Simple Pll using a ceramic resonator.

How the idea came to life to build a simple PLL without a counter or microprocessor.

In 2010 my “homebrew” general coverage receiver needed a stable oscillator. I was fed up to continuously retune the receiver. After a lot of struggling I got a PLL/14bit counter working. One of the problems to overcome was that a PLL tunes in steps. Obviously, when you want to listen to a CW or SSB station you need fine-tuning. The steps my PLL made were about 2,1KHZ. Impossible to tune in exactly to any station, even an SSB station. The way I overcome this was that I made the reference crystal oscillator for the PLL tunable. A crystal can’t be pulled very much but after much effort, the reference frequency of the PLL could be changed so much that the output frequency of the oscillator changes slightly more than 2.1KHz. So in practice, the general coverage receiver has buttons to tune the homebrew receiver close by a station, in steps of 2.1KHz, and finely, fine-tuning is done with a potentiometer (which changes the reference frequency of the oscillator a bit). up to this day, the system works stable, flawless and is practical in use.

Likely there are other ways to fine-tune with a PLL. Ways I’m not aware of. I have no idea how commercial PLL’s manage to fine-tune. I’ve seen schematics with two PLL’s combined. None of these are comprehensible to me. I’m not an EE engineer.
When I started the general coverage project I hadn’t even realized a stable oscillator is a must and had only a faint idea about PLL controlled oscillators. Accordingly, I was very satisfied with my homebrew result and solution for fine-tuning.

The best tutorial on how a PLL works, in my opinion, is “Phase-locked loops” by Tony Van Roon, VA3AVR, easily found on the net. Tony describes the circuit without complex math, no need to repeat that here.

Fed up with listening alone on the shortwave bands I decided to try a transceiver. Something simple, a CW only 40/30/20M band set. So I needed a new stable oscillator. To speed up the project I bought a modern DDS kit at “Kent electronics”.

Above you can see the modern magic circuit in the middle of the front panel of the CW transceiver. It tunes from 0 to 60MHz. There is nothing (!) wrong with the kit, however very soon I got dejected with the DDS.

Several reasons, the tuning range of the DDS was overkill and out of place for a simple homebrew 40/30/20M CW band transceiver. Additionally, all the circuit blocks were copies of other people's projects and I had the feeling nothing of me was inside the transceiver. Starting from 2014 on the first QSO's were made with the transceiver but by using a kit for the one circuit that's crucial for success, a stable oscillator, made achievement hollow. It felt like cheating on an exam. Another major reason for the dissatisfaction was that the kit had no quick way to switch between frequencies. So the consequence was I needed several seconds to switch between transmit and receive, a plain hindrance for a practical CW transceiver...

So scrapping the DDS? hmm... A free-running oscillator is no option and a Crystal or ceramic resonator oscillator can't cover a complete CW band. Replacing the DDS with another homebrew PLL was logical but I was not looking for worth to build a new one. Lots of work and an additional problem was that the PLL only needs to tune three small portions (CW) of three already small band on shortwave. Anything more is in fact again overkill. I have actually no knowledge of how to program a PIC microprocessor. The wide range control circuit for the PLL of my general coverage is made with a 14 bit counter made out of four standard logic IC, the control of the counter with four 555 timer IC's, pffff, building such an elaborate circuit is fun once, but probably teeth grinding the second time 😊. How to solve the fine-tuning problem however was easy, I already knew a solution, use a tunable reference oscillator.

At one point I had an idea. The planned PLL oscillator only needed three relatively small frequency ranges... What if I used a ceramic resonator instead of a crystal in the reference oscillator? A ceramic resonator can be pulled much more than a crystal. Could it be pulled enough so that, if the PLL only had one fixed oscillator division, the output frequency covered a complete CW band? Now that would simplify things! No need for a 14 bit counter! But if so, would the frequency be stable enough?

A search on the net learned me that there are no examples to be found of PLL"s with such an approach. Moreover, I can't even find a schematic of a "normal" PLL that uses a resonator instead of a crystal. I guess resonators are presumed to be too unstable for PLL. A sentence in the online book "From crystal set to sideband" from Frank W. Harris, came to mind, "never assume anything".

