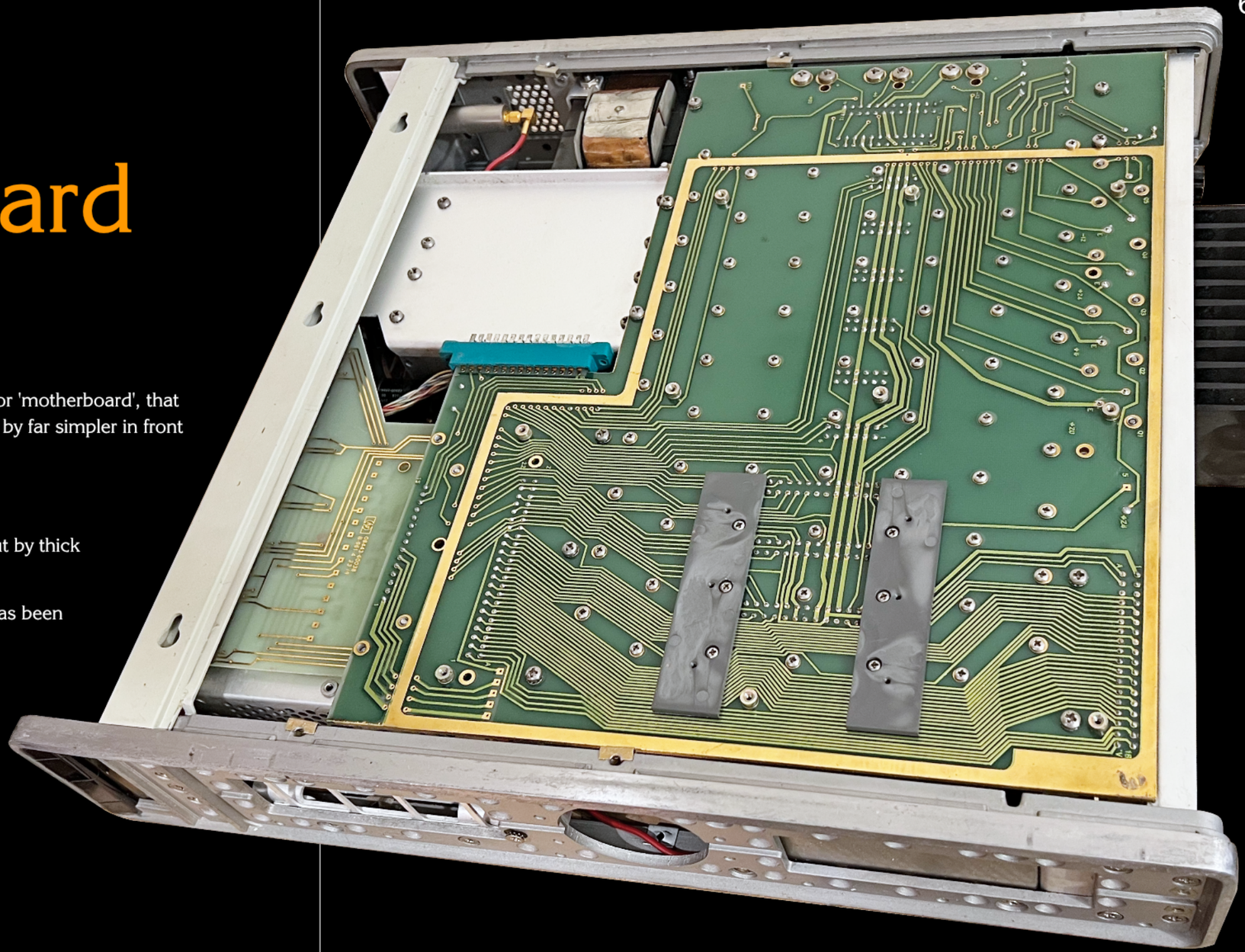
## A tiny bus interconnection

Essentially, the entire instrument is assembled onto the main circuit board or 'motherboard', that carries a little interconnecting bus, possible in an essentially analog design, by far simpler in front of the buses that we are used to see in digital equipment.

## Shielding

Everything in the 8443 is heavily shielded, not by a thin metallized sheet, but by thick aluminum or iron sheets.

In the picture, the motherboard bottom side, were the heavy metal shield has been removed for the photo.

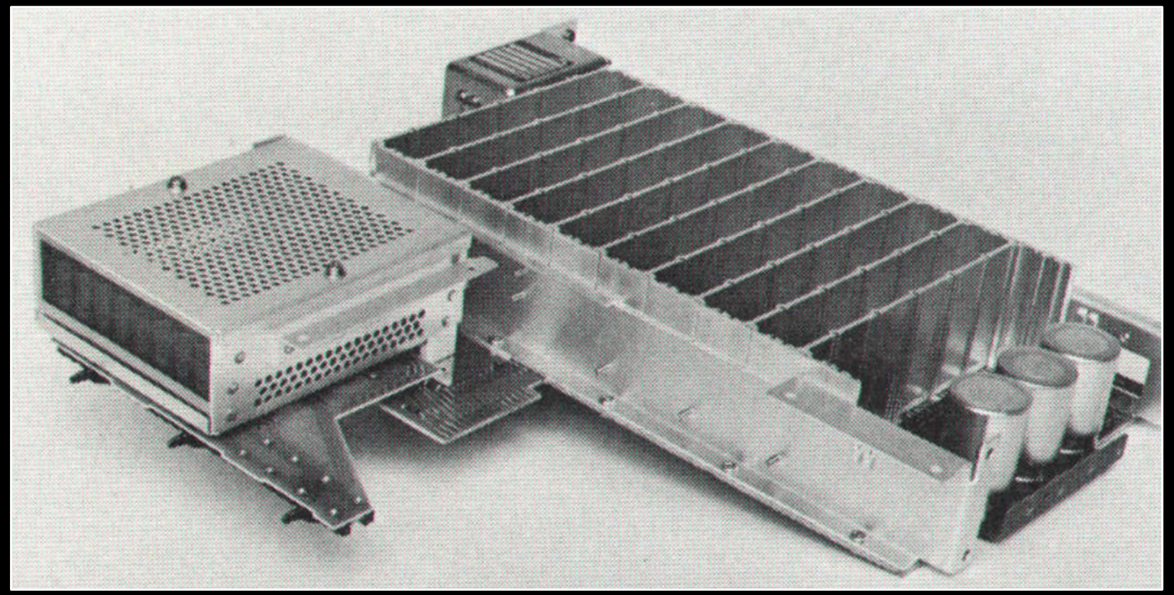


# Pockets, slots or drawers?

Beautiful aluminum extrusion are used to create segregated spaces for each electronic board Interlocking aluminum extrusion 'pockets' are mounted directly to the board (I would name them “slots” or “drawers”, but the meaning is the same).

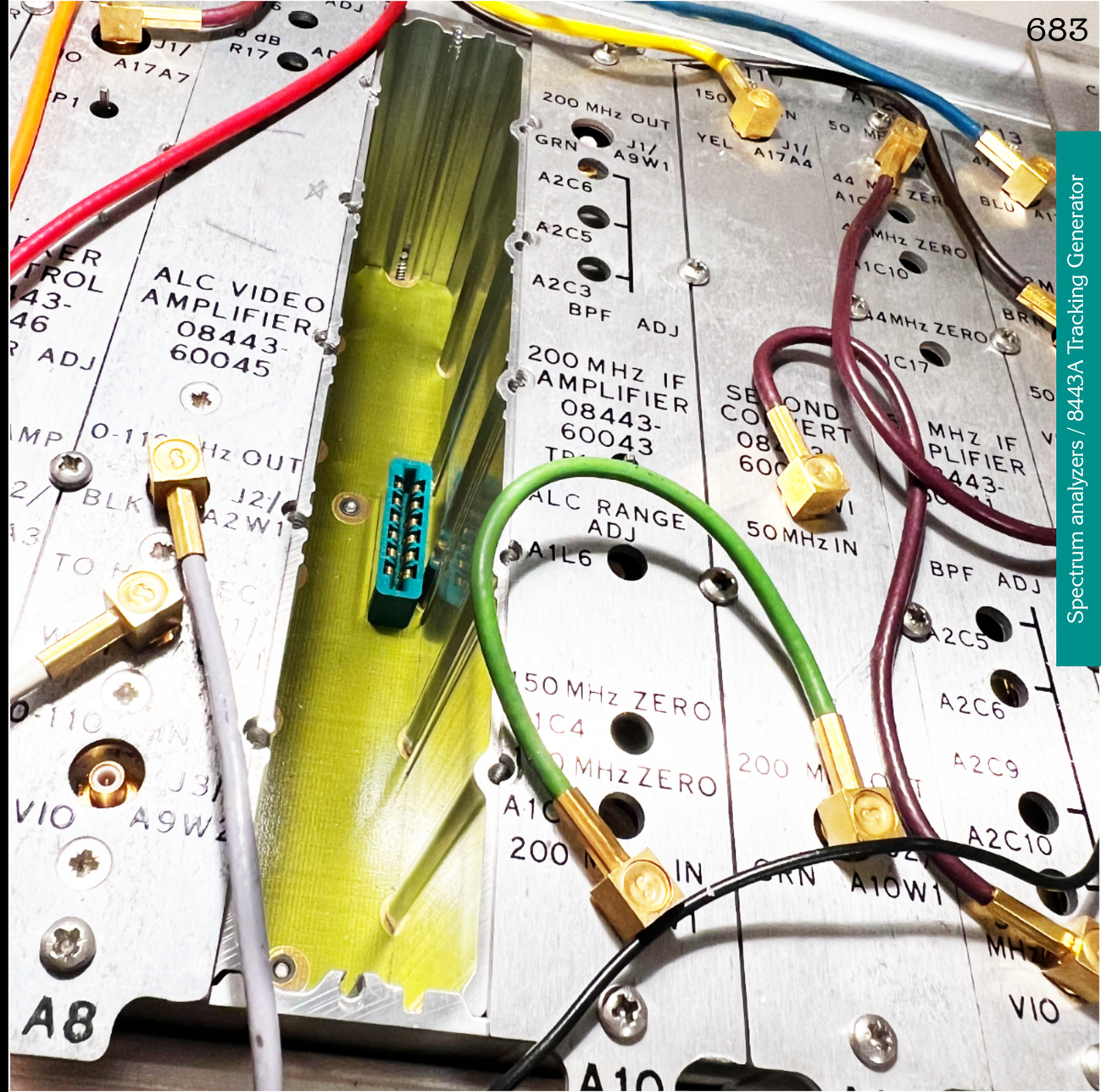
The major board assemblies plug into these pockets and become individually sealed modules. The front panel switch board assembly and the counter box also plug directly into the motherboard.

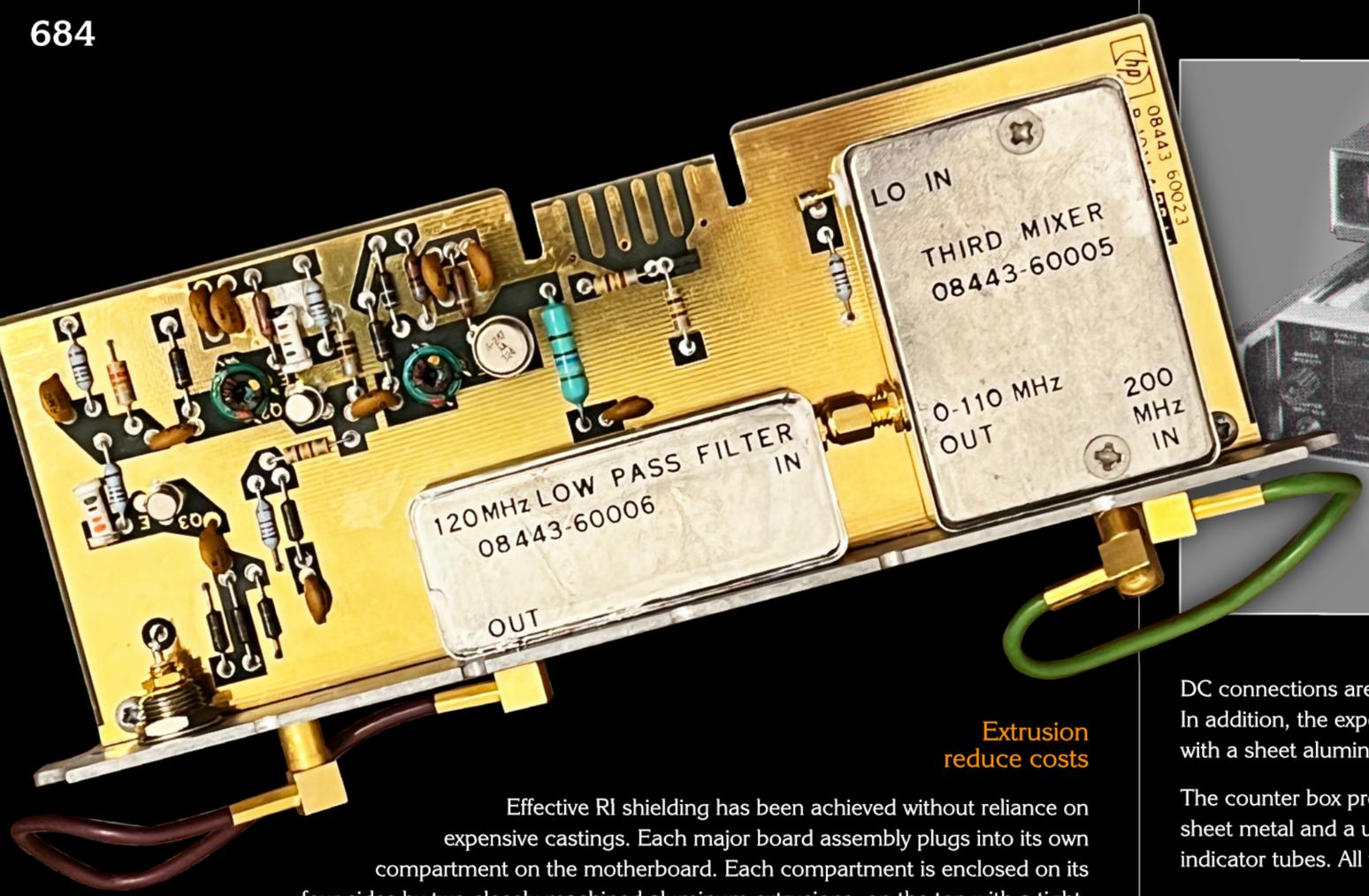
The only hand wiring in the instrument is for the potentiometers on the front panel and the primary and secondary transformer windings.







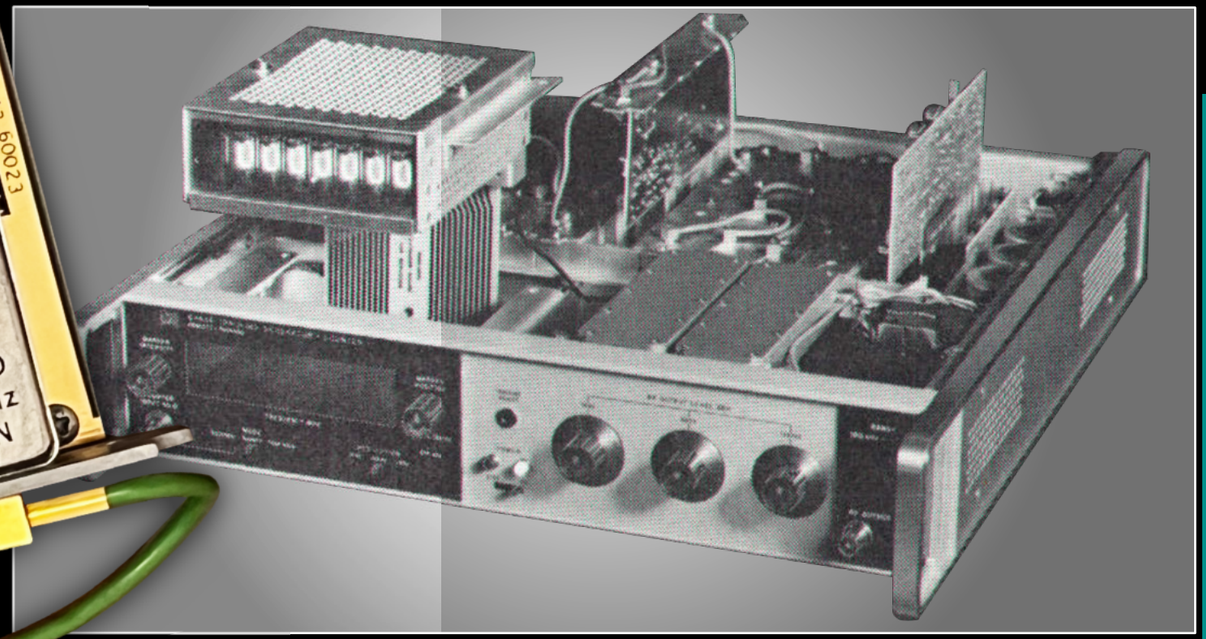





## Extrusion reduce costs

Effective RI shielding has been achieved without reliance on expensive castings. Each major board assembly plugs into its own compartment on the motherboard. Each compartment is enclosed on its four sides by two closely-machined aluminum extrusions, on the top with a tight-fitting cast aluminum cover, and on the bottom by the ground plane on the motherboard.

In some cases where high RF attenuation is required, critical circuits have been installed in additional shielding cans inside their compartments. High-level RF signals are carried between modules in double-shielded coaxial cable.



DC connections are made through the motherboard through small circular holes in the ground plane. In addition, the exposed leads and connector pins on the bottom side of the motherboard are shielded with a sheet aluminum cover.

The counter box provides RF shielding of the low-frequency counter circuitry using overlapping riveted sheet metal and a unique metal etched screen in front to attenuate the RF radiating from the numeric indicator tubes. All this results in a unit well shielded against RI susceptibility and radiation.

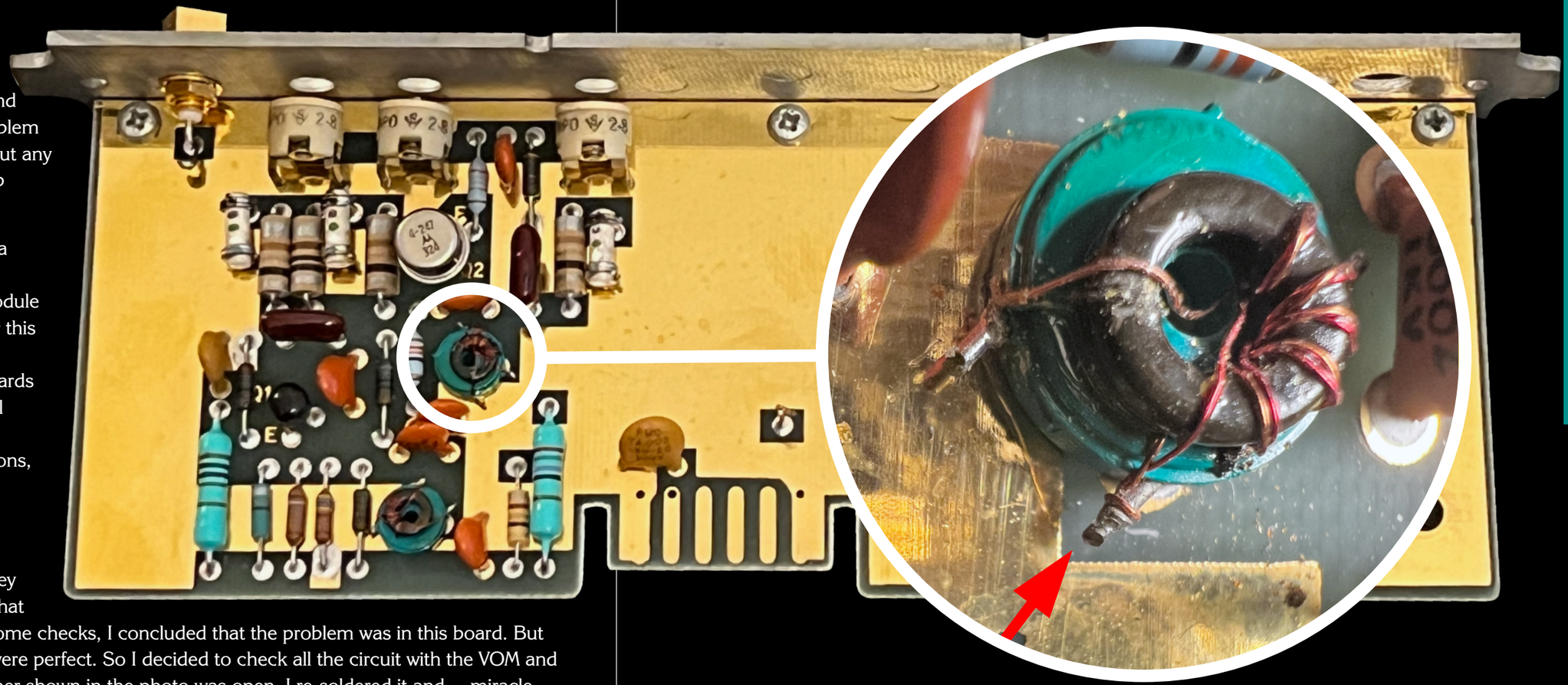
## Look and feel

Compatibility with the 8552/8553 Spectrum Analyzer has been accomplished by using the same panel color arrangement, similar panel trim and matching recessed dials for attenuation readout.

# Serviceability

To achieve good serviceability all circuits are modularized and arranged in logical order in agreement with the instrument block diagram. Test points and signal paths are accessible so that a problem can be isolated to a single module without any disassembly other than removing the top cover.

Then, with the removal of a few screws, a faulty module can easily be unplugged, removed and replaced. A fast factory module exchange program is being instituted for this product. Isolating problems below the module level is also simple. Extender boards are the only tools necessary to expose all circuit boards including the counter, for troubleshooting under operating conditions, as shown at right, below.



## Repairing

I had the opportunity to understand if they were telling the truth. The second unit, that with the Nixies, was not working. After some checks, I concluded that the problem was in this board. But everything was OK, even the transistor were perfect. So I decided to check all the circuit with the VOM and discovered that one end of the transformer shown in the photo was open. I re-soldered it and… miracle, the fault was gone!

# More repairs

## Recovering from a shock

I have a second, spare 8553B, which has suffered some violent shock. Obviously I wished to repair it.

The first point has been to dismount the front panel, less trivial than it seems. Then I invented the trick you see in the photo to straighten the frame, before straightening the panel itself.

## Tracking adjustment

One of the most critical components in the RF portion of the 8443A is the 3-MHz crystal oscillator. If the TG output signal is to track the Spectrum Analyzer accurately, the 3-MHz oscillator's frequency must match the center frequency of the 3-MHz IF crystal filters within a few hertz. The oscillator was designed around the same crystal that is used in the IF filters to minimize tracking errors from thermal drifts; in consequence, the crystals in both instruments drift in the same direction at approximately the same rate.

To permit an adjustment of approximately ±150 Hz about the center frequency of the crystal, the 3-MHz oscillator has a variable capacitor TRACKING ADJUST, accessible from the front panel. To tune it, do as follows (8443 manual, page 3.3):

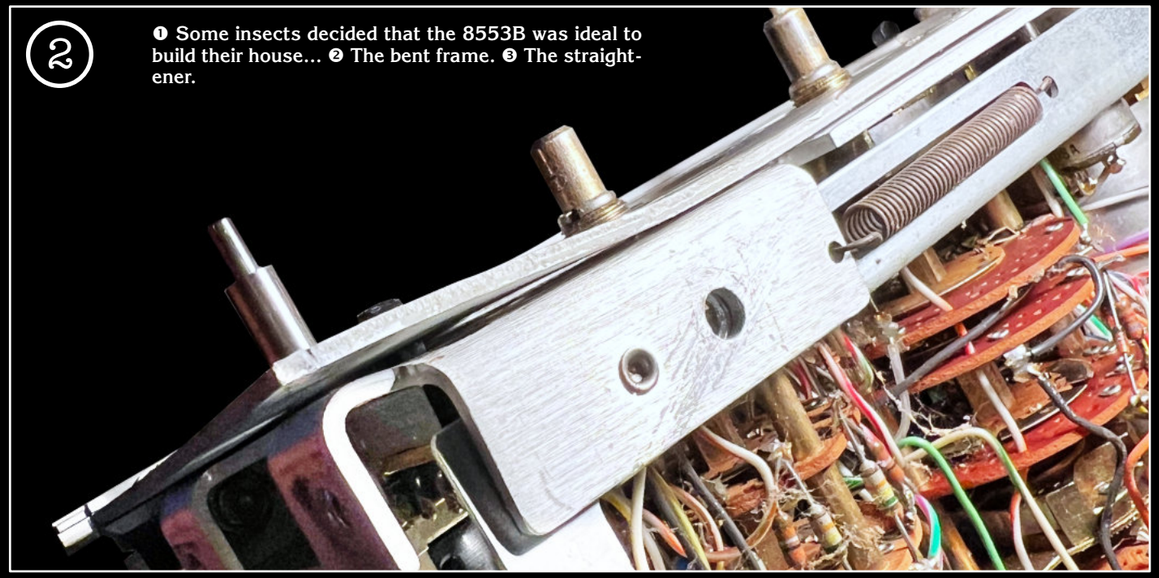
- connect the model 8443A RF OUTPUT to the analyzer RF INPUT;
- place the MODE switch in the MARKER position and the RESOLUTION switch in the 1 kHz position.
- tune the analyzer to a frequency below 10 MHz;
- set the model 8443A RF OUTPUT LEVEL to -30 dBm;
- set the 8553 to ZERO scan at the narrowest bandwidth;
- set the 8552 to the LINEAR mode at 1 mV/ Div;
- Adjust the 8443A TRACKING ADJUST for maximum vertical deflection on the analyzer CRT.

This assures that the 3 MHz oscillator in the 8443A first converter is tracking the 3 MHz IF frequency of the 8552.

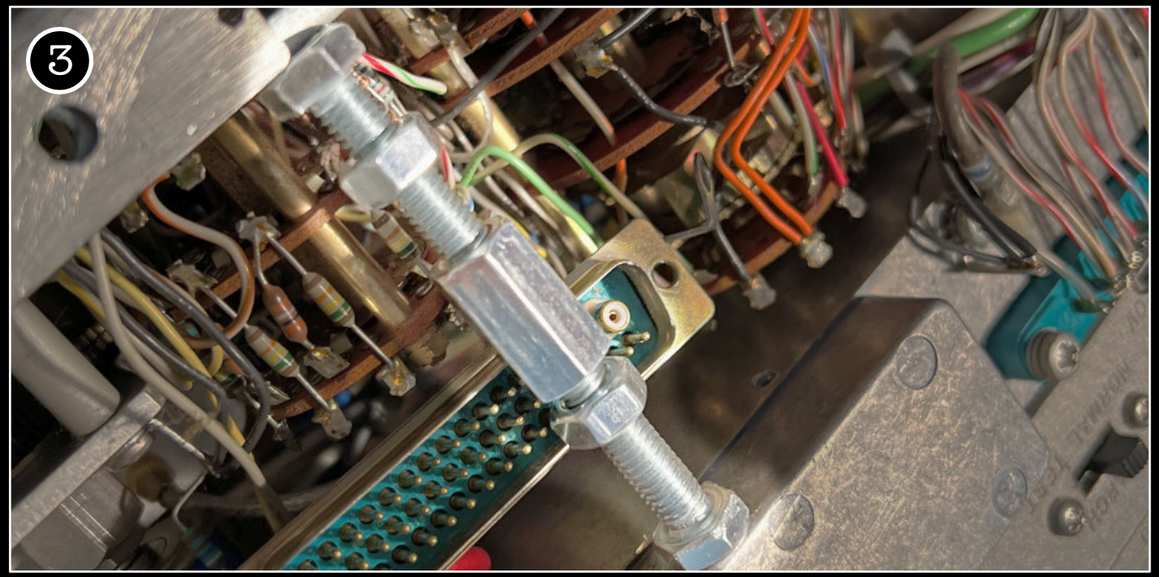


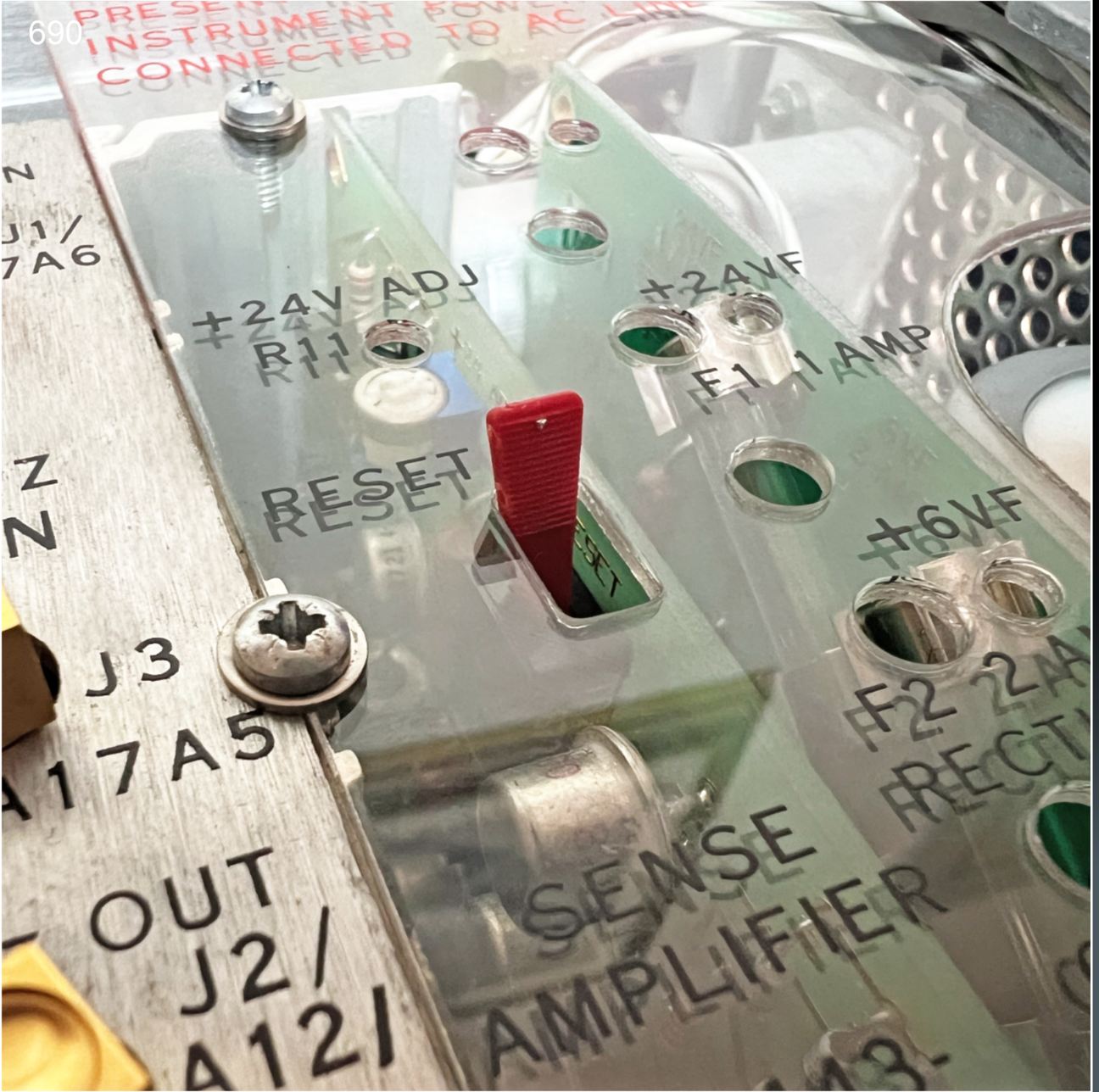





❶ Some insects decided that the 8553B was ideal to build their house... ❷ The bent frame. ❸ The straightener.








# More Faults

Pages added on July 3 2024



## They Are Old, it May Happen…

When writing about the HP 180 Oscilloscope Series, I took the opportunity to use again the 141T with the Seven-Segment 8443A Tracking Generator, but …horror! It no longer works. When I switch it on, never happens.

I think of the most common things, but not, the problem is real. I discover that sometimes it starts, but just for one second. No way, I must open it and try a repair.

When they are old, it may happen that something goes wrong…

## Starting the Investigation

When I open the box,  I note that there is a small lever named RESET (photo on the left). It tempts me… I press it and… the 8443A magically starts. After a variable time, however it stops again.

Fearing the most terrible causes, like an intermittent overload in some unknown part of the circuit, I begin studying the manual. I have two editions of them, both are rather unclear. In one of them, they neither describe the RESET lever.

Anyway, I see that the power supply is not too complex. Yes, I might fix it…

## Electronics for Pigs?

I understand that this small lever is used to reset a circuit said crowbar, which protects the equipment from overvoltages. I never heard of it, so I had to search it on the Internet, discovering that is known and described.

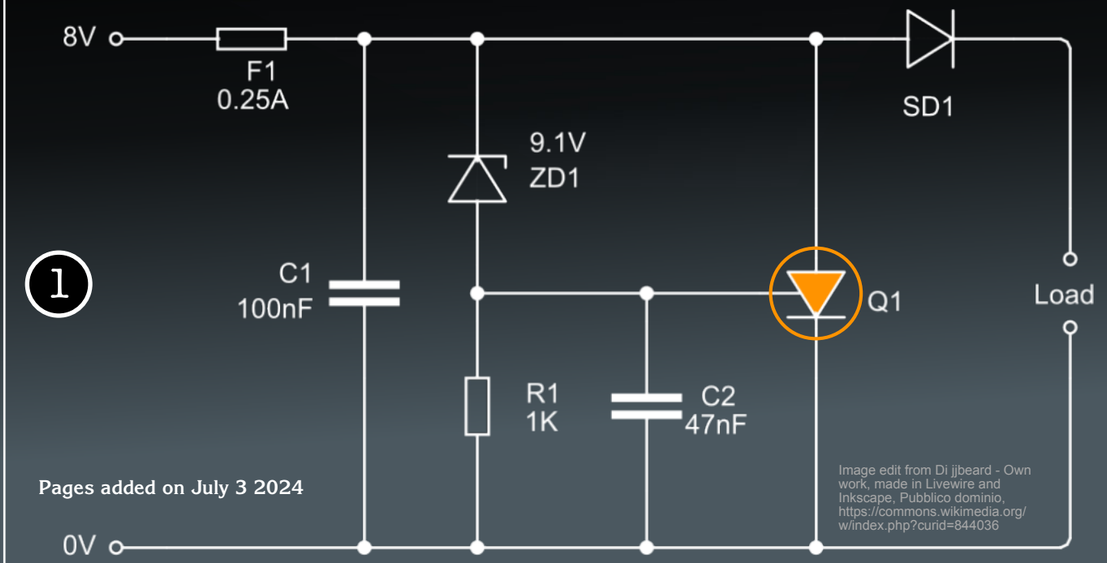
Seeing it, I also remembered that I had already met it before, but I didn't know its name. See the next page for few details.

# The Crowbar Circuit & the Pigs

A crowbar circuit is an electrical circuit used for preventing an overvoltage or surge condition of a power supply unit from damaging the powered circuits (load). It operates by putting a short circuit or low resistance path across the voltage output, like dropping a crowbar across the output terminals of the power supply. Very often, it is implemented by mean of an SCR, activated by mean of a zener diode to detect the overvoltage condition.

The literal Italian translation is *Piè di Porco* (Pig's Foot), i.e. *an iron bar with a flattened end, used as a lever*, often by thieves and burglars.



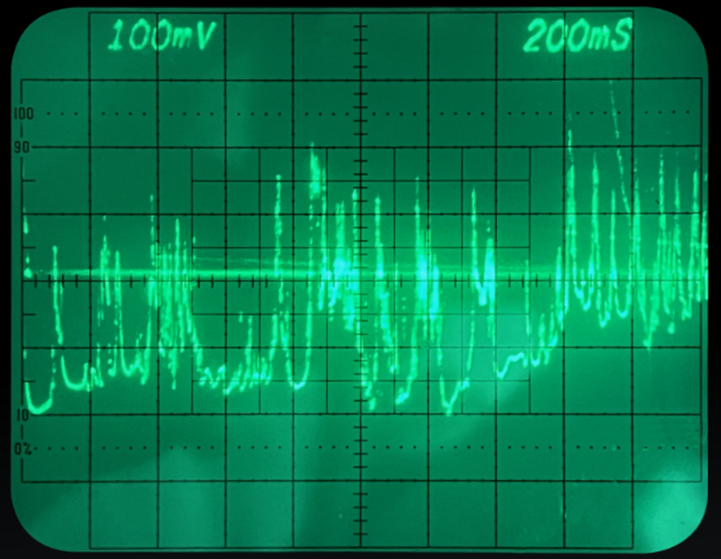



❶

Pages added on July 3 2024

Image edit from Di jjbeard - Own work, made in Livewire and Inkscape, Pubblico dominio, https://commons.wikimedia.org/w/index.php?curid=844036






**❶ The crowbar circuit (from Wikipedia). ❷ The recapped 8443A. ❸ The original capacitors are bigger but nicer. In the end, I reset them in place, as explained in the text.**



## The Mysterious Noise

Considering that the protection is triggered by an overvoltage, the problem shouldn't be an overload by some circuit. But what else?

I start checking the +24V; it is almost correct in value, but I note that it is affected by a random noise which which manifests itself as rather short over/under voltages of about 2V (photo 2). I am rather sure that this is the cause which triggers the crowbar.

## Preconceptions

In these cases, for me the most usual suspects are the big filter capacitors, so I decide to check them, but they seem to be good. Nevertheless, I replace them with new ones. It is rather easy with the 8443A, because they are very accessible and have bug screws; there are no difficulties soldering new modern and smaller capacitors in their places

As expected, nothing changes [*eventually I will restore the originals, see below*].

## Stand-by Mode

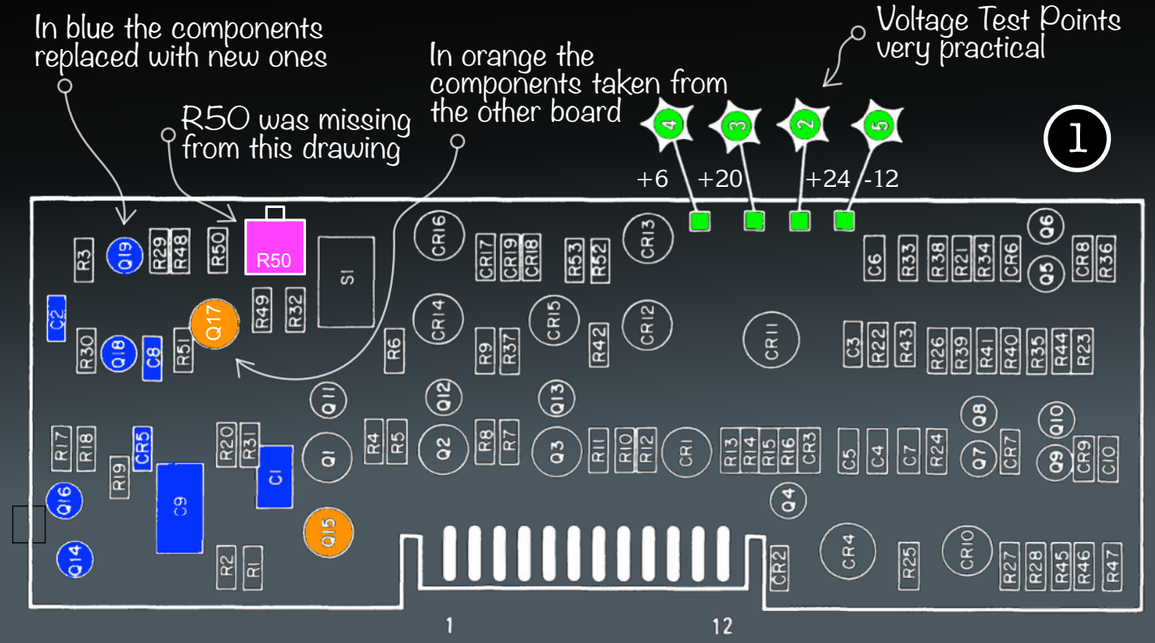
The 8443A, like many other HP instruments, has the hated Stand-by Mode. This means that when you think "I switched it off", that's not true, and the equipment remains instead partially on, in this case to keep powered the oven of the frequency reference oscillator. Differently from others, this 8443A warns you with a panel light, to signal that it is not really off. However, this feature does not solve the problem of having an external switch to really power on and off the tracking generator.

Studying the circuit, I realize that in stand-by mode, only the +24V remains active; all the other voltages are switched off.

The problem appears also in stand-by mode, and this allows to exclude most of the other circuitry as a possible cause.

## The A14 Board

Then I move to the A14 Sense Amplifier Board, which somewhere else is named Low-Voltage Regulator, and focus only on the +24 section. I am lucky, because I have two of them, one from this



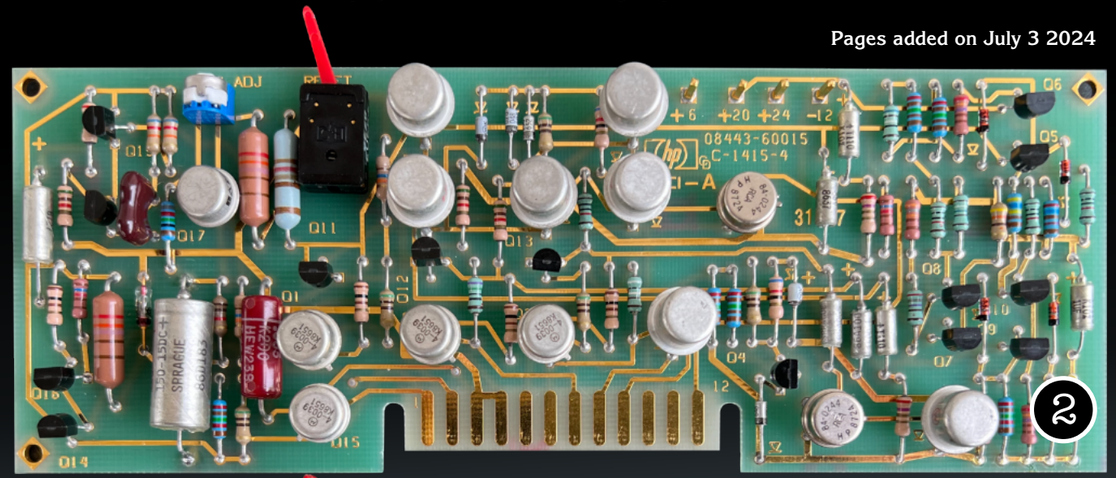


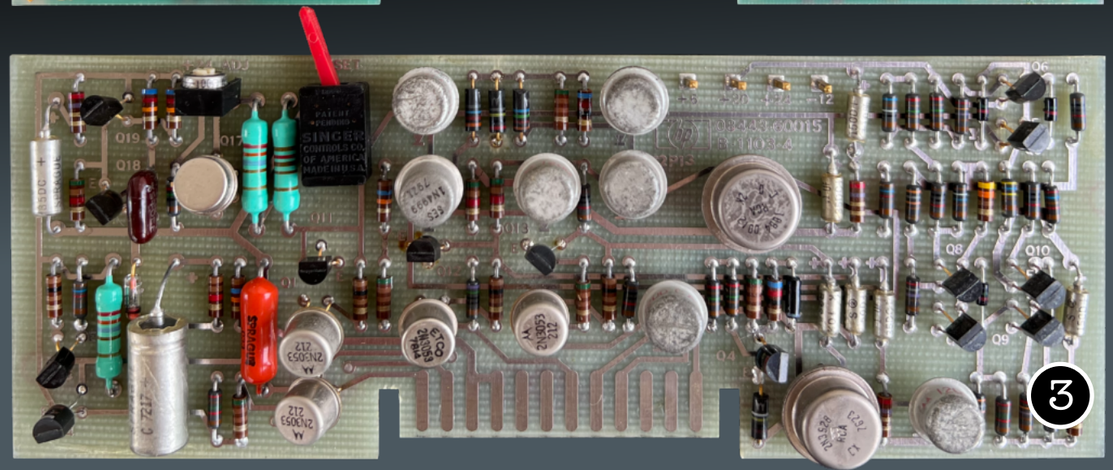

8443A, the one with the seven segment display, and the other from the older 8443A, that with the Nixies. Unexpectedly: the second board works perfectly, with no noise. This makes my job much easier: the problem is definitely in the A14 board.

Here starts a long session with few results. Exasperated I replace all the interested capacitors, the

❶ A14 Sense Amplifier Board component layout. ❷ The A14 board we are talking about. ❸ Another A14 board from the older 8443A, the one with Nixie display. Note the evolution to a gold-plated PCB.

Pages added on July 3 2024



1854-0071 transistors (with 2N3904), the Zener diode CR5 and swap with the other board Q15 and Q17. Nothing to do, the problem remains. I check all the resistors values: the bad board (newer) gives much more precise readings. Nevertheless, the problem remains.

In this work, I used a printed copy of the layout, marking all the progressively checked components. But I note that on the manual's layout, R50 is missing. So I didn't check it! Do you want to see that... yes, it should be 100 ohm and is 2.7 k! I replace it and the board works perfectly now.

## Italian Proverbs

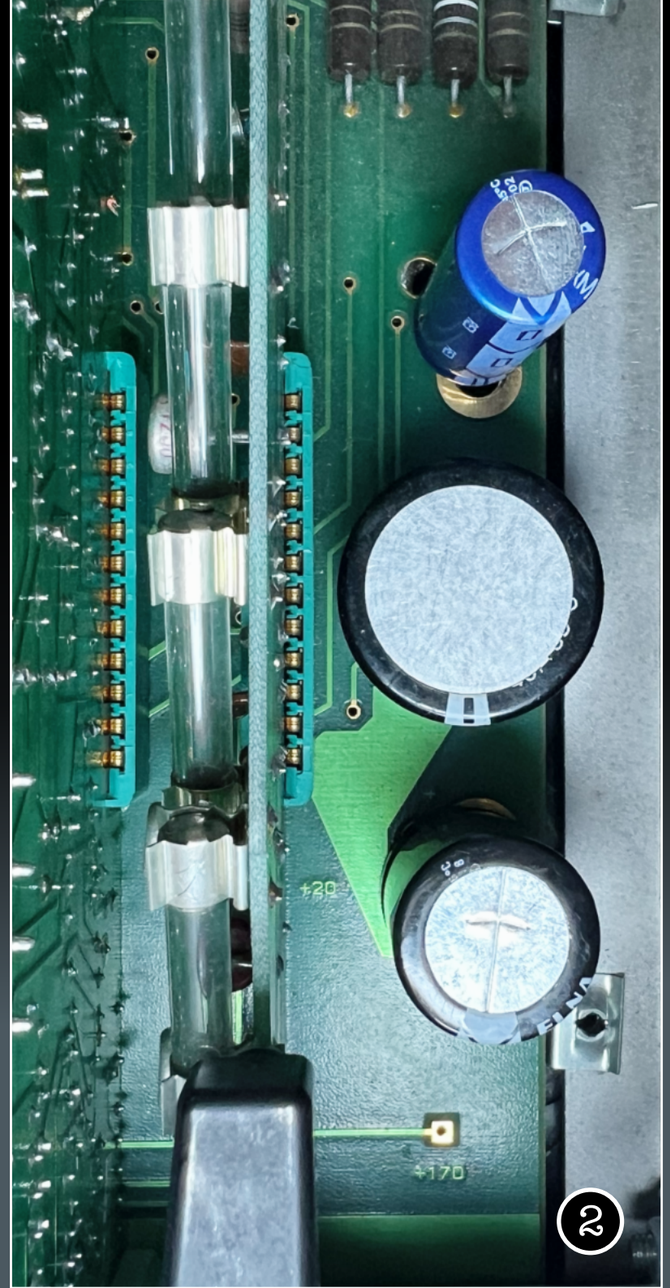
Eventually, considered that the old capacitors were good, I reset them in place. In Italy we say that *the eye also wants its part*. It means that the look is important as well, not just the functionality.

I like to keep the equipment as original as possible, so I reset in place most of the replaced components. No reason to change them, if they are good, and the new capacitors are not so attractive as the old ones.

**❶ The +24V connection pin on the crystal oscillator oven module. It uses a discrete amount of current, keep it clean from oxide (see also next page). ❷ The oven module with the connector that caused the problem (circled in red).**



Pages added on July 3 2024





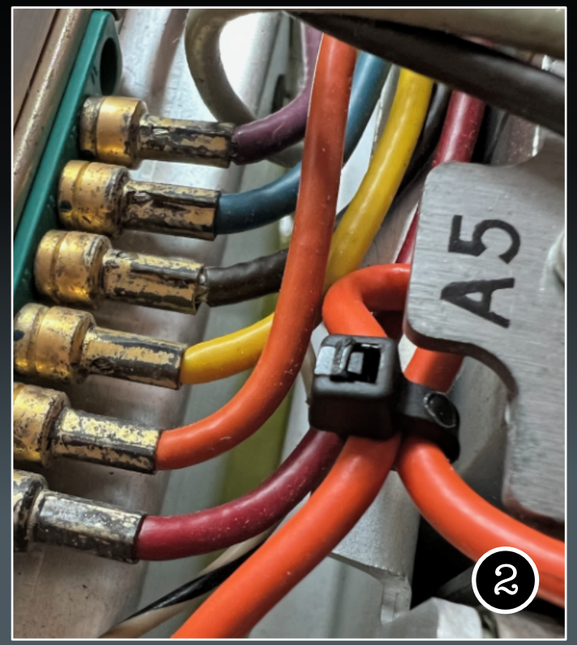

## Me Too!

My other 8442A, the Nixie Guy, was jealous of Seven Segment, and, seeking for my attention, started having an erratic behavior. It worked correctly when used as a normal digital frequency meter, but said “00000” when used with the 141T. In addition, sometimes it showed a wrong reading, lower than expected.

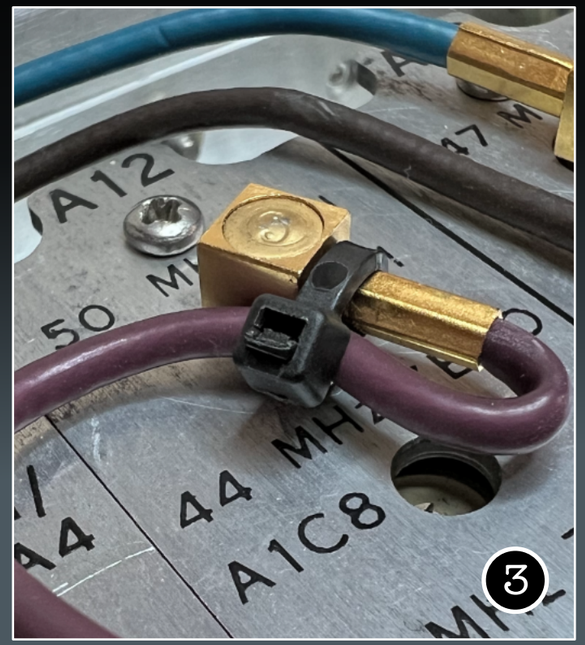
Again I feared something terrible, but it was just throwing a tantrum. I soon discovered that the problem was in the coaxial cables that link the various boards inside the equipment.

The best solution would be replacing all the cable, but it was too difficult for me, even if I had the connectors. A simple solution is to find the position where they work and fix theme in that position by using a cable tie, as shown in the photos. Not elegant, but it works.

❶ The +24V connection pin on the oven module (circled in red).
❷ and ❸ How I fixed the coaxial cable problem using cable ties.



2

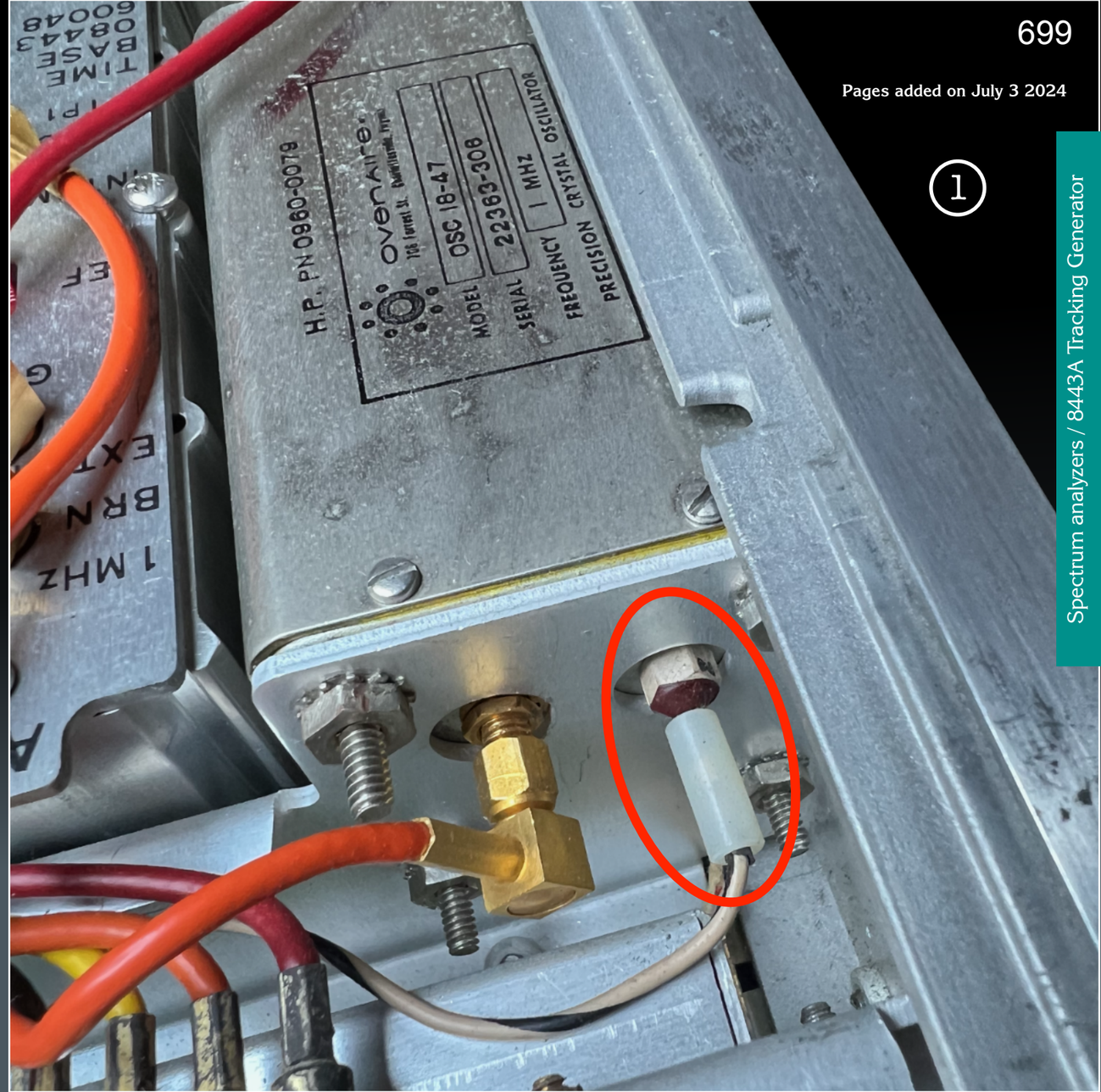


3



Pages added on July 3 2024





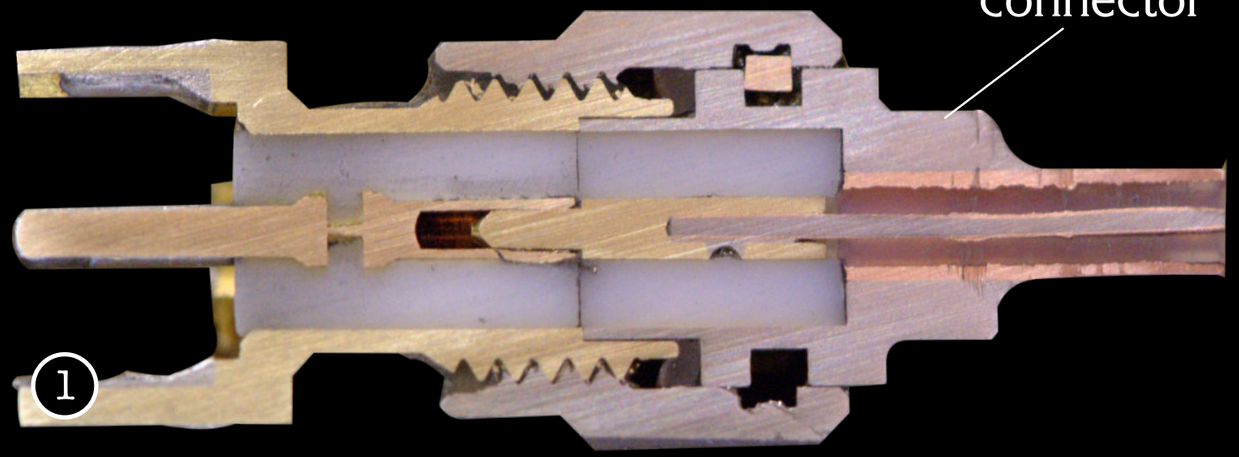
1

# SMA Connectors

In these wonderful instruments there are a lot of gold plated RF connectors. There is often some confusion about them, and it's easy to find conflicting definitions. I thought then it could be useful trying to clarify the various types. The "source of law" is the MIL-STD-348 military standard "PERFORMANCE SPECIFICATION FOR RADIO FREQUENCY COAXIAL, TRIAXIAL, AND TWIN-AXIAL CONNECTORS AND INTERFACES". I refer here to rev. B, February 9, 2009.

**SMA connectors** (SubMiniature version A) are semi-precision, 50 Ω impedance, 12 GHz, coaxial RF connectors developed in the 1960s for coaxial cable and have a screw-type coupling mechanism. They are probably the most common today, even on many modern RF modules, such as GPSs, Wi-Fi, Bluetooth, mobile data network modems etc.

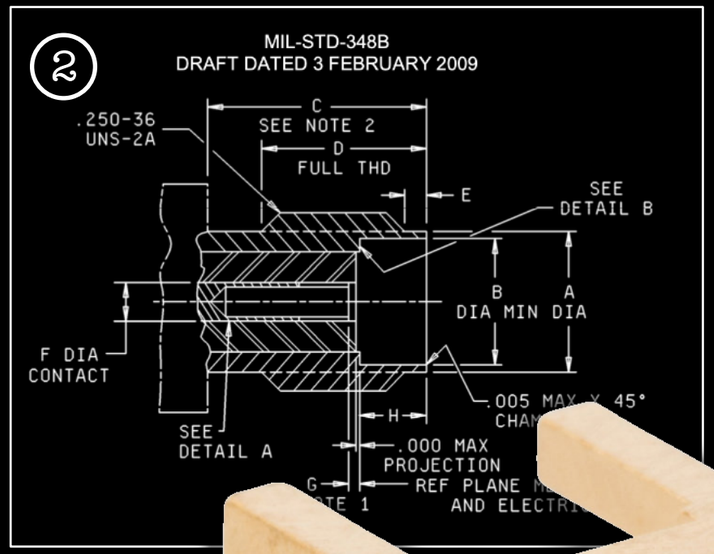
❶ SMA male/female connectors section. This beautiful photo is an editing by me of the original photo from Wikipedia (by TubeTimeUS - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=78637483)
❷ SMA female connector mechanical drawing.
❸ SMA female connector dimensions.
❹ SMA female connectors.




1



2




| Dim. Ltr. | Inches (mm) | |
|---|---|---|
| | Min. | Max. |
| A | .208 (5.28) | .216 (5.49) |
| B | .1810 (4.60) | -------- |
| C | .218 (5.54) | -------- |
| D | .170 (4.32) | -------- |
| E | .015 (0.38) | .045 (1.14 |
| F | .049 (1.24) | .051 (1.30 |
| G | .000 (0.00) | .010 (0.25 |
| H | .074 (1.88) | .078 (1.98 |
| J | .043 (1.09) | .047 (1.19 |
| K | .000 (0.00) | .010 (0.25 |
| L | .0355 (0.90) | .0370 (0.9 |
| M | .105 (2.67) | -------- |
| | .168 (4.27) | ---- |

3

4



SMA female connector

# SMB Connectors

**SMB connectors** (SubMiniature version B) are semi-precision, 50 Ω impedance, 12 GHz, coaxial RF connectors developed in the 1960s for coaxial cable. They feature a snap-on coupling and are available in either 50 Ω or 75 Ω impedance. They offer excellent electrical performance from DC to 4 GHz (from Wikipedia).

❶ SMB male connector from HP 8568B display module.
❷ SMB female connector.
❸ A very special RT connector that links the 8443A Tracking Generator to the 8553B/8552B Spectrum Analyzer







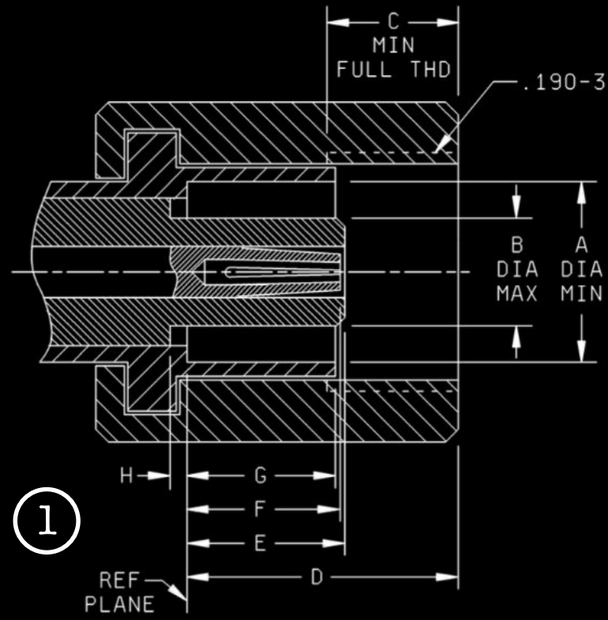

SMB female
connector



# SMC Connectors

**SMC connectors** (SubMiniature version C) are screw-on connectors that operate up to 10 GHz. These connectors are a threaded version of snap-on SMB connectors but different from the SMA that we have already seen above. This screw-on mechanism permits a vibration-proof connection suitable for semi-permanent connections and for use in mobile equipment with low VSWR requirements.

❶ SMC female connector mechanical drawing.
❷ SMC female connector dimensions.
❸ SMC male and female connectors. The photo is by DH4YM, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=11396323.



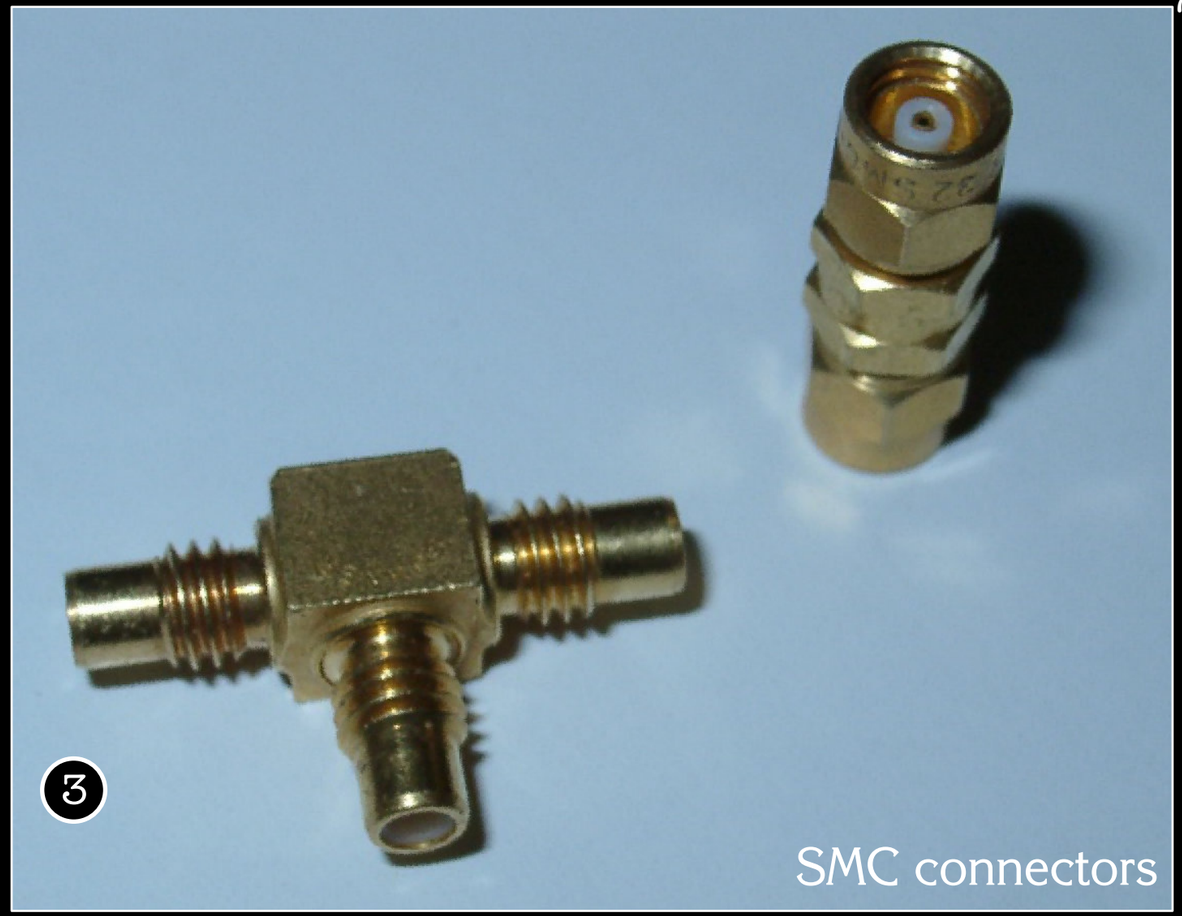

2

| Dim. Ltr. | Inches (mm) | |
|---|---|---|
| | Min. | Max. |
| A | .147 (3.73) | -------- |
| B | -------- | .081 (2.06) |
| C | .110 (2.79) | -------- |
| D | -------- | .233 (5.92) |
| E | -------- | .134 (3.40) |
| F | -------- | .134 (3.40) |
| G | -------- | .122 (3.10) |
| H | .000 (0.00) | -------- |
| J | .110 (2.79) | -------- |

SMC female connector








## Connectors' gender

The MIL-STD-348 subminiature connectors follow a rule somewhat different from the others. Normally, a "plug" is called male and a "jack" female. In this case, we consider instead the center pin to define the male, as shown by the photos in these pages.

# Spectrum analyzers

Subsection

## 8557A+853A

# 8557A Spectrum Analyzer

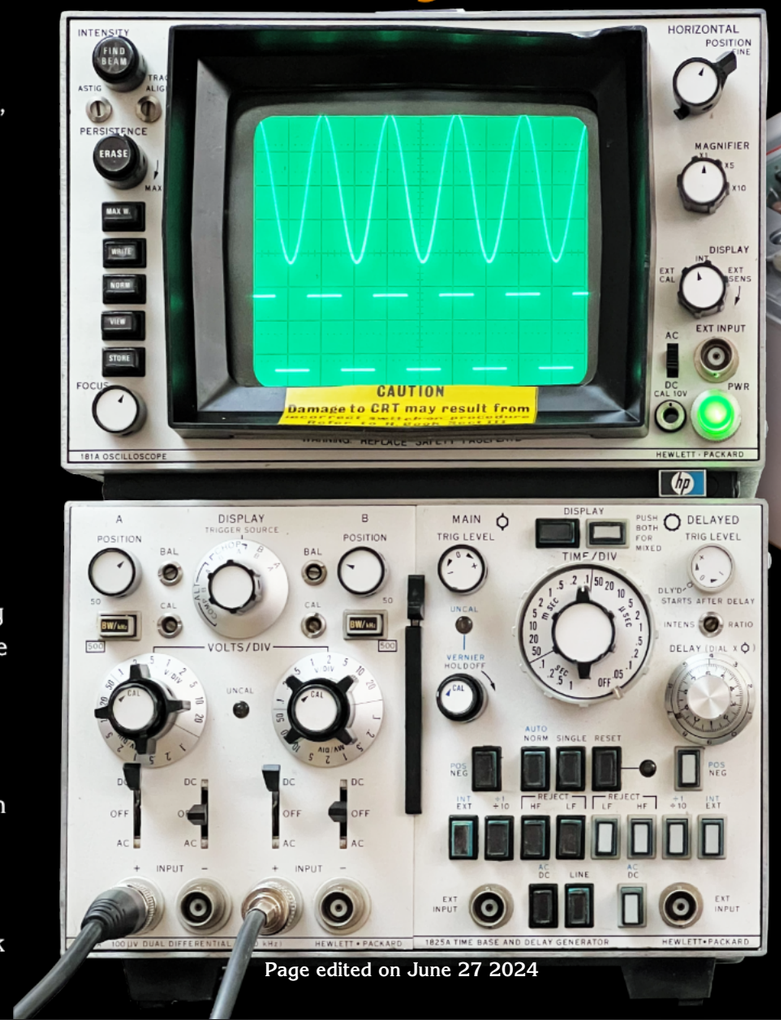
Plug-in oscilloscopes were all the rage in 1975, and both HP and Tektronix had their rich offer of them. You can read about HP 180 Series in the Oscilloscopes section of this book, and much about Tektronix in my other books, like, for example, that about the Tektronix 7000 Series.

Both HP and Tek gradually introduced plug-ins which widened oscilloscopes' application to become logic or spectrumc analyzers and other.

The Model 8557A was a 10 kHz to 350 MHz spectrum analyzer which plugged into any 180 series oscilloscope (possibly storage), making it simply a dedicated display.

Fully calibrated and easy to use, it provided an economical means for making frequency domain measurements in the RF range.

HP said "Although low in cost, the 8557A features high performance and accuracy". But what did they mean with "low cost"? In 1976, it was priced at $3,450, plus the 180 oscilloscope that was listed around $1,400÷2,500, depending on the model (more than $26k in 2023).








## Simple, 3-knob operation

With the 8557A, most measurements are a three step process. Center the inverted marker under the signal to be measured: its frequency is displayed on the digital readout. Zoom-in on the signal by decreasing the frequency span; bandwidth, sweep time, and video filtering are set automatically. Raise the signal to the top of the CRT: read its amplitude (in dBm) off the reference level control.




1975

The 8557A is built in a way that we already met and that we will meet again, with many relatively simple boards inserted on a main mother board. The RF boards are shielded by an aluminum extrusion box with a small panel and RF connections are performed by external cables with gold plated SMC connectors.

# 8557A spectrum analyzer

## Absolute amplitude calibration

With the 8557A, signal levels can be read directly from the CRT in dBm (dBmV for Option 002) without the use of external standards or calculations. The signal level represented by the top CRT graticule line is always indicated by the reference level control, and vertical scale factors of 10 dB/div, 1 dB/div, or linear can be selected. That is true: with some gears and mechanical tricks, it is very easy and error-free making

## Continuously variable video filter

Video filtering is a function of resolution bandwidth. A constant degree of filtering is maintained when the bandwidth control is changed, as when zooming-in on a signal. Noise measurements can be easily made in the "MAX" position (1.5 Hz bandwidth).

## 8557A Specifications

- **Frequency range**: 10 kHz to 350 MHz.
- **Frequency display span** (on a 10-division CRT horizontal axis): 12 calibrated spans from 20 MHz./ div to 5 kH../div in a 1, 2, 5 sequence. In "F" or full span the analyzes displays the full 10 kHz to 350 MHz. In "0" the analyzer is a fixed-tuned receiver.
- **Accuracy**: frequency error between any two points on the display is less than +10% of the indicated frequency separation.
- **Digital frequency readout**: indicates center frequency or start frequency of the frequency display span. In full span, the readout indicates the frequency at the marker.
  - **Accuracy**: (after zeroing on the LO feedthrough): ±3 MHz + 10% of FREQUENCY SPAN PER DIVISION setting.
- **Absolute amplitude calibration range**
  - **Log calibration range**: from - 117 dBm to +20 dBm in 10 dB steps. Reference level vernier, 0 to -12 dB continuously.
  - **Log display ranges**: 10 dB/div on a 70 dB display and 1 dB/div on an 8 dB display.




- **Bandwidth ranges**: 3 dB resolution bandwidths of 1 kHz to 3 MHz in a 1. 3. 10 sequence. Resolution bandwidth may be coupled to frequency display span al a ratio of two display spans per resolution bandwidth.

# 853A display

Seven years later, in 1982, HP introduced the 853A, an alternative to the 180 oscilloscope, dedicated only to be paired with the 8557A (and with its more performing brother 8758A, which could reach 1.5 GHz), and in this form I met this kind of equipment, that Francesco Sartorello gave me hoping that I could repair it (I will tell you later of this fix).

The 853 is something more modern than an old CRT oscilloscope, because it has a digital part, capable of digitizing and storing the screen content, and performing other functions.

With it, signals are displayed on either of two independently stored digital traces. Display processing capabilities include Max Hold, digital averaging, and trace normalization for extended measurement capability. A built-in microprocessor manages the display operation, as well as providing access to built-in test routines for display calibration and test.

## Two configurations

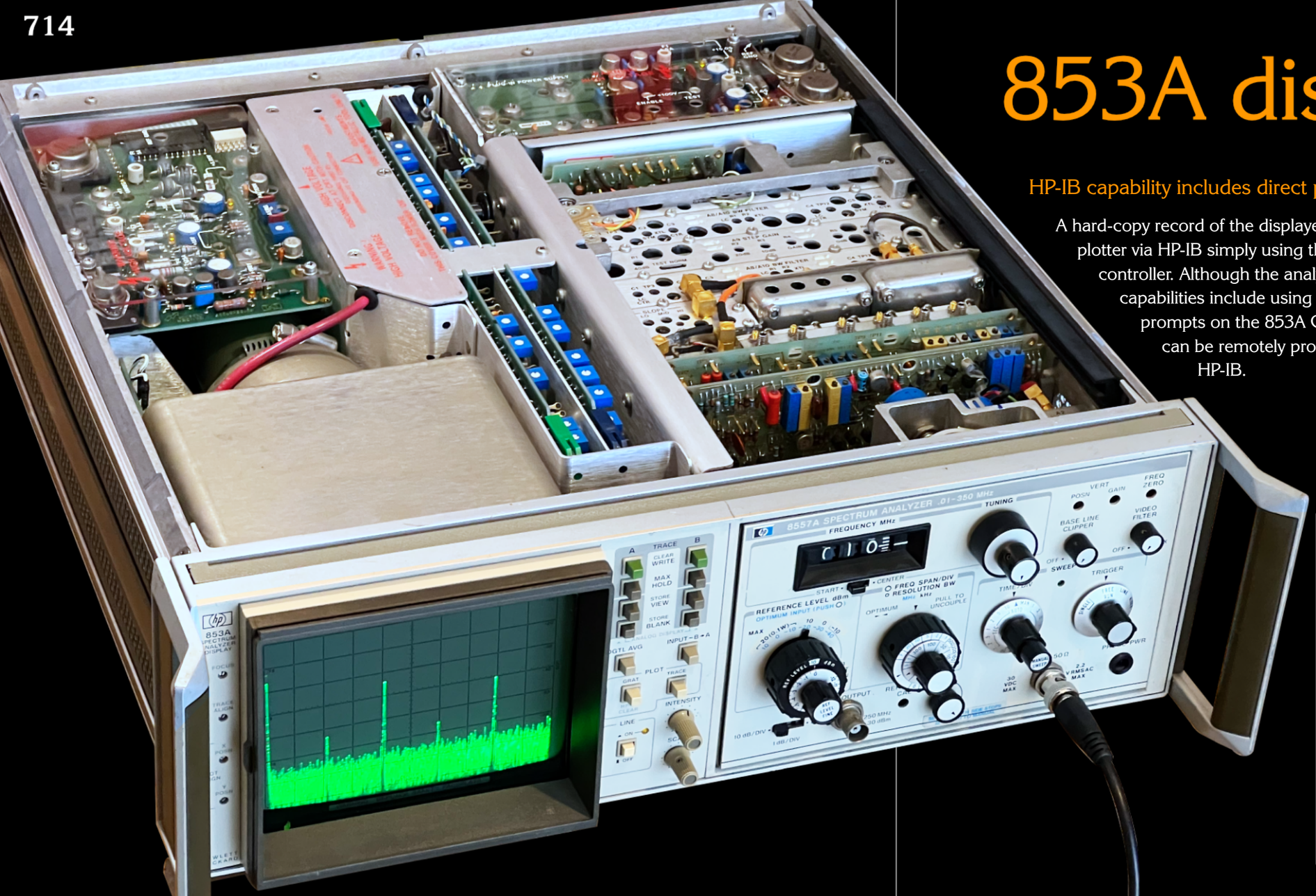
The display is offered in two styles. The 853A is a ruggedized, portable mainframe complete with tilt-bail handle and drip proof, protective front cover. The 853A is ideally suited for rugged, field service environments and any areas where system mobility is required. The 853A Option 001 (pictured here) offers the digital display in a full module bench or rack mount configuration.

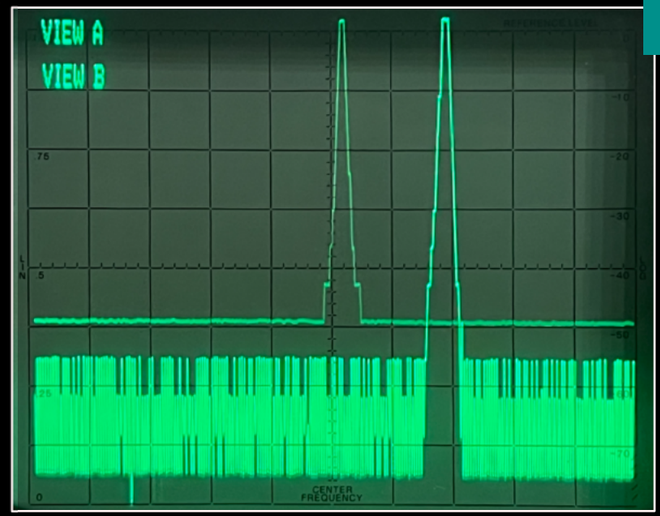
1983

# 853A display

## HP-IB capability includes direct plotter control

A hard-copy record of the displayed traces and graticule can be made on a digital plotter via HP-IB simply using the 853A's front-panel pushbuttons without using a controller. Although the analyzer controls are not programmable some HP-IB capabilities include using a controller for recording trace data, or operator prompts on the 853A CRT. The digital display and processing functions can be remotely programmed and analyzer sweeps can be initiated via HP-IB.



# 853A spectrum analyzer display

## Better than an oscilloscope

Thus, the HP 8557A Spectrum Analyzer could be used with a 180 oscilloscope or with the 853A Spectrum Analyzer Display.

