The HP-01

Repair Kit

Bernhard Emese , Dec. 2016, Rev. 1.10

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HP-01 Manual Revisions

Rev 1.00 July 1st 2016 initial release

Rev 1.10 Dec 5th 2016 Welcome Text

Introduction

If you are the owner of a HP-01 wristwatch, you know that it is a jewel of ingenuity and a jewel in design as well.

A jewel of ingenuity because its interior is a marvel of miniaturized arrangement of chips, which where developed exclusively for this watch. For the time of its coming to market in 1977 it was a real challenge of combining a watch and a calculator in a small housing for wearing it as a wristwatch.

A jewel of design because its twenty-eight buttons and the red LED display, embedded in a robust steel case with a massive metal bracelet, reminds of a science-fiction device and whenever you wear it, it attracts attention to the people, who spot it.

Although the interior of the HP-01 is made of very durable materials and the silicon chips are sealed in a ceramic housing and all connections between them are made of pure gold, there were several things that could damage it. The most common of all is the battery leakage, which usually occurs at the end of its life time. The leaking acid could etch away the gold traces inside the tiny buried vias, which connect the conductive paths between the five ceramic layers. If that had happened, if only one connection in the inner layers was lost, there was no chance of repair, even if all silicon chips were still intact.

That happened to me. When I bought my first HP-01 it was not working. By opening the case I could see, that the previous owner had left the batteries too long inside and they destroyed the electronics as described above.

Not at once, but gradually arising, I thought: How could a repair be possible?

Collectible

The HP-01 is a highly demanded collectible. A couple of highly skilled engineers were developing this masterpiece at a time, where they gave ultimately the best to achieve the highest degree of what electronics could perform.

Its prices vary depending on the condition and whether you want to buy the naked watch or a complete set with stylus, original manual and original golden package. In any case it is expensive.

Of course the prices do also depend on whether the watch is still running or whether it is dead. But increasing the price for your collectible should not be the main reason for repairing it. It just would be very enjoyable to see the LED display digits light up again and wearing it as a real and useful watch, knowing, that nothing will destroy it again.

But I forgot to think about the possibility that you are the original owner. Then it was really expensive for you, but well worth it

The idea of the "*new HP-01*"

I admit, that the idea of repairing an HP-01 did not come into my mind too early. When I bought my first HP-01 watch, a gold plated one, it wasn't working and I opened it like I did with any other HP calculator trying to fix it somehow. As mentioned before some paths were corroded, which were damaged and etched away by a leaked battery. I tried to reestablish some connections, but couldn't restore the watch's functionality. It was hopeless. Only after having collected some experience with emulators for the arithmetic chips of early HP calculators, I could imagine to build a replacement for the HP-01. And of course, one stimulus for going on in this direction remained: to repair my own HP-01 gold.

Early in this year, in January 2016, I found time to read the US patent 4158285 and copied the program listing, I added the jump addresses and was able to run parts of this prototype code on my PC. I recognized, that I could be able to squeeze the code into a microprocessor and thought about a schematic, which made the project more and more realistic. The goal could only be achieved by carefully choosing the right RTC chip in combination with a suitable microprocessor. After finding an ultra low power and ultra high precision RTC chip, which was normally used in electronic heat cost allocators, I became confident to build a battery powered precise watch circuitry, which could fit into the HP-01.

Many steps had to be taken, before the final result was working. Building a prototype board, which in fact did not fit into the case, but allowed to test the power consumption and the software. Making a redesign of the board with many changes and improvements. And finally extracting the original HP-01 ROM microcode, which was a real odyssey by itself.

I hope the result is worth for you. For me it is in any case, because now I can wear a HP-01 gold on my wrist, which shows me the time whenever I need it.

The Repair Kit

If your HP-01 display didn't light up by pressing a key, and you already replaced the batteries, either by yourself of let it do by a specialist, and the display remained dark, there was no way in the past to do anything else for repair, nobody could reanimate the beautiful HP-01 watch.

Unlike a normal pocket calculator of the same era, which could be opened easily and sometimes only a bad contact had to be found, the reason for the failures of the HP-01 were less trivial and mostly hidden inside the ceramic layers and therefore were beyond repair. Often some conductive paths were etched away by a leaking battery and even worse, one of the vias, the small little holes to change the conductive layer, were affected. If one of these connection were lost, there was no way to reestablish them, even with a microscope and a SMD soldering station.

A most common part for failure was also the reset spring contact, a very thin gold plated special small metal sheet used to connect the RESET input to battery minus by the very small reset button. Either the plate was broken or completely missing. Trying to resolder it in the right angle to the battery pad was very difficult and often resulted in a wrong position or more damage than before.

Another cause of failure was preprogrammed by the mechanic construction of the reset button. After inserting new batteries, the manual tells you to press the small reset button for starting up the watch, but often, if there was no response and the owner felt some despair, the reset switch was pressed again and again and way too hard and caused to break the via connection just below the reset button, which was unfortunately placed directly there. If this happened, the circuit could never be started again.

Other failures of the electronics could occur in many ways inside the ceramic housing just by getting in age or having inserted the batteries the wrong way.

However the keyboard and other mechanical components are build very robust, and a thick gold layer protects the keyboard contact area for surely over hundred years.

Now for the first time a replacement is available for this famous device. All you need is to remove the LED display from the original circuit and use it for the “new HP-01”.

Replacement

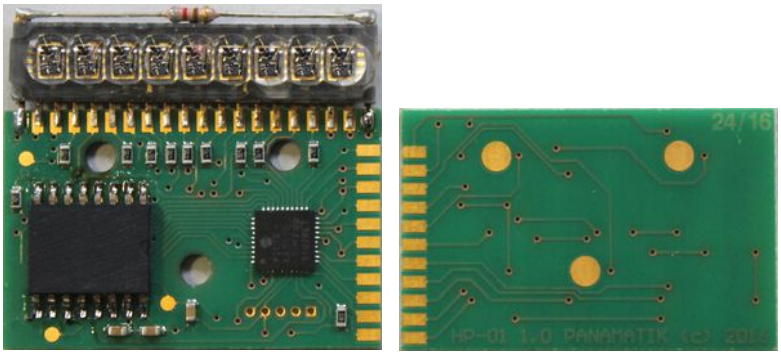
Because the replacement of the HP-01 circuit is not trivial, you normally should take the offer to send the complete watch to PANAMATIK and it will be sent back to you as a repaired device. Additionally you will get your ceramic hybrid module, which is now not longer used, either opened or still closed for your showcase. But this is the all inclusive package and of course the more expensive way. If you want to save costs and you are a skilled technician, you can do the replacement by yourself as described below. It is up to you whether to decide for the easy or the hard way. If you decide to send the complete watch for repair, we will guarantee to take care and not touch any parts, which could get scratched accidentally, and the package will be insured for up to 1000 $, or higher if requested. If not, please read carefully the following description before doing the first step.

Preparations

Before you start, search for a smooth surface, a small carpet or fluffless cloth, to lay the watch on. You don't want to make any scratch on the surface of the bezel or the LED display cover.

The HP-01 repair kit replaces the complete ceramic hybrid module. and assumes, that the LED display and the mechanical surroundings are still intact. The replacement procedure consists of three steps. First open the case and remove the hybrid module, where the LED display is attached. Remove the display with a hot air station carefully from the ceramic substrate, to not overheat because it is irrecoverable and cannot be ordered by amazon. Then attach the display to the new HP-01 module and reinsert it into the watch.

The “new HP-01” module consists of two printed circuit boards, one contains the processor and real time clock, the other is the keyboard contact area.