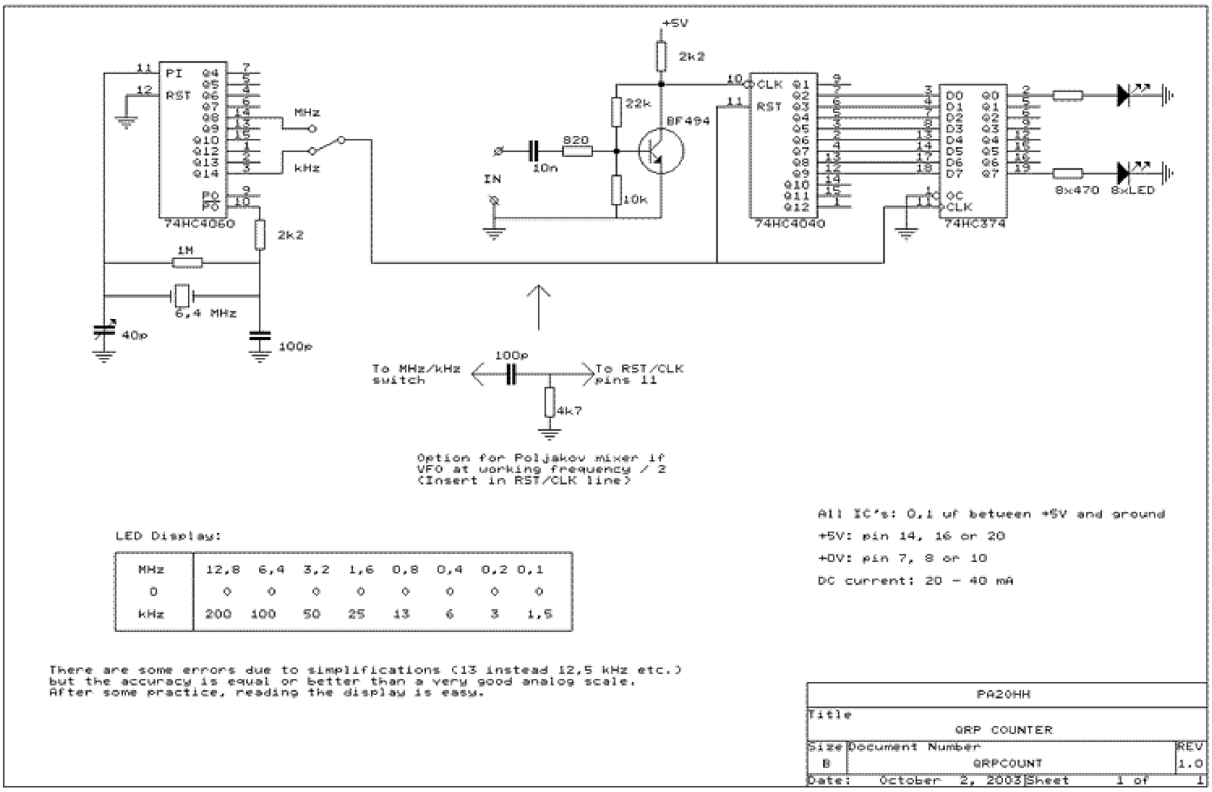
The planned PLL should cover from 7,000 to say 7,040 MHz secondly from 10,100 to 10,150 MHz and finally 14,000 to 14,070 MHz.

Quick calculations learned me that it was not unlikely that, if the reference oscillator of a PLL was controlled by a resonator, it could be pulled enough so that the PLL covered more than that, just by tuning the reference oscillator alone.
Therefore avoiding lots of PLL control

circuitry. Only one way to find out.

The test version.

A KISS frequency counter is the first thing I needed. Luckily I had one made in 2008. The KISS frequency counter is easy to make, uses standard components and is accurate. It was too cumbersome for use in the wide range general coverage receiver it was intended for and was swapped with a PIC frequency counter. So, it was ‘gathering dust’ anyway.