Among the oscilloscopes, you could choose the **182T**, a normal persistence cabinet style display, the **181T** which offered variable persistence and storage or the **181TR**, a rack mount configuration.

All 180T-Series displays provided non-buffered rear panel auxiliary outputs (for unattenuated vertical horizontal, and pen lift outputs).

However, they do not offered the digital display, HP-IB and direct plotter dump capability, nor the portability features of the 853A.

## Like an Apple II

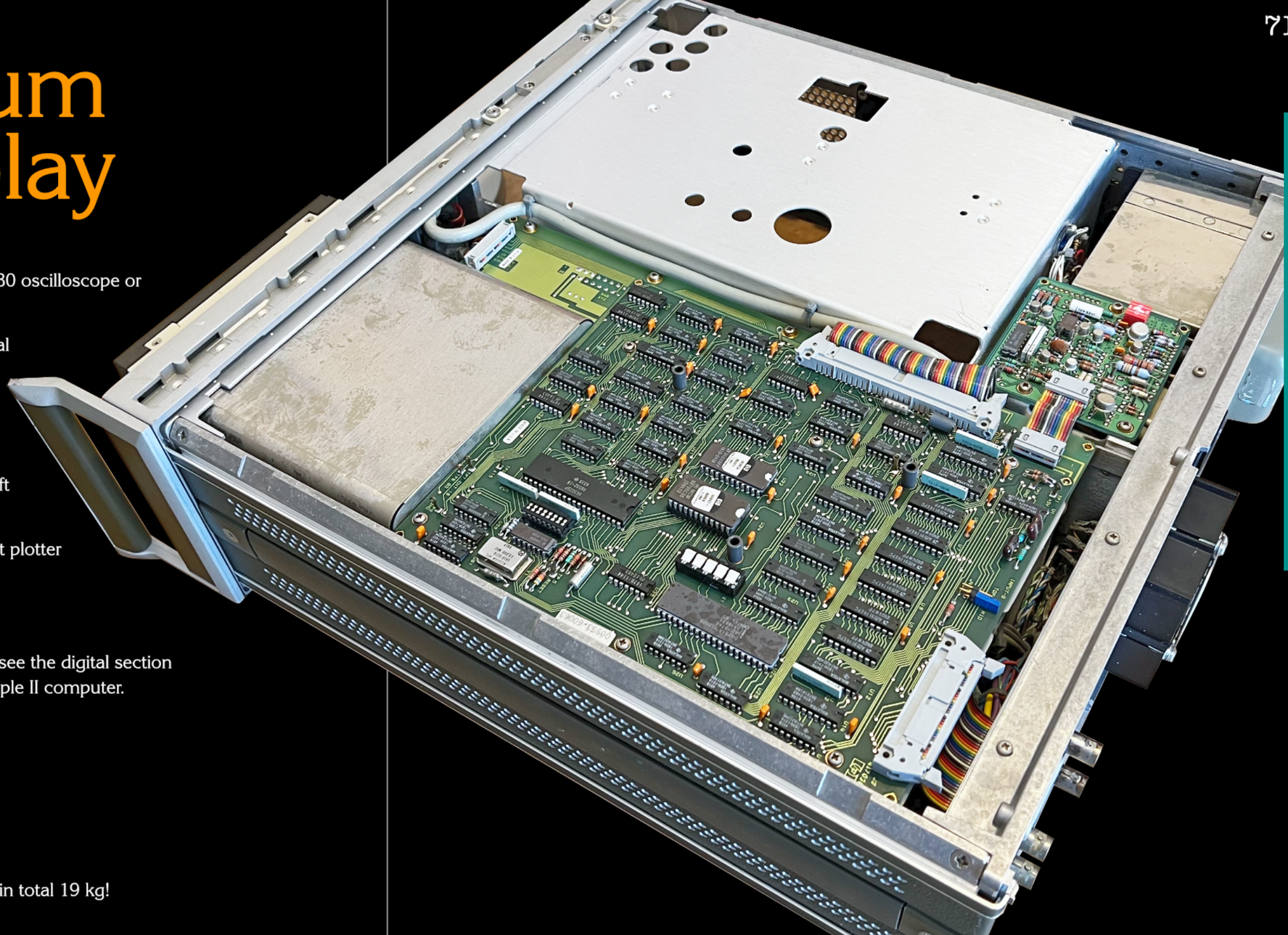
Here in the photo, the bottom side of the 853A, where you can see the digital section described above. It uses a 6502 processor, the same used in Apple II computer.

## Weight

It is incredible how could HP make these instrument heavy:

- Model 8557A: net, 4.5 kg (10 lb);
- Model 853A: net, 15.9 kg (35 lb).
- Model 853A Opt 001: net, 14.5 kg (32 lb).

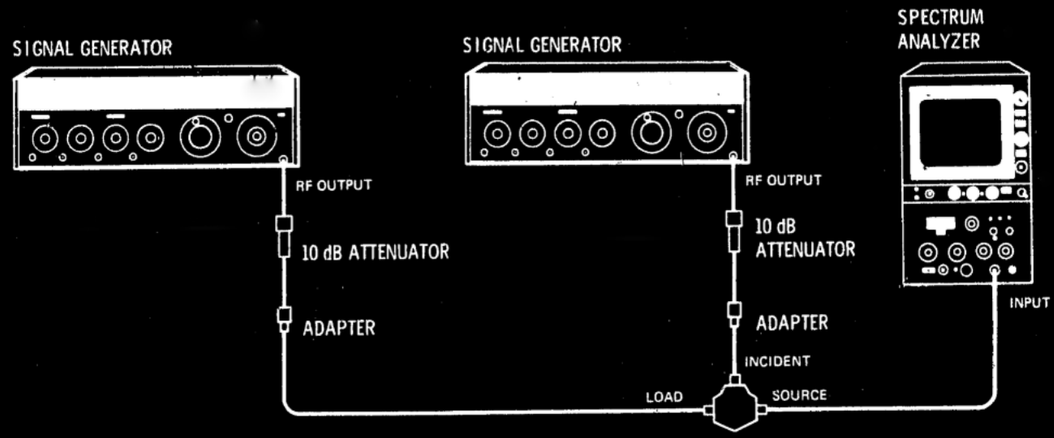
The vaunted portability of the Opt. 001 here depicted weighted in total 19 kg!



# How many trimmers!

The calibration of this instrument doesn't seem to be simple. For the only 8557A, the manual lists about 70 adjustment controls and the list of the required instruments is about two and a half pages long, plus one page of dedicated tools (adapters, extenders, cables etc.). As you can see in the photo, no shortage of trimmers also on the 853A side…

Maybe that in the future I will try a calibration of a spectrum generator, but now they can wait.

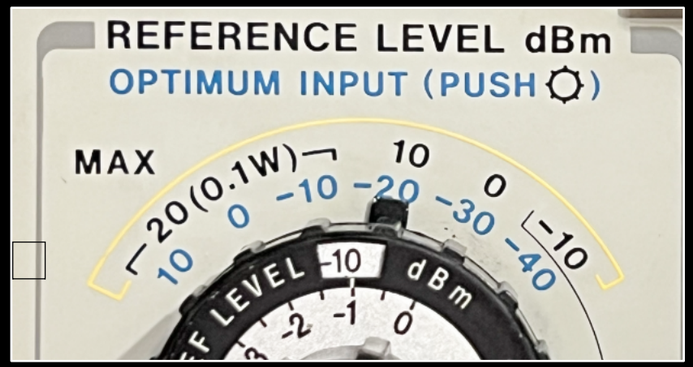


# Mechanic geniality

We have seen that the 8557A/853A was a true HP instrument, as you can immediately judge from its weight.

Looking inside, you remain fascinated by its wonderful die-cast aluminum castings and by the gears that inevitably performed the functions that, in the years, would be gradually integrated in the digital/software part.

**Easy!** This combination uses the mechanics for the tuning command and for the amplitude reading system, very ingenious, that allows you to quickly read the value in a snap. Just use the knob to position then signal to the top of the graticule and read the value on the knob. In the case below, you can easily evaluate -10 + -1 = -11 dBm.

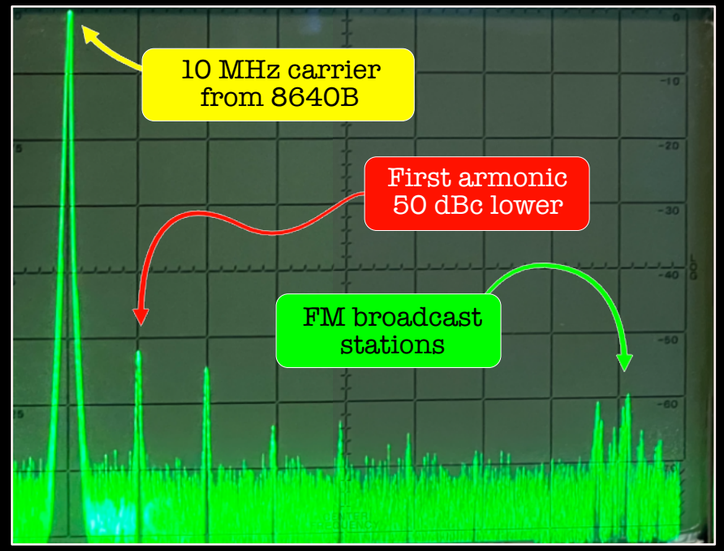







# 8640B check

Having here a spectrum analyzer for the first time, I wanted to check the famous 8460B spectral purity. Initially, I thought a fault: how many harmonics! But the scale is logarithmic and the old 8640B still now well complies to the spec (+10dBm: <-30 dBc). In this case, we are at -50 dBc (dBc are related to the carrier value).






# You can't always win

I was rather worried having to fix this gear for my friend Francesco Sartorello. I never dealt before with a spectrum analyzer (from inside, I mean), and and I didn't want to lose face over it.

Like every time someone wants to make a good impression, the devil had his tail in it, and when I went to Francesco's with repaired 853A, it didn't work properly, and I had to bring it home again.

Initially I thought I was lucky: most of the problems of this equipment seemed to be of mechanical origin and not too difficult to fix.

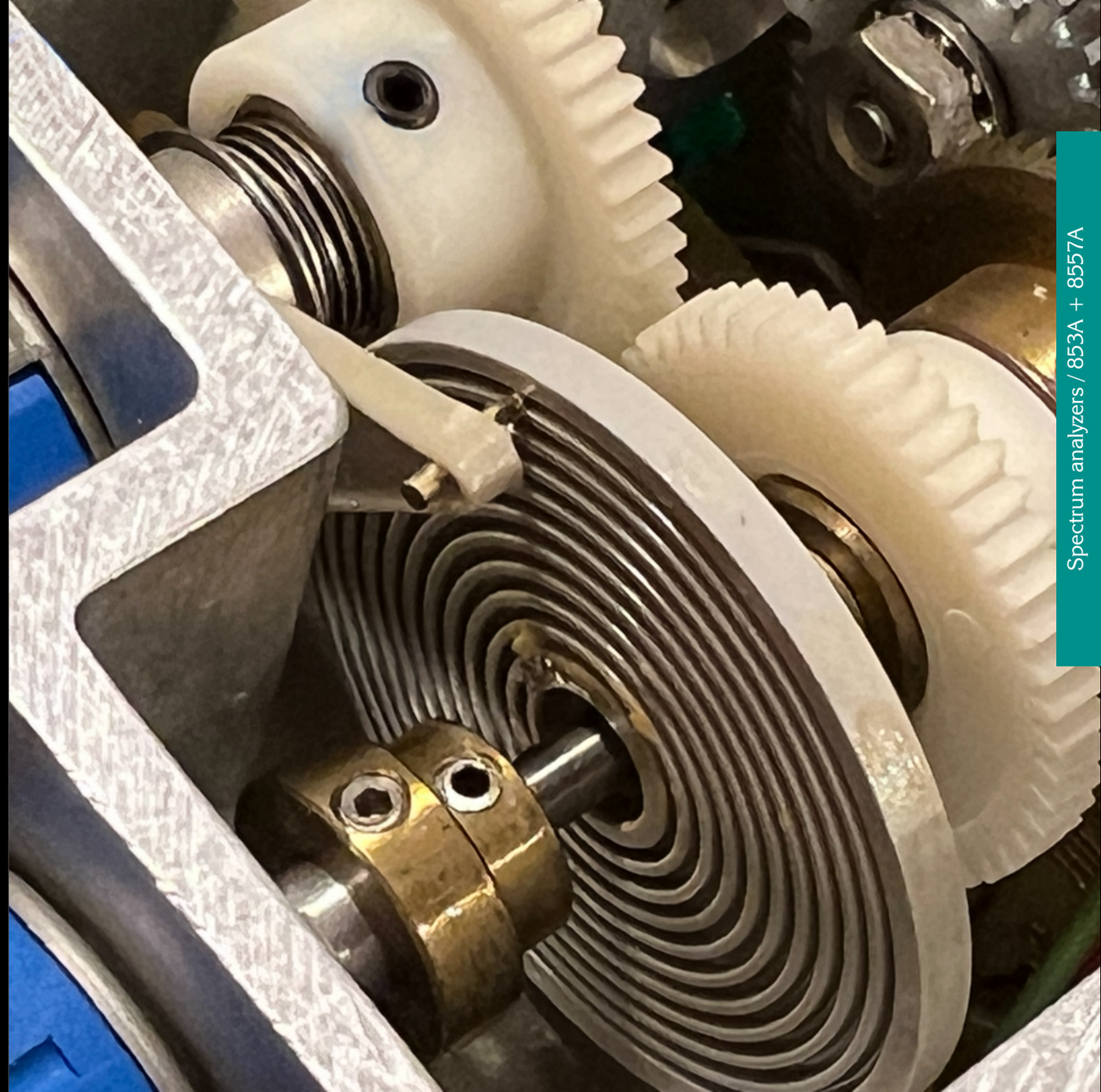
**It doesn't start.** Really, this was not a problem. The analyzer didn't start, or, better, when the unit started, a rather confuse screen was displayed. But this is a wanted behavior: it's enough to press the PLOT/GRAT button and the normal screen is displayed.

**COARSE TUNING locked knob:** it was jammed by dirty and probably old grease. I cleaned it with WD40C (don't forget the "C" or you damage all) and lubricated it with just micro-drops of oil. Now it runs perfectly smooth.

**FINE TUNING stuck knob:** that was much worse. It had the same problems as the COARSE knob, but id didn't move the frequency scale. I could soon understand that the problem was in a broken teeth on a lever that, driven by a spiral groove, moves an entire potentiometer, i.e. makes it to turn (not the spindle, the whole potentiometer). But how to fix it? I tried many solutions, and eventually I used a cut steel nail, after having drilled a small hole in the lever (see the photo on the right). The nail has then been enforced by a drop of Attack glue. It seems to work, if you don't use it too much…

**FREQ SPAN/DIV stuck knob:** this knob should be pull-able, but it was stuck. I studied the problem and was not finding a solution. In the end, I tried to pull it with a screwdriver blade and …it moved! So, very patiently and with the help of the WD40C, I could restore its functionality.

At this point I thought I finished, and brought back the instrument. As I told you, really it was not finished.



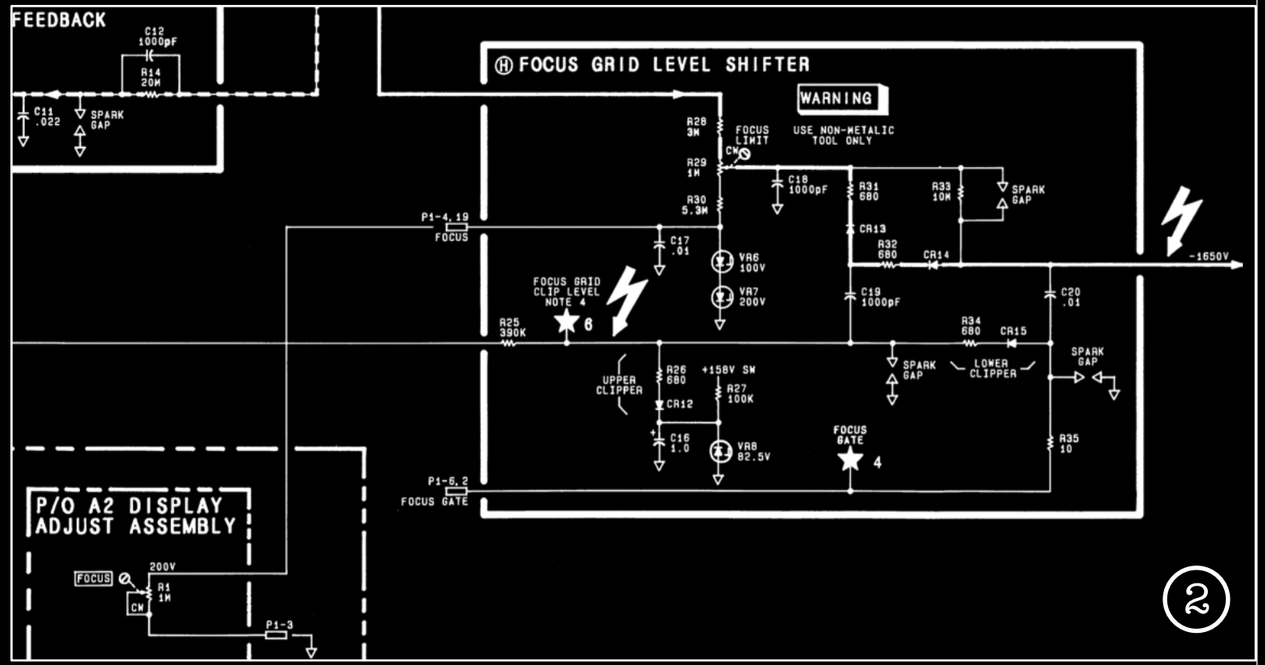
**Focus problem.** The residual problem was a bad trace focus on CRT and an excessive intensity on start-up. I under-evaluated it because it used to disappear after a few minutes. To front it, I bought the manuals from the very good Artek Manuals, and they promptly sent them to me.

I spent countless hours on this problem, specifically on the focus circuit here below. Eventually I decided to extract the High Voltage board and check most components. The critical ones were good (high voltage resistors and electrolytic capacitors), while most of the aged resistors were about 10-15% more than expected. I was going to give up, when I decided to follow the adjustment procedure listed in the manual for the HV part, and the problem reduced sensibly, so much that I decided to stop. I was not completely happy, for having not understood the problem, but not completely unhappy. You can't always win.

Notice that the problem finished after 3-4 minutes after startup, but, to reproduce it, I had to wait several hours. Perhaps more a residual charge problem than of temperature?

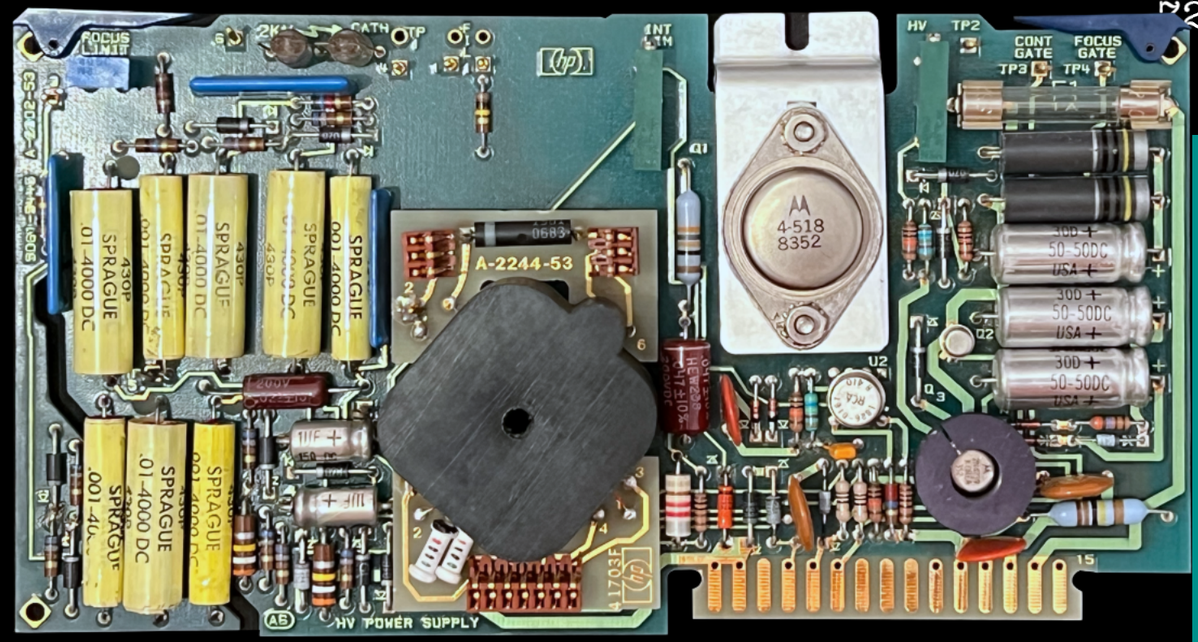



1

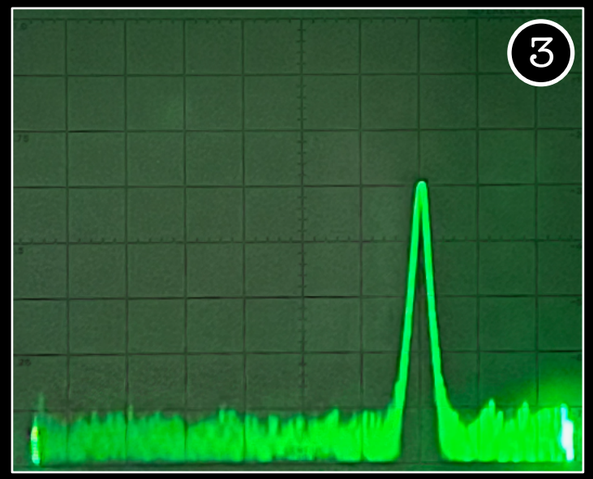



2

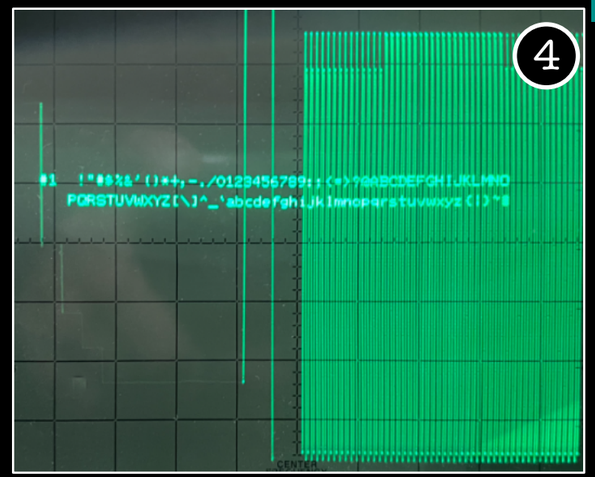





❶ The coveted 853A service manual is not available on the Internet. I bought it from Artek Manuals, always kind and efficient. ❷ The 853A focus circuit. ❸ The problem on startup (too much of intensity and low focus). ❹ Not everyone knows that the 853A has built-in test routines. To access them, switch it on pressing the PLOT/GRAT button. The CRT quality is much better than my photo.



3



4

# Spectrum analyzers

## Subsection
## 8568B (and 8567A)

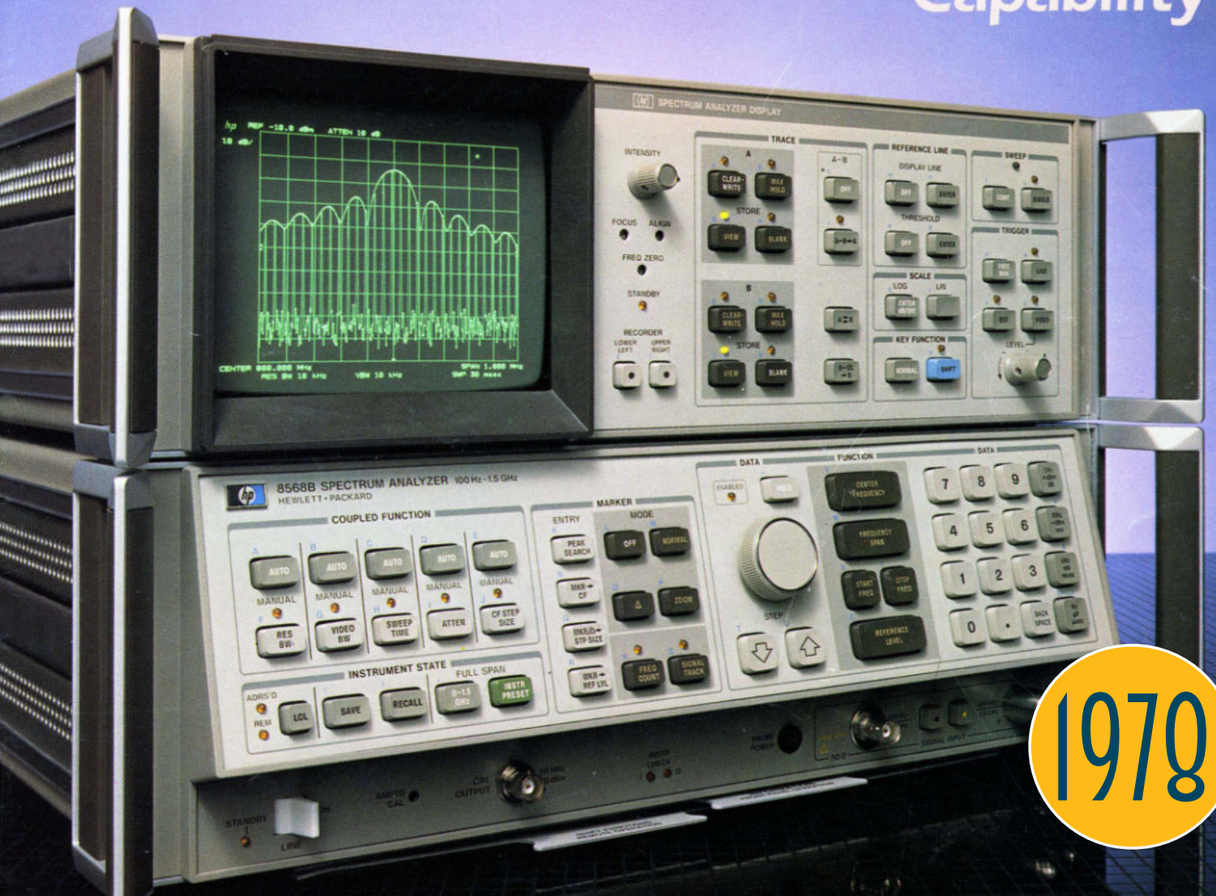


A giant leap and a milestone in Spectrum Analyzers, it was the most expensive instrument in HP's catalog, where it remained for almost 20 years. Still today one of the most fascinating classic pieces of equipment.

# 8568B RF Spectrum Analyzer

100 Hz to 1.5 GHz

Outstanding Precision and Measurement Capability




## Introduction

According to CuriousMarc guru “In 1978, HP came up with an instrument that would represent a giant leap in spectrum analyzers, and with his big brother the HP 8566 introduced in 1980, the 8568B would remain the gold standard for a long time. Heck, it is still a standard. It was the most expensive instrument on the catalog” (see later for the prices), and will remain in catalog until 1997, almost 30 years.

Introduced in 1978, when HP’ offer for Spectrum Analyzers was composed basically by few models (two already described in this book, the 855x/8552 in the 141T mainframe and the 8557A plug-in and brothers), the 8568A achieved a significant improvement in signal-analysis capability, with microprocessors controlling its operation and its advanced technology and performances.

With a measurement range of 100 Hz to 1500 MHz, and such features as synthesizer-controlled tuning, resolution bandwidths as fine as 10 Hz over the full tuning range, 90-dB log display, excellent spectral purity, and digital storage with display annotation, it made a major contribution to the field of spectrum measurement, and was a forerunner of a family of new models, like the “B” edition, the 22 GHz 8566A and the “cheap” 8567A, as well described herein.

These features rely heavily upon the internal digital processors, which also give the analyzer unparalleled ease of operation and full HP Interface Bus compatibility, which made the power of spectrum analysis measurements practical and cost effective in production line applications as well as in unattended spectrum surveillance and similar applications [revised from https://www.hpmemoryproject.org].

## A little history

The 8568A appeared in 1978 catalog and, as anticipated, was followed in 1980 by the 22-GHz 8566A.

In 1985, hardware for both Spectrum Analyzers were updated to 8568B, and 8566B. This update mainly consisted of a change of the internal microprocessor of the analyzers. The 8568A, and 8566A were equipped with the processor developed by HP for the 9825A calculator, which was, at the time of their development, by the mid-1970s, more powerful than any microprocessor available on the consumer market. Ten years later, the weakest microprocessor available on the market was ten times more powerful than the 9825A processor, and cost ten times less. It was time for the two successful Spectrum Analyzers to take benefit of this considerable performance improvement from the consumer sector. A retrofit-kit was offered for $4000,00 USD to upgrade the 8568A/8566A to a 8568-66B [from https://www.hpmemoryproject.org].

Later, in 1986 catalog, the new 8567A (10 kHz - 1500 MHz) was introduced, practically a low-cost 8568B with reduced performances and aiming the EMI testing market, thanks to built-in firmware to reduce the test time and lessen the data processing load on the computer side. I own one of them as well, arrived from Germany, in a very good condition (it had still the hated seals after the last calibration - hated because removing them is definitely uneasy).

## Not cheap

In the table below, some prices. Note that the both 8568 and the 8566 really dropped their prices from 1978 to 1986; probably an effect of competition.

## One of the first microprocessor-based

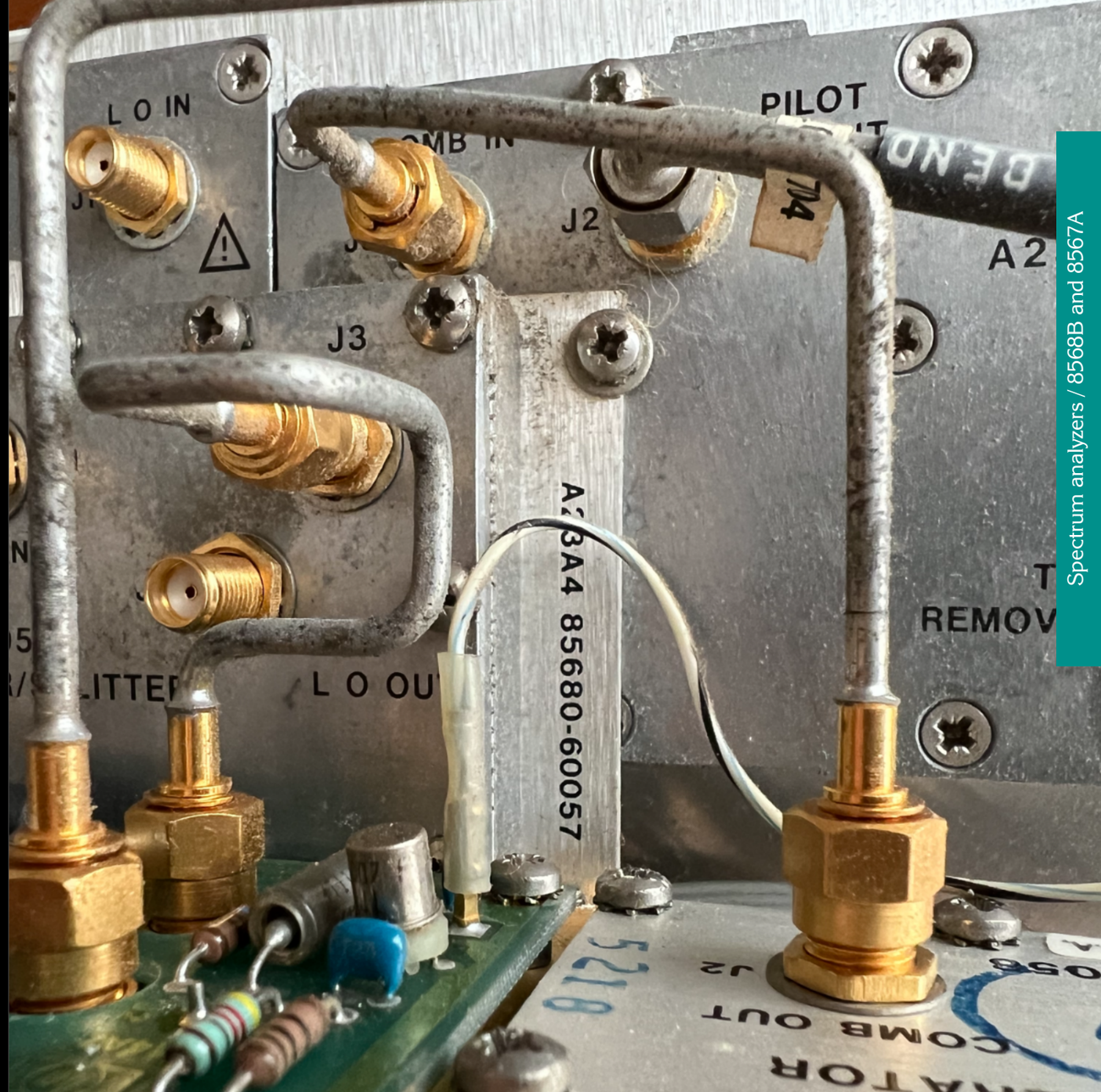
The 8568 is a high performance spectrum analyzer for bench or HP-IB systems use, which operates over the 100 Hz to 1500 MHz frequency range. A sophisticated phase lock system combines "synthesizer like" tuning and frequency accuracy with superior local oscillator spectral purity to make narrow resolution bandwidths practical at RF frequencies.

The analyzer was one of the first designed around a controlling microprocessor, which allowed significant improvements in performances, a completely new user experience, and an unparalleled programmability. This overshadowed a bit other new outstanding solutions, like the YIG oscillator that we will try to describe in the following.

## Composition

The 85680A/B RF section (the lower part) was used with the 85662A IF-display section (the upper part) to form the 8568A/B Spectrum Analyzer (the 85662 was always “A”).

| Name | Type | Notes | Price USD | in year | Today USD |
|---|---|---|---|---|---|
| 8568A | 100 Hz ÷1.5 GHz | The original model | 27,800 | 1978 | 130,100 |
| 8566A | 100 Hz ÷22 GHz | High-bandwidth model | 47,500 | 1980 | 175,750 |
| 8568B | 100 Hz ÷ 1.5 GHz | Updated CPU model | 34,600 | 1986 | 96,200 |
| 8566B | 100 Hz ÷ 22 GHz | Updated CPU model | 55,000 | 1986 | 152,900 |
| 8567A | 10 kHz ÷ 1.5 GHz | Low-cost, EMI model | 27,000 | 1986 | 75,060 |



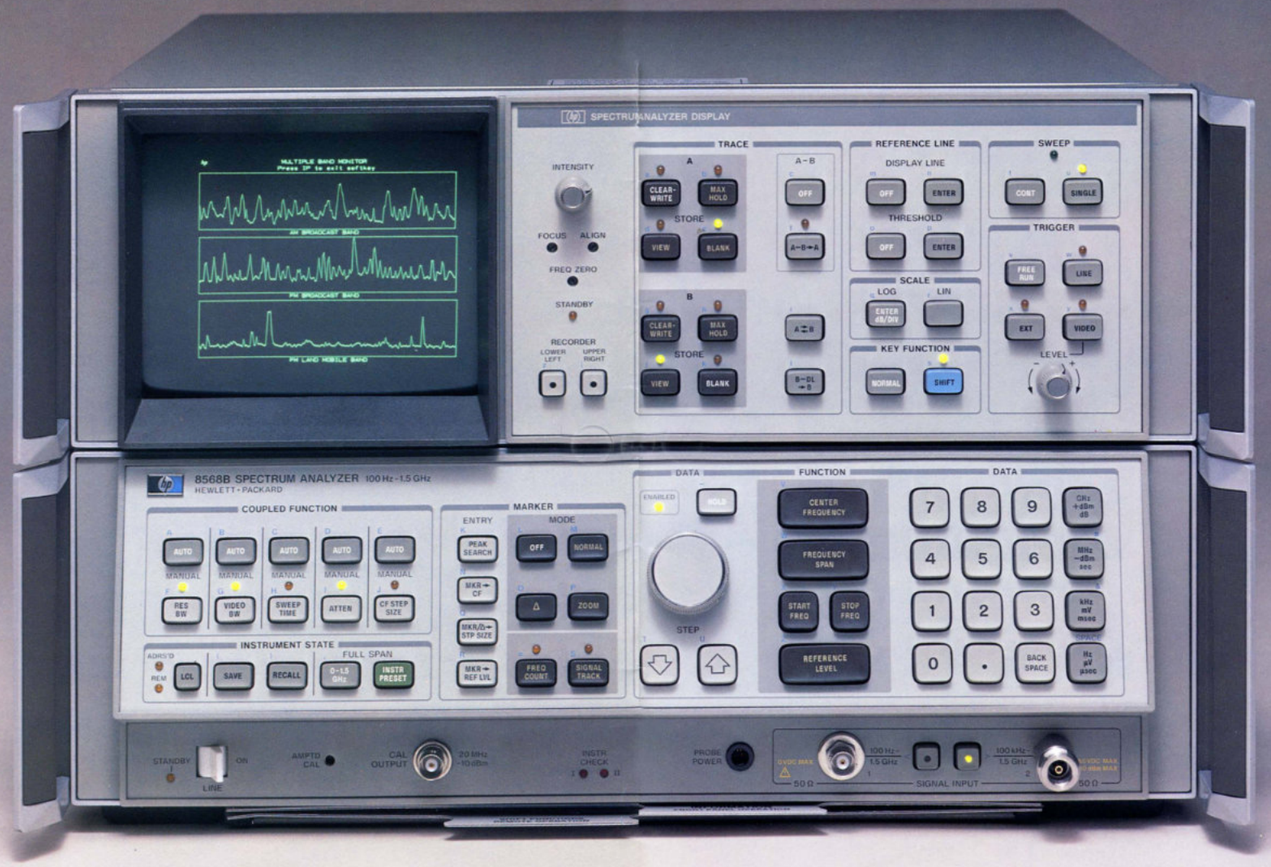
# The HP 8568B RF Spectrum Analyzer

## Equipped with Tools that Provide Fast, Precise Measurement Solutions



Normally in my books I try to use mostly the material I directly produce, but this wonderful brochure from 1985 is too tempting to resist.

Probably, it has been produced for the “B” version launch. It can be downloaded from https://www.curiousmarc.com/instruments/hp-8568b-spectrum-analyzer together with many other documents related to this splendid instrument.




- Exceptional RF Performance
- Measurement Aids
- Easy-to-Use Front Panel
- “On-Board” Computing Capability
- Powerful Signal and Trace Processing Functions
- Decision-Making Capability
- Distributed Processing with a Computer
- Direct Plotter Output
- Stores and Executes Custom Measurement Routines

The unit presented here is of the “B-type”, which followed the original 8568A in 1985, with the main difference in the central microprocessor.

Most of the information contained in these pages are however applicable also for to 8566x and the 8567A.

# 8567A the little brother

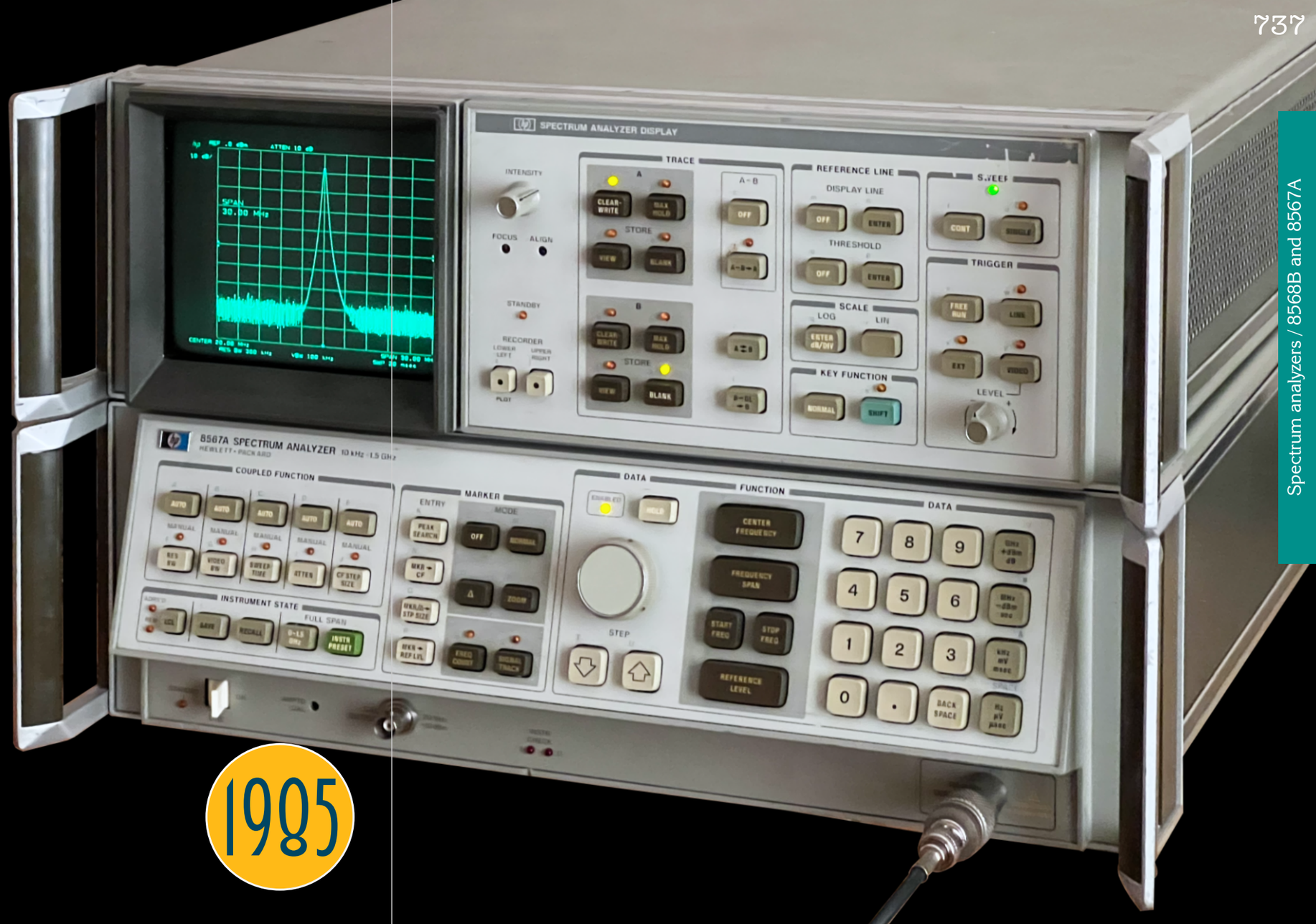
The 8567A is the little brother of the 8568A. From outside, it is not easy to see the differences. The most evident is the lack of the second input.

Some of the specifications are relaxed, but the most important differences lay in the frequency range. The 8567A starts at 10 kHz instead than 100 Hz, but the upper limit is the same: 1,500 MHz.

The point that I find to be the weakest is the minimum bandwidth resolution, limited to 1 kHz, instead of 10 Hz, that allowed a less stable frequency reference, with lower stability.

My 8567A is in better conditions than the 8568B and perfectly working, then obviously my preferences go to the bigger brother, that more needs my care.

Note the beautiful front handles. My 8568B, instead, has the Opt. 908 rack flange kit, that however I removed because, when it is not necessary, it makes simply more complicated handling these heavy instruments.



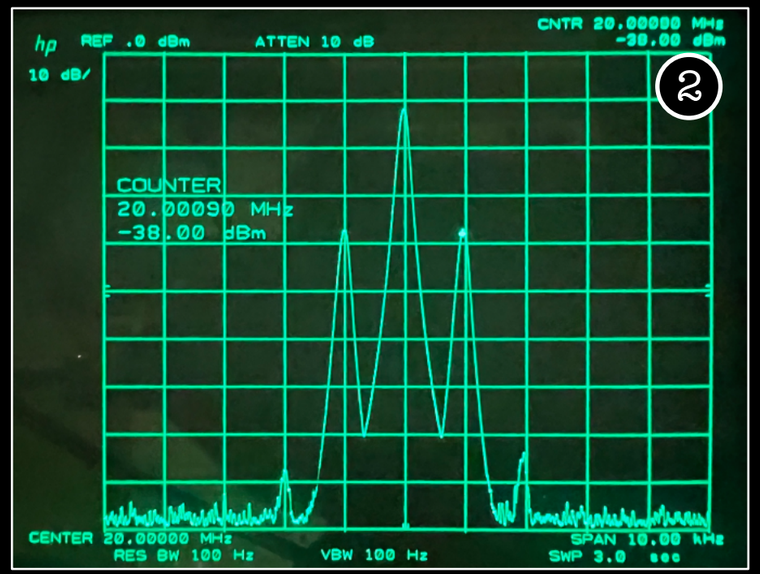
# Performances

As we know, a Spectrum Analyzer is essentially a receiver with a different output (subsequent models will have also a loudspeaker to listen to the output signal). With this in mind, we can be even more astonished from 8568's data, like frequency range, dynamic range and selectivity, down to 10 Hz. Let briefly view below these exceptional performances, with the help of the 8568A brochure.

From audio to UH frequencies. The frequency measurement range extends from 100 Hz to 1500 MHz with dc and ac coupled inputs, i.e., from audio to ultra-high frequencies. Exceptional stability enables the use of a 10 Hz resolution bandwidth over the 100 Hz to 1500 MHz tuning range of the analyzer. That is due also to the YIG oscillator, which we will describe later.

Amplitude measurement range. The amplitude measurement range extends from +30 dBm to -135 dBm with a 90 dB calibrated display, and the input is protected from accidental overload. Calibration units can be selected from dBm, dBmV, dBuV, and volts. The analyzer measures signal levels as low as 32 nV (across 50 ohms).

Measurement accuracy. High repeatability and features such as the tunable marker with frequency count allow measurements to be made more accurately and

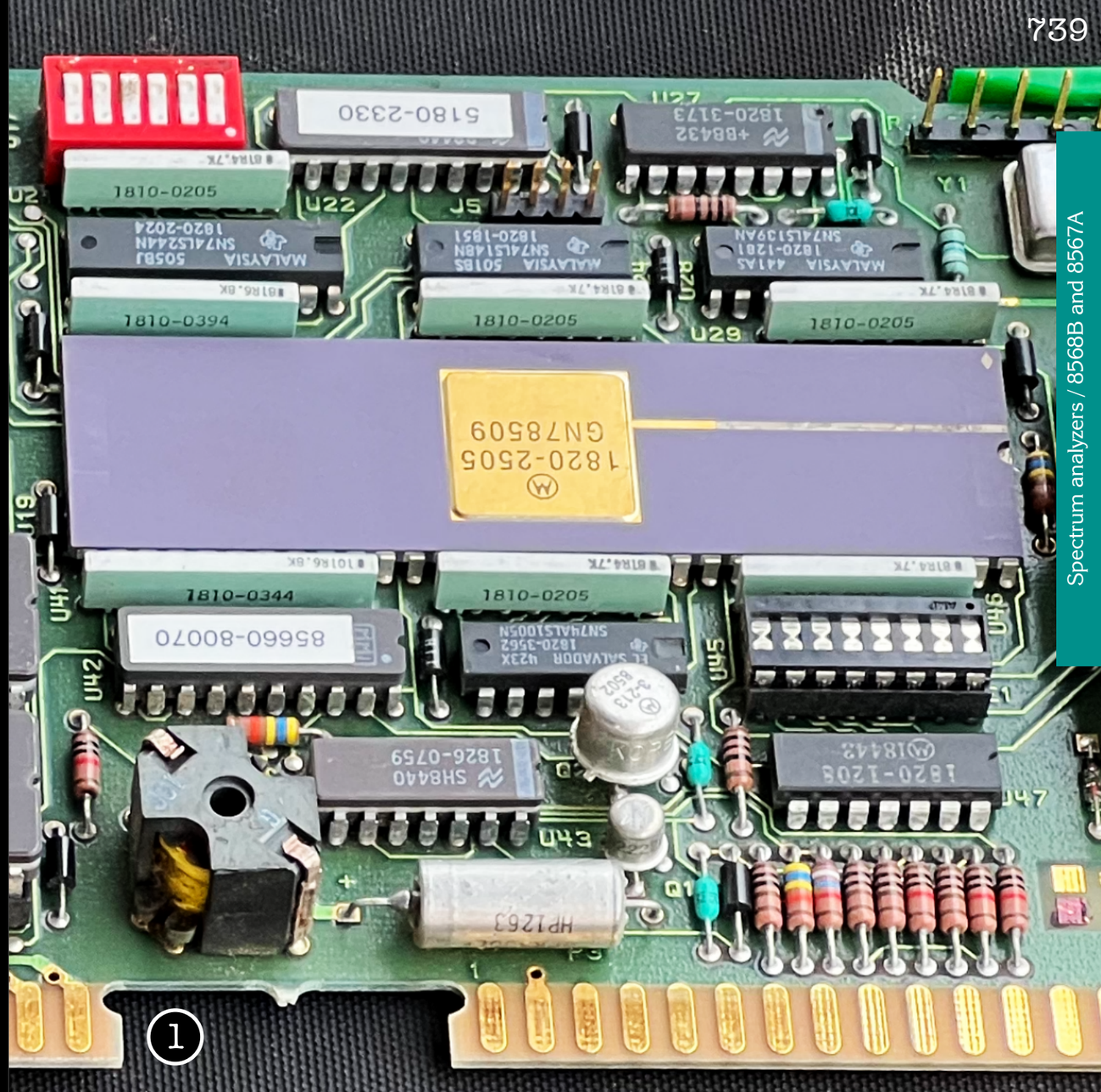



❶ A large part of the new functions and performances are due to the microprocessor control, for the first time or so added to an instrument. In this photo the second generation CPU from my 8567B, a beautiful 64-pin ceramic chip.

❷ The display assumes a new role in the Spectrum Analyzer, like when, eight years before, Tektronix added the readout to oscilloscopes. Note the number of data: center frequency, span, resolution and video bandwidth, attenuation, sweep time, etc. Other information is displayed when required in this case, for example, the frequency counter value. Despite small caps, the writings are perfectly readable.





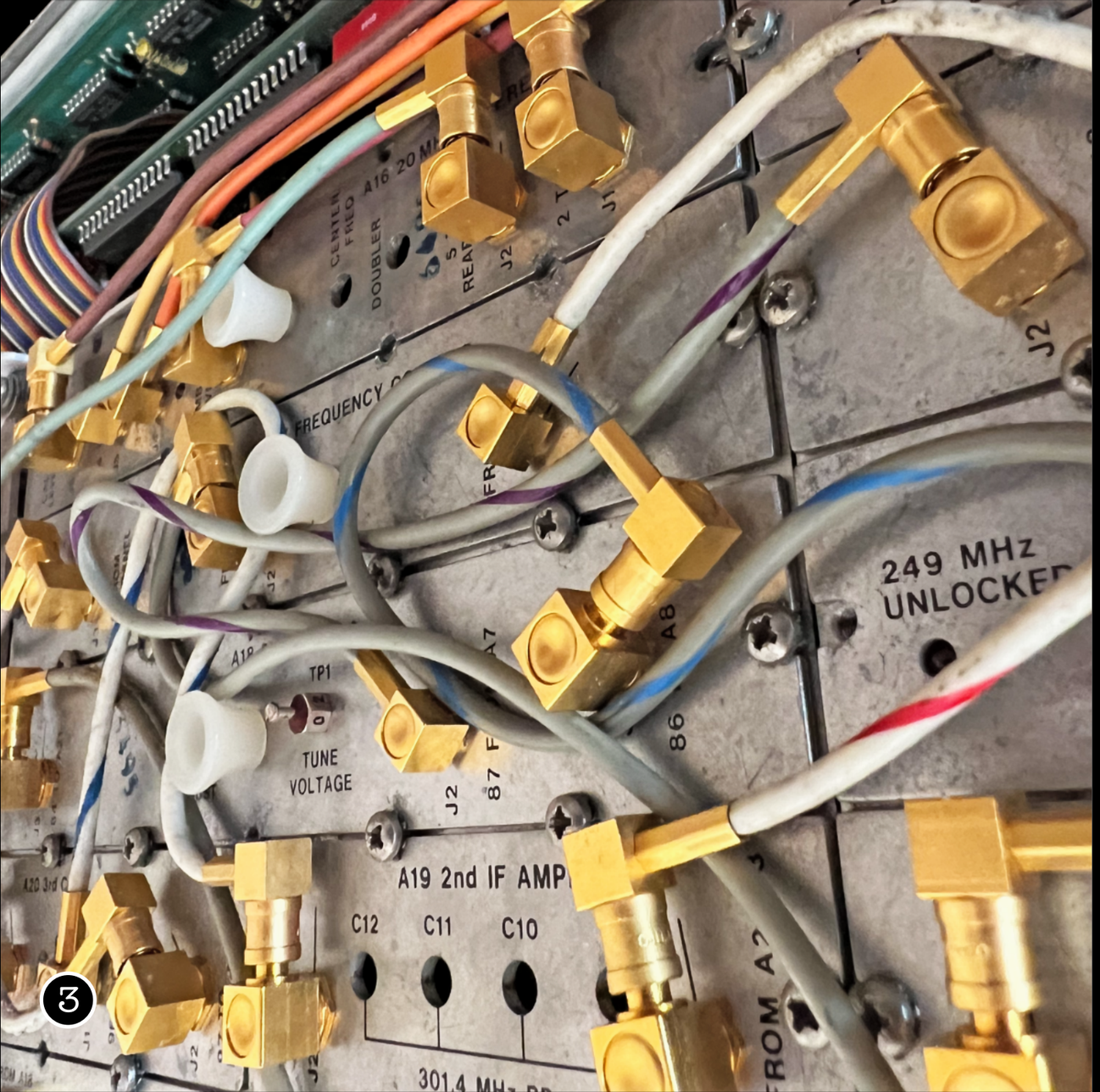


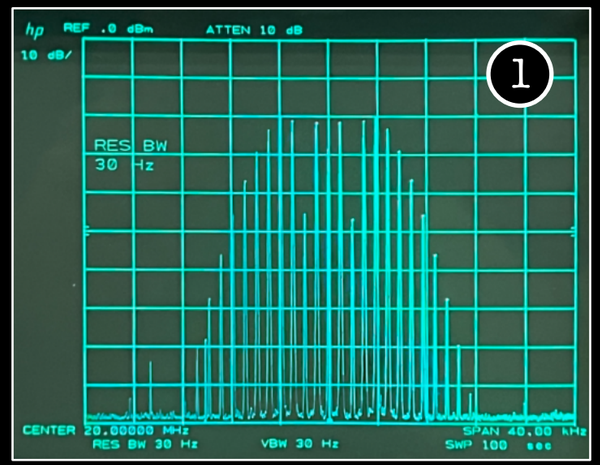
conveniently than ever before. Less than $1 \times 10^{-9}$/day frequency error ($5 \times 10^{-6}$/day for the 8567A), together with spectrum analyzer selectivity, make counter frequency accuracy possible even when measuring small signals in the presence of large ones. An internal error correction routine reduces the amplitude measurement uncertainty due to changes in various analyzer controls. Under automatic control, the analyzer's exceptional repeatability may be used to further characterize sources of measurement uncertainty, and thereby enhance accuracy.

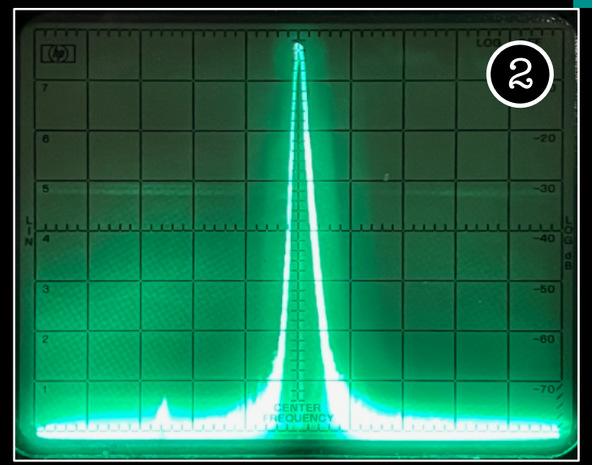
Resolution bandwidth (selectivity). 10 Hz to 3 MHz resolution bandwidths are used in a 1, 3, 10 sequence (1 kHz to 3 MHz for the 8567A). An appropriate bandwidth is always available to provide proper resolution for an frequency span. A narrow 10 Hz bandwidth makes possible the resolution of 50 Hz sidebands that are > 60 dB below the peak of a 500 kHz signal, while internal line-related sidebands remain below the filter response. Wide 1 and 3 MHz bandwidths with "Gaussian" shapes improve sensitivity and transient behavior when measuring impulse noise, such as electromagnetic interference, or demodulating wideband spectra.

Single sideband phase noise. Single sideband phase noise is more than 80 dB below the peak of a CW signal at frequency offsets > 30 times the resolution bandwidth setting, for resolution bandwidths <300 Hz. Single side-band phase noise is typically > 80 dB down and 200 Hz away in a 10 Hz resolution bandwidth at 1500 MHz.

**❶ Representation of a 20-MHz, -10 dBm signal, FM modulated with a 1 kHz signal for a deviation of ±5 kHz. The SA bandwidth has been set to 30 Hz. ❷ The display of the previous 8553B/8552A looks incredibly outdated. ❸ The 8568B general construction technique is similar to the previous models, with many boards encapsulated in a heavy aluminum structure and connected by a motherboard from one side and coaxial cables from the other, with a lot of SMA and SMB connectors. Quality is paid not only with dollars but also with weight (45 kg for the entire instrument).**



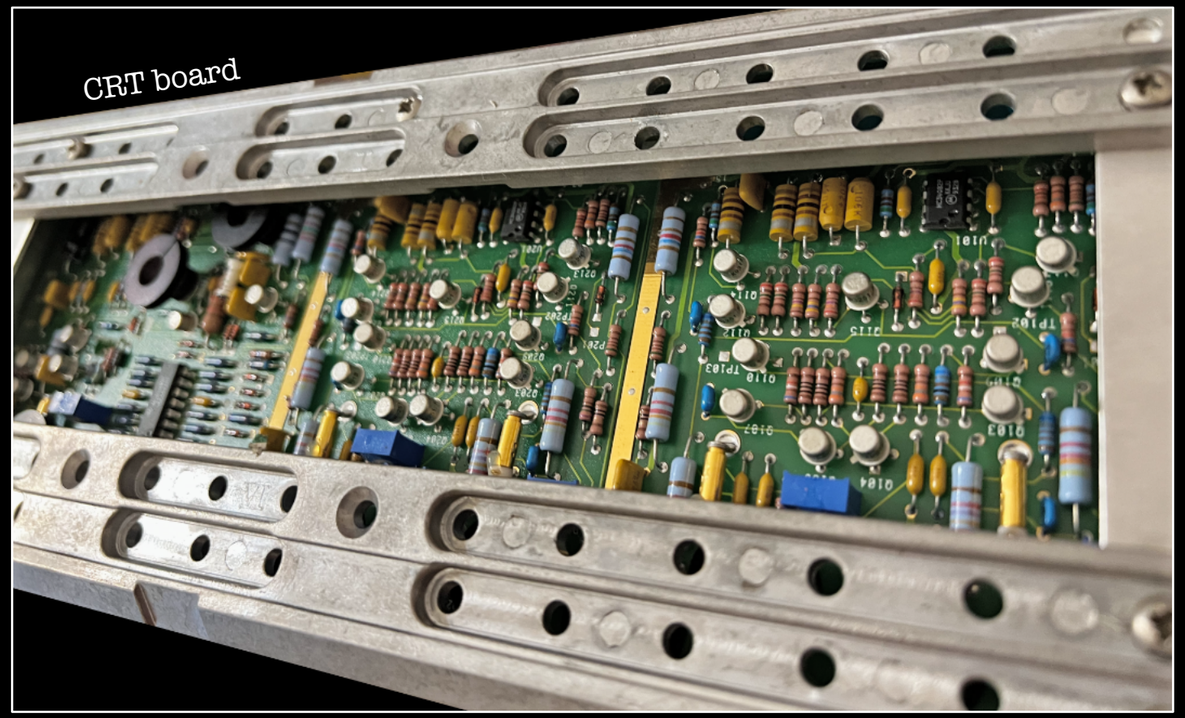



Dynamic range. I already told you that I am not an expert, and thus I wanted to better understand the concept of “dynamic range”, of which I had only an intuitive idea.

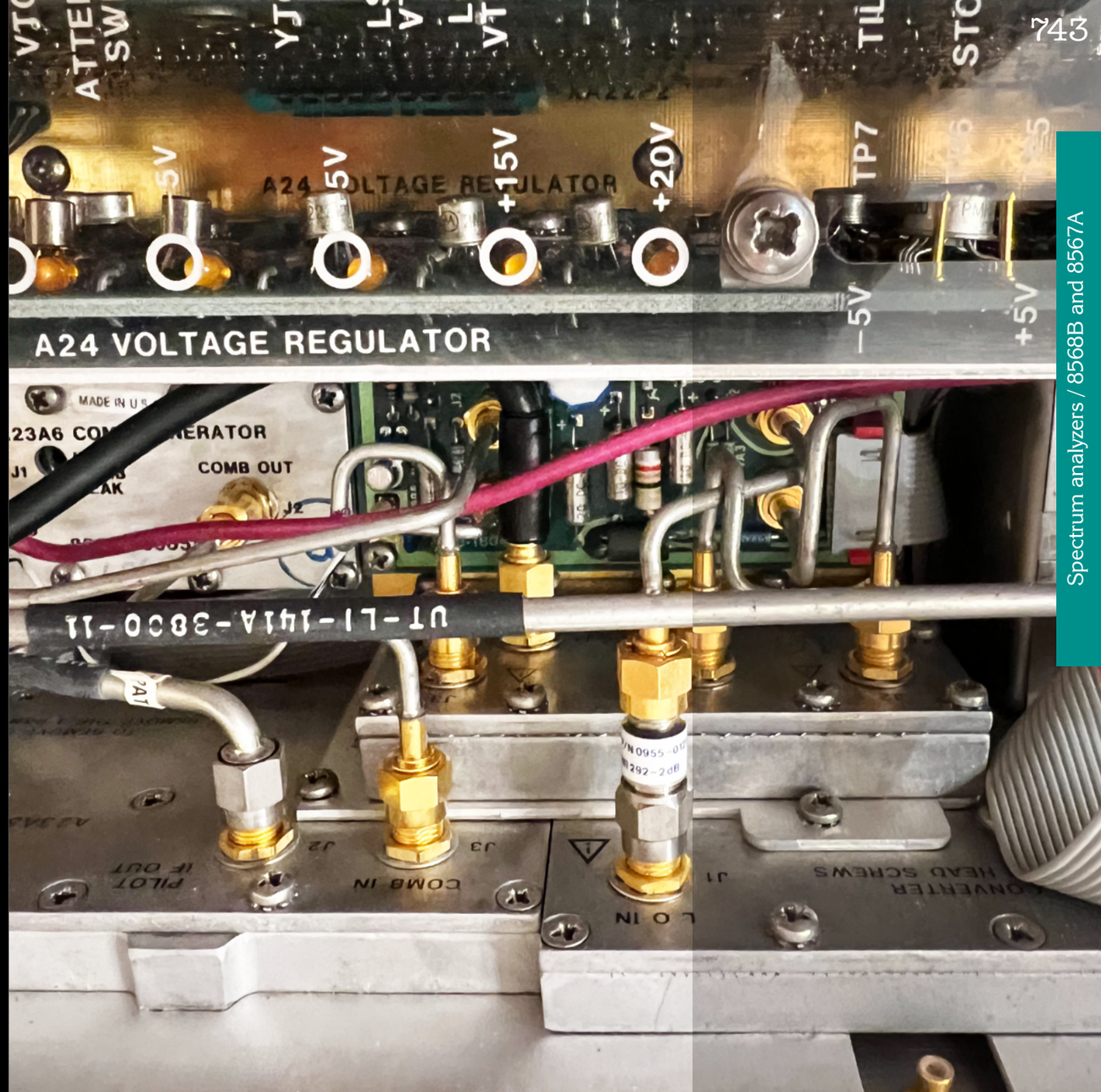
I discovered that, on this theme, experts spend a lot of complicate words and formulas, but I could find a definition, perhaps not perfect, but clear enough for me “Signal analyzer dynamic range is the maximum power ratio (in dB) between a high power signal and low power signal that are present at the input of the signal analyzer – such that both signals can be discerned and measured at the same time or in the same display”.

In the case of the 8568B, the spurious-free dynamic range measures 80 dB with signal levels at the input mixer lower than -50 dBm. Harmonic and intermodulation distortion products can typically be measured 90 dB below the peak of a signal.







# Selectivity matters

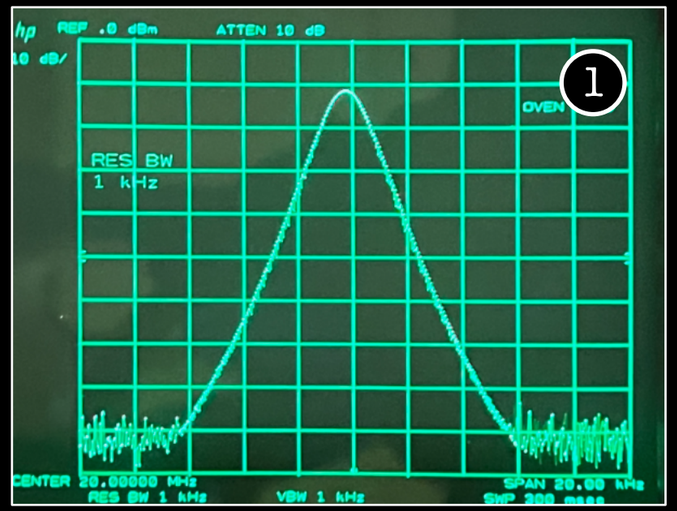
Why is bandwidth so important in a Spectrum Analyzer?

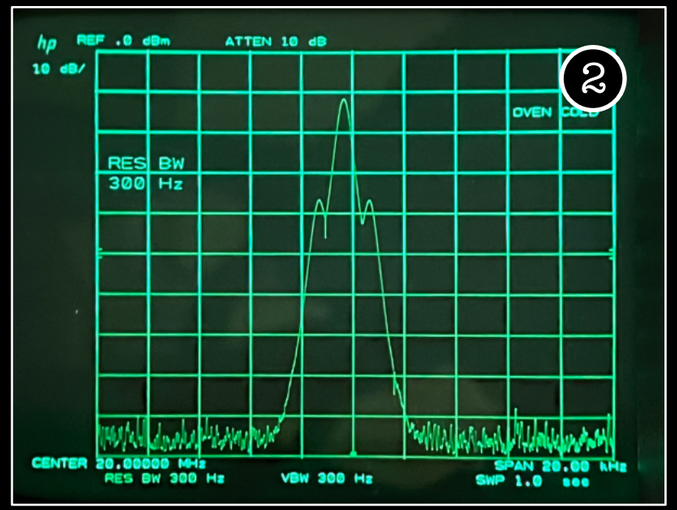
Let's start considering a generic continuous wave carrier. For definition, it has constant frequency and amplitude. A real oscillator is however characterized by phase noise, defined as the noise arising from the rapid, short term, random phase fluctuations that occur in the signal. These random fluctuations are caused by time domain instabilities called as phase jitter.

Even with a very low phase noise, an oscillator will not produce just a vertical line, as you can expect, but something like the gaussian shown in figure ❶, taken at resolution bandwidth (RBW) of 1 kHz (as confirmed on the bottom left corner of the photo).

That is due mainly to the SA selectivity. Imagine the diagram as 1,000 points wide and high (as it really is in the 8568B). For each position, the SA reads the carrier amplitude and sets a point on the screen at x = frequency, y = amplitude.

If the SA's bandwidth was extremely narrow, you should have all the points set to zero except when you are at the carrier frequency $f_0$. If the bandwidth is broader, when you get






near $f_0$, you receive some signal, more and more approaching $f_0$. The same happens on the right side of $f_0$, when the read signal decreases.

If we reduce the RBW to 300 Hz (❷), we observe two peaks on the carrier sides, and we start suspecting that this is an AM modulated signal, with two sidebands on its sides.

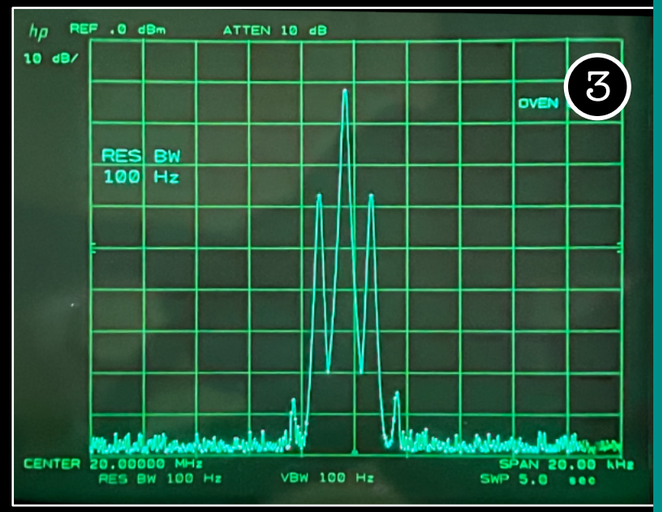
Photos ❸, and ❹ with 100 Hz, and 30 Hz bandwidth, confirm that the more the bandwidth is narrow, the more the frequencies are show as vertical lines. The effect is like increasing the resolution of the diagram.

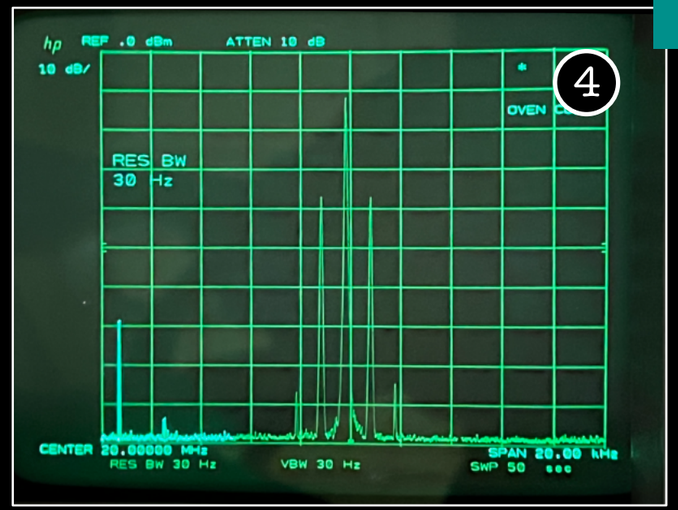
By the way, we discover that there are also other two sidebands, due to distortion in the modulating signal.

Note that increasing the resolution the sweep time increases passing from 200 ms @ 1 kHz, to 1 s @ 300 Hz, to 5 s @ 100 Hz, to 50 s @ 30 Hz, as it is logical to expect. We pay in time the more faithful representation of the reality (in the 30 Hz photo, there are some spikes due to electric environment noise, more probable in a long-duration sweep and not related to the specific measurement).

From a certain point of view, selectivity is one of the most important features of this instrument. The little brother 8567A, that, as we said, is the lower cost edition of the 8568, is limited in bandwidth to 1 kHz minimum, sensibly reducing its usability field.

❶ Representation of a 20-MHz, -10 dBm signal, modulated 10% with a 1 kHz signal. Bandwidth = 1 kHz. ❷ Idem, with BW = 300 Hz. ❸ BW = 100 Hz. ❹ BW = 10 Hz.



# How did we do before?

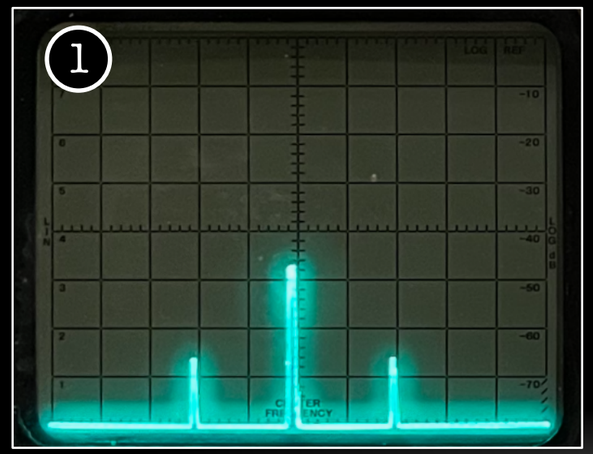
For curiosity, I tried the same measurements with the older 8553B/8552B Spectrum Analyzer, also described in this book, which offers a minimum bandwidth of 10 Hz as well (photo ❷ on the right)

It was very tough, and after almost an hour of trying I gave up. The critical point is the frequency stability. Yes, I know that my 8253B/8252B is very old, but probably things were not so different when it was new.

With high scan speeds, your hand can compensate small frequency drifts of the 8253B/8252B, but we are requiring a span as little as 20 kHz; if the frequency drifts only 25 kHz, the envelope goes out of the screen. When the sweep becomes tens of seconds, it is almost impossible to keep it on the screen.

I succeeded, but at a lower frequency, thanks to the better stability of the 8253B/8252B in the 10 kHz-11 MHz range - picture ❶ is at 500 kHz (by the way: I understand why the 141T mainframe has the CRT storage; with these low bandwidth values, the scan time is always of several seconds, and in some way a storage system is required, digital or analog).

Returning back to the 8568B it's a dream: just few keys and you immediately obtain a perfect diagram.




❶ Diagram of a 500 kHz signal on the 8253B/8252B; time/div = 10 sec; scan width/div = 0.5 kHz; bandwidth = 10 Hz.

❷ The 8253B/8252B spectrum analyzer in the 141T mainframe.



# Phase noise

We touched on the subject of the phase noise concept in the previous pages. Let's talk a little more about it.

An ideal Spectrum Analyzer. We said before that a **real Spectrum Analyzer** does not represent correctly an **ideal oscillator** output, due to its too wide bandwidth resolution, and we have seen that it will more behave like an ideal SA the narrower the bandwidth is.

Now let's imagine the opposite: we have an **ideal Spectrum Analyzer** and a **real oscillator**. Again we will not see just a vertical line, because of the oscillator's phase noise (and probably some other thing).

An ideal oscillator. The output of an ideal oscillator is usually a purely sinusoidal signal, which can be described mathematically as:

$$V(t) = A \bullet \cos(\omega t + \Phi).$$

That says that the oscillator's output V is a function of the time, with an amplitude that varies from maximum to zero following a sinusoidal law, with a fixed phase Φ. The amplitude module A, the frequency ω and the phase Φ are constant. A pure sinusoid that therefore appears as a single narrow spectral line, in the frequency domain, with all of its power at a single frequency.

A real oscillator. For a real-world oscillator the signal requires a slightly more complex function to be described:

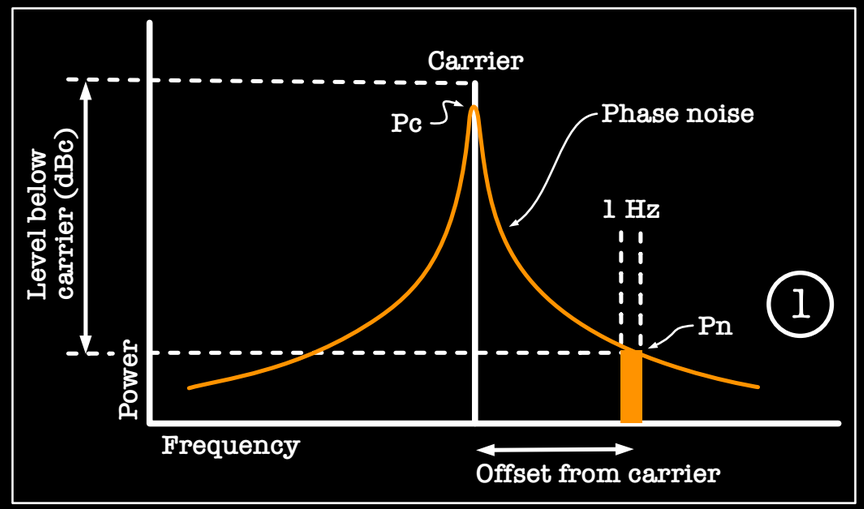
$$V(t) = A(t) \bullet \cos(\omega t + \Phi(t))$$

With this, we simply say that also the maximum amplitude A and the phase Φ are a function of time, i.e., they vary instead of remaining constants. In which way? The equation does not say it: their variations happen in an unpredictable or random fashion. In the time domain, phase variations cause a shifting of where the sinusoid crosses the x-axis: a phenomenon often referred to as jitter. In the frequency domain, these variations create sidebands extending out from both sides of the ideal carrier.

Generally phase noise is not desirable and must be minimized. For example, in the local oscillator of a superheterodyne receiver, it can decrease sensitivity and selectivity.

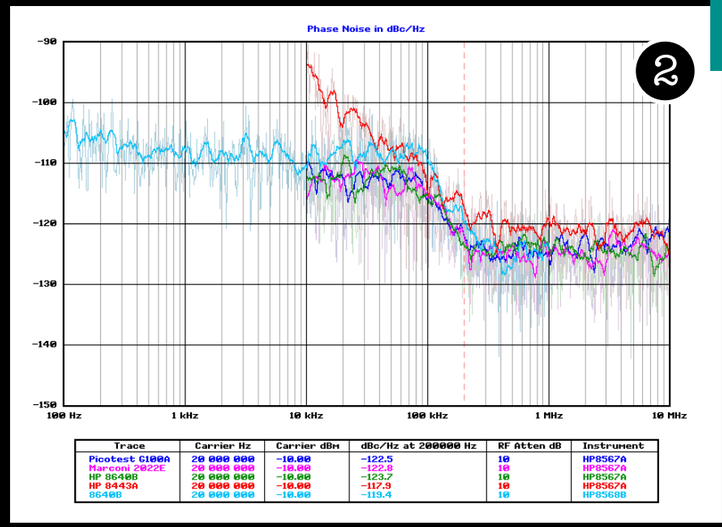
Measuring PN. The phase noise can be measured with a Spectrum Analyzer. The first step is measuring the






power of the carrier (Pc), that is, the nominal oscillator output signal, as an absolute power in dBm. Next, the noise power (Pn) within a 1 Hz bandwidth is measured at a given frequency offset from the carrier. Subtracting the carrier power from the noise power yields phase noise (L(f)) in units of dBc/Hz. Note that these values will always be negative. Phase noise measurements normally involve repeating this process at different frequency offsets from the carrier and producing the so-said phase noise plot, which is normally logarithmic also on the frequency axis to give a more detailed view in proximity of the carrier [part from Understanding phase noise fundamentals, Paul Denisowski, Rhode & Schwartz].

