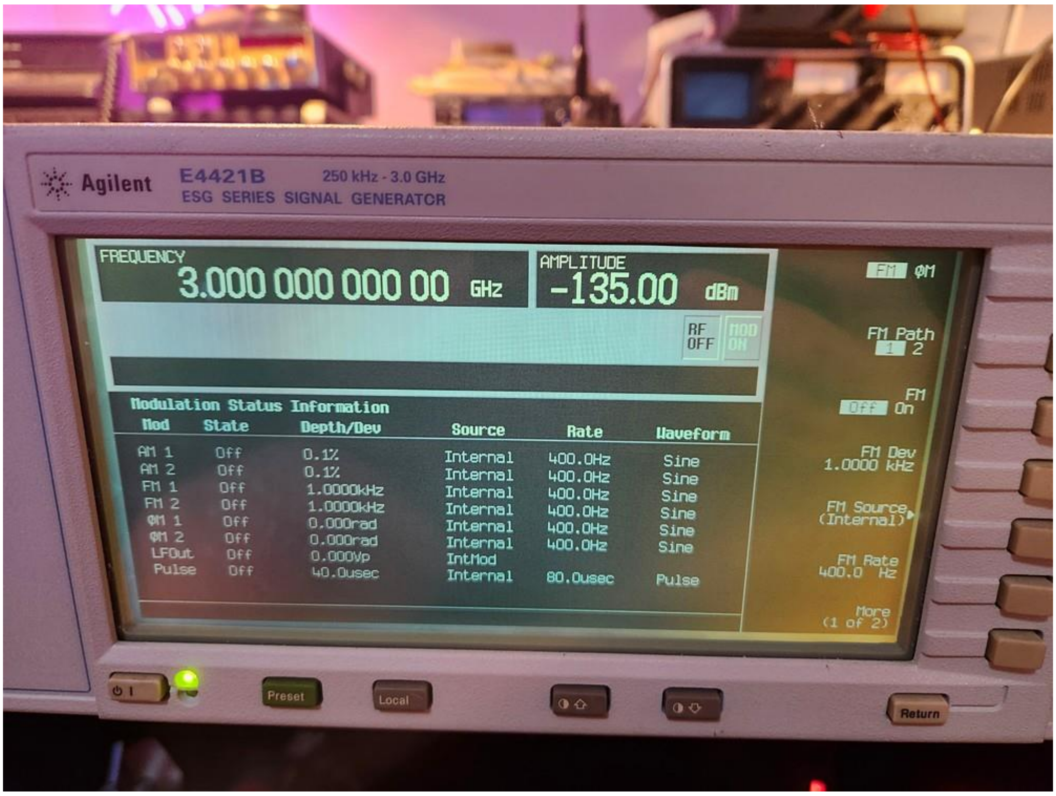
Repairs to Agilent ESG series, signal generator E4421B
Specification = 100KHz to 3GHz, -136dbm to +25dbm

Bordering on enthusiastic insanity or perhaps total stupidity, I accepted an offer to purchase a second hand HP/Agilent signal generator, asis (reported as working fine!)

These were produced by HP instruments in the late 90’s and early 2000’s and generally were superb laboratory quality instruments. On Ebay there are several E4421A-B for sale across the world, priced from AU$2000 to about AU$6000. Plus freight. Still commanding high prices.



One problem is that calibration is done by readily available HP software (runs only on everyone’s Windows 95 OS) for free from HP, but as part of the testing and calibration all test units are polled on a data buss, GPIB (General Purpose Interface Buss) and **specific HP units must be used**. The software wont play ball unless the suite of instruments are **all** available and communicating. $100K is an estimate to setup. Any change to modules, ie attempting to upgrade or replace can also force a calibration requirement. Very locked down! Software has been coming into test instruments in a big way for years as normal practice. One Ebay advert just for a calibration, quotes $3K.

So the unit arrived and it works. Initial testing for frequency accuracy and level however showed some major frequency problems. It’s specification with a standard reference oscillator (this one is the standard type) is better than 1ppm over 0C-55C. ie 10Hz error over that variation in temperature. The 10MHz TCXO (temperature compensated crystal oscillator) was measured at 150-300Hz high. The unit has user coarse and fine adjustments in software to tune the crystal reference, but with both of these set to zero it was still high by about 100Hz. Any signal generation at 3GHz would be 300 times worse than at 10MHz, resulting in an error of nearly 100KHz. Not ideal for “accurate test equipment” and not within normal specification.