Being rude over the simple design, it is perfect for a three-band narrow range CW transceiver.

I never could find the 6,4MHz crystal as specified and used a 6MHz crystal so my version measures wrong. But that's not the point, the point is you have an exact idea where you're at, where you come from and able to go back on a previous frequency.

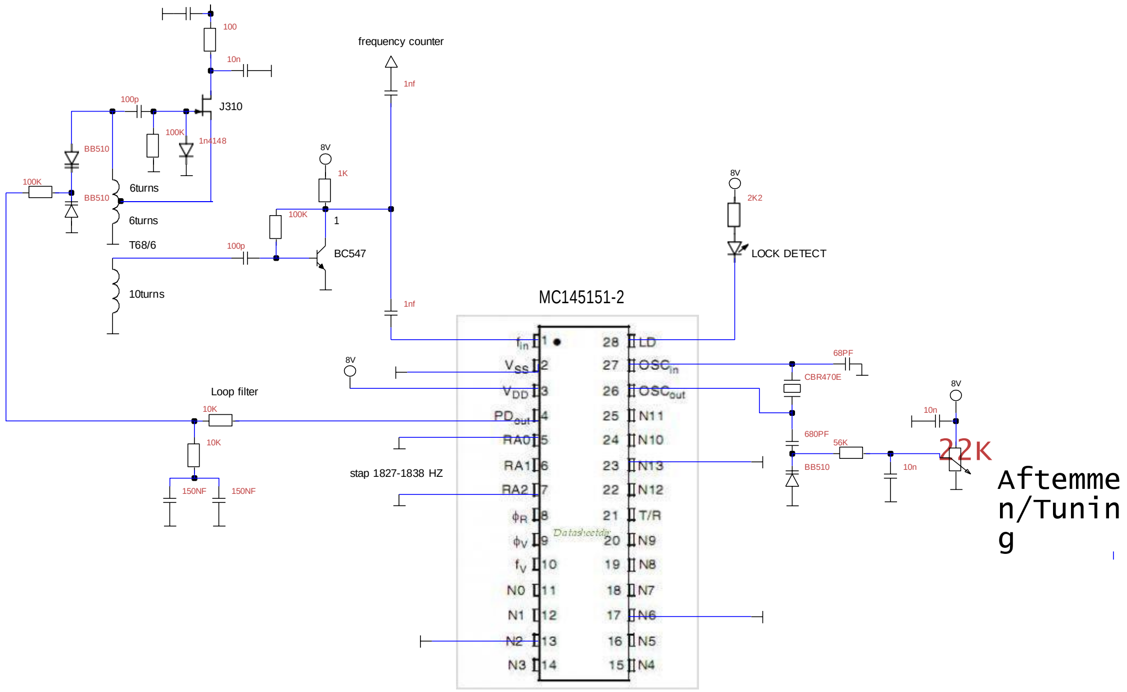
The whole concept of the KISS frequency counter fits exactly in with a simple three- band CW transceiver and is practical and fun to use in that application. A humble BC547 will also do instead of the BF494. How this clever circuit works is described on the website of PA2OHH. A site well worth visiting.

The second thing I needed was a PLL IC. I guess modern PLL chips are in SMD packages and have a serial control port. Because I'm not skilled in programming microprocessors I need a PLL chip with a parallel control port and preferably a DIL package. Such a chip exists, the Motorola MC145151-2. It is obsolete but can still be purchased on eBay. By accident, I bought an SMD version in China. I managed to solder on it but after many experiments, one of the lead broke off and then I bought two DIL package versions in Great Brittan. There are many fake electronic parts around on eBay but all three IC's were "the real thing". And they were cheap too! The DIL versions cost 7 Euro.