Both have gold plated contacts and need to be put together by 11 wires and be fixed perfectly aligned in 1 mm distance. Because the display has to be soldered to the lower processor board before attaching and fixing the upper board, there is no easy way to Do It Yourself. But anyway it is described here how to do it the best way.

Disassembly

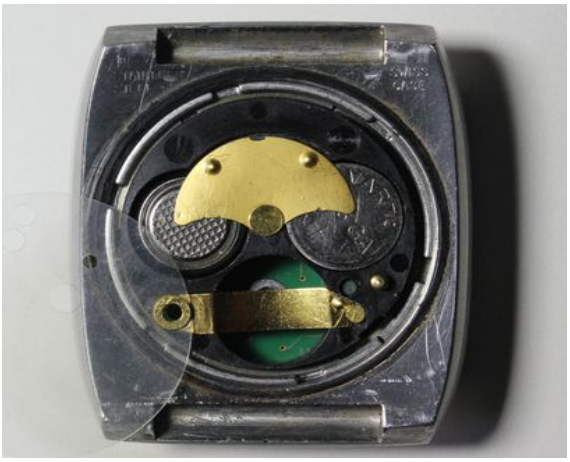
A tricky part for itself is to open the case. There are many descriptions about opening a HP-01 watch for replacing the batteries. And also for going deeper inside and removing the hybrid module. A nice one can be found at http://bytecollector.com/hp_01.htm. I will repeat a brief description here by myself in case of websites could get offline.

Step 1.)

Remove the rear cover. It is not necessary to remove the watch band, but it is helpful to open it. This is very easily done by standard procedure removing the spring bolt at the closure. If you don't own an original battery replacement pack with cover removal tool, you can use a watch case opener. But be careful. Even with this dedicated tool you can make scratches to the case. Don't try a screw driver, you will definitely ruin the case. Turn the cover counterclockwise until it is open. Put aside the rear cover. Be careful not to touch the inner side, because this is the membrane of the piezo buzzer. Remove the batteries.

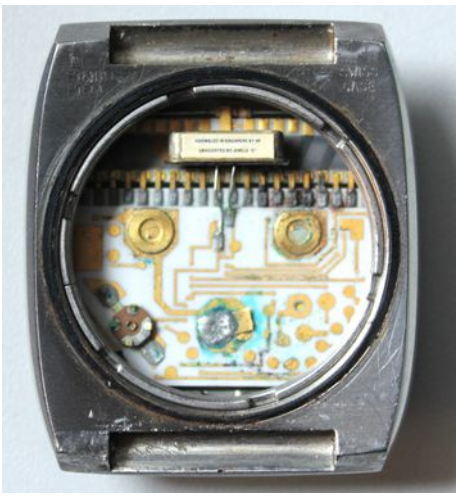
Step 2.)

Now you can see the two slotted rings. First you have to remove the inner ring. It fixes the black plastic battery holder. If you don't have special tool like a needle-nose pliers, you can use also tweezers, which you have to bend outwards until the tips fit into the two opposite slots of the inner ring and turning them counterclockwise. If the inner ring is moving and gets free, you can do the remaining turns with a small screw driver. If it is completely removed you can remove the plastic battery holder.



Step 3)

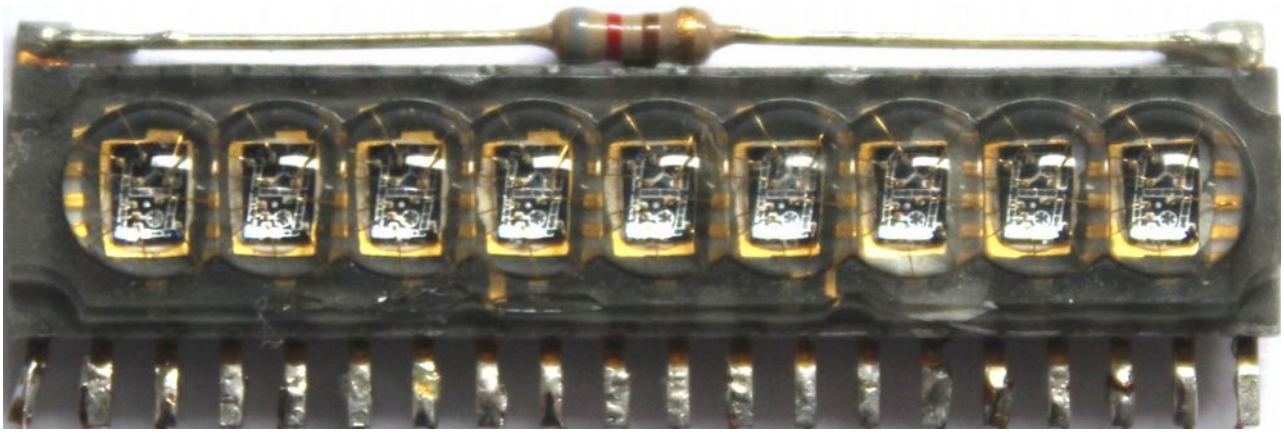
The bottom side of the hybrid module with the crystal and the display attached can be seen in this image below, it is caught in a woefully condition.



Next you have to remove the outer ring. This ring has a left handed thread. You have to move it **clockwise!** Again use tweezers or your special needle-pliers to make the first turn. After some turns you have to loosen the front housing against the back housing and go on, before the two housings can be separated. Remove the outer ring, which is split at one side.

Step 4.)

Now we remove the hybrid module. It is recommended to check the functionality of the display before going on. If the display is not working the repair is not possible and it is very difficult to get a display as a spare part.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
R1	b	col	1	e	2	3	c	4	5	d	6	dp	7	8	g	9	a	f	R2

HP-01 display 20 pins from left to right.

R1, R2 resistor 820 Ohm, a-g 7 segments, dp lower dot, col upper dot, 1-9 digits

There are 81 independent segments, arranged in a matrix of 9 segments and 9 digits, which allow to control each of them separately. It is possible, that one or more of the tiny bond wires, which connect the segments, are corroded. If you connect a voltage of 2,5 Volt with a 220 Ohm resistor each segment should lit up dimly. This is the proof, that it is still intact. If you have a Digital Volt Meter with diode check or resistance measurement feature, you can just connect the probes to the display pins. The diode voltage should be sufficient to light up the segment. Try it with a common red LED before testing the precious display. The above pin description helps you to find the right segments. The digits are common cathode, you need to connect the negative voltage to the digit number and the positive pole to the segment. Try every segment and the two dots of every digit, until you know that your display is OK. Then decide to go on. You still can return and go all the way back from here.

Step 5.)

The hybrid module is ready now for unsoldering the display. You have to remove the crystal first to get the area free for the next step. It is not possible to unsolder the display pin by pin. At least I couldn't do it. The twenty gold pads are real heat sinks, they glue your soldering iron to the pad if you try. They have to be heated up all at once. You need a suitable air pistol to heat up all pins together. It is your responsibility to find the right temperature and not to overheat the display. I cannot tell you how to do that without risk. I don't have enough experience for being sure what is the right way. You may mask the surrounding of the pads with Capton ribbon tape to protect them from too much heat. Probably aluminum foil could do the same. But I don't know, which is the best method. The only thing I can tell is, that I removed the display of two watches without damage by hot air even without masking. Fortunately only the back side of the display will be in the hot air stream. After one or two minutes the contacts should be heated up beyond the tin melting point and the display can be grabbed by tweezers. Now you have done the worst tricky part.

