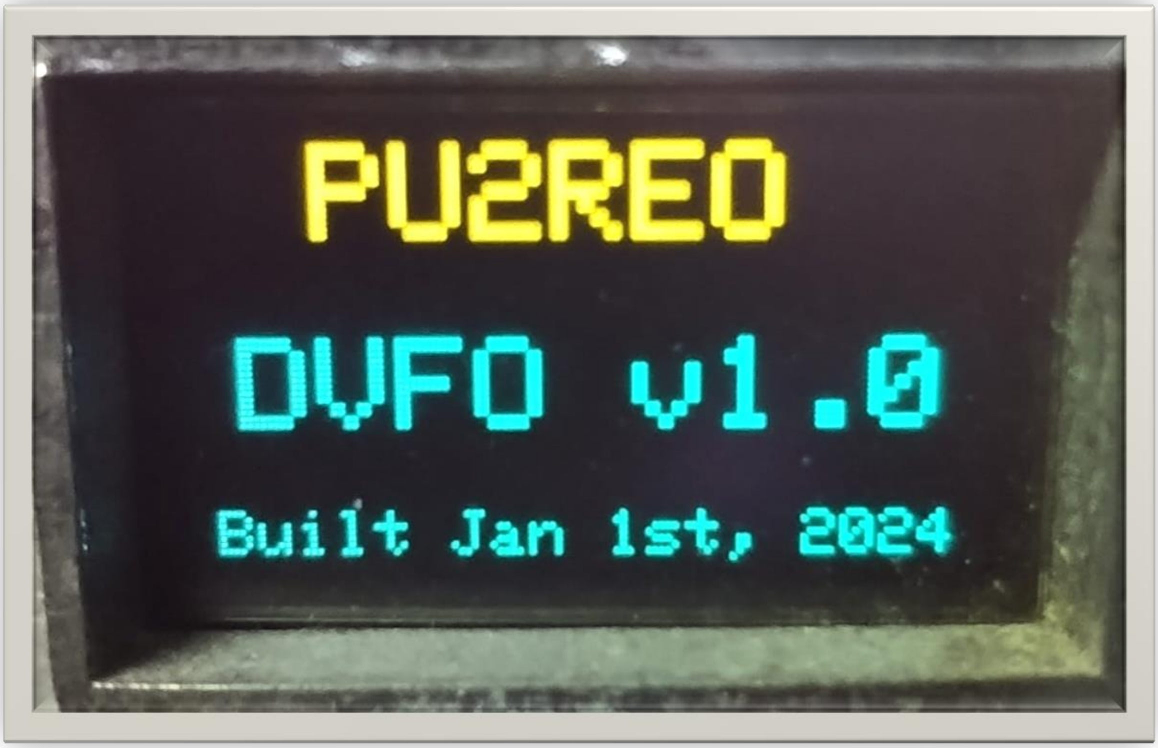


PU2REO – Digital Variable Frequency Oscillator v1.0

User & Technical Manual

1. Preface

All the things you're about to see had started a long time ago, when internet was about to be invented. Me and my Late Cousin Leme – may his soul rest in peace – spent countless nights thinking about how we could improve VFO systems applied to CB radios, our passion at the time. We had no Google.com at the time and manufacturers were reluctant to provide technical information, even electronic schematics and Integrated Circuits documentations. Long story short, all information we had at the time were from empirical tests and studies.

Time has passed and now, almost all information we need is a mouse-click away.

Time to revive an old dream.

2. Disclaimer

All the things described below requires specific knowledge in Analogic Electronics applied to CB Radios and its operating modes, programming, schematics reading and interpretation, soldering and removal of soldered components. So, decide to do it or not at your own risk. You can easily burn out your equipment or damage it beyond the repairing, and I cannot be held responsible for it.

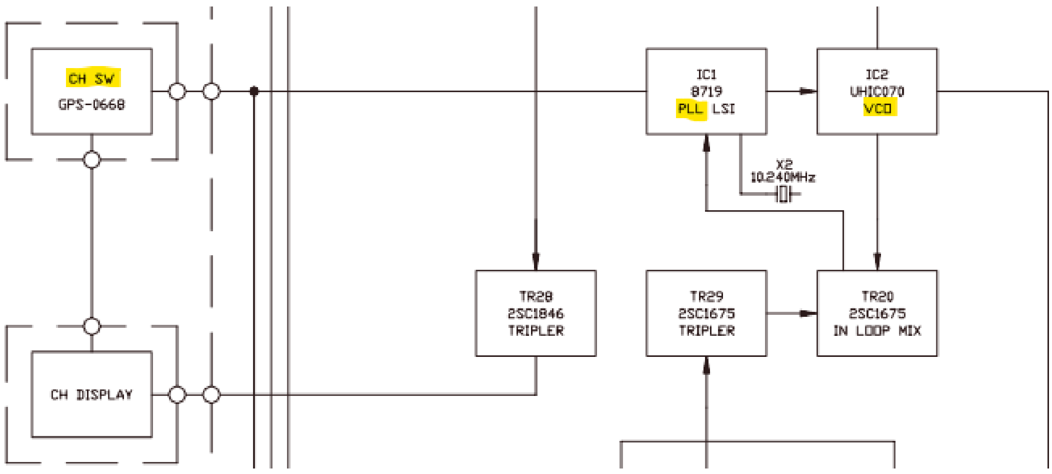
3. What do VFO, VCO and PLL mean?