Obviously, the PN measurement will be more accurate with a narrow bandwidth resolution, confirming its importance in a Spectrum Analyzer. The 8568, with only 10 Hz, is thus an ideal instrument for this analysis




**❶ Phase noise definition. ❷ A Phase Noise Plot, obtained with the KE5FX free software (http://www.ke5fx.com/gpib/pn.htm). Note that all the plots have been taken on the 8567A, except the cyan one that extends below 10 kHz thanks to the 8568B bandwidth.**

# User experience

Thanks to the microprocessor based architecture, the front panel concept of the 8568A was completely new in front of previous generation equipment, and produced a completely new user experience, even if that term had not been coined at the time.

Almost no instrument had got a keyboard before, or a multi-function knob, or was so simple to use.

To activate a function the user just need to push the appropriate key. Most keys has a second function that can be activated with the SHIFT key (only a letter is reported on the panel for the second function, see the manual for the complete list).

Data values can be inputted using the main knob, the step keys or the keyboard, something never seen before, and the functions selected by pressing a button.

All the setting are shown on the CRT, which deserved now the “display” name, and a hardcopy of it could be printed on a plotter (and thus, all the settings associated to the recorded trace were printed as well).



# Exceptional quality CRTs

Since the 8568B's approach to front-panel does not provide settings indication with the traditional knobs, the display becomes the primary means of annunciating operating conditions. To avoid confusion with signal trace data, all status information is displayed on the periphery of the 10×10-division graticule. One exception is the "active function", with its current values. For example, the MARKER Δ in the photo here, with the delta value for frequency and amplitude.

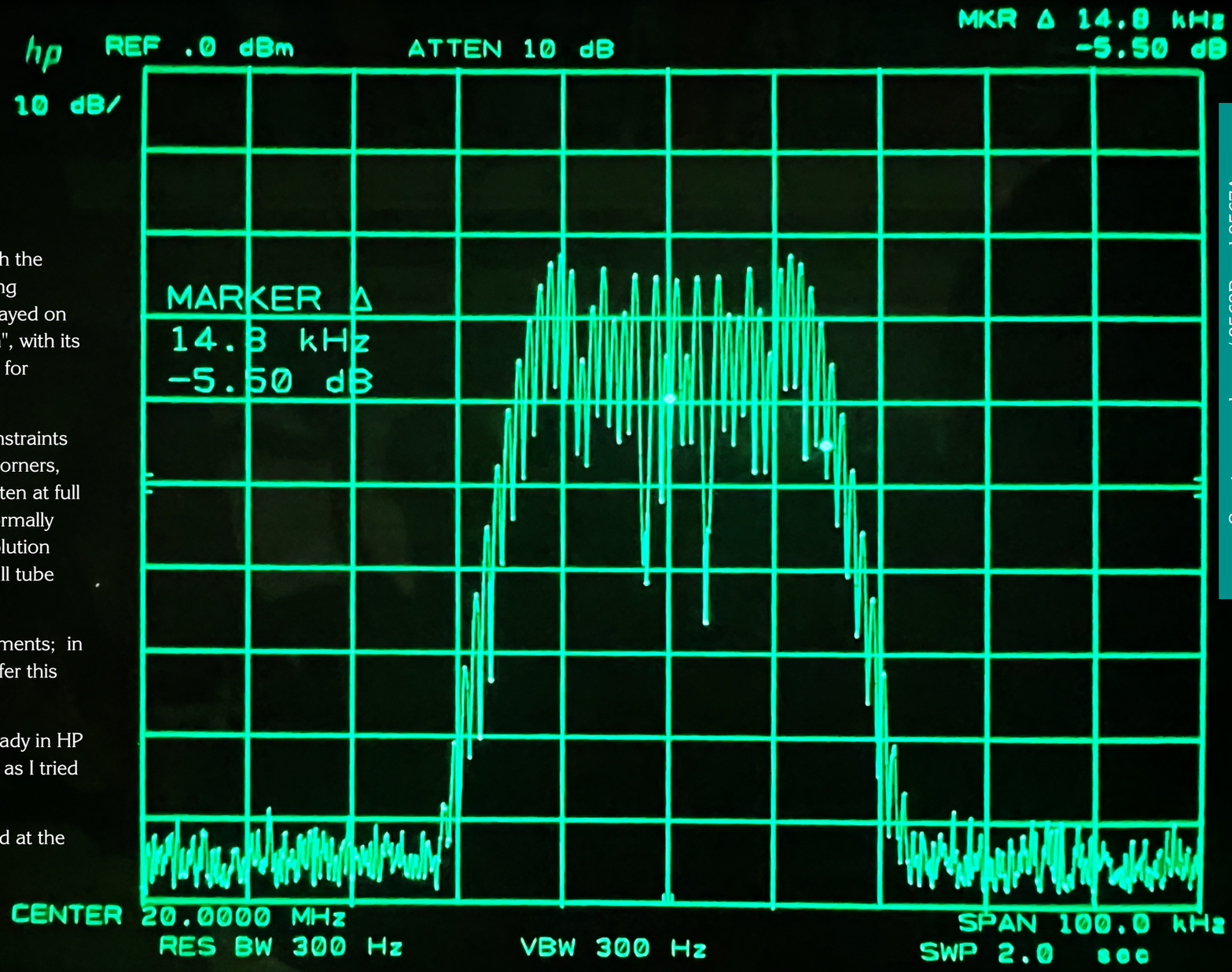
This display usage improves the human-machine interface but imposes critical constraints on the CRT. For example, any CRT beam defocussing is most pronounced at the corners, where status information is written in small characters. Also, graticule lines are written at full beam intensity because of the large beam deflections incurred, a condition that normally causes significant defocussing. These constraints require the choice of a high-resolution CRT with tight control of beam spot size as well as adequate brightness over the full tube face.

Standard oscilloscope CRTs, optimized for other needs, do not meet these requirements;  in my opinion, none of the CRTs of the oscilloscopes described in my books could offer this level of performances.

HP had however the right answer in the 1332A X-Y display, a standard product already in HP catalog, from which they took the CRT for the 8568. Its quality level is exceptional, as I tried to reflect in this photo, despite resistance from my iPhone.

The resolution is not explicitly declared, but it was about 1024 x 1024, a true record at the time.

An improved CRT contrast filter was also developed to meet the diverse requirements of high visual contrast, RFI suppression, and operator safety.



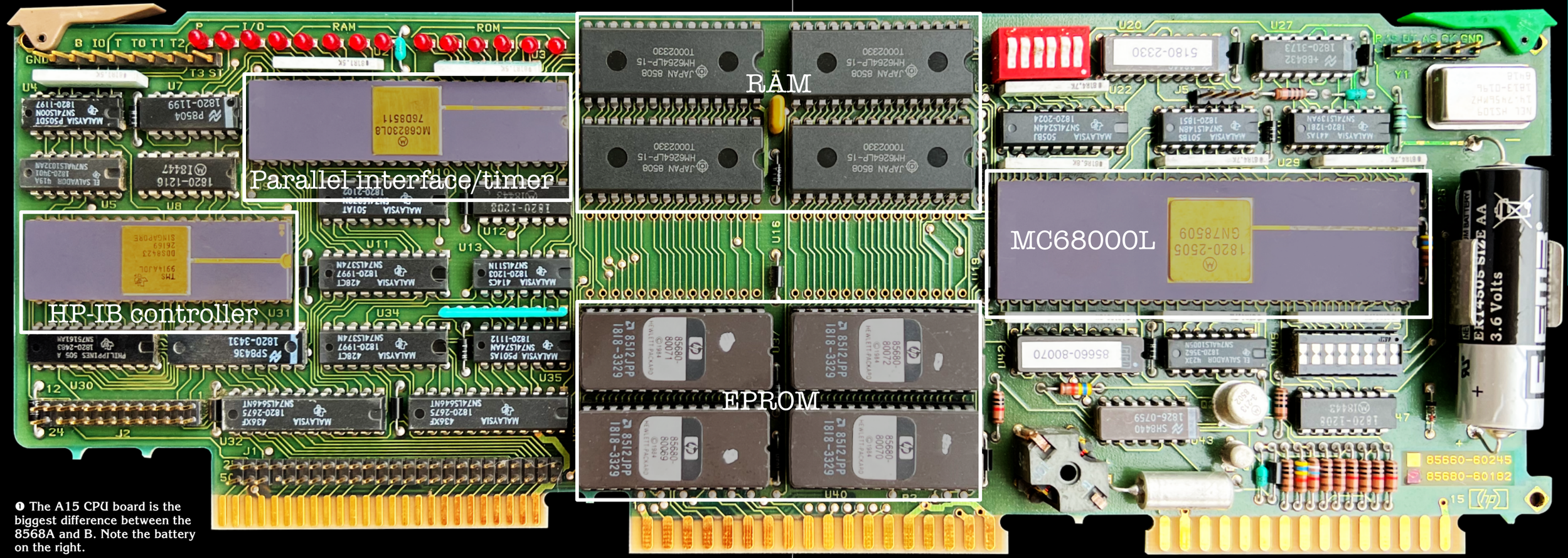
# The digital section

This is the part of the story that I can understand better, and so is moderately interesting to me, even if reminds me a lot of things of that time, when I was developing boards and the related software as well.

The board of my 8568B that you can see below is the main difference with the "A" model, and was introduced in 1985. The original design used the same 12-bit processor of the 9825 computer, at that moment among the best performing on the market. As we already noted, the processor part was the most prone to obsolescence, in a period when new micros were announced every day.

## Two units and three processors

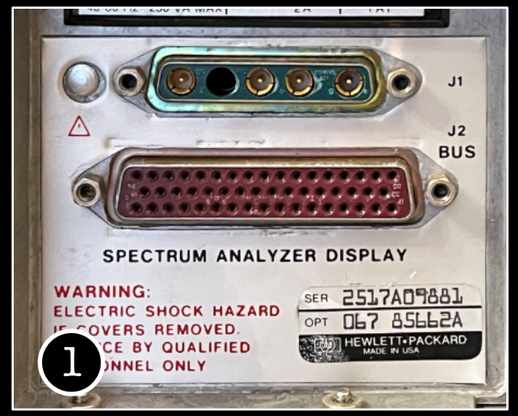
The block diagram ❷ on next page shows the overall architecture of the digital part. The analyzer is divided in two parts, the RF Unit (85680A) and the Display Unit (85662A), connected by two cables: one full-digital (50-pole), the other full-RF-analog, composed by four coaxial cables (❶). Three processors were used in total: the Main Processor, the Video Processor and the HP-IB Controller.

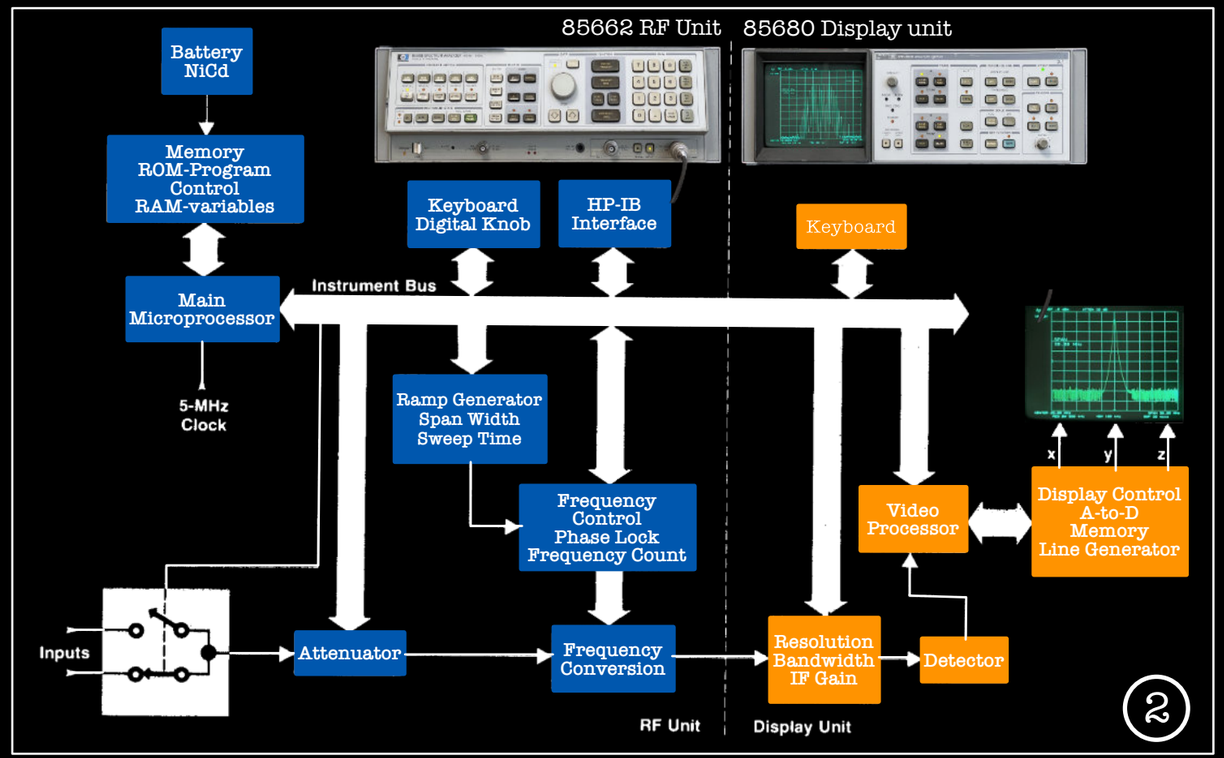



❶ The A15 CPU board is the biggest difference between the 8568A and B. Note the battery on the right.

## We have just the thing for you (main µP)

The choice of the first microprocessor was governed by the desired measurement resolution. Model 8568A has a frequency resolution of 1 Hz at 1500 MHz, which requires 10 decimal digits or 31 binary bits to represent a frequency. Thus, either a 10-digit BCD processor or one that handles double-precision 16-bit words was needed. At the time that development work on this instrument was getting under way, the only processor that appeared capable of doing the job was one under development in the desktop computer R&D labs at HP's Loveland, Colorado, facility. This microprocessor, intended to be used in the 9825A desktop

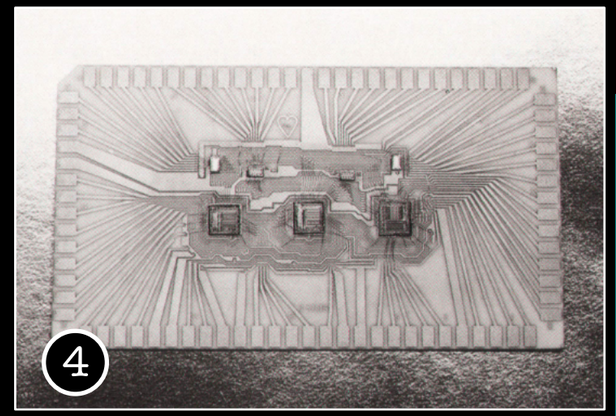











computer (❸), was 16 bits wide and had 12-digit BCD capability. The instruction set and processing speed were sufficient to permit real-time parameter modification with the tuning knob while also servicing the scan, the automatic phase lock, and the display update. These capabilities also enhanced the HP-IB operation.

This hybrid single chip (❹) was based upon an internally developed NMOS process that provided the 9825A Desktop Computer with a CPU that had the speed and power of the HP Model 2100A 16-bit Computers on a hybrid circuit (fig. 1) small enough to fit in a vest pocket. Two of these hybrids were used in the Model 9845A Desktop Computer. As noted, a different CPU was chosen for the B model, a standard Motorola MC68000L.

## The video section

The display system went beyond the digital-storage and character-generating systems found in previous spectrum analyzers where the user made readings by comparing the trace on the CRT to a reference line on a fixed graticule. Besides digitizing and displaying data, the 85662A display system of the 8568A provided display capabilities such as marker readout, graticule generation, presentation of three data traces and labels for measurement documentation, and other features normally found at the time only in graphics display equipment. These capabilities simplified the operation of 8568A and made the measurement results easy to interpret.

❶ The connector that link the 85662A Display Unit to the RF Section. The whole internal bus runs through the bigger cable. Note the multiple RF connection of the smaller one. ❷ The 8568A overall block diagram. ❸ The 9825A computer, "donor" of the microprocessor architecture, could remain fully operational when opened for servicing, thanks to the hinged printed circuit boards, that made accessible both their sides. ❹ The 9825A hybrid CPU here; it seems that they didn't give it a commercial name, as we use today.

A block diagram of the display system is shown here on the right. The system had been built around a separate, 12-bit digital processor responsible for the three tasks of signal processing, communications with the instrument's main processor, and display processing. The signal processing task includes detection, digitization, storage into memory, and the data calculations for the max hold and normalization functions. Communications with the main processor are handled between sweeps or while the progress of the sweep is suspended. Information going to the main processor includes measurement data, memory contents, and present position of the frequency sweep. Information coming from the main processor includes signal conditioning commands, processed data, and the description of the CRT display contents. The display description is sent in the form of a display program and stored in memory. The display program, by allowing looping and the use of subroutines, is a more efficient means of describing the display than an ordered list of X-Y pairs.

## The HP-IB interface

For the HP-IB interface an 8-bit microprocessor architecture was selected. This freed the main instrument controller from handling the HP-IB protocol. In addition, the power of the microprocessor allows pre-processing of the incoming data. This is mainly concerned with interpreting the 171 mnemonics for the main instrument controller, which defines the front-panel keys in terms of the single ASCII code character printed adjacent to each key. For example, when the HP-IB microprocessor receives CF, it converts it to v, the character adjacent to the CENTER FREQUENCY key, and passes it to the main controller, but we will see later more in depth.

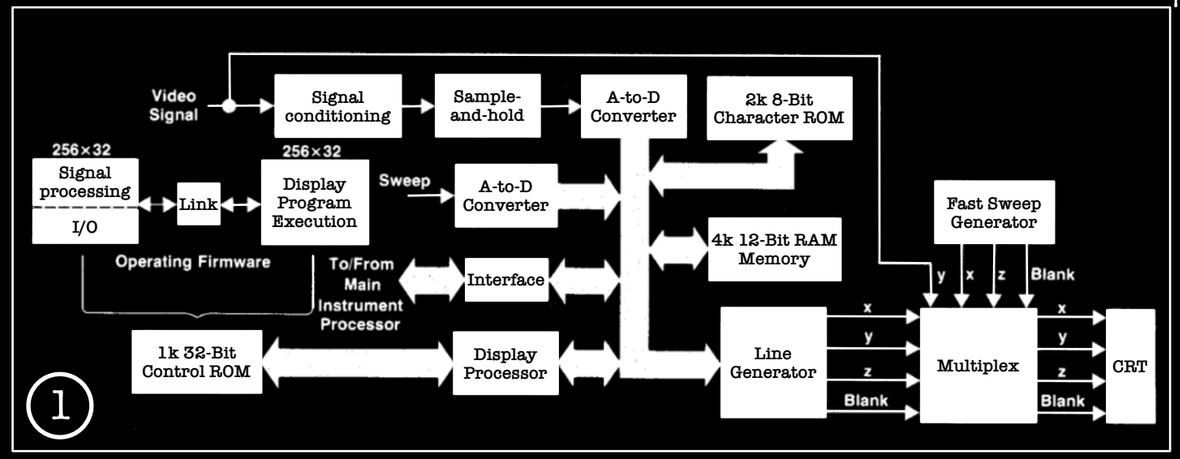
## A modular approach

It was decided to design the hardware on a modular basis with a minimum amount of interfacing between modules. The primary interface is to the 50-line main microprocessor bus, that travels also to the Display Unit by means of the connecting cables that we already described.

## Firmware development

Since the microprocessor hardware was not available initially, the software needed to be hardware independent. The first instrument prototype actually used a minicomputer as a controller. As the design progressed, various configurations of the microprocessor were used as they became available. To deal with these design constraints, a high-level language (ALGOL) was used for writing the instrument's control programs. As always for old gears, you will expect that I tell you that I had a love story with ALGOL, but it is not so. Sure, I heard at the time of ALGOL, but I never had the opportunity to deal with it. I learn today that






**Develop. tools implementation**

| Software Tool | Language | Number of Source Lines | Number of Machine Instructions |
|---|---|---|---|
| ALGOL compiler | Tree Meta | 1132 | 25747 |
| ASSEMBLER | Tree Meta<br>HP 2100 ass'y | 300<br>400 | 10709 |
| LOADER | Tree Meta | 200 | 7094 |
| OPTIMIZER | Tree Meta | 185 | 7646 |
| Subroutines shared by above | HP 2100 ass'y | 1340 | included in above |
| XREFS | Tree Meta | 230 | 6900 |
| Other tools | Tree Meta | 450 | 12750 |

2

**Instrument implementation**

| Routine | Language | Number of Source Lines | Number of Machine Instructions |
|---|---|---|---|
| Main control | ALGOL | 2325 | 12672 |
| Math and service routines | Assembly | 1915 | 1429 |
| Processor verify routine | Assembly | 390 | 291 |
| Speed critical routines | Assembly | 560 | 456 |

3

ALGOL is considered the forerunner of many other programming languages, including PL/I, Pascal, and C. For example, it introduced code blocks and the begin...end pairs for delimiting them.

There were several reasons for choosing a high-level language, most of which are obvious today: higher developers' productivity, hardware independency, simpler documentation etc. Where the speed or efficiency of the language was insufficient, there was always the possibility of resorting to assembly language, though improvements in the compiler or high-level code would be tried first. Indeed, the HP's task was not only the 8568A code development but as well the development of the development tools, what today is called the Software Developer's Kit, including the ALGOL compiler itself. The adjacent tables show the amount of code written. The HP Journal from which I took the information, says that an average of 12.5 lines of code of high-level language, was written per working day during the course of the project.

Surprising the small quantities of code written: in this memory space, today we don't even fit an icon…

**❶ Video section block diagram. ❷ Code written to build the development tools. ❸ Code written for the instrument itself.**

# Measurement aids

Measurements can be made following conventional "zoom" techniques using the center frequency, frequency span and reference level functions, or with the help of certain measurement aids. A preset button sets all analyzer controls to a convenient starting point; coupled functions, such as resolution bandwidth and sweep time change automatically as frequency span is reduced to maintain a calibrated display. A tunable marker is available for directly measuring a signal or speeding the process of magnifying the portion of the spectrum to be analyzed.

With the marker set to the signal peak, the signal's amplitude and frequency, to counter accuracy, are numerically displayed on the CRT. A second marker, useful for modulation or distortion measurements, makes relative measurements by displaying the difference in amplitude and frequency between the two markers. Marker information enables the operator to step between evenly spaced portions of the frequency spectrum such as communication channels or signal harmonics; the noise level at the marker can be converted to RMS noise density normalized to a 1 Hz bandwidth. The marker may also be positioned at the peak of the largest signal on the screen and used to zoom-in on signals automatically.

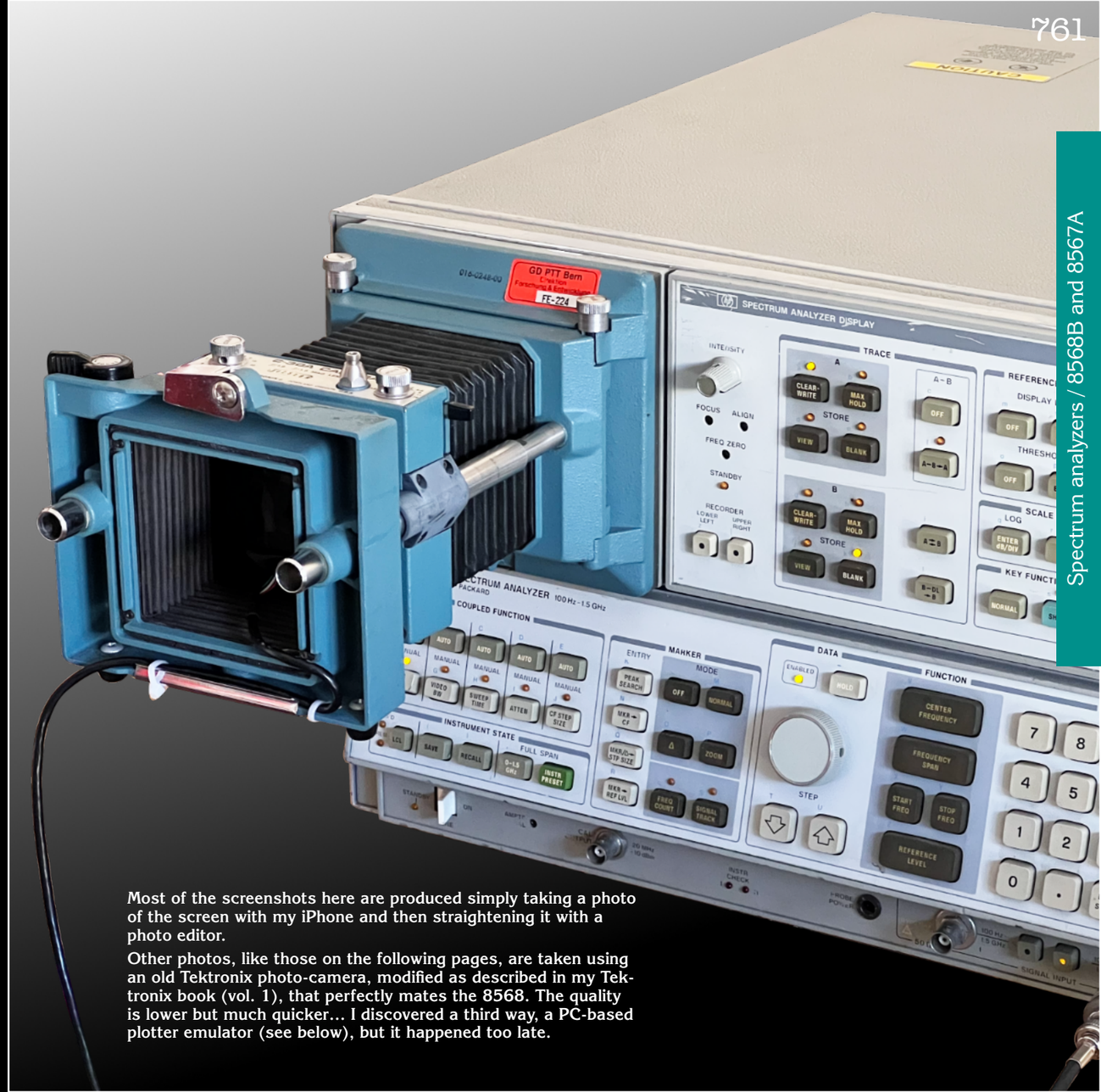
Once the analyzer's controls have been adjusted, all settings can be saved in memory and later recalled to repeat the measurements. An internal battery maintains the contents of memory in the event of a power failure.

All displayed information resides in a digital memory from which the CRT is refreshed at a flicker-free rate. Display titles may be added. A trace may be viewed real-time or stored; max hold displays the largest amplitude at 1001 points across the CRT over successive sweeps to aid in the measurement of residual FM or drift. Up to three traces may be observed simultaneously and arithmetic between traces or a trace and reference display line is possible for comparison or frequency response normalization.

Most of the above functions are absolutely common today, but perhaps you can imagine what it meant in 1978 only if you directly lived that experience, passing to all that from the world before, made up of rotary knobs and mechanical gears.








Most of the screenshots here are produced simply taking a photo of the screen with my iPhone and then straightening it with a photo editor.

Other photos, like those on the following pages, are taken using an old Tektronix photo-camera, modified as described in my Tektronix book (vol. 1), that perfectly mates the 8568. The quality is lower but much quicker... I discovered a third way, a PC-based plotter emulator (see below), but it happened too late.

# AM modulation

Let's present an example to show how easy could be measuring the percentage modulation of a signal for three different signal generators:

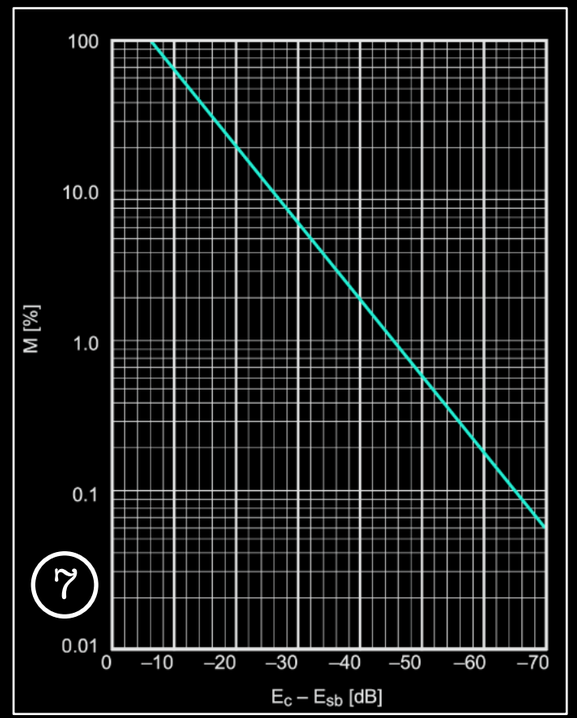
- my beloved HP8640B;
- a Marconi 2022E;
- a very good Picotest G5100. Incredibly similar to HP 33220A, maybe HP just rebranded it?

They all are set for 20 MHz, -10 dBm, modulated 10% with 1 kHz sine wave. On the 8568B you must only connect the signal, press CENTER FREQUENCY, 2 0 MHz, FREQUENCY SPAN 20 kHz, PEAK SEARCH, Δ, ↑ (up arrow). In this mode you get the diagrams shown in the photos here.

The modulation frequency is shown on the left and is almost 1 kHz for all. How to get the modulation percentage? Just look at the table here; the sideband peaks are about 25 dB lower than the carrier. So, according the table, the modulation is about 10%.

Note that not all signal generators behave in the same way. The Picotest has not any sign of distortion in the modulating signal (there are not other sidebands). The 8640B has small signs of distortion, while the Marconi is the worst with two extra sidebands.

For greater modulation indexes you could find better to set the SA in LINEAR mode (and in volt). The modulation index is (2 x Vsideband) / Vcarrier.




❶❷ The Hewlett-Packard 8640B signal generator, described in this book and its signal spectrum.

❸❹ The Marconi Instruments 2022E.

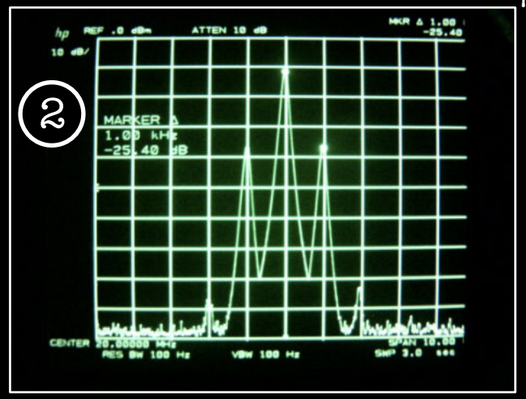
❺❻ The Picotest G5100.

❼ This table allows to calculate the modulation index as a function of the level difference between the carrier and the sidebands level. It is taken from the very well done "Guide to Spectrum and Signal Analysis" (by Anritsu), that I recommend as a valuable information source.



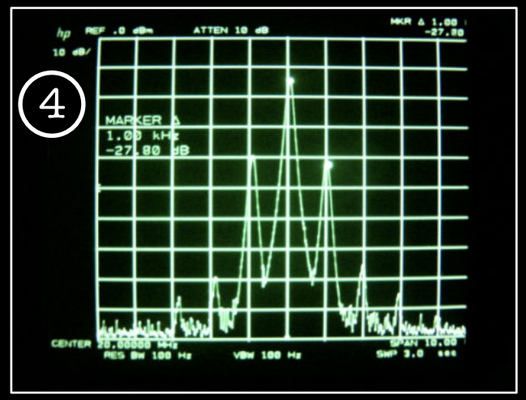




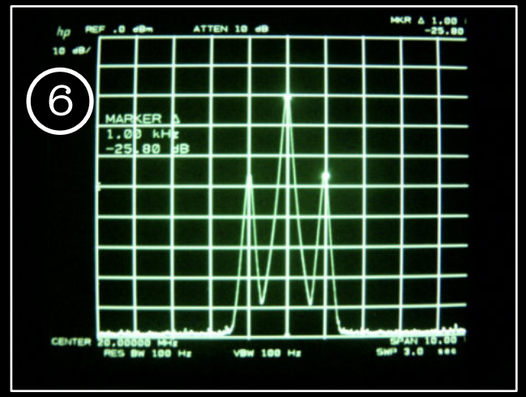












# Programmability

## Never by chance

This is an important and not new topic on which we will dwell a bit. Programmability is something related to the basic structure of the instrument. To be programmable, a device must be able to adjust its controls upon the reception of a command. It's evident that one thing is to design equipment with potentiometers, switches, variable capacitors or inductors that can be actuated by hand by the human operator; a completely different thing is making the device virtually rotate them when we ask it to do so.

## Structurally ready to be controlled

The design of the 8568A allows controlling it via the HP Interface Bus (HP-IB or GP-IB, IEEE Standard 488-1975, see below). Almost everything that can be done by the front panel can be issued remotely; even better, the remote control enables many other functions that are not possible from the front panel.

For example, the analyzer can be tuned with the precision of a synthesizer (while retaining analog sweep and exceptional spectral purity). Its internal architecture facilitates the remote programming of all function settings and the output of CRT trace and marker readout information; the display itself is accessible for annotation purposes or to draw traces or graphics.

## A measurement system

Thanks to this architecture, the analyzer becomes a measurement system that can operate standing alone or under the control of a computer and that can be programmed in different ways; we are now far beyond the pervious generation instruments No wonder that the 8568B has been so much appreciated until nowadays.

## Tektronix 7854

HP had to solve a problem very similar to Tektronix, which, for the 7854, finally decided for an external keyboard with an HP-calculator-like logic. In my book about Tektronix (vol. 1), I precisely imagined the 7854 like a 7904 oscilloscope with an HP-67 inside and an HP-IB interface as well.

With the 7854, all the commands of its RPN language can be sent through the HP-IB, which reacts exactly as if the equivalent keys had been pressed on the Waveform Calculator (i.e., the bombastic name they gave to a simple external keyboard) or on the front panel. Commands are executed in the order in which they are received, regardless of the source of the command.

To send a command to the 7854 through the GPIB, the command mnemonic or numeric command is sent, as it appears on either of the 7854 keyboards, separating each mnemonic with a space.

## HP 8568B logic

HP went further with the 8568B, which accepts:

- command from the front panel;
- commands from the front panel, prefixed with the SHIFT key; however, they didn't report the shifted second meaning on the keyboard, but just a letter, so you need always the manual or the reference cards;
- commands stored in the analyzer, entering their mnemonic thru the front panel shifted keys. Definitely cumbersome and not practically usable;
- command sent in real time from a computer via HP-IB;
- command sent from a computer via HP-IB and stored in the analyzer and associated to a number (said "softkey"), recallable with the SHIFT key (e.g., SHIFT 100 followed by the **Hz/µV/µsec** key).

## Real time execution

In a short, you can send friendly commands from the HP-IB to the instrument, and they are executed in real time. Examples:

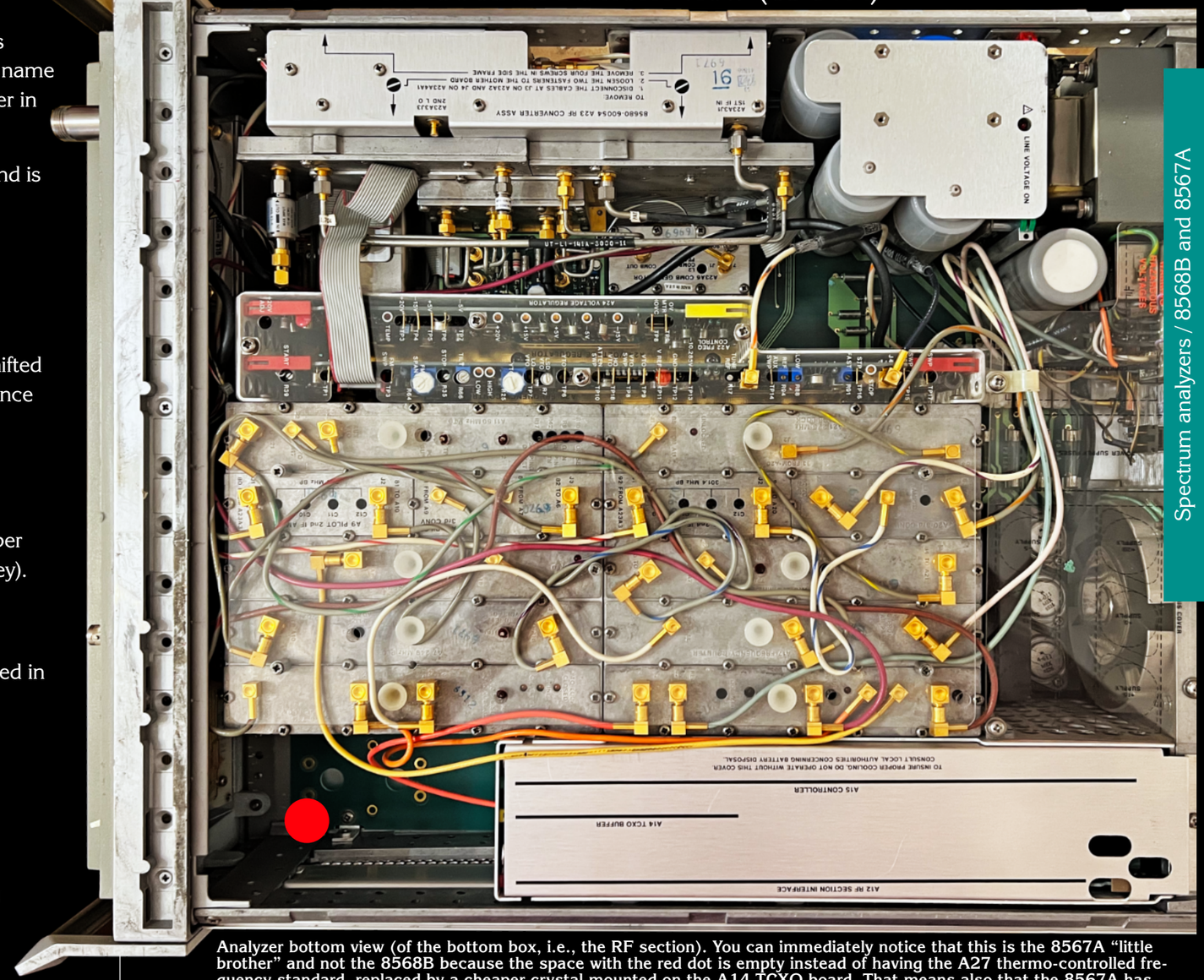
- `CF 20MZ` set center frequency to 20 MHz
- `SP 40KZ` set span to 40 kHz
- `CF?` request the current center frequency value
- `SP?` request the current span value
- `RB 100` set the resolution bandwidth to 100 Hz

Built-in firmware features such as instrument preset, peak search and zoom further simplify writing software.





# 85670B RF section bottom view (8567A)




Analyzer bottom view (of the bottom box, i.e., the RF section). You can immediately notice that this is the 8567A "little brother" and not the 8568B because the space with the red dot is empty instead of having the A27 thermo-controlled frequency standard, replaced by a cheaper crystal mounted on the A14 TCXO board. That means also that the 8567A has not the "OVEN COLD" message.

## Stored execution (DLP)

A downloadable program (DLP) is a program written in spectrum analyzer commands that is loaded into the analyzer's 16K bytes of RAM, and can be fully executed within the spectrum analyzer, whether run from the analyzer's front panel or from the computer. A DLP allows the analyzer to evaluate data it collects without the help of a controller. Powerful software can be written by using a DLP in a computer program, especially if the DLP and computer program utilize the high level functions of the "B".

You can send a list of commands to the analyzer, simply preceding them with the FUNCDEF command and include them between marks, to make them to be stored in the instrument's memory and not immediately executed. These command sequences are named functions and are practically programs, that can even call each other and include control statements like IF/THEN/ELSE, REPEAT/UNTIL etc. Let see a simple example:

- `DISPOSE ALL` clear all the memory
- `FUNCDEF Z_OOM, @IP; CF 100MZ; SP 10MZ` instrument preset then set center frequency=100MHz and span = 10 MHz

You can recall this function by simply sending Z_OOM via the HP-IB link.

## Learn mode

These functions may even be entered from the instrument front panel using "learn" mode, but it is really cumbersome and unpractical.

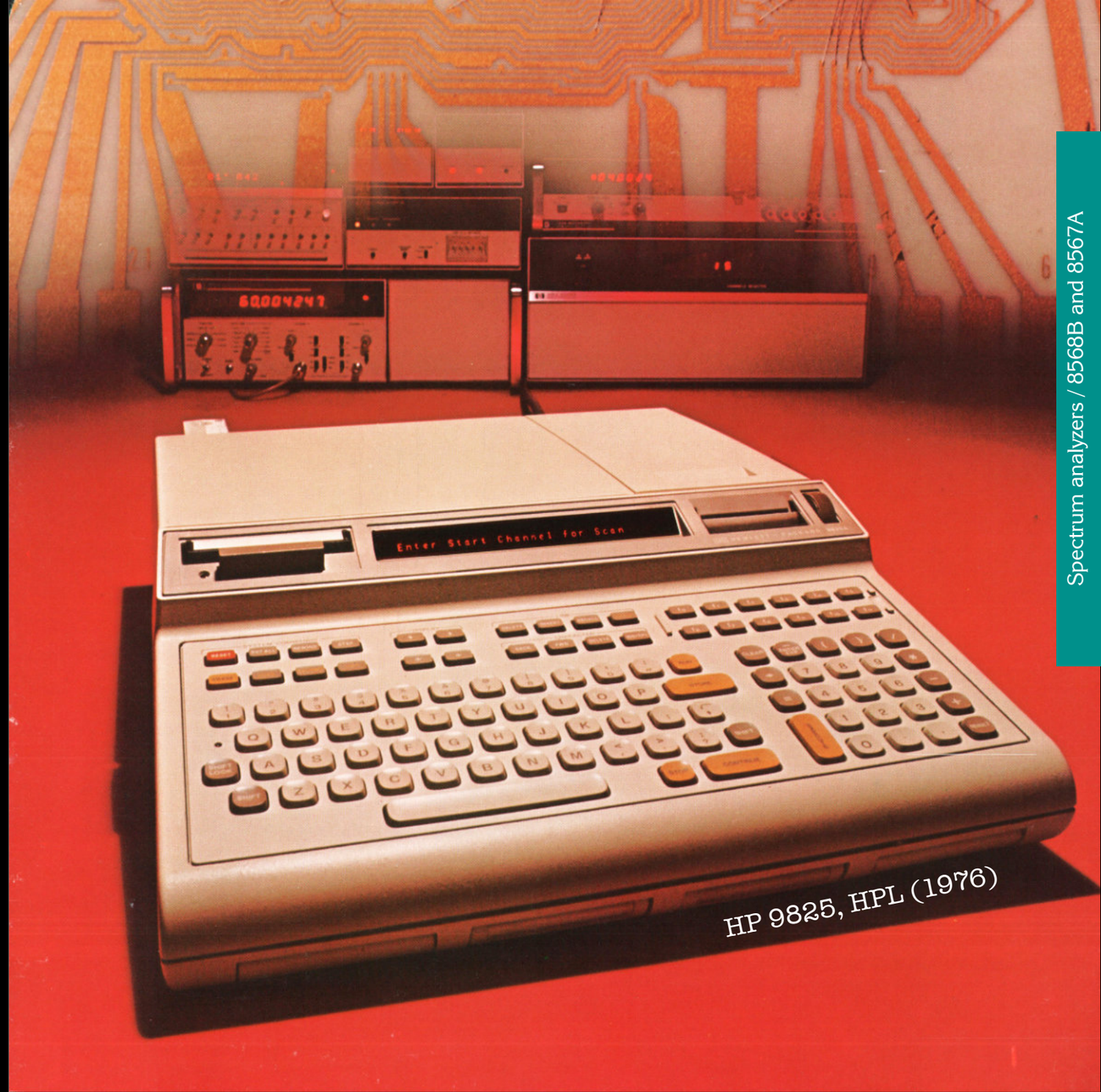
## Softkeys

It is possible to associate a code to a function with the KEYDEF command and then recall this function from the front panel pressing SHIFT followed by that code and by the **Hz/μV/μsec** key. E.g.:

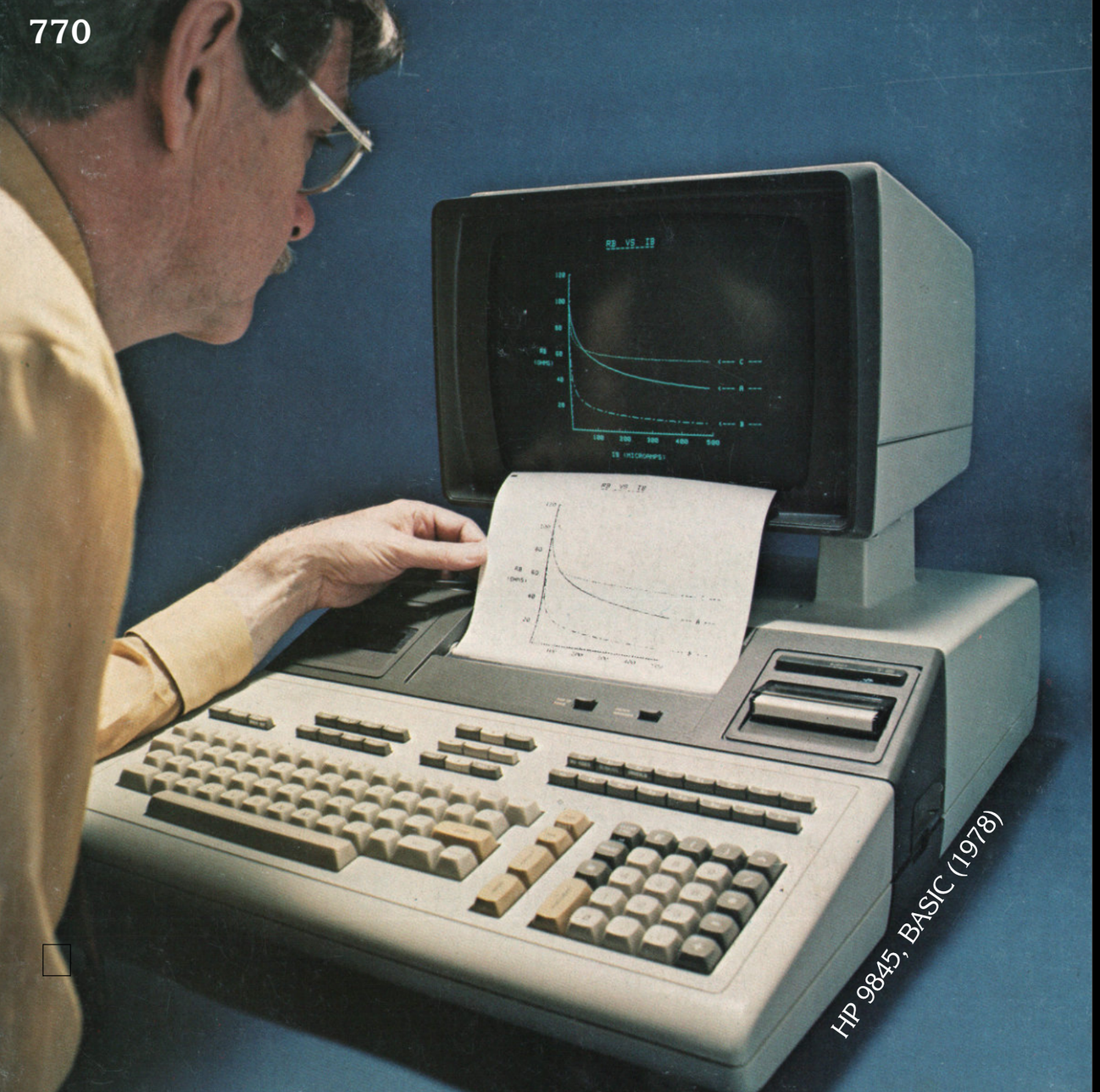
- `DISPOSE ALL` clear all the memory
- `KEYDEF 100, Z_OOM` link softkey 100 to the Z_OOM function. Press SHIFT 100 Hz to activate.

Either for immediate execution, either for storing them in the analyzer memory, you can send these commands in the way you prefer, e.g. via a serial terminal emulator, typing them with your hands

Softkey programming lets you develop the analyzer's measurement "personality" by allowing you to create custom firmware functions for your measurement needs.




HP 9825, HPL (1976)



HP 9845, BASIC (1978)





# Computer control

More often you will use a computer and a high-level language to send them in sequence, earning furthermore editing possibilities: using the program, you just modify it and run again. With a computer, you can also get the responses from the device and process them as you like, exploiting so the full computer power.

## Which computer?

In 1978, the Personal Computer as we know today was still far to come, while microcomputers were not yet ready for these challenges. With the word “computer”, they intended probably something like a 9825 with HPL language or a 9845 with BASIC (or any other HP computer).

Being instruments much more long-lived than computers (the 8568B has “buried” many computers…), years later, also the marvelous HP-85, described in this book, could be used as well, as we are going to see.

## Computer advantages

Today it is obvious, but the they felt the need to say that the primary advantage of computer control is the execution of complicated or time consuming measurement routines with a minimum of involvement by the operator.

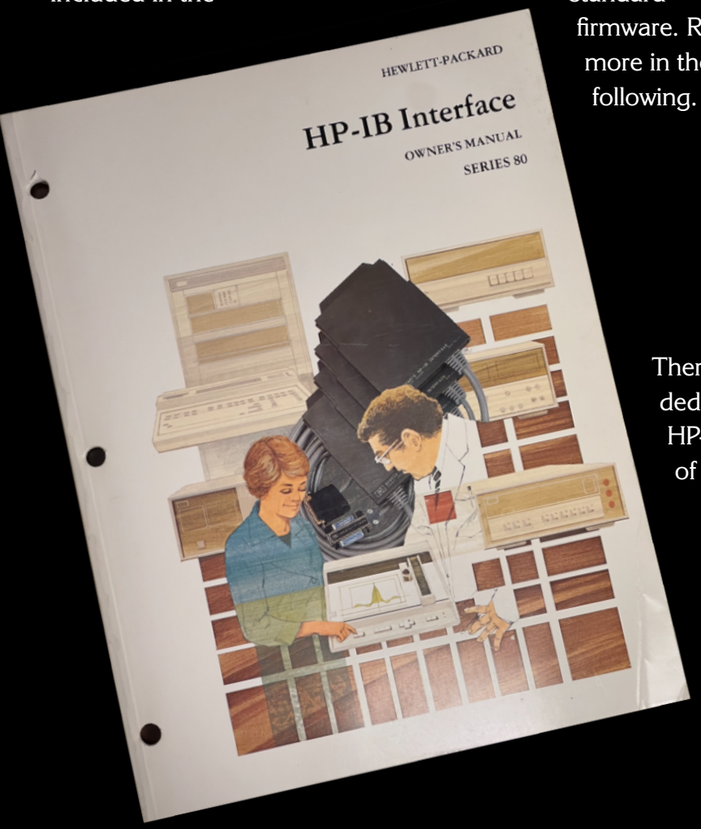
This capability is especially useful in production line testing or unattended measurement situations such as spectrum monitoring. An analyzer may be joined by other instruments in a distributed system, or be controlled remotely through a data communications network. External control is desirable for setting the proper analyzer function values, reading data, performing any numerical manipulation required (including error correction), analyzing the results, and providing output data in a convenient format on a printer, plotter, or the analyzer CRT.

## Fiddling with computers

I was very curious about HP-IB programming, that I never used, and started some tests using a Prologix USB interface with a simple terminal emulator. The 8568B answers correctly and so other instruments that I tried.

I find not very intriguing to use a modern computer with the 8568B. In addition, simple BASIC interpreters are no longer easy to setup, especially if you want to use serial ports; thus, I decided to try the HP-85 (also described in this book) as a system controller, buying a 82937A interface for it.

The HP-85 HP-IB interface was originally accompanied by its manual, that I could not find on the net. Luckily I own one, and that helped me to start. The I/O ROM is also required, but in my case, being my HP-85 of the B type, that I/O ROM is already included in the standard firmware. Read more in the following.




```
10 S=7 @ ! VARIABLE S IS SELECT CODE
20 SET TIMEOUT S;500
30 ON TIMEOUT S GOTO 100
40 FOR I=0 TO 31
50 DISP "SPOLL DEVICE # ";I
60 S1=SPOLL(S*100+I)
70 PRINT "DEVICE ";I;" NOT PRESENT"
80 NEXT I
90 STOP
100 ABORTIO 7
110 PRINT "DEVICE ";I;" NOT
120 GOTO 80
130 END
```

There is a chapter dedicated to the HP-IB at the end of the book.





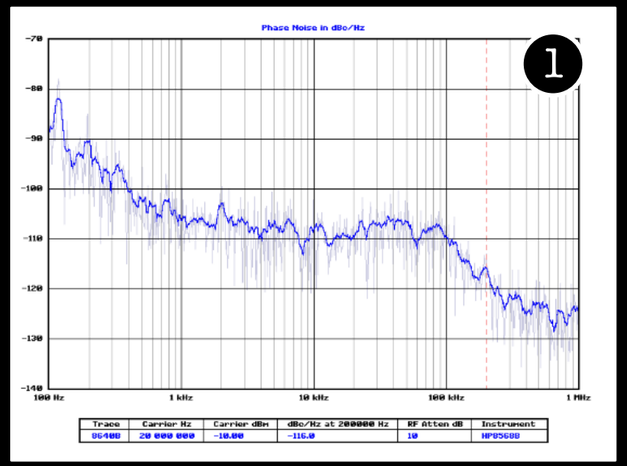


# Third-party software

When you setup the HP-IB interface you can use it to develop your programs, an activity that I find very intriguing. You can also use as well programs developed by HP or third party, to better exploit the capabilities of this Spectrum Analyzer. Here you can find two examples, both from wonderful KE5FX (John Miles) web site.

## Phase noise measurement

PN.EXE is a graphical Win32 application that lets you acquire, display, overlay, caption, and print noise plot (.PNP) files. It offers many of the capabilities provided by Agilent's 85671A phase-noise measurement package (diagram ❶).



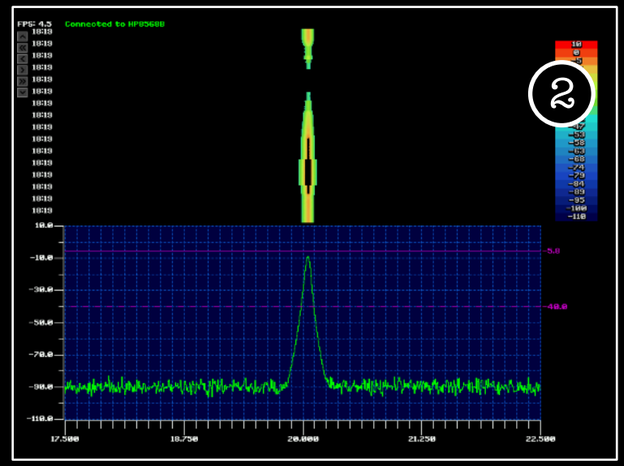

## Spectrum surveillance

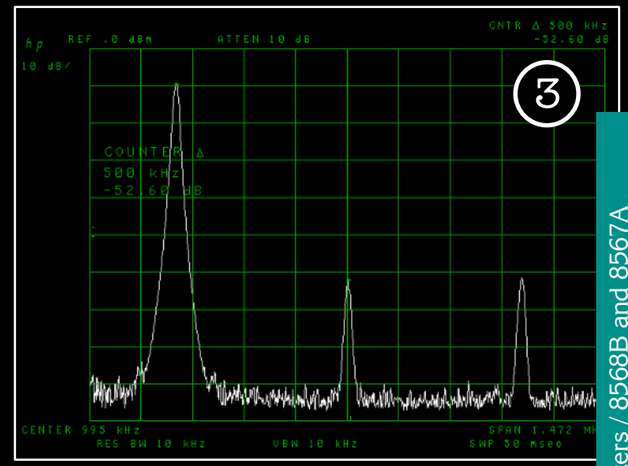
SSM.EXE is a graphical Win32 program that lets you acquire a succession of spectrum-analyzer display traces over time, with the option to save and replay the acquired data (diagram ❷). Applications include long-term stability testing, RF interference and link-quality surveys, weak-signal communications, and signal intelligence/TSCM work.

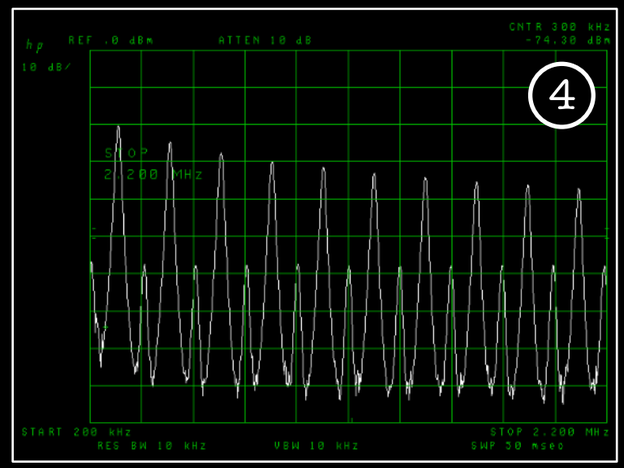
## 7470A plotter emulator

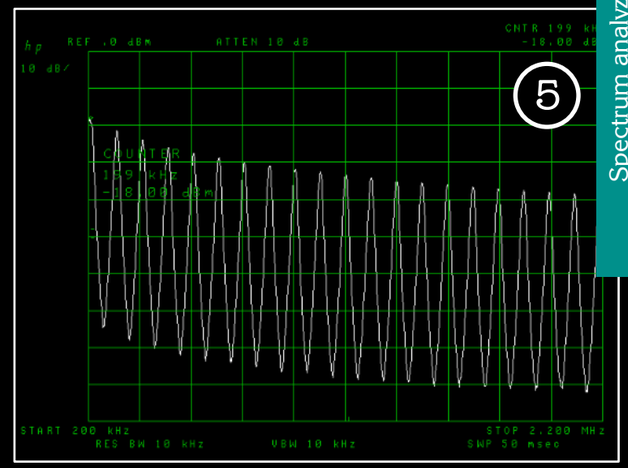
7470.exe is a Win32-based emulator for the HP 7470A plotter. It will acquire an HP-GL/2 plot and render it in a window. The plot can then be printed, viewed as an overlay with other plots, or saved in several different graphics file formats as well as its original HP-GL/2 format (diagrams ❸, ❹, and ❺).

**❶ The phase noise plot of my 8640B (8568B). ❷ Spectrum surveillance; in black the zones outside the limits set by the user (8568B). ❸ A carrier and its spurious emissions. ❹ The typical harmonics of a square wave. ❺ Harmonics of a sawtooth wave.**




With the help of 7470.exe, you can capture screenshots from GPIB-based test equipment such as digital oscilloscopes, spectrum analyzers, logic analyzers, and more. 7470.exe can even recognize certain instrument models and and request plots from them without user access to their front-panel controls. I tested it and produced the diagrams on front page. With the 8567A or the 8568B is very easy to use and it didn't give me problems. Just choose the analyzer type from the GPIB menu and press the button RECORDER/LOWER LEFT. With HP 54202 or Tektronix 2430A/2440 it was not so easy and the results were not so good. The http://www.ke5fx.com web site contains many other free applications.

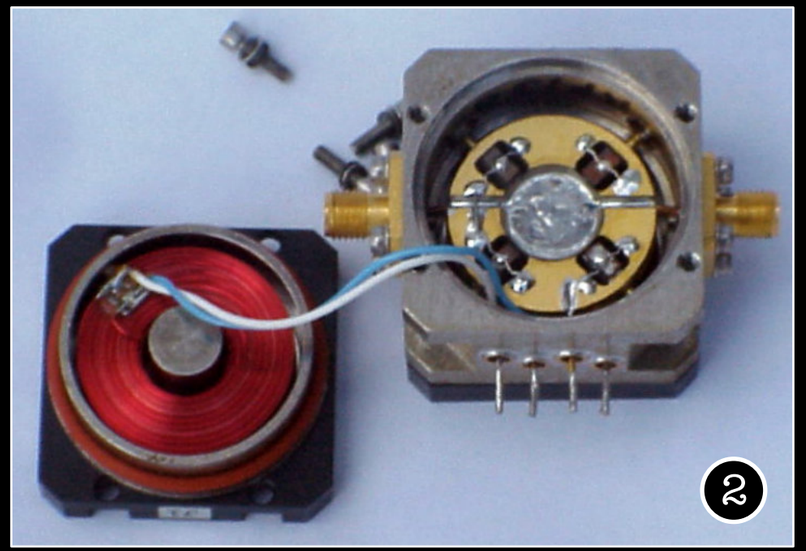
# An Yttrium hearth

## YIG, what's that?

I had never heard of YIG before, and was rather annoyed by the fact that neither the manuals, neither the HP Journal gave information about the main oscillator, named YTO (YIG Tuned Oscillator), that, furthermore, was my first problem with my new 8568B, as I will tell you in the diary part of this chapter. From the schematic diagram, I could only understand that was something capable to generate a frequency as a function of a current. Almost hopeless, I tried to search Google about YIG oscillators, and I discovered a world of information I never knew.

The YIG Tuned Oscillator (YTO) is the only direct signal source to provide multi octave tuning bandwidths in excess of 10 GHz. In this case, it ranges from 2,050 to 3,550 MHz.

The heart of the YIG Tuned Oscillator is the YIG sphere. YIG (Yttrium, Iron and Garnet) spheres are manufactured from a synthetic crystalline structure, which is grown in platinum crucibles. These batches of crystal are then diced, tumbled, ground and polished into very small spheres. For most applications the nominal diameter of YIG spheres is in the order of 0,5 mm.

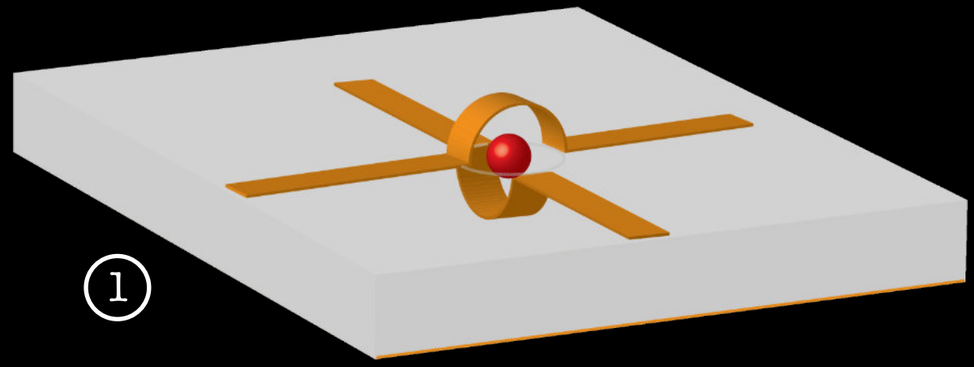



Due to the ferrite properties of YIG spheres, they resonate at microwave frequencies when immersed in a magnetic field. The frequency of resonance is very linear and increases at a rate of 2.8 MHz per gauss of applied field.

The YTO is tuned using the "Main Coil", which creates an electromagnet from the oscillator housing. Proper

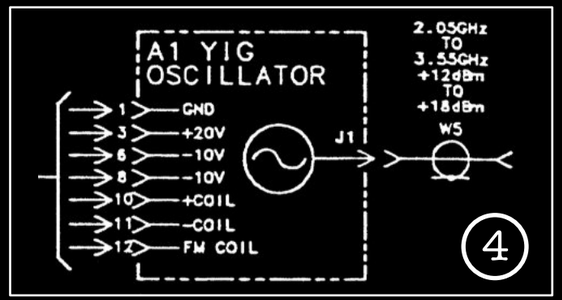


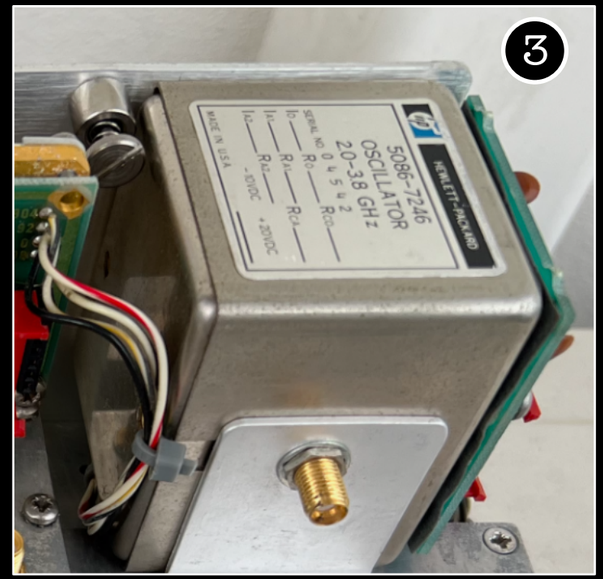





circuits are provided from the 8568 to generate this magnetic field.

Hyper-technological inside, from a practical point of view, it is a very simple object, as you can see in the electric diagram reported here. Note a separate coil for the frequency modulation.




❶ Simplified schematics of YIG-resonator coupling to micro-strip network (By c.w. - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=36884929)

❷ YIG filter partially disassembled. The electromagnet is on the left. The module with YIG sphere and input and output coils is on the right. (By Avpu - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=6969531)

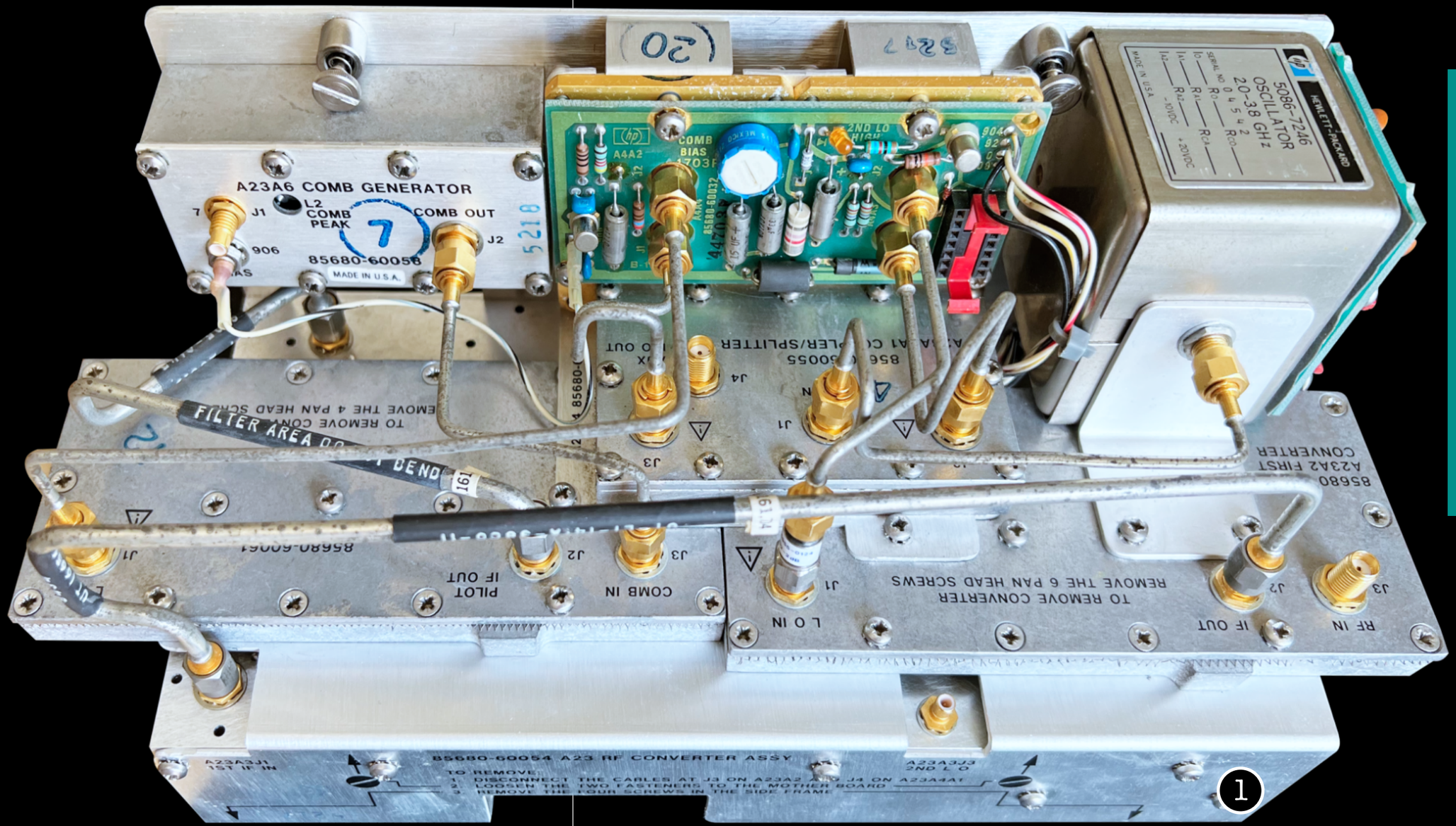
❸ The 8568 YTO is identified as A23A1 in the manuals and is contained in the RF section A23.

❹ The YTO in the electrical schematic diagram.Besides the power supply, it requires only the current for the main coil and for the frequency modulation coil.

# The RF section

The basic concept in Model 8568's RF section follows traditional practice (block diagram ❶). The input signal is up-converted to 2 GHz, so that image frequencies can be removed by low-pass filtering at the input, then down-converted to the 20-MHz IF in two steps, so that unwanted sidebands from the mixing processes can be removed. Resolution bandwidth filtering occurs in the IF section.

High resolution and programmability imposed rigid requirements on the performance of the analyzer's RF system, shown in block diagram form in. Measurement accuracy requires a know-edge of the exact amount of frequency translation that occurs as the input signal is converted to the fixed intermediate frequency where bandwidth filtering occurs, and the local oscillator's residual FM must be held to less than 1 Hz, a level commensurate



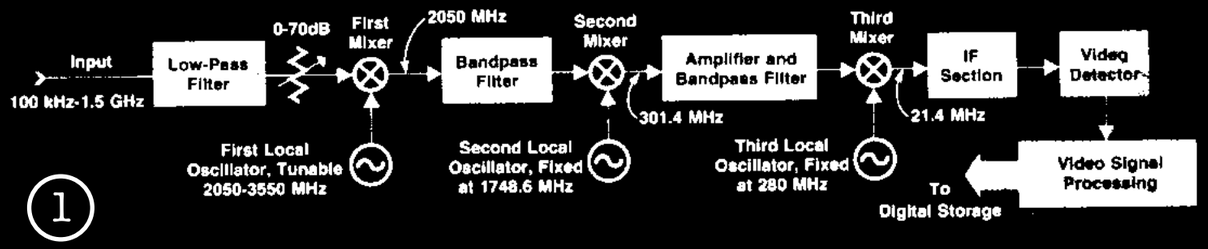
with the 10-Hz narrowest resolution bandwidth of the 8568. The 90-dB display range called for a reduction in the local oscillator's phase noise of 20 dB over that of the best of previous analyzers operating up to 1500 MHz.

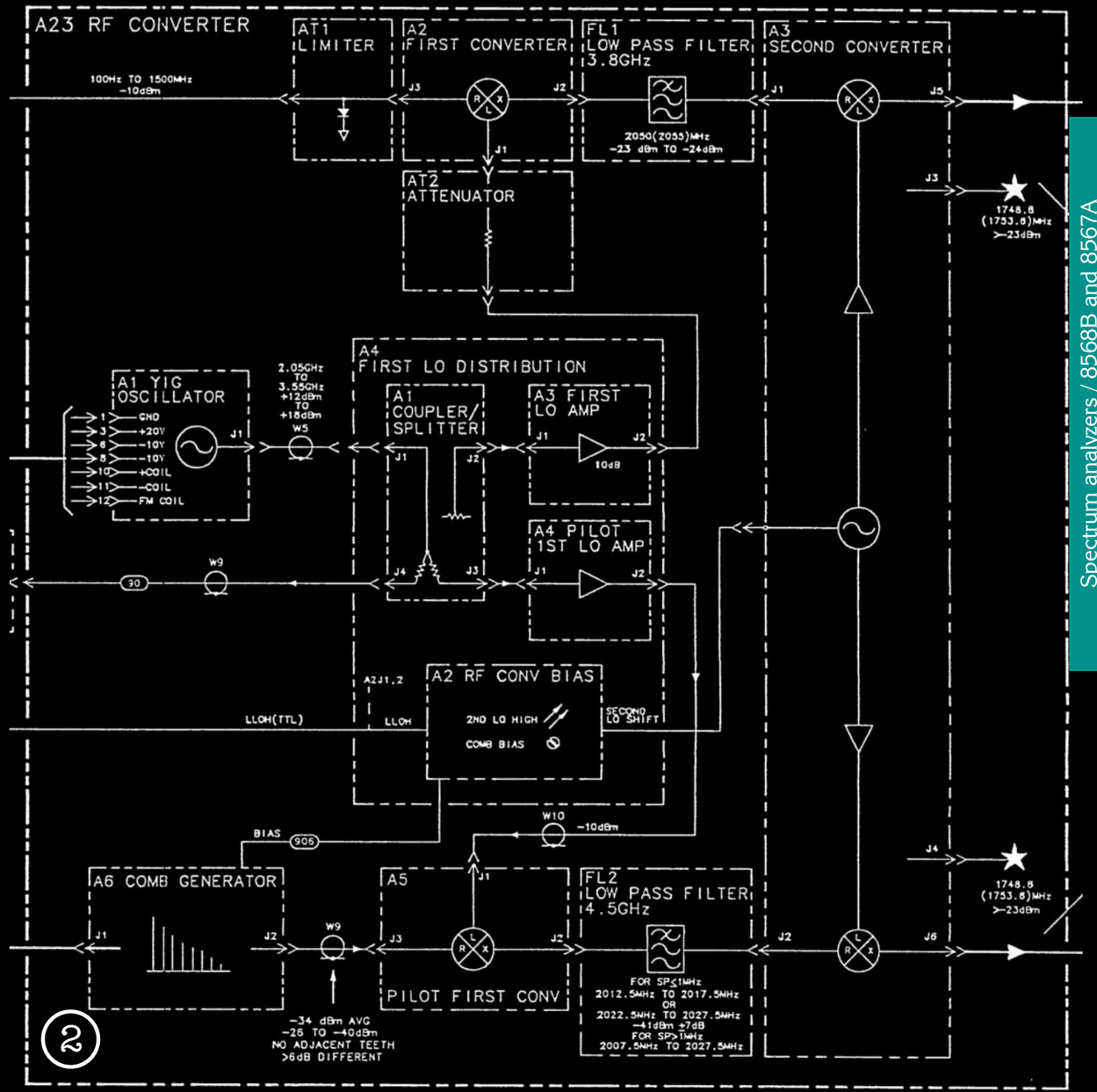
It was clear that merely improving on previous methods of stabilizing the RF system would not give the desired performance because these methods stabilize only the first local oscillator. Furthermore, they provide no frequency information about any of the local oscillators. Therefore, to achieve the required low phase noise, plus frequency stability and accuracy, a new phase-lock system that locks all the local oscillators in one loop was devised.

The new phase-lock system, shown in fig. ❷, uses a second frequency-conversion path driven by the same local oscillators that drive the measurement signal path. The input to this "pilot" path is derived from a 20-MHz reference that is accurately controlled in frequency and that has very low phase noise.

The reference frequency is formed into very narrow pulses in a comb generator to obtain harmonics to greater than 1500 MHz. The 20-MHz harmonic closest to the selected center frequency is converted to the IF in the pilot path and appears at the phase detector as fpl3. This is compared with a 20-MHz signal from the reference oscillator and the resulting correction signal tunes the first local oscillator in the proper direction to achieve phase lock. Once the loop is locked, any phase noise, instability, or drift in any of the three local oscillators is cancelled by the loop.

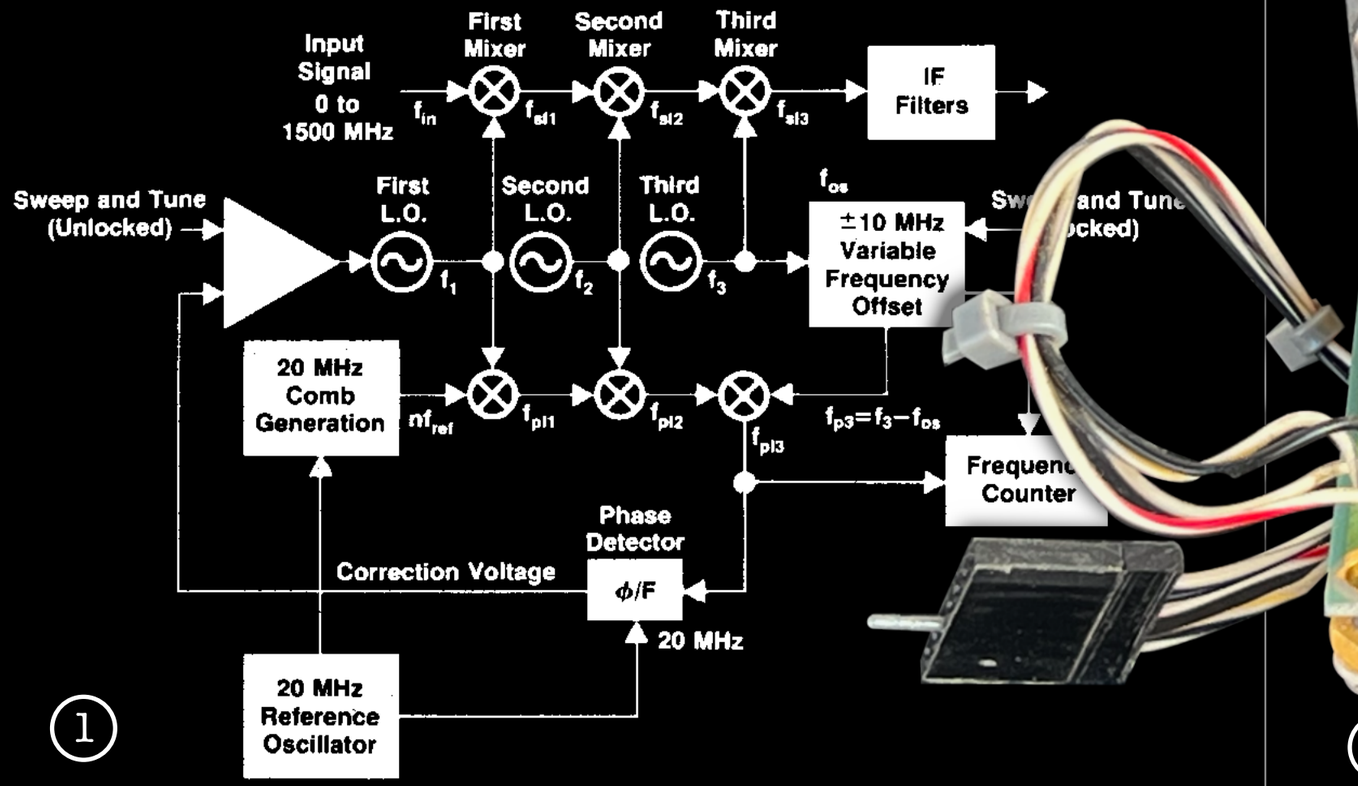
Tuning the instrument to center frequencies between the harmonics of 20 MHz is accomplished by offsetting the frequency of the third local oscillator using accurately controlled frequency-synthesis techniques. This causes the first local oscillator to change frequency by an equal but opposite amount [from HP Journal, 6/1978].