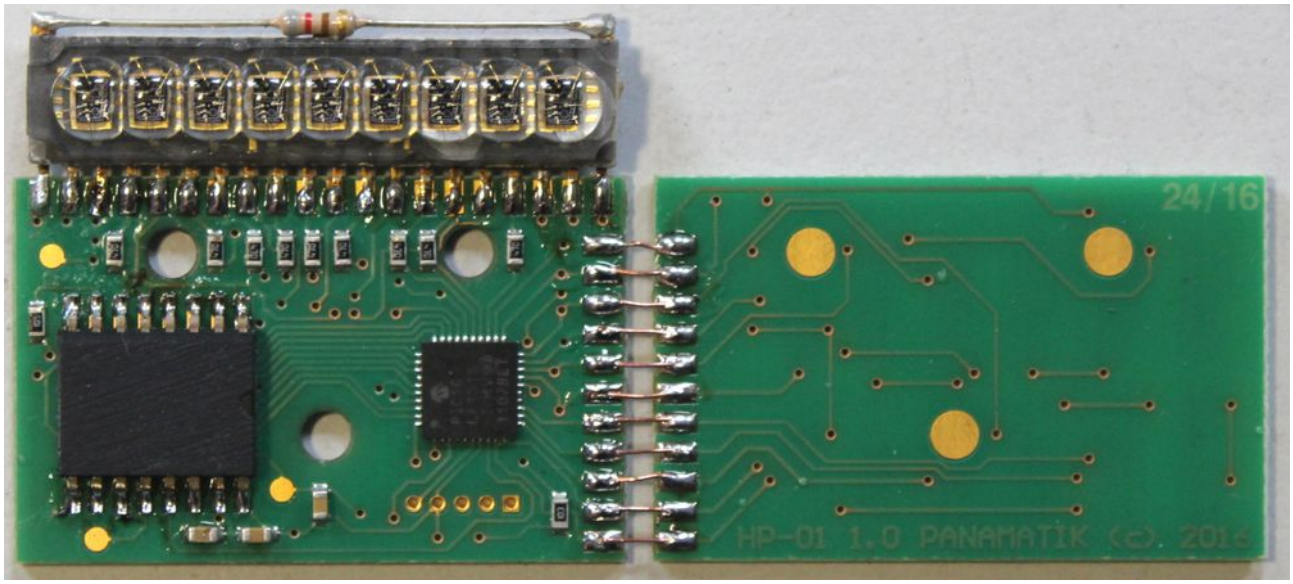
Disclaimer:

When using these instructions for repairing your HP-01 wristwatch, or in any other case of using the new HP-01 for any purpose, you are aware, that you alone have the responsibility. Due to the limited availability of the original HP-01, PANAMATIK was not able to predict any possible circumstances, which may occur. Therefore it does NOT take responsibility for any damage that can occur directly or indirectly from using these instructions or using the new HP-01. We assure, that we tried to take care and took any precautions to provide you with all the information required for a successfully repair. Proceed only if you agree with these terms.

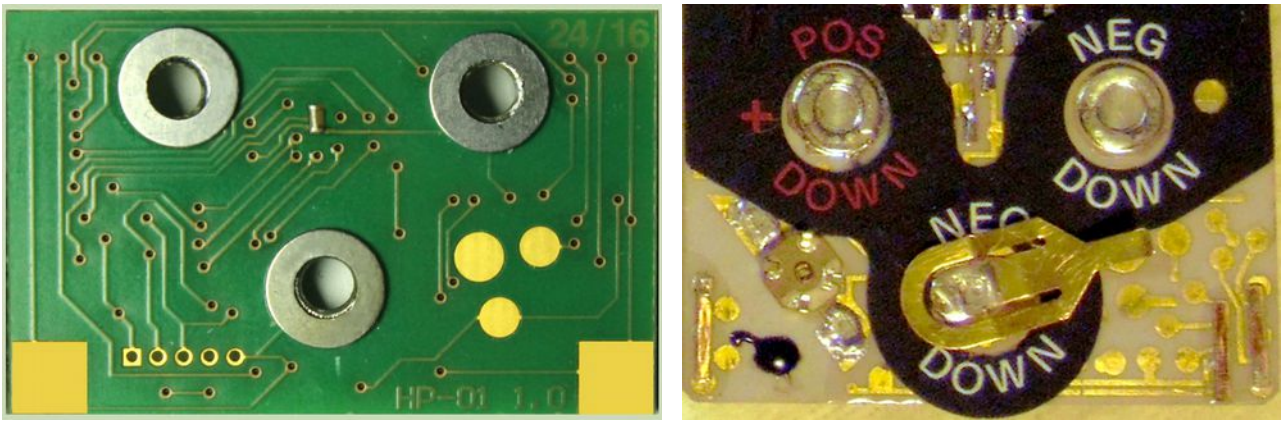
PANAMATIK

Assembly

Your repair kit consists of the processor board and the keyboard. They are already attached together and connected by 11 copper wires, but not folded, because this can be done only after the display is mounted. The Real Time Clock chip PCF2127 was filed off on both sides by about 1 mm before assembly, otherwise the board would not fit into the watch case later.



The battery contacs are made of stainless steel shim rings, which match exactly with the three holes of the plastic cover from your original HP-01, that shows the battery polarity.



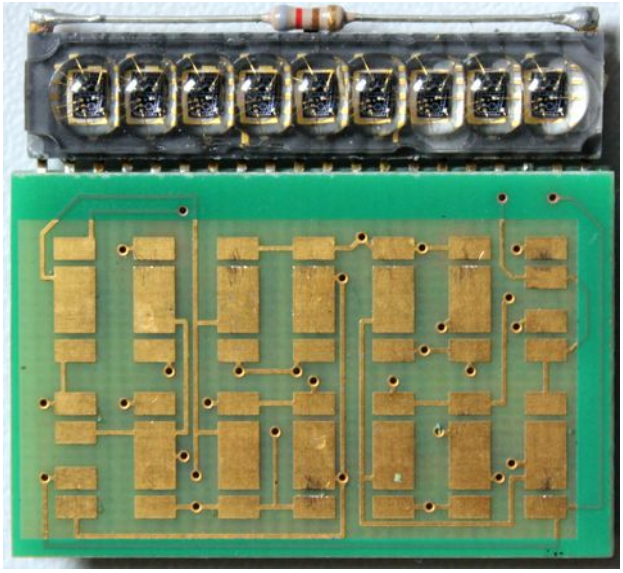
Battery contact area

Step 1.)

Solder the two opposite pins of the display to the processor board horizontally with the display side up. Be sure, that the display is horizontally aligned properly. Then solder the rest of the pins. Adjusting the display after this step is not possible, except by removing it again, this time with the front side in the hot air stream. Please try to avoid it.

Step 2.)

Flip over the keyboard and align it perfectly above the processor board. Be sure that it is parallel to the processor board and does touch the RTC chip plane. Be aware, that the eleven copper wires allow this procedure only once, they will break if bent several times. On the other hand the ductile copper wires are a great help for adjusting the boards.



Now your “new HP-01” module is ready.

Step 3.)

To protect the 11 copper wires against electrical shorts with the case, place the delivered small red plastic isolator sheet to the left of the housing and insert the new HP-01 module.

Step 4.)