First I tried a one band version to test the principle and especially the stability. Tuning is done with a BB510, 500pF varicap. For a short while, BB510's were available via a regular internet dealer. BB510's are in SMD packages and my very young colleague Robin soldered a couple of them for me on a piece of PCB. Eventually, he forced (!) me to try to solder a BB510 on a piece of PCB, and yes, I managed 😊. Obtaining such MW varicaps isn't easy. BB212's should do just a well and I've seen many on eBay. By using a temporary potentiometer control for the varicap it's easy to establish if the tuning range of the oscillator you've built falls into the frequency range you need.

Hooking up the MC145151-2 is pretty easy also. The chip has an internal oscillator. Frequency of the ceramic resonator is 470KHz. It can be pulled from 467,7KHz to 470,5KHz with a varicap. At the time I was very surprised it couldn't be pulled more. Surely it can be pulled more but eventually, it was enough for my purpose.

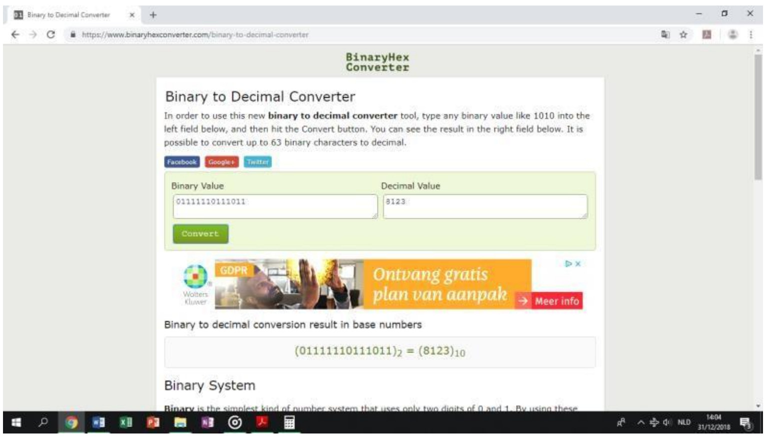
Pins 5, 6 and 7 set the reference frequency division (RA0, RA1, RA2). They have internal pull up resistors so all that's needed are connections to ground to set the division. RA0 and RA2 are connected to ground which results in a division of 256 according to the datasheet. So the frequency "steps" the PLL will use are 467.7/256 = 1827 HZ minimum and 470.5/256 = 1838 HZ maximum, depending on the tuning of the reference frequency.



The test circuit.

Output to control the oscillator is taken from PD, pen 4. Input is fed to pen 1. Also using the “lock detect” output is very handy, always good to know what’s going on.

Leaves us the oscillator divider setting. Normal PLL’s are tuned via this division. My goal was one fixed setting and thus avoiding **lots** of circuitry (and work). Here comes the parallel port of the MC145151-2 at its best for simple home brewing. The division is set with pin’s N0 to N13. 14 bits to be set. N13 is the most significant bit, N0 the least significant bit. These pens have also internal pull-up resistors, an open pen is, therefore, a 1 and connected to ground 0. The division must be set with a binary number, luckily there are online convertors for guys like me.



The setup was just a test so I didn’t do much effort to end up in the right frequency range, as long as I ended up at a frequency my test oscillator can actually work, I’m okay. The division was set on 8123. The output of the PLL was directly connected to the varicaps, yes, without loop filter. The output of the oscillator would obviously not be clean but this way I'm sure that if there is no lock, at least the loop filter isn't to blame.

Plug and pray.

The test circuit worked just as expected from the start. The final test circuit above tunes indeed from (1827x8123=) 14,8MHz to (1838x8123) =14,9MHz.

100KHz, much more than any ordinary crystal VXO. The circuit behaves like a VXO multiplier. Stability was beyond expectation.

Something to watch out for. Not all ceramic resonators are stable enough. I had to try some out of my junk box before I had a useful prototype. The modern tiny resonators are completely hopeless. The big ones are the ones you need to try.
Another thing to watch out for with an MC145151-2 is the numbering of the oscillator divider pin's, N0 to N13. N0 to N9 are successively located from pin 11 to
20. The last four bits are not successively located. N10, N11 is "swapped" with N12, N13 location wise. Don't be fooled like me and lose lots of time trying to understand a glitch that can be avoided with a little less assumption.