# Separate rails

I have never seen before this scheme. In simple words, they built two parallel circuits: one is for the normal signal, as you would expect, the other is for the frequency control. This helps us understanding the components of the RF section. We have the mythical VTO, followed by a splitter, each of them is driving a separate converter (mixer), one for the signal, the other coming from a “comb” generator, i.e., a generator that produces a lot of harmonics used to lock the loop. In this page you can see the splitter A23A4, with the two 2-4 GHz hybrid amplifiers A23A4A3and A23A4A4, that boost 10 dB the signal from the YTO before going to the mixers (one for the signal and one for the comb signal, see one of them in the following page).




1



## A4A1 Splitter




2

# Interesting details

❶ The two hybrid amplifier that, driven by the splitter, drive the first signal converter and the converter for the comb signal. They can still be found on eBay, should you need them.

❷ One of the two above said converters (mixers) A23A2 and A5, with just two diodes inside and few resistors. They are very similar, but not identical. I would like to fully understand how do they work… How could they calculate the geometries? Interesting theme for future insights.

❸ (on next page) The second converter A23A3 is a wonderful block of (very heavy) tooled aluminum, with very few electronic components. I didn't dare going further opening it. The cover, removed in this photo, is locked by "just" 34 screws.

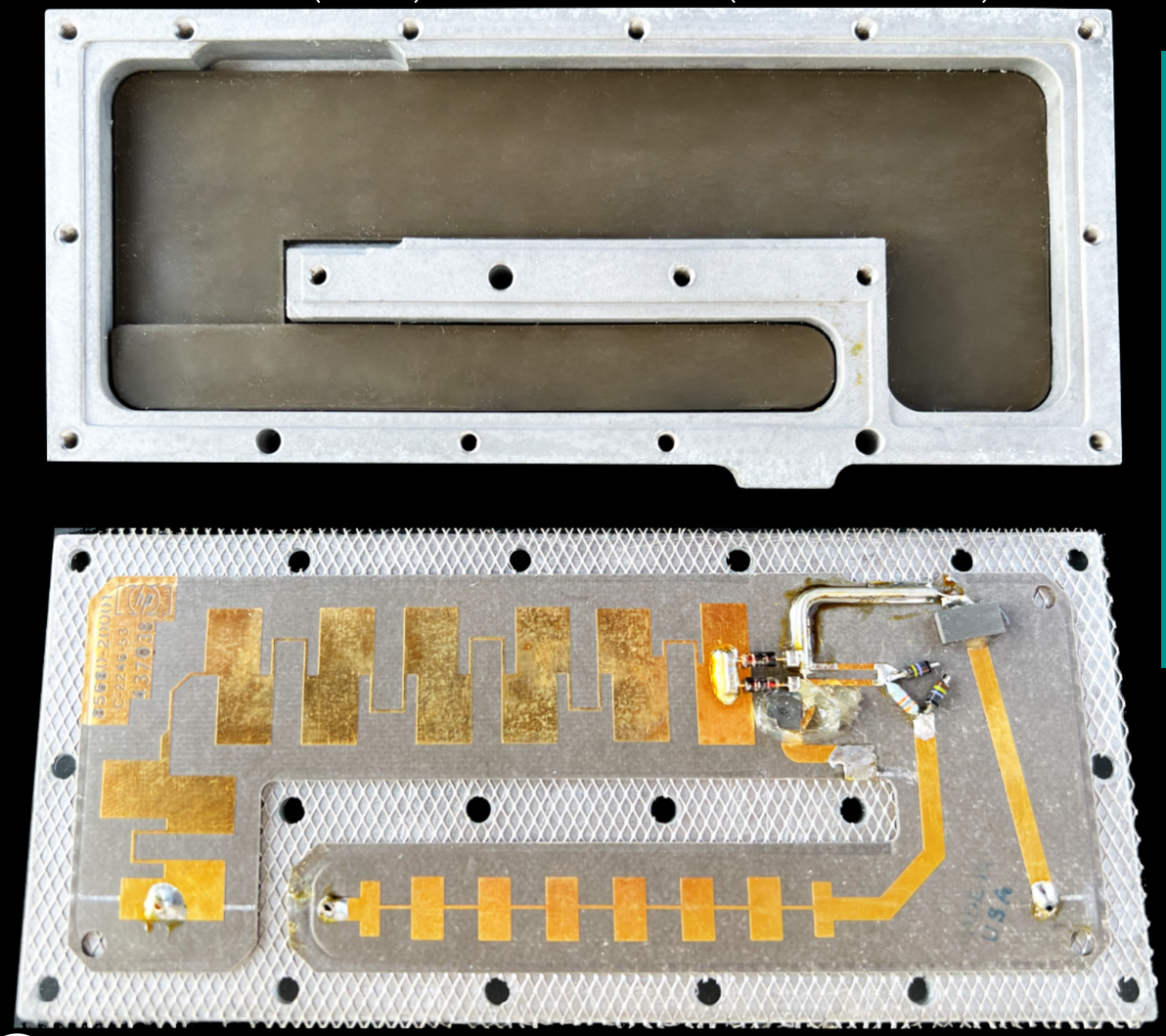
## The two hybrid amplifiers (A4A3 and A4A4)



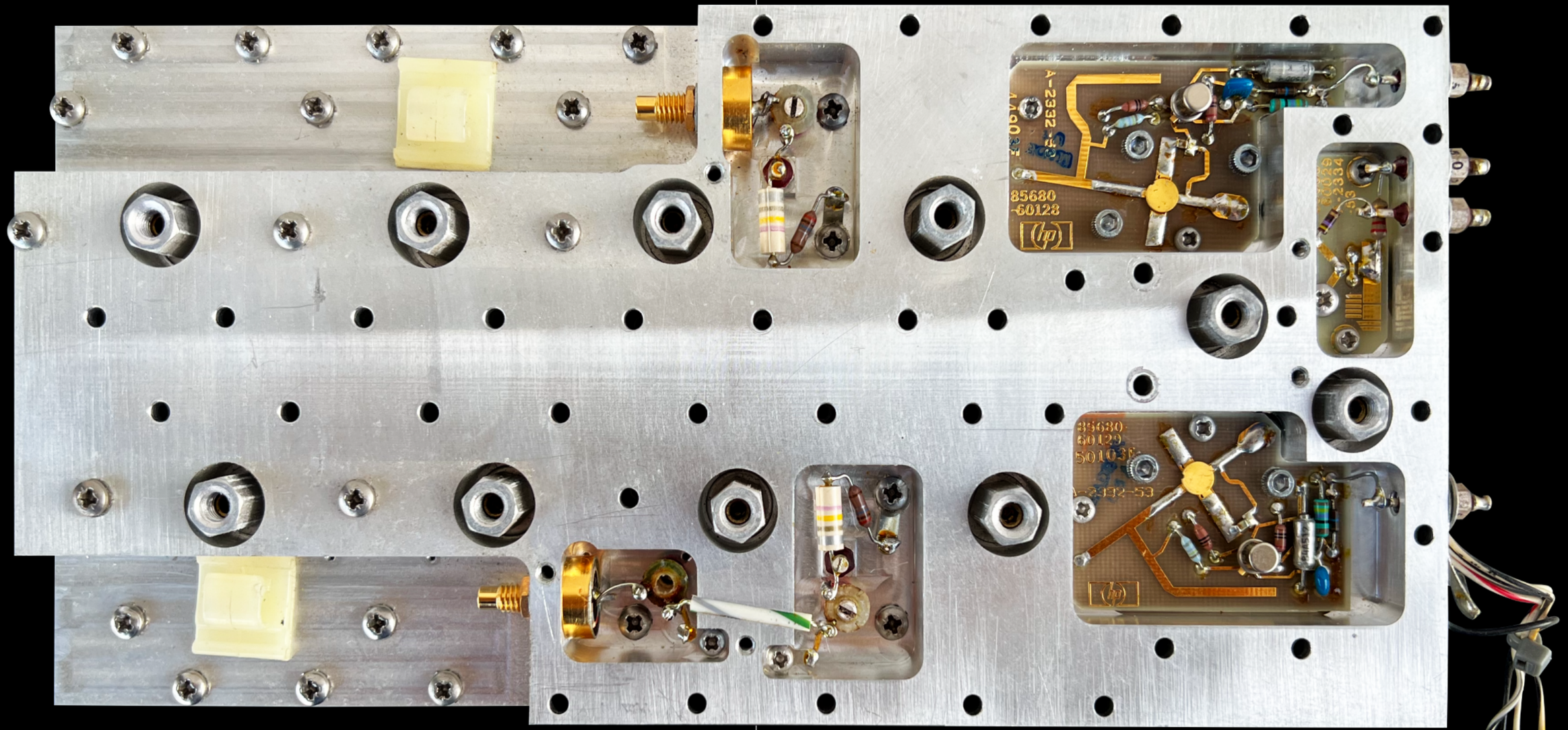

1



## First converter (mixer) and comb mixer (A23A2 and A5)

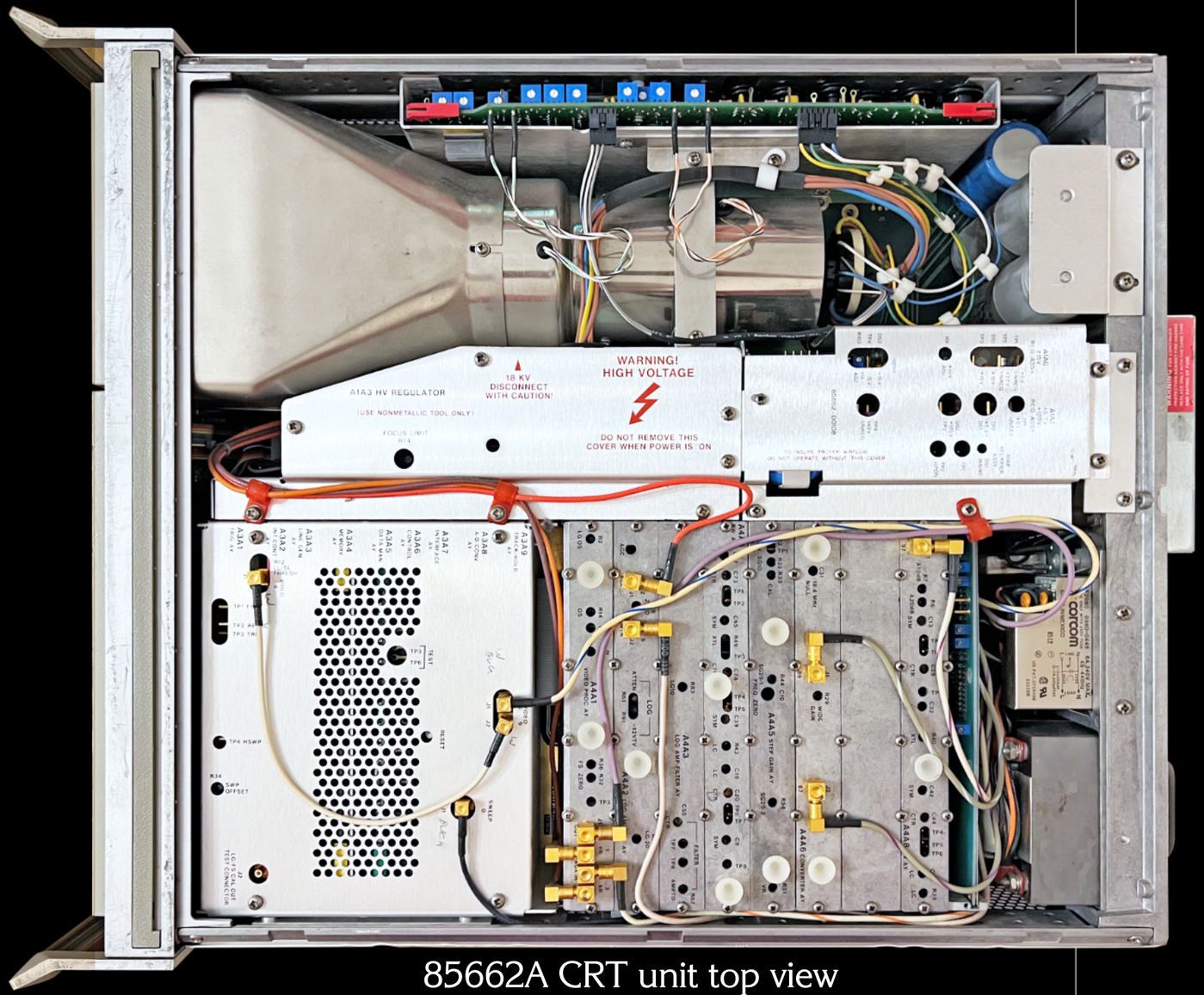


2

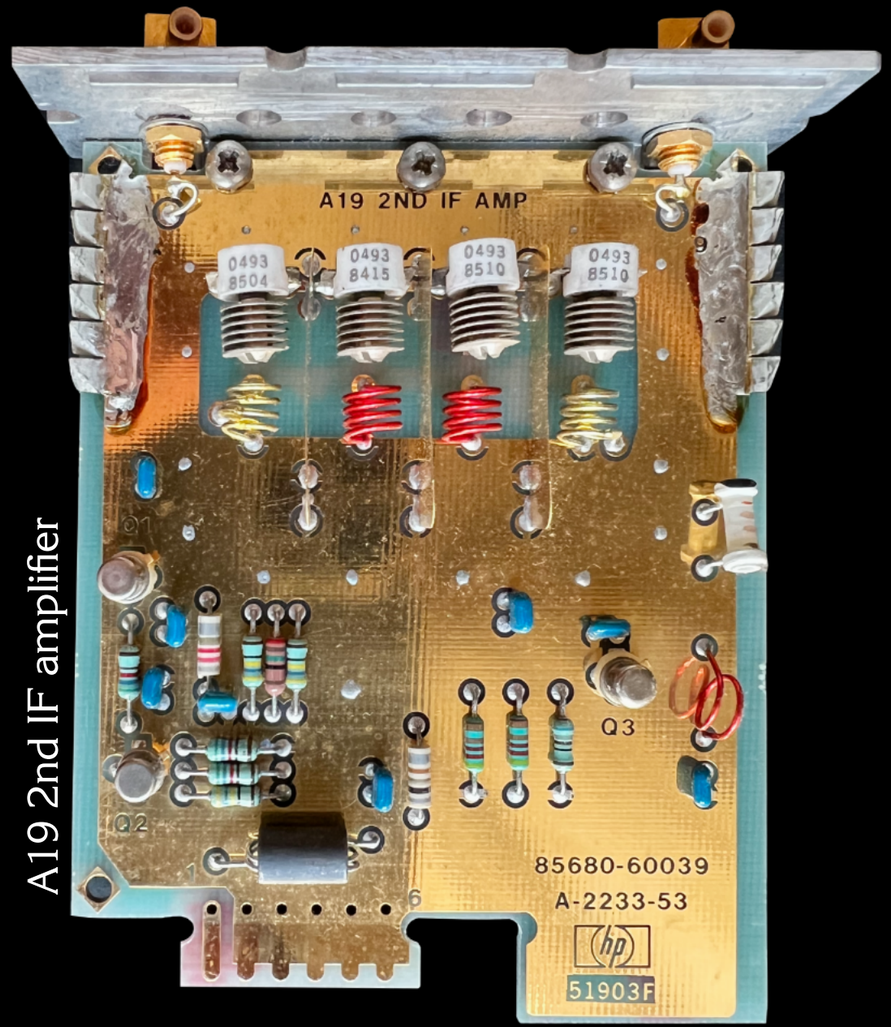



③

Second converter




85662A CRT unit top view




A19 2nd IF amplifier

# My dear Diary…

Differently from other equipment I present here, I describe the events related to my 8568B in real time, so that making you part of my work and my emotions.

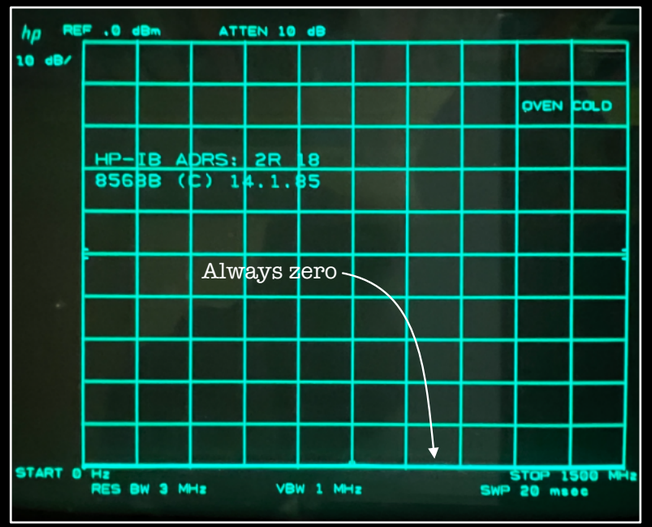
19.7.2023 I bought this unit few days ago on eBay. The ad said that the screen was switching on, but no key was accepted and no signal trace appeared on the screen. The price was more than good and the seller was not too far from home, so I could spare the shipment as well.

I have just carried it home and now I start testing it with some worries. Was it a good buy? Will I be able to repair it? The instrument is very complex, maybe the most complex I ever touched, and I am not an RF expert.

I mount the two *really* heavy boxes on the bench, I connect them with the special interconnecting cables and I flip the main switch. A strong fan noise starts (much louder than my air conditioner). The unit starts and slowly the display appears. The intensity is not too high, but the screen is clear and well defined. Error messages appear on the screen OVEN COLD, BATTERY and YTO ERROR. No key is detected, whatever I press.

Uhm, this seems a typical stuck key problem. I check and I find a blocked key. I move it with pliers and magically the keyboard comes to live. Wow, that's good! I start fiddling with the front panel, and the instrument appears to be completely responsive.

But there is no signal trace. Or better, looking carefully, I see that it is there, but is flattened on the lower line of the graticule. I connect a signal generator but no signal appears on the screen. Well, that would have been too easy. I note that the OVEN COLD message disappeared but YTO ERROR and BATTERY are still there.




❶ The 8586B upon its arrival; it is visibly dirty and sad, and with one of the red alarm pilot LEDs on.

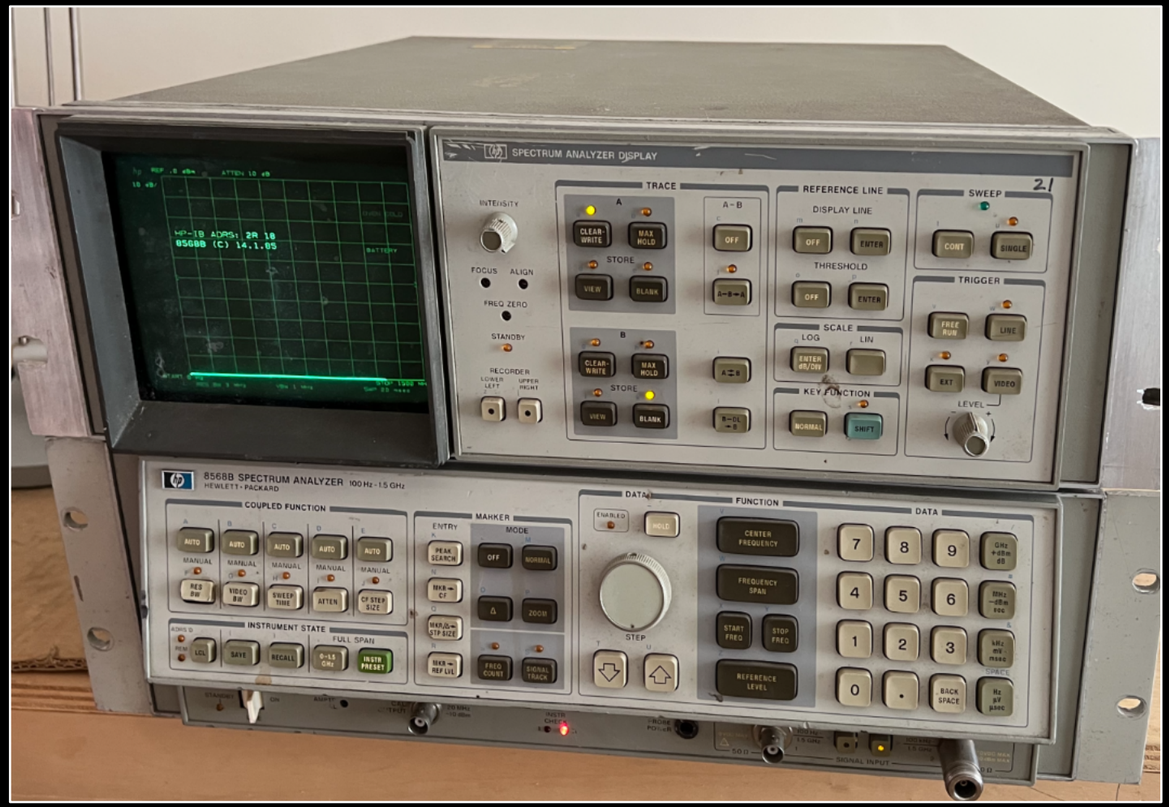
❷ Most of its functions operated correctly, but no signal trace is present on the screen, or better, it is always zero. There is also an YTO ERROR, in this photo already fixed by replacing the battery.





23.7.2023 I tested again the 8568B. The YTO ERROR message persists, together with the BATTERY. I think that it is better to fix first the battery problem, even if I believe that it is not related with the YTO. I dismount the CPU board. The battery is visibly in crisis. I can find a new one on Amazon, and I order it.

24.7.2023 I'm a clean freak; not in general but for my electronic stuff. First, I like that the equipment shine like new, but also I believe that a thorough cleaning helps knowing the instrument and often allows detecting some critical situation. So I start the 8568B cleaning. It was not very dirty and in a couple of hours I finish.



YTO ERROR. I downloaded from the Internet the manuals but I cannot find in them the YTO ERROR, neither directly something related to. I try to study the manuals and I see that YTO is the first Local Oscillator (LO) used for the first frequency conversion. I continue studying reading the HP Journal 7/78, while my imagination runs. Probably the YTO oscillator is faulty, but it seems to be sealed, surely it cannot be repaired. What can I do?

Then I observe that the HP Journal says that this oscillator goes from 2,050 to 3,550 MHz, while the manual says from 2,000 to 6,200 MHz. At this point, I notice that the manual you can find on the Internet is for the bigger brother 22 GHz 8566B.

I discover that the right manuals are available from the very good Artek Manuals and I order them.

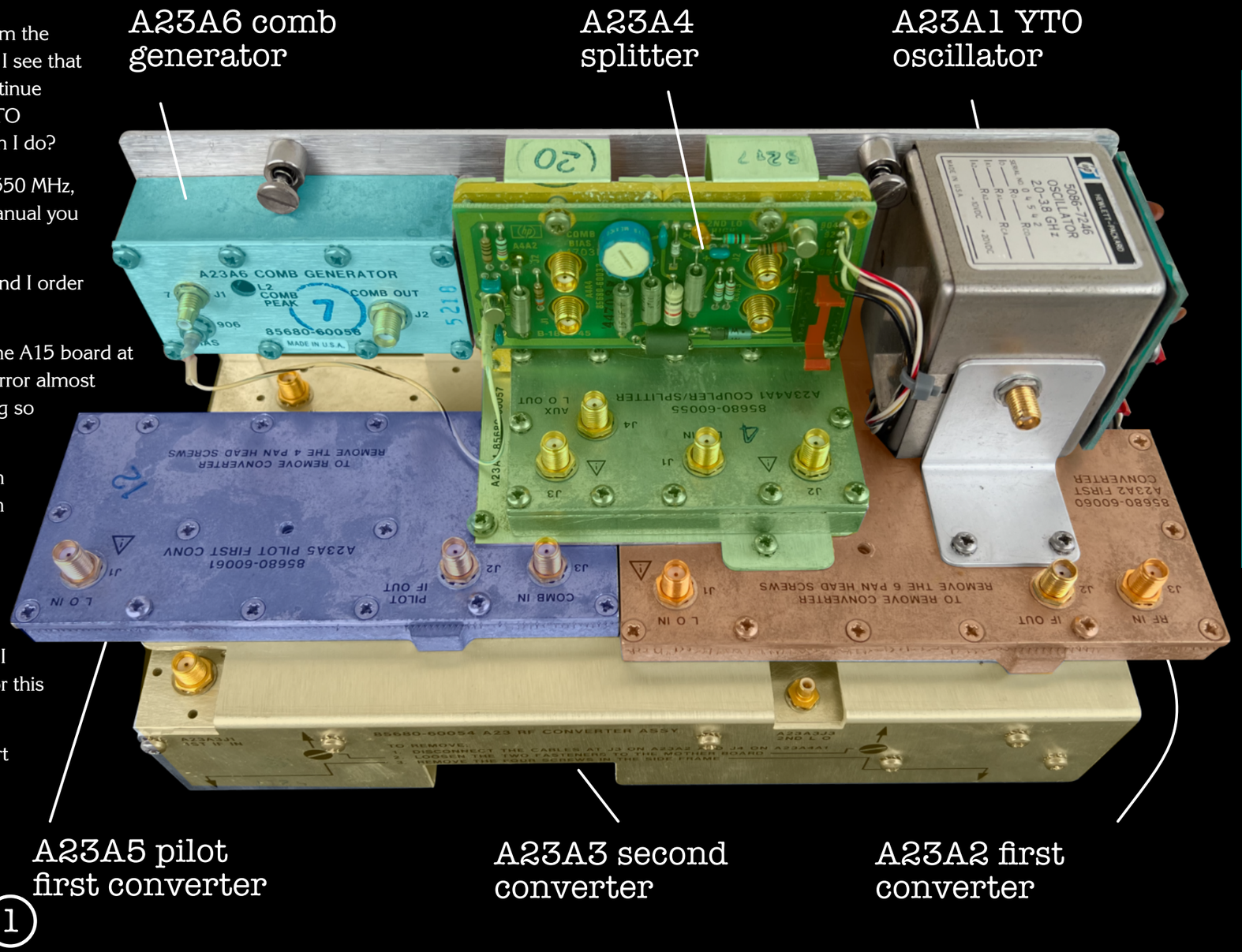
25.7.2023. The battery arrived. I install it and you can see it in the big picture of the A15 board at page 754. I reinitialize the instrument (RECALL 8) and, to my surprise, the YTO error almost disappear. It shows from time to time only when I rotate the frequency knob. Being so lucky? But the signal is not yet present.

RF-section take-apart. At this point, I take the decision to dismount the RF section (A23), aiming to see if there is just visible faults but above all to understand if I can watch some signal connecting in some way another Spectrum Analyzer.

I proceed with extreme caution; one of my biggest fears is to add some problem with my dumbness, and this is really a complex instrument. In few hours, all the gear is split apart and I am fascinated by these wonderful components, so different from “my electronics”. The number of screws is incredible, so many that I eventually use the electric drill. At least, I have now a lot of items to photograph for this book.

26.7.2023. While I am driving back home, I ask myself: why did you decide to start from the head (the first RF section) instead of the tail, where you are definitely stronger?

Reassembling A23. So, when I get home, I decide to reset everything to its place, taking photos and hoping that I did not break anything. Switch on, everything is as before.




1

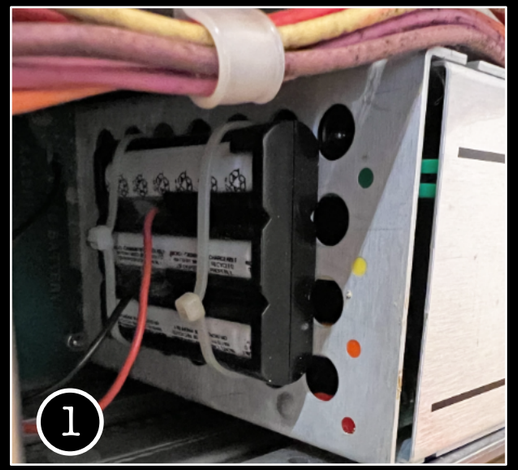
Manuals arrive. In the meanwhile the new manuals arrived and I greedily start studying them. I learn that:

- the YTO error belongs to the 8568B and means that YTO did not tune close enough to the required center frequency. I accept that it can briefly appear rotating the knob;
- there are many other checks that I can do before handling the soldering iron.

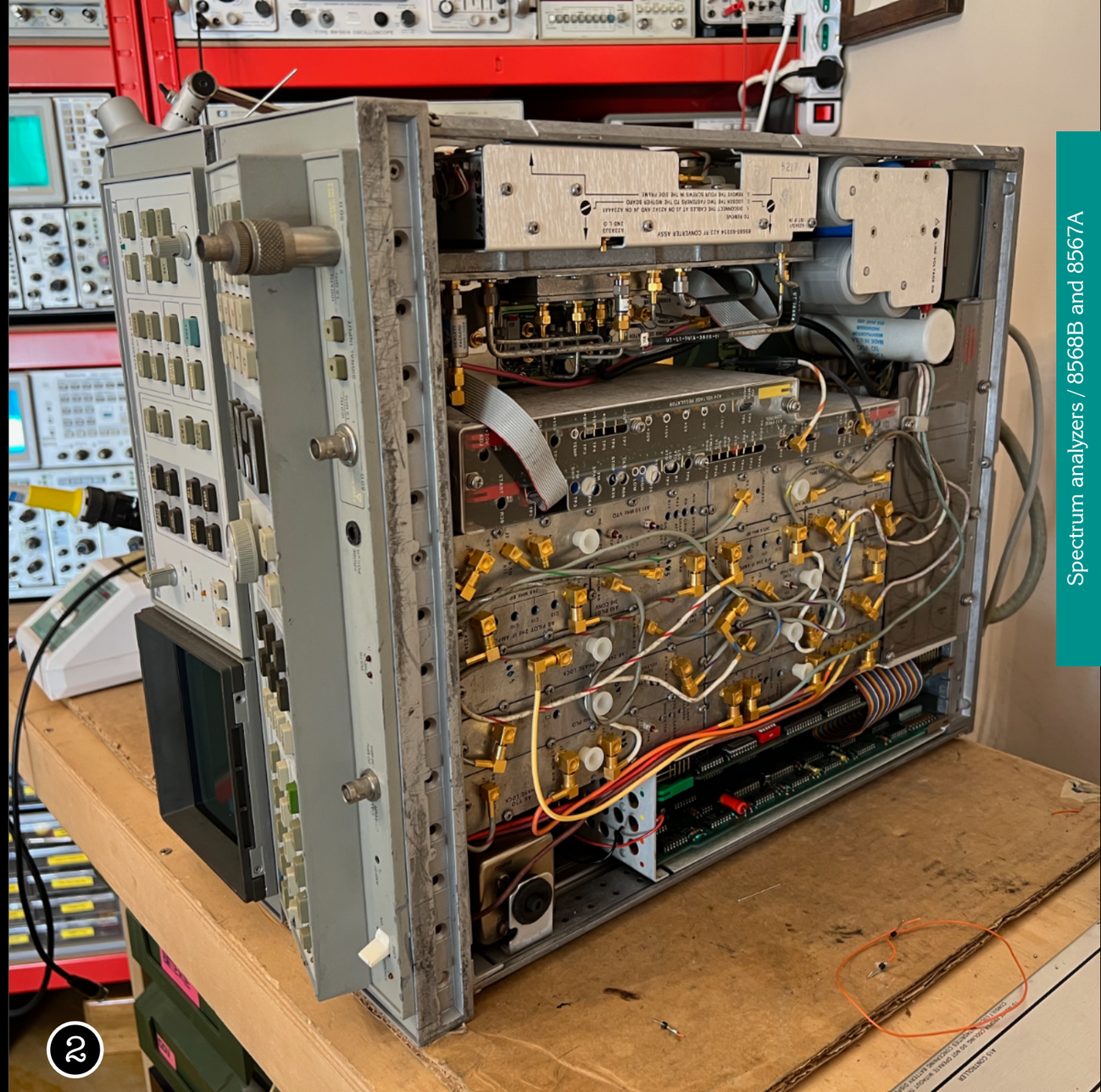
A second battery? By the way, I observe that there is a second battery (see photo), that I did not note before. Funny: it has the same package as the old HP-35 calculators and similar, and is of the rechargeable type (Ni-Cd). It is in bad conditions, and for now I prefer to simply cut it out.

Special commands. The 8568B can accept many commands that go beyond the keys you can see on the front panel. For example, the KSR command that can be activated by pressing SHIFT followed by the key labelled "MKR REF→LVL". This function displays many of the internal frequency control parameters in the upper left corner of the CRT display (see the picture). These parameters are the programmed values determined by the A15 Controller. For example, following an (INSTR PRESET), a SHIFT (MKR -› REF lVL (KSR) displays a series of values that seem to be correct. There are also other commands (e.g., KSJ, KSN) to check the various frequencies, and all seems to return reasonable numbers (photo ❶ on next page). So, the frequency side is all OK, but still no trace is displayed.

A/D test. I understand now that the SA's display always operates in digital mode, i.e., the trace that I cannot see but that I should see is not produced analogically on the CRT, but is digitally converted and displayed by the video display controller, like a graphic image. Here I feel more confident, and luckily I find on the manual that it is easily possible to make a test of this section (85662A manual, that of the SA's part that includes the CRT, A1 board, page 2). For this test, remove cable 96 from A3A9J1. Then jumper A3A8TP1 to A3A9TP3 and push Instrument Preset. This substitutes the sweep ramp for the video input (the




❶ The second battery. ❷ This two-parts instrument can be rather comfortably serviced by removing its covers and placing it on its left side. In this way you have access to both sides, while the mother-board front each other on the internal. Very intelligent.



manual says that the resulting screen should be that of A3A8 board, figure 7, but in my manual it is too clear and difficult to read, so refer to the picture here).

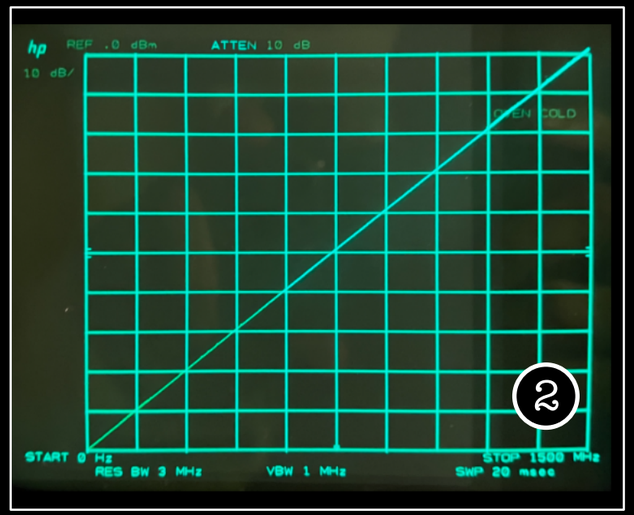
In my case, the display is correct, so the A/D converter and what it follows is correct.

Using an external display. That is rather easy: connect the rear-panel SWEEP and VIDEO RECORDER OUTPUTS to an oscilloscope. These signals are correct and the CRT of my old Tektronix 7633 looks like a Spectrum Analyzer, with the typical noise on the lower screen. But again, a signal on the 8568B does not produce any effect.

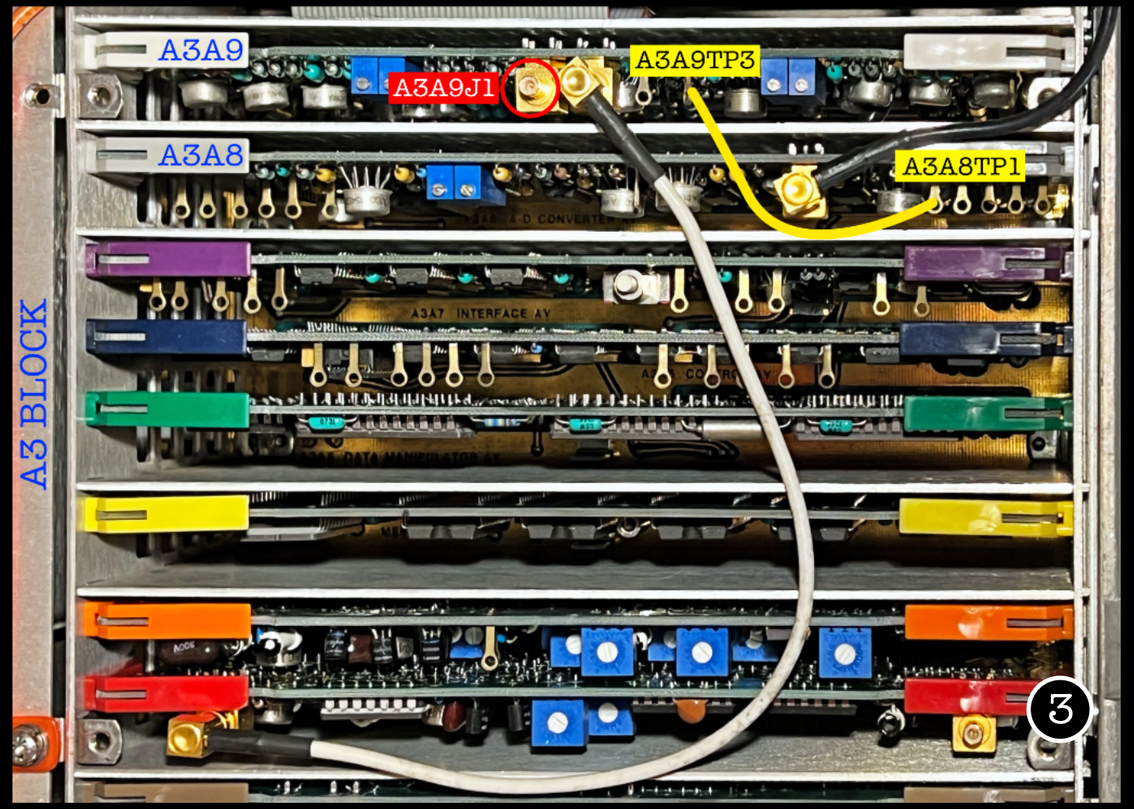
IF OUT connector. On the rear-panel there is a IF OUT BNC. Curious, I connect it to the oscilloscope and… a strange envelope appears but… wow, the envelope behaves in accord with the input signal and the SA settings. If I change the signal's frequency, it moves left or right. If I increase the signal's amplitude, it gets taller. So the stuff behaves like a Spectrum Analyzer! But why my 8568B's CRT does not show what it should?

OK, for now it's enough. I will continue next days. I go to bed and before sleeping I study the manual to understand where the IF OUT connector comes from. I cannot find in the manuals the description of the rear connectors, so I investigate the schematics. Oh, yeah, here they are (picture ❶ on next page). But, what… what does that mean? Want to see that… Yes, a closure seems to be required between OUT and IN.






❶ The KSR command output. From thin non-retouched photo of the screen you can also appreciate the high quality of the CRT display, that allows to read even the smaller writings.

❷ The diagonal line produced as explained in the text confirms that the ADC and the following stages are properly functioning. The picture contained in my manual (and probably in yours) is not well digitized and I was not sure that a complete diagonal line was expected (even if you can understand it from the text).

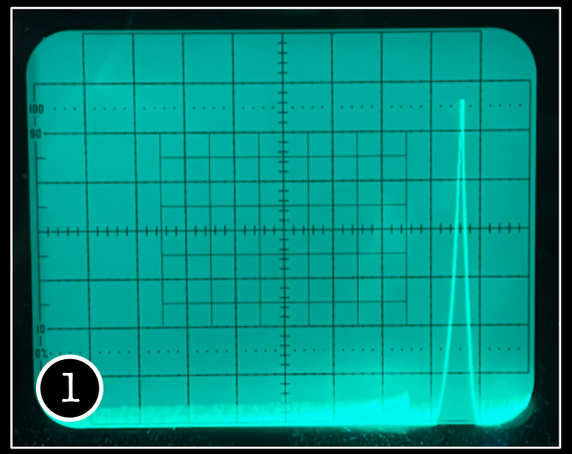
❸ All these boards go under the A3 name, and are ordered from A9 downward. Removing the A3A9J1 connector and connecting the A3A9TP3 and A3A8TP1 test points, yo obtain the diagonal line represented in photo ❷. All of them are protected by a cover that must be removed to access the boards.

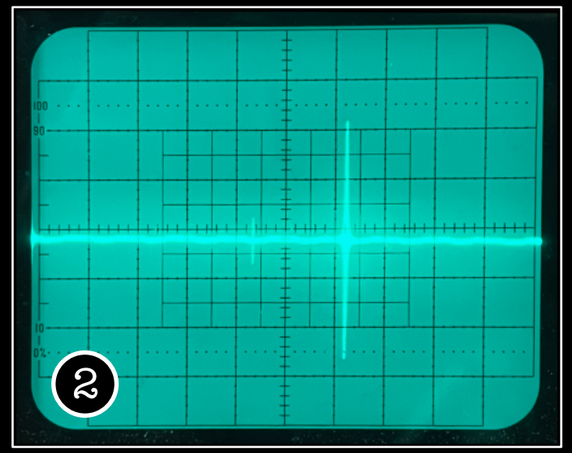
The victory! In a snap I get dressed and start testing again. I add a BNC cable between IF OUT and IN and another between VIDEO OUT and IN. Switch on and… GREAT! It works! Incredible joy! Fiddling again, almost everything seems to be OK. It's really enough for today, I will go on tomorrow.

27.7.2023, the calibrator. The calibrator outputs a -50 dBm signal instead on -10. I dismount the board and study the schematic diagram. It runs around a single IC. Translated from HP-ese, it is a LM3146. I order it in China, 5 ICs for 12$, including shipment, but it will arrive at the end of August. I must wait.

4.8.2023, self calibration. Even without the internal calibrator, I try the self-calibration (SHIFT/SPAN) with an external signal generator set at 20 MHz, -10 dBm (like the internal). After some attempts, it works.

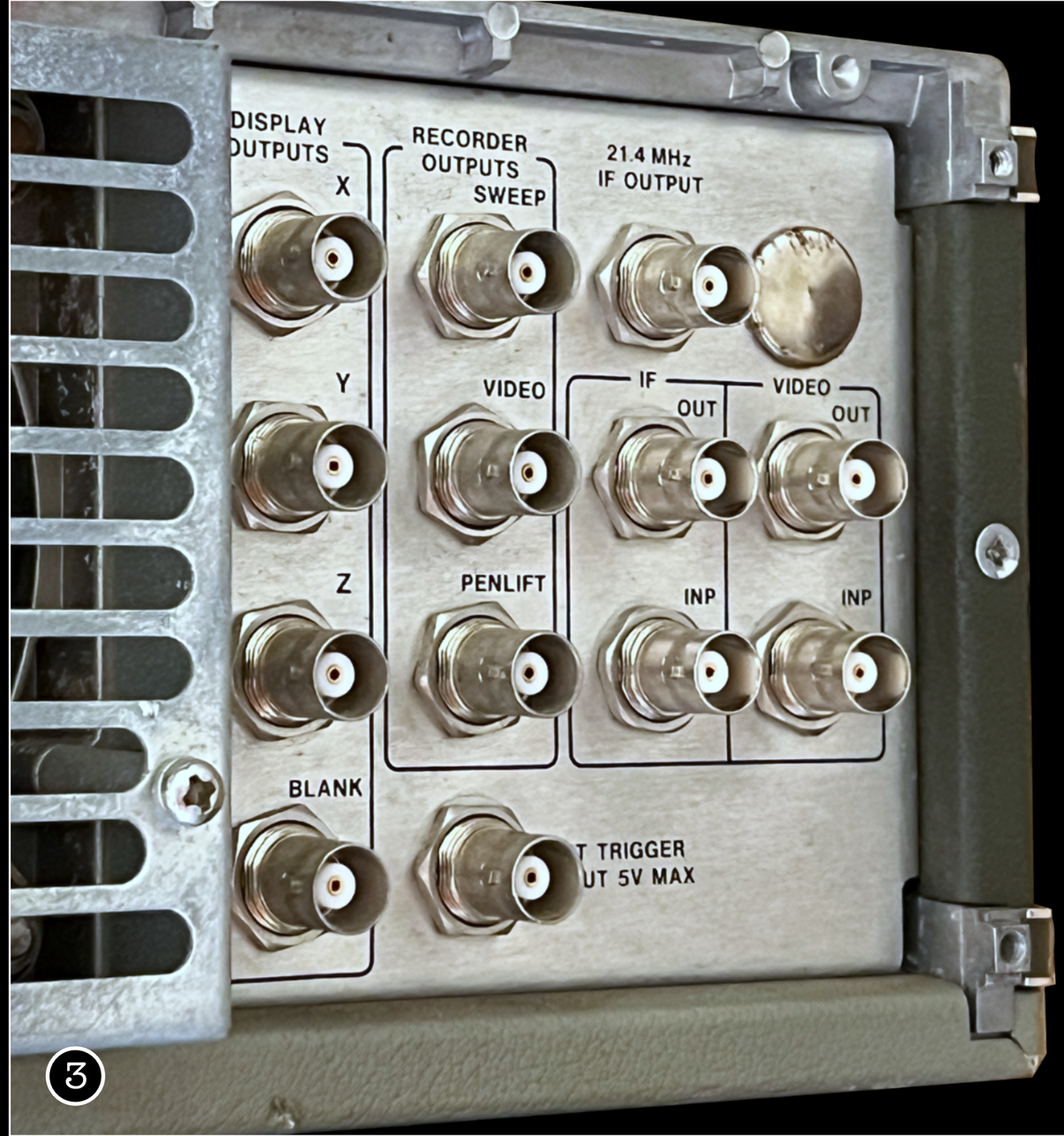
❶ Once applied the closures to the VIDEO and IF IN/OUT, you can connect an oscilloscope in x-y mode to the RECORDER OUTPUTS (VIDEO to vertical amplifier and SWEEP to the horizontal). It will behave like the spectrum analyzer display, but without the text, added by the digital section.
❷ The IF OUT signal behaves like describe in the text. It allows to understand if the RF section operates correctly.
❸ How the 8568B back panel appeared as they delivered to me.

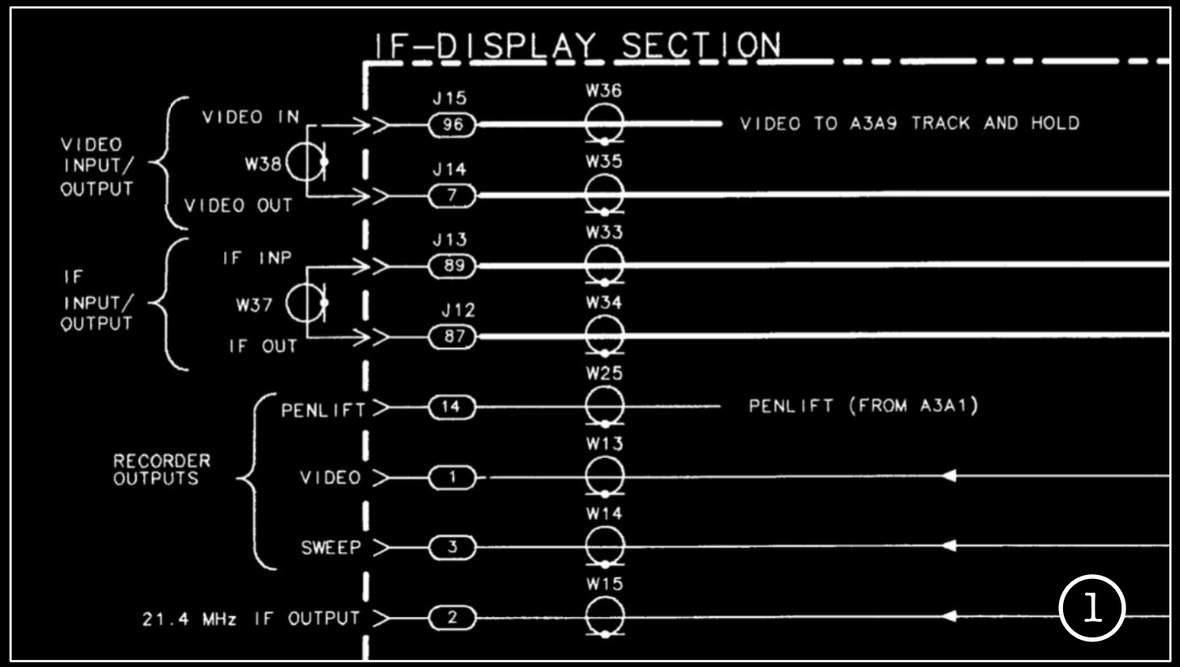


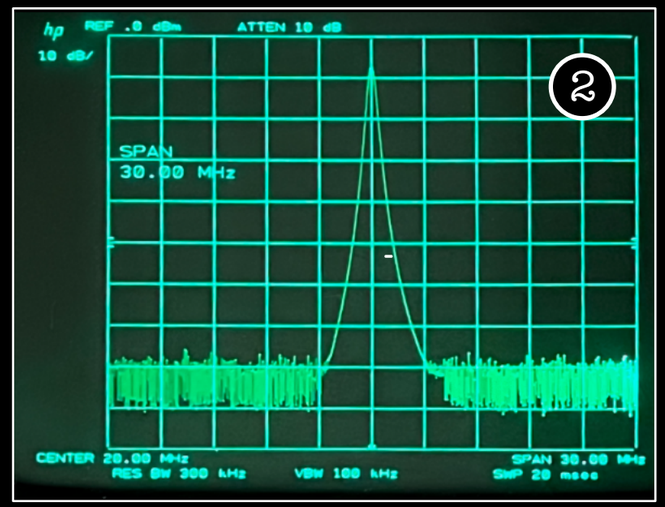










❶ The 85662A schematic diagram (the upper box of the two composing the 8568B) shows that IN and OUT must be closed externally. The lack of these cables had led the previous owner to think that the unit was faulty (and also me, in the beginning). They are used for the connection to the optional Quasi-Peak Detector device.

❷ When I saw that, I was extremely happy!

❸ To be honest, the manual says that these jumpers are required in the installation section. I wonder how many people read it in these 45 years.

❹ How the 85662A back panel should look in normal operating conditions. This is my 8567A as it arrived.



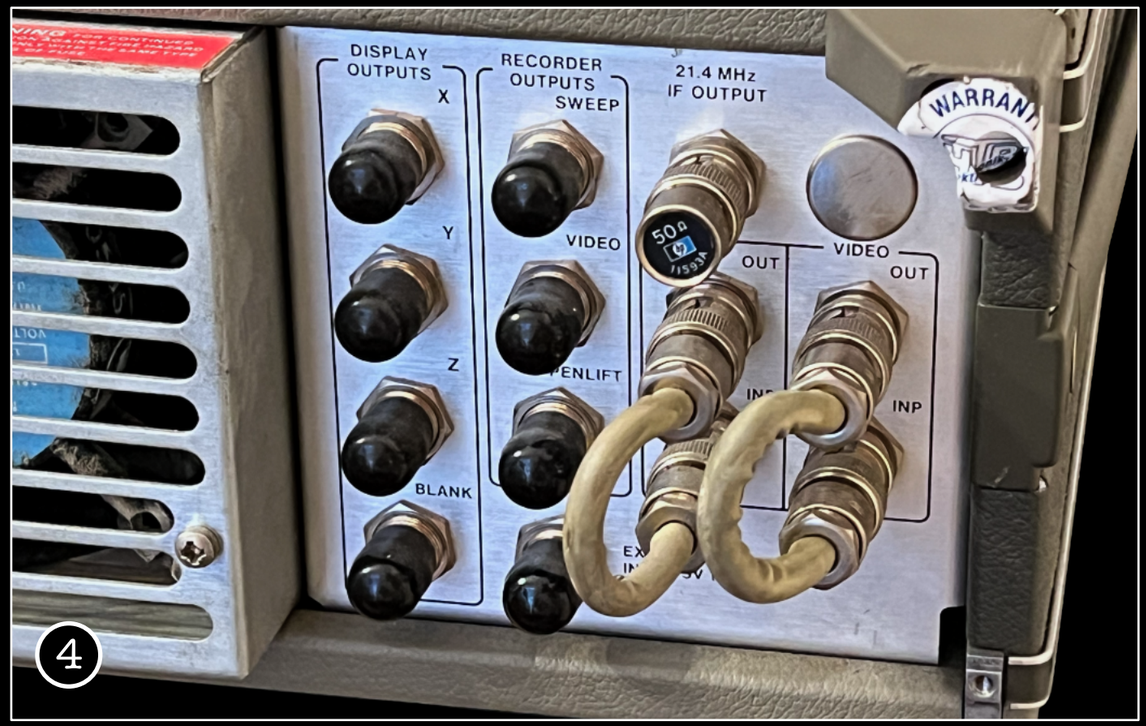


In the shipping containers is an accessory package. This contains two power cords, two fuses, one Type N Male to BNC Female adapter, and two instrument interconnect cables. Also included (already attached to the instrument) are cables W37 and W38.

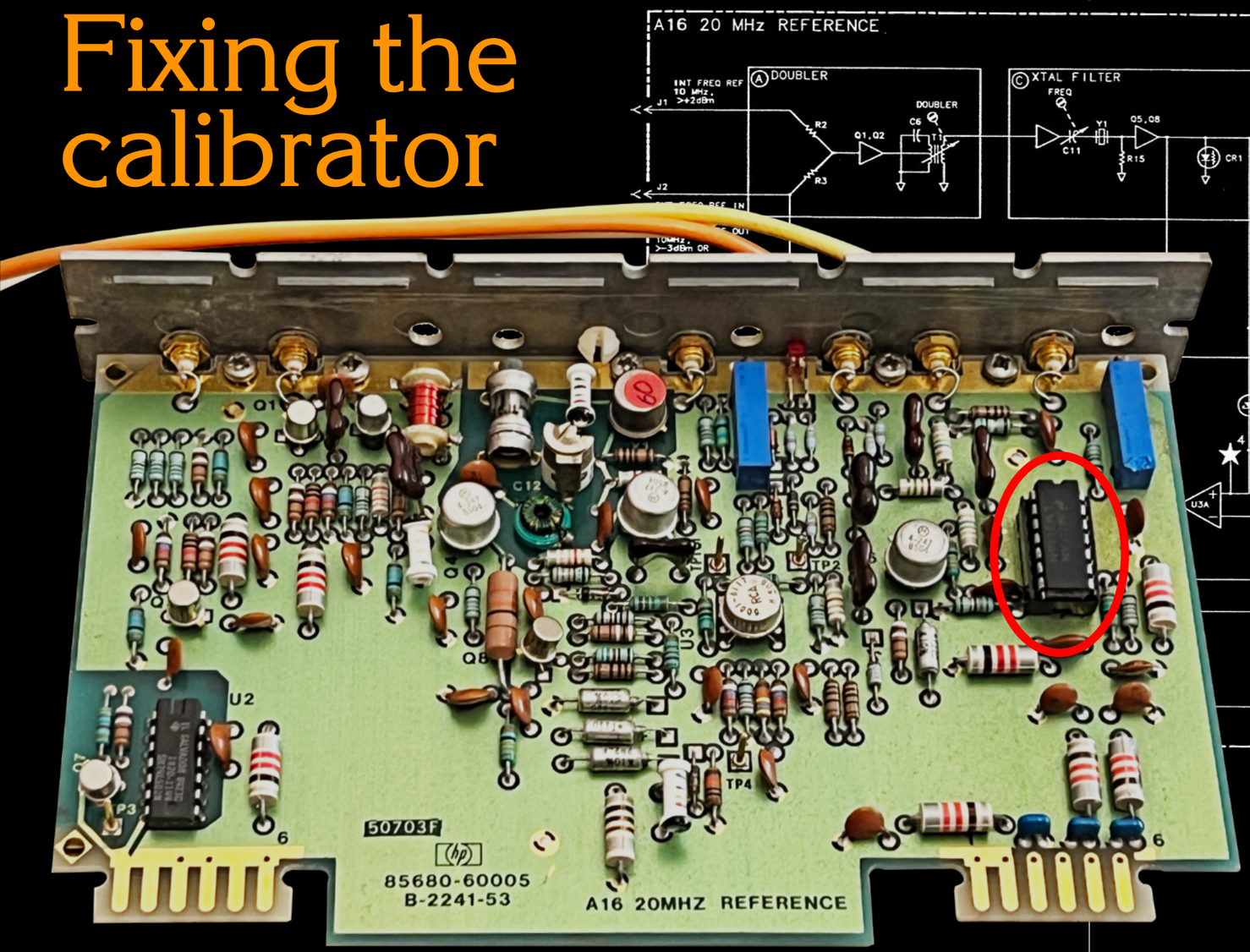
**NOTE**

**Cables W37 and W38 are only removed for connection of the IF and VIDEO ports to the HP Model 85650A Quasi-Peak Adapter. If the analyzer is used without the HP 85650A Quasi-Peak Adapter, W37 and W38 must be connected for the analyzer to operate.**

3



# Fixing the calibrator




The 8568B's calibrator was not running properly. The output signal was -50 dBm instead of -10. I hoped it was the simplest solution possible and luckily it was. I ordered in China a new 1858-0032 U1 chip, a LM3146. Inexpensive but slow (to arrive). I removed the old chip and replaced it with a socket. The repair worked immediately.

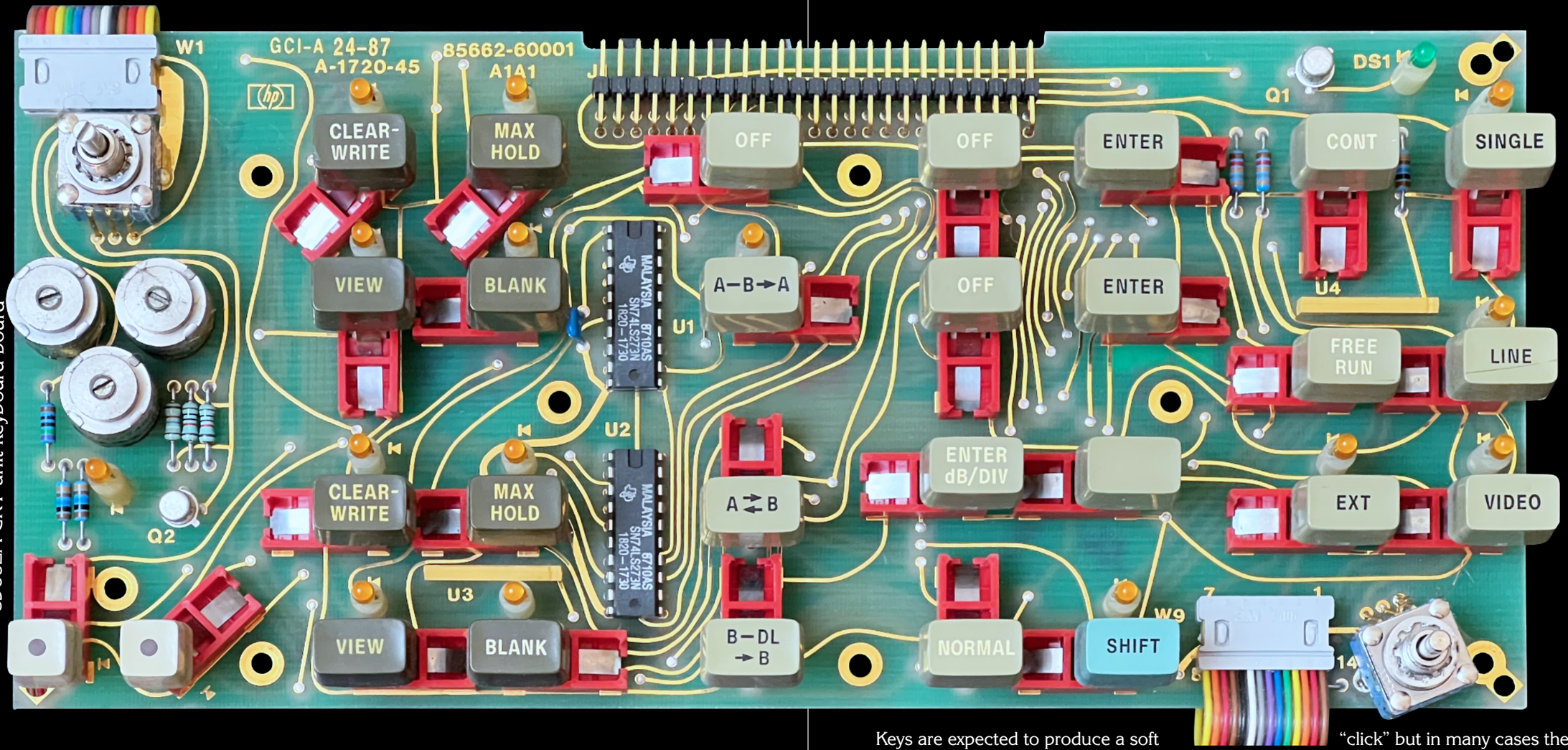
It is rather easy to mismatch cables, when you work. Probably, someone connected a signal to the calibrator instead of the input. For this reason, I try to use always some kind of plugs on the unused BNCs.




# Keyboards

Keyboards were something new in laboratory instruments, and have a great part in 856xs' charm. Personally, I like them much more than any colored touch screen. These keyboards are big, heavy, robust and, by themselves, have more components than a modern tablet… by I love them!

Page added 14.1.2024

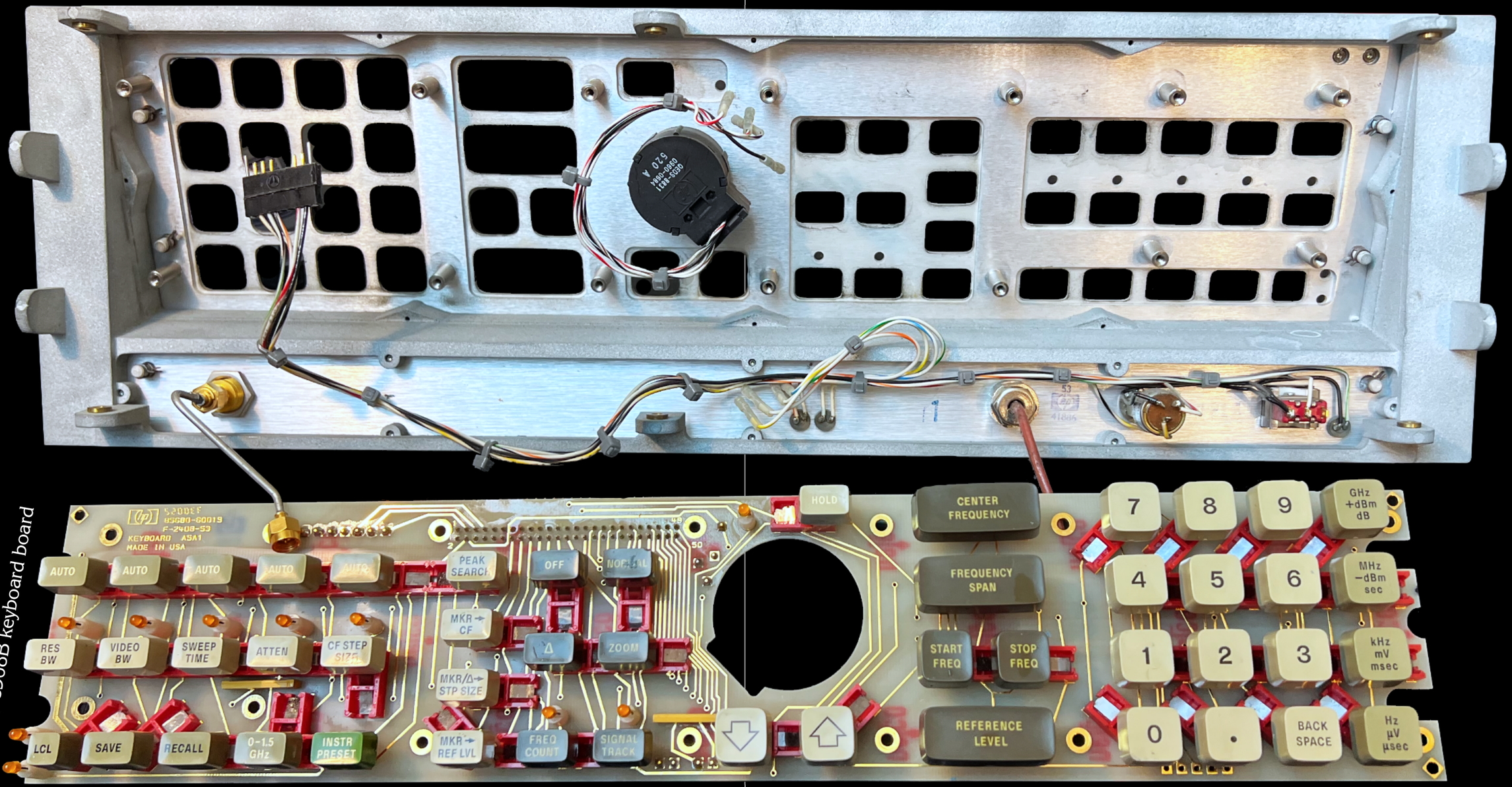



85662A CRT unit keyboard board

# Keys maintenance

Keys are expected to produce a soft "click" but in many cases they will produce a ugly KLACK, very unpleasant. The cure is rather simple. Remove the front panel by removing the screw on the four sides, remove the keyboard board, sprinkle the keys' mechanism with WD40 Contact (definitely not normal WD40!), and exercise them more times. Magically, the keys return to click and the effect remains also when the WD40 dries. It is also the opportunity for a better panel and keys cleaning. It's worth it; your instrument will look newer and will be more pleasant to be used.

Page added 14.1.2024




8567A / 8568B keyboard board

Page added 14.1.2024

# Conclusions

The 8568B used to be one of the most expensive SA on the market and still today is one of the eBay stars, despite the competition of the modern equipment. For a working 8568B, more than 1,000 euros are normally required, and at least three times as much for the “big brother” 8566B (currently, someone is asking 9,600 USD for one of them …but asking is easy!).

Even with my limited experience in RF instruments, I can anyhow understand that the 8568 has been one of the most important spectrum analyzers ever, and it is; other arrived, more modern and better, but probably no one before or later has marked such a deep furrow with the past like it.

I reserved many pages to the 8568B (& family). It was not difficult; an instrument like this could allow you to talk indefinitely, being a real treasure trove of technical wanders, each of them deserving an entire book.

# Bibliography

| P/N | Year | Notes |
|---|---|---|
| | | Commercial documents |
| | 1979-1986 | HP catalogs |
| 5952-9394 | February 1985 | 85068B Technical brochure |
| | June 1976 | HP Journal, HP 9825 overview |
| | June 1978 | HP Journal, HP 8568A overview |
| | November 1977 | HP Journal, An NMOS process for high-performance LSI circuits |
| | August 1979 | HP Journal, HP 8566A overview |
| | February 1985 | HP Journal, YIG oscillators |
| | | Operator's manuals |
| 08568-90002 | October 1978 | 85068A Spectrum analyzer operation |
| 08568-90041 | February 1984 | 85068B Operating and programming manual |
| 08568-90045 | June 1984 | 85068B Operator's handbook |
| 5952-9356 | November 1980 | 88566A/8568A Operating guide for 9835/9845 computers |
| | | Installation/verification/adjustments |
| 08568-90119 | September 1983 | 85068B Installation and verification manual |
| 08568-90011 | December 1978 | 85068A Operation verification |
| 08568-90118 | September 1993 | 85068B Performance tests and adjustments manual |
| 08568-90118 | February 1985 | 85068B Performance tests and adjustments manual |
| | | Service manuals |
| 85662-90085 | December 1993 | 8562A Troubleshooting and repair manual. |
| 85680-90137 | May 1991 | 85670A-85680B Troubleshooting and repair manual vol. 1 |
| 85680-90137 | May 1991 | 85670A-85680B Troubleshooting and repair manual vol. 2 |
| 08568-90048 | December 1984 | 8566B/8568B IF-display section vol. 2 |
| | | |




This in the photo is my own 8568B; it has not the handles because it arrived with the rack mounting kit, that is not very practical, and so I removed it. I will find some way to cover the sides.

Spectrum analyzers / 8568B and 8567A

# Calculators



Much earlier than a Personal Computer like today we intend it

# Calculators



Subsection

## HP-35 calculator

The first scientific calculator ever

# The first 350 years of the slide rule

The slide rule was invented around 1620–1630, shortly after John Napier's publication of the concept of the logarithm. In the seventies, you could buy a slide rule ("Regolo calcolatore" in Italian, "Slipstick" in the USA) in different sizes and models, and they were not cheap, but you had no alternatives for multiplications, divisions and for functions such as exponents, roots, logarithms, and trigonometry.

1972. In 1972, however, something happened that in few years would make the "regolo" completely disappear. Hewlett-Packard introduced the HP-35. For the slipstick, there would not be the second 350-years.



Before opening the HP-35 casket that you can see here below, lets chat a little about how got Hewlett-Packard to the HP-35 and I to the HP-35.

Photo by © Raimond Spekking / CC BY-SA 4.0 (via Wikimedia Commons), CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=106943663



This is for me a very painful subject, even though at the time I knew nothing of that, and to be honest, I didn't know anything about it until a some years ago, when my friend Luigi Sassoli told me the story.

In the second part of the seventies, I was literally in love, among others, with the HP 9800 computers. I got, don't remember how, some brochures that I have consumed by dint of looking at them. Later, I learnt that the 9800 was a descendant of the 9100 and that… the 9100 was probably invented in Italy by Olivetti.

Yes, you say, as Italian you say that everything has been invented in Italy, like Russians with Popov… It is not so. If from one side we can be proud of it, by the other we must feel ashamed for the way we Italian managed all that.

You must know that, after WW2, Adriano Olivetti created a company like few in the world, with 50,000 employees, leader in the world for typewriters and electric mechanical calculators.

Adriano was was really a visionary entrepreneur: he thought his company as part of the society, building not only gears but also houses and hospitals for his employees.

At Olivetti, ideas found an ideal fertile ground, and, at the end of the fifties, Olivetti started operating in the computer field, creating the ELEA division.

In 1960, Adriano died, and the painful part of the story begins. The Olivetti family found new partners for the company: FIAT and IMI/Mediobanca, state financial enterprises. That was the beginning of the end.

These financial partners had no industrial vision nor ideas. The top of shortsighted strategies was the declaration of Vittorio Valletta (linked to Mediobanca) at the meeting of Fiat's entry into the Olivetti capital on 30 April 1964: “Olivetti is structurally solid, it will be able to overcome the critical moment without major difficulties. However, a threat hangs over its future, a mole to be eradicated: having entered the electronics sector, for which investments are needed that no Italian company can afford”.

Unluckily, that's Italy.

olivetti

# The Programma 101




Photo: Di Olivetti (progettista/ costruttore), Bellini Mario (designer), Perotto Pier Giorgio (inventore/ progettista) - Catalogo collezioni (in it). Museoscienza.org. Museo nazionale della scienza e della tecnologia Leonardo da Vinci, Milano., CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47910885

1964





In this division, Pier Giorgio Perotto, with a small team and limited means, started the project of the first personal computer in the world, industrially produced: the Programma 101.

At the time, all the computers were big and expensive, but the Perotto's dream was "a friendly machine to which to delegate those operations which cause mental fatigue and errors, .... whose use was within everyone's reach, not expensive and with the size of other office products which people were used to".

The Programma 101 was a completely new product with completely new original solutions, like the delay line memory and the magnetic card. The printer was also a completely new project.

During the development something occurred which risked interrupting the project. In May 1964, the new partners decided to sell the Electronics Division to General Electric. Perotto has an idea that saved the Programma 101 project: during a night, he with his team modified all the P101 documents changing the world "calcolatore" (masculine) in "calcolatrice" (feminine). In Italian, this difference is fundamental: the masculine is a big computer, the feminine is a desktop calculator. In this way, the project was saved and remained in Olivetti.

The Programma 101 was launched at the 1964 New York World's Fair, with an incredible success and despite the wish of the management to hide it. 40,000 units were sold; 90% of them in the United States, where the sale price was $3,200, versus 100,000 required for a traditional computer. About 10 Programma 101 were sold to NASA and used to plan the Apollo 11 landing on the Moon.

The sales were so successful that at the end of 1966 Underwood, a US company controlled by Olivetti, asked to be able to manufacture the P101 on US soil in order to also be able to supply the offices of the federal administrations of that country. In the meantime, as early as March 1965, the patent on the technical solutions adopted by the computer had been filed with the competent US office. The maneuver turned out to be appropriate because Hewlett-Packard, which had bought 100 units of Programma 101, started producing a similar device, the HP 9100A, logically similar to the P101. When the patent infringement was contested, the US company reached an out-of-court settlement, recognizing Olivetti a royalty fee of 900,000 dollars. Perotto had previously sold to Olivetti all the patent rights for one dollar.



On YouTube there is a video from History channel that tells all the Olivetti Programma 101 story "When Olivetti invented the PC". It is interesting how a thriller movie, I recommend it.

# The HP-35

Now that I told you the story of the 9100, the HP's first scientific calculator, we can go on opening the casket of the HP-35. Note that, differently from the instrument, we use the “HP-” prefix in front of the model number (also the manuals follow this rule).

## What it is

The HP-35 is a scientific pocket calculator that combines the portability of the old slide rule with the precise accuracy and problem-solving power of many desktop scientific calculators. As easy to use as an adding machine, it went far beyond the conventional four-function pocket calculators available at the time. It handles transcendental functions like trigonometry, logarithms, and exponentials (as well as common mathematical functions), with single key strokes, thus eliminating referral to trig or log tables. It displays up to ten significant digits and automatically positions the decimal point throughout its 200 decade range ($10^{-99}$ to $10^{99}$). Compared to a slide rule, it provides answers in a fraction of the time with unprecedented accuracy.

## Operational stack and memory

The HP-35 provides four registers to serve as an operational stack for intermediate values, plus a fifth register for constants. This feature is found on some computers, but only rarely in a calculator. For both simple and complex problems requiring intermediate values, the stack holds the intermediate results, then brings them back automatically at the appropriate time for further processing. This eliminates scratch notes or re-entry of intermediate values. For review purposes, stack control keys permit any register to be shifted back into the display.

## Automatic decimal point positioning

On the HP-35, values can be entered in either floating point or scientific notation. Answers in the range from $10^{-2}$ to $10^{10}$ are displayed in floating point with the decimal properly positioned automatically. For






❶ The HP-35 itself. ❷ The genuine leather pouch (perhaps for the first and last time). ❸ The power supply; my original has been lost and replaced; this one is a USA version, 110 V only. ❹ the precious little manual, explaining the Reverse Polish Notation;

values outside this range, answers are displayed in scientific notation with the exponent of 10 displayed at the right.

## Battery or ac operation

The HP.35 operates from its own nickel cadmium batteries or from ac power. Batteries are recharged automatically when on ac operation. Battery operating time is four hours.

## Optional accessories

- Security cradle: securely locks calculator into a cradle which can be attached to desk or work surface for protection against pilferage. Price, including six-foot stainless steel retaining cable, $24.50.
- Battery holder: holds an extra set of batteries for recharging outside the calculator so you always have a fresh set. Price, including batteries, $18.
- Field case: rugged felt-lined case protects against dust, weather and bumps. Price, $19.50.

## General specifications

Single keystroke functions
- Arithmetic: Add, Subtract, Multiply and Divide
- Trigonometric: Sin x, Cos x, Tan x, Arc Sin x, Arc Cos x, Arc Tan x
- Logarithmic: $Log_{10}$ x, $Log_e$ x, and $e^x$
- Other functions: $x^y$, 1/x, $\sqrt{x}$ and data storage and positioning keys

Power
- AC: 115 or 230 V, ±10%, 50 to 60 Hz, 5 watts
- Battery: 500 mW derived from nickel cadmium rechargeable battery pack.

Physical
- Length: 5.8 inches (14.7 cm)
- Width: 3.2 inches (8.1 cm)
- Height: 0.7 to 1.3 inches (1.8 to 3.3 cm)
- Weight 255g (recharger 142g)

Temperature range: 0°C to 40°C operating

Accessories included:
- AC adapter and battery recharger (115/230 V)
- Soft case with belt loop
- Safety travel case, which holds both calculator and recharger and is compact enough to fit most standard attache cases
- Self-adhesive owner name tags for the unit and accessories
- Operating manual





1972




Here below: one of the self-adhesive owner name tags included with the HP-35. This one has been written with the famous IBM Selectric, the radical innovation that completely disrupted the typewriter market.

Photo by Scs - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=12073489

## History

In about 1970, Bill Hewlett challenged his co-workers to create a "shirt-pocket sized HP-9100" (hence the Olivetti P101 connection). We already saw that, at the time, slide rules were the only practical portable devices for performing trigonometric and exponential functions, as existing pocket calculators could only perform addition, subtraction, multiplication, and division.

A marketing study done in early 1971 warned HP that there was a limited market for a pocket-sized calculator with scientific and mathematical functionality (maximum 50,000 units) —it also recommended that the new calculator be the size of a typewriter or adding machine. But Bill Hewlett was convinced that engineers would prefer a calculator that would fit into a shirt pocket. In the first three years after its introduction in 1972, sales of the HP-35 Scientific Calculator exceeded 300,000 units. So you can understand the difference between a true entrepreneur and the usual “experts”.

The HP-35 was developed in two years, at a cost of approximately one million dollars with twenty engineers. At the time, three to five years was a typical HP development cycle.

Introduced at 395 USD (almost 2,900$ today) the "35" got its name from the number of keys. Like the desktop 9100 the HP-35 used reverse Polish notation (RPN) that we will describe later.

The HP-35 was available from 1972 to 1975 and in 2009 was named as an IEEE Milestone. The HP-35 was described in the 6/1972 issue of the HP Journal, that will help us in these notes.