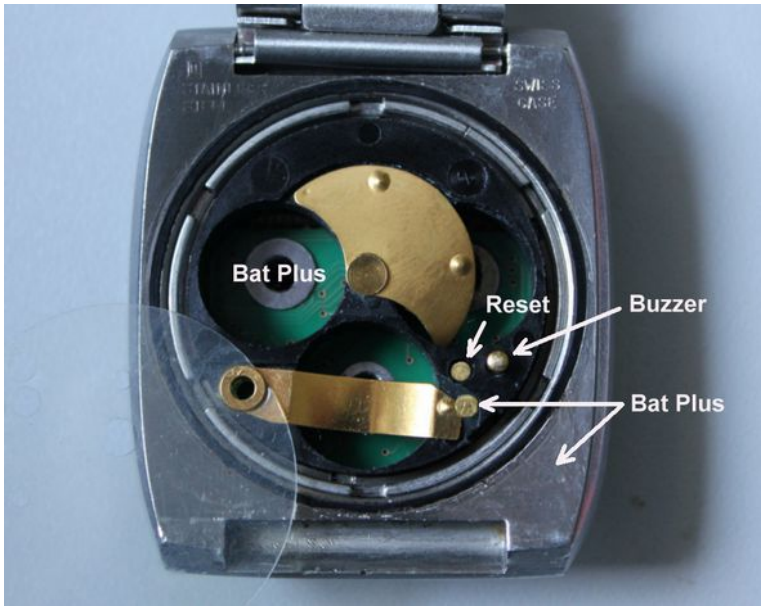
The next steps are the reverse procedure of the opening. Insert the outer slotted ring with the slots pointing to you. Make certain, that it is moving freely. Now attach the back housing with the wrist band and turn the ring **counterclockwise**! until it is fixed and waterproof.

Step 5.)

I admit, that the next step is a rather tricky fiddly or dodgy one. Sadly the new HP-01 module is about 0,5 mm thicker than the original, even though the RTC chip has been made as flat as possible and the printed circuit thickness is the smallest manufacturing size. Normally the black battery case should fit into the key and slot of the case. But it is very tight now. Try to fix the inner ring while keeping the battery case in place. It will try to turn with the ring. Be careful that the buzzer spring contact keeps located above its pad. You can adjust it until the inner ring is completely fixed. Be careful not to bend the golden plated springs. If the inner ring is fixed you have won. The rest is easy.

Step 6.)

Make sure, that the electrical contacts are correct by a circuit indicator or resistance meter.



Battery Plus must be connected to the case, the contact is established by the inner ring. The Buzzer and Reset may not be connected to Bat Plus. Check that there is no contact between them. If there is any contact, you have to turn the battery case until it is exactly horizontally and you have to check the correct location of the spring contacts, which of course cannot be seen below the battery holder.

The Reset contact is not used, it is not connected to the circuit.

Step 7.)

Now insert the batteries. You need only two LR44 batteries in the upper places, Be sure they are correctly poled according to the label, left is positive down, right is negative down. Don't insert a third battery, it will cause a short. Leave the place unpopulated. The third place below the two battery cells is meant for temporary inserting a goldcap/supercap for keeping the time and date, during a battery change as described later.

As soon as you connect the two batteries by the golden half-moon shaped blade, the display should show zero and a dot at the left side "**0.**".

But before you close the contact between the two cells and to be sure, that everything went fine, check the current. You measure the power consumption by inserting an Amperemeter between the half moon shaped contact and the battery, either the right or the left one, which is not yet connected. It should show 5-10 mA for the first seven seconds, then the current should fall to about 2 uA.

Step 8.)

Now attach the rear cover carefully with the cover removal tool, which is coincidentally also a cover attachment tool. Hear the alarm buzzer by setting the Stopwatch to "**00:00:01**" and start the countdown. When reaching zero after one second the buzzer must beep 10 times. If not, you have to readjust the buzzer contact and check that battery plus is connected to the watch case..

Your HP-01 is operable and you have my congratulations! You have repaired your HP-01. What you need now is the Owner's Guide for this unique calculator. A small overview of its functions is given in a later chapter.

Features

Normally there is no need to add new features for the HP-01. Just the pleasure to have a fully working LED watch back again into life is all we could expect. It doesn't make sense to add 100 additional registers, because this calculator may never be used for difficult high school calculations.

But I couldn't resist to add at least a few useful features

Revision and Serial Number

If you press f 0 you will get displayed the revision and serial number of your HP-01 module. On the left you can see the actual software version as "**r1.0**". On the right you see your 4-digit serial number "**1234**". The display vanishes after three seconds like any other function to enter sleep mode.

HP Logo

This sequence displays the "**HP-01**" logo. Nothing else.

Operating time

This function shows the accumulated operating time as minutes and hours of battery use as "**HHHH:MM**". Whenever you press a button and the display is active, this counter adds some seconds to the operating time and gives you an estimate for the battery usage since the last battery replacement. If the display is off, there is nearly no battery consumption. Therefore it is important to know how many hours the watch was active. Assuming that new SR44 battery cells have a capacity of 150mAh and 8-10 mA power consumption, they should last about 15 to 20 hours. As the time is displayed for three seconds, you can display it at least 18000 times. If the operating time is beyond 20 hours you should keep some new batteries at hand.

Show Welcome Text

When ordering the new HP-01 repair kit it will be customized to your name and address. You can specify any text of up to 48 characters. This text is stored permanently and will be your inital welcome text after battery replacement. After invoking this key sequence the actual welcome text will be displayed as ticker text repeatedly until you press any button.

 ***Enter Welcome Text***

Since firmware revision 1.1 you can modify the initial welcome text and you can enter any text you want. Your personal text will be stored until you change the batteries or you modify your text again. The maximum text length is 80 characters.

After starting text entry with the above key sequence the ticker text will be displayed but is not moving. The first letter on the left will blink to indicate, that you can select the character for this digit. You can select from a 64 character set, which is part of the ASCII Table from 32 to 96 and contains all numbers, all letters and some special characters. As the 7-segment display cannot display all characters like X or % it will be a mix of capital and small letters doing its best. If you found your letter you can advance to the next digit and finally terminate the text entry. The „End of Text“ marker is shown as digit with all segments on including the semicolon.

You can choose one of the following actions:

 Select space character. Clears the actual digit

 Select the next ASCII character of 64 possible characters

 Select the previous ASCII character of 64 possible characters

 Start automatic character selection forward until you press any key.

 Start automatic character selection backward until you press any key.

 display next digit of your text to modify

 display previous digit of your text to modify

 Start automatic text forward until you press any key

 Start automatic text backward until you press any key

 Go back to the first digit of your text.

 Mark the actual digit as “End of text”, leave text entry and show result.

Pressing any other button will also leave text entry but without changing the “End of text” marker and the actual text will be displayed moving from right to left.

Text Speed

Since revision 1.1 you can change also the speed for displaying the ticker text in a wide range. Just press the following buttons while the ticker text is displayed.

 Increases the speed

 Reduces the speed

  ***Original Mode***

When you insert the batteries you can decide, whether you want to disable the above mentioned features, which could reveal the presence of the new HP-01 circuit inside your watch from outside. If you just press any button after battery change, the watch will become the extended version and all features are enabled. However if you press the above sequence as the first two keystrokes, the display shows the text "**Original**", indicating the HP-01 is now in original mode and all special features are disabled. You cannot change the selected mode later, you have to remove the batteries again.

How to build a watch?

The main goal for building a wristwatch is to keep power consumption low and have a suitable accuracy. But there is more to do, which is described in this chapter.