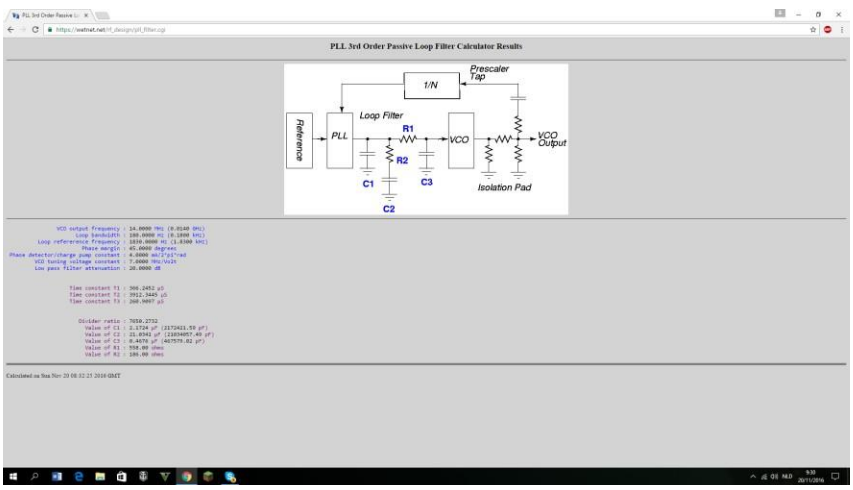
Constructing this PLL isn't so hard if it is done step by step.

1) First, build an oscillator and be absolutely sure its capable of the frequency range you need. This is done by testing the oscillator with a simple potentiometer control.

2) Do the Pll divider calculation right, not very difficult with online calculators.

3) Hook up the PLL temporary without a loop filter, this way you are sure you can't have any loop filter lock problems.

4) Finally, the loop filter… Without, the control pulses make the output frequency unusable. The filter must filter out the control pulses yet not be to narrow or the PLL loses its lock. It's a very complex piece of math for anyone who has not much more than basic mathematical skills, someone like me. Again online calculators help out.