However its been normal for a long time, on any frequency related test gear, to have “EXTERNAL REFERENCE” inputs and outputs. So by providing an external 1,2,5 or 10MHz signal of 0-10dbm level, sine or square wave, this would cause the instrument to lock to that source and be as frequency accurate as the external. Outputs of 10MHz can also be daisy chained from device to device.
Not a problem to get around, or so I thought. Connecting my Leo Bodnar precise GPS reference unit on 10MHz would be the answer. Not so. For some reason **all** external signals tried on 1MHz, 2MHz, 5MHz

and 10MHz produced an “OUT OF LOCK” error in the generator. Damm. Foiled again Batman! Were there two faults? This is looking like a real Port Mac sinker.

How can an external reference of known accuracy be “OUT OF LOCK”? Its the signal the generator should be locking to! This bad situation is getting worse. Using my budget “GPS Controlled Signal Generator” on any other random frequency, ie 3MHz, strangely produced a “LOCKED” result. (Maybe it was at the limit of the smart design). No corrected output was possible.

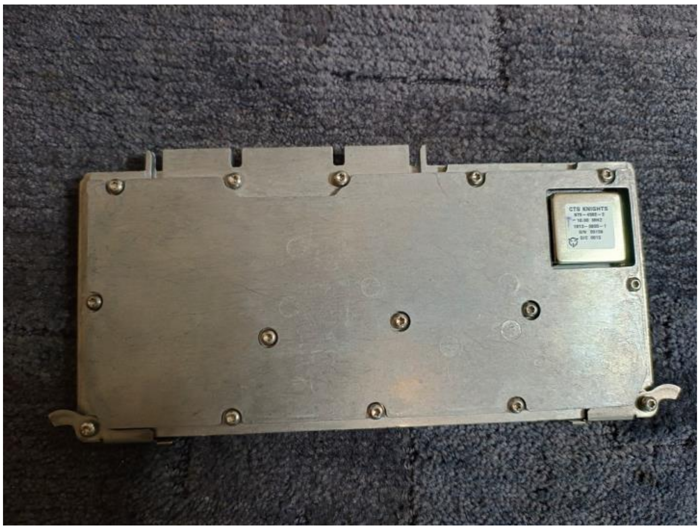
Next step was to delve into the circuits, how does this thing work? Circuit schematics were duly obtained by waving a plastic card at a Romanian, who had scanned all 950 pages,
(that’s just the schematics) in good quality. These were NOT available anywhere else that I could find.

Let the fault finding begin. The reference module at 10MHz is simply a metal block made by CTS Knights, an electronics part manufacturer. The circuit with its external reference detection, locking, comparing the incoming signal, dividing and several PLL’s, had me going round in repeating circles for some time. When finally I came to a conclusion (read here = lucky guess) and the light went on. The internal 10MHz might be used to verify that an external signal is close to, or better than itself. Otherwise the internal signal may just as well be used. 1,2,5,10 are all compared to the internal frequency, and as the internal frequency was WRONG, it was reporting that the external was WRONG too, even when it wasn’t.

At least that was my theory on how one fault could make two! This was verified by on purpose miss-adjusting the external reference by 100-300Hz, where it was then reporting as “LOCKED”.

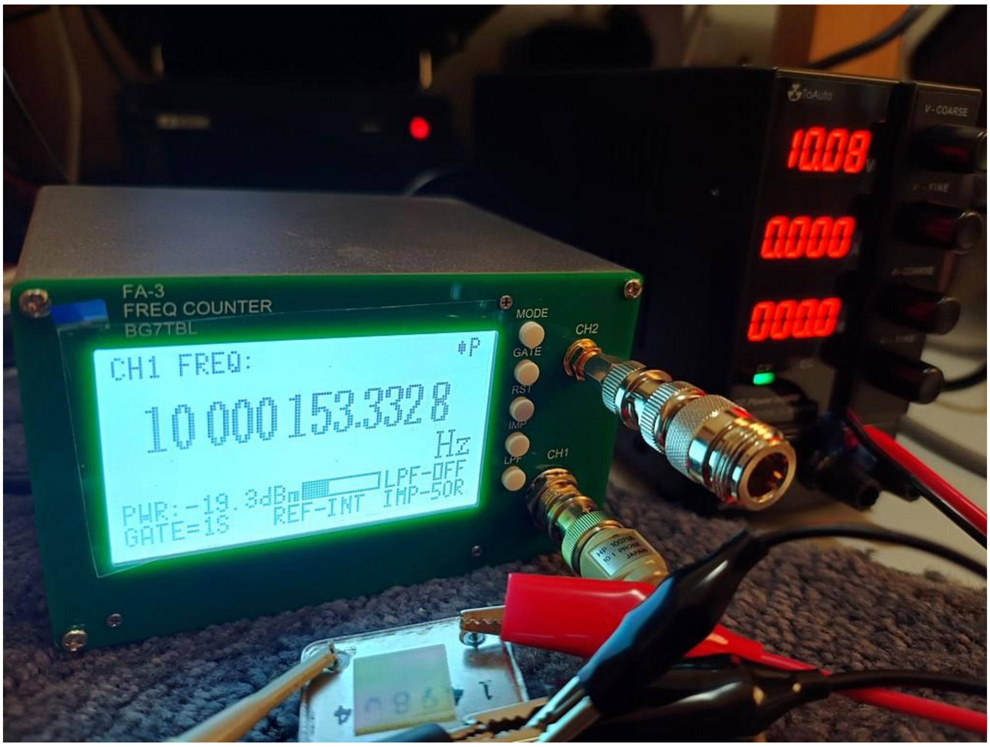
So now we get to fix stuff.