Power consumption

At 3.0 Volt the “new HP-01” consumes less than 2 uA. Two standard SR44 cells in series have nominal 3.0 Volt and claim to have capacities of up to 175mAh, which can be up to real 150mAh. This implies, that with two cells the new HP-01 will run about 79000 hours, this is more than 9 years. Of course you want to show the time occasionally and the display lights up when you press a button, this shortens the battery life. But it should give a good feeling, that the batteries will not be drawn empty when the watch is just waiting for its next mission somewhere at a party or meeting? Assuming 8-10 mA power consumption if the display is on, the battery lifetime still lasts about 15 to 20 hours in active mode. Time display vanishes after three seconds, thus you can display the time 18000 -24000 times. If you recall the time once every hour, lets say twenty times a day, it still lasts 1000 days, which is several years.

Accuracy

The accuracy of time, date and stopwatch is completely dependent on the chosen RTC chip. The PFC2127T It is a so called “Accurate Real Time Clock” with integrated temperature compensated quartz. The specification according to the data sheet is +-3 ppm from -30 °C to +80 °C. What does that mean? It means after 1 million seconds it will deviate by +-3 seconds. As a year has 31,5 million seconds, the deviation will be about 1 1/2 minute per year or 8 seconds per month. These are theoretical values and I don't know yet the real accuracy, which also depends on layout and environment influences. A normal clock quartz has specification of +-20 ppm and is 6 times less accurate. What you need to know: the RTC chip does perform a temperature measurement every 4 minutes and adjusts the resonant frequency of the quartz according to the measured temperature to get higher accuracy. If you change the ambient temperature of the HP-01 very often, by leaving the house in winter every hour, it will be perhaps measurable less accurate. It would be desirable in that case to measure the temperature more often. This is possible, but there is a tradeoff between power consumption and frequent temperature measurement, therefore I decided for best power consumption. But I'm sure you will wear your HP-01 most of the time in your living room or place it in your well tempered showcase, then you will not have to complain about accuracy.

Power down mode

The main part of the successful replacement is of course the HP-01 firmware emulator, which runs the original microcode. Other than a normal HP calculator emulation, the HP-01 code has a SLEEP instruction to enter sleep mode. When this instruction is executed, further execution of instructions is stopped until a key is pressed or another wakeup event occurred. After entering sleep mode the display still could show the actual time for some

seconds or the running stopwatch. The display is driven completely by hardware. It finally shuts down when the display switches off after some seconds. But still then the time and date is counting and the stopwatch could be running forever.

For having a very low power consumption and achieving years of battery lifetime for the “new HP-01”, it was necessary to put the PIC processor in hardware power down mode as soon as the display shuts off. The power down mode should not be confused with the above mentioned HP-01 sleep mode. In power down mode, the processor only needs 20nA, which is nothing, and all clocks are stopped and it is not possible to display anything. Only four things must be active in power down mode: a counting clock with date and time, a running stopwatch if started, checking the alarm time, and the possibility to wake up by any key press. Fortunately the RTC chip can handle the date and time and alarm. And by a special feature of the PIC processor called "Interrupt On Change" the processor will wake up by any key pressed.

In fact if the time will be set, it will be written to the RTC and the time will be read from the RTC and displayed every second if the time button was pressed. Also the date is managed stand alone in the RTC and will be read, whenever it is displayed. The RTC chip also offers an alarm time register, which perfectly fulfill our needs of the HP-01 alarm function, in that way, that it can wake up the processor if the alarm matches the actual time. After wakeup the processor has to check, whether the wakeup was triggered by key press or by alarm and react accordingly.

But none of them can handle a stopwatch! It is not possible to emulate a running stopwatch if the RTC has no stopwatch or with a sleeping processor. And this is an important function. There is only one solution. They have to help each other.

The Stopwatch

If the PIC processor has shutdown all its clocks and has fallen deep asleep, it anyhow accepts a single external clock signal at one of its input pins, which is able to count an internal 16-bit timer upwards. And the RTC is able to deliver that accurate clock signal, which can be connected to this external clock input. So both together can build a counting unit, which does not need to wake up the processor. As the stopwatch counts in 1/100 seconds, it would be desirable to have a 100 Hz clock from the RTC. But according to the data sheet this is not possible, it can generate either a 1 Hz or 1024 Hz signal. 1 Hz is too slow, 1024 Hz is too fast. But by using a 1:8 prescaler in the PIC timer module, the 1024 Hz can be divided to 128 Hz and voila, this is a good approximation. 128 pulses represent one second of stopwatch count. Now it is easy to calculate the 1/100 seconds from 1/128 seconds just by making a multiplication. In fact, there have to be done some more calculations to get the actual stopwatch displayed from the timer value, as the stopwatch is able also to count downwards and the 16-bit hardware timer can only count upwards and it can count only 512 seconds (8 minutes 32 seconds) before it overflows. Fortunately the overflow can be programmed to wake up the processor. If a wakeup occurs by timer overflow, which happens about every 8 minutes if stopwatch is running, the processor just

adds or subtracts 512 seconds to the stopwatch base value and goes to sleep again. If the  button is pressed the display shows the stopwatch as the stopwatch base value plus the actual timer value.

Date

We assume intuitively that the internal representation of the date will be day, month, and year. And indeed the RTC chip does it this way. But whenever a date is entered into the HP-01, it will be converted in “days since January 1st 1900”. This implies, that whenever a date is set via  sequence, it must be stored in the RTC chip, but this time as days, month and years. There was no escape, I had to write my own conversion routines GetDaysFromDate() and GetDateFromDays() to make the two parts compatible.

For some unknown reason most of the RTC chips store the year only as two digits and don't distinguish between the twenty-first and the past century. But the HP-01 does. Its range is defined from 1.1.1900 to 12.31. 2099. I had to find a free register to store the century, but this was not too hard to find in the unused weekday alarm register.

Here is an implementation in C for Get date from days, which I tried to keep as simple as possible. If anybody has a more elegant or more compact solution, it will be appreciated.

```
// Get date from days, valid days range is from 1.1.1900-12.31.2099
// calculate day 1-31, month 1-12,year 000-199 (1900-2099) from number of days
// since 1.1.1900, days = 0 is 1.1.1900
// years, which can be divided by four, are leap years, except full century
// years, with exception of 400 century years.
// 1900 was not a leap year, 2000 was a leap year.

extern uint8_t day,month,year;

void GetDateFromDays(uint32_t days)
{
  uint16_t d; // use 16-bit days intermediate variable for smaller compile size
  uint8_t  n; // intermediate variable

  if(days >= 365)      // treat 1900 as leap year to simplify calculation
     days++;

  n    = days / (365*4+1);  // n= no of 4 years periods, including one leap year
  year = n * 4;             // first approximation of year
  d    = days - n * (365*4+1);  // d=remaining days 0-1460, up to four years

  if(d>=366)        // more than one year left? first year is always leap year
  {
    d--;            // reduce by one to treat every year as not leap year
    n     = d / 365;            // number of years 1-3
    year += n;                  // add 1-3 years
    d    -= n * 365;            // subtracts three years
  }
```

```
// now days of one year are left in variable d, either d=0-365 if leap year,
// or 0-364 if normal year

  for(month=1;month<=12;month++) // month 1-12
  {
     n = DaysOfMonth[month-1];
     if(month==2 && (year & 3)==0 && year!=0)
       n++;       // add 1 day at february if leap year, 1900 is not leap year
     if(d >= n)
       d -= n;
     else
       break;          // no more days left for another month, exit loop
  }
  day= d+1;            // d=remaining days, add one for day from 1-31
}
```

LED display

The original HP-01 circuit had a specialized display driver chip, which contained a constant current source, regulated indirectly by a single 820 Ohm resistor to display the nine digits. It had the function of limiting the forward current of the LED segments, giving them the right brightness. Regulating the LED current this way is a very elegant solution. In the new HP-01 module this method could not be used, because there was no suitable constant current chip available which fit into the limited available size. Instead 9 resistors of 22 Ohm are used, which control the current passively. But this needs the assistance of a very special software timing. Using a passive resistor per digit leads to a bright digit '**1**' and a dim digit '**8**'. If only one or two segments are used like a dot or the number 1, it gets the full current, and a dim digit if all segments are n, i.e. when displaying the number '8', where the current is divided into all segments. When treating every digit the same, this effect could be clearly seen and is not tolerable.