According to Wikipedia[1], *a* ***variable frequency oscillator (VFO)*** *in electronics is an oscillator whose frequency can be tuned (i.e., varied) over some range. It is a necessary component in any tunable radio transmitter and in receivers that works by the superheterodyne principle. The oscillator controls the frequency to which the apparatus is tuned.*

By the same source[2], ***a voltage-controlled oscillator (VCO)*** *is an electronic oscillator whose oscillation frequency is controlled by a voltage input. The applied input voltage determines the instantaneous oscillation frequency. Consequently, a VCO can be used for frequency modulation (FM) or phase modulation (PM) by applying a modulating signal to the control input. A VCO is also an integral part of a phase-locked loop. VCOs are used in synthesizers to generate a waveform whose pitch can be adjusted by a voltage determined by a musical keyboard or other input.*

Last but not least, ***phase-locked loop or phase lock loop (PLL)***[3] *is a control system that generates an output signal whose phase is related to the phase of an input signal. There are several different types; the simplest is an electronic circuit consisting of a variable frequency oscillator and a phase detector in a feedback loop. The oscillator's frequency and phase are controlled proportionally by an applied voltage, hence the term voltage-controlled oscillator (VCO). The oscillator generates a periodic signal of a specific frequency, and the phase detector compares the phase of that signal with the phase of the input periodic signal, to adjust the oscillator to keep the phases matched.*

That said, almost all the 70 and 80's CB radios[4] – taking into consideration some small variances in design – relied on the latter two devices to work: The PLL generating voltage outputs, accordingly to the channel selector, and the VCO taking PLL's output voltage and converting it to frequency.



Part of a Block Diagram from a "Well Known" old CB Radio

[1] Wikipedia, The Free Encyclopedia. Variable-frequency oscillator, Accessed on 12/24/23, 17:15 (UTC).
[2] Wikipedia, The Free Encyclopedia. Voltage-Controlled oscillator, Accessed on 12/24/23, 17:29 (UTC).
[3] Wikipedia, The Free Encyclopedia. Phase-Locked Loop, Accessed on 12/24/23, 17:39 (UTC).
[4] Wikipedia, The Free Encyclopedia. Citzens Band Radio, Accessed on 12/24/23, 17:32 (UTC).

Our main goal, from this moment on, is to design DVFO – Digital Variable Frequency Oscillator, and make it a replacement for the PLL/VCO pair.

4. What's a DVFO?

Putting it simply, it is a variably frequency oscillator digitally controlled.

For our endeavor, we will use two distinct kinds of device: Control Device and Frequency Generator.

4.1. Control Device

It's the device used to control our Frequency Generator, a "CCC"[5] **Arduino®[6] Nano**. For those not familiar with Arduino Family, *it is an Italian open-source hardware and software company, project, and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices. Its hardware products are licensed under a CC BY-SA license, while the software is licensed under the GNU Lesser General Public License (LGPL) or the GNU General Public License (GPL), permitting the manufacture of Arduino boards and software distribution by anyone.*

Arduino® Nano is an intelligent development board designed for building faster prototypes with the smallest dimension. Arduino Nano being the oldest member of the Nano family, provides enough interfaces for your breadboard-friendly applications. At the heart of the board is ATmega328 microcontroller clocked at a frequency of 16 MHz. It is the first embedded microcontroller in the Nano series with minimum functionalities, designed for mini projects from the maker community. With a large number of input/output pins gives the advantage of utilizing several serial communications like UART, SPI and I2C. The hardware is compatible with Arduino IDE, Arduino CLI and web editor and has these main features:

(1) ATmega328 Microcontroller
- High-performance low-power 8-bit processor
- Achieve up to 16 MIPS for 16 MHz clock frequency
- 32 kB of which 2 KB used by bootloader
- 2 kB internal SRAM
- 1 kB EEPROM
- 32 x 8 General Purpose Working Registers
- Real Time Counter with Separate Oscillator
- Six PWM Channels
- Programmable Serial USART
- Master/Slave SPI Serial Interface

(2) Power
- Mini-B USB connection

[5] CCC stands for "**C**heap **C**hinese **C**lone", plenty available on e-stores.
[6] Wikipedia, The Free Encyclopedia. Arduino, Accessed on 12/24/23, 20:32 (UTC).