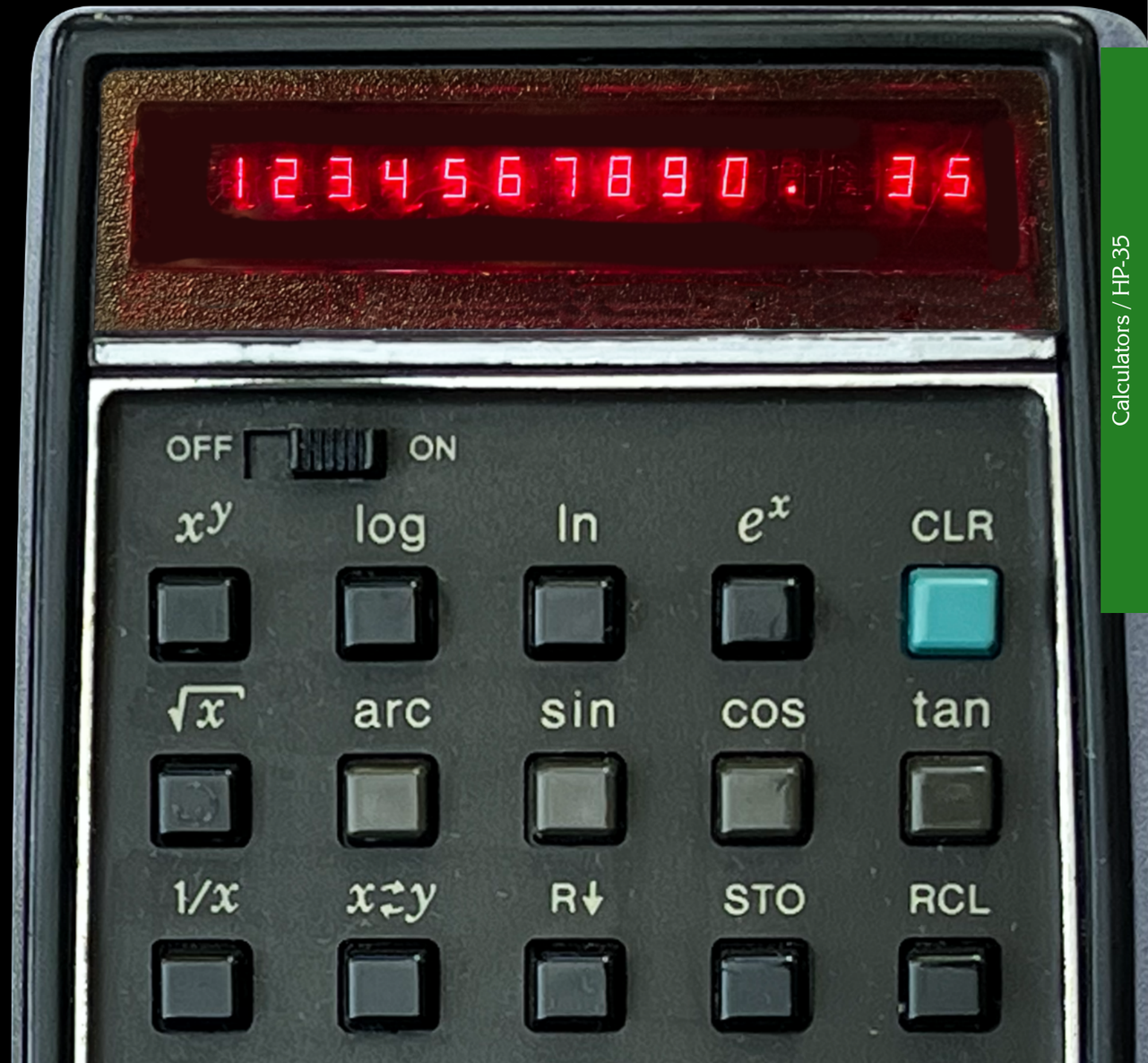
## The HP-35 and me

I discovered the HP-35 in 1973, when I was preparing for the electrical engineering exam (that we call “Electrotechnics”) at the university. Everybody used the slide rule for the calculations, something that I loved because it gave you the look of an engineer with the girls, but really hated because it made me making a lot of errors, especially about magnitude orders (to let you understand the girls’ topic: in that old time, an engineer was often the hero in the movies, not like today when he is normally the accomplice of the perfidious multinationals).

A University mate proposed me to buy two HP-35, one for each, and get a discount. My father was not in general keen to give me money, but in this case he didn't want to make a bad impression on my friend's family and decided to buy to me as well the mythical HP-35, not only a wonderful tool, absolutely innova-







tive, but also a status symbol that produced crowds every time you took it out. If I remember correctly, the standard price 230,000 Liras but buying two we paid “only” 220,000, a lot of money then. In hindsight, it was a good investment, that probably addressed the course of my life. The one here photographed is exactly mine; only the power supply has been replaced, being my original one lost in the years.

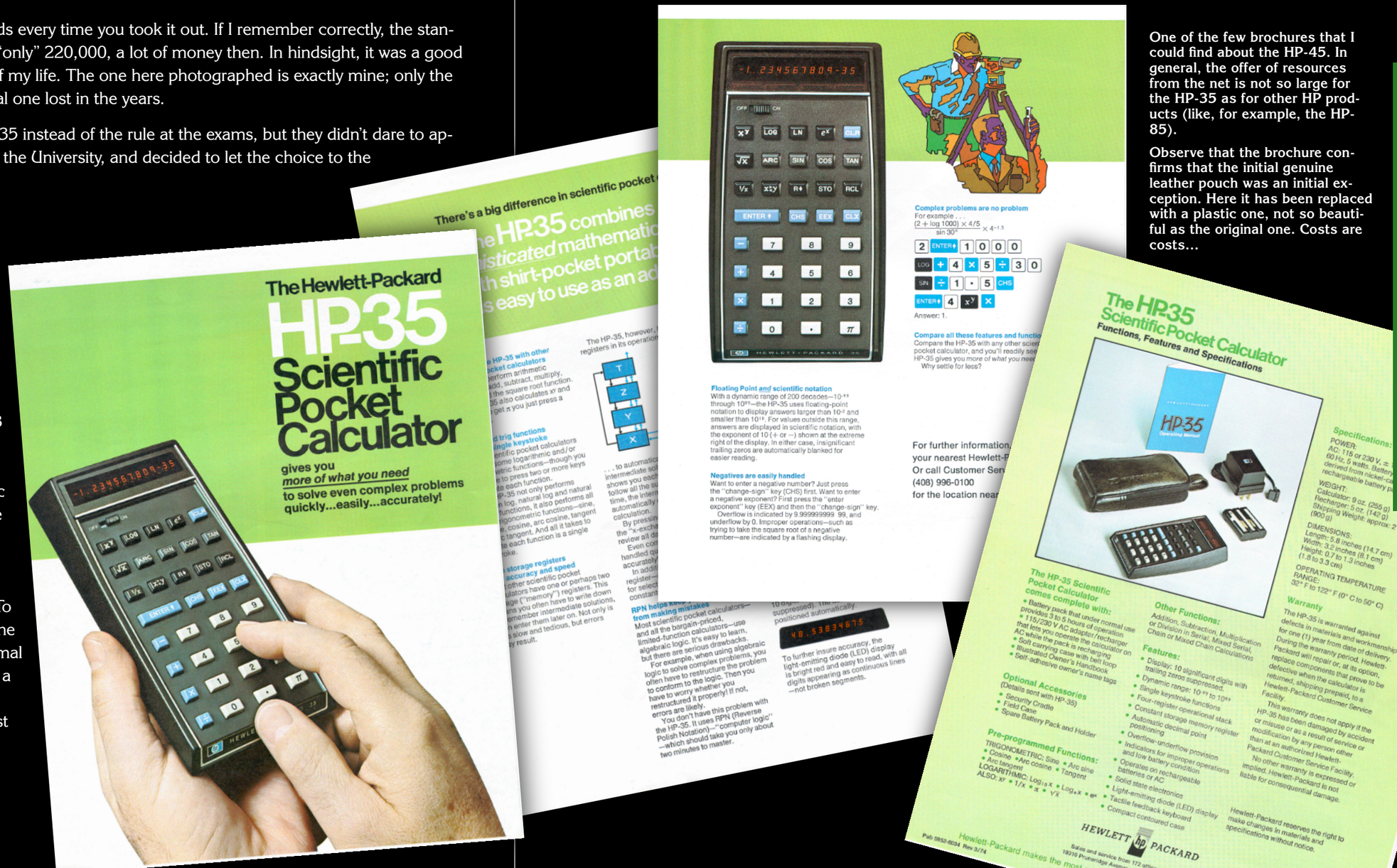
Professors were uncertain if letting us use the HP-35 instead of the rule at the exams, but they didn’t dare to appear “old”, right in the engineering department of the University, and decided to let the choice to the students. Honestly, having it was a big privilege.

## Some trivia

Some curiosities from Wikipedia:

- the HP-35 was 5.8 inches (150 mm) long and 3.2 inches (81 mm) wide, said to have been designed to fit into one of William Hewlett's shirt pockets;
- it was the first scientific calculator to fly in space in 1973;
- HP-35 calculators were carried on the Skylab 3 and Skylab 4 flights, between July 1973 and February 1974;
- it was the first pocket calculator with a numeric range that covered 200 decades (more precise 199, ±10±99).
- the LED display power requirement was responsible for the HP-35's short battery life between charges — really about three hours. To extend operating time and avoid wearing out the on/off slide switch, users would press the decimal point key to force the display to illuminate just a single LED junction,
- 100,000 HP-35 calculators were sold in the first year, and over 300,000 by the time it was discontinued in 1975—3½ years after its introduction.






One of the few brochures that I could find about the HP-45. In general, the offer of resources from the net is not so large for the HP-35 as for other HP products (like, for example, the HP-85).

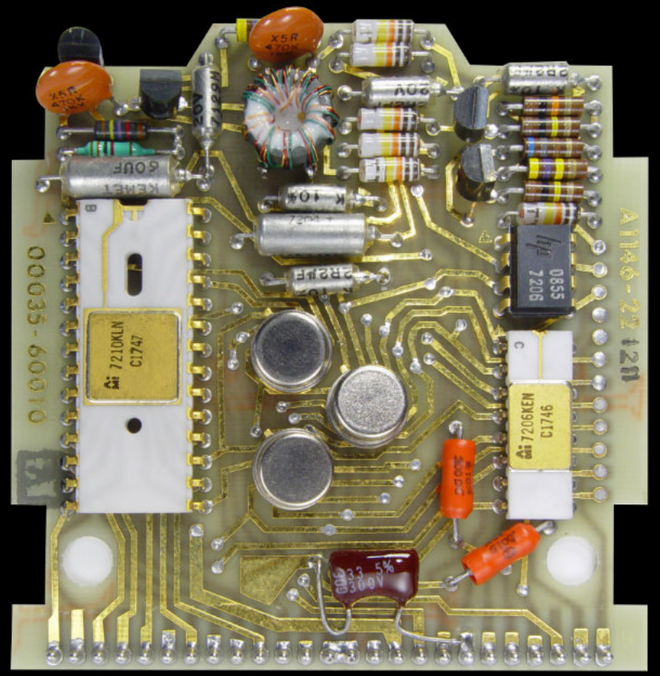
Observe that the brochure confirms that the initial genuine leather pouch was an initial exception. Here it has been replaced with a plastic one, not so beautiful as the original one. Costs are costs...

## Three superpowers

At the time of HP-35 introduction, many four-function electronic calculators had appeared on the market, initially from Japan and then from many U.S. manufacturers, among which, probably, Texas Instrument, but the 35 had three features that set it apart from them:

- **First**, none of the four-function calculators has transcendental functions (that is, trigonometric, logarithmic, exponential) or even square root.
- **Second**, the HP-35 has a full two-hundred-decade range, allowing numbers from $10^{-99}$ to $9.999999999 \times 10^{+99}$ to be represented in scientific notation.
- **Third**, the HP-35 has five registers for storing constants and results instead of just one or two, and four of these registers are arranged to form an operational stack, a feature found in some computers but rarely in calculators.

The HP-35 has thus basically the same functions and accuracy of other HP scientific calculators, but, with its 250 grams, is portable, stays in a shirt pocket, and allows 3-hour operation from rechargeable batteries, at a cost any laboratory and many individuals could easily justify.




By Kucharek 16:25, 16 September 2006 (UTC) - own scan, Public Domain,https://commons.wikimedia.org/w/index.php?curid=1178762

## Data entry

The keyboard has a good feel and use double-injected keys (see HP-85). You will never find an HP-85 with worn-out keys. Entry is entirely free-field, that is, digits will be displayed exactly as they are entered, including leading or trailing zeros; scientific notation is allowed with the EE key A key is provided for π. Each key has only one meaning; that limits the number of functions but is very practical.





The two boards composing the HP-35, taken from the June 1972 HP Journal. Note the "oilcan" keys described in the text, that after so many years normally continue to work properly, and the rough PCB that today seems to be designed by an hobbyist. The PCB in this photo was probably a hand soldered prototype: the vias are not filled with solder like in the photo on the left.

Subsequent models will have up to four meanings for key. Note that the exponent key is $x^y$, so require to press x↔y or to mentally reverse the input. Subsequent models will have $y^x$.

## Display

The display consists of 15 seven-segment LEDs, a position is reserved for decimal point. Today it appears incredibly small, but at the time it looked wonderful; the difference from to be or not to be. Very good the automatic choice for passing to the scientific notation and the trailing zeroes suppression. Improper operations, such as division by zero or the square root of a negative number, cause a blinking zero to appear.

## Registers and Control Keys

Five registers are available to the user. Four of these, called X, Y, Z, and T, form an operational stack. The fifth, S, is for constant storage. (For clarity, capital letters refer to the registers and lower-case letters refer to the contents of the registers.)

Five keys are used to transfer data between registers. The ENTER key pushes the stack up, that is, × is copied into Y, y into Z, z into T, and t is lost.

This key is used as a separator between consecutive data entries, such as in the power example just described. Roll down, R↓, is used to view the contents of X, Y, Z, and T. Four consecutive operations of this key return the registers to the original state with no loss of data.

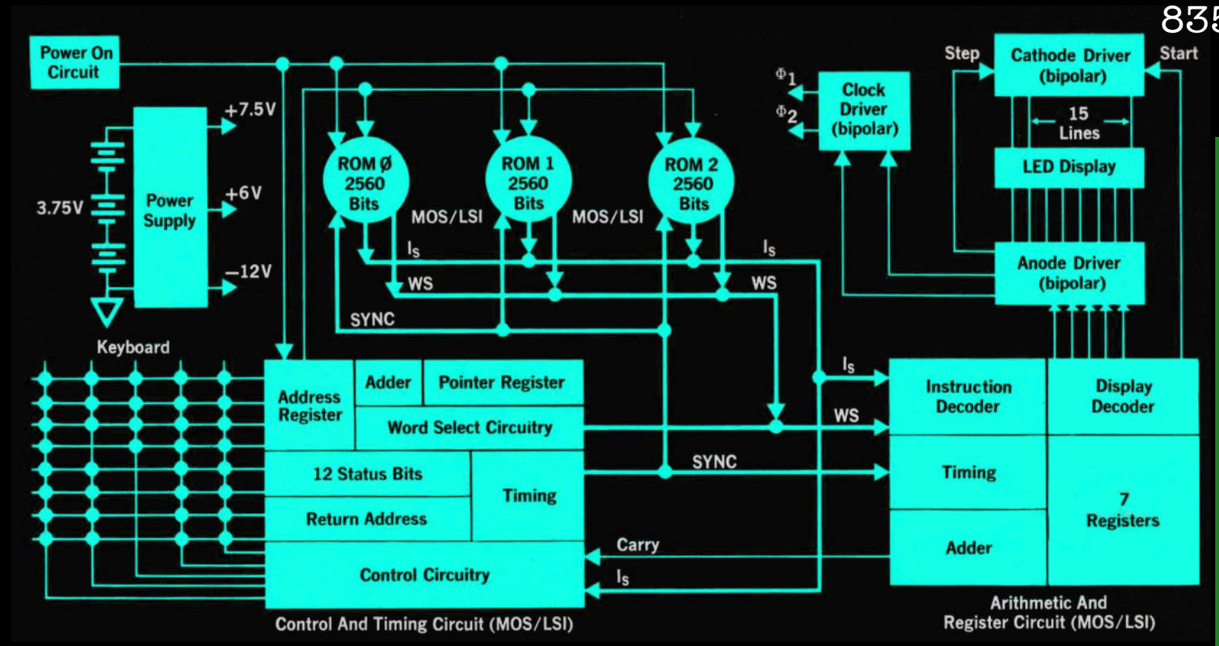
The contents of X and Y can be exchanged using x↔y; this is useful if the operands have been entered in the improper order . The operational stack is automatically pushed up when possible, avoiding non-necessary ENTER. The stack automatically drops down following any two-operand function. For example, to do the problem (3X4) + (5X6) the key sequence is: 3, ENTER, 4, X, 5, ENTER, 6, X.

On the back of the calculator is an instruction panel that provides the user with quick answers to the most commonly asked 'how-to-do-it' questions.

## Inner working

An HP-35 contains five MOS/LSI (metal-oxide-semiconductor/large-scale-integration) circuits: three read-only-memories (ROMs), an arithmetic and register circuit (A&R), and a control and timing circuit (C&T). The logic design was done by HP and the circuits were developed and manufactured by two outside






vendors. Three custom bipolar circuits were manufactured by HP's Santa Clara Division: a two-phase clock driver, an LED anode driver/clock generator, and an LED cathode driver.

The HP-35 is assembled on two printed circuit boards (see pictures). The upper board contains the display and drivers and the keyboard. The lower and smaller board has all the MOS logic, the clock driver, and the power supply. Sorry for non having produced many photo of the internals, but dismounting these unit you damage the back label, and I wish to avoid that.

The calculator architecture, seen by today's eyes, is rather strange; it is organized on a digit-serial, bit-serial basis. I try to resume here the most important concepts; for more details see the 6/1972 HP Journal.

The HP-35 organization (see block diagram) minimizes the number of connections on each chip and between chips, thereby saving area and cost and improving reliability. Each **word** consists of 14 BCD digits, so each word is 56 bits long. Ten of the 14 digits are allocated to the mantissa, one to the mantissa sign, two to the exponent, and one to the exponent sign.

**Three main bus lines** connect the MOS circuits. One carries a word synchronization signal (**SYNC**) generated by a 56-state counter on the control and timing chip. On another bus, instructions (**Is**) are

transmitted serially from the ROMs to the **control and timing chip** or to the **arithmetic and register chip**. The third bus signal, called word select (**WS**), is a gating signal generated on the C&T chip or by the ROMs; it enables the arithmetic unit for a portion of a word time, thereby allowing operations on only part of a number, such as the mantissa or the exponent.

The **control and timing circuit** (C&T) performs the major non-arithmetic, or housekeeping functions in the calculator. These include interrogating the keyboard, keeping track of the status of the system, synchronizing the system, and modifying instruction addresses.

The **keyboard** is arranged as a five-column, eight-row matrix. It is scanned continuously by the C&T chip. When contact is made between a row and a column by pressing a key, a code corresponding to that row and column is transmitted over the Is line to the read-only memory (ROM). This code is the starting address of a program in ROM to service that key. Key bounce and lockout are handled by programmed delays.

Preprogrammed mathematical routines are stored in three **ROM** chips, each of which contains 256 instructions of 10 bits each (256 x 10). All the HP-35 firmware with all its arithmetic, logarithmic, and trigonometric functions used only 767 words ( 7,670 bits). One word only remained free.

A specific select code is assigned to each ROM chip. Only one of the three ROM chips is used at any time.

The **arithmetic and register circuit** (A&R) executes instructions coming in bit-serially on the Is line and is divided into five areas: instruction storage and decoding circuits, a timing circuit, seven 56-bit registers, an adder-subtractor, and a display decoder. An advantage of the bit-serial structure is that interconnections require only one gate per line. The adder-subtractor computes the sum or difference of two decimal numbers.

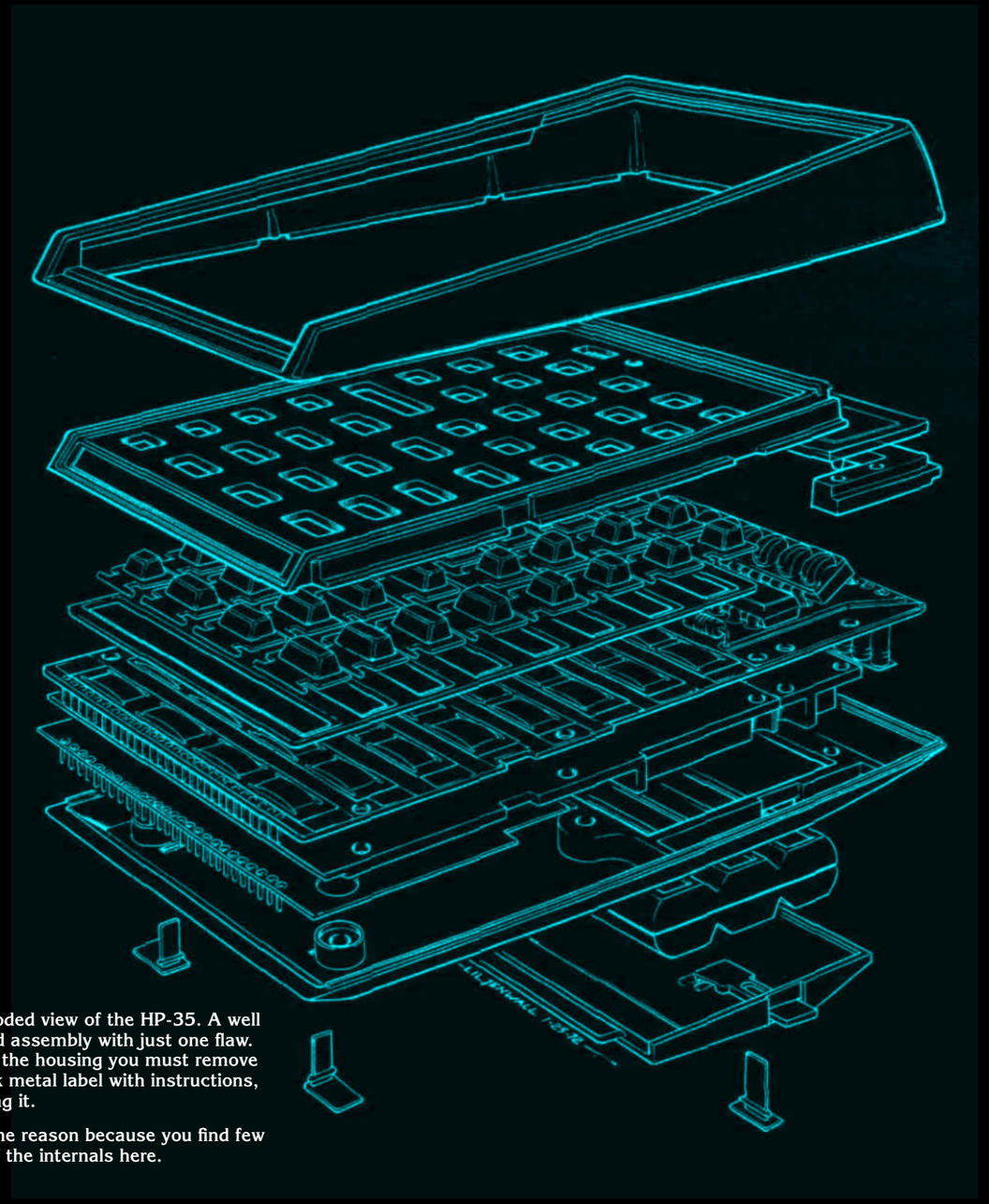
## Simulation and Test of the MOS Circuits

In designing elaborate integrated circuits like the C&T, A&R, and ROM chips, two questions that have to be answered at the very beginning are: how is the design to be checked? and how is the final integrated circuit to be tested?

The first question has two answers. One is to build a breadboard and compare its operation with the desired operation. A second answer is a computer simulation of the circuit. When the MOS circuits (C&T, A&R, and ROMs) for the HP-35 were being designed, the computer simulation approach was chosen over a TTL or MOS breadboard. It was felt that the hardware breadboard wouldn't be an exact model of the







**An exploded view of the HP-35. A well designed assembly with just one flaw. To open the housing you must remove the back metal label with instructions, damaging it.**

**That's the reason because you find few photo of the internals here.**

final circuits anyway, and two or three months of development time could be saved by computer simulation because people could work in parallel rather than serially on a breadboard.

A general-purpose simulation program, HP-DABEL, had just been developed by Jim Duley of HP Laboratories. This was used to check out each gate, each circuit, each chip, and finally all the chips together. Each MOS circuit is designed as a network of gates and delay elements. For each gate output an algebraic equation was written as function of the inputs to the gate. This produced a large set of algebraic equations to be evaluated every clock time. A printout was available so the operation of any of the gates or delay outputs could be observed, as if with an oscilloscope probe. In this respect the computer simulation was much better than a hardware breadboard.

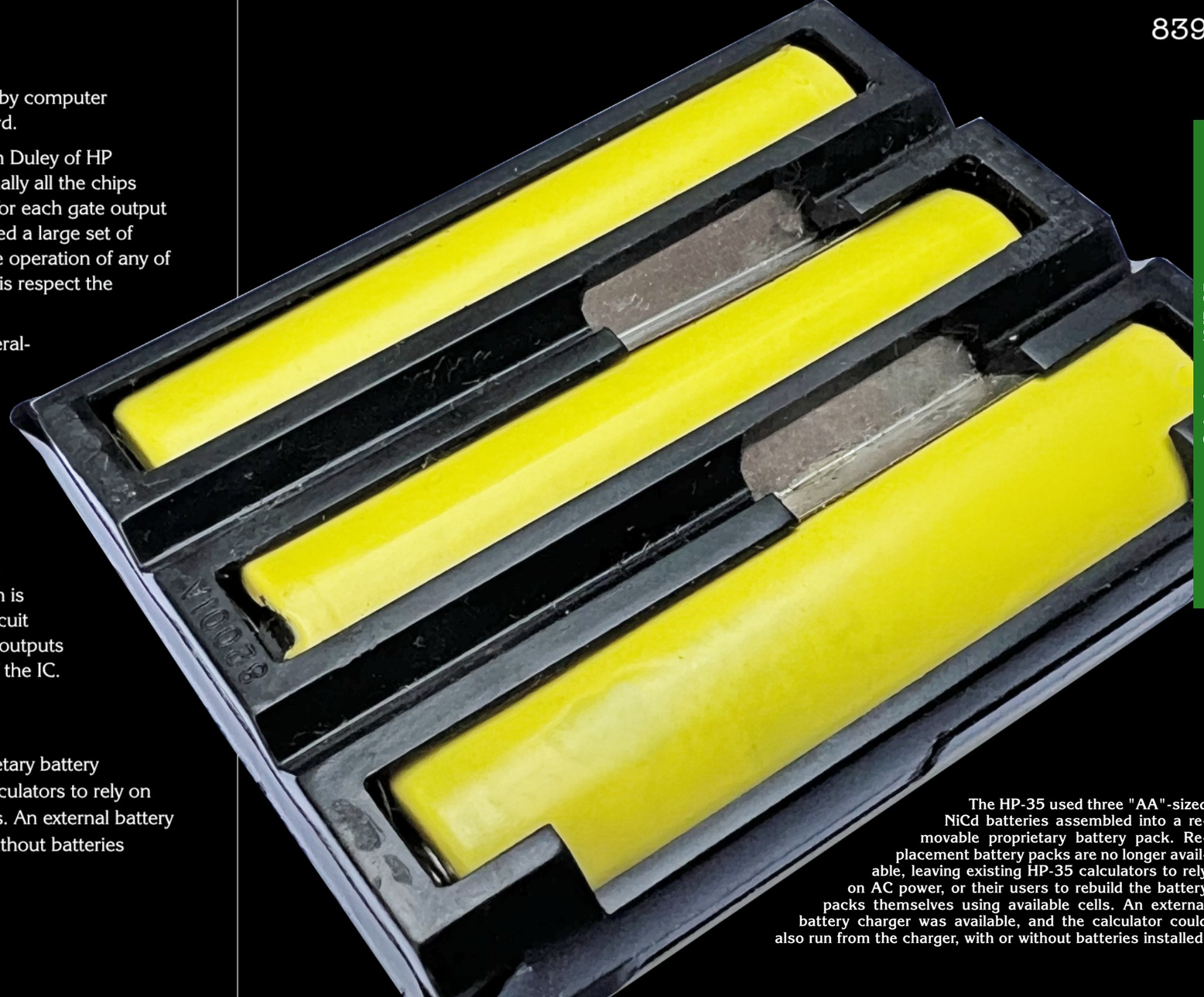
Because of the large number of equations to be evaluated each clock time the general-purpose simulation program was too slow to use for evaluating the algorithms implemented in the ROMs. For this a higher-level simulation was used, so only the input/output functions of each subsystem had to be specified. This was fast enough that all the algorithms could be checked, even the transcendental functions. If anything went wrong it was always possible to stop the program and step through it until the trouble was found. Correcting a problem was a simple matter of changing a punched card or two. These are advantages a hardware breadboard doesn't have. The simulation approach proved very successful. It saved a lot of time not only in logic design, but also in generating the test patterns to be used for testing the final integrated circuits. After a simulation is running successfully a pattern for each input is specified such that virtually every circuit element will be exercised. By running the program and recording all the inputs and outputs a complete test pattern is generated. This is recorded on tape, ready for final test of the IC.

## Battery

The HP-35 uses three "AA"-sized NiCd batteries assembled into a removable proprietary battery pack. Replacement battery packs are no longer available, leaving existing HP-35 calculators to rely on AC power, or their users to rebuild the battery packs themselves using available cells. An external battery charger was available, and the calculator could also run from the charger, with or without batteries installed.







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## Keyboard

Requirements for the HP-35's keyboard were particularly difficult. The keyboard had to be re-liable, inexpensive, and low-profile, and to have a good 'feel'. The chosen solution was based on the 'oilcan' or 'cricket' principle, that is, curved metal restrained at the edges can have two stable states. The larger board shows the etched metal keyboard strips running horizontally. At each key location the metal is raised to form a hump over a printed-circuit trace running underneath. Depressing a key snaps the metal down to make contact with the trace. The keys have a definite 'fall-away' or 'over-center' feel so that there is no question when electrical contact is complete.

## Display and drivers

It was apparent early in the HP-35 planning that new display techniques would be required. Existing light-emitting-diode products used too much power and cost too much. HP Associates developed a magnified five-digit cluster which saves both power and cost and is packaged in a convenient 14-pin package. Each digit has a spherical lens molded in the plastic over it, as shown in this photo. A slight reduction in viewing angle results, but for the handheld calculator this is not a problem.

LED's are more efficient if they are pulsed at a low duty cycle rather than driven by a dc source. In the HP-35, energy is stored in inductors and dumped into the light-emitting diodes. This drive technique allows a high degree of multiplexing; the digits are scanned one at a time, one segment at a time.

Customized bipolar anode and cathode driver circuits incorporating the required features were developed and manufactured by HP. The anode driver generates the two-phase system clock and the segment (anode) drive signals, decodes the data from the arithmetic and register chip and inserts the decimal point, sends shift signals to the other axis of the multiplex circuitry (the cathode driver), and senses low battery voltage to turn on all decimal points as a warning that about 15 minutes of operating time remains (really, when they appeared you had a very short time of life). The cathode driver contains a 15-position shift register which is incremented for each digit position.



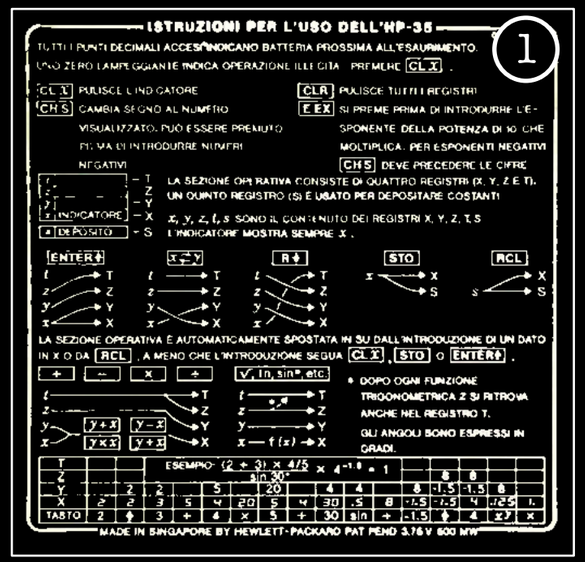
The LED display taken from a short distance. You can see the “lenses” that make bigger the digits, and glimpse the chip internals. The opto devices offer from the market was still limited and HP designed and produced its own displays.

# The Reverse Polish Notation

The HP-35 taught me the Reverse Polish Notation; if you want to calculate 3 + 7 x 5, you have to type (3) (ENTER) (7) (ENTER) (5) (x) (+). Not very intuitive at beginning, but very practical when you get used to, and still now I am more comfortable with it than parentheses, and keep in my iPhone an HP-35 emulator that I use instead of Apple calculator.

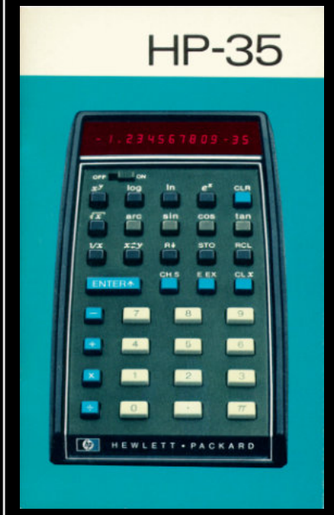
The HP-35 manual was very well done and you can see few pages from it in the facing page.

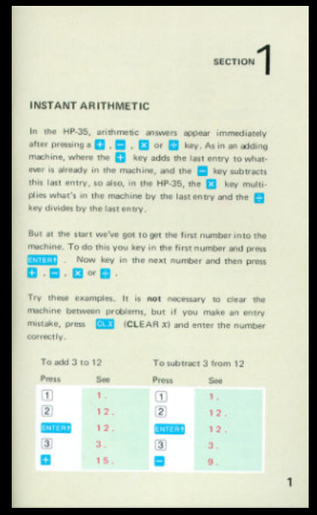
We loyal to HP calculators were convinced of the absolute superiority of the RPN, but, years later, writing my own programming language interpreters, I understood that it was simply the way to save a fair amount of complexity and code (that would not fit the small ROMs), not an advantage for the user. But RPN was our flag and we were its proud soldiers…

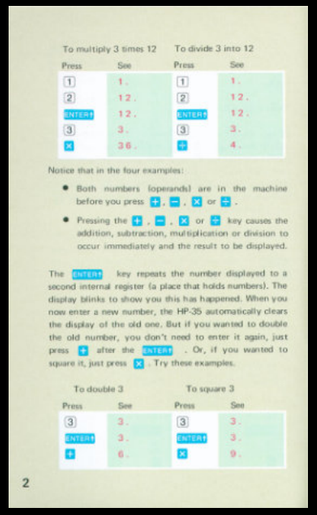






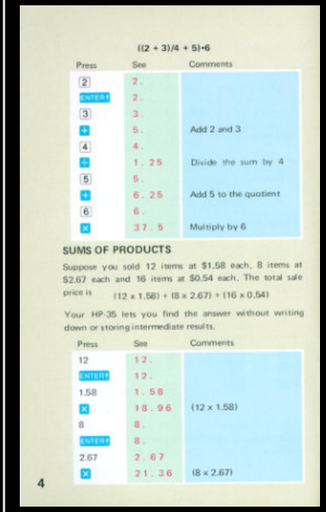


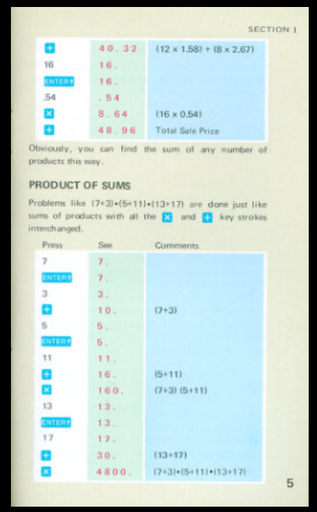



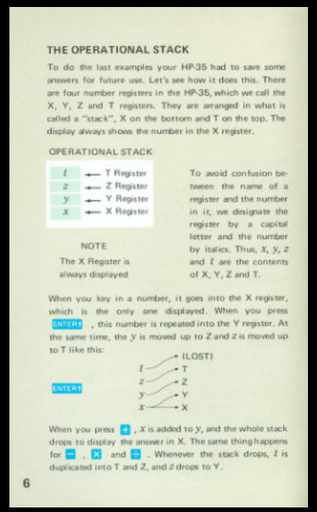



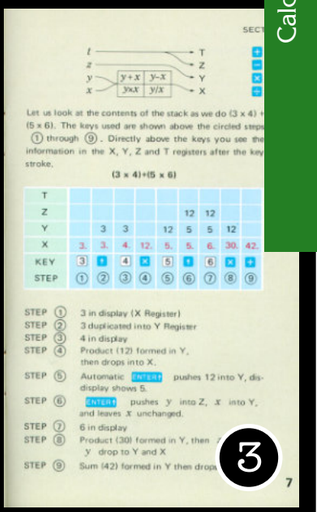







❶ The back plate with the instructions in Italian, clearly from my HP-85. It is damaged because I had to remove it to access the screws that keep the box closed, to fix the main switch (❷), one of the critical elements of this old calculator. ❸ The HP-35 manual in English.

# Calculators



Subsection

## HP-45 calculator

A luxury HP-35

# HP-45

Presented in 1973, the HP-45 scientific calculator was the luxury version of the popular HP-35 with many additional capabilities.

It was HP's first scientific calculator to have a shift key. This was such a novel feature at the time that HP credited the key with nearly doubling the computational power of the calculator.

The HP-45 added the ability to do trig functions in Radians or Grads, polar to rectangular conversions, decimal degrees to/ from degrees minutes seconds, basic statistics %, % change, n! etc. It was also the first pocket calculator, to have 9 storage registers in addition to the 4 level stack.

The HP-45 also added 10x and replaced $x^y$ with $y^x$. It also added the now ubiquitous LAST X key and $x^2$. The latter was placed on an unshifted key where it makes sense.

Another feature added on the HP-45, was the formatted display. It added both fixed and scientific displays with a choice of the number of digits displayed. The HP-35 had only what is now




1973

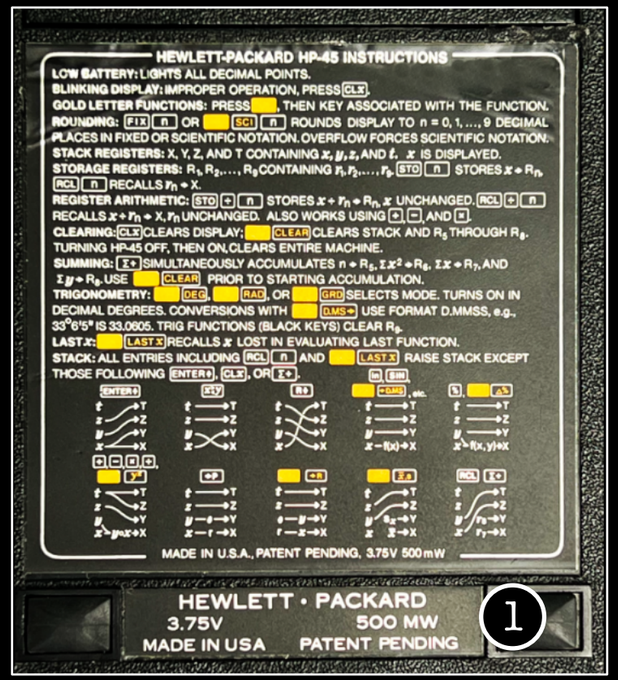
## General specifications

- Pre-programmed functions
- Arithmetic: add, subtract, multiply. divide, square root, square.
- Trigonometric (decimal degrees, radians or grads): sine, are sine. cosine, arc cosine, tangent, arc tangent, rectangular /polar coordinate conversions, vector arithmetic, conversions between operating mode and degrees/minutes/seconds.
- Logarithmic: natural logarithm, natural antilogarithm, common logarithm. common antilogarithm.
- Statistical: mean, standard deviation, sum-of-the-squares, factorial.
- Other: $y^x$, 1/x, π, %, Δ%, metric/U.S., unit conversion constants, reg-arithmetic, data storage and positioning functions.

commonly called "standard mode". In fixed mode the HP-45 would display sufficiently small numbers as zero.

It also added conversion factors for a few units like in/cm. When you pressed one of these conversion factor keys, the conversion factor was entered into the x register and then the user could use it to multiply or divide as needed.

[text from https://www.hpmuseum.org/hp45.htm]













❶ The HP-45's back label. ❷ The HP-45. ❸ The HP-35. ❹ The HP-41C.

# Calculators



Subsection

## HP-67 calculator

Almost a computer…

# The HP-65

I've told you about HP-35 and HP-45 for both historical and emotional reasons, but their appeal is limited, particularly with today's eyes.

For our perverted minds, in fact, more complicated toys are required to arouse our interest. From this point of view, positively the HP-67 fulfills this requirement.

However, the HP-35/45 story should have been continued talking about the HP-65, of which it represents the evolution, so some help from Wikipedia about this calculator are mandatory.

With a giant leap forward compared to the previous models, the HP-65 was the first handheld calculator introducing the programmability concept, being capable not only to store sequences of key, but also to take decisions, based on arithmetic or logical comparisons.

Besides this logical innovation, the HP-67 featured also an important technical innovation: the built-in magnetic card reader/writer, last legacy of the Olivetti Programma 101, miniaturized so that requiring just a little resizing of the calculator's housing. The memory technology of the time did not allow to keep the program when the power was switched off, and the to the possibility given by this jewel to transport code and data opened an entire new world of marketable applications, giving everybody the possibility to afford a computer for personal use.

One of the secrets of HP successes was also the completeness of the documentation and the provision of programs, very complete and including algorithms for hundreds of applications, including the solutions of differential equations, stock price estimation, statistics, and so forth.

The HP-65 had storage for 100 steps and could still fit in a shirt pocket.

Photo by John Crane 59 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=95349479







# The HP-67

The HP-67 was presented in 1976 as an improved successor to the HP-65, and was based on the 20-Series of calculators (HP-25, HP-19C etc.) introduced a year earlier. The HP-97 desktop version, technically similar, was also equipped with a thermal printer.

The HP catalog didn't list anymore prices for the calculators and the concept of Manufacturer's Suggested Retail Price (MSRP) was introduced. In this case, HP recommended a price of $450, today 2,400 USD, i.e. sensibly less that the HP-35 original price (the HP-97 was at 750 USD).

In 1976, the microcomputer phenomenon had not yet exploded and this was still one of the few possibilities to purchase a relatively low-cost programmable device.

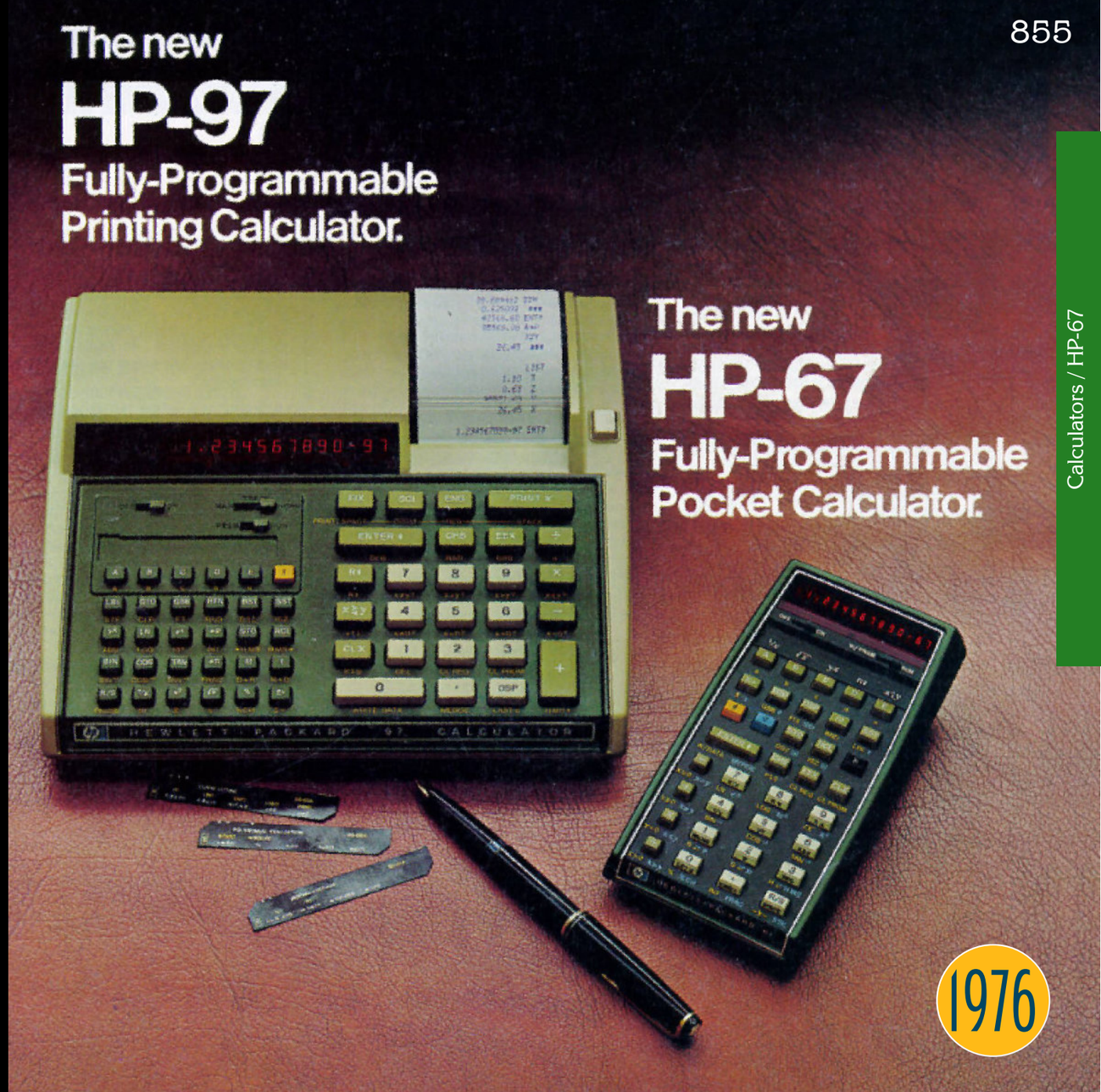
Really, it was not easy to program an HP-67 and, even if untold, you were using something like an assembly language, with up to four meanings per key and a cumbersome editing logic. Not knowing it, things were easier and however …you could! Many technicians and engineers, thanks to these devices, could afford programming and write also applications relatively complex. Furthermore, we have to give HP credit for being able to create documentation capable to transform whomever in a software programmer, when really interested to.

In few word, a small wonder machine capable of doing incredible things that you would never expect from something capable of fitting your shirt pocket.

By John crane 59 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=95349479







# The HP-67 and me

Like some other of toys I present in my books, I didn't own an HP-67 at the time; I could purchase the unit that you can see here in the photos very many years later. In the HP-67 days I was already working on microprocessor, and most of us used to look down on the programmable calculators; Instead, I studied a lot the HP-67 to write something similar on a Fairchild F8, with some success.

In truth, from this point of view, the HP-67 seemed to me better than it was; it was a long time before I really used an HP-67, discovering how uneasy it was dealing with those odd key codes (my interpreter was much better also for editing the program …but it required a Teletype ASR-33 that few people could afford. In reality, I used to use an Olivetti TE-300 (in the photo below), incomparably better of the ASR-33 as much as a luxury car compared to a tractor).




1




2

❶ The HP-67. Note the "tall" keys, hosting a label also on the front face.Up to four meanings are provided for each key. ❷ The power supply.e. ❸ The Olivetti Te 300 was probably the best mechanical teletype ever, incredibly precise and quiet. In Italy, they were very common in the 5-bit Baudot version for the Telex service, but for us only the ASCII version was interesting.

# Programs

## Key codes, the winning idea

The logical innovation, the programmability, relied on the technological evolution of LSI chips, but, apart from the card reader, the HP-65/67 was substantially an HP-35 with a more powerful CPU and more memory that allowed to write more complex firmware. Storing key sequences to make them programs was rather obvious, the problem was to find a way to allow the editing of these sequences using a minimal calculator display. The winning idea was the use of keycodes.

## Keycodes

In the HP-65/67, each key on the calculator is identified by a numerical two-digit keycode, given by the row/column physical position of the key on the keyboard. For example, the keycode 31, identifies the 3rd row of the keyboard, 1st key in that row. Something like the assembler opcodes but much more intuitive. In this way, the user can “see” the stored sequence, reading the keycodes on the display. In the example, the user read 31 and by counting down three rows and looking at the first key on the calculator keyboard, can see which the key is.

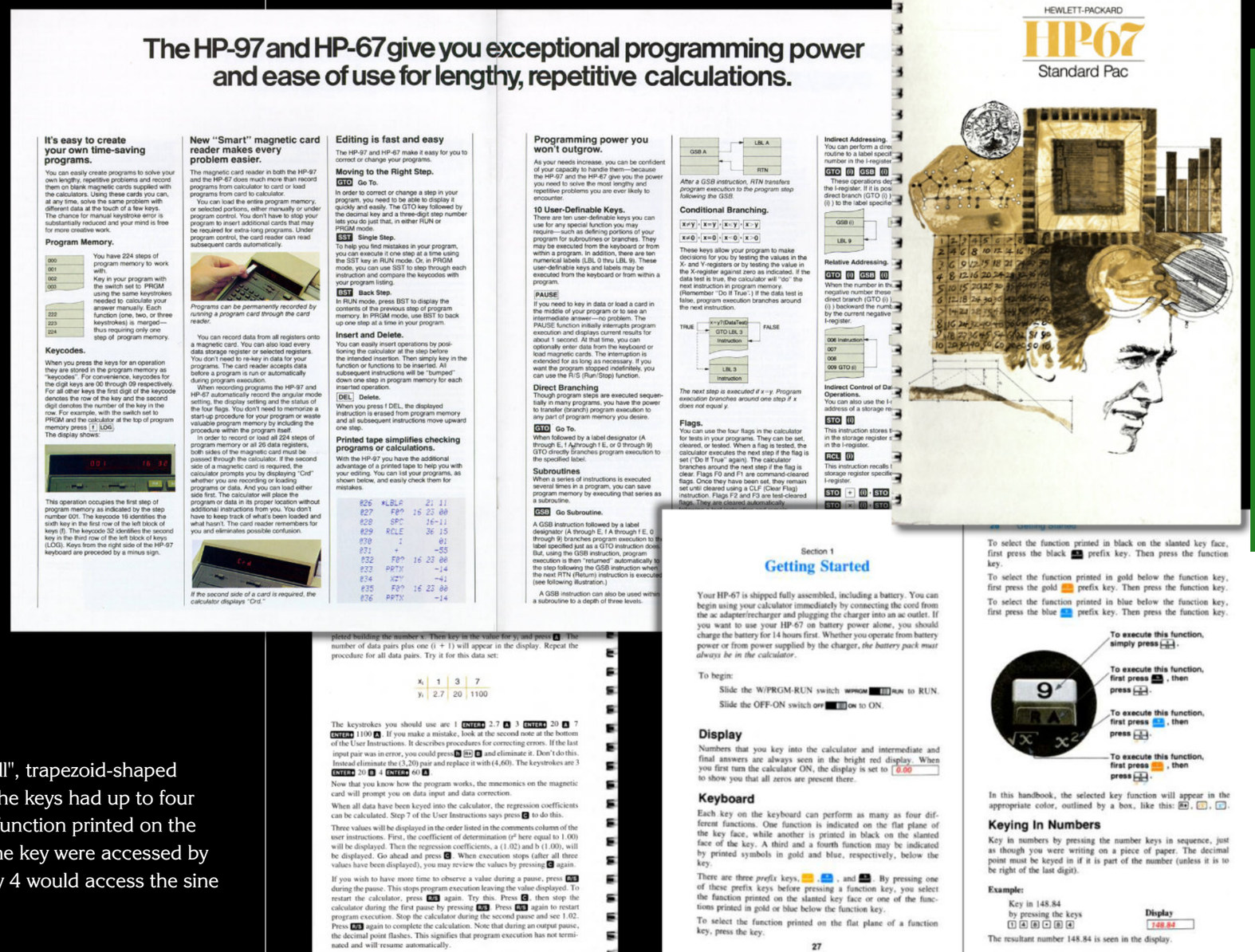
This good idea has a drawback anyway: keycodes are different from HP-67 and HP-97, that has a different keyboard layout. If you learn the codes for one, they are not good for the other.

## Shift keys

The HP-65/67 have more functions that keys. Then, the HP-65 introduced the "tall", trapezoid-shaped keys that would become iconic for many generations of HP calculators. Each of the keys had up to four functions. In addition to the "normal function" printed on the key's face, a "gold" function printed on the case above the key and a "blue" function printed on the slanted front surface of the key were accessed by pushing the gold “f” or blue “g” prefix key, respectively. For example, f followed by 4 would access the sine function, or g followed by 4 would calculate 1/x.







The HP-97 and HP-67 give you exceptional programming power and ease of use for lengthy, repetitive calculations.

It's easy to create your own time-saving programs.

New "Smart" magnetic card reader makes every problem easier.

Editing is fast and easy

Programming power you won't outgrow.

HEWLETT-PACKARD
HP67
Standard Pac

Section 1
Getting Started

Your HP-67 is shipped fully assembled, including a battery. You can begin using your calculator immediately by connecting the cord from the ac adapter/recharger and plugging the charger into an ac outlet. If you want to use your HP-67 on battery power alone, you should charge the battery for 14 hours first. Whether you operate from battery power or from power supplied by the charger, *the battery pack must always be in the calculator.*

To begin:

Slide the W/PRGM-RUN switch WPRGM RUN to RUN.

Slide the OFF-ON switch OFF ON to ON.

Display

Numbers that you key into the calculator and intermediate and final answers are always seen in the bright red display. When you first turn the calculator ON, the display is set to 0.00 to show you that all zeros are present there.

Keyboard

Each key on the keyboard can perform as many as four different functions. One function is indicated on the flat plane of the key face, while another is printed in black on the slanted face of the key. A third and a fourth function may be indicated by printed symbols in gold and blue, respectively, below the key.

There are three *prefix* keys, f, g, and STO. By pressing one of these prefix keys before pressing a function key, you select the function printed on the slanted key face or one of the functions printed in gold or blue below the function key.

To select the function printed on the flat plane of a function key, press the key.

To select the function printed in black on the slanted key face, first press the black prefix key. Then press the function key.

To select the function printed in gold below the function key, first press the gold prefix key. Then press the function key.

To select the function printed in blue below the function key, first press the blue prefix key. Then press the function key.

To execute this function, simply press .

To execute this function, first press f, then press .

To execute this function, first press g, then press .

To execute this function, first press STO, then press .

In this handbook, the selected key function will appear in the appropriate color, outlined by a box, like this: , , .

Keying In Numbers

Key in numbers by pressing the number keys in sequence, just as though you were writing on a piece of paper. The decimal point must be keyed in if it is part of the number (unless it is to be right of the last digit).

Example:

Key in 148.84 by pressing the keys 1 4 8 . 8 4

Display 148.84

The resultant number 148.84 is seen in the display.

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## Programs

The stored sequence of keys is said program. In the HP-67, program memory consists of 224 "steps" which are numbered from 001 to 224, together with a top-of-memory marker, step 000.

Each step of program memory can "remember' a single operation, whether that operation consists of one, two, or three keystrokes. Thus, one step of program memory might contain a single-keystroke operation like CHS, while another step of program memory could contain a two-keystroke operation, like STO 6.

A slide key allows to chose the normal or the program editing modes.

## Decisions

Among the many functions offered by these calculators, there are decision keys like X=0 or x<y.

Each conditional essentially asks a question when it is encountered as an instruction in a program. If the answer is YES, program execution continues sequentially downward with the next instruction in program memory. If the answer is NO, the calculator branches around the next instruction. Something like SKIP IF NON ZERO in assembly language.

## Editing

In the program mode, the calculator shows you a step with its position and the keycodes contained in that step, like

```
001 31 54
```

Keys are provided to move in the program and to modify it.  The manuals explain all that in a very good way, with tons of examples, that make sweeter the bitter pill. Only with the help of coding sheets things become easier, exactly like in assembly programming before having assemblers available.




Some parts of the HP-67 kit. ❶ The owner's manual, a true masterpiece for clearness and completeness. ❷ The power supply.e. ❸ The replaceable battery pack. ❹ The quick reference card. ❺❻ The standard pack, a set of useful programs that you could load in a snap, thanks to the pre-written magnetic cards. A good reason more to buy the HP-67.

# The card reader

## Resuming

At this point, we understood that the HP-65/67s are only “bigger” HP-35s with a more complex firmware that implements a more complex operating system and an interpreter, that allows to write, edit and execute programs.

## Technical innovation

It’s time now to look at the technical innovation, i.e., the wonderful card reader/writer (since now we call it just reader, implying that it can as well write data on the cards).

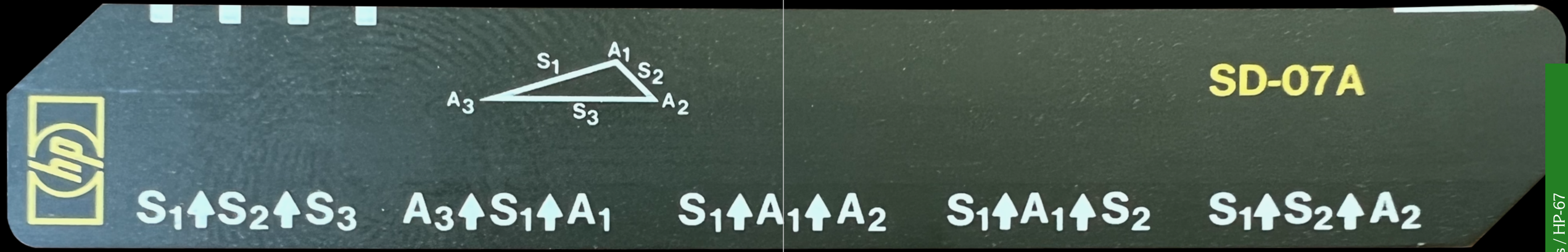
As noted, this is still a legacy of the Olivetti Programma 101 project, fully based on reading and writing of cards, but miniaturized and with a flavor of geniality, with the use of the cards as labels for the first hotkeys in the story (or so). In fact, when inserted into an extra slot between the display and the keyboard, the printing on top of the card would correspond to the top row of keys (A - E), which served as shortcuts to the corresponding program entry points.

## No shortage of ideas (by Robert B. Taggart)

It is interesting to read on HP Journal 5/1974 the history of the magnetic card reader development.

“One thing we had was an abundance of ideas for tiny card readers” - says Robert B. Taggart on the HP Journal 5/74. The HP-65 card reader project began in the electronic research laboratory of HP **before the introduction of the HP-35**. The basic design goal for the card reader was to propel a magnetic card the size of a piece of chewing gum at a constant speed of 3¾ to 6½ cm/s. Of course, it also had to fit inside the HP-35 package.

**Cards are inserted from the right side of the calculator, until they are “caught” by the motor. No specific command must be issued before. If the program is too long to stay in the upper track, the calculator displays a “Crd” message to ask to turn the card 180° and read it again.**




Many schemes were tried, including music box mechanisms, hand feed, gravity feed, and dashpot systems. Motor-driven schemes didn't generate much enthusiasm at first. But one day while digging through a file on motors that was about to be discarded, I found a brochure describing a Swiss-made motor less than 1.5 cm in diameter. Within a day we obtained two samples. They had ample torque and their unique construction provided very low brush noise. The motors had a tested lifetime of over one thousand hours (and forty years, we could add today).

These tiny motors turn at speeds in excess of 10,000 RPMs. The problem of reducing this high speed down to 6 cm/s was solved by using a worm gear, which provides a large speed reduction in one stage. Other schemes were tried but the worm and wheel combination proved best.

Gripping of the card under all conditions was another problem that had to be solved. The card is very small and would be handled extensively. Even grease could not be allowed to stand between a card and good gripping. Plastics and rubbers of various kinds and textures were tried. We tried to put tire-like treads into the rubber and even put ridges in the card for better grip. But finally we found a polyurethane rubber with the right texture that grips even when the card is coated with oil.

The major problems we faced were caused by trying to squeeze so much information onto such a short card. If the card could have been longer the design would have been much easier. However, having a short card offers the user the convenience of labeling the top row of keys with the program card. This restricted the length of the card to less than the width of the calculator. All kinds of things become critical in trying to read and write on short magnetic cards in such a small machine at 300 or more bits per inch.

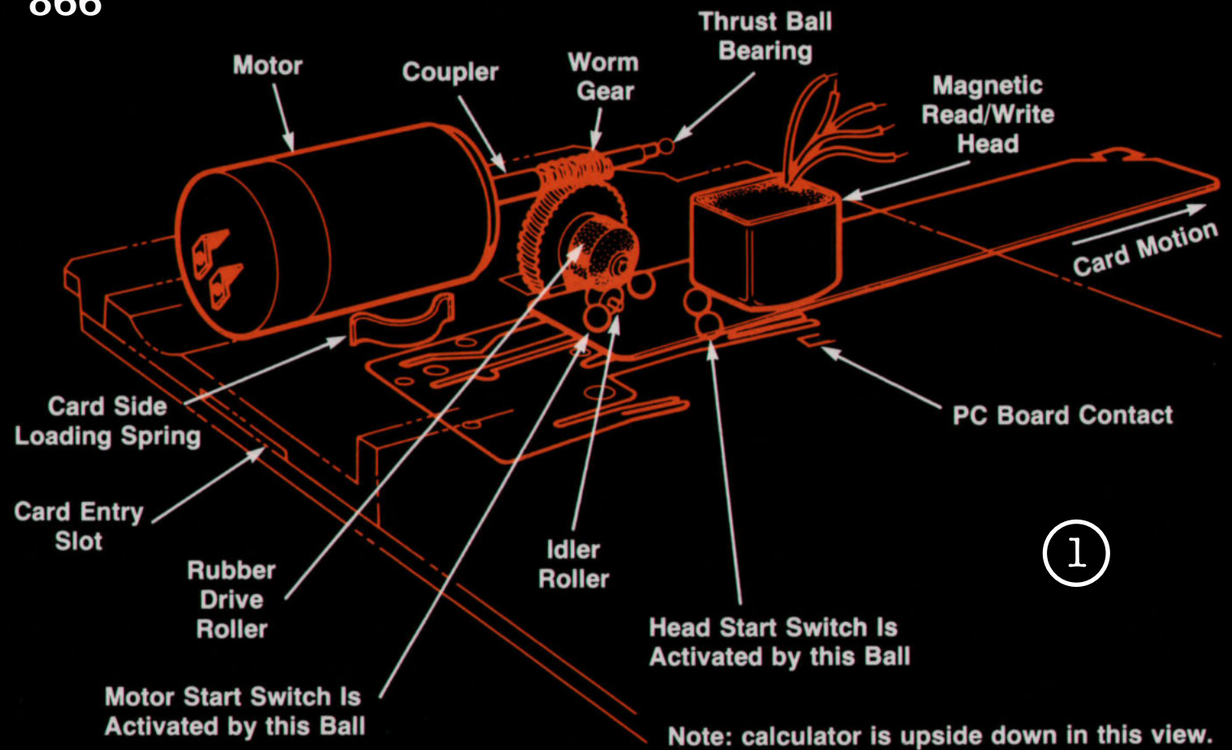
**Above: one of the cards of the HP-67 standard pack, supplied with the calculator. Note the cut corners, to make it read-only and protect against unwanted writing. Note also the labels that correspond to to the A, B, C, D and E when inserted it the special slot.**

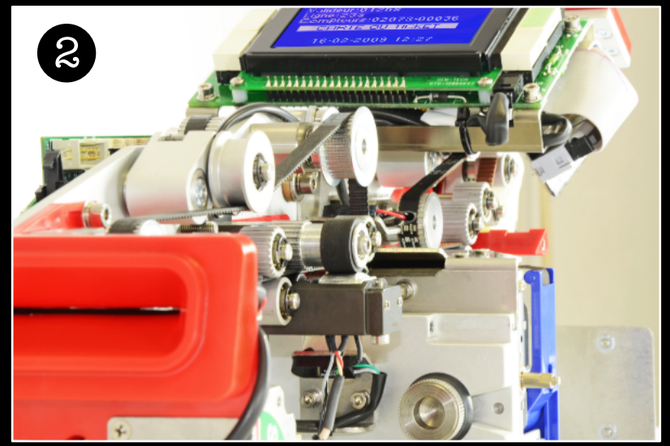
Azimuth alignment of the magnetic head at 400 bits per inch must be accurate within ±0.25°. The best way to align heads with this precision is under a microscope. But can you align a head to this kind of accuracy in a molded plastic part? Based on the HP Manufacturing Division's confidence in the plastic we decided to try. We succeeded, thereby achieving a significant cost saving over using a metal frame. Using such a short card required bunching the magnetic head very close to the drive roller and gear train.

This unusual geometry combined with the tight tolerances of ±1 mil (0.0254 mm, two hundredths of a millimeter and a half) on some dimensions made the reader frame a complex challenge.

The short card and higher bit density created numerous problems related to keeping the vibration of the drive train to a minimum. Of all the problems we faced this proved to be the most difficult. Finding the right process for making the worm gear and refining that process to a high degree made it possible. A method was developed to couple the worm gear to the motor and all these ideas combined to provide the necessary precision and smoothness. The bit-to-bit speed variation was held to less than 10%.

Another challenging problems involved inventing the switches that follow the card in its movement, the speed of the card, and the temperature range, in a device that had to stay in a volume of 1.25 × 1.25 × 2.5 cm.




❶ The HP-65/67 magnetic card reader

❷ I designed some magnetic high-speed ticket validators in 2003, and can witness that it was not easy to reliably process the tickets even with precision mechanics, like that shown in the photo. Criticalities arise with temperature, magnetic head alignment, speed and much other, like the tickets' physical conditions (users don't preserve them carefully). According to ISO standards, my tickets had up to 220 bit per inch, less than the HP-67 (but they had to go much faster that the HP-65/67). All that makes me understand the wonderful job they did, moreover with that small plastic structure.





## How the Card Reader Works

In figure ❶ there is a drawing of the card reader. As the card is inserted into the right side of the machine, it is forced against one edge of the card slot by one of two tiny leaf springs. This helps align the card with the magnetic head. Pushing the card farther into the machine causes it to activate the motor start switch when the card approaches the rubber drive roller. This turns the motor on.

Each of the three switches in the card reader is activated in the same way. The card displaces a nylon ball resting on the bottom of the card slot. Movement of the ball forces a tiny finger of copper to move up-ward. The end point of this copper switch finger makes contact with a contact pad on the underside of the keyboard printed-circuit board. The contact point of the switch moves a distance several times the thickness of the card to provide a reliable contact.

Each switch is adjusted to the proper contact position during assembly.

When the bipolar motor circuit is turned on a precise voltage is fed to the motor terminals to establish the motor/card speed to within a few percent. The motor turns at a speed near 10,000 revolutions per minute. The motor is directly coupled by a tiny polyurethane sleeve to a miniature worm gear. The end of the worm gear rests against a thrust ball bearing and drives a helical gear. The helical gear is pressed onto the hub of the polyurethane rubber drive roller, which grips the card.

Once the motor is turned on by the motor start switch the user must push the card another small fraction of a centimeter so the rubber roller will grip the card. The card is then pinched and driven between the rubber roller and a fixed tiny idler roller made of nylon. The card proceeds through the machine toward the magnetic read/write head. Little bumps in the plastic support plate combine with the switch balls to wrap the card over the gap of the head.

As the card passes the magnetic gap of the head the leading edge of the card activates a second switch.

This switch starts the write or read circuitry, depending on the position of the W/PRGM-RUN switch. Activation of this second switch lets the circuits know that the card is over the head and is assumed to be moving at the proper speed.




1

At nearly the same time that the second switch is activated, a third switch may or may not be activated depending on whether the corner of the card is cut off. This is the file protect scheme, which prevents the user from writing over a previous program. When the second switch is activated the third switch is interrogated. If the third switch is not activated (the corner being cut off) the machine will not write over that card when the calculator is in the W/PRGM mode.

The data is written/read by a two-track recording scheme which is described elsewhere. As the card proceeds out the left side of the calculator it is held against the side of the card guide by a second side-loading leaf spring. When the trailing edge of the card passes the motor start switch the motor and read/ write circuits are shut off. The card may then be removed from the machine.

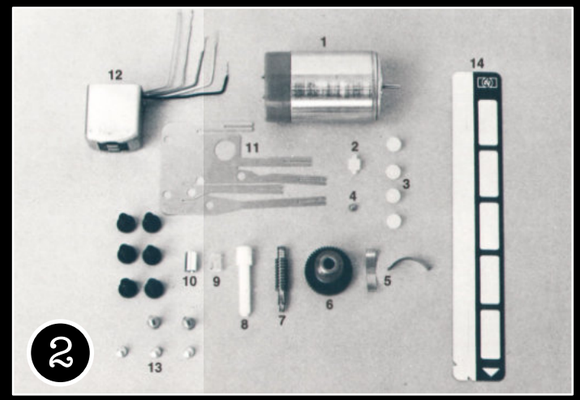
Figure ❷ shows the card-reader parts disassembled.

## The key to success

The card reader has been probably the most important key to the HP-65/67's success, because it opened the door to that awful and wonderful thing that we call software. You could start not only creating and selling your own applications, but also drawing on the HP (or third party) wide software collection.

**HP Application Pacs** enabled users saving significant time in solving a wide range of problems. They allowed to put the full power of the HP-67 to work instantly.

A wide variety of programs - in science, engineering and business - had been made available on prerecorded magnetic cards. Application Pacs contained 19 to 26 preprinted, prerecorded program cards, a program card holder and a manual of complete documentation.




2

# Calculators



Subsection

## HP-41C calculator

The last true heir of the original HP-35?

# HP-41, the last heir?

The manual also provides operating instructions, equations, limits and warnings, and sample problems with solutions for each program in the Pac.

In the large HP calculators' family, the HP-41 seems to me to be the last true heir of the ancestor HP-35. Perhaps, the last HP calculators had less individuality, personality or soul. Up to the 41, the HP calculators were "the dream of having a real computer"; subsequent models became just another anonymous accessory of our technological lives.

The comparison with steam locomotives is again very close: unpractical, illogical, inefficient, they have conquered our imagination ever since we were children. The modern and perfect high-speed trains, that I use very often, don't arouse in me the same emotions.

Produced from 1979 to 1990, it was an instant success, although, already in 1982, the new HP-75, and then the HP-71B, introduced BASIC programming, making de facto obsolete the 41-Series. Nevertheless, the HP-41 appeal was still strong and allowed it to survive for many years more. After forty years, crowds of enthusiasts are still fascinated by this wonderful piece of technology and by its cumbersome logic, still extremely intriguing and amusing to investigate.

In addition, I discover today what I didn't know, i.e., that the HP-41C had a second life, thanks to its expansion slots that I thought were only for the card reader or the printer, with a complete world of incredible peripherals, also to manage instrumentation via the HP-IB (GP-IB) bus, as we are going to discover together in the following pages.

These notes want only to be a tribute to this wonderful last hero and to its history, that you will find better described in the many resources available online.



I bought this HP-33C in the eighties, and it didn't leave a footprint in my heart. It was already a pure consumer product, or so it seemed to me.

## The most powerful ever

In 1976 the HP-41C was defined as the most powerful personal handheld calculator that HP had ever designed, with over 130 preprogrammed functions and many advanced features, including a continuous memory that retains its information when the calculator is turned off, an alphanumeric liquid crystal display with status annunciators, a full alphanumeric keyboard that can be customized to fit user needs, and sophisticated but simple programming, including advanced editing, local and global labeling, specific loop control, flexible indirect addressing, and expanded decision-making capabilities.

## A “quasi-computer”

HP aimed to promote its HP-41C to the role of “quasi-computer”, i.e., something called a calculator that looked like a calculator but accepted peripheral devices like a computer: a printer, a magnetic card reader, add-on memory modules, an optical wand, and many others, with a large number of functions, not limited any longer by the shift keys. Some of them remained accessible by single keystrokes, like a calculator's, but other functions could be accessed by spelling out their names on the alphanumeric keyboard, like on a computer.




# The HP-41C




The HP-41C 14-segment LCD screen allowed to display uppercase letters, digits, and a few punctuation marks. Some fonts needed to be twisted arbitrarily (e.g. to distinguish S from 5) and lowercase letters were unreadable (only a through e were possible). The future HP-71B will use a 5x7 matrix for each character, an important improvement that will remain standard for many years.





# HP-41 technology

## Better hardware, better software

From a general point of view, we could say that at the end of the seventies the hardware technology was sensibly improving. The new CMOS technology offered more integration, higher performances and low power consumption. More and more memory was available, and HP developers could then exploit it to write more complex and powerful software, that produced a significant overall evolution of old calculators.

Thanks to the CMOS technology and to the LCD display, the HP-41C power consumption was exceptionally low: finally you could forget the battery recharge status, nightmare of the previous calculators with LED display. A set of non-rechargeable, N-type batteries was enough for months, and, if you didn't use it, even for years (I can personally confirm it).

The HP-41C had in addition the "Continuous memory" (the "C" in the name stands for that), and any time you switch it on, you find it exactly where you left it.

## Display

To achieve these results, and to show alphanumeric strings, the HP-41C introduced a 14-segment liquid-crystal display instead of the traditional 7-segment LED. Its quality was reasonably good but still it was not a matrix display: many characters, including lower case letters, could not be shown.

The display system consists of a 12-character, 14-segment liquid crystal display and a display driver hybrid that holds two display driver circuits. These are sandwiched together with connectors and clips. There are 75 connections between the LCD and the hybrid and 15 connections to the logic board.

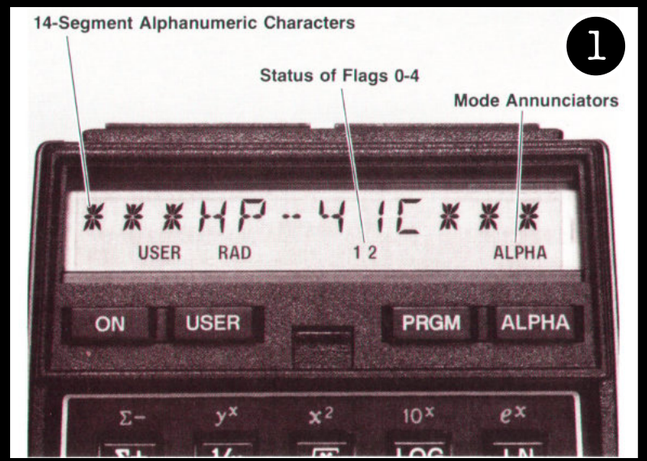
Information for each character is stored as a 9-bit string. Seven bits are used for the character's ASCII equivalent-only 80 characters are decoded and displayed and two bits are for the punctuation field. There is a separate bit per digit for the annunciators. The data from the CPU can be sent in 9-bit, 8-bit, or 4-bit (for numerics) fields in single-character or multicharacter form, from left or right side. The display can also be shifted left or right one digit at a time.

All the column data is updated each time new information is sent and the decoded outputs are buffered in a three-bit shift register for each column. This is necessary because the columns are scanned at a slow rate; it also allows the display to be system-independent during STANDBY mode.

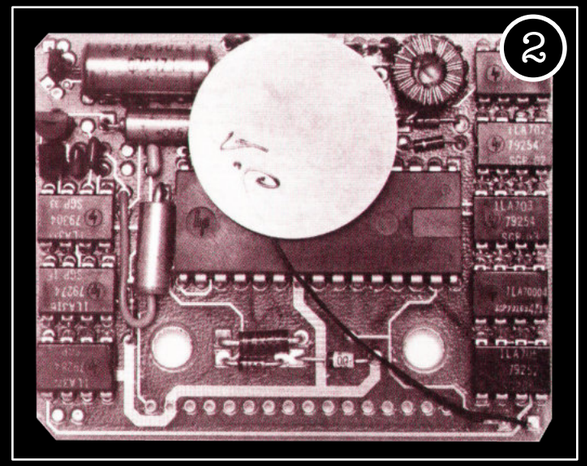
## CPU & ROM

The CPU is one of eleven CMOS circuits inside the HP-41C that were all developed and are fabricated within Hewlett-Packard. In the design process, various computer-aided design tools were used for logic and circuit simulations, digitizing, and design rule checks to provide faster development and assure more accurate and reliable circuits.

Inside the CPU, there are five working registers (A, B, C, M, and N), one 8-bit register, one 14-bit status register, two pointers, and four subroutine return registers. The CPU supports 16 bits of ROM address, 10 bits of data register address, 56 keys with two-key rollover capability, 14 flag inputs and eight flag outputs. In the HP-41 C, the flag output line is dedicated to driving the audible beeper.




❶



❷

In addition to these addressing and register capabilities, other CPU enhancements include new peripheral instructions to meet I/O demand, software-programmed on-off logic, automatic reset circuitry, and a new instruction to read ROM contents as data. The new instruction, CXISA, is especially useful for reading lookup tables, application ROMs, and ROM checksums.

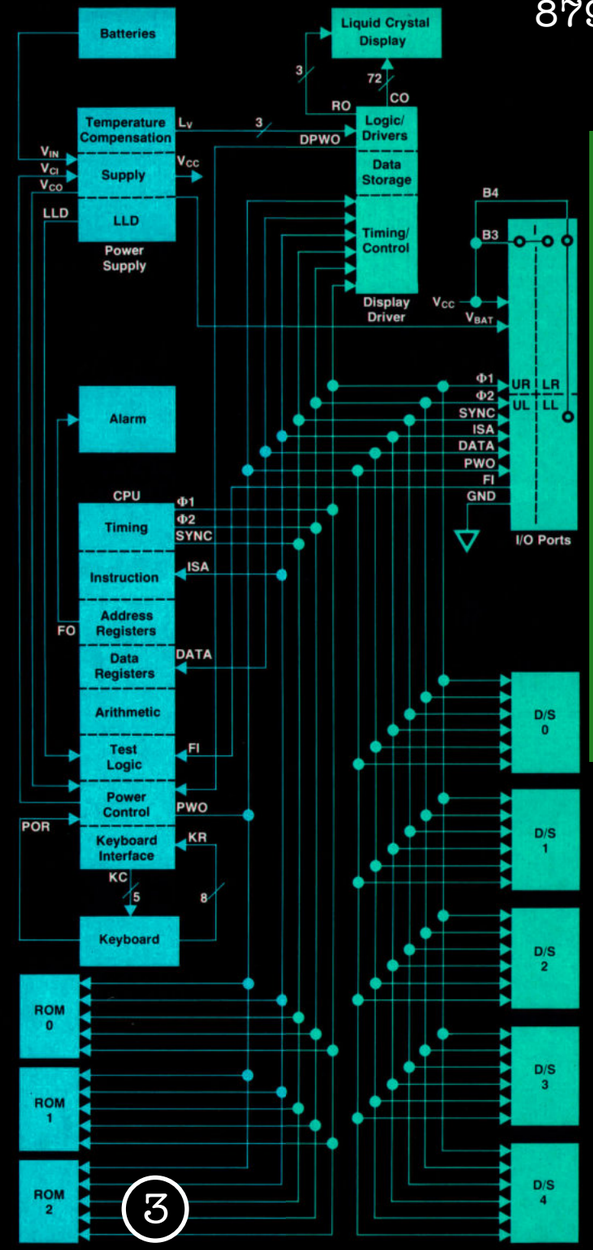
The HP-41C contains 12K words of system ROM (read-only memory), partitioned into three ROM chips with 4K words of 10 bits in length. That is 16 times more ROM than the HP-35 and more than twice that of the HP-67. The system can accommodate four plug-in application ROM modules at the same time, each containing one or two ROM circuits; the ROM operates in the same way in all four ports. The number of possible application ROMs is not limited by the hardware.