All LED displays are driven multiplexed, each digit is shown only for a ms, then the next digit is shown. After 9 multiplex cycles, which is normally 9 ms, because there are 9 digits, the cycles will be repeated. This saves significant power and signal lines. To achieve the same brightness for each character in the new HP-01 the time for each digit is trimmed according to the number of segments used. The more segments are used, the longer the digits is ON. The 'ON' time for each digit depends on the character displayed. This is precisely balanced and can be controlled accurately by a timer. This leads to a constant brightness for each digit, regardless of what character or number is displayed.

If the battery voltage decreases at the end of battery lifetime, the display will become darker, but when using SR44 cells, they have a constant voltage up to the very end of their lifetime, therefore I do not expect to see this effect. And if it becomes visible it is time to change the batteries.

Alarm buzzer

The new HP-01 would not be complete without also implementing the alarm sound. There is a hidden piezo speaker, which is integrated into the rear cover. An intermittent alarm beep of about 5 seconds is output if the alarm time is triggered or the countdown reaches

zero. The frequency of the buzzer is just below 800 Hz, which I tuned with an original HP-01. In contrast to the original HP-01 the text '**Alarm**' appears in the display while the alarm sound is active. If the watch is in sleep mode, just the Alarm sound can be heard.

Errors

If new batteries are inserted and the processor powers up, it checks the communication to the RTC chip. If the chip doesn't answer the message "**Error 1**" will appear after power up. If this happens you have disconnect the battery power and connecting again. Normally the number "**0.**" should appear. If this Error is shown permanently, the RTC is damaged and you have to send the watch back for service. If the time was lost by any reason, perhaps because the batteries were too weak, "**Error 2**" will be shown. If this Error is shown repeatedly and the Operating time is high, you should consider to change the batteries.

Battery replacement.

The new HP-01 module can be operated with voltages as low as 1.8V and as high as 3.6V. The nominal voltage of two SR44 cells is 3.0 Volt. This allows you to squeeze the milli Ampere hours from the battery cells until they are really empty. Nevertheless this will happen some time.

If the display gets dim when the lifetime of the batteries is nearly reached, you have to replace the batteries. The easiest way is to remove them, insert new ones and set the time and date again. Always replace the two upper batteries and leave the lower single battery place empty. Other than the original HP-01 which used three cells, the new HP-01 uses only two cells and it would cause an electrical short if you would insert a third battery.

But the empty third battery slot can be used during battery replacement, because there is also a procedure for keeping the watch running during battery replacement. After you opened the rear cover you can see the empty battery slot below the two cells. Before removing the batteries insert a suitable supercap of 0,1 F with negative down and wait two minutes for charging. Then replace calmly the batteries and you can remove the supercap after the work is done. If all goes well, the date and time is still valid and you have some more years to wait for the next battery change.

It is highly recommended to use SR44 cells instead of LR44 cells. they have more capacity, which compensates most of the higher price, but even more important, their characteristic keeps the voltage nearly constant until the end of the lifetime, which gives you a bright display until the last days of usage, while with LR44 the brightness constantly decreases during their lifetime

Bernhard Emese,

HP-01 Repair Kit
January to July 2016, Revision 1.1 Dec 2016

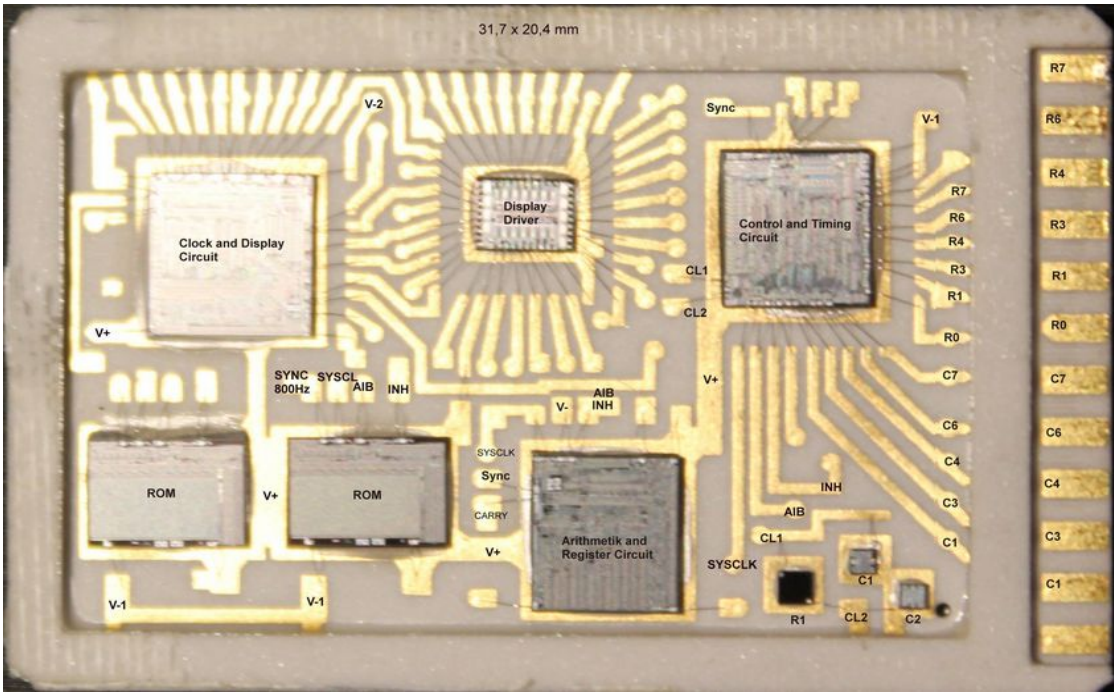
The Technology

The engineers of HP used much more dedicated hardware than today, they thought in single Flip Flops and gates, instead of modules to patch together. This gave the chips enormous power and performance even with low clock frequencies of only 38400 Hz compared to 1 MHz in the new HP-01. Today we can use multi purpose chips which lots of resources and MHz clocks to our service. Nevertheless it is still not easy to compete with the specifications of the original HP-01 and a challenge to choose the right components.

For making this replacement possible, it was necessary to run an emulation of the original microcode on a modern microprocessor.

The HP-01 calculator watch does not belong to the „Classics“, nor to the „Woodstocks“ calculator series, nor to any other generation of HP calculators, which were made at that time. It is a class of its own. And this is true especially in respect to its technology. The hardware is undoubtedly unique, and the firmware does not run under any of the emulators available, it could not be emulated by „nonpareil“, nor by any other emulator.