<u>Part A</u>



Top left = original diecast encased module, top and bottom.
Right top = TCXO module.
Bottom = Reference module with TCXO removed.

After removing the crystal module from the PCB, and setting up a test jig, it showed exactly what I had originally thought, phew!!! Errors of 100-300Hz and not anywhere close to spec at all. Pulling the control pin to ground or 10Vdc (in the actual circuit it could vary from +14V to -14V) again proved the 10MHz was way off by a factor of 10 times worse than any specification. These are pretty specialised and the exact part was going be a real problem to obtain = likely “Unobtanium” status.



External to PCB, TCXO testing shows the bad error!

<u>So lets pull this sucker apart and fix it!</u>

TCXO split apart - with guide arrows to help later on with re-assembly.

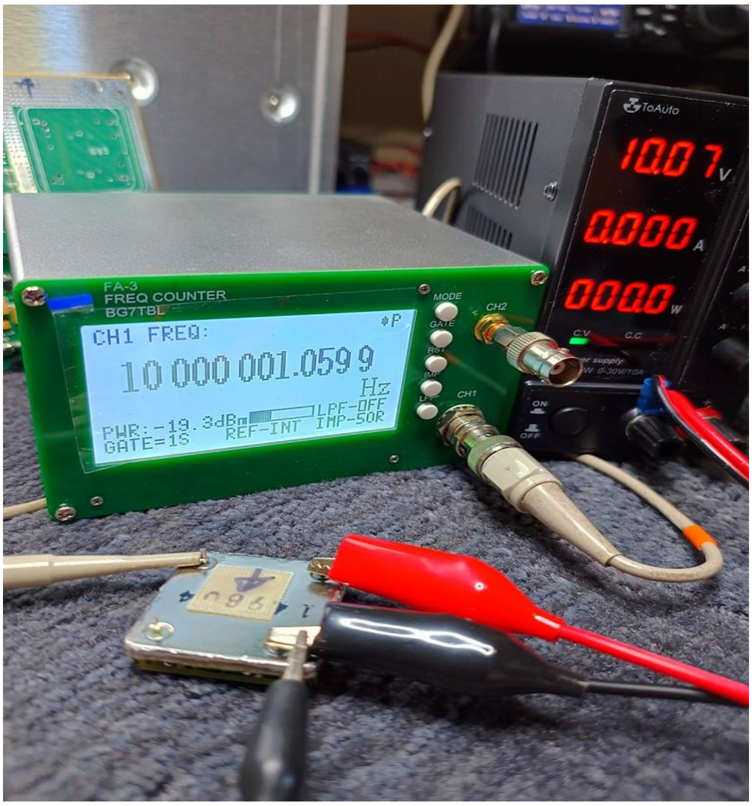
Top view of the TCXO.

In a forum, someone offered this help.

“**Crystals are a mechanical resonance device. They actually move (vibrate) at their resonate frequency, which is the consequence of their mass and stiffness. The stiffness is a fundamental property of quartz, but the mass is a property of the particular bit of quartz in your package. Over time, the vibration of the crystal will cause shedding of microscopic bits of quartz off its surface, thus reducing its mass. A reduction in mass causes an increase in frequency. This is called ageing and is completely normal. Making good crystals involves a lot of cleaning to remove any loose bits of quartz as well as any surface contaminates that are likely to migrate off over time. The best crystals undergo a lot of specialised processing to minimise ageing, but it's not possible to eliminate it completely**.”