## Data Storage

There are five data storage circuits, each containing 16 56-bit registers of RAM (random-access memory). One of these circuits is allocated for internal storage, including the stack, display register, program pointers, and so on. The other four chips provide the user with 64 registers that can be partitioned between data and program memory at a rate of seven bytes of program per register.

**❶ The HP -41 alphanumeric display. ❷ The HP-41C logic board (CPU). ❸ The HP-41C block diagram.**






❸

# HP-41 memory



In addition to the internal data storage, the HP-41C allows 16 more data storage circuits to be plugged into the system, four in each port. The I/O ports each have two pins that provide port address information to the plug-in memory modules. The memory modules are all identical and any number of them (up to four) can be in the system at any time.

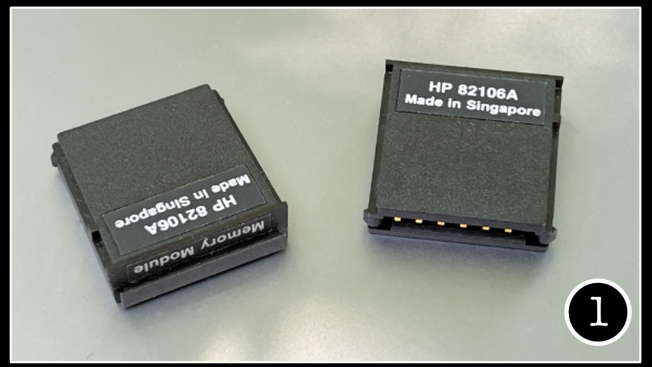
## The memory seen by the user

From the user's point of view, the HP-41C has a main memory of 63 registers of 7 bytes each. Each register can hold either a number, a 6-character string, or up to seven program steps (which use a variable number of bytes).

The user can add memory modules, allowing more programming steps and/or more data registers. Each HP 82106A memory module adds 64 registers, and the calculator can hold up to four of them, for a grand total of 319 registers.

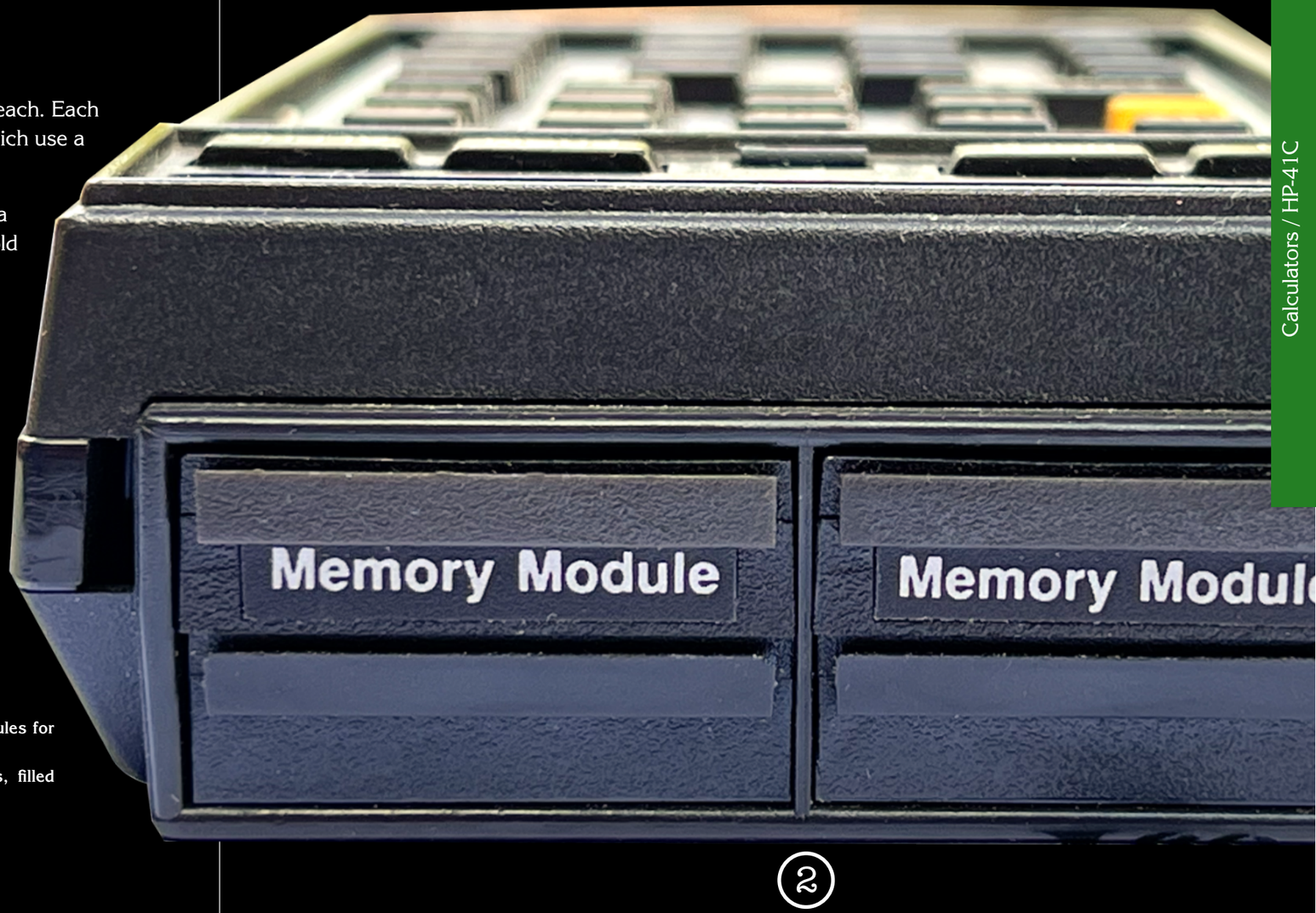
Someone says that these 2 kilobytes or so of the full expanded configuration was considered huge for the time, and probably it was so for the calculators' users, but most microcomputer in 1980 had already 48/64 k RAM.

HP designed a module holding all four in one slot, the so-called Quad Memory Module. The HP-41CV (V being the Roman numeral for 5) included this memory module on the main board, thus providing five times the memory of the HP-41C, and four available slots.




**❶ The HP 82106A memory modules for HP-41C**

**❷ The HP-41C expansions slots, filled with two memory modules.**



# HP-41 innovations

## Innovations

As mentioned, the HP-41C, like the HP-65 did, introduced many innovations, such as:

- a powerful, low power architecture, that included the LCD display;
- the introduction of alphanumeric keyboard and display and in general the capability to manage alphanumeric quantities;
- advanced expansion slots, using the HP-IL bus, that allowed to connect many devices such as printers, plotters, displays, storage devices (floppy disk drives and tape drives), test equipment, etc.

## The calculator goes alphanumeric

Alphanumeric display was one of the big HP-41C innovations. It increased user friendliness and greatly eased program editing, because the functions were displayed by their name. The old HP-65/67, as we saw, displayed programming steps as a list of numbers corresponding to the row and column coordinates; not exactly user friendly.

In addition, it could display, for example, error messages, like "DATA ERROR" instead of simply displaying a blinking zero; it could also specifically prompt the user for arguments ("ENTER RADIUS") instead of just displaying a question mark.

## Overcoming the concept of shift key

Earlier calculators needed a key, or key combination, for every available function. The HP-67 had three shift keys (gold "f", blue "g" and black "h" prefix keys), with up to four meanings for each key.Clearly, a more convenient and flexible method of executing the calculator's instructions was needed.

The HP-41C had a relatively small keyboard, and only one shift key, but provided hundreds of functions. Every function that was not assigned to a key could be invoked through the XEQ key (pronounced EXEQTE — "execute") and spelled out in full, e.g. XEQ FACT for the factorial function.

Moreover, the calculator had a special mode where the user could assign any function to any key if the default assignments provided by HP were not suited to a specific application.





# HP-41 functions

- String control: keyboard alpha mode selection; alpha mode off; alpha mode on; alpha recall; alpha shift left; alpha store; alpha view; append; clear alpha register; compare strings; execute.
- Audible beeper control: beeper; tone of beeper.
- Conditional: X=Y?, X=0?, X>Y?, X>0?, X<Y?, X<0?, X=Y?, X≤0?, X+Y?, X+0?.
- Conversions: decimal to octal; degrees to radians; hours (decimal) to hours, minutes, seconds; hours, minutes, seconds to hours (decimal); octal to decimal; polar to rectangular; rectangular to polar.
- Display: append display; clear display; engineering notation; fixed point; scientific notation.
- Editing: back step; clear program; correction key; delete program memory lines; go to line number; go to program name; single step.
- Flags: clear program flag; "flag clear" test; "flag clear" test and clear; "flag set" test; "flag set test and clear; set program flag.
- Mathematics: addition, antilogarithms (common and natural); division; exponential (y*); logarithms (common and natural); multiplication; percent; percent of change; pi; reciprocal; square; square root; subtraction.
- Miscellaneous: Advance paper; power off; keyboard power on/off; power on (continuous); shift.
- Number alteration: Absolute value; change sign; enter exponent; fractional portion of number; integer portion of number; modulo function (remainder); round; sign of x.
- Programming: decrement and skip if equal; end of program; execute subroutine; go to; go to end of program; increment and skip if greater; label program; pack program memory; pause; program mode selection; prompt; return; run/stop; stop.
- Stack control: clear stack; clear X-register; enter; exchange X and any register; exchange X- and Y-register; roll down; roll up; recall into stack; store into stack.
- Statistics: accumulation correction; accumulation; clear statistics registers; factorial; mean; standard deviation; statistical register block specification.
- Storage: clear all storage registers; LAST-X register recall; recall; size of register configuration store; storage register addition, division, multiplication and subtraction; view register contents.
- Trigonometry: arc cosine; arc sine; arc tangent; cosine; degrees mode; grads mode; hours, minutes, seconds addition and subtraction; radians mode; sine; tangent.
- User defined: assign; catalog list; copy; user mode selection.

## The language

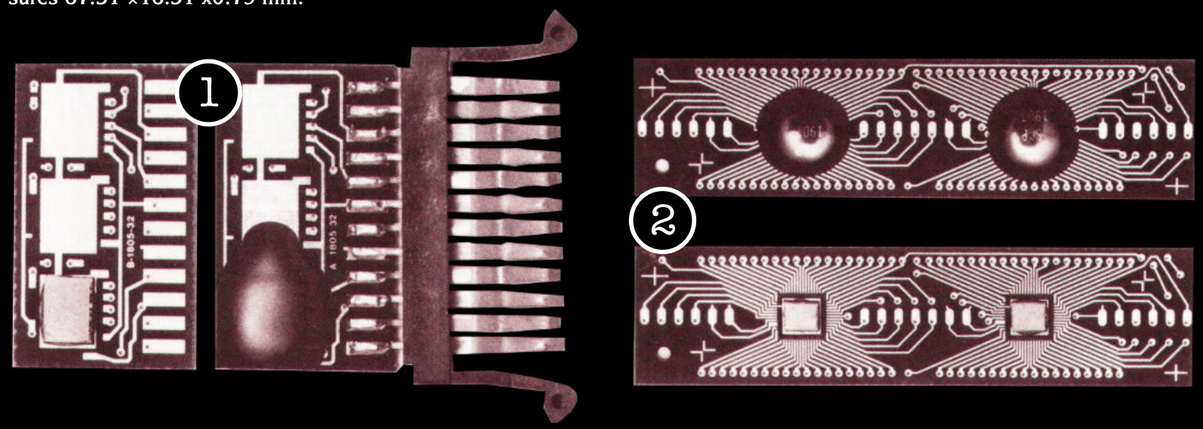
The programming language used on the 41-Series was an evolution of the previous HP-67 calculators, but with many improvements and extensions. The alphanumeric approach made it more similar to “true” computers. For this reason, someone proposed a new name for this language, resulting in a competition that was won by "FOCAL" for "Forty One Calculator Language". Initially, that confused me, because FOCAL was also the name of one of the first programming languages that I learnt and used on the Digital Equipment PDP-8. Probably to avoid copyright problems, the name was never formally adopted by HP.

## A self-contained system

The continuous memory made the HP-41C a self-contained system: you don’t need an external storage device, because when you switch it off nothing is lost. HP will use this concept again, for many of the “soul-less” calculator that we referenced in the introduction. But to replicate the success of the HP-65/67 that’s not enough: no removable storage media, no software libraries. An external mass storage unit was thus mandatory.

I don’t own a card reader, but its continuous memory allows me to play with this calculator. A wonderful toy indeed, with endless amusing possibilities.

**❶ ROM modules contain one or two chips, each measuring 3.71 by 5.00 mm and containing 40K bits. The bit pattern is customized for each application. There are 7-9 bonds per chip and ten connections via a reflow-soldered contact frame to the HP-41C. The substrate measures 23.37 ×13.72 x0.79 mm. ❷ Display driver module contains two chips, each measuring 4.17 by 3.63 mm. There are 54 bonds per chip, 14 connections to the HP-41C, and 72 connections to the liquid crystal display. Reflow-soldered contact tabs connect to the mainframe and flexible conductive strips connect to the LCD. The substrate measures 67.31 ×16.51 x0.79 mm.**



# HP-41C peripherals

For the first time a calculator has four expansion slots with the system bus, just like a computer. New accessories are presented together the HP-41C:

- a card reader allows the user to record and read programs on magnetic cards, HP-67/97 compatible;
- a portable thermal printer/plotter
- an optical wand to read and enter programs and data from printed bar codes;
- memory expansion modules;
- plug-in application modules with preprogrammed solutions to problems in specific areas.

## 1984 Hewlett-Packard peripherals for HP-41

- HP 82104A Card Reader
- HP 82161A Digital Cassette Drive
- HP 82153A Optical Wand
- HP 82143A Printer/Plotter
- HP 82162A HP-IL Thermal Printer/ Plotter
- HP 82905B Impact Printer
- HP 2671A/G Alphanumeric/ Graphics Thermal Printers
- HP 3468A Digital Multimeter
- HP 3421A Data Acquisition/Control Unit
- HP 7470A Graphics Plotter
- HP 82166C HP-IL Interface Kit
- HP 82164A RS-232C Interface
- HP 82169A HP-IB Interface
- HP 82938A Series 80 Interface
- HP 82165A GPIO Interface
- HP 92198A Mountain Computer 80-Column Video Interface
- HP 82168A Acoustic Coupler
- HP 82160A HP-IL Interface Module
- HP 82180A Extended Functions/ Memory Module (built into the HP-41CX)
- HP 82181A Extended Memory Module
- HP 82182A Time Module (built into the HP-41CX)
- HP 82183A Extended I/O Module
- HP 82184A Plotter Module
- 00041-15042 HP Automatic Start and Cassette Duplicating Module
- 00041-15043 HP-41 Development Module




❶ The HP 82161A Digital Cassette Drive uses a digital-quality mini-cassette, capable of storing up to 128K bytes of information. Files can be located easily by name on the cassette drive. Rewind time is under 30 seconds and read/write operations are executed at nine inches per second, with search speed at 30 inches per second. All tape movement is under microprocessor control.

❷ The HP 82162A HP-IL Thermal Printer/Plotter.

# Controlling instrumentations

## Hewlett-Packard Interface Loop (HP-IL)

With the HP-41C, HP introduced the Hewlett-Packard Interface Loop (HP-IL), a bit-serial interface designed for low cost, battery-operable systems. With it, it was possible to use the HP-41 as system controller, capable of transmitting and receiving data, and performing a wide variety of information management and instrument control functions. The 82160A HP-IL Interface Module plugs into any one of the four ports in the HP-41, to connect it with the family of HP-IL peripherals and instruments.

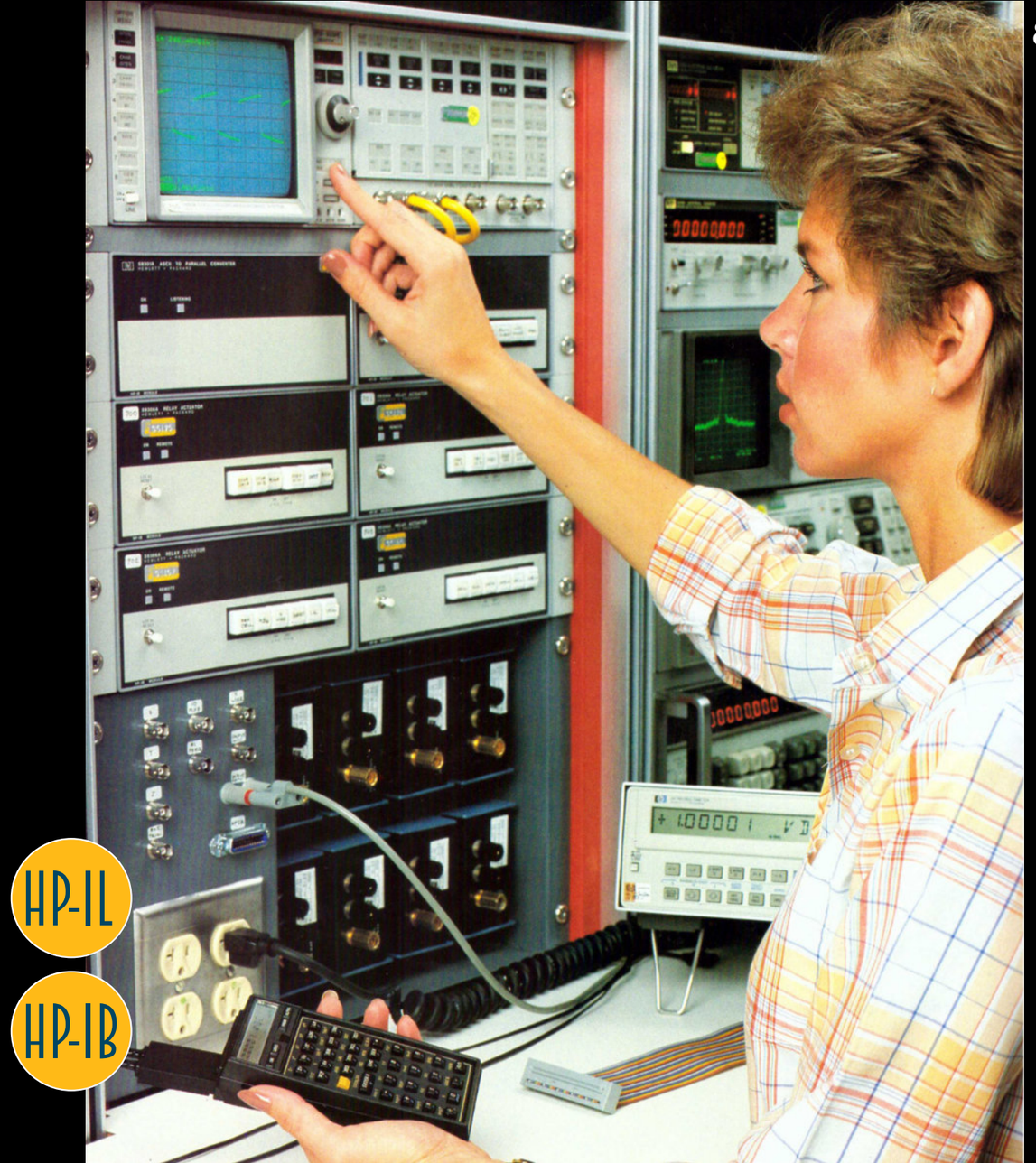
## HP-IB (IEEE-488)

The HP 82169A HP-IB Interface links low-cost HP-IL (Hewlett-Packard Interface Loop) systems with high-performance HP-IB (IEEE 488) lab equipment:a variety of peripherals, instruments, and computers, including HP-IB-compatible devices made by HP (more than 120 at the time) and many more offered by other manufacturers. You can find many of them here and in my books about Tektronix oscilloscopes.

## Other interfaces

Other interfaces were provided, e.g., for a serial RS_232C interface, Genera Purpose I/O etc.

I don't know how successful was this strategy; probably it was good for small systems or where the small dimensions of the HP-41C were required. With 10÷30 k$ oscilloscopes or spectrum analyzers, the controller cost was not an issue, and a 9800 or 80 computer could be a better choice.



# Software

The facing page is taken from the 1983 “Series-40 Advanced Programmable Calculators” catalog (P/N 5953-5579), a very interesting publication were the whole 41-world is described. The list makes clear how HP products were much more than a simple product, but a universe where users could always find the solution to their needs.

The ROM-based application 'pac' modules added up to 4 kilobytes of read-only memory (some up to 8 kilobytes, but these were simply two independent 4K modules in the same box). Most modules held dozens of programs written in the HP-41C programming language, FOCAL, and came complete with exceptional detailed manuals.




### HP-41 prices (1980/ USA)

- HP-41C Calculator, $295 (1,100).
- 82104A Card Reader, $195 (720).
- 82143A Printer, $350 (1,300).
- 82106A Memory Modules, $45 each (167).
- 00041-15001 Standard Application Module, $30 (130).

In parentheses the prices referred to 2023. The HP-41C was rather expensive; in few years, most microcomputers offered look and performances of a true computer, with a lower price.

## Hewlett-Packard HP-41 Software Overview



### For Business Applications:

**Application Pacs** . . . . . 28-29
- Financial Decisions
- Home Management
- Mathematics
- Real Estate
- Securities
- Standard
- Statistics

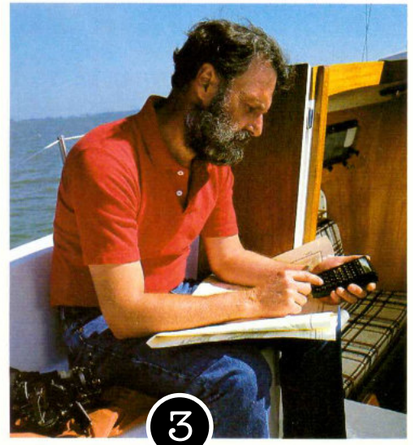
**Solutions Books** . . . . . 29-30
- Business Statistics/Marketing/Sales
- Calendars
- Home Construction Estimating
- Lending, Savings and Leasing
- Real Estate
- Small Business
- Time Module Solutions



### For Scientific Applications:

**Application Pacs** . . . . . 28-29
- Aviation
- Clinical Lab and Nuclear Medicine
- Mathematics
- Navigation
- Petroleum Fluids
- Standard
- Statistics
- Surveying

**Solutions Books** . . . . . 29-30
- Chemistry
- Geometry
- High-Level Math
- Optometry I
- Optometry II
- Physics
- Surveying
- Test Statistics
- Time Module Solutions



### For Engineering Applications:

**Application Pacs** . . . . . 28-2
- Aviation
- Circuit Analysis
- Machine Design
- Mathematics
- Navigation
- Petroleum Fluids
- Standard
- Stress Analysis
- Structural Analysis
- Surveying
- Thermal and Transport Science

**Solutions Books** . . . . . 29-3
- Antennas
- Chemical Engineering
- Civil Engineering
- Control Systems
- Electrical Engineering
- Fluid Dynamics
- Geometry
- Heating/Ventilating/ Air Conditioning
- High-Level Math
- Mechanical Engineering
- Physics
- Solar Engineering
- Surveying
- Test Statistics
- Time Module Solutions

### Entertainment:

**Application Pacs** . . . . . 28
- Games

**Solutions Books** . . . . . 29
- Games
- Games II

# Bibliography

Judging from the huge documentation available online, we can deduce that a lot of people love this calculator very much.

I took most of information and much text from HP Journal 3/1980 and Wikipedia (English), where the subject is treated very well, and where you can find many references to other web sites and documents.

Among the many, I suggest http://www.hp41.org in particular, because it contains really a huge quantity of interesting documents, including books and HP internal documents.

Other sources of valuable information are that I used are:

- https://www.hpmuseum.org/
- the 1983 “Series-40 Advanced Programmable Calculators” catalog (HP P/N 5953-5579);
- HP-41 Sales Training Manual;
- the original HP-41 manuals.



# Computers



The precursor today's computers. So much the same, yet very different.

# Computers



Subsection

## HP-85 Personal Computer

Perhaps arrived too late, it was a big success however.

# HP-85

Hey, this is not an instrument! Yes, I know, but there are many reasons to talk about it. First, it has been used to control many instruments via the HPIB interface, but, above all, because I like it very much, and it has been one of my flames at the time, too expensive to be afforded just for fun. In addition, it is one of the “true HP” products, and it is so fully compliant with the spirit of this book.

## First of a lineage

Briefly, the HP-85 was the first member of the HP 80-Series family of HP microcomputers that was introduced at the end of 1979. But that says little; to appreciate the HP-85 it is necessary to remember the world when it was presented, a moment that I remember very well and that I will try to describe here.

## A long story

As we saw in the previous chapter, the story began much earlier, when HP acquired from Olivetti the Programma 101 project; a big mistake by we Italians, and the start of an empire for HP. From this acquisition, the extremely-charming and easy-to-use 9800-Series of desktop programmable calculators sprung up, a “quasi-personal” alternative to minicomputers like Digital Equipment or Data General.

From this seed, HP's handheld programmable calculators like the HP-67 followed; we tried to describe them in the previous chapter.

## Korinna font

In this chapter we have used the Korinna font, with titles in orange, as a tribute to the HP-85.

This setting used to be the one of many HP-85 commercial documents.

1979

## Too late?

Well, the HP-85 was the last heir of this lineage, that, from a certain point of view, arrived a little late, because, at the end of the seventies, the personal computing was assuming more precise connotations, with the CP/M operating system, which would later become the MS-DOS. The smarter users snubbed it; with a similar price, they could buy something more up-to-date, more powerful and flexible.

## However a big success

Nevertheless, the HP-85, was targeted to engineers, scientists, and business users, and was a success. It was a compact machine comprising an integral screen, mass storage device (tape) and thermal printer. Although by no means lightweight, it was luggable; HP even offered a carrying bag. And, above all, it offered a large number of accessories, including ROMs, adapters, and interface modules.

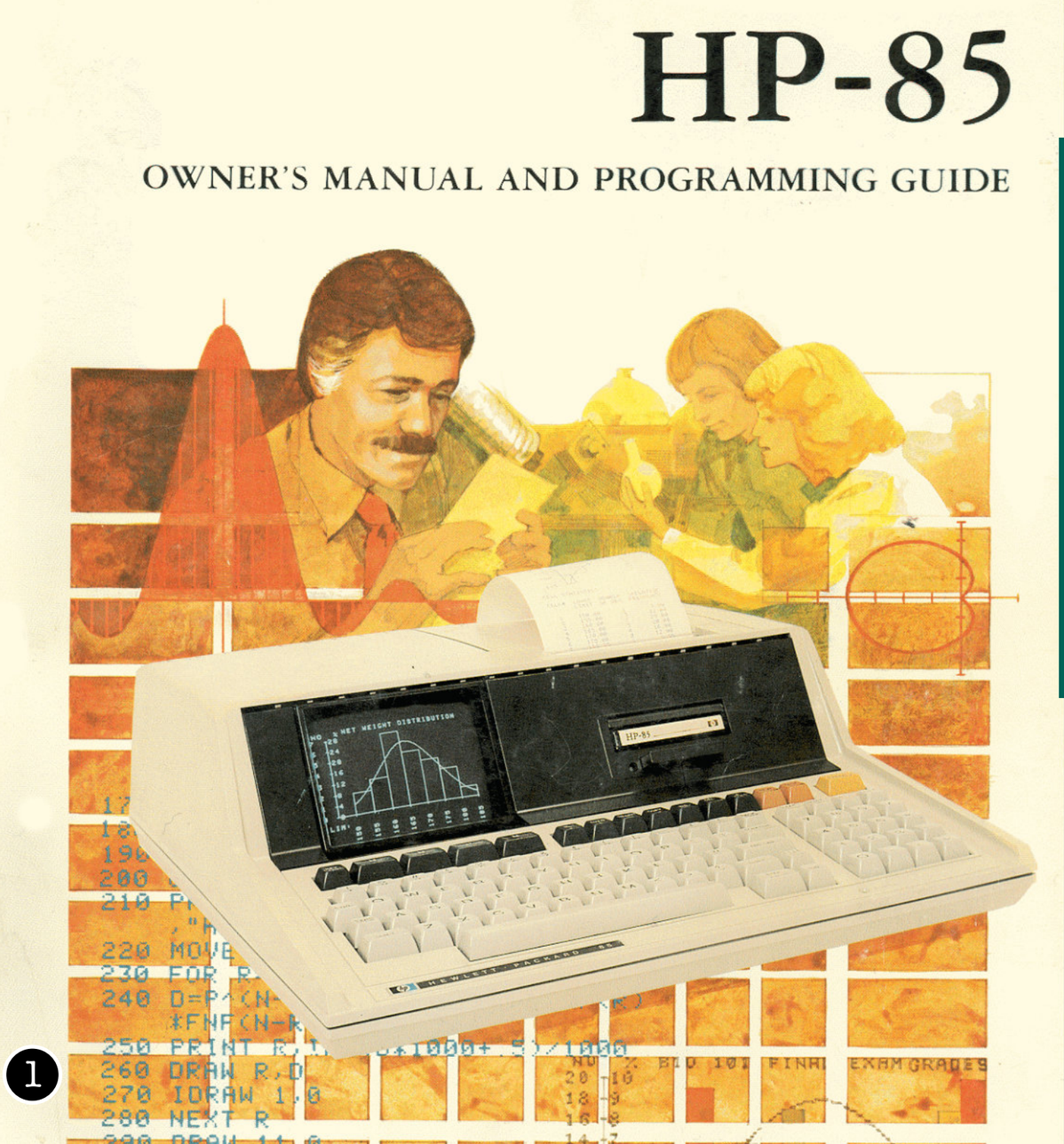
## The HP-85

The basic HP-85 costed $3,250 (in the States), and consisted of a microcomputer with a custom 8-bit processor and several other custom integrated circuits, a data cartridge drive for DC-100 tape cartridges, a video display with a 5-inch screen with resolution of 256 by 192 dots (defined as “high-resolution”) capable of graphics and 16 lines by 32 characters of text, a keyboard, and thermal printer. The unit had 16 K bytes of programmable memory (14,500 for the user) expandable to 32 K bytes, and 32 K bytes of read-only memory, with the operating system and the BASIC package.

## Other members of the family

Other members of the family, the HP-83 and the HP-87, did not include a printer or a tape; the HP-86 provided a larger screen in the form of an external monitor and began having a more modern approach. Among the mid-life improvements of the basic design, there was the HP-85B, here mostly described, with additional built-in features and more memory. Unless necessary, we will not make distinctions here between the HP-85 (said “A”) and the HP-85B.

**❶ The beautiful mainframe manual of the HP-85 is a masterpiece, not only for the graphics, but for its extreme clarity and friendliness, which contributed to make you proud using an HP product. Sometimes, I think that a good documentation has the capability to make better a limited product, exactly like a bad documentation can destroy the best one.**



## The CP/M as well

HP tried to target also normal users, and, to do that, confirming what I told you above, was forced to introduce a CP/M add-on card with a Z80 inside. But it was only a way to follow a market, which was changing quickly its preferences.

## Slow!

In the eighties, I created a Z-80 computer with a BASIC interpreter, named G5, for an Italian electronic magazine; starting from it, I entered then the industrial market, which become my life. My BASIC (sources still available) was incredibly better (and faster) than HP's one in some aspects, including the screen editor, at least in the base version, and you could build the whole computer with few dollars. But HP was unbeatable when you considered the huge quantity of libraries and extensions (for example, the wonderful matrix add-on), the multitude of peripherals, and, above all, instrumentation buses like HP-IB and HP-IL.

## A great classic

I wish to say that what I told about my BASIC is not completely fair, because I wrote it in 1983 (starting from something existing), when new powerful components had become available (e.g. the TMS9929 video processor). At that time, one or two years made the difference.

But having afforded a project basically similar to the HP-85 makes me more aware of the immense work performed by the HP engineers, which still today continues amazing me.

In my opinion, the HP-85 can be considered one of the great classics in the computer history, as confirmed by the high number of enthusiasts that still now love, repair and restore them. While there were hundreds of types of CP/M computers, other than the Altair 8800 and IMSAI 8080, the rest are mostly forgotten. The HP Series-80 has endured with its individuality, and is definitely unforgettable.




The 32-character-per-line thermal printer was provided for hard copy output. A set of 128 ASCII characters was available for printing when outputting alphanumeric copy (e.g., program listings). The printer prints alphanumeric copy bidirectionally at a nominal rate of two lines per second. Short lines are printed faster than long lines. A COPY key lets the user obtain a copy of the CRT display on thermal paper. If the CRT is in the graphics mode, the printer prints in one direction only and the print output is rotated 90° to allow for strip-chart plotting. To compensate for variations in paper, printheads, and the type of printing being done, the HP-85 gives the user the ability to lighten or darken the intensity of the output. The roll is very big: as much as 120 meters long.






# Resources



## Internet resources

I could not imagine how much interest is still there for the HP-85. Among many, I suggest four (in each of them you can find many references to other sites):

- Series 80 (http://www.series80.org/index.html);
- HP Computer Museum (http://hpmuseum.net);
- HP Series 80 Forum (https://groups.io/g/hpseries80);
- Curiousmarc (https://www.curiousmarc.com/computing/hp-85-scientific-computer), a true genius, spanning the most interesting topics in electronics, with dozen of well-done videos.
- Floppy days (http://www.floppydays.com) dozen of vintage computer podcasts, where great characters tell you their histories.

On all of them, plenty of manuals, software and other kind of documents, a real cornucopia for the HP-85's lovers.

## HP Journal and catalogs

Another precious resource is the HP Journal. I remember that I was a subscriber to it, and how I looked forward to the arrival of each new issue, that made me feel privileged.

Today HP Journal can be downloaded in electronic form from http://hparchive.com, another wonderful web site that offers a lot of other documents, including the HP catalogs, wonderful books that HP distributed freely and that, like Tektronix ones, fueled our dreams of sci-fi instruments that we could not, even remotely, afford.

Today, HP Journal helps us very much, rebuilding the history of these old gears, which we like so much to restore and preserve.

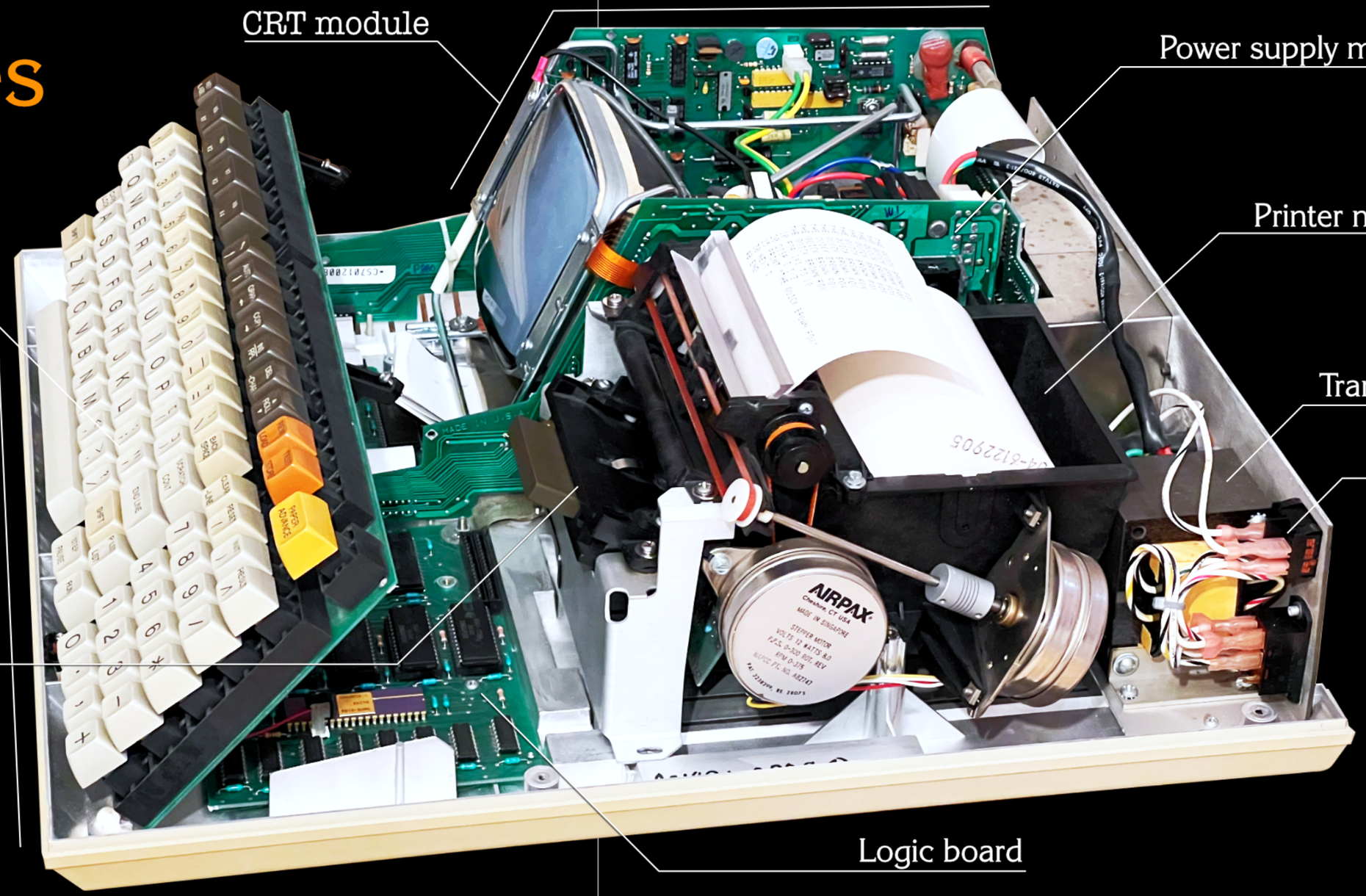
## HP Journal issue 7/1980

The July 1980 issue (here in the photo) of the HP Journal was dedicated to the HP-80, and I used it to enrich the content of these pages with information that I found very interesting indeed. You can download the complete issue if you want to read all the details, that I necessarily summarized here.

# Modules

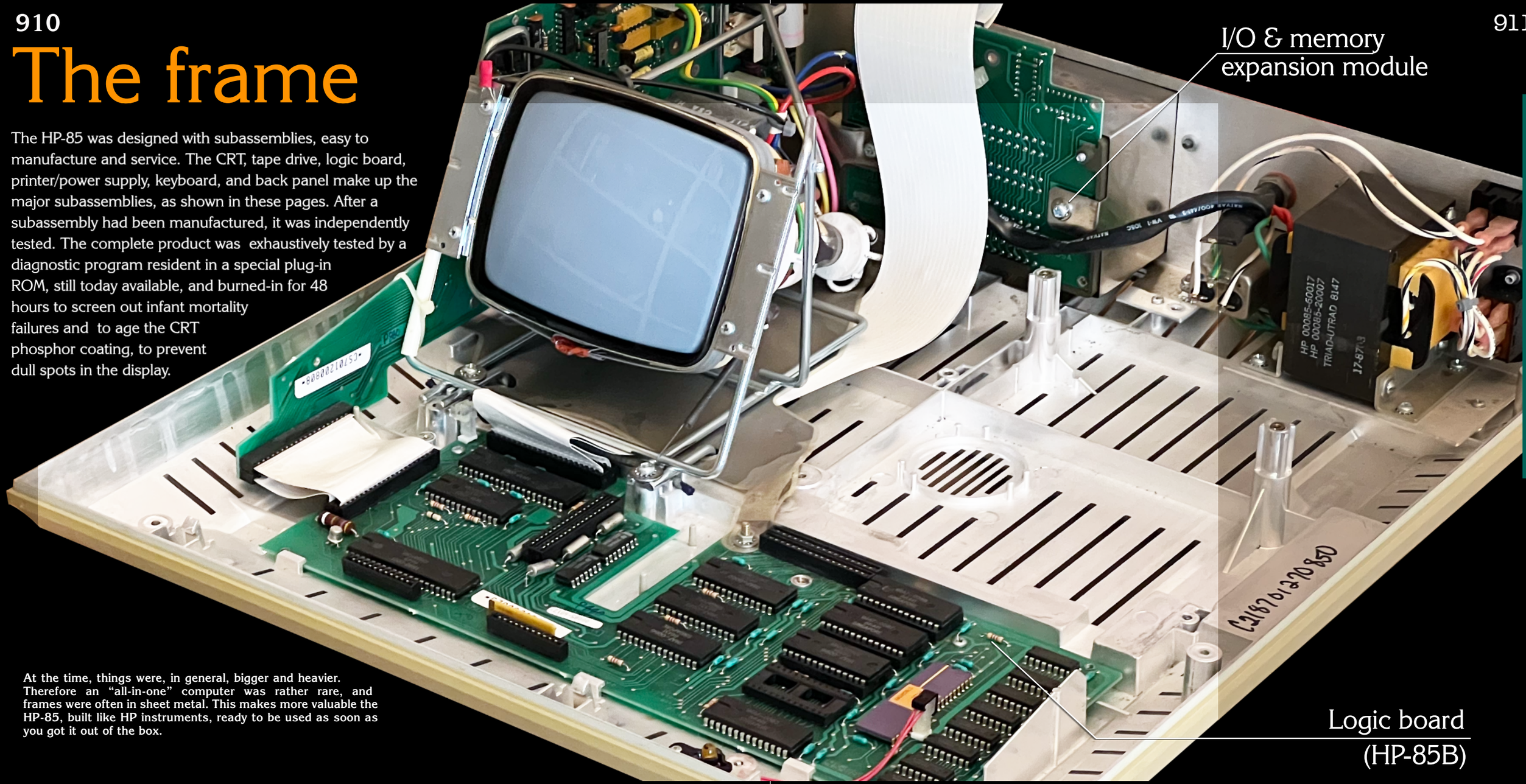


# Modules

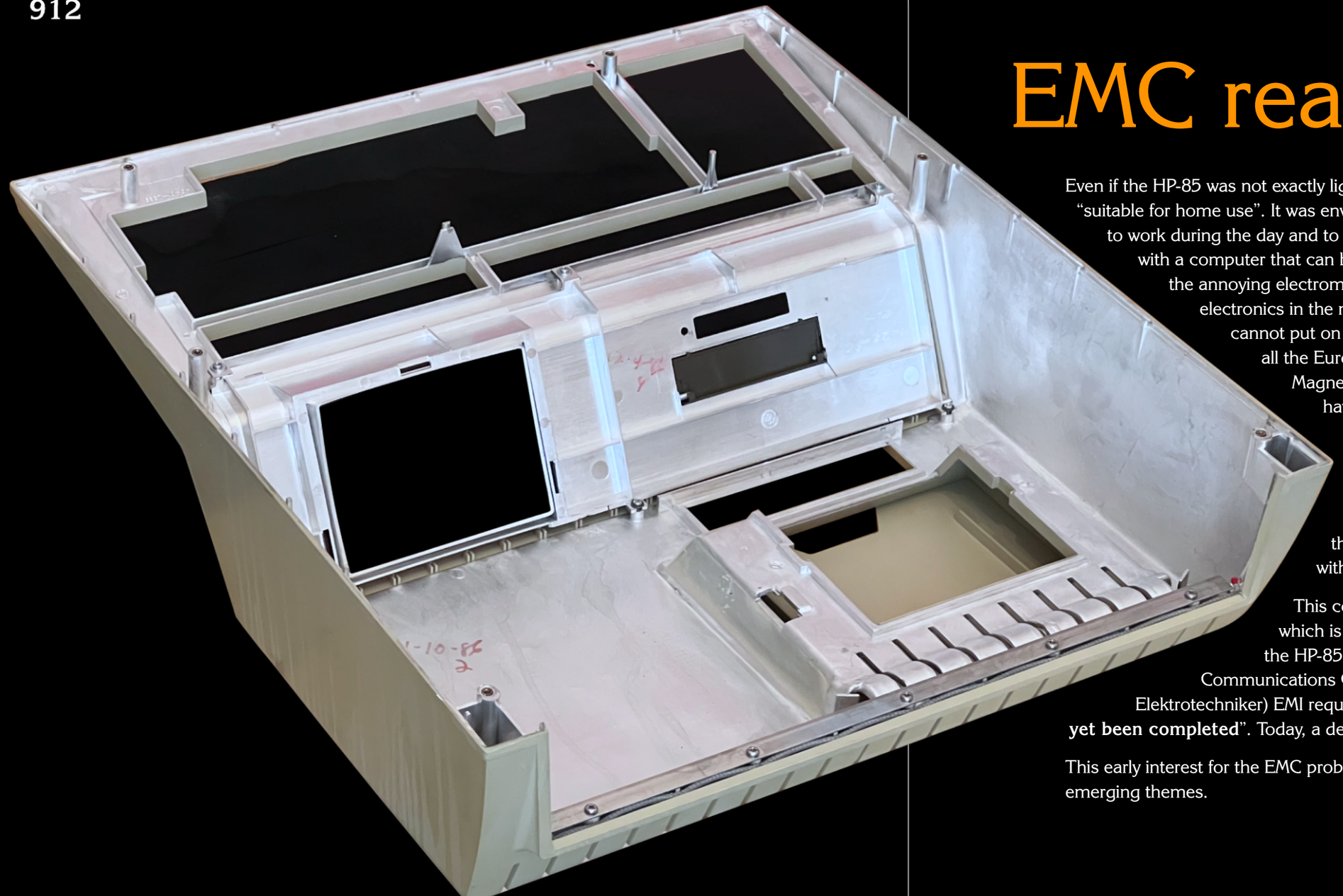

CRT module
Power supply module
Printer module
Keyboard
Transformer
Switch
Data cassette module
Logic board
AIRPAX
Cheshire, CT USA
MADE IN SINGAPORE

# The frame

The HP-85 was designed with subassemblies, easy to manufacture and service. The CRT, tape drive, logic board, printer/power supply, keyboard, and back panel make up the major subassemblies, as shown in these pages. After a subassembly had been manufactured, it was independently tested. The complete product was exhaustively tested by a diagnostic program resident in a special plug-in ROM, still today available, and burned-in for 48 hours to screen out infant mortality failures and to age the CRT phosphor coating, to prevent dull spots in the display.




At the time, things were, in general, bigger and heavier. Therefore an "all-in-one" computer was rather rare, and frames were often in sheet metal. This makes more valuable the HP-85, built like HP instruments, ready to be used as soon as you got it out of the box.



# EMC ready

Even if the HP-85 was not exactly light according to today standards, it was declared "suitable for home use". It was envisioned that the HP-85 would accompany its owner to work during the day and to the owner's home at night. To provide the customer with a computer that can be used at home, the design had to include barriers to the annoying electromagnetic interference (EMI) generated by the electronics in the machine. That seems funny today; in Europe, you cannot put on the market anything that does not fully comply with all the European Community Directives, including the Electro Magnetic Compliance ones (EMC), and in the States they have equivalent rules.

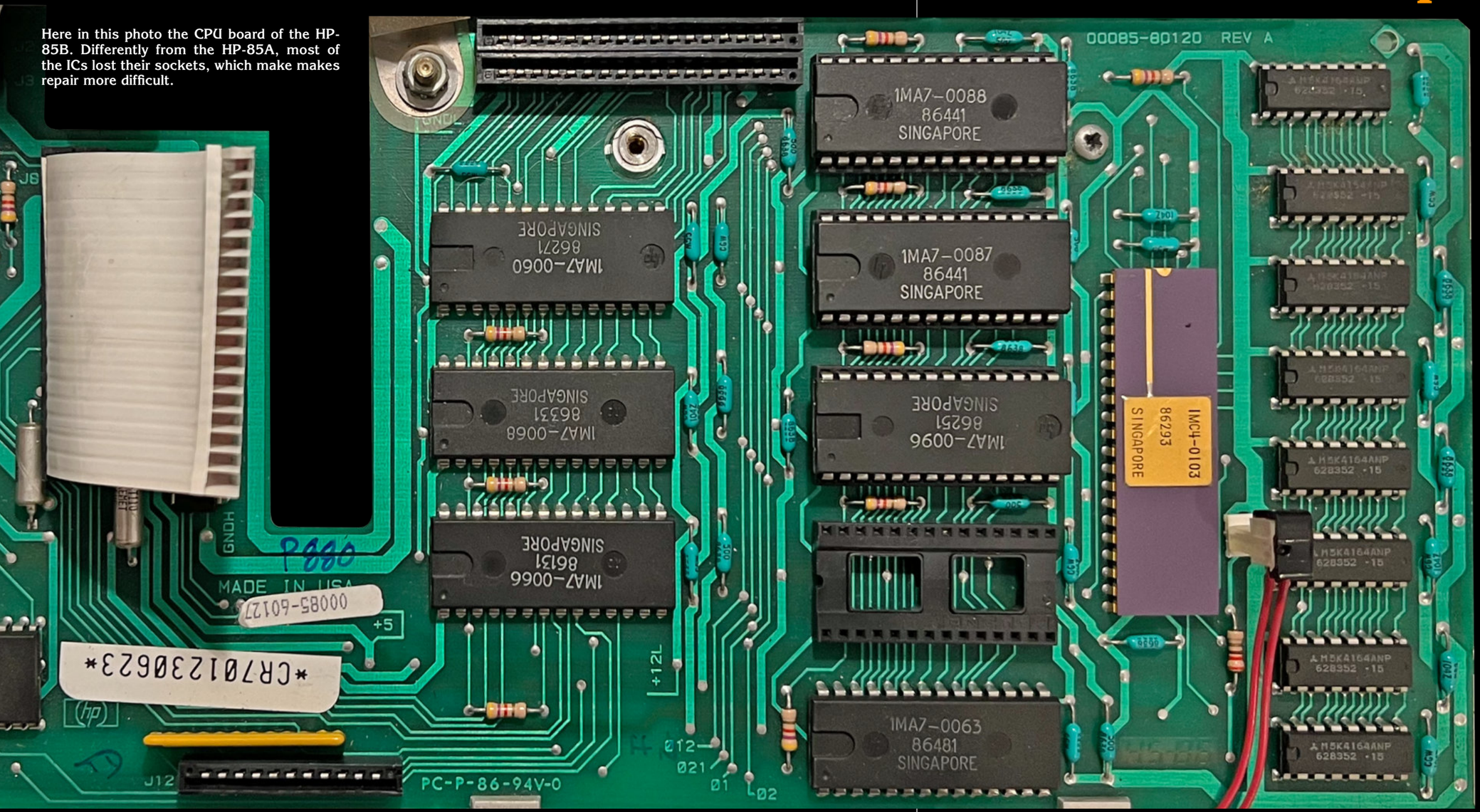
At that time some components were taught to be silenced, and HP chose a drastic solution: instead of reducing noise at source ( i.e. changing the circuits) they decided to shield the HP-85, making the plastic top and bottom cases completely metallized with a thin coat of aluminum.

This conductive shield is tied to the sheet metal back panel, which is grounded. They candidly confess: "It is expected that the HP-85 **will** meet applicable U.S. FCC (Federal Communications Commission) and German VDE (Verband Deutsches Elektrotechniker) EMI requirements. However, the certification process **has not yet been completed**". Today, a declaration like that could be fatal for your Company…

This early interest for the EMC problem was however a sign of the great HP attention to emerging themes.

# The central processor






Here in this photo the CPU board of the HP-85B. Differently from the HP-85A, most of the ICs lost their sockets, which make makes repair more difficult.

The HP-85A was driven by a custom processor, essentially a calculator chip. This CPU was very unconventional; it had an 8-bit multiplexed data / address bus, and all the memory and peripherals had address latches with built-in incrementing logic. Like the calculator chips it was derived from, it operated directly on BCD numbers, i.e., without roundoff errors. The clock ran at a frequency of only 625 kHz.

The HP-85A contained 16 k bytes of RAM, which could be extended to a total of 32 kilobytes with a 16 kilobyte RAM module (82903A) that fit into one of its four plug-in module slots.

In 1983, the HP-85B was introduced. It was an extension of the A, with 64 kilobytes of RAM, plus built-in Mass-Storage, solid state disc (EDISC), and I/O ROMs.

Although the HP-85B had 64 kilobytes of RAM, only 32 kilobytes could be accessed as program memory; the other 32 kilobytes could be accessed only as EDISC.

# The HP-85 CPU

Contemporary processors included the 8 bit 6502, 6800, 8080/85 and Z80. There were also 16 bit processors, including 8086, 68000, TMS9900, and Z8000. All of these had fairly conventional instruction sets, registers, and two's complement binary arithmetic. This CPU can process binary or even floating point BCD quantities (add, subtract, compare, move – not multiply or divide) with a single instruction. A global flag selects the arithmetic mode (binary or BCD). What on the Z80 I did with a library, can be performed directly by this CPU.

With an ingenious mechanism based on data boundaries, you can process from one to eight bytes with a single instruction, while numeric quantities may be one of three BCD types: real (8-byte), short (3-byte), and integer (4-byte).

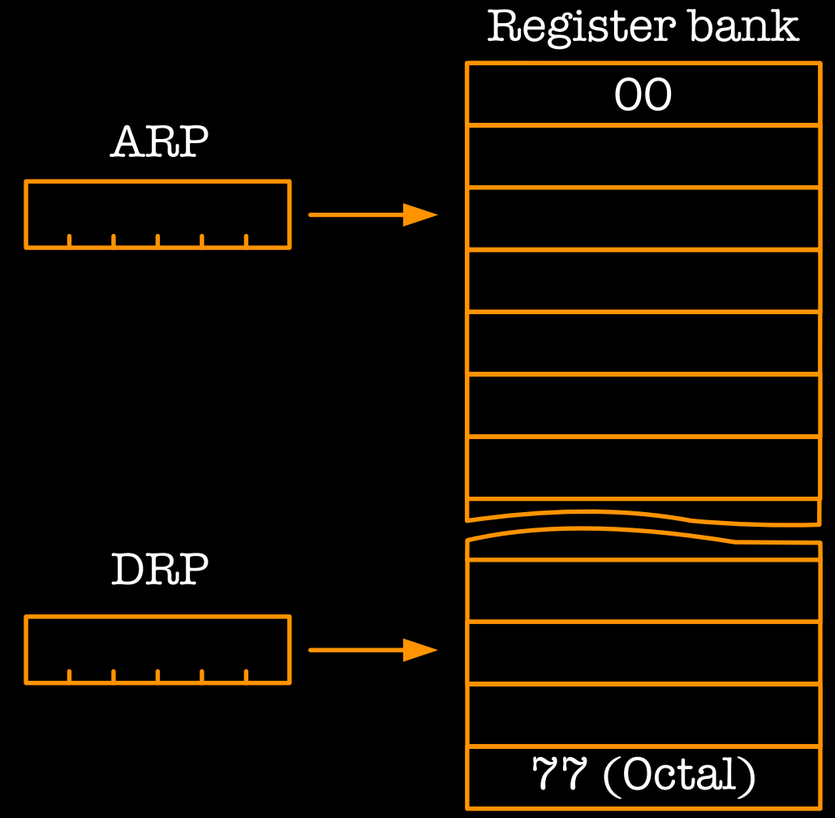
The heart of the CPU is the register file of sixty four 8-bit bytes. Direct access to any of the individual registers is possible. The first 32 registers can be accessed as register pairs, providing sixteen 16-bit registers. The second block of 32 registers can be accessed as 4 variable length registers with a minimum length of 1 byte, and a maximum length of 8 bytes (64 bits). Variable length is implemented through selection of the starting register, but always ending on the last register of the next 8 byte boundary. The diagram on the following page shows the organization of the CPU registers, which are numbered from 0 to 77O, and specified by R0 - R77. Some of the registers in the CPU register bank are dedicated by hardware to specific tasks.

In real or floating-point format, the mantissa is a 12-digit quantity expressed as a magnitude. Each digit consists of four bits. The least significant digit, represented by M11, is stored in R42. The most significant digit, represented by M0, is stored in R47. The number is normalized; thus, there is an implied decimal point between M0 and M1 in R47. The sign of the mantissa is stored in the least significant digit of R41. A zero is stored as the sign of the mantissa if the number is positive; otherwise, a nine is stored. The exponent is a three-digit number stored in R40 and in the most significant digit position of R41. Exponents are expressed in ten's complement form.

Integer variables are stored in three bytes, with five digits and a sign. Short variables are stored as a mantissa sign (SM) an exponent sign (SE), five mantissa digits, and a two-digit exponent.

Many and powerful addressing modes made this CPU very modern and complete. Due to the NMOS implementation technology, low power goals (no noisy fans), and the quite uncommon 4-phase non-overlapping 12V clocks, the processor is significantly slower than contemporary processors listed above, with a clock frequency of 625 kHz.

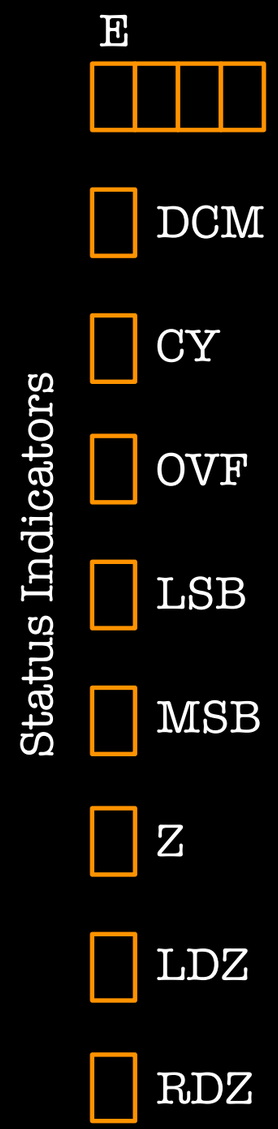





| | Real | |
|---|---|---|
| 40 | E1 | E2 |
| 41 | E0 | MS |
| 42 | M10 | M11 |
| 43 | M8 | M9 |
| 44 | M6 | M7 |
| 45 | M4 | M5 |
| 46 | M2 | M3 |
| 47 | M0 | M1 |

| | Integer | |
|---|---|---|
| 45 | D1 | D0 |
| 46 | D3 | D2 |
| 47 | S | D41 |

| | Short | |
|---|---|---|
| 44 | E0 | E1 |
| 45 | M3 | M4 |
| 46 | M1 | M2 |
| 47 | 0 0 SM SE | M0 |



# The printer

A million years ago, I designed the hardware and the software of an industrial thermal printer, and so the theme is rather intriguing to me. As described previously, the HP-85 printer can print text and graphics. The main objectives of the new design were high printing speed and a low manufacturing cost. In the photo, the printing mechanism with its companion printed circuit board, that contains all of the printer electronics, as well as the power supply, as shown in following pages.

All of the required **electronics**, except for the high-current drivers, were integrated into one NMOS integrated circuit, the printer controller, that provides internal buffering of up to 32 characters and a 5X7 dot matrix character generator.

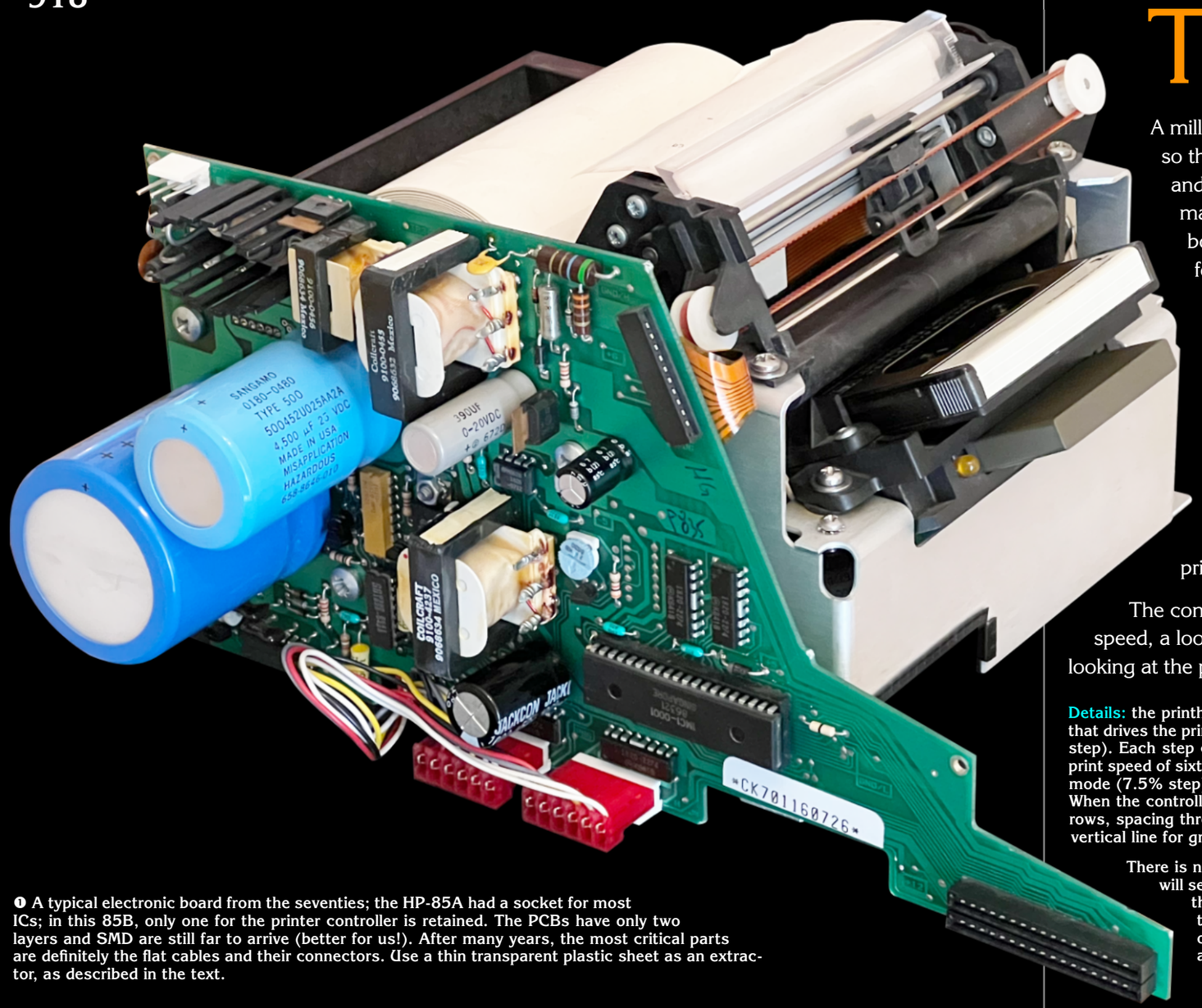
The **printhead** consists of eight thin-film resistors arranged in a vertical column. The entire printhead is moved across the paper so that when the correct resistors are activated at specific times, a character is formed.

An eight-position **rotary switch** is connected to select eight preprogrammed print intensities (7 is the darkest) by varying the pulse duration of the signals applied to the printhead resistors.

The controller is capable of printing **bidirectionally** for alphanumeric copy; to maximize the print speed, a look-ahead algorithm is built into the chip. The controller decides which direction to print by looking at the present line length and the next line length.

Details: the printhead assembly is moved across the paper by the head drive motor. This motion uses a 7.5° (48 steps) step motor that drives the printhead assembly with a toothed belt. The resolution of the motor is doubled by driving it in a half-step mode (3.75% step). Each step corresponds to one dot column of printout. The motor is driven at 448 steps per second, which is equivalent to a print speed of sixty-four characters per second. Paper feed is accomplished by use of an additional step motor. It operates in a full-step mode (7.5% step) and steps at one-third the rate of the head drive motor. Each step corresponds to one dot row of paper advanced. When the controller finishes printing a line, it automatically advances the paper. For alphanumeric copy, the paper advances ten dot rows, spacing three dots between lines. For graphics copy, it advances only eight dot rows; thus it is possible to print a continuous vertical line for graphics plots.

There is no home switch designed into the printer. At the first PRINT command after system power-on, the system firmware will send a home command to the printer controller. Knowing that this is the first home command received since power-on, the controller drives the printhead assembly all the way to the left. The assembly moves toward and eventually contacts the left wall of the frame. After the motor has been given 256 pulses, the controller then reverses the direction of the motor and moves the head assembly four steps to the right. Then it turns off the power applied to the motor and resets all internal position keeping logic. In this manner, a home position is established.




❶ A typical electronic board from the seventies; the HP-85A had a socket for most ICs; in this 85B, only one for the printer controller is retained. The PCBs have only two layers and SMD are still far to arrive (better for us!). After many years, the most critical parts are definitely the flat cables and their connectors. Use a thin transparent plastic sheet as an extractor, as described in the text.

## Efficiently powering the printer

The energy stored in the motor inductance is returned to the unregulated 32Vdc supply through the catch diode (see the power supply section later). This not only increases the power efficiency of the system, but also lets driving the step motor at a higher rate. The field built up in the motor can be collapsed faster by returning the current to a high-voltage supply (in my opinion they are selling as a miracle a simple diode paralleled to the coil…).

## Thermal printhead

Designing a thermal printer controller and its software is not a too complex task, and almost any good engineer can do it. I remember that the biggest problem I had to solve was a hardware circuit capable to switch off the current before an error in the firmware could burn the printing head. My printer had a fixed head (i.e., a line of dots as wide as the paper). In this case, by contrast, the head is moved across the paper by a stepper motor.

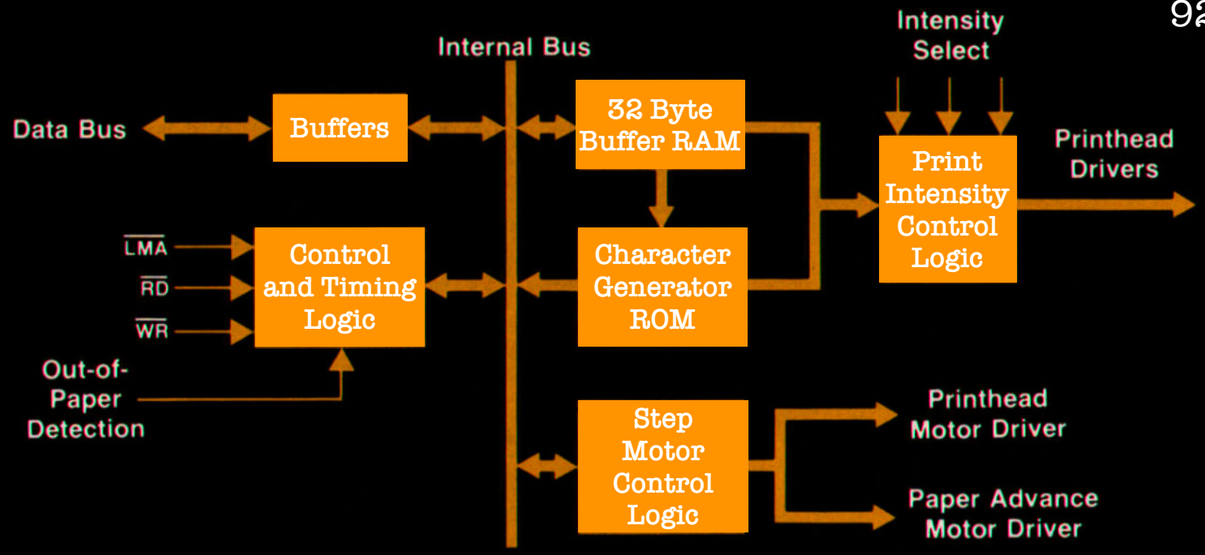
The "real" piece of technology of a thermal printer is in the printhead. In this case, it contains eight resistors, arranged in a single column, with an overall height equal to one character. Each resistor is 0.36 mm (14 mils) tall by 0.28 mm (11 mils) wide. In operation, the resistors scan over a thermal-sensitive paper, creating a colored dot on the paper whenever a resistor is energized. A small amount of lateral elongation occurs during printing because of the movement of the printhead across the paper before the resistors completely cool down. This widens the dot, making it appear to be square.

To have the resistor heat up quickly and to reduce power consumption, the resistors are formed on a thermal barrier of glass, which is deposited on a ceramic substrate. Making the thermal barrier too thick slows the cool-down time of the resistor, smearing the trailing edge of a formed dot. Accurately controlling this barrier balances both power use and print clarity.

An objective in the HP-85 printer design was to give the user the ability to control the darkness of the print by varying the energy dissipated in the printhead. Through reliability testing, it was discovered that a change of only 10% in the printhead energy dissipation changed the printhead life by a factor of two. I believe that most users always used the darkest setting. I do this too, but the paper I use is vintage. Perhaps today's thermal paper is more sensitive.

Details: Ordinarily, a six-micrometer-thick layer of aluminum oxide is deposited over the resistor to protect it from wear and chemical attack caused by the paper. Inspection of failed printheads indicated that chemical attack was accelerated with increased energy dissipation. It was observed that the increased thermal cycling created cracks in the brittle protective layer,






thus letting the paper chemicals penetrate through the layer to destroy the resistor film. To inhibit crack growth and/or act as a chemical or ion barrier, the idea of depositing an additional film of tantalum-aluminum within the protective overcoat was evaluated. The initial results were substantially improved printhead lifetimes. Production implementation of this design has yielded two to three-fold increases in printhead life, providing a very acceptable printhead reliability of greater than 85% after five years of use. Considered that my printer, like others, still works rather well, I believe that we can confirm that.

## Printer motors

The low-cost objective of the printer design precluded use of a high-cost, high-performance motor. Therefore, two identical permanent-magnet step motors were used to advance paper and to move the thermal printhead. Each is a stamped-frame motor with forty-eight steps per revolution.

## Belts

One of the common HP-85 problems are the toothed-belts. Here are the belt specifications, if you need (from https://vintagecomputers.sdfeu.org/hp85/85repair.rtf):

- paper belt: 80T80 or 80MXL by 1/4 inch wide, T80 / MXL meaning 0.080-inch tooth spacing, and 80 teeth long. A 78-tooth-long belt works fine too.
- printhead belt: 175T80 or 175MXL by 1/8 inch wide, T80 / MXL meaning 0.080-inch tooth spacing, and 175 teeth long.

# Power supply

The power supply is, as usual, the part where I spend a large part of the time I dedicate to this old stuff. In this case I was very clever, finding genial ways to create incredible and useless problems for myself.

## My experience with the power supply

You have to know that I own this HP-85 since many years. I tried to restore it, but something happened and I was forced to give up, waiting a for better time. The last problem to solve was the cassette drive; I tried some solutions, but with no success. So I was convinced that my HP-85 was completely operating, but for the cassette.

For this book, I recovered the HP-85 from the cellar and switched it on. But… it no longer started. Don't worry, I said to myself, surely it is a capacitor… So I opened it and checked the voltages. The +12V was at about 7. Let's stop and think about this. I disconnected the power supply from the rest but, doing that, I noticed that a flat cable was inserted in a wrong way and was shorting the contacts.

What terrible mistake! When I closed it for the last time, clearly I was not careful enough.

So I tested the power sup-

ply alone. All the voltages were good, but the +5V rail was really 6.5 V. Ah, what a harsh situation; probably the 5 V going to 6.5 V has destroyed some important chip… Anyway, I decided first to fix the power supply, then investigate the remainder. But, misfortune within misfortune, the schematic diagrams that I downloaded from the net did not correspond with my board. So I patiently tried to rebuild the schematic. First I thought that there was some mismatch with the 6V, but not, the 6V was OK and the +5V was too high. Maybe the PSU needs a load? So I tried to add a load on the +12V, discovering that it worked perfectly until 1 A, but the +5V was too high. A day spent rebuilding the schematic and checking all the signals and the inner working of the SG3524 switching controller. Everything was OK but the +5V output. Let's go to bed now…

## The morning after

The morning after, my friend Curiousmarc (see about him later) told me: are you sure you are working on a HP-85 "A"? Yes sure, I thought, silly question… I remember perfectly that… Or not? I check and I discover that my machine is really a "B" model! So I start seeking for the B schematics, but they are not easy to find. Eventually, I found them on GroupsIo. Wow, I am again in the race.

With a fresher mind, I started again, made stronger by the right manual and schematic diagrams for the B type, until I noticed in the manual that the +5V must be tested with a 300 mA load. Hope. Silly me, I added the load only on the +12V! I add the load, and the +5V goes OK.

Probably all is OK and the problem was only the wrongly inserted flat. The point is now: did it cause permanent faults? I see that a guy made a similar mistake and destroyed something.

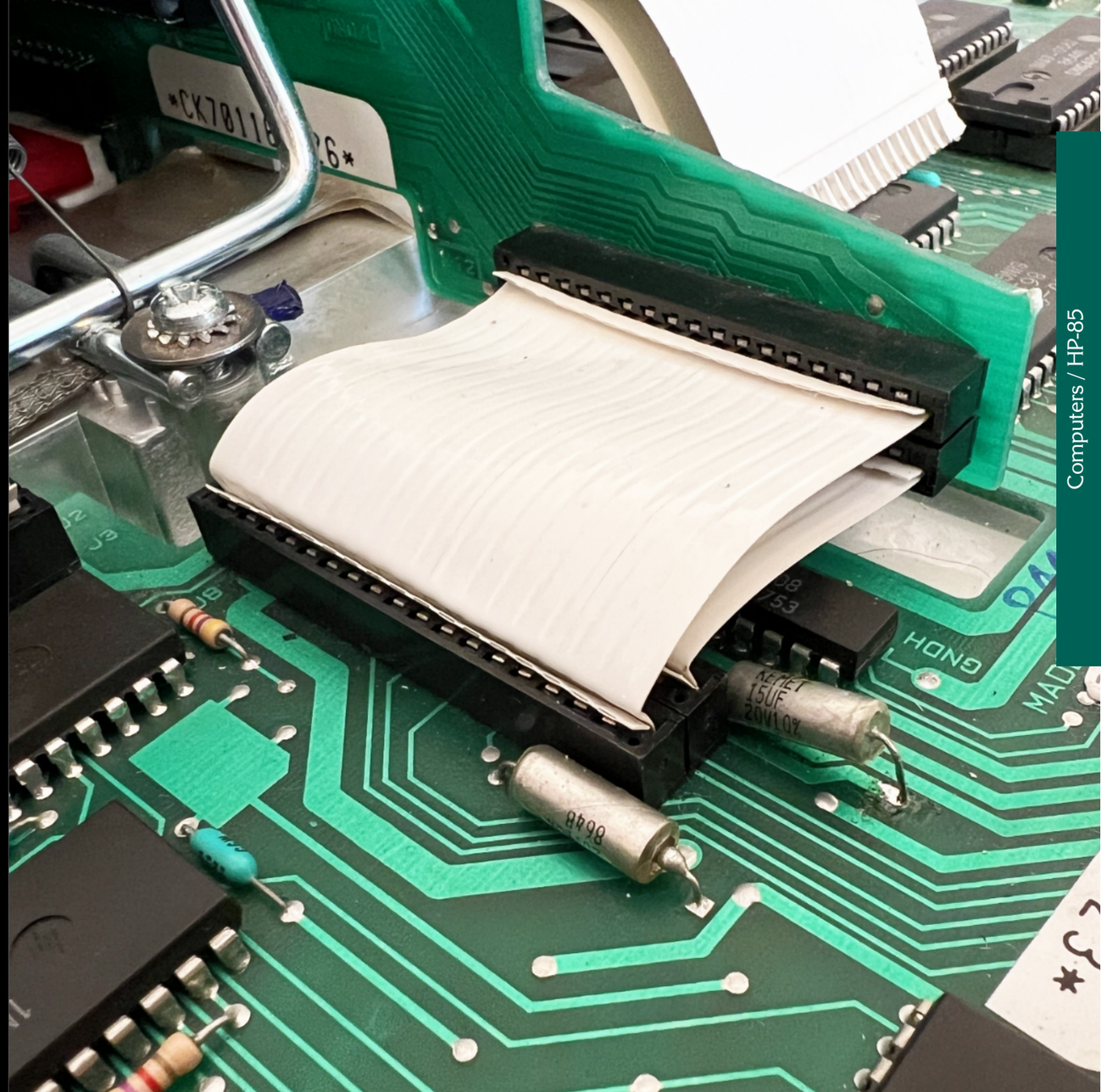
I reassemble everything and… switch on! The HP-85 starts but writes "ERROR 23".

## Error 23?

What is it the ERROR 23? I search on Internet and it seems that it means that the RAM chips are faulty. Ah! But it works… how can be that explained?

I decide to calm down and check better on the manual. To know exactly the problem, you must use the command ERRL, after ERROR 23. I get 7, that means that the cassette drive is not present, and effectively I did not connect it. So: no faults, I am just too anxious…

**In the photo: these flat cable are used to connect each module to the others and deserve all our attention. If forced, they can be inserted misaligned, and this can cause unexpected permanent damage. Always use a light and a magnifying glass to be sure that the pins are properly aligned and check twice.**



# PS circuit

## Efficiency

The efficiency of the power supply has been taken in great attention in the HP-85 design; it was no longer the time for linear power supplies. The regulation at low frequencies was also important, since annoying CRT display modulation results if trace amounts of ac line ripple are present. Switching spikes can also cause ripples in the display.

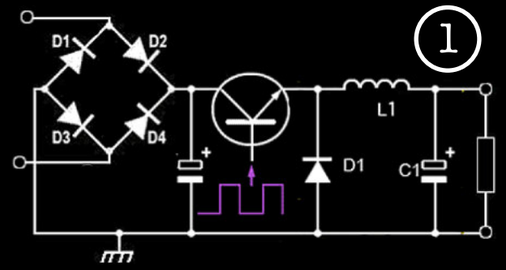
## Why going in details

The self-generated problems that I described above forced me to study this interesting power supply circuit; I hope what I learnt can help others to repair these valuable computers.

In this page, you can find the HP-85A block diagram (❷) and, in the following ones, parts of the HP-85B's power supply schematic diagram (❸ and ❹).