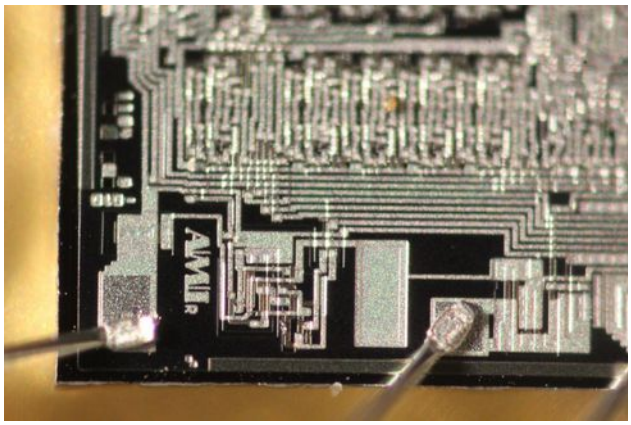
And even if there was an emulator, the microcode could not just be run. The HP-01 had much more hardware specific functions integrated, which were not part of the firmware. The stopwatch hardware for example will be started and stopped by special instructions forward and backward, and will be displayed even if the processor sleeps. There were some other registers representing the real time clock and date, which count independently of the processor, managing a 200 years range from 1900 to 2100 including leap years, they are spread over different chips, combined in the hybrid module of the HP-01.

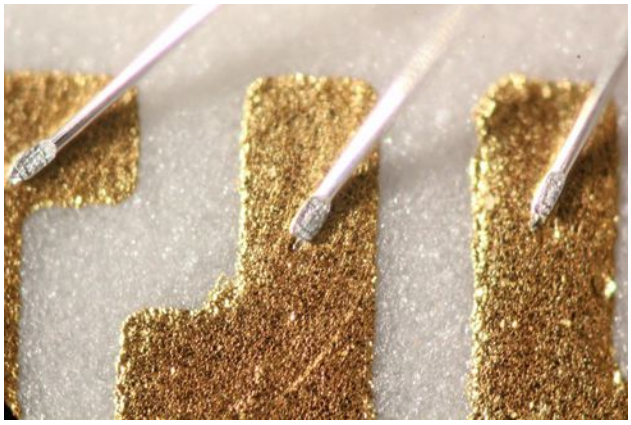


HP-01 Hybrid module

Reading the ROM code

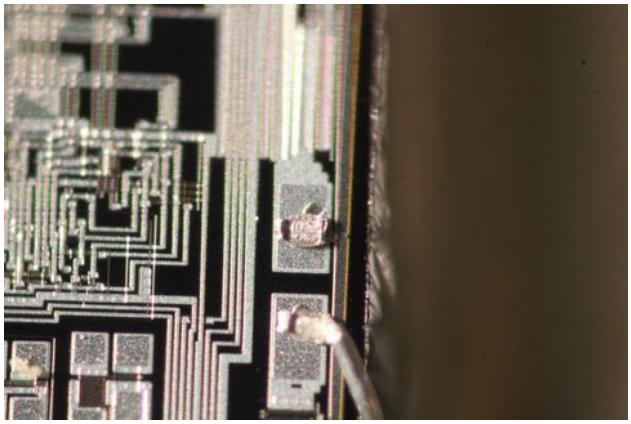
More than one year before I actually made the “new HP-01”, I planned to read the original ROM of one of my two HP-01s for making an exact replica as part of my repair kit at all costs. But I did not even know how to open the sealed ceramic case. For a long time it just lay in my drawer waiting for what to come. Then, in February this year 2016, I took some courage and heated up the case and could melt the glue, that connected the upper and lower ceramic parts and for the first time I could separate them and see the hybrid module and its 6 silicon dies inside. All the years before, there existed only a black and white photo, which was reproduced in the December 1977 HP Journal. Now the first color photos could be taken.



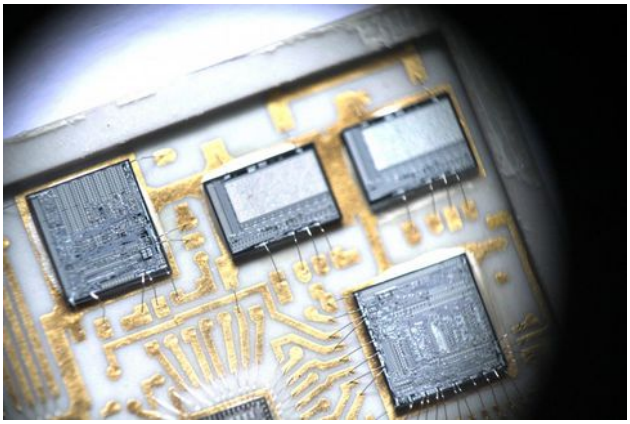


Tiny bond wires

Again after hesitating many weeks before going on, I finally connected 1.5 Volt power to the module and tried to measure some signals with the oscilloscope. This was very difficult, because I could damage easily one of the tiny bond wires while applying the probes. And after 10 Minutes of measuring exactly this happened. I knew I never could reconnect any bond wire, and I saw my last chance gone to get to the ROM code.



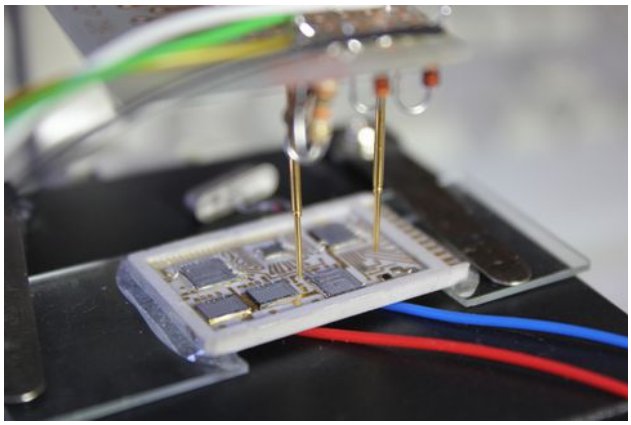
The missing bond wire

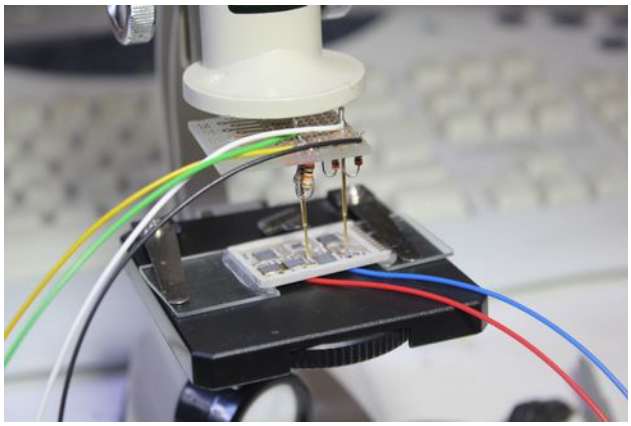


Two 1k ROMs of the HP-01

My idea just to listen to the instructions and call every possible function step by step to collect the ROM code was no longer possible, because the watch wasn't running any more. As I recognized later the carry bit of the Arithmetic and Register Circuit was ripped off and the program flow was wrong, it not even came out of the initialization and was caught in an endless loop. But I was very lucky that it was not another more important signal.

The bond wires near the ROMs were still intact. And possibly they could be read by applying addresses externally and reading the operation codes. But how could I apply probes without fear to damage the circuit even more? I got the idea to buy expensive spring loaded pogo pins and to use the old toy microscope of my son as an elevator to establish the contacts. This was indeed very practical. Then I was thinking about how to injects the signals. It turned out, that this time I had to deliberately rip off another bond wire to inject my signals. Before doing this, I tried to cut one of the gold paths by a scalpel, with no avail, then I tried to cut the trace with a 0.6 mm drill and a small drilling machine, with no success. The conductive paths behaved like steel instead of gold. The only remaining chance was to remove the bond wire. Fortunately this went well. First I thought that I needed four connections to apply system clock and sync signals and so on. Then I could reduce the no of pins necessary from four to only two for connecting a PIC microprocessor to apply the addresses asynchronously. It needed also a passive bidirectional level converter to interface from 3.3V to 1.5 Volt. Always knowing, if I made another mistake it would be over. Buying another HP-01 just for damaging it as well, was beyond my imagination.