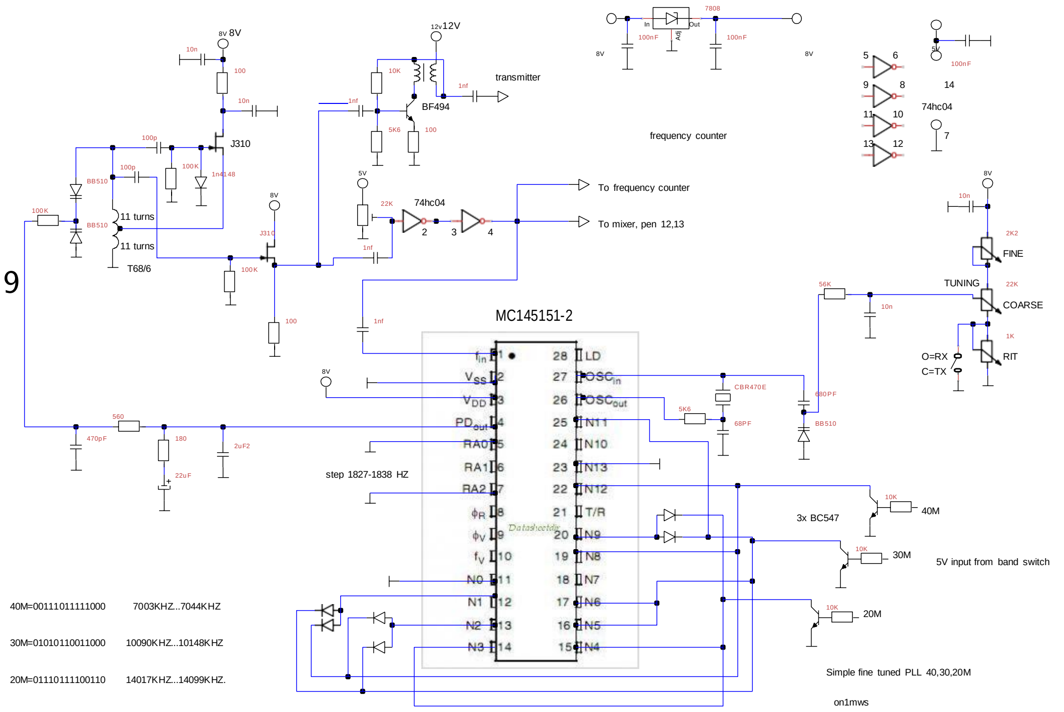


You have actually a choice of selecting a calculator. The one thing every calculator asks is the filter bandwidth. This must be 1/10 of the reference frequency, in the case of my PLL that's 183HZ.

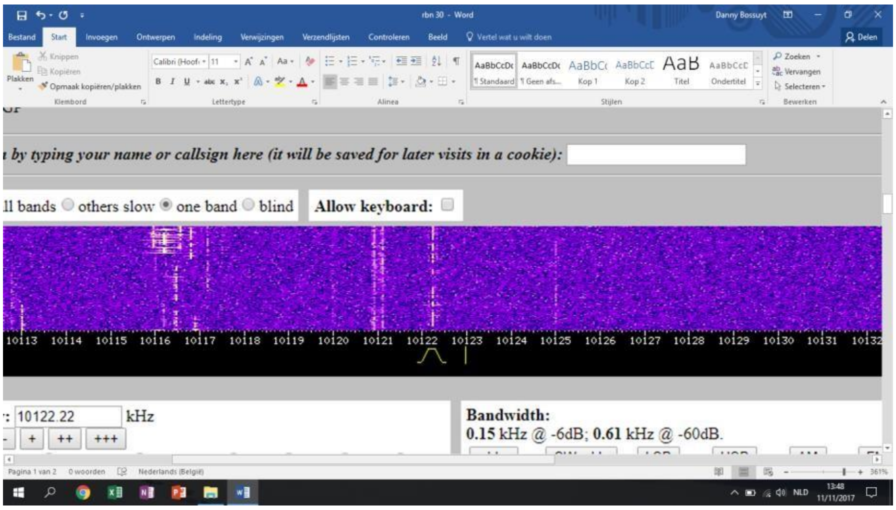
Final version.

Satisfied and amazed with the test I started the three-band version. It's basically the same but now with three oscillator division settings. A front panel band switch lets one of the transistors conduct. Diodes are used to "isolate" one binary setting from another.

Eventually, the finished oscillator can be tuned from 7003 to 7044KHz, from 10090 to 10148KHz and in conclusion from 14010 to 14099KHZ. Precisely the ranges for CW on the 40/30/20 M band. Nothing more, nothing less. Notice that the range gets greater if the frequency is increased. Also, it was very easy to add RIT control.



Stability is up to this day (2021), five years on, perfect. When I tune into a station I never have to re-tuning. The potentiometers are normal ones. Not expensive ones. At the start I worried that crappy potentiometers could rain on my party but after all these years I'm sure they are not critical.