## The +12V regulator

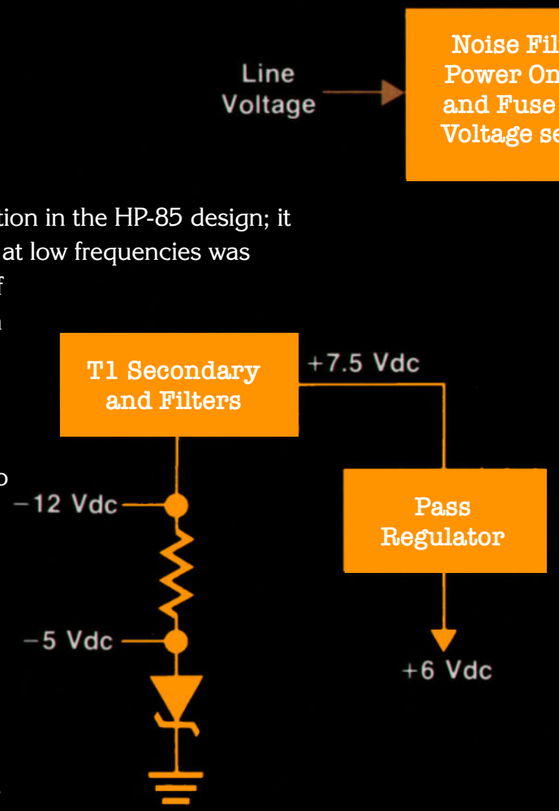
The +12V part is almost identical in HP-85A and B. Its basic circuit is almost exactly a Step-Down Switching Regulator ("buck", picture ❶ below), managed by the SG3524 controller that I met again in Tektronix oscilloscopes. Beyond the Service Manual, I could find valuable information about this circuit on the HP Journal 7.1980.




1

## The buck Switching Regulator

This is the basic switching type; when the transistor switches on, the current flows in the capacitor/load and produces a magnetic field around the coil. When the transistor opens, the magnetic field collapses into a back-emf



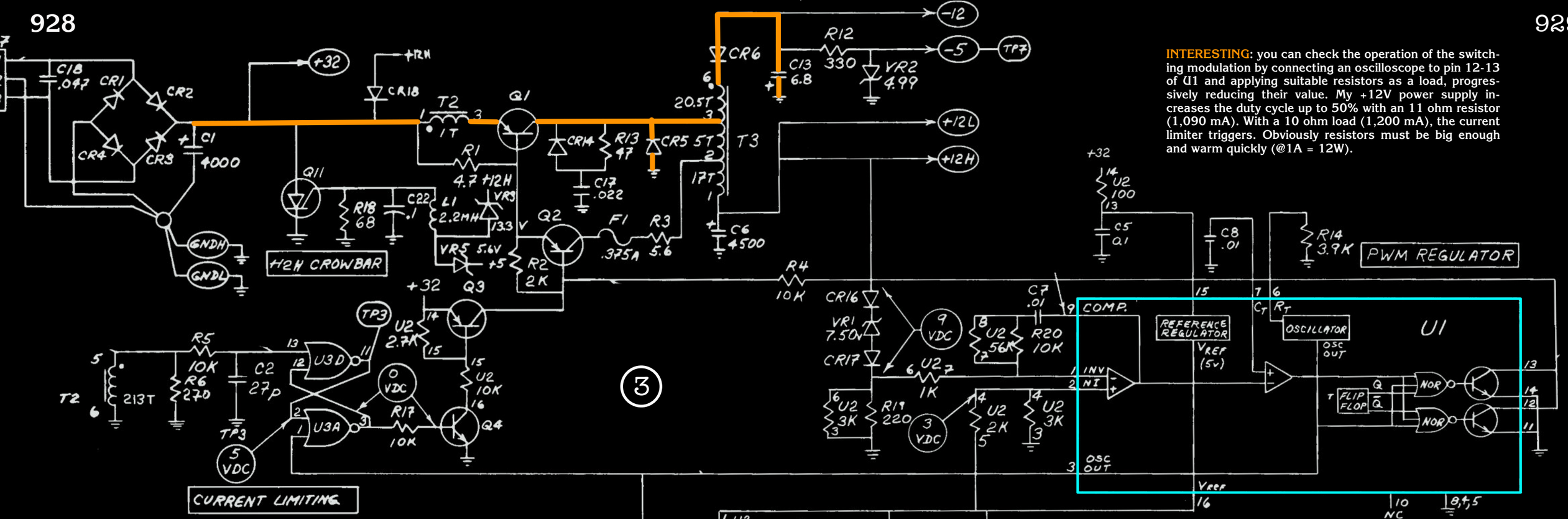




2

that finds the reference in the diode, and thus again flows in the load, exactly like a flywheel. Properly opening and closing the transistor, we can stabilize the voltage on the load, with a minimum waste of energy. This task is performed by the SG3524 controller (in blue in figure ❸), that monitors the output level. In the same figure, you can see marked in orange the main current path so that to see the similarities with the basic scheme of the buck regulator.

The SG3524 is synchronized by a 32-kHz pulse train from the CRT controller to twice the CRT horizon-




*INTERESTING*: you can check the operation of the switching modulation by connecting an oscilloscope to pin 12-13 of U1 and applying suitable resistors as a load, progressively reducing their value. My +12V power supply increases the duty cycle up to 50% with an 11 ohm resistor (1,090 mA). With a 10 ohm load (1,200 mA), the current limiter triggers. Obviously resistors must be big enough and warm quickly (@1A = 12W).

## CRT SYNCHRO

tal line scan rate (CRT SYNCHRO signal), but it works also independently, i.e., when not synchronized with the CRT, if you want just work on it.

The unregulated 32-volt input absorbs the large kickback voltages from the printer drive motors, thus recycling energy.

It is not immediately evident from the schematic, but T2 coil on the emitter path of Q1 is really a transformer; its secondary winding is drawn in the CURRENT LIMITING section. This transformer monitors large peaks such as those that occur during printing. High current peaks shut off Q1 in less than two microseconds. This feature prevents problems inherent in driving inductive loads while staying within a safe operating area. If the twelve-volt supply is shorted, the input power will drop, the short acting as a finite current with zero output voltage.

A + 12V over-voltage sensor crowbars the unregulated 32-volt supply if Q1 is shorted. The other supplies do not have an over-voltage failure mode.

## +5V regulator

This part is completely different between A and B models. The A uses a separate dc-to-dc converter. In the HP-85B (the one I worked on), the circuit (❹) has been dramatically simplified and made similar to the +12V section (if you look carefully, you can see the buck regulator in it).

This regulator does not use a separate controller; the transistor command is obtained in a very simple way, using the sawtooth signal produced by the SG3524 and a voltage comparator with a reference voltage. Simple but it works.

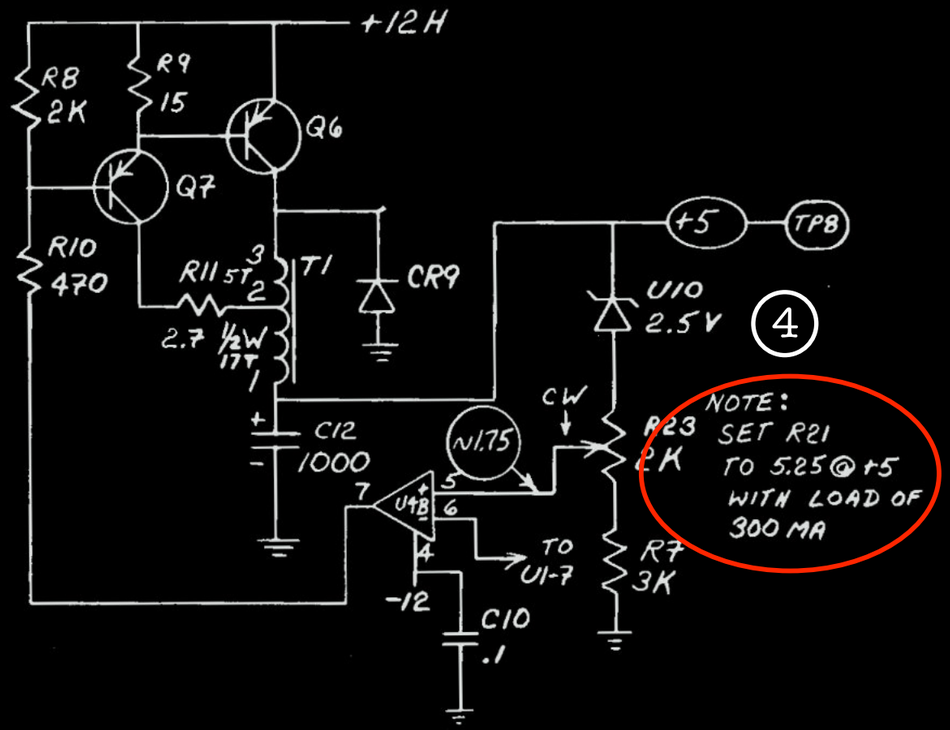
## Lesson learnt

The note circled in red in the diagram is fundamental if you want to check the power supply standalone, and it is the reason that made me lose a lot of time, because I had 6.5 V with no load.

## Other voltages

The output transistor Q1 drives transformer/inductor T1, which acts as a lossless voltage-averaging reactance. The filtered side of T1 provides + 12V. During Q1's off time, the flux change in T1 remains constant, so the - 12V and + 7.5V outputs from T1's secondary winding do not need pass regulation.



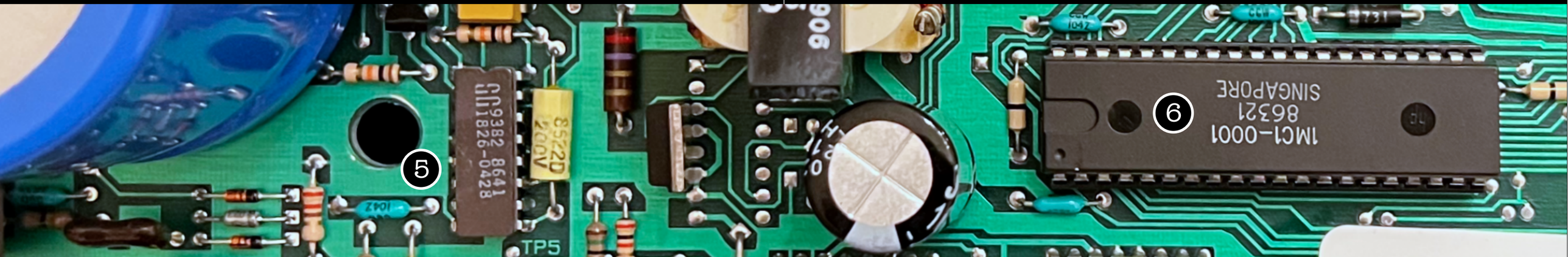



❹ The +5V schematic diagram with the precious note regarding the load to apply before checking the voltage.

❺ The SG3524 switching controller is not marked as you expect, like most of the other components. HP had an its own identification system. You can find on the net tables to get back to the original component marking. That was done to ensure the quality of the components (and probably also for commercial reasons).

❻ On the power supply board there is also the single chip printer controller and the related power line drivers.





Notice in this picture the capstan that physically moves the tape. Restoring it is a must on those old machines, because the original material has deteriorated in the years. Notice also the magnetic head; you can see easily that it manages two traces. The electronic board, on the rear, is small and simple compared to the many functions it performs.



# The cassette module

The HP-85 data cassette was probably chosen to recycle the consolidated and successful technology of the 9825-Series.

## The most reliable(?)

Among the many resources that you can find about the HP-85, it is interesting to read the article about it originally appeared in BYTE Magazine, March 1980 by Christopher P. Morgan. It says that "…one of the main differences between the HP-85 and most other small systems on the market is its use of data cartridges for reading and writing programs and data. This is not surprising, since the company expects to sell the unit in large quantities to professionals, and the data cartridge is one of the most reliable forms of mass storage available today".




Today that seems rather surprising: the HP cassette was much better than the ancient musical cassette recorders, and I have no data to say if the cassette was "one of the most reliable form of mass storage" (but I have doubts…); surely it was a looser against more efficient floppy discs, at the time now available in quantities, as demonstrated by history.

However, thanks to the operating system embedded in the BASIC ROMs, it could supply a world of functions. A cassette could hold about 200 kbytes and there could be a maximum of forty-two named files per cartridge. Cartridge rewind time was 29 seconds; search speed was 152 cm (60

inches) per second; data transfer speed was 25.4 cm (10 inches) per second; and tape length was 43 meters (141 feet). With the data cartridge system, the user could create data files, input arrays into the computer with a single program statement, store an "autostart" program that is automatically loaded and executed at power-on, and secure programs from unauthorized access.

## Just a curiosity: data cassettes and crabs

“Granchio” (pronounced grunkeeo) is an Italian word which literally means “crab”. But “you took a crab” means that you said something completely wrong, convinced that it was true. In this case, the Byte Magazine article took a big “granchio” saying that each cartridge could hold “780 program records consisting of 192 K bytes each, or 850 data records of 210 K bytes”.

I asked the 80-Series GroupsIO about this point, and I received an answer from **Everett Kaser**, one of the greatest expert of the HP-85 and author of the wonderful HP-85 emulator (briefly described at page )

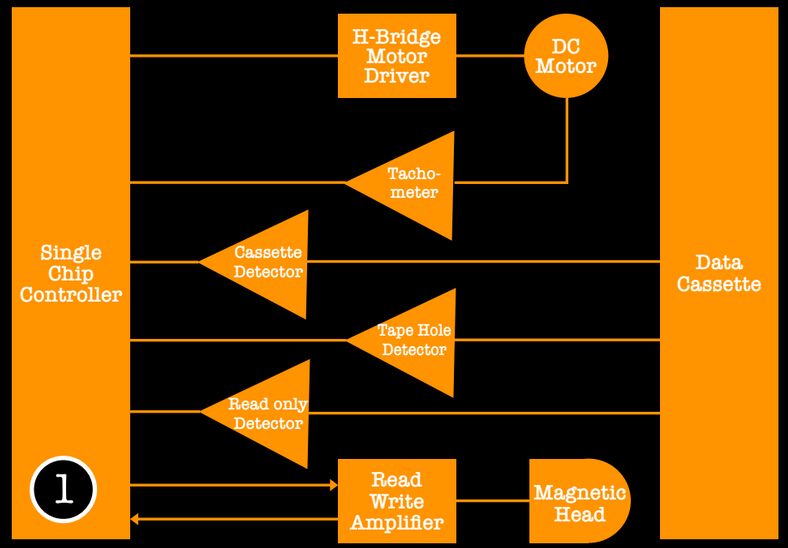
“My VAGUE memories are that tapes could hold around 210 Kbytes. When storing programs (BASIC, Assembly language, and binary programs), there was 256 bytes of data per record, with "inter-record gaps and markers," including (if memory doesn't lead me astray) a 6-byte record header that indicated things like which track it was on, which file# (as in the index into the 42-entry directory), and which sector of the file). When storing data (in DATA files), it got a little more weird, because when writing numbers, each number took 8 bytes, but when writing strings, there was a 3-byte "string header" at the beginning of the string, and if the string spanned more than one sector, then there was another 3-byte string header at the beginning of each succeeding sector (which included the length of the string segment in that sector, along with a "string marker". The numbers were always written in REAL format (a packed 12-digit BCD mantissa and a 3-digit nines-complement exponent, and a 1-digit (4 bit) mantissa sign). The string marker in the 3-byte "string header" used invalid BCD hex values (in the 0x0A to 0x0F range) to indicate "start of string", "middle of string," or "end of string". That's how the system READ code knew whether it was a number or a string "coming up" in the DATA stream.  So, again, if memory serves, the 210 Kbytes was "raw storage"capacity, but the 6-byte record header might have to be subtracted from that, and you also have to subtract 4 sectors for the two copies of the tape directory, and... it's messy.”



# More software than hardware

The 7/1980 HP journal issue gives us a lot of information about the inner working of the cassette drive, built around a) a dedicated chip; b) a mountain of software that runs inside the HP-85 main CPU. And I am not joking saying a mountain: thanks to this software, as we noted above, you can use the cassette almost like a disk, with dozen of functions that allow to use a real file system for programs and data.

In the diagram here on the left, you can see how clever the designers have been, conceiving a unit relying at maximum on software, i.e., reducing the hardware at the minimum possible. The single chip mostly contains the counters that require speed (see its block diagram ❷ here on the left). Don't forget that, differently from today, the integration level was limiter to few components.



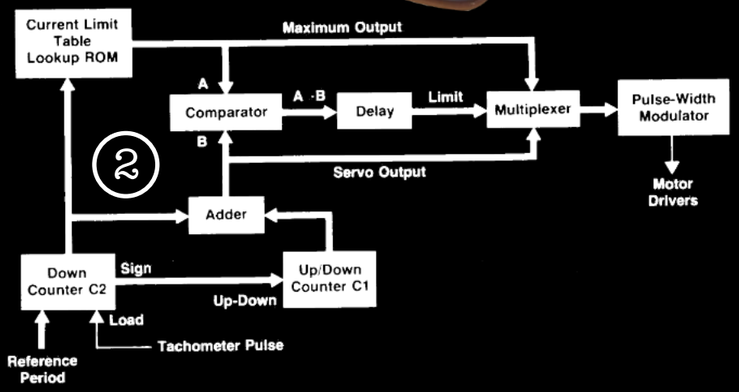

## Restoration

Today, the cassette module is probably the most critical part of the HP-85, and probably you will need to deal with it if you are going to restore your HP-85. Differently from a car restoration, you will need not only to fix the motor (the cassette drive), but also the fuel (the data cassettes), as we are going to see.







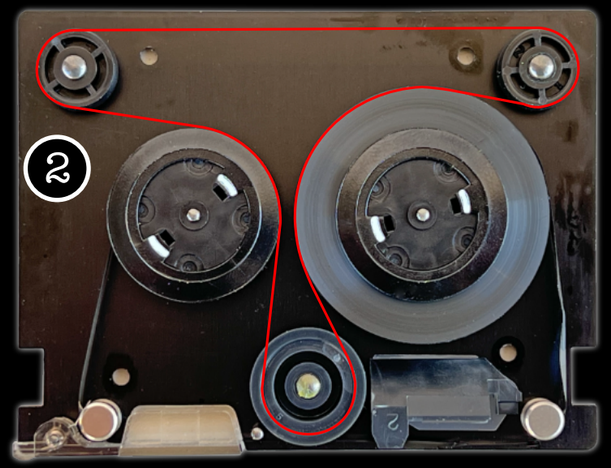




❶ The cassette drive board simplified block diagram. ❷ The tape controller single chip block diagram: for a detailed description see HP Journal 7/80. ❸ The cassette drive board seen from the solder side. Marked with a red dot, the test points that you can find in the schematic diagram. The small triangles points the connection of the lamp used for the tachometer that must be desoldered before dismounting the motor. In the red circle, the added 1.8 k ohm resistor used to increase the write current to use the DC2000 cassettes (see the text). The yellow rectangle tells where it is necessary to file about 1mm of the board, again to use the DC2000s.

# Data cassettes

The cassettes, i.e., the "fuel" for the HP-85, are a critical point. The original cassettes were named 98200, also called DC200. According to Curiousmarc, data cassettes can fail in a million different ways, and he is probably right. The problem is that they are not any longer available. Even if you can find them brand new in their sealed box, they will not work, as I can confirm for direct experience, because the tape glued to itself and when you try to move it, the magnetic coating detaches, as shown in photo ❶, leaving the bare transparent support. I read that you can try to fix it keeping them for some hours at high temperature with a very low humidity. In my company, I have a climate chamber, and tried this operation, but with no result.

Furthermore the driving belt (red in photo ❷) tends to break with extreme ease. Curiousmarc discovered that you can use 4 ¼" Plastibands to replace the original belt. On Amazon they are incredibly expensive, so I did not test this solution; however my tapes are damaged and so would be useless to repair the belts.



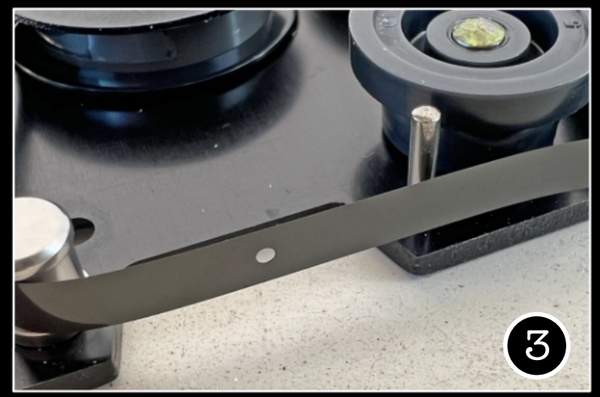

The only possible solution seems to be using DC2000 data cassettes, still available rather easily. On eBay. They are mechanically similar to the DC200.

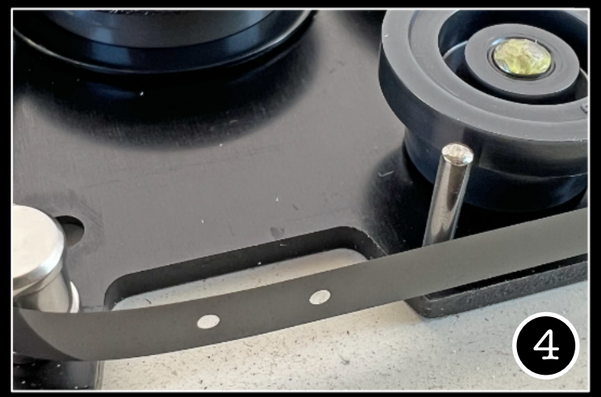
To use them you must a) raise the capstan approximately 2 mm (see next); b) add a 1K8 resistor in parallel to R1 to increase the writing current (the DC2000 tape has a higher magnetic coercitivity); c) slightly widen the hole in the PCB, as shown on previous page.

❶ A HP98200 cassette with the damaged tape.; Note the transparent sections.
❷ The driving belt (in red) that, driven by the capstan, moves the tape.
❸ The hole in the tape used to signal the approaching end of the tape.
❹ The two holes used to signal the end of the tape.







# The capstan

As we wrote, the capstan is one of the most weak part of the HP-85's design. Better, probably it was considered a wearable part, and it should be replaced from time to time. The problem is that the original spare part is not any longer available, so we must invent something. Many kind of solutions have been proposed. Years ago I tried to cover it with two layers of heat shrink tube, but it did not last long.

A possible solution is to coat it with Plastidip (❸), a commercial liquid rubber product. It is very expensive and not readily available in Italy, so I wanted to use a similar product, the Liquid Rubber from Bostik (❷), but I preferred to do some tests before on few screw heads (❻). The results were not good; the product is too dense and seems to never dry completely; it remains sticky, and is almost impossible to have a regular surface.

In the end, the solution I chose is a latex tube (external diameter 3/8", internal ¼"). It can be purchased by Amazon (❺). I have not yet tested it long, but it seems good. I added two washers on the head of the capstan, so that making it taller about 2 mm to use also the DC2000 cassettes. The washer have been glued with Super Attak (❹) and are clearly visible in photo ❶. As you can see in photo ❼, it seems to match rather well the DC2000's pulley. Update: don't glue the latex, the glue destroys it. Another important note: my friend **Piero Andreini** (see below) succeeded replacing the rubber part without dismounting the cassette drive, using just pliers and with much patience, directly from the cassette opening. A silicon, soft tube is perhaps better than latex.

I am not an expert, most information here comes from the Curiousmarc videos. If you are interested, you must definitely visit his web page.

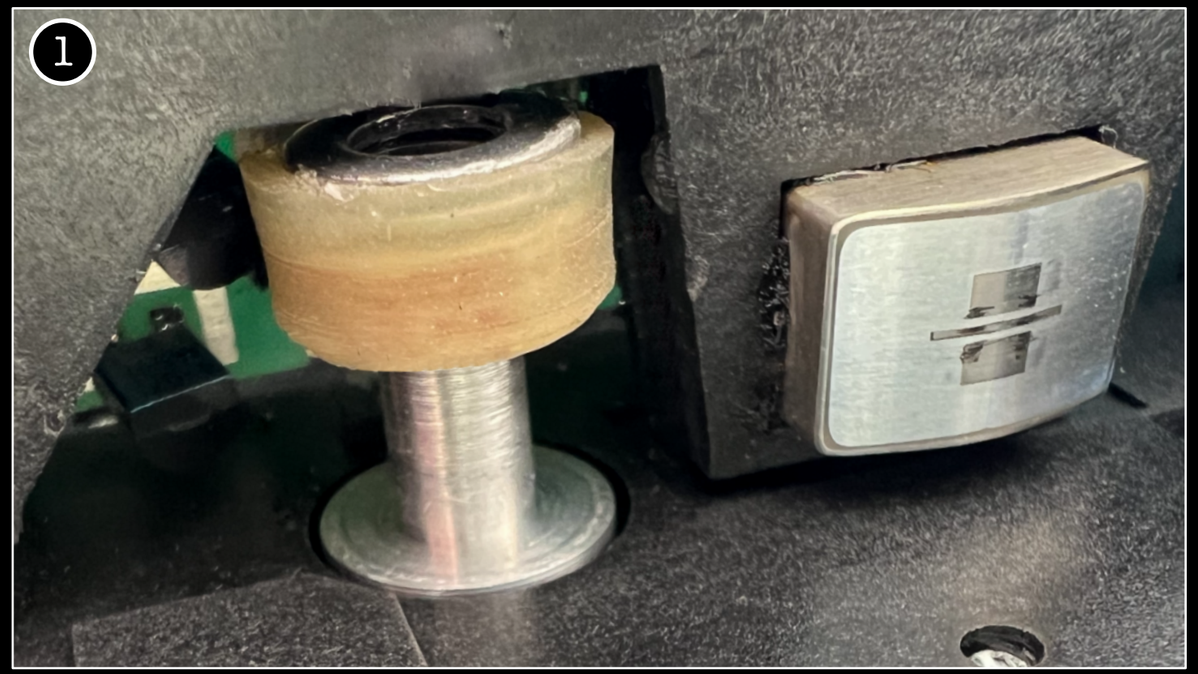












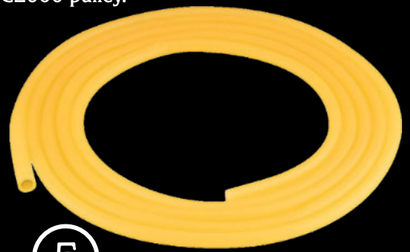













❶ The capstan, refurbished with latex tube. Note the two washers glued on top of it, to make it taller and match also the DC2000 cassettes. ❷ The Bostik Gomma Liquida (liquid rubber) that I tested is not good for this kind of application. ❸ The PLASTI DIP rubber coating, used with success by Curiousmarc to renew the capstan. I did not test this solution, that is said to be the best (see Curiousmarc videos). ❹ The Loctite Super Attak, used to glue the washers on the capstan. ❺ The 3/8" (1/4" internal) latex tube. ❼ How the capstan matches the DC2000 pulley.

# The display

One of the items characterizing the HP-85 is its high-quality, small size, low-power CRT display.

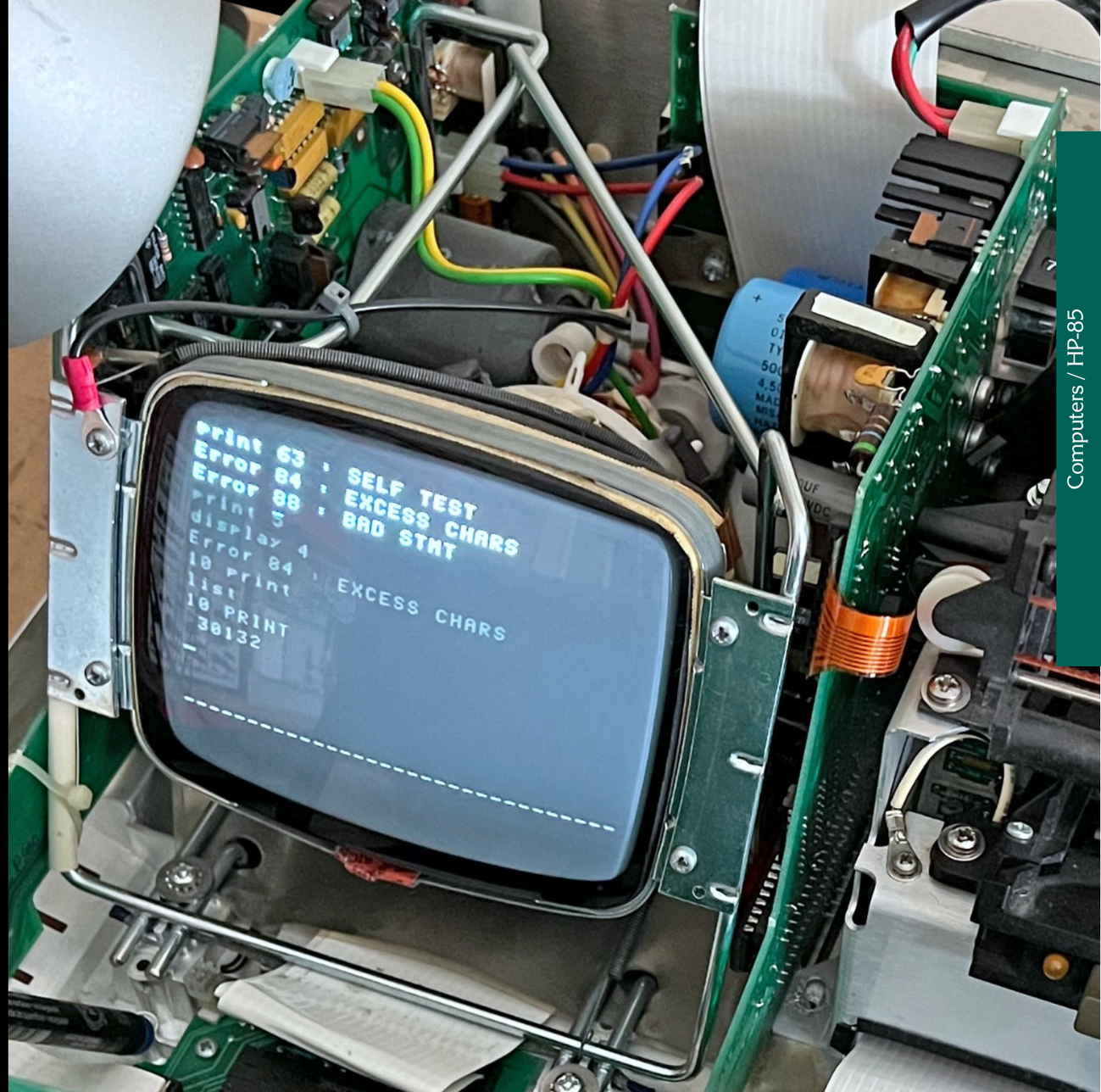
The 127-mm diagonal, black-and-white, electromagnetic-deflection CRT can display information in the form of lines of alphanumeric characters or provide a plotting area for graphics output. During tape operation and thermal printing, the display is switched off to conserve power.

## CRT Controller

The CRT unit has a digital interface and is connected to the CPU bus through an NMOS controller IC whose function is twofold. Its primary function is to interact with the mainframe memory, CRT, and display refresh memory so that data may be displayed as it is updated by the user. Its secondary function is to provide signals to the CRT drive circuitry for horizontal and vertical timing and character generation.

The alphanumeric display produces 16 lines of 32 ASCII characters, with a 5x7 dot font. In graphic mode, the resolution is 256x192. The CRT phosphor is white, against the 80s green trend. The memory keeps 64 lines in total, of which 16 can be displayed, and a graphic screen. The graphics data maps directly from one bit of RAM to one dot on the screen. Three-quarters of the available refresh RAM is dedicated to graphic information storage.

**The magic moment: when, after many efforts, the toy you love returns to the life is priceless. The different quality of the various lines is not real but is a consequence of iPhone photo camera. Really, the quality of the display is still good and stable. The phosphor white color gave a modernity feeling in front of the then more common green. The speed is very low also in text mode, but probably the limit is on CPU side as well. The display's brightness is controlled by a trimmer accessible from the rear panel.**



# The keyboard







The HP-85 keyboard weights almost as much, if not more, than a modern portable computer by itself. At that time, most of us did not accept compromises, when talking of keyboards. Today, mechanical keyboards are back in fashion for video gamers, but this old HP one is hard to beat for its supreme quality. Note the double injection keycaps, that never wore off.

# The I/O system

In the late 1970s, many microcomputers still used the S100 bus architecture or, however, had the capability to accept expansion cards, like the Apple II. Also the HP-85 had this provisions, for four expansion modules, much better engineered than the competitors. Each module was boxed in a plastic body, making it more suitable to a less-technical public. These modules fell in two categories:

- generic plug-in modules
- interface modules

## Generic plug-ins

- **82903A 16K Memory module** for HP-85A only.
- **82967A Speech synthesis module**: allows speech output of over 1500 words/sounds/phrases. Requires 32 Kbytes memory, a flexible disc drive and a standard 8 ohm speaker or headphone.
- **82928A System monitor**: provides the necessary hardware to aid in developing and debugging assembly language programs. The HP 00085-15007, 82928A and 82929A form a complete set of tools.
- **82929A Programmable ROM drawer**: lets you use the firmware created with the Assembler ROM. You can plug in standard EPROMs that you can program yourself in your own code.
- **82936A ROM drawer**: provides mounting for up to 6 of the firmware enhancement ROMs-(see next pages). Plugs into any port on the back of a Series 80 Computer. Only one ROM drawer can be used at a time.

## Interface modules

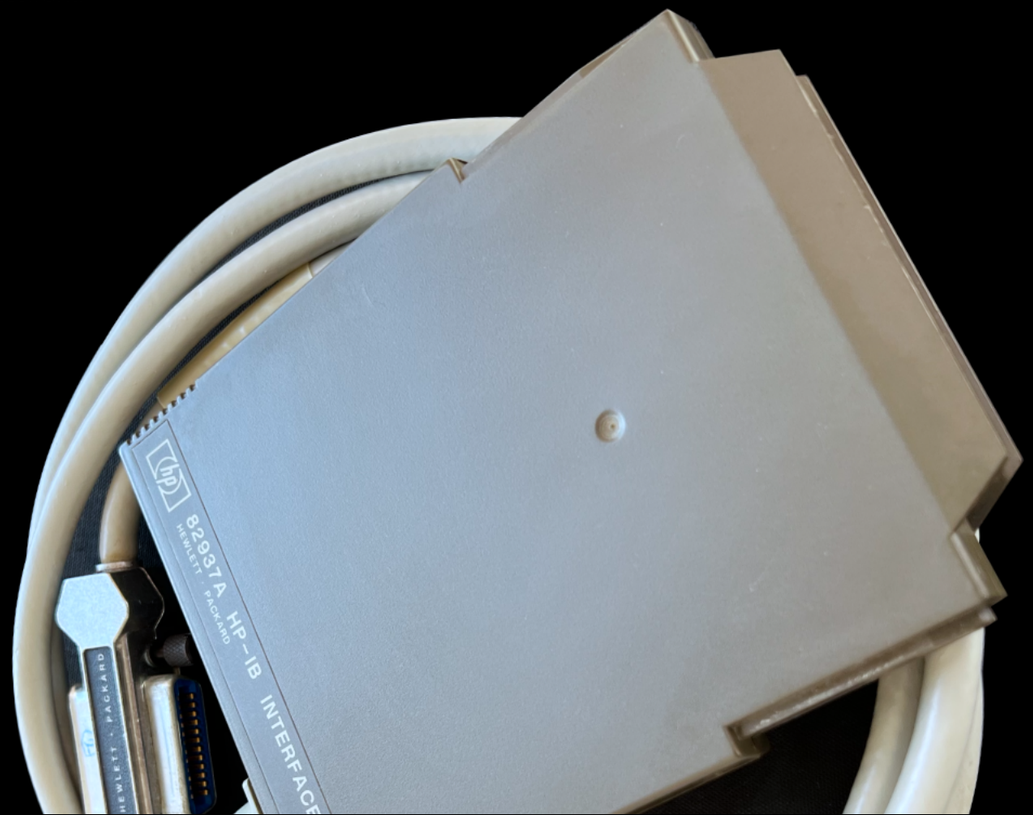
- **82169A HP-IL/HP-IB Interface:** to use the HP-85 as a translator between the HP-IL and HP-IB standard buses;
- **82937A HP-IB Interface:** the HP Interface Bus (HP-IB), aka GP-IB in the standard accepted form, is an easy to use hardware and software interface system that permits bidirectional, asynchronous communication among a wide variety of instruments and peripherals, like many of the instruments described in this book.
- **82938A HP-IL Interface:** the HP Interface Loop (HP-IL) is a bit-serial interface that combines low power, small size and low cost. With HP-IL, you can interface as many as 30 devices, with up to 10 meters of cable between each device.
- **82939A RS-232 serial Interface**
- **82940A GPIO Interface:** two output-only 8-bit ports and two bidirectional 8-bit ports. They can be used as separate 8-bit ports or as 16-bit ports.
- **82941A BCD Interface (Binary Coded Decimal)**: 11 digits of 4-bit BCD input or output data plus 4 sign bits for one or two channels.

  **82949A Centronics-type Printer Interface**

  **82950A Modem:** operates at speeds of 110 or 300 baud. It connects directly to the telephone line and is compatible with Bell 103/113 modems.
- **82966A Data Link Interface:** to talk with most other HP computer products on a common network.







# OS extensions

A point of strength of HP calculators used to be the large software add-on availability, either at system, either at application level.

The HP-85 could also accept ROM cards in its I/O slots. Each ROM card (82936A) could accept up to six ROM plug-ins; each ROM plug-in was a matchbox-sized plastic package that snapped into one of the sockets on the ROM card. Since each ROM was "bank-switched" (the CPU turned them on or off as needed) a user could plug in as many ROM cards as needed (up to four, anyway).

These ROMs enhanced the capabilities of the BASIC interpreter. The most important were (marked with an asterisk those included as default in the HP-85**B**):

- 00085-15001 **MASS-STORAGE ROM**: provides the capability to interface the HP-85 with the HP 8290X-series Flexible Disc Drives or the HP 9134A/9135A Winchester Disc Drive.
- 00085-15002 **PLOTTER/PRINTER ROM***: gives the ability to control plotters and external printers. Allows data to be transferred to an HP plotter. Also provides single commands to dump CRT graphics and alpha screens to any HP dot matrix printer.
- 00085-15003 **I/O ROM**: gives the extended functions needed to control its optional I/O interfaces. Provides straightforward input/output commands that enhance the BASIC language capability.
- 00085-15004 **MATRIX ROM***: gives a powerful set of statements and functions for working with arrays. Both matrices (2-dimensional arrays) and vectors (1-dimensional arrays) are supported. Ideal for those who need matrix computation.
- 00085-15005 **ADVANCED PROGRAMMING ROM***: gives the user extended functions for the BASIC interpreter. Extends your control over data, programs and system operations. I find it very interesting, and dedicated an extra page to it (see below).
- 00085-15007 **ASSEMBLER ROM***: provides the capability to write customized assembly language programs that can be executed from the user memory or burned into EPROMs. Used often with the HP 82928A (System Monitor ROM) and HP 82929A (Programmable ROM Drawer). More in the following.
- 00085-15012 **ELECTRONIC DISK (EDISC) ROM**. The HP-85 may accept up to 4 HP-82908A 64 Kbytes, or HP-82909A 128 Kbyte RAM cards. The EDISC ROM allows some of this memory to be used as a high-speed RAM disc speeding access to programs and data.

In the picture: the 82936A ROM Drawer. Note the fine implementation of the ROMs, not just a simple chip to be inserted in a socket, as it would have been normal for us electronic engineers, but a plastic module impossible to be inserted in the wrong way and more suited to the HP-85 public.

# Advanced Programming ROM

The Advanced Programming ROM adds important features to the HP-85 BASIC, like these:

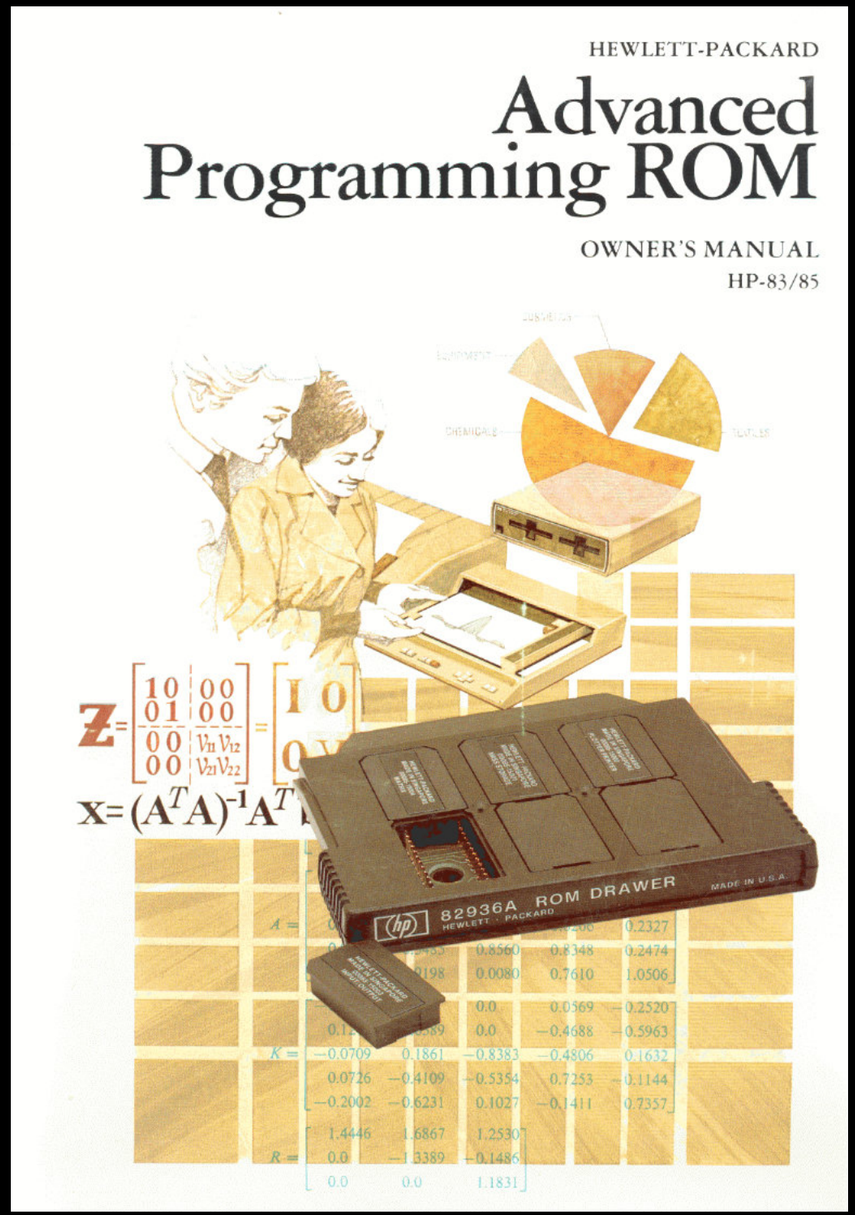
- position the cursor during program execution;
- read string information directly from the display;
- create string arrays;
- execute subprograms;
- use the entire keyboard for branching operations;
- set, clear, and test 64 program flags;
- find and replace program variables;
- merge programs;
- cross-reference both program statements and program variables.

Among them, the most relevant is probably the capability to use subprograms. Subprograms are separate BASIC programs which can reside in memory along with your main BASIC program. Subprograms may be called into memory from the mass storage device, and they may be eliminated from memory selectively or as a group to make room for other subprograms.

Parameters can be passed to subprograms by address or by value. Passing parameters by address will return any altered values to the main program. It should be noted that the actual variable names used in the subprogram do not have to be the same names used in the main program. For instance, a main program can “call” a subprogram, passing addresses for “X” and “Y” . The sub- program, however, could use variable names “A9” and “C7” (for instance) instead of X and Y. By passing variable addresses, the subprogram changes to A9 and C7 would by assigned to X and Y in the main program. This means that you have complete freedom to call your variables as you wish in the main program, without worrying how they are called in the subprogram.

An equally powerful feature is the ability to pass parameters by value. In this case the subprogram can perform its functions without affecting the values of variables in the main program. In other words, a subprogram can also have “local variables” which won’t interact or affect the variables in the main program.






The ability to call subprograms from mass storage and the use of global (parameter passing by variable address) and local variables is a tremendous enhancement that resembles the “procedures” found in advanced computer languages like Pascal. It means that common program functions such as data editing, file handling, or similar routines need to only be written once. After they are written, you may use them in countless other “main” programs, greatly expanding your ability to write programs quickly and efficiently. You may build a library of common routines, and “call” them from main programs only as needed [from an article by Dale Flanagan, NEW80S magazine, issue 5, 1983].

This capability surprised me very much: I wouldn’t have expected to find these modern possibilities in this small old machine.




# Besides change

## Small talks

The times they are a-changin' sang Bob Dylan in 1965, and also for computers the change never stopped in the seventies and eighties. Like for all technologies, in the beginning the change is faster; the innovation curve is steep and the amusement, like its mathematical derivative, is maximum. When the curve flattens, the amusement tends to zero, as demonstrated by modern computers and smartphones, sadly almost identical from one year to the next.

As I told you, the HP-85, in my opinion, was introduced a little too late; many microcomputers offered comparable or better performances and possibilities. That was even more true in 1983, when HP presented the 85B. Few months later respect to the HP-85B, Apple introduced the Macintosh. The first was the last representative of prehistory, the second the first of the modern era, distant each other a short time but light-years at the same time.

## Let's investigate that piece of gear

I had more reasons for learn using the 85. First, I wanted to setup a simple controller allowing me to manage my beloved instruments through the HP-IB interface, also to better diagnose and repair them, being able furthermore to learn and write here something about the HP-IB, as I have been promising since the first Tektronix book (see later).

In addition, I wanted to describe how it was using the HP-85. As I told you, I have an old score to settle with it since the first eighties, when I was producing CP/M based computers and was scared by the new HP's baby, that in any case never became a treat.

## Using the HP-85

Starting from the tail, I say immediately that the 85, by itself, was probably less powerful than most CP/M machines, and that programming it is not very easy, with its small-size display and no text editor. Writing even a simple program, requires time, patience and self-training.

The HP-85, like other BASICs of the time, does not allow to use symbolic names for the variables and for the subprograms (differently from the 85 assembler of which we will talk later). Short display lines (32 characters!) with limited editing possibilities do not ensure a very high productivity.

## The language

It is interesting to see how the Series-80 BASIC compared to the other BASICs of the time. Surely, its rich set of commands was far more advanced than its competitors. Some of them didn't even have an ELSE clause, and required PEEK and POKE to access many features. Series-80 BASIC could survive without PEEK and POKE until EBTKS added them these days.

One of its limit was the “pure BASIC” variable names composed only by a letter and a number; however, in the HP-86/87 new versions, it did have 32-character variable names and symbolic labels.

Microsoft BASICs supported long variable names, but only the first 2 characters were

# Development lineages

There were two main lineages for calculator and PC development at HP:

## Colorado

- HP 9100 (calculator);
- Series 9800 (calculators and HPL/BASIC PCs);
- Series 200 (originally BASIC, later Unix workstations);
- Series 9000 (Unix workstations).

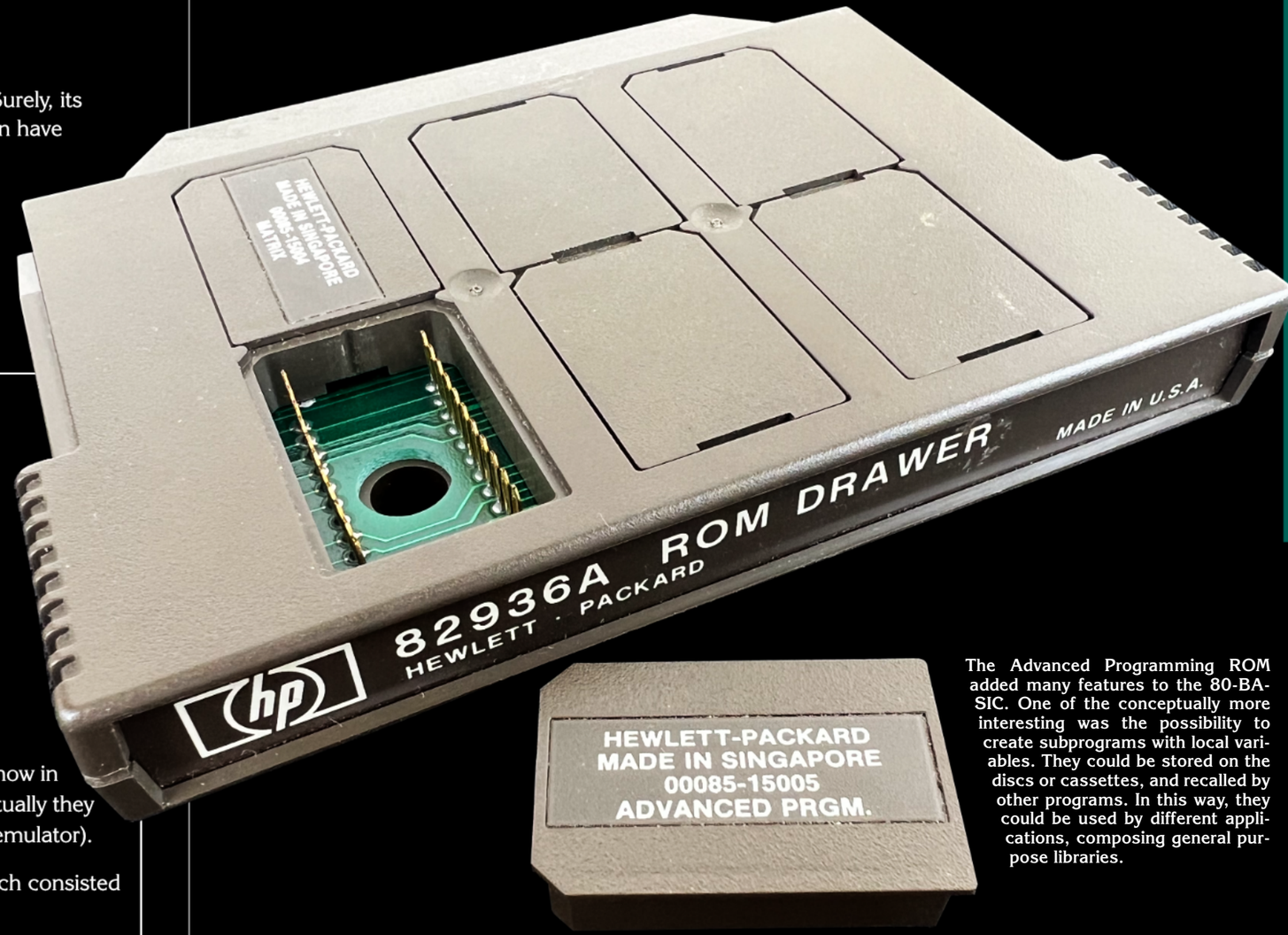
## Oregon

- handheld scientific calculators (HP-35, etcetera);
- Series 80 PCs (HP-85, etcetera). Read, in the interesting Everett Kaser historical notes, how in Oregon passed from handheld computer to the HP-85, with all the difficulties that eventually they overcome in the best way (these notes are in a file README.TXT downloaded with the emulator).

In addition, there was a PC with BASIC based on a terminal (HP 2647), and Series 100 which consisted of CP/M (HP 125 and 120) and MS-DOS (HP 150, 110, etcetera) PCs.








**The Advanced Programming ROM added many features to the 80-BASIC. One of the conceptually more interesting was the possibility to create subprograms with local variables. They could be stored on the discs or cassettes, and recalled by other programs. In this way, they could be used by different applications, composing general purpose libraries.**

significant. Also, Microsoft BASICs didn't support labels until AmigaBASIC was released in 1985.

Series-80 BASIC did not have structured programming constructs like WHILE loops, SELECT blocks, or block style IF / ELSE / END IF. However, most other contemporary PC BASICs also lacked these things. Only Acorn BASIC and BBC BASIC did have some of them.

Very interesting in the HP-80 BASIC were the subprograms, made available by the Advanced Programming ROM. The concept is even modern, and allows a form of encapsulation, like the object oriented programming. You can define subprograms (finally with symbolic names!) and pass them parameters (still in the single letter + number form), while they can have also local variables (again not symbolic), and you can even decide to pass the parameters by value or by reference (a pointer to them). But each single subprogram must be contained in a dedicated, homonymous file. If you have 50 functions, you need 50 files, and you can edit them just one by one, after having loaded them. However, that allowed to create library of functions, sharable among many programs.

## Not just a computer

It is not difficult to understand that one of the reasons of the HP-85 success was the way in which the product arrived: not just a computer, but a complete system, with tons of manuals, options, software and accessories. Like for the RPN calculators, the important was not the product itself, but how they were capable of making every customer an enthusiast, self-taught sustainer.

## Conclusions

We can conclude that for us, complex things' lovers, the HP-85 is simply perfect: one of the most fascinating computers from that era, much more than any anonymous CP/M or MS-DOS computer.

Besides its limits, thanks also to the optional ROMs, the 85 has a lot of functions and possibilities indeed, and from our today point of view of silly compulsive accumulators, it is an endless toy which can ensure days and days of continuous enjoyment.



# Piero Andreini

In 1975 I established the first Italian firm producing microcomputers. It was named first Micropi and then General Processor, and had some success at the time. In 1981, we produced the GPS-4, based on CP/M or MP/M. Maybe that almost one thousand of them had been produced.

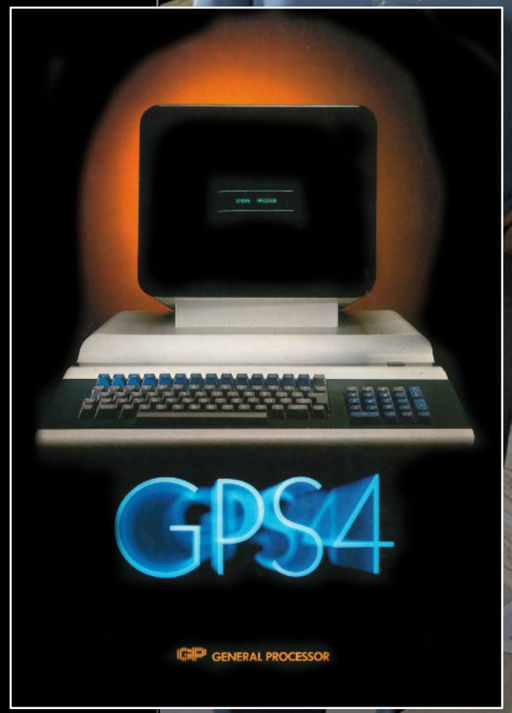
Today few enthusiasts are collecting and restoring them.

I met Piero Andreini for the first time at an exhibition of ancient computers in Rome, where he presented a restored GPS-4, and asked me to sign it. Obviously, it made me proud, and I was happy to do that, but it was above all the opportunity to get a new precious friend.

Piero (active on GroupsIO) is big a collector of old computers and a real expert, even if he is very shy and tries to minimize his competences (as real experts often do…).

Friends are precious resources, and Piero is also a great person… not only he risked his 82937A board to repair mine, but only thanks to him I could repair by HP-IB interface. In addition, Piero lent me his 9121 and 9133 that you can find described here. Thanks again Piero!






The GPS-4 had the typical microcomputer architecture of the eighties, with a Z-80 CPU (two really), 64 kbytes of RAM, two floppies (5 or 8 inches) and one hard disk. To notice, the housing: we had not the money for the construction of the moulds, so we realized it using only sheet metal. The architect who designed it was very clever; despite of the difficulties of the sheet metal, that does not offer the flexibility of the plastic, he could achieve a design that is still attractive even after forty years. I left the company in 1982, which survived few years until the Commodore, Spectrum etc. tide.

# The 82937A HP-IB interface board

## A different, non-inexpensive approach

An HP-IB interface is normally considered the means to interface instrumentation like oscilloscopes, spectrum analyzer, frequency counters, signal generators and many others. In the case of the HP-85 (and family), it is much more important, because it has been delegated also to interface normal peripherals like printers, floppies and fixed discs. This choice was another limit of the HP-85, because normal users had to pay for the interfaces and their monumental cables and connector, vs. the competitors who used inexpensive interfaces (think Apple II) or kept the discs inside the main box, furthermore saving extra power supplies, cables and connectors.

## The 82937A

This interface conforms to the Institute of Electrical and Electronics Engineers' (IEEE) Standard 488-1978 and supports a wide variety of operations, enabling you to communicate with and control peripheral devices. We will talk again of it in a dedicated chapter

## Different approaches for different users

The connection to HP-IB compatible printers and other peripherals was simple enough and could be performed by most users. The instrumentation interfacing was more often performed by expert technicians, who used to write programs for that, either for the nature itself of the problem, either because the standard is related only to the interface, and each instrument has its own different logics and command sets.








❶ The big 82937A HP-IB interface.
❷ The typical (and monumental) dual-face HP-IB connector




# Interface board plug-in ROMs



This interface requires one of three available ROMs to perform input-output operations. The type of ROM used determines which bus operations can be performed. The available ROMs include:

- Mass Storage ROM (part no. 00085-15001 for the HP-85/83);
- Plotter/Printer ROM (part no. 00085-15002 for the HP-85/83 and part no. 00087-15002 for the HP-87);
- I/O ROM (part no. 00085-15003 for the HP-85/83 and part no. 00087-15003 for the HP-87).

The Mass Storage ROM supports interfacing of available disc-drive units, and the Plotter/ Printer ROM simplifies interfacing plotter and printer devices. The I/O ROM is a general purpose ROM and is used in a wide variety of applications.

Note that there were other ROMs required for some peripherals like the 9133 Winchester fixed disk:

- Extended Mass Storage (HP-8B only, part no. 00085-15013).

# Repairing the 82937A interface board

I bought the board from a very kind person in NY, who was convinced that the board was rightly working, but it was not, so I decided to try the reparation, together with my friend Piero Andreini.

After examining the bus signals, we noted that:

- the board was responding correctly from the HP-85 point of view;
- all the signals on the CPU-side were correct;
- almost no activity was present on the HP-IB side.

We concluded that the problem should be in the 8049 microcontroller, that acted normally from the 85 bus point of view but which did not transfer data to the HP-IB bus.

Piero had a good 82937A, and generously decided to unsolder and remove the 8049s from both the boards, replacing them with sockets, so that we could test the chips and the boards.

In this way, we could understand that one of the two 8049 chip was faulty. Luckily, an EPROM version of the 8049 exists: the 8749H. I could buy some of them (D8749HD), brand new, for few euros in China, so the problem was only a long wait.

When they arrived, another problem arose: few programmer can write these old microcontroller. Again Piero Andreini solved the situation, having a suitable EPROM programmer (All07).

The file for the programmer is the 1820_2437_HPIB.bin, available from GroupsIO thanks to Everett Kaser (https://groups.io/g/hpseries80/files/Hardware/8049_IO_ROMS.zip).

The new chip worked perfectly. It is somewhat too tall, so, with the socket, slightly presses on the cover, that remains imperceptibly swollen, but I prefer to keep the socket for any future replacement.




**In the picture, the new chip mounted on the socket. The greater height is evident.**

# The 9121 drive

## Disc or disk?

I don't know why, but sometimes we use the word "disc" (like in Compact Disc) and sometime "disk" (e.g., floppy disk). For what I know "disc" is the English word used by HP instead of the American "disk".




1982

The very nice 9121D is more an accessory of the HP-85, instead of a base component. The HP-85 was rather a rough machine, or, better, it was representative of the old microcomputer generation based on a ROM BASIC, which had also the function of operating system, like Apple II (and in this sense, it was probably superior). But times were changing, and users started to prefer the machines equipped with a disc loadable operating system, i.e. CP/M or Mac OS (in this case named "Finder"). The CP/M board was the fortune for the Apple II, and also HP offered a CP/M board, but all that stuff was too expensive (computer, interfaces, floppies, ROMs...).

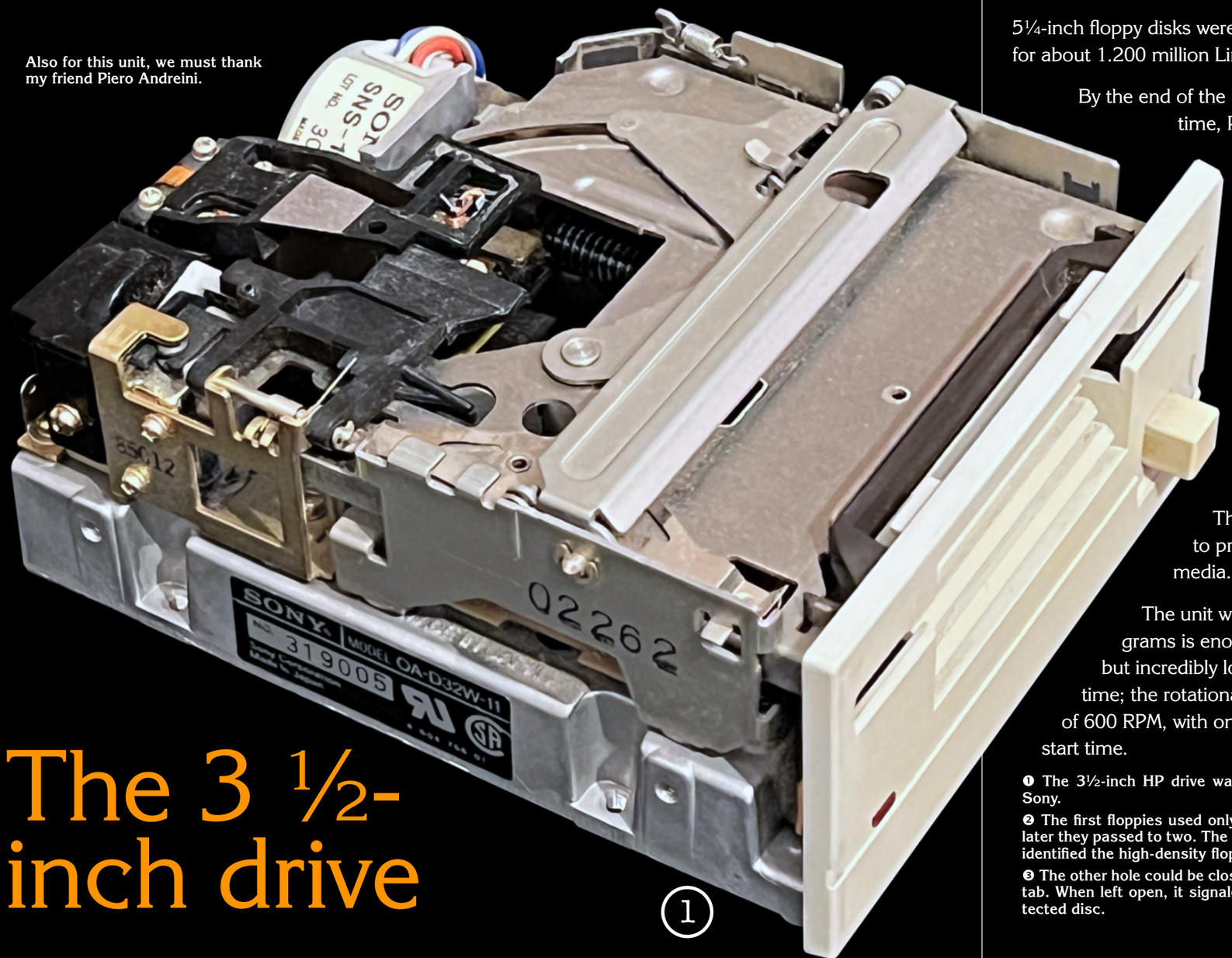
Today, we would name the HP 9121D/S as "floppy disk drive", but HP called them "Disc Memories, random access, data storage devices", probably to mark the difference with the HP-85 sequential data cassette.

Introduced in 1982, the HP 9121S contains a single 3 ½ -inch disc drive providing 270 kbytes of storage capacity, and remained in production for five years. The HP 9121D contains two 3 ½ -inch disc drives providing a total storage capacity of 540 kbytes (270 each). The HP-85 data cassette contains about 200 k, but the reliability and speed are much lower. These quantities make us laugh today; among all the thousands photos contained in my books, only five or six are small enough that could stay in one floppy disk, but at the time, a floppy disk could represent a very good media for most users, with the removability advantage. With the D model, you could also solve once for ever the copy problem. All that at a price: the dual drive unit costed $1,750, about 5,500$ today, and you had to buy also the HP-IB interface, the Mass Storage ROM and the 82936A ROM drawer, if you had "only" an HP-85 and not an HP-85B that has this ROM built-in.

The 9121, lent to me by my friend **Piero Andreini**, is interfaced through HP-IB using the AMIGO command set, with those wonderful thick cables, weighting a ton each and flexible like an iron pipe, that allow an easy interconnection of many devices, in particular instruments.

Also for this unit, we must thank my friend Piero Andreini.

# The 3 ½-inch drive




1





5¼-inch floppy disks were an absolute novelty in 1976, when I purchase a Shugart SA-400 with controller for about 1.200 million Liras; with the same money you could buy an Honda 400 motorcycle.

By the end of the 1980s, 5¼-inch disks had been superseded by 3½-inch disks, and during this time, PCs frequently came equipped with drives of both sizes. The advantages of the 3½-inch disk were its higher capacity, its smaller physical size, and its rigid case which provided better protection from dirt and other environmental risks.

The HP 3½-inch Flexible Disc was a Sony random-access drive, available in both single-and dual-head configurations. The single-head version was used in the HP 9121D/S and HP 9133 A/B/V/XV products. The dual-head drive was used in the HP 9133D/H, HP 9122D/S, HP 9114A and HP 9153A.

The first appearance of a 3½-inch floppy was 1983 HP catalog, with the 9121, which, in addition to low-cost, reliability, and speed of random access, offered the possibility to use the new smaller and more compact discs. The 3½-inch single-sided drives provided the same amount of storage capacity of the 5 ¼-inch (270 Kbytes), thanks to the increased track density: 135 tracks per inch, compared to 48 tracks per inch of older ones.

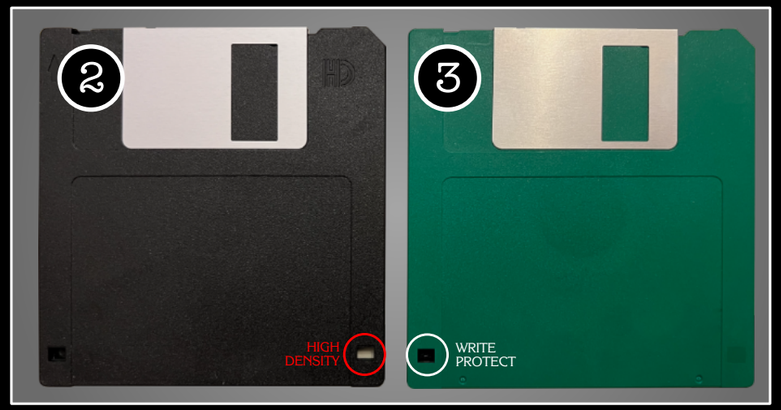
The media was finally totally enclosed in a shirt-pocket-sized, hard plastic envelope to protect it from contamination. A built-in hub reduced centering problems of the media.

The unit weight of 650 grams is enormous today but incredibly low at the time; the rotational speed was of 600 RPM, with one second of start time.

**❶ The 3½-inch HP drive was produced by Sony.**

**❷ The first floppies used only one side, but later they passed to two. The hole on the left identified the high-density floppies.**

**❸ The other hole could be closed by a sliding tab. When left open, it signaled a write-protected disc.**



# Using the 9121

A primer for new users. If you are lucky enough to own the HP-85B and the 9121 (or other discs like the 9133 that we are going to see later), you will find here a short primer, which could have saved me hours if I had it available. In addition, most of these things are good if you own another disc or the wonderful EBTKS board, that we will introduce later. In the next chapter, instead, we will go in more details on the HP-IB.

Setting it up. Each 9121, like most HP-IB device, has DIP switches that allow to setup the device address in the range 0-7. From the BASIC point of view, the second drive (the right one) is identified as the first plus one (i.e., 701, as described below).

Besides my personal problems/errors, using the 9121 with my HP-85B was straightforward: just set its address switches, and you can immediately start using the 9121 thru the 82937A HP-IB interface. I set them to 000, so I referenced the 9121 as `700`. Be sure that the DIP switch number 4 (test) is in the upper position (we will talk later of the test mode). If you have an HP-85 (non-B), you need to add the Mass Storage ROM. For bigger disks, you need also the Extended Mass Storage ROM, but we will describe that later talking about the 9133 Winchester disc.

MSUS (physical identifiers). From the HP-85 point of view, each unit is identified by the "msus" (Mass Address Unit Specifier), i.e. its **physical identifier.** If you leave the 82937A interface at the default address setting 7, the left drive is identified by "`:D700`" and the right by "`:D701`". The cassette has the "`:T`" msus.

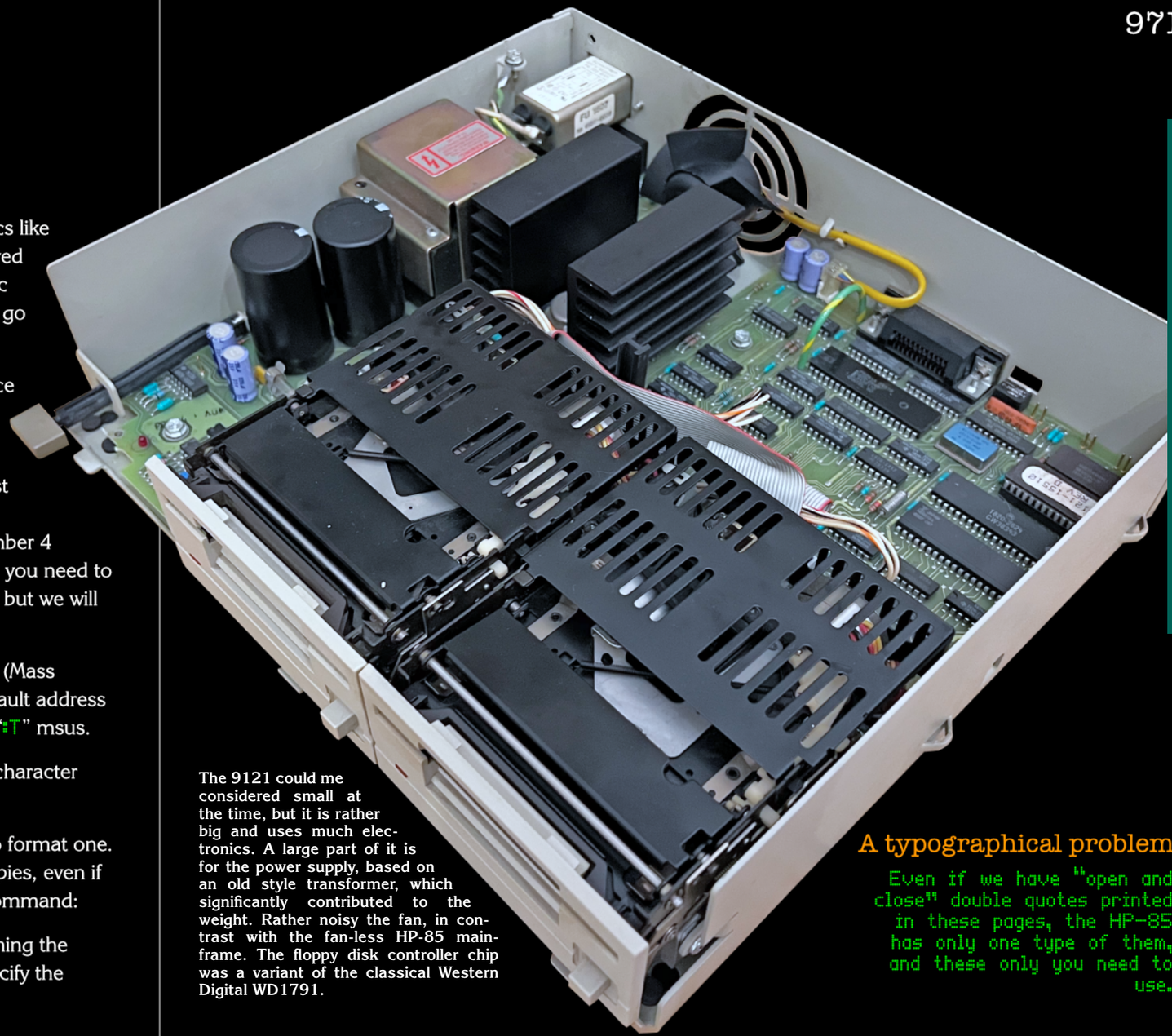
Volume labels (logical identifiers). You can assign a label of your choice to each drive, up to 6 character long. E.g. "`DRIVE0`". We see soon how to assign these names.

Formatting a floppy. Probably you don't have a floppy formatted for the 9121, and you need to format one. The 9121 is very flexible and you can use any type of floppy; my unit operates also on HD floppies, even if in theory it shouldn't (the capacity remains the same, of course). To format a floppy, use the command:

`INITIALIZE "DRIVE0", ":D701"` that also assigns the label `DRIVE0` to the drive containing the formatted floppy. You don't need to specify other, the unit knows what it need (but you can specify the







The 9121 could me considered small at the time, but it is rather big and uses much electronics. A large part of it is for the power supply, based on an old style transformer, which significantly contributed to the weight. Rather noisy the fan, in contrast with the fan-less HP-85 mainframe. The floppy disk controller chip was a variant of the classical Western Digital WD1791.

## A typographical problem

Even if we have "open and close" double quotes printed in these pages, the HP-85 has only one type of them, and these only you need to use.

interleave factor and the directory size if you want).

Assigning Volume Labels. You don't need to format a disc to assign a Volume Label. You can assign a volume label (logical identifier) to an msus (physical identifier) with the command:

```
VOLUME ":D701" IS "MYCAT"
```

You can go back and forth between msuses and Volume Labels with the functions `VOL$(":D701")` and `MSUS$(".DRIVE1")`. Note that the VOLUME command doesn't operate with the cassette, reducing drastically the usability of the volume labels.

Saving your program. You can save your program with either command:

```
STORE "MYNAME.DRIVE0"  (volume label, logical drive identifier) or
STORE "MYNAME:D701"    (msus, physical drive identifier)
```

The same for loading them, with the `LOAD` command.

Listing the directory (drive content). You can see the floppy directory with the command `CAT ":D701"` or `CAT ".DRIVE0"` (note the "." dot). Again, you can choose the physical or the logical identifier.

File identifiers. Each file is identified by the name, that can be 6 character long on the cassette and 10 on the floppy. If you have more storage devices, you must tell the computer where is the file you wish to reference. That is done adding the msus in tail or the Volume Label, like follows:

```
LOAD "MYFILE:T"
STORE "MYFILE:D701"
STORE "MYFILE.DRIVE0"
```

When you use the Volume Label, you need to add the dot.

The MASS STORAGE. To avoid adding every time the location to the file name, you can define the current (default) drive, with the command:

```
MASS STORAGE IS ".DRIVE0"
```

Or, again, with the msus:

```
MASS STORAGE IS ":D701"
```



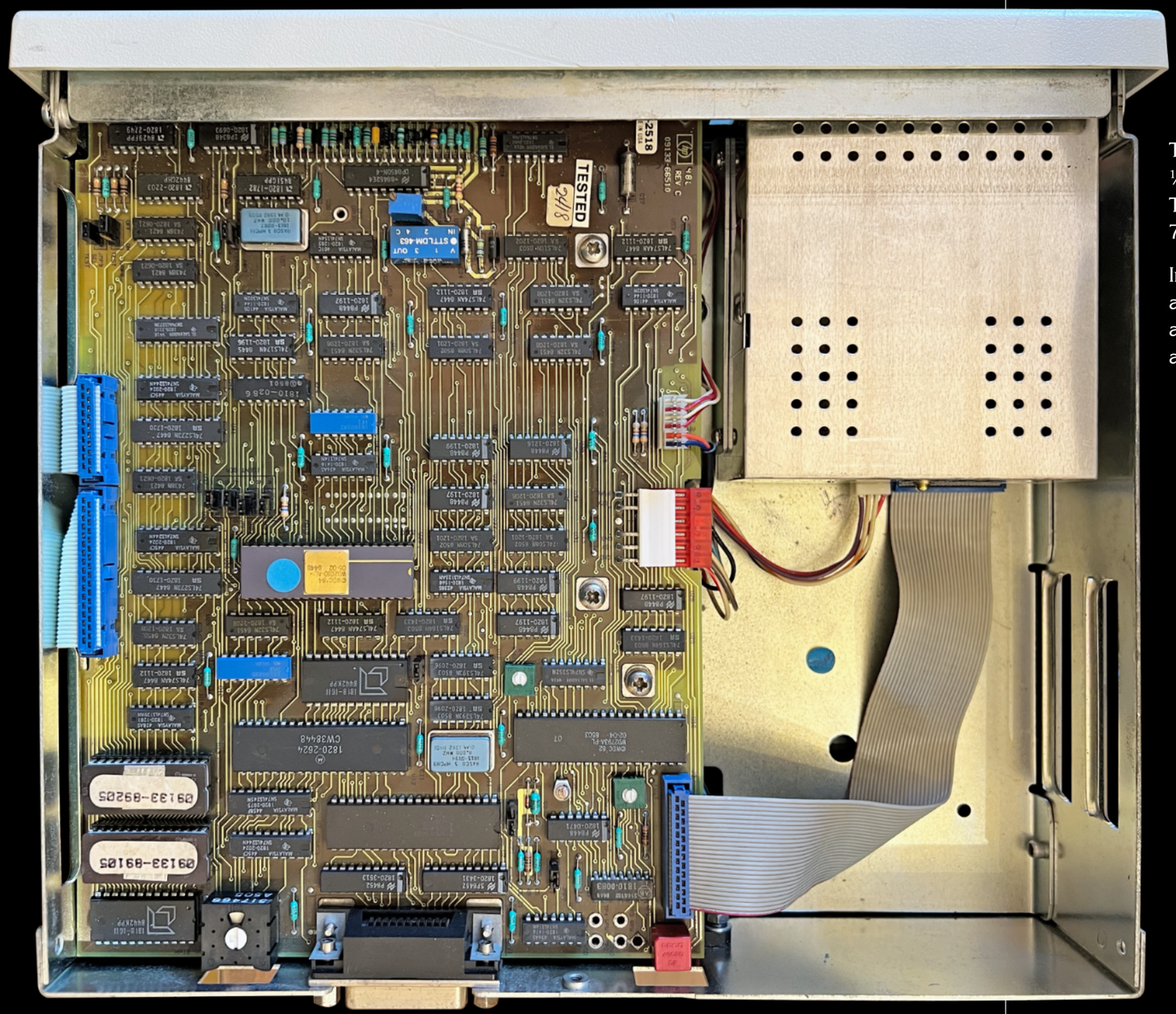
For example, in this way you can use the `CAT` command without any argument. `MASS STORAGE` can be shortened in `MSI`.