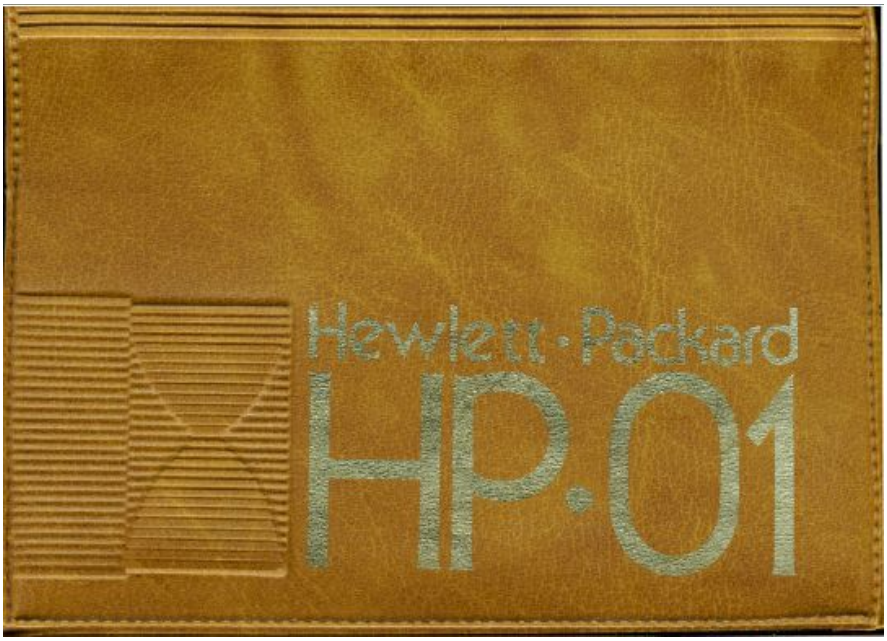
After two days, the program was working and all preparations were made, the interface was working. And with all my courage I connected the HP-01 with the PIC processor (I used an new ACT for this purpose) via the interface and got miraculously a signal from the ROM. It answered the opcode of address 0000. Immediately I saw that it was a jump instruction. This was what I expected. Then I could increment the addresses via terminal and could write down the next opcodes. And they also made sense. They were similar to the beginning of the prototype microcode, that was published in the US patent 4158285. Only a few hours later I was able to read and verify the complete 2k ROM code automatically.

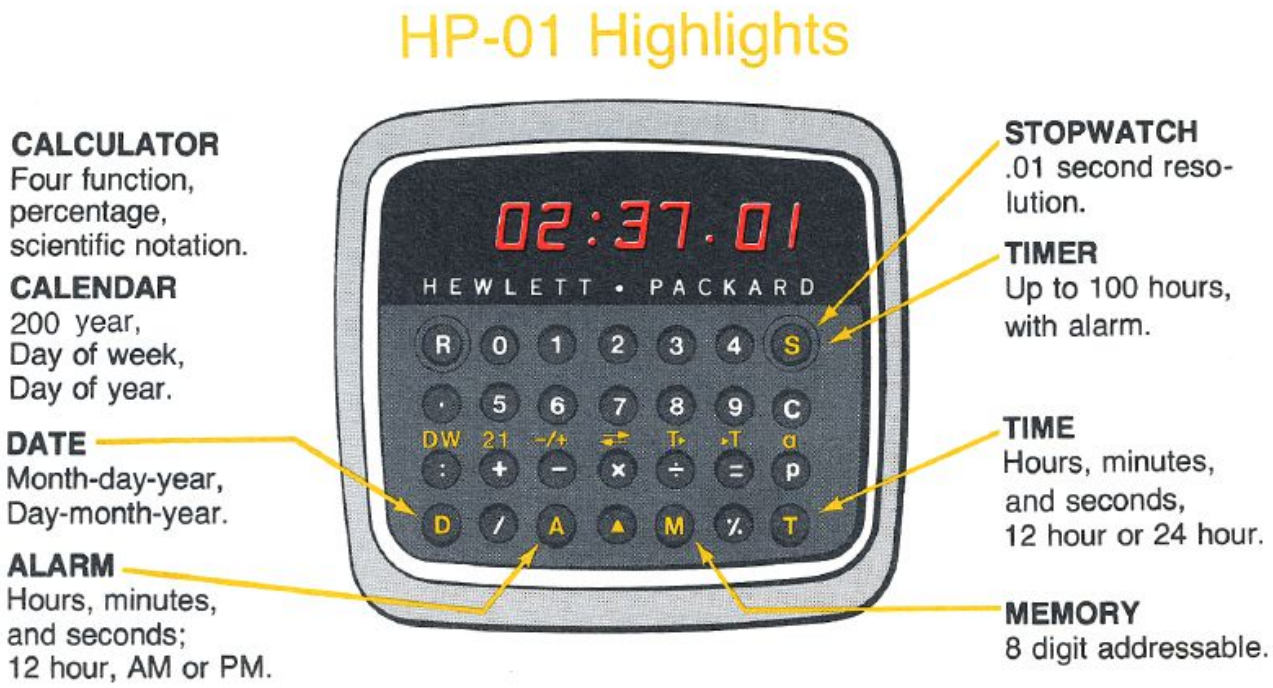
The original HP-01 microcode is now used in the new HP-01 repair kit.

Appendix A

Users manual

What you need to operate your repaired HP-01 is the Owner‘s Guide for this unique calculator. It is not included in this manual. To achieve a real leather bound „HP-01 Owner‘s Guide“ you must be very lucky to buy a complete HP-01 watch with all its accessories at an auction, or you are the original owner and bought it together with the HP-01 decades ago. It is not possible to reprint the complete 100 pages user manual here. But you will see an overview of the HP-01 functions on the next page as a brief introduction.





Key sequence	Function
0-9 .	Numbers and decimal point for number entry
+ - x ÷	The four basic arithmetic operations
%	Percent operator
=	Show result of arithmetic operation
:	Time Entry
/	Date Entry
C	Clear entry to **“0.”**
T	Show actual time
D	Shows actual date
S	Show Stopwatch, press again to start/stop the Stopwatch
R	Lap Time if Stopwatch is running, else reset Stopwatch
A	Show Alarm Time
M	Recall number, time or date, which was stored in memory
Δ M	Store number or time or date in memory
Δ T	Set Time
Δ D	Set Date
Δ A	Set Alarm Time, toggle Alarm active
Δ S	Set Timer for counting backwards
P	Enter PM time
Δ P	Enter AM time
Δ .	Switch between 12h/24h mode if time is displayed
Δ .	Switch between mmddyy and ddmmyy if date is displayed
Δ :	Show day of week
Δ /	Show day of year
Δ +	Set date to 21st century
Δ -	Change sign of number or time
Δ x	Exchange x and y register
Δ ÷	Convert Time to decimal hours
Δ =	Convert decimal hours to Time
T + or - hours Δ T	Change time zone
D + or - days Δ D	Adjust date
S x number =	Dynamic calculation
number x percent % =	Calculate percent of number
number + or - percent % =	Calculate net amount and discounts

HP-01 Schematic