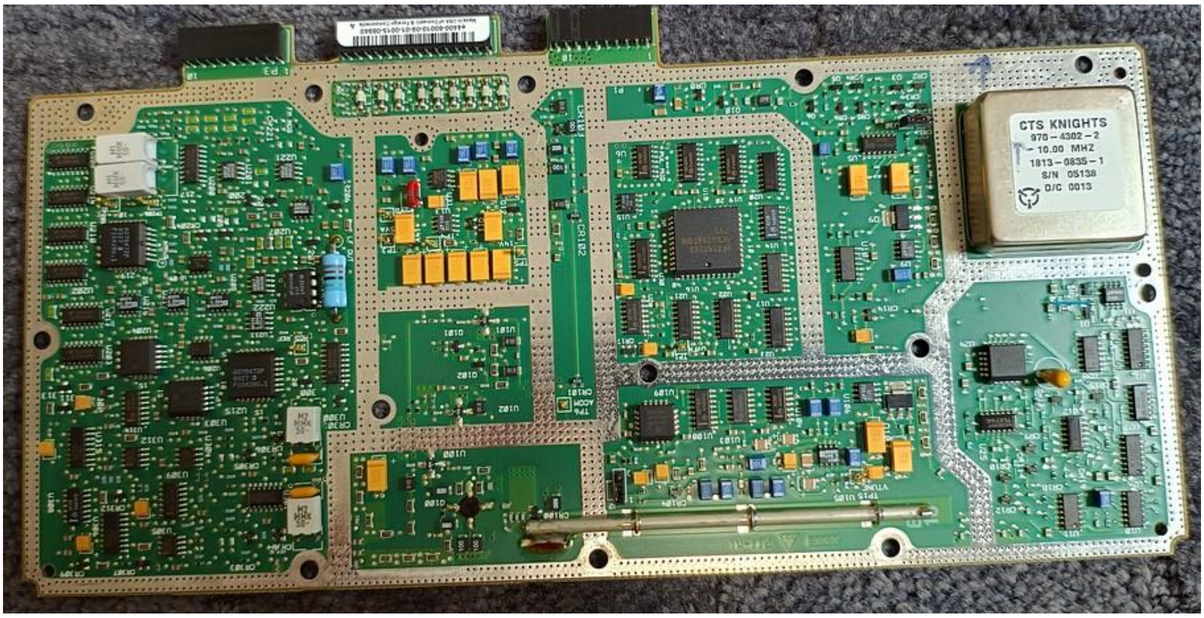
Very interesting and quite correct, a good refresher of some of the things already learnt in previous practice. I again tested the module and verified the crystal frequency was too high for normal use and not “pullable” to frequency by any control voltages. Soldering the crystal connections and hoping thermal shock might fix it, did not. I also noticed some weird jumping of frequency at times. Eventually I put this down to the changed characteristics of the crystal, randomly affecting the oscillator operation.

I attempted several things, like changing the oscillator feedback capacitors, which made a difference, but waaaay toooooo much! After **many** experiments (taking several hours) I applied a 1.5pf capacitor (constructed of 3 x 4.7pf SMD in series) across the crystal, and viola, frequency dropped right into the sweet 10,000,00x area. After heating and cooling it was oscillating reliably and within the desired frequency zone. The quiescent tune pin sitting at 4V was spot on 10.000,001MHz, pulling to ground now 100Hz lower, and 7V was 100Hz higher.



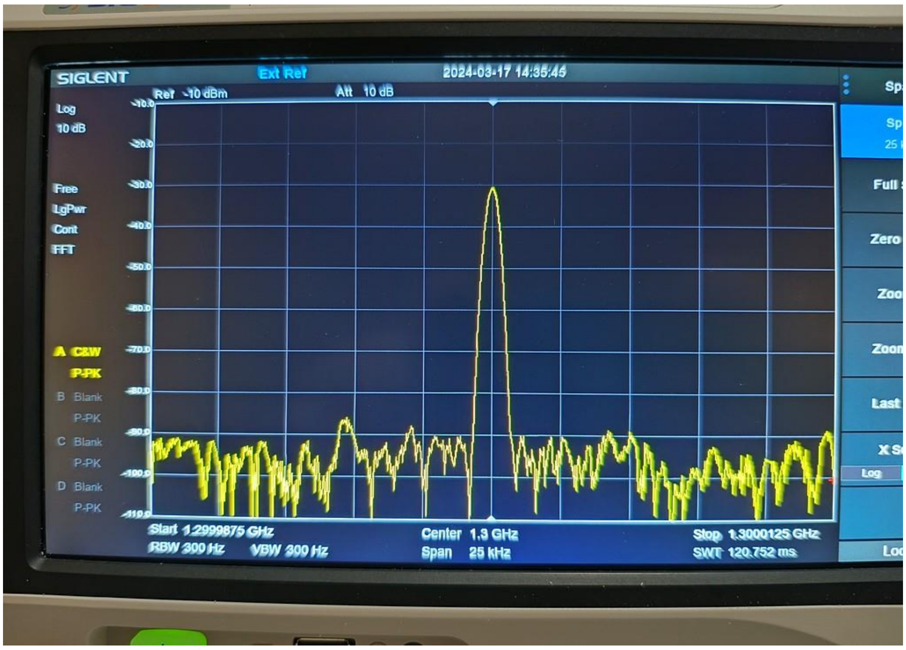
Now we are crystal cooking!