An electronic drive. The HP-85B has a 16 k, electronic drive that is automatically created at power-up. It can be accessed with the `:D700` msus or `.ED` Volume Label. It is moderately useful, because when you switch the computer off (or when the programs hangs) the content is lost, but can be used for some temporary purposes.

Ready, set, GO! With this little information, you can start quickly using your HP-85 and agreeing with me that it is a very rough machine, and thus a very fascinating one.



# The 9133 drive




The HP 9133/34DH and L products are random access data storage devices containing a 5 ¼-inch Winchester drive providing 15, 20 and 40 Mbytes of storage capacity respectively. The HP 9133 also has a 3 ½-inch Flexible Disc Drive with a maximum storage capacity of 710 Kbytes. This unit also is part of the Piero Andreini's wide old computer collection.

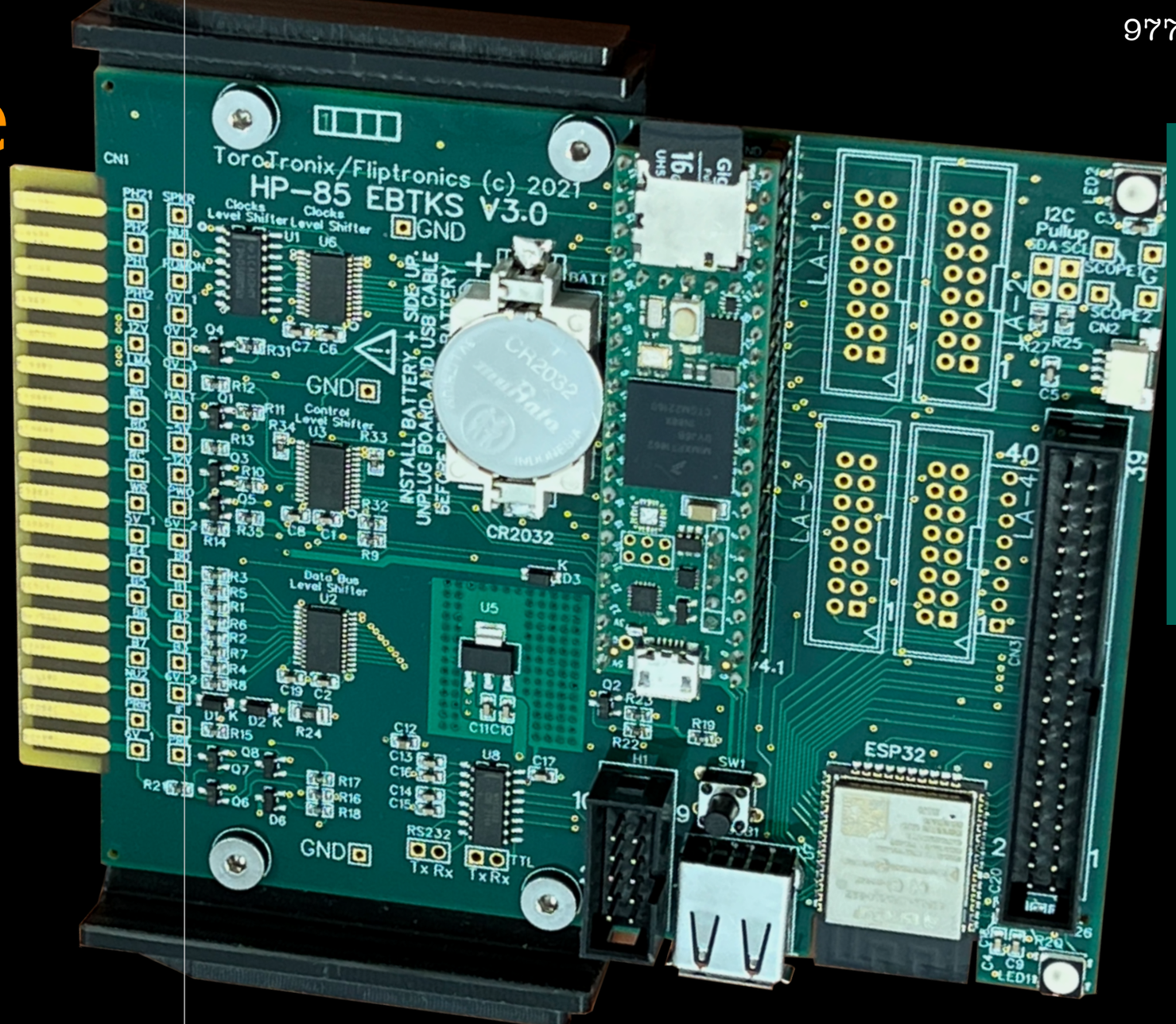
Initially, I could not use it, because I didn't have the Extended Mass Storage ROM. When I added it, thanks to the EBTKS board, I could see and format it. It took about 20 minutes and resulted in about 58,000 256-byte blocks. I used the "zero" configuration and the "2" address (that means that you see it as :D720 (not 702), while the floppy is :D721).



# EBTKS board, the HP-85 Nirvana

Finding a working disc drive for the HP-85 is not easy and very expensive. But today there is an alternative, which, furthermore, fixes for ever the cassette problem: the marvelous EBTKS board, which does a lot of things:

- Tape drive emulation, using the 16 GB SD card to store Tape images. Theoretically the SD card could hold about 200,000 tape images. To use this service, the existing tape drive must be disabled by unplugging the two flat-flex cables.
- Disk drive emulation, using the 16 GB SD card to store Disk images. The number of disk images will depend on whether the emulated disk is a floppy or Winchester disk drive. We hope to support multiple disk drive types.
- RAM to fill the top 16 kB of the HP-85A.
- EDISK: up to 256 kB of Extended Memory for HP85B, and HP86/87 computers.
- All the 12 published ROMs already present on the card, plus new AUXROMs specific for the EBTKS.
- Over 70 new keywords.
- No-jumper configuration. Configuration of options (like which ROMs are active, initial tape/disk image loaded) is under control of an easily editable CONFIG.TXT file on the SD card.
- CRT. Direct access to the CRT to move cursor and read/write text
- Improved auto-start program can include multiple commands or a simple batch file.
- Only one slot. The EBTKS requires only one slot in the I/O backplane
- HELP facility (still in development)
- EBTKS Console using serial-over-USB
- An alive project. Other features are still in development.



# My EBTKS experience

Initially, I was uncertain about the EBTKS board, mostly because I didn't know it, but everyone was speaking well of it, so I decided to purchase it, also because I wanted to describe it here. I paid for it 180 USD, shipment included. Philip from Fliptronics (http://www.fliptronics.com) was very helpful during the purchase phase, the packet was sent immediately, and arrived earlier than expected. Eleven days from paying to arrival from the USA is a record in my experience. I paid about other 10 euro for custom and other 20 for some"handling" by UPS.

The board was perfectly packed and specifically configured according to my needs. It is professionally built, with the slot guides already installed.

It worked immediately after installed and perfectly, without conflicts with my many other HP-IB peripherals.

The only thing that I didn't understand was that the default MASS STORAGE is ":D300" and not ":T" (the emulated cassette), as I though, but that was good for me, who wished to keep the cassette drive running. I asked some help to Philip, who promptly answered me, and I could also re-enable the cassette drive and start working. Why the cassette? Because I repaired it and love it, even if I am not going to use it.

You could ask me why I am so dumb to enjoy all that :), but, provided that I am, I find the EBTKS the best buy to complete the HP-85, with the possibility to explore all its complexities (the EBTKS includes all the ROM and application pacs).

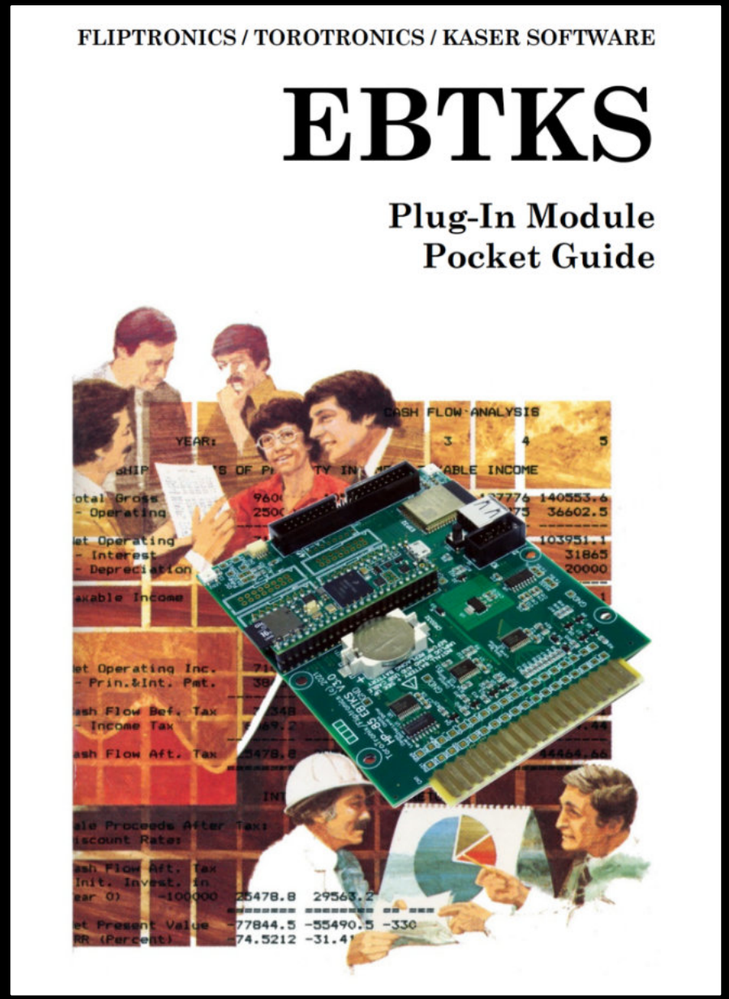
The EBTKS is a wonderful toy that ensures you the possibility of endless amusement. I had two specific expectations, which both have been fulfilled:

- the Extended Mass Storage ROM, to use the 9133 Winchester drive;
- my wish to explore the HP-85 assembly language - keep on reading.

Last but not the least, the EBTKS does not require any modification; just remove it and you have again your equipment without any loss of originality.








## A small but great sign

**This above is the EBTKS Pocket Guide. Just a bit in the immense EBTKS project, which however witnesses the great attention of the Authors to the users' needs. Even the cover graphic has been thoroughly designed in HP style!**

# The EBTKS project

The EBTKS project is an equal effort of 3 people:

Philip Freidin (California): original concept for project, and co-designer of the overall hardware and software architecture. All diagnostic functions and EBTKS side of the implementation of all the new keywords. Manufacturing, shipping, end user support.

Russel Bull (Melbourne Australia): co-designer of the overall hardware and software architecture. Most of the hard work to implement the tape and disk emulation. Implementer of the critical bus protocol emulation.

Everett Kaser (Oregon): the 70+ new keywords implemented as 32 kB of new ROMs (equivalent to the efforts of the original HP 85 design team's 32 kB of System ROMs. Extensive collaboration with Philip to fit these new ROMs into the EBTKS implementation architecture. Endless source of insights into how the Series 80 computers work at the lowest level.

The project also depended on the effort of all the people who have made the ROM and software PACs down-loadable from many sites.

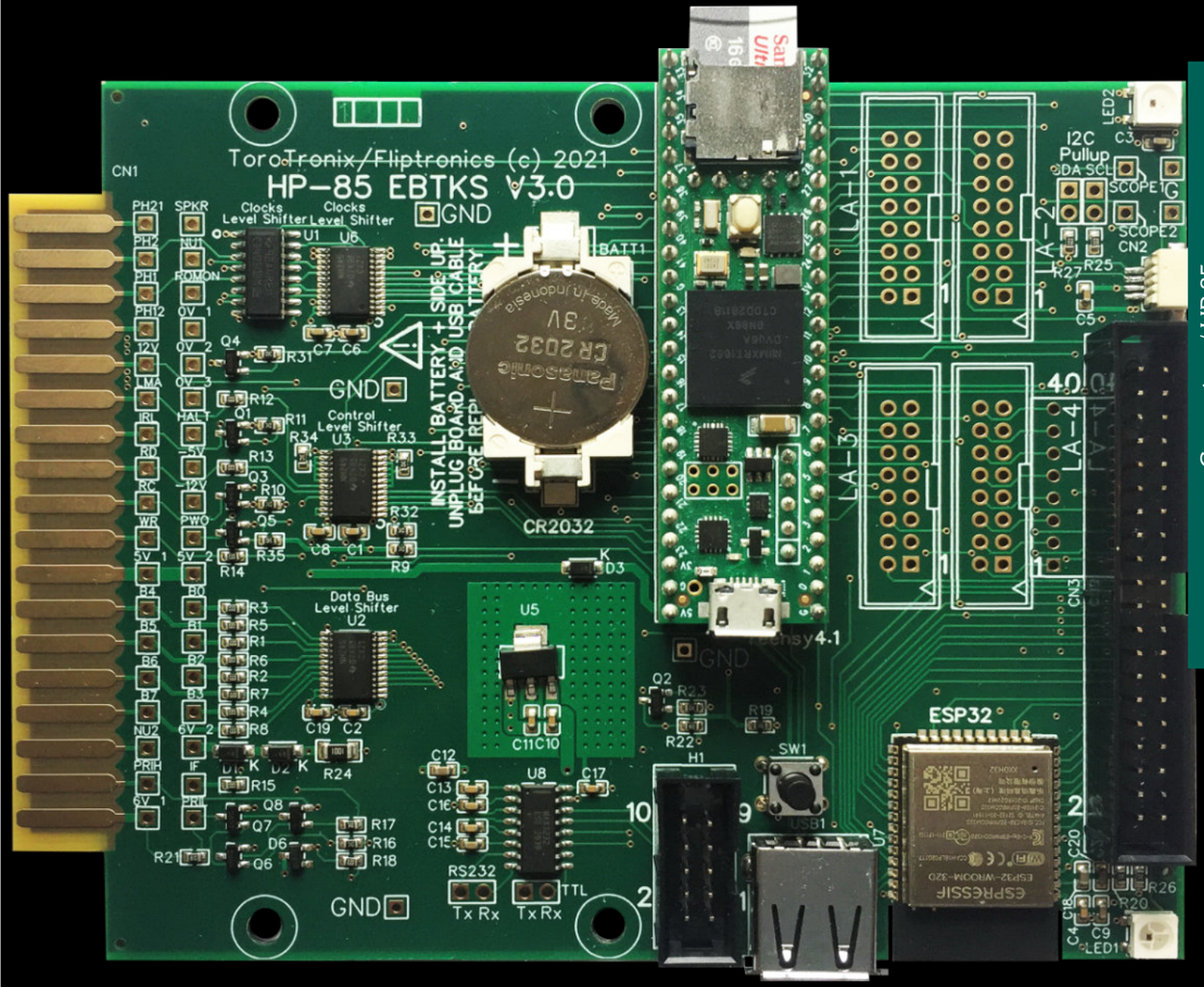
EBTKS draws upon all of these resources to create the data on the SD cards. Much of the information has been drawn from various Series-80 emulators including MAME and Everett's.

Schematics by people who had made previous add on boards, were also referenced.

The HP museum in Australia provided hardware to Russell (for the early part of the project he did not have access to any HP85), even sharing Philip's oscilloscope screen in California with Russell in Melbourne, between 9:00 pm and 5:00 AM California time.

Even for people without a Series-80 computer, Everett's Series 80 emulator was used as a test bed for the the new keywords, and as such, it emulates most of the programming environment extensions that EBTKS provides.





# The HP-85 assembler and me

As I told you, even if far in time, I have a discrete experience about BASIC ROM-based systems like the HP-85, but I was curious about the solution adopted for the assembly. For me assembling was editing a text file, passing it to the assembler program, linking, loading and debugging. How to do that on the 85? You need to study the original Assembler ROM manual, well done and not to difficult to understand. But if you want just have a taste, simply follow us below.

Writing and editing the program. I must admit that the solution adopted for the HP-85 is very simple and elegant. Having the Assembler ROM, you can switch between two operating modes with the `ASSEMBLER` and `BASIC` commands. When you are in ASSEMBLER mode, you can type-in the assembler program in the same way as a BASIC program, with line numbers and all the rest. You need only adding a leading space when you want to write a line that does not begin with a label.

Saving the program. So, when you entered your program with the HP-85 syntax, first save it like you would do with a BASIC program but use the `ASTORE` instead of the `STORE` command. Not mandatory, but you should choose a name ending with an “S” (for “source”). Also, saving the program is not mandatory, but it is prudent, should something happen during the assembly process. Example:

```
ASTORE "PIPPOS"
```

Assembling the program. Now we are ready to assemble the program simply by issuing:

```
ASSEMBLE "PIPPOB"
```

The name `PIPPOB` is a name for the assembled program, that you can choose freely; the important is that you don’t use like me the same name as the source, because the HP-85 cannot distinguish files only by their type. The final “B” stays for “binary”, but again it is not mandatory.

If you added a `LST` command in your file, the assembly process lists the assembled file on the printer. If you don’t want to end up in poverty for printer paper, you can before issue the command







```
PRINTER IS 1
```

which redirects the output to the CRT. If you own the EBTKS board, you can redirect the output to a text file on the SD using instead `PRINTER IS 310`. Possible errors are obviously signaled.

If successful, the ASSEMBLE command also load the binary program in memory.

Creating assembly programs. Besides fun, the most probable reason to use assembly is to write extensions to the HP operating system, adding new keywords. Two type of program can be written: binary programs, that are loaded and executed in RAM, or ROM programs, destined to be stored in a ROM. Writing them is slightly different, we see here only the first ones. A binary file remains resident in memory and becomes immediately operative, as explained below.

Presetting the EBTKS board. To preset the EBTKS board, switch off the 85, extract the SD module and mount it on your computer with a suitable adapter. I copied it in a safe place and edit the CONFIG.TXT file as explained in the EBTKS site. I used directly a simple text editor instead, being careful to not mismatch the file structure. Presetting the EBTKS board for using the assembly is easy, just check that the Assembler ROM is enabled (true) in the CONFIG.TXT file as follows:

```
    {
      "description": "Assembler ROM",
      "filename": "rom050",
      "enable": true
    },
```

The Assembler ROM came together a cassette and a floppy with companion files. The image of the floppy is already present in the EBTKS board, but you need to mount it, statically or dynamically. In the first case you create a “fixed” new drive with it, in the second you need to use the new MOUNT command provided by the EBTKS. I chose the first method. It’s easy.

First copy the file `/EK_Disks/disks0/85AssemblerROMdisc` to the `/disks/directory`, and name it `85AssemblerROMdisc.dsk`.

Now you need to create the new unit, with `msus$303`, after the `msus$302`, as shown below:

```
  {
    "Comment": "msus$ 302",
    "unit": 2,
    "filepath": "/disks/Floppy_scr.dsk",
    "writeProtect": false,
    "enable": true
  },
  {
    "Comment": "msus$ 303",
    "unit": 3,
    "filepath": "/disks/85AssemblerROMdisc.dsk",
    "writeProtect": false,
    "enable": true
  }
```



The green part is the old one, the orange the new. Note the added comma after the green section and no comma after.

When you reboot, you can see the new drive by typing `CAT ":D303"`. We are ready to afford our first assembly program.

The example. The example I used is the FTOC program contained in the section 6 of the manual. It adds a new function to the 85 to convert Fahrenheit degrees to Celsius, with a new function FTOC(x).

```
MASS STORAGE IS ":D303"     so we are on the companion disk
PRINTER IS 1                to don't have the listing on the printer
PURGE "FTOCB"               we want to be sure that we really reassembled it
ASSEMBLER                   switch to assembly mode
READY                       prompt message from the assembler
ALOAD "FTOCS"               load the source file
ASSEMBLE "FTOCB"            this assemble the program and leave the binary loaded in RAM
.... list is produced
READY
0 ERRORS
FTOCS(32)                   lets test...
  0                         OK, it works!
```

Using the binary program. We exploited the automatic loading in RAM of the binary program in consequence of the assembly process. The binary assembled file is however present on the disc. The Assembler ROM is necessary to create the binary program, but not to use it. If you start from scratch, or simply exit from assembler mode to BASIC, you must execute the command `LOADBIN "FTOCB"` and the new FTOC command will become available to standard BASIC programs, with no other action (see the

photo). If you like, you can insert this command in the Autost program, so that it is executed automatically at the boot.

The global file. This is not an assembly language course, neither I could be a teacher, but I have a little suggestion. Using assembler on the 85 is rather different from the old gold times when you had to do all the work by yourself, creating all of your program. Here you mostly "interconnect" a number of system functions, that are many, powerful and well described in the manual. They reside at fixed addresses in ROM, but, to avoid using directly these addresses, you use a symbolic reference. E.g., instead of using 52137 you use SUB10. On the companion disk, you can find the "global file", i.e. a file containing the definitions of these symbolic address; in this way, you don't need to redefine them in your source code. In a modern compiler you would use `#include "global"`. Here we have not the include function, but we can add a line with `GLOB GLOBAL`, with the same result. The supplied global file does not contain all the required addresses (see the box on the right). But we can easily update it as shown next.

Extending the global file. The global file is a binary file, generated compiling the `GL01S` file, as well present on the disk. Or better, because it would be too long, `GL01S` terminates with a `LNK GL02S` that links the `GL02S` file. A simple, but effective trick. So I created a third `GL03S` file (fig. ❷) with my new labels and modified the `GL02S` file to terminate with a `LNK GL03S` (fig. ❶). It is also required to move the `FIN` line, that signals the physical end of the file, from `GL02S` to `GL03S`.

To produce the new global file, just use the `ASSEMBLE "GLOBAL"` command.

**Why the GLOBAL file was not complete?**

```
.....
4280 UPCUR.  DAD 35264
4290 UPCURS  DAD 35362
4300 VAL$.   DAD 3207
4310 VAL.    DAD 3250
4320 WAIT.   DAD 65701
4330 XAXIS.  DAD 32303
4340 YAXIS.  DAD 32347
4350 YTXS    DAD 53242
4360 ZROMEM  DAD 44066
4365         LNK GL03S
```

1

```
10 !*****************************
20 !*   HP-83/85 ASSEMBLER      *
30 !*        GLOBAL FILE        *
40 !*        SECTION   3        *
50 !* (c) Hewlett-Packard Co.   *
60 !*           1980            *
70 !*****************************
80 !
90 !
100 SUB10   DAD 52137
110 MPY10   DAD 52562
120 DIV10   DAD 51644
130         FIN
```

2




## Why the GLOBAL file missed some entries?

(by Everett Kaser)

There are two reasons:

1) HP didn't want to release ALL the entry points that a programmer might want to use, because they might want/need to MOVE some of those entry points in the future, for bug fixing and revisions. In the few revisions they did (bug fixing on the 85A ROMs, and the 85B, which had significant changes to the system ROMs).

2) HP was concerned that users might damage their hardware (such as turning on the thermal print-head too long and burning it out, or turning on the tape motor and running the tapes off the end of the spool, etc.), so they intentionally limited the set of entry points and I/O definitions provided for the HP-85. They relaxed all that a little bit for the HP-87/86.

You could find a more complete globals85.txt (and globals87.txt) from the HP system development, slightly tweaked, in my CAPDIS program, available on my HP-85 page at: http://www.kaser.com/hp85.html as well as in the ASM85 package, which is available in the Groups.IO FILES section at: https://groups.io/g/hpseries80/files/Software%20-%20non-Series%2080.

There are minor differences between those two. Doing a comparison, it looks like the CAPDIS version is the better, with a few additions (brought about by disassembling ROM code :-), and corrections (NARREF was originally explained as "NOT ARRAY REF" when it really meant "NUM ARRAY REF", as in a numeric array variable reference).

# Everett's emulator

## Endless HP-85

Writing these books, I had the opportunity to describe many devices. For each of them, it is normal for me to continue adding some pages, as soon as I discover new information or news, even after having closed a topic.

But in this case, i.e., for the HP-85, this seems to me to be an endless process. Every time I think "I finished", I discover a new branch that would require a book by itself, and that fills me with new enthusiasm.

## The Everett Kaser Software HP-85 page

In this case, I am referring to the HP-85 of Everett Kaser, to his fantastic personal story and his HP-85 emulator.

## The emulator

Using the Everett's emulator, you have at your disposal a virtual HP-85, 100% similar to the real one. You can configure with the ROMs that you wish, and insert in the emulated disc or cassette drives, all the possible application packs and much more, like the games that Everett created for the 85.

What I personally found more exciting, is the possibility to run the emulator in debug mode, seeing the CPU registers, the disassembled code, through which you can step the execution. Even better than the real HP-85!




## Everett's story

A result like this seems almost impossible to most human beings, and probably it is. But Everett is the one who wrote the Assembler ROM code in HP, and thus he is for me like a football champion in the eyes of the fans. Read his story in the README.TXT file included in the emulator. It's worth it.

# Emulator's debugger

## HP-85 Assembler

After perhaps twenty five or more years I no longer program in assembler, I find extremely intriguing the possibility to learn the HP-85 assembler, with a "new" and very interesting CPU (for me…), in addition to a wonderful set of operating system functions. In my opinion, the relative easiness of adding new keywords and functions is one of the most exciting HP-85 possibilities.

When I used to write programs in Assembler, I normally had available an In Circuit Emulator (ICE), which allowed you to "see" the CPU "from inside".

The Everett's emulator includes also this function, and it is possible to stop the execution, examine the CPU registers and the memory, exactly like you could with an ICE (something like that is possible also with the real HP-85, but you need to add the System Monitor board).

## Questions & answers

I had some doubts regarding these functions, and the experts promptly answered me. I report the information I got, should it interest other people.

Question: after having loaded a bin program, how can I find its address so that I can place a breakpoint there and trace the execution?








Answer (by Martin Hepperle): you can set a breakpoint without having to know the load address of the program. Just place a

```
BYT 336   ! DEBUG BREAK
```

into your code and the emulator will break into the debugger. There you can inspect and modify memory and disassemble code (octal 336 is an undefined opcode implemented as a break in the emulator, so this will not work on the real hardware).

Answer (by Everett Kaser): in general, you can use the address at BINTAB (101233 on HP-85). You could:

- break into debug mode;
- press D to disassemble at an address;
- enter 101233;
- combine the two bytes shown at 101233;
- press D to disassemble at that address, which is the beginning of the binary program.

For example, I mounted the Game Pack 2 disk, then did:

```
LOADBIN "CATB"
```

Then, used the menu (but you could also press CTL-F8) to break into the debugger, then D at 101233 showed:

```
101233  160 322  BINTAB  RAM  02
```

That's the address, and the two bytes (lo byte, hi byte) at that address, because the built-in disassembler has been told that's a 2-byte RAM location (called BINTAB).

Those two bytes are represented in octal (because that's what the original development team used in the way-back machine), and because there are 8 bits, but octal uses three bits per digit, it's awkward to combine them. 160 322 is, reversed into MS-to-LS, 322 160, which is then in binary 11 010 010  01 110 000. If we 'smoosh' those together we get 1101001001110000, and then if we regroup, starting from the LS (right-hand) end, we get 1 101 001 001 110 000, which is 151160. That's the long way, as with just a little practice, you're just shifting the bits in the MS byte RIGHT one bit position and adding the LS shifted-out bit to the lower byte as the MS bit. E.g.:
`11 010 010` → shit right `01 101 001` (shifted out bit = `0`)
`01 110 000` → adding the shifted out bit `0` in MS position) → `001 110 000`
So the result is `01 101 001 001 110 000`, i.e., octal `151160`

The emulator CAN display the addresses in HEX (by clicking on the OCT/DEC/HEX box at the top-left of the debug display, just beneath the blue menu box). Unfortunately, that was added not too many revs ago, and the input dialogs (such as the D disassembly address) only accept OCTAL inputs.

Anyway, with that address of 151160, you can now do a D disassembly at that address, an you'll be looking at the beginning of the binary program (BPGM, “CATB” in this case) in memory. At this point, it will be just a



list of bytes. But, if you RIGHT-click on the 151160 address line in the disassembly, change the display type to ASC, you'll then see that the first 6 bytes of the BPGM is "MOUSE ". If you in the GLOBALS85.TXT file that is included with the ASM85 cross-assembler package, you'll find these defines:

```
!
!  PCB CONSTANTS
!
P.TYPE  EQU 6
P.LEN   EQU 7
P.COM   EQU 11
P.SUBR  EQU 11
P.DATL  EQU 13
P.DATA  EQU 15
P.RMEM  EQU 17
P.FCNT  EQU 21
P.GCNT  EQU 22
P.PBVL  EQU 23          ! SUB PAR PASS BY VAL
P.SFLG  EQU 25          ! SECURITY FLAGS
P.SCOD  EQU 26          ! SECURITY CODE
P.GO    EQU 30
P.FIRS  EQU 33          ! FIRST TOKEN AFTER LINE #
```

PCB means Program Control Block; more information about it in: https://groups.io/g/hpseries80/wiki/1846

Right at the top of that page is the description of an HP-85 PCB. Basic programs and binary programs BOTH have a PCB. This PCB is created automatically by the Assembler when you start with the NAM statement. The PCB is 30 (octal) bytes long, and for BPGMs, MOST of it is empty (zeroes), because BPGMs don't have/need all the stuff that Basic programs have.

So, back to the disassembly. You'll note that the byte after the 6-byte name of the BPGM has a value of 002. That's the TYPE byte (P.TYPE in GLOBALS) at offset 6 in the PCB. The TYPE byte is used bit-by-bit, and the above Wiki page shows you what they mean. In this case, TYPE 002 means it's a Binary Program. The rest of the PCB is 0's.

BUT... the NAM statement adds one more thing after the PCB: a two byte location which, when first assembled, is 0. But the LOADBIN command sets that location to the address at which the BPGM is loaded (the same as the value at BINTAB: 151160, in this example (160 322). Why? Because... BPGMs are, generally, written and assembled with RELATIVE addresses, so that the BPGM can be loaded at different locations, depending upon whether the machine has 16K or 32K of RAM, for one reason, BUT the system turns the ADDRESS TABLE (coming up) into absolute addresses when the BPGM is loaded, to make the

system run faster. If the user does a STOREBIN, those absolute addresses get stored to the file, and any future LOADBIN needs to take those into account, so it needs to know where the BPGM was last loaded, so it can adjust that address table to the new addresses (in case it's stored on a 16K and loaded on a 32K machine, or vice-versa, or any other address weirdnesses).

SO, there are
- 6 bytes of NAME
- 1 byte of TYPE
- 21 (octal) bytes of 0
- 2 bytes of loaded address
- 2 bytes of RUNTIME table ptr
- 2 bytes of ASCII table ptr
- 2 bytes of PARSE table ptr
- 2 bytes of ERROR MESSAGE table ptr
- 2 bytes of INIT ROUTINE ptr

An assembly listing of the BPGM will show the table of ptr offsets and everything after it, but if you don't HAVE the source code, you can pick it apart using this (and other :-) knowledge.

So, again in the CATB example, if you RIGHT-click on lines at specific addresses and set them to various data types and lengths:

```
ADDRESS  TYPE  SIZE  WHAT IT IS
161160   ASC   6     program name
151166   BYT   1     type byte
151167   BSZ   21    rest of PCB
151210   DEF   2     loaded base address (same as BINTAB value)
151212   DEF   2     RUNTIM ptr
151214   DEF   2     ASCII ptr
151216   DEF   2     PARSE ptr
etc, etc, etc.
```

Once you set a disassembly type with the RIGHT-click dialog, that continues on until another address is encountered with a disassembly type.

So, once you find the line (easier with an assembly listing that shows the relative addresses), which can then be added to the BINTAB value to arrive at the absolute address, which allows you to skip most of the above,



click on the line to get the yellow 'cursor' box on that line, then press F10 to toggle a breakpoint there (see the "QUICK REFERENCE" near the start of the HELP, or the docs/readme.txt file, which is the same.)

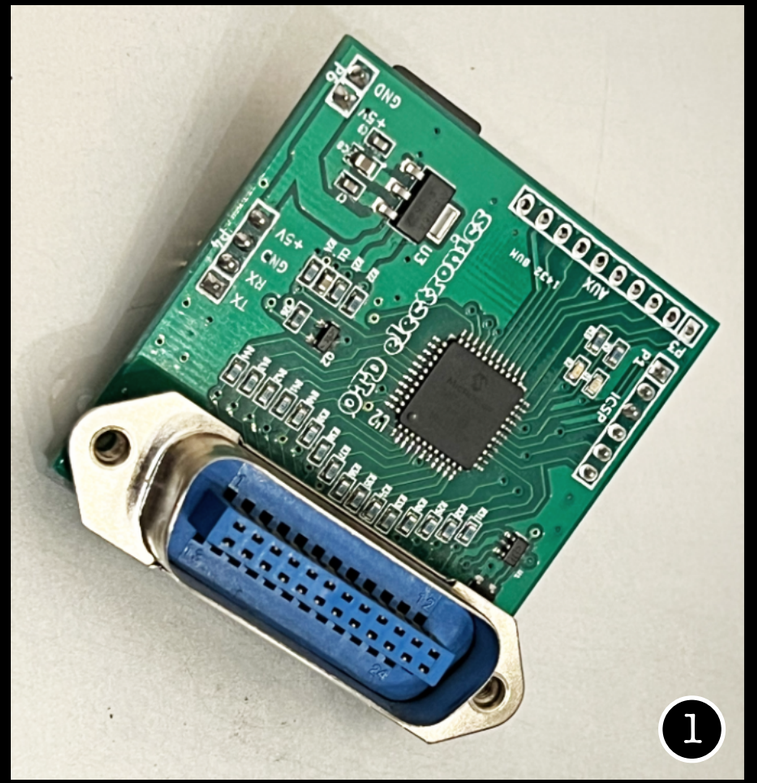
Question: is there available a cross-assembler for the 85?

Answer (by Felix): you can download Everett's cross assembler source code from

https://groups.io/g/hpseries80/files/Software%20-%20non-Series%2080/asm85.zip

Felix attached also the latest version of his variant of the source code that compiles and runs on Linux. It adds an extra feature presented in https://groups.io/g/hpseries80/topic/84871210#5675

Question: how can I remove the blue emulator menu, that covers part of the screen?



1

Answer (by Everett Kaser): sorry, no way to get rid of the menu or move the debug windows. That's another item I can add to the enhancement wish list. Meanwhile, don't run the emulator at "double-sized" (set in the EMULATOR OPTIONS dialog). Uncheck that, and then you should be able to stretch/adjust the window size so that the menu and debug displays don't overlay the HP-85's display.

## Disk emulators

❶ Recently, I discovered that there are several GP-IB disk emulators, often based on open projects. This in the photo (again thanks to Piero Andreini), is very small and very nice.

However, even if less expensive, they seems not so convenient, compared to the wonderful EBTKS, which adds a lot of other features.

# “My” HP-85

I mentioned you more times my BASIC interpreter, with which, in the first eighties, I tried to replicate, at least in part, the wonderful **HP-85**, and so I feel the need to tell you the whole story.

In the first half of the eighties, I had left the General Processor that I founded, and had a job which was more commercial- than technical-oriented. The wolf loses its fur but not its vice, we says in Italy, and I was suffering having no bytes to squeeze. So I decided to create a small project, for CQ Elettronica Italian magazine: a Z-80 computer that could replicate, on a smaller scale, the famous Apple II, Commodore, Spectrum etc. But my model remained always the HP-85. Even if later I wrote several compilers for industrial use, at the time I had no knowledge enough, and so I started up from an existing BASIC interpreter, of which I never knew who the author was, and modified it adding many functions and, above all, the drivers for the Texas TMS 9129 video display controller. The G5 project, that was its name, was published in 1983, and many enthusiasts built it, with nice results, so that the editor asked me to write also a book about it. The language was named GBASIC, not for my name, but for “graphic”.

The G5 had also a digital cassette. An important editor asked me to show it, for a possible cooperation, and I was excited for that. I went to Rome to present my toy, but the demonstration failed. I was astonished and could not understand why. Returned home, I discovered that the problem was only the dirty magnetic head. It wasn't meant to be…

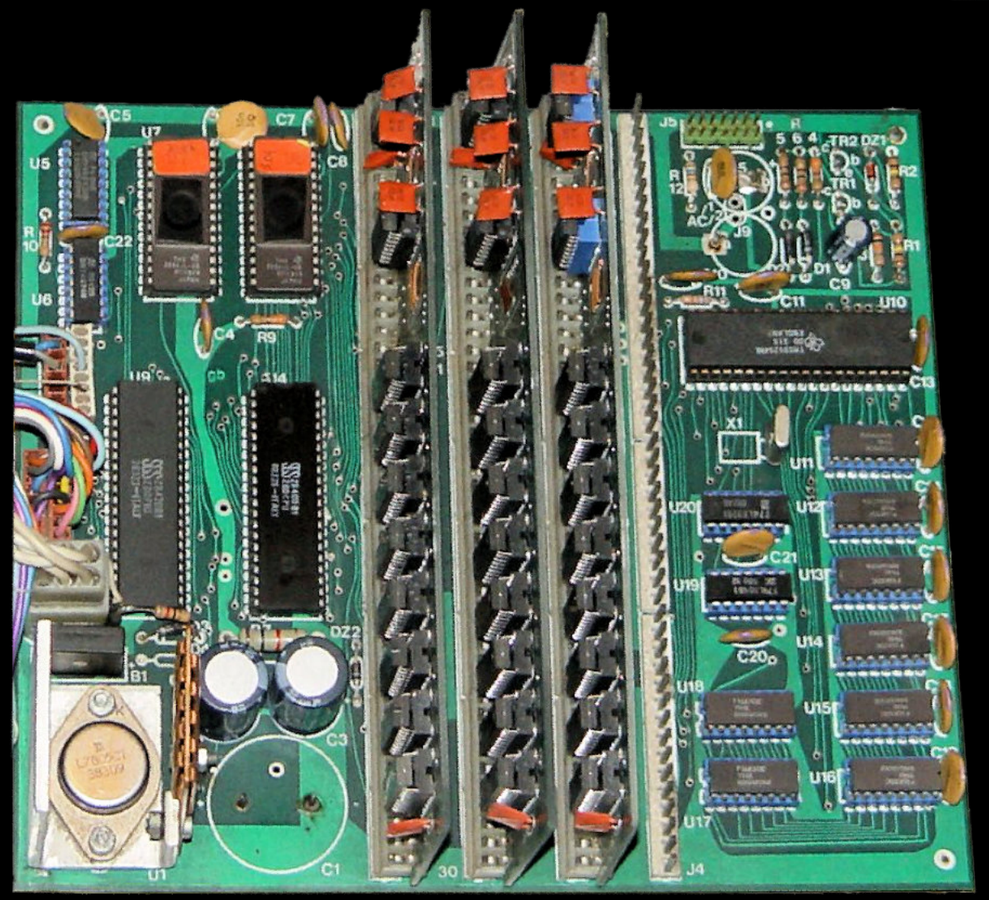
Just yesterday Piero Andreini discovered that there is a vintage computer museum where the G5 is presented, with a picture of it, that I reproduce here. The board was marked “DIGINEL”: it was not a company, but Nella was the name of my then beloved dog…

Years later, I decided to return to be a hardware and firmware designer, and started a new activity to produce projects for the electronic industry. The GBASIC was the starting point, and I designed countless boards based on it. The interpreter grew and grew, getting a lot of features, and become a small operating system, including a mini RS-485 LAN. All the source code is still available.

Based on the GBASIC experience, later I wrote the Mxm Operating System, first used by our customers, that become the base of all my current company’s products, until replaced by Linux in 2003. But that is another story…







The 1983 G5 microcomputer

Thanks to http://www.museodelcalcolatore.it/singolo.php?cod=265&ord=1

# ASM85, the cross-assembler

I believe that we HP-85 enthusiasts should have built an equestrian monument to Everett Kaser. The latest confirmation comes from the ASM85 cross-assembler, that can be run on PC, Linux and Mac and can be downloaded from GroupsIO. It is ultra-fast and with a little trick you can run it on DOS as well. Well, not under real DOS, but in a Windows 95 DOS window.

Why DOS? For me, because under it I have my favorite text editor, the Norton Commander and other stupid things that I love. With an alternative perversion, I can use ASM85 on my Mac (since some years I don't use any longer a Windows PC, but now I got myself one, mainly to run the Everett's emulator and the EPROM programmer).

Under DOS, I had to slightly change the ASM85 executable with a binary editor, to short to 8+3 characters of the `globals85.txt` file name, otherwise too long. However the ASM85 source code is available, and, if you can recompile it, you can avoid this mean trick.

From a MacOS terminal window, you need to make the ASM85 file executable (`chmod u+x ASM85`) and perhaps tell MacOS that you want to use it, even if it is not coming from a registered Mac developer. To do that, launch it from a Finder window. The Mac says "Shame on you! You cannot run an impure application in this sacred temple" (with different words, but this is the concept). Then go to Privacy & Security and you will find a button to allow ASM85 execution. After another severe interrogation, you will be allowed to execute ASM85 (even if implicitly disapproved). This is a sample run:

```
giovannibecattini@MBP-di-GIOVANNI MacOS % ./ASM85 -85 85_asm.src
10 ROM filler bytes added
0 errors
0 warnings
giovannibecattini@MBP-di-GIOVANNI MacOS %
```

Waiting for the equestrian monument, in the meantime we wish to say a big thank you to Everett!





# Mistakes

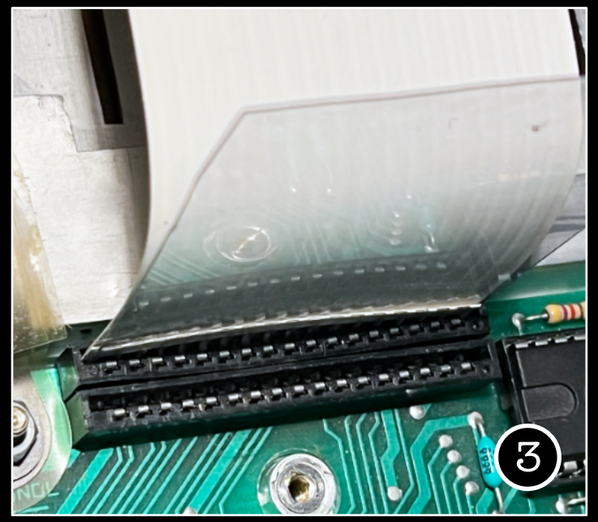
I add here a little resume of my MIMs (More Important Mistakes) which I made working on the 85.

Cassette presence sensor - the cassette presence sensor is a simple mechanical contact, that, in my case, was failing. Probably, many years ago I told it: “I will take care of you later, now I just short you”. For this mistake I lost about one day. First: I totally forgot it. Second: the jumper I made was wrong. Third: it cannot work this way. Probably there is a cross-check done by the software, which has available also the tape hole sensor. In a short: when the system boots, if the cassette sensor is active and, if there is not really a cassette inside the drive, the cassette motor starts endless and the system never arrives to command prompt level. I imagined the worst faults, but the problem is easy to fix. Reaching the sensor is very difficult, so I simply elongated it, with a micro-clip of heat shrink tube, fixed with a drop of Super Attak (photo ❹).

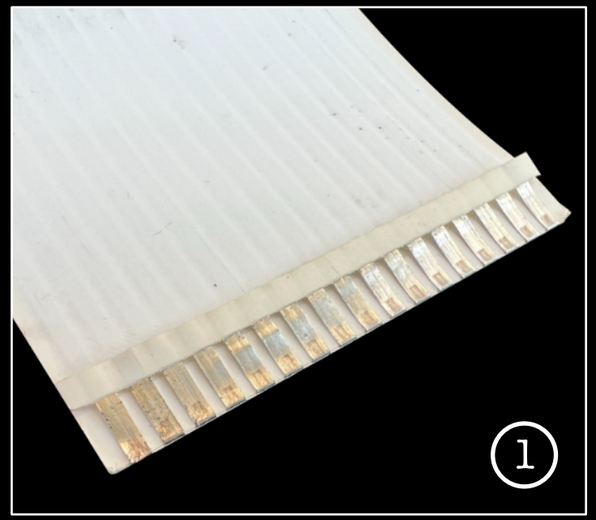
Driving the motor directly - the cassette uses a common DC motor. So I thought “I can test the capstan independently from the controller” and connected it to a 12V power supply. Yes, the motor can work this way, but the cassettes no. The drag is too strong, and in this way I broke the belts of two cassettes, a bad one and the only DC2000 I had.

Inserting the flat cables - All the modules are connected by flat cables (❶) that insert in a PCB connector (❷). Even if it seems impossible, you can insert them the wrong way if you, like me, are clever enough. Beware. Doing so, you risk serious permanent damages. Always check twice their correct alignment with the pins (no short!).

Removing the flat cables - Flat cables sometimes remains “hooked”, and, if you pull them too strong, the pins of the PCB are distorted and reversed. Luckily, I could patiently restore them without breaking them. Again, the great Curiousmarc help us with a trick. Before pulling, insert a subtle plastic shim as shown in the photo ❸, and magically the flat will get out easily.

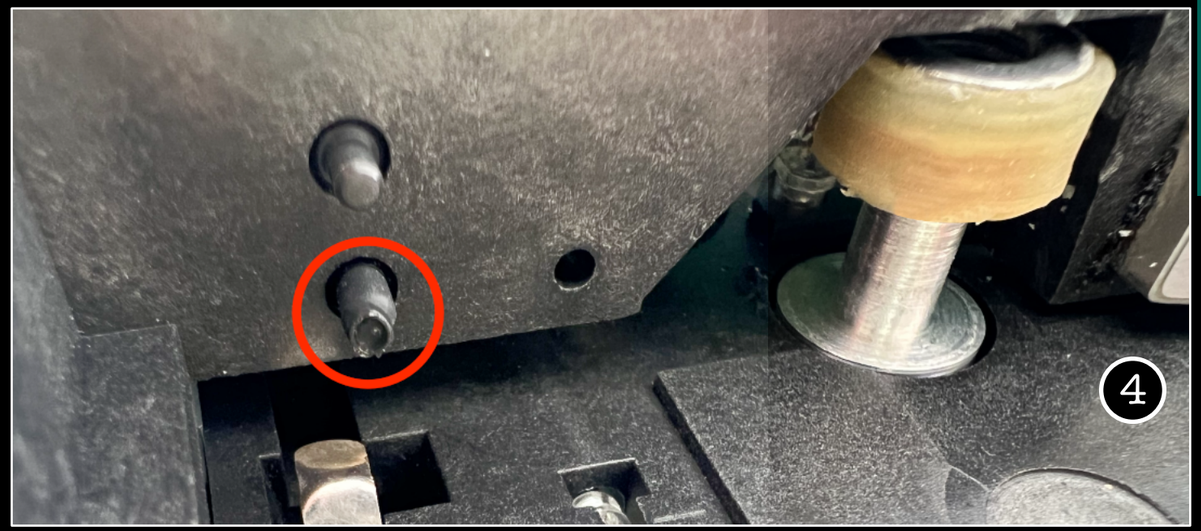











❶ The flat cable and its hated terminal strips.
❷ The connectors where the flat cables are inserted.
❸ To remove tough connectors, insert a piece of plastic that you can obtain from common packing blisters.
❹ The cassette presence sensor, with the small extension described in the text.

# Conclusions

You can love the HP-85 or not, but we must agree that it left his mark on computer history. From a certain point of view, it was already old for a large part of its life, but that is the best proof of how much it was beloved by its users, and still today we are amazed of how much a single brand was capable to offer. Today is, in my opinion, one of the most interesting pieces of that gold time.

I am very happy of owning one of them, especially now that the mythical EBTKS board allowed me to unleash all its power, being able to use all the original ROM and the countless application packs. Furthermore, it is perfectly suited to my ancient and wonderful HP instruments, that I can control by using it.

I hope that the true experts of this incredible piece of equipment will forgive me for the many mistakes or silly things I wrote here, with a great passion for this ancient computer, but with a limited knowledge.



# Thank you!

Differently from other topics, the HP-85 is an endless chapter. Every time I think I finished, I understand that there are oceans of new things to be studied and described.

My first draft of this document has been significantly improved by the friends from hpseries80@Group.IO, who patiently reviewed it and, with their suggestions, allowed me to reduce the number of silly or incomplete things I wrote. In particular, I want to mention (in alphabetical order):

- Piero Andreini, my personal friend, who made possible the HP-IB interface rapair, and wo supplied the 9121 and 9130 drives, plus the required knowledge;
- Philip Freidn, one of the authors and the frontman of the mythical EBTKS board, who, in addition, reviewed also almost all the content of this chapter;
- Gastone Garziera, one of the guys of the Olivetti Programma 101 team;
- Everett Kaser, the man of the equestrian monument;
- Randy Kindig from Floppy Days;
- Darryl Ramm who, among the many corrections, suggested me the orange color and the new Korinna font. I liked it so much that I used it also in the other books.

Thank you, guys!

# HP-IB / GP-IB

## An interface bus for all

Hewlett Packard Interface bus

Introduced by HP, the HP-IB, (aka GP-IB – General Purpose Interface Bus) has been historically the instrumentation interface bus until few years ago, and it is still in use somewhere.

# GP-IB interface bus

## What it is

GP-IB (General Purpose Interface Bus) is a short-range digital communications 8-bit parallel multi-master interface bus originally developed by Hewlett-Packard as HP-IB (Hewlett-Packard Interface Bus) and then defined as IEEE-488 standard. For brand's respect, in this book we try to use the term "HP-IB" when talking about Hewlett Packard devices and "GP-IB" for the others.

Although old and based on thick, heavy, and rigid cables that looks like water pipes, it became the standard way to talk with test instruments, even if today it is widely surpassed by other type of connections, like USB and Ethernet. Instruments are however much more long-lived than computers; many of them have this very valuable interface and are still in use, not only by us enthusiasts of classic equipment. Thus, learning and equipping to use the GP-IB makes sense and is convenient for us.



❶



❷





## A partial standard

In 1975, the IEEE standardized the HP-IB as Standard Digital Interface for Programmable Instrumentation, IEEE 488. They could not call it with the HP name, so it became the GP-IB (General Purpose Interface Bus). The standard was revised in 1987, and re-designated as IEEE 488.1. These standards formalized the mechanical, electrical, and basic protocol parameters of HP-IB, but said nothing about the format of commands or data.

In 1987, IEEE introduced Standard Codes, Formats, Protocols, and Common Commands, IEEE 488.2, that provided for basic syntax and format conventions, as well as device-independent commands, data structures, error protocols, and the like. While IEEE 488.1 defined the hardware and IEEE 488.2 defined the protocol, there was still no standard for instrument-specific commands. Commands to control the same class of instruments, e.g., multimeters, varied between manufacturers and even models. The United States Air Force, and later Hewlett-Packard, recognized this as a problem, and then invented new standards (TML, SCPI etc.), but that all happened years later (mostly from Wikipedia).

So, "our" HP-IB sets a standard for communication, but not for the command semantic. So, every instruments has its own command set.

## How does it work

The HP-IB parallel bus employs 24 wired connections (16 signals and 8 grounds) and this explains the fat cables. They connect up to 31 devices numbered from 0 to 30. However, the maximum number of devices on the same physical bus is 15, and its length is maximum 20 meters.

That means that you must in some way set or know the address of the instrument you want to use.

Control and data transfer functions are logically separated; a controller can address one device as a talker and one or more devices as listeners without having to participate in the data transfer. It is possible for multiple controllers to share the same bus, but only one can be the "Controller In Charge" at a time.

The maximum data rate is about one megabyte per second. The slowest participating device determines the speed of the bus [most information is taken from Wikipedia].

❶ The SD Prologix GP-IB / USB interface costs about 300 euros. We see later possible, less-expensive alternatives.

❷ The typical HP-IB 24-pin pass-thru connectors can easily be stacked. Despite their complexity and weight, you can find these cables on Amazon for 18 euros with one day delivery.

# GP-IB interfaces

## Using the Prologix USB interface

I started my experiments with HP-IB using a Prologix USB interface, just because I had it.

The driver. To use the Prologic USB interface, you need a driver for your computer that allows to see it like a serial port (the Prologix uses a FD245 USB/serial chip). Go on https://github.com/gotmc/prologix and follow the instructions.

For Mac OS, open a terminal window and enter “brew install ftdi-vcp-driver --cask” (if you don’t have brew, go on https://brew.sh).

The terminal emulator. Now you just need a serial terminal emulator and you can start communicating with the Prologix interface. I use the free SerialTools for Mac.

Testing it. To see if it is working, you can try commands like **++ver** or **++help**, that are directed to the interface and not to the bus. To talk with the instrument, you must first set the instrument and inform the interface of the device you want to talk with, using the **++addr n** command, where n is the device number (the default address for the 8568B is 18). Then you can try to hide and show the graticule on the CRT with the commands **KSm** and **KSn**, or those already seen on the previous pages.

## Alternatives

There are several open-source projects on the Internet to build an inexpensive interface, alternative to the Prologix, which costs about 300 euros, much less than some professional interfaces, but rather expensive IMHO.

These project are based on popular, low-cost microcontroller boards. I wanted to try one of them and chose Agipibi, is a cheap GP-IB interface based on the Arduino Mega board or higher models. You can find it here: https://github.com/Twilight-Logic/AR488/tree/master. The authors are Thibault Vincent and Mathias Helsen. The main features are:

- system controller role;
- act as talker or listener in full address space;
- multiple concurrent listeners;



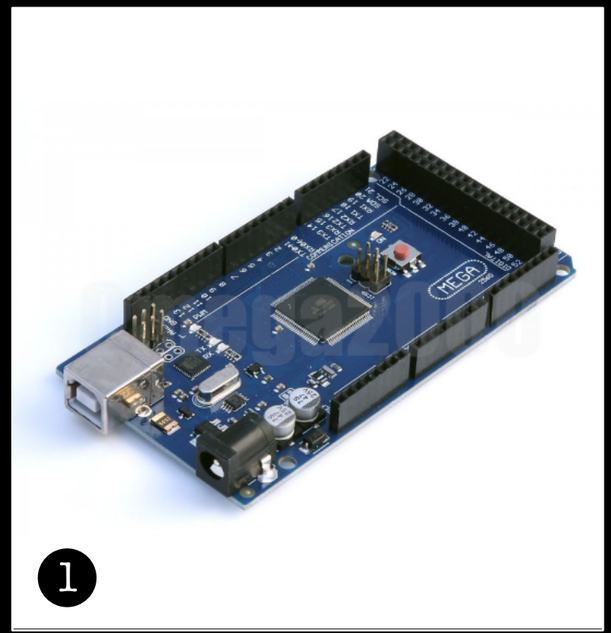
- switch instruments to remote mode;
- (un)lock front panels;
- fast reading (Arduino is buffering chunks of data);
- group trigger;
- timeout handling when reading bus;
- Python examples for the Tektronix 2432 oscilloscope (and thus 2430A, 2431L and 2440).

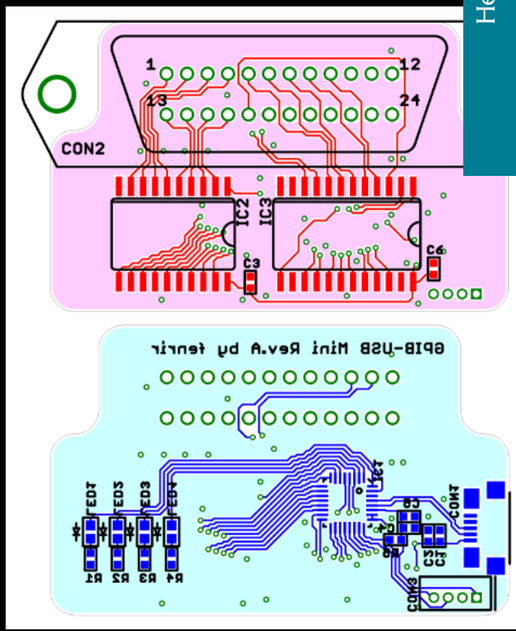
New features are still under development, such as:

- SRQ request interruption and serial polling;
- more examples for Tektronix scopes;
- bridge to LabVIEW with a Python script (TCP server).

I tried to build one, without using line drivers for the cable, as they suggest when you don’t have long connection lines, and the results were good. The total cost was 25 euros for the board and 18 for the GP-IB, both from Amazon.

**❶ The Arduino Mega board. ❷ Another nice project for a Prologix like interface (https://github.com/hugen79/gpib-usbcdc/tree/master)**



# The HP-85 as a controller



## An alternative

The Prologix or the Arduino-based solutions were or too modern or expensive for me, so I decided to switch to use my beloved HP-85 computer as a controller.

Let's see some examples using the HP-IB with the HP-85. We already spoke about this old computer, its limits and its wonders. Now let's see a practical use of it, still relevant today, if you want a quick and dirty way to interact with your instruments, without having to learn a lot about modern programming, which leads you to use billions of instructions to do what you can do with a small BASIC program.

## Nothing to configure

A beautiful feature of the 85 is also that there is nothing to install nor configure. I just inserted the 82937A board, leaving its address to default (7) and connected it to an instrument, leaving it at its default address. Nothing more.

In this way, I could immediately start sending commands and reading answers.

You can issue commands directly from the keyboard or create a little program like in the examples that follow.

**Even if using that small screen seems awkward, when you get used to the HP-85, it becomes even pleasant, also for its splendid keyboard of a today forgotten, but very practical, mechanical type.**

## HP-856x spectrum analyser

Let's see how to write a simple program to control an 856x Spectrum Analyzer (SA) and read a waveform from it. Let's see then our sample program.

```
10 DIM A$(1000)
15 ! SET CENTER FREQ AND SPAN
20 OUTPUT 718; "CF20MHZ;SP1MZ"
25 ! SINGLE SWEEP; TAKE A SWEEP
26 ! SET FORMAT, GET TRACE
30 OUTPUT 718; "S2;TS;O3;TA"
35 ! READ THE 1000 SAMPLES
40 FOR N=0 TO 999
50 ENTER 718; A(N)
60 NEXT N
70 END
```

We first OUTPUT a string to device 18; the initial 7 is the address of the interface board times 100, because you could have more HP-IB interfaces. For us, it is always 700. The string contains two commands: CF set the center frequency to 20 MHz and SP set the span to 1 MHz. Very simple and straightforward. On statement 30 we send again another string with four commands:

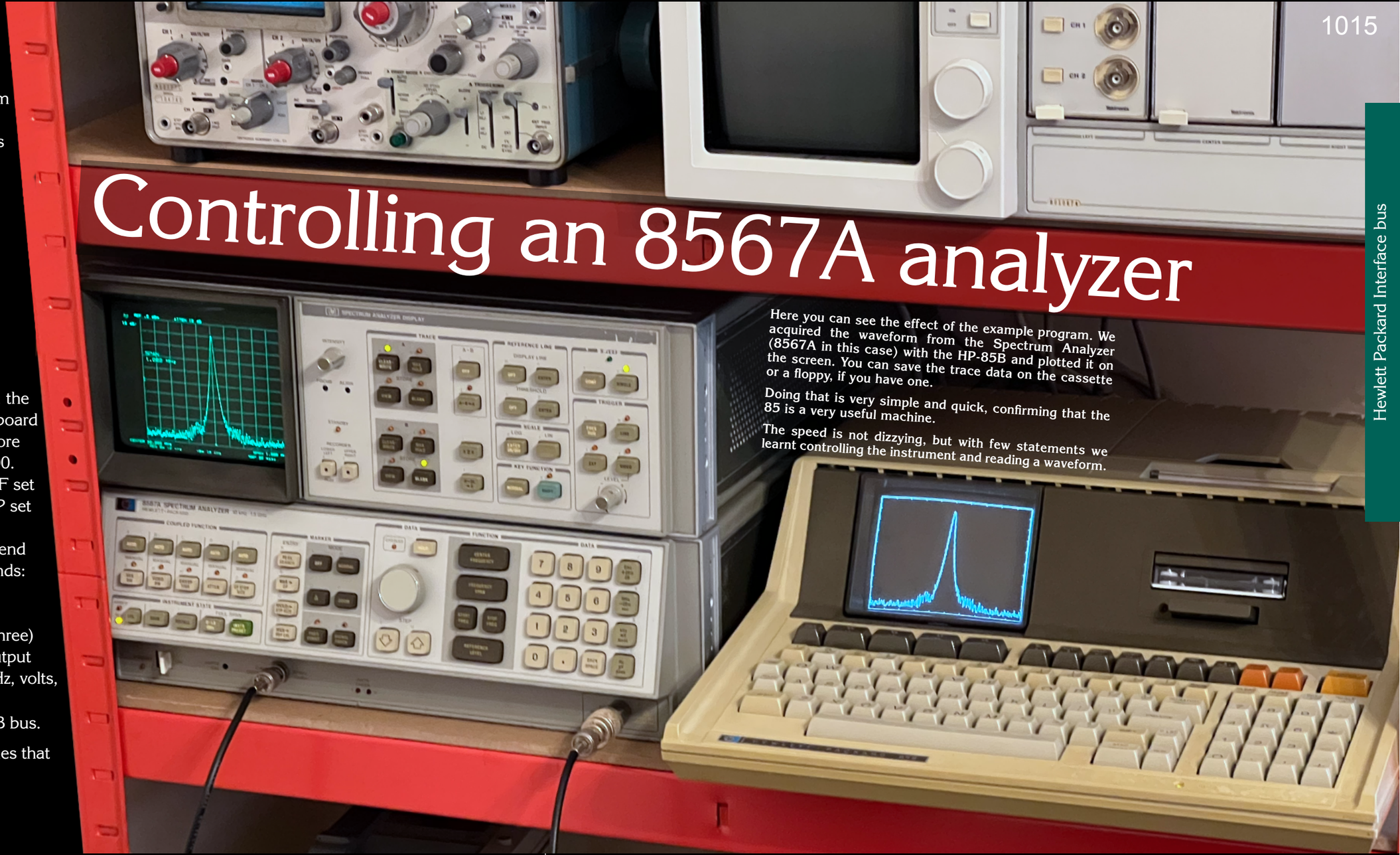
- S2, sets the SA for single sweep;
- TS, takes a sweep of the wave;
- O3 ("o" like "Operation", not zero three) sets the output format. It selects output format as real numbers (ASCII) in Hz, volts, dBm, or seconds;
- TA, output trace A toward the HP-IB bus.

The 40-50-60 loop gets the 1,000 values that compose the trace.





# Controlling an 8567A analyzer



Here you can see the effect of the example program. We acquired the waveform from the Spectrum Analyzer (8567A in this case) with the HP-85B and plotted it on the screen. You can save the trace data on the cassette or a floppy, if you have one.

Doing that is very simple and quick, confirming that the 85 is a very useful machine.

The speed is not dizzying, but with few statements we learnt controlling the instrument and reading a waveform.

## Plotting the waveform

Having the trace data in the A$ array, is not difficult to create a plot with it, like in this simple example.

```
240 ! PLOT THE TRACE IN GRAPHIC MODE
250 GCLEAR
260 SCALE 0,1000,-100,0     ! SCALE AXES
270 PENUP
380 XAXIS 0,100             ! DRAW THE FRAME
390 XAXIS -100,100
400 YAXIS 0,10
410 YAXIS 1000,10
420 FOR N=0 TO 999          ! DRAW THE TRACE
430 PLOT N,A(N)
440 NEXT N
```








The GP-IB connectors are “bi-fronted”; one side is a male and the other a female. In this way they can be easily “stacked”, connecting the various peripherals like water pipes (even from the physical point of view, so big and rigid the cables are….).

The screws are not very practical and underlying ones often turn when they shouldn’t.

If the screws are black colored, the thread is in millimeters, otherwise in inches.

# Read a waveform from a Tek 2440

I found it less easy to read the Tektronix 2440 oscilloscope, but eventually I succeeded, and you can see the resulting program on the right.

The 2440 accepts commands to select the mode: **ASCII** (`DAT ENC:ASCII`) or **binary** (`DAT ENC:RPBINARY`).

Fearing that the 85 strings could not contain any possible character (like in C language, where zero is considered the string terminator), I started trying to read the waveform in ASCII format.

```
10 DIM A$[1200]
20 DIM N(1100)
30 OUTPUT 704 ;"DAT ENC:
RPBINARY"
40 OUTPUT 704 ;"DAT SOURCE:CH1"
50 OUTPUT 704 ;"CURV?"
60 ENTER 704 ; A$
70 GOSUB 120
75 SCALE 1,1024,0,255
76 GCLEAR
77 PENUP
80 FOR I=1 TO L
90 PLOT I,N(I)
100 NEXT I
110 STOP
120 ! DISPLAY BUFFER
130 H=NUM(A$[8,8])*256
140 L=NUM(A$[9,9])+H-1 @ ! -1
FOR CHECKSUM
150 ! DISP "BUFFER LEN=";L
160 FOR I=1 TO L
170 ! DISP NUM(A$[10+I,10+I]);
180 N(I)=NUM(A$[10+I,10+I])
190 NEXT I
200 RETURN
210 END
```

## ASCII mode

I could not find a way to get the waveform **value after value**, like I did with the 856x. I could get only a single string with 1000+ values inside, comma-separated. On the next page, you can see the 2440 formats (table ❶); for example, in return to the `CURV?` command, you could get in `A$`:

```
CURVE
```

The string must be long enough to keep the 1024 values which compose the waveform. I set the length to 6000. If it is too short, the ENTER command stops when it should.

There is no specific function in 80-BASIC like the sscanf of C to retrieve each single value from the read string; you can build a suitable function, but I preferred to try the binary mode, which promises also to be faster.





## Binary mode

In binary mode, things went better, and I could happily understand that the 80-BASIC allows to have **any binary value** inside a string, that behaves so like a generic memory buffer. Reading the oscilloscope answer was even easier than expected. Just issue the `CURV?` command and read `A$`, i.e., the reply. Clearly, the string must be long enough to receive all the values (in this case 1000 + something, I set 1200). **Notice** that as default in the HP-85 the first element of an array or string is 1, not 0.

The 80-BASIC, allows you to use only a portion of a string content: `A$[X,Y]` returns the string bytes from x to y. If x is equal y, you can peek every byte in the string.

Table ❷ on the front page presents the 2440 binary format (**notice** that some editions of the manual **wrongly** say that this is ASCII format – I am sure of this, because I used that in this table).

Knowing the 2440 returned binary string format, it becomes easy to read the waveform, as shown in the small program reported on the previous page where you can see also the read waveform on the 85's screen. It seems to be "longer" than the one on the oscilloscope's CRT, because the buffer is longer than the displayed portion.

| Byte | ASCII | Decimal | EOI (1 = asserted) |
|---|---|---|---|
| 1 | C | 67 | 0 |
| 2 | U | 85 | 0 |
| 3 | R | 82 | 0 |
| 4 | V | 86 | 0 |
| 5 | E | 69 | 0 |
| 6 | <SP> | 32 | 0 |
| 7 | 3 | 51 | 0 |
| 8 | 5 | 53 | 0 |
| 9 | , | 44 | 0 |
| 10 | 5 | 53 | 0 |
| 11 | 4 | 52 | 0 |
| 12 | , | 44 | 0 |
| XXXX | , | 44 | 0 |
| XXXX | 4 | 52 | 0 |
| XXXX | 1 | 49 | 1 (Only if term = EOI) |
| XXXX | <CR> | 13 | 0 (If term = LF/EOI) |
| XXXX | <LF> | 10 | 1 (If term = LF/EOI) |

① 2440 ASCII format

## How could it work?

However, I was not completely happy with the result, because **I could not understand** how it could work. How can the HP-85 stop reading the string, when each character can have any value?

The point is that I mixed a piece of the picture. The **EOI** is not (only) a character (like LF or CR/LF), but is signaled also by **a wire in the interface** (see the tables here). So, in binary mode, there is not a terminator character, and all the bytes are read until the EOI line assertion.



| Byte | ASCII | Decimal | Hex | EOI (1 = asserted) |
|---|---|---|---|---|
| 1 | C | 67 | 43 | 0 |
| 2 | U | 85 | 55 | 0 |
| 3 | R | 82 | 52 | 0 |
| 4 | V | 86 | 56 | 0 |
| 5 | E | 69 | 45 | 0 |
| 6 | <SP> | 32 | 20 | 0 |
| 7 | % | 37 | 25 | 0 |
| 8 | <Bin Count MSB> | 4 | 04 | 0 |
| 9 | <Bin Count LSB> | 1 | 01 | 0 |
| 10 | 5 | 53 | 35 | 0 |
| 11 | T | 84 | 54 | 0 |
| | | ... | | |
| | | ... more waveform data | | |
| | | ... | | |
| 1033 | A | 65 | 41 | 0 |
| 1034 | <Checksum> | XX | XX | 1 (Only if term = EOI) |
| 1035 | <CR> | 13 | 0D | 0 (If term = LF/EOI) |
| 1036 | <LF> | 10 | 0A | 1 (If term = LF/EOI) |

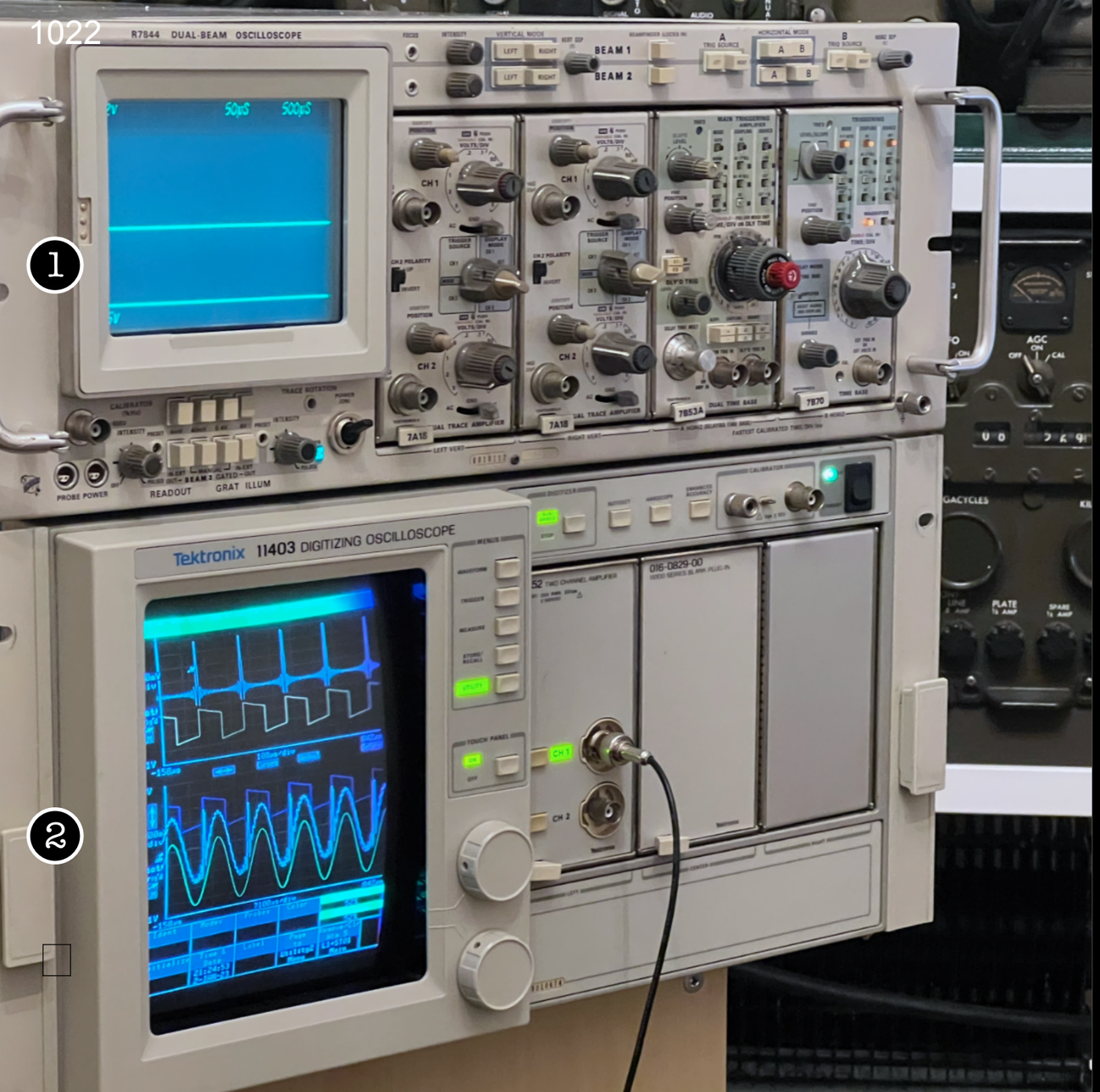
② 2440 binary format

## Different logics

Another point that I had to understand is that **every instruments** has **its own logic**. So, for example, the HP8567A must be "entered" for each byte of the waveform, by using the `ENTER` command more times, while the Tek 2440 wants that you use just one `ENTER` command. Probably both can be set differently, but as default they work in this way and I could not find a way to change this behavior (honestly, I didn't seek it).

**❶ Tektronix 2440 ASCII format for the CURVE? command.**
**❷ Tektronix 2440 binary format for the CURVE? command. Note that on some manuals, it is wrongly labeled as ASCII example 2.**








# Tektronix 11403

The Tektronix 11403 is one of the first digital storage oscilloscopes, described in one of my other books. Among its features, a large set of GP-IB commands (usable also via its RS-232 interface).

After having written the small program for the 2440, I thought that it could good also for the 11403, but I had soon to change my mind. Everything is similar, if you want, but completely different in essence.

First, the 11403 has a larger buffer, and the trace values are represented in 10-bit, instead of 8-. But also the commands are different, as shown in this small BASIC fragment. In few words: if you want to use the GP-IB, you must thoroughly study the manual of each instrument.

```
  5 ! A SIMPLE PROGRAM TO ISSUE SOME COMMANDS TO THE 11403
 10 DIM A$[100] ! ENOUGH TO TEST SOME COMMANDS
 20 OUTPUT 704; "UID?" ! ASK THE MAINFRAME/PLUG-INS SERIAL NUMBER
 30 ENTER 704; A$
 35 DISP "S/N="; A$
 40 OUTPUT 704; "POW?" ! GET HOW MANY POWER-ON HOURS
 50 ENTER 704; A$
 60 DISP "HOURS="; A$
 80 OUTPUT 704; "DATE?" ! FROM THE 11403 RTC
 90 ENTER 704; A$
100 DISP "DATE="; A$
120 OUTPUT 704; "WAVFRM:ASCII" ! SET ANSWERS IN ASCII FORMAT
130 OUTPUT 704; "CURVE?" ! ASK THE WAVEFORM
140 ENTER 704; A$
150 DISP A$ ! SHOW THE FIRST CHARACTERS OF THE WAVEFORM
160 END
```

❶ A Tektronix R7844 dual beam, analog oscilloscope from the seventies.
❷ The 11403 oscilloscope is one of the first Tektronix DSOs. It was the most advanced Tektronix oscilloscopes in 1986. It had a limited sampling rate (500 kSa/s), but a color display, the touch screen and an extended set of GP-IB commands, usable also via the RS-232 interface, included in the base configuration.

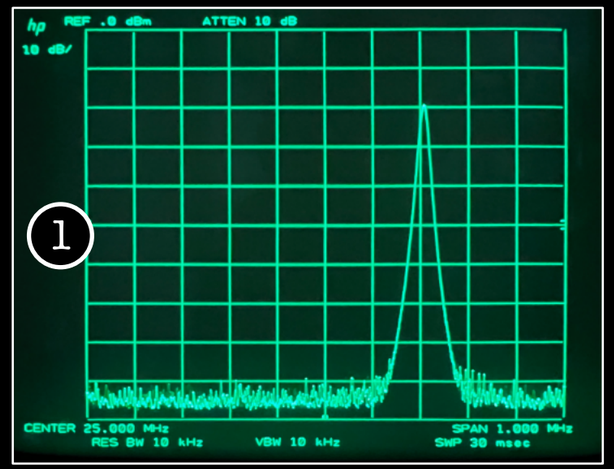
# Stored programs

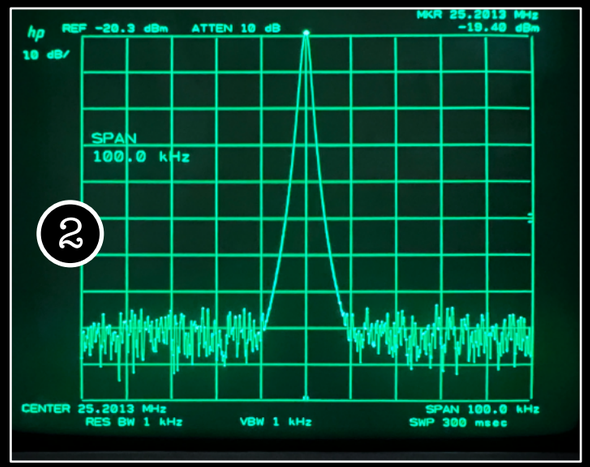
Let's return to the Hewlett Packard 856x spectrum analyzers. In addition to the direct execution of GP-IB commands, they furthermore allow to store programs inside the unit itself, and to recall them with a softkey. A complete programming language, with statements like REPEAT and UNTIL, is implemented in the instrument. It was a good idea: when fixed functions were required, they could be stored, without needing anymore a dedicated computer.

In theory, you can create them by the front panel, but this is definitely unpractical; a computer like the HP-85 can be used to create, store and edit the program, and to download it into the instrument.

This simple program finds the highest signal on the screen and zooms on it. To recall, just press SHIFT, 6, Hz. In the picture, the effects of the Z_ZOOM function.

```
10 OUTPUT 718; "FUNCDEF Z_ZOOM,@;"
15 ! SET MARKER ON THE HIGHEST, KEEP IT ON CENTER
20 OUTPUT 718; "MKPK HI;MKTRACK ON;"
25 ! SET SPAN, MOVE MARKER AT REF LEVEL
30 OUTPUT 718; "SP100KZ;TS;MKRL;"
40 OUTPUT 718; "@;"                    ! END OF THE FUNCTION
50 OUTPUT 718; "KEYDEF 6, Z_ZOOM;"     ! ASSIGN TO KEY 6
60 END
```






At first sight, this program is very similar to the other examples that we saw before, but the FUNCDEF command in line 10 specifies that the command must be stored, not executed. By the way, line 30 says also that @ will be used to close the function, i.e., to close the store mode. This closing is performed by statement 40. Line 50 associates this function to the 6 key.

**❶ Let's use the Z_ZOOM function to zoom on the highest peak on the CRT. Simply press SHIFT, then the assigned key (the key 6 in this case). ❷ Here we have pressed SHIFT, 6, Hz: the highest peak is centered and reported to the reference level. In this photo, you can see the SHIFT, the 6, and the Hz 6 keys. Note that every key has a letter associated. In theory you could use them to write your program directly on the analyzer, but that seems more a punishment than a possible job.**