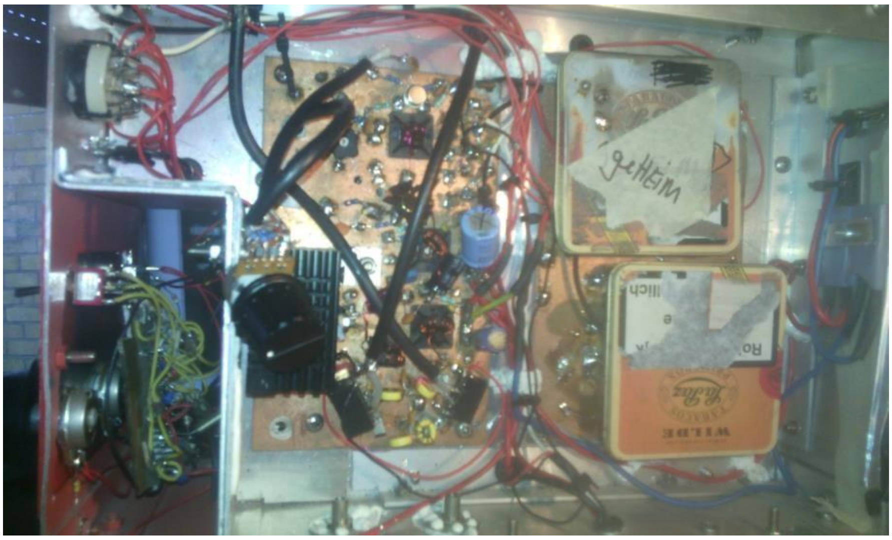


Here you can see the oscillator signal, transmitted with the onboard QRP PA stage, on a web SDR receiver. It looks good and it sounds good.

A picture of the final oscillator.

The “transmitting” circuits of the transceiver are soldered in cigar boxes I get for free from Patrick, a smoking colleague. I’ve become a huge fan.. very practical and effective.

On the left the PLL chip and on the right the, later on added, loop filter. Up to this day, I’m astonished by the stability coming from a small yellow block component.



Because I never found any circuit on the net that resembles the “simple PLL” I wrote “geheim (=secret)” as a joke on the PLL box.

And here the end result. The KISS frequency counter fits the simple transceiver concept like a glove. In the middle the main tuning knob, to the right the fine- tuning. It feels like you’re tuning a free-running oscillator, just as accurate, but **hidden is PLL stability**. The RIT control, the knob on the left, and the one-switch R/T makes the simple homebrew PLL far superior to the previous DDS kit in use.

What I love about it is its simplicity. Besides the PLL chip, there is not much more circuitry. Construction isn’t so hard with the help of online calculators, eBay and a step by step approach. And it is pretty cheap compared to a DDS kit.

Tuning with a PLL combined with a “poor man’s” ceramic resonator turned out to be a viable option. The circuit has perhaps more potential. Higher frequencies must be possible and the tuning range increases with increased output frequency. I wouldn’t be surprised this circuit could tune the complete 40M band in a super heterodyne receiver. Also surely it must be conceivable to pull a ceramic resonator more in frequency than I did. My circuit, however, fits its purpose so I’ll leave it alone.

The DDS kit has a future as a signal generator ahead, a much more suited application for that modern marvel.

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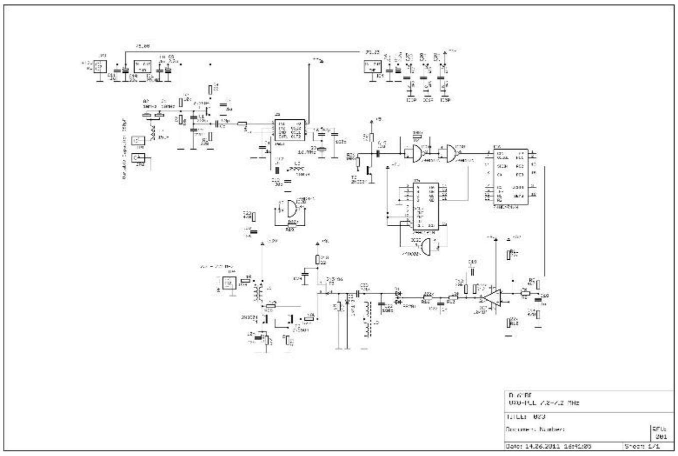
Any comment or critic is welcome.

In 2021 I run across ‘The Flexible VXO-PLL’ designed by Rolf Heine “PLL/DDS frequency generation systems are complex and need sophisticated programming and measurement. On the other hand a lot of home-brewers don't want to use microprocessor driven PLL circuits or DDS systems, although they don't want to miss rock stable frequency generation. Here is a simple, low-cost but very effective solution for this. DL6ZB”.



Rolf doesn’t use ceramic resonator but real crystals but besides that his design has the same basic idea. Rolf’s design also uses standard logic IC’s which are still on sale at ridiculous low prices.

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