I assembled the TCXO back into its metal case base, rechecked it, powered it off and on many times, then left it overnight to test. Next morning it was still performing acceptably well, so I reassembled the TCXO case and then refitted it to the reference PCB. Yes it must be in the right way, as the arrows line up :)



So now the real test, assemble, plug module in and turn unit on, and pray to the service gods!

Everything looked normal on power on. It was even reasonably close to 10MHz. Adjusting by the software coarse and fine brought it right on target. I then connected the external 10MHz GPS locked reference. Wham, it locked to the EXT REF with no unlocked message. What a relief.



Result above is with everything locked to the external GPS reference and measuring a 3GHz generated CW signal (maximum frequency of the generator) it reveals an error of only 0.36Hz.

Testing will continue for some time. The FA-3 frequency counter spits out the frequency in ASCII code at every poll period (based on the counters gate time). This can be collected and graphed by “TimeLab” software for trending and Allan Curves, (I will find out what they really are one day).

My research on “GPSDO GPS disciplined oscillator units” show they can be accurate to between 1x10-12 to 1x10-13 accuracy, after approximately 1 day of averaging readings with 4 or more satellites received.

10,000,000.0000Hz with 1x10-12 error worst case
0.01Hz error
So at 3GHz the error would be 0.01x300=3Hz.

10,000,000.000000Hz with 1x10-13 best error achievable
0.001Hz error
So at 3GHz the error would be 0.001x300=0.3Hz.

Pretty good reasons why calibration laboratories are using GPS satellites as a frequency reference. Common discussion and measurements are now working to a few parts per **Billion**.

E&OE. I have taken poetic license to simplify these adjustments and calculations, just to demonstrate approximate principles.

Notes: Fess up time. I have had previous experience dismantling and repairing Anacad low noise DC-DC modules, as used in NEC DTV 5KW transmitters. (similar size and format to the crystal reference).

<u>Part B</u>

While checking amplitude and modulation output over whole ranges, I noticed on the spectrum analyser it appeared to be deaf, but only on levels between -32dbm and -52dbm (previous measurements only used at -25dbm or higher for the frequency counter). Above was fine, below was fine. Adjusting the signal level and listening to the mechanical relay operations, all sounded correct at every 5dbm. Powering off and on more than once made no difference. I then went through the whole range from 20dbm to -136dbm 1db at a time and wrote down the mechanical attenuators actions. Hey, now it works again. So now we have a random signal amplitude problem! Oh dear.
Research pointed to the mechanical attenuators (a high output power option) which have miniature O-rings that deteriorate, collapse and sometimes fall off inside the attenuator. These can jam the relays or plungers, as well as reduce the plunger travel, causing intermittent and random, sometimes complete failure of certain attenuation steps. Sounds like a perfect fit. (Did I every say ASS0? = Assume nothing!) So I ordered a set of O-rings. Size required was 2mm OD, x 1.8mm ID, by 0.5mm thick. These are really quite minuscule!

Thank goodness Youtube has several demonstrations on how to dismantle and refurbish these attenuators in different pieces of HP/Agilent gear. These range from 3-6 section units with 70db to 130db either manually or electronic switchable. This appears to be a common problem.

The O-ring kit duly arrived. Out with the attenuator and dismantled with my heart in my mouth!

But what a shock! Not one O-ring showed any sign of failure. (bearing in mind, that in 24 years of use this unit showed a total of 34000 hours of use, 200 power up cycles, and attenuator actions of **8.6 million**.

WOW and WOW). In some products HP boasts of 2 million to 5 million possible attenuator actions life. This one well and truly exceeded that. Quality gear for sure.

Careful examination of the surface of the gold leaf plated contacts revealed some small oxidation and the odd crud build up. Not daring to breathe and working under a bright magnifying lamp, I cleaned all contacts, then reassembled and tested.

Perfect operation again.