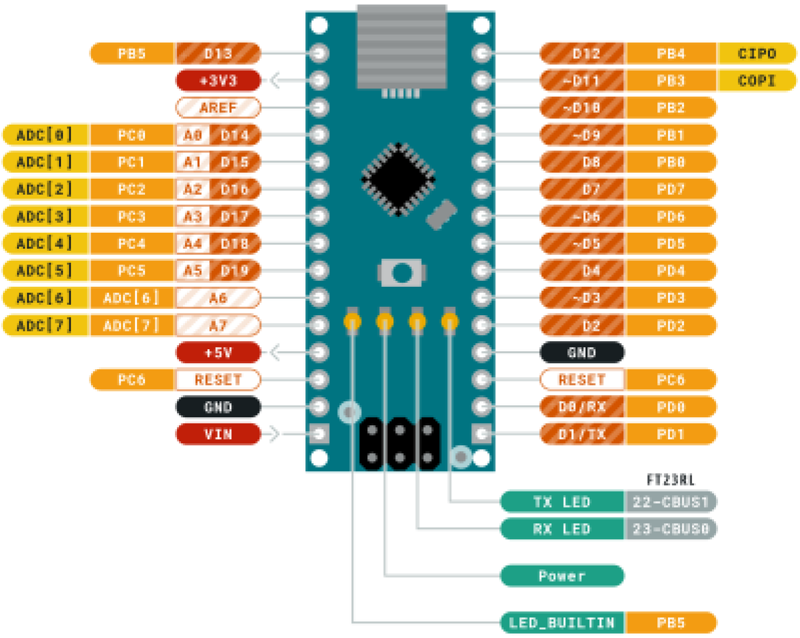
- 7-15V unregulated external power supply (pin 30)
- 5V regulated external power supply (pin 27)

(3) Sleep Modes

- Idle
- ADC Noise Reduction
- Power-save
- Power-down
- Standby
- Extended Standby

(4) I/O

- I/O
- 20 Digital
- 8 Analog
- 6 PWM Output



Arduino Nano Pinout, courtesy of Arduino.cc.

7.2. Frequency Generator

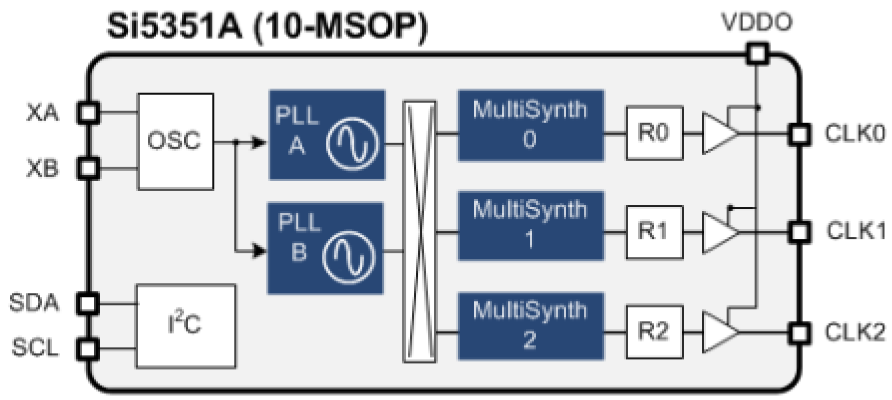
It's the device where all the frequencies needed will be generated, after the calculations/control made by the control device. In this case, we'll be using a "CCM"[7] powered by **SkyWorks' (Former "Silicon Labs") Si5351A - I^2C-Programmable Any-Frequency CMOS Clock Generator.**

[7] CCM stands for "**C**heap **C**hinese **M**odule", plenty available on e-stores.

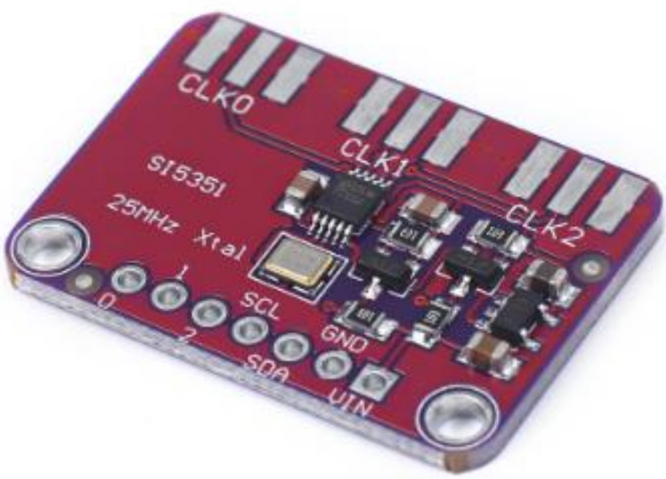
The Si5351 is an I^2C configurable clock generator that is ideally suited for replacing crystals, crystal oscillators, VCXOs, phase-locked loops (PLLs), and fanout buffers in cost-sensitive applications.

Based on a PLL/VCXO + high resolution Multisite fractional divider architecture, the Si5351 can generate any frequency up to 200 MHz on each of its outputs with 0 ppm error. Three versions of the Si5351 are available to meet a wide variety of applications.

The Si5351A generates up to 3 free-running clocks using an internal oscillator for replacing crystals and crystal oscillators.



Si5351A - Functional Block Diagram (courtesy from SkyWorks)



CCM powered by Si5351A – Plenty available in e-stores

All communications between Control Device and Si5351A module will be made via I^2C protocol.

8. Our testbed: Cobra 148GTL - PCB EPT014811Z

Cobra 148GTL – Courtesy of RigPix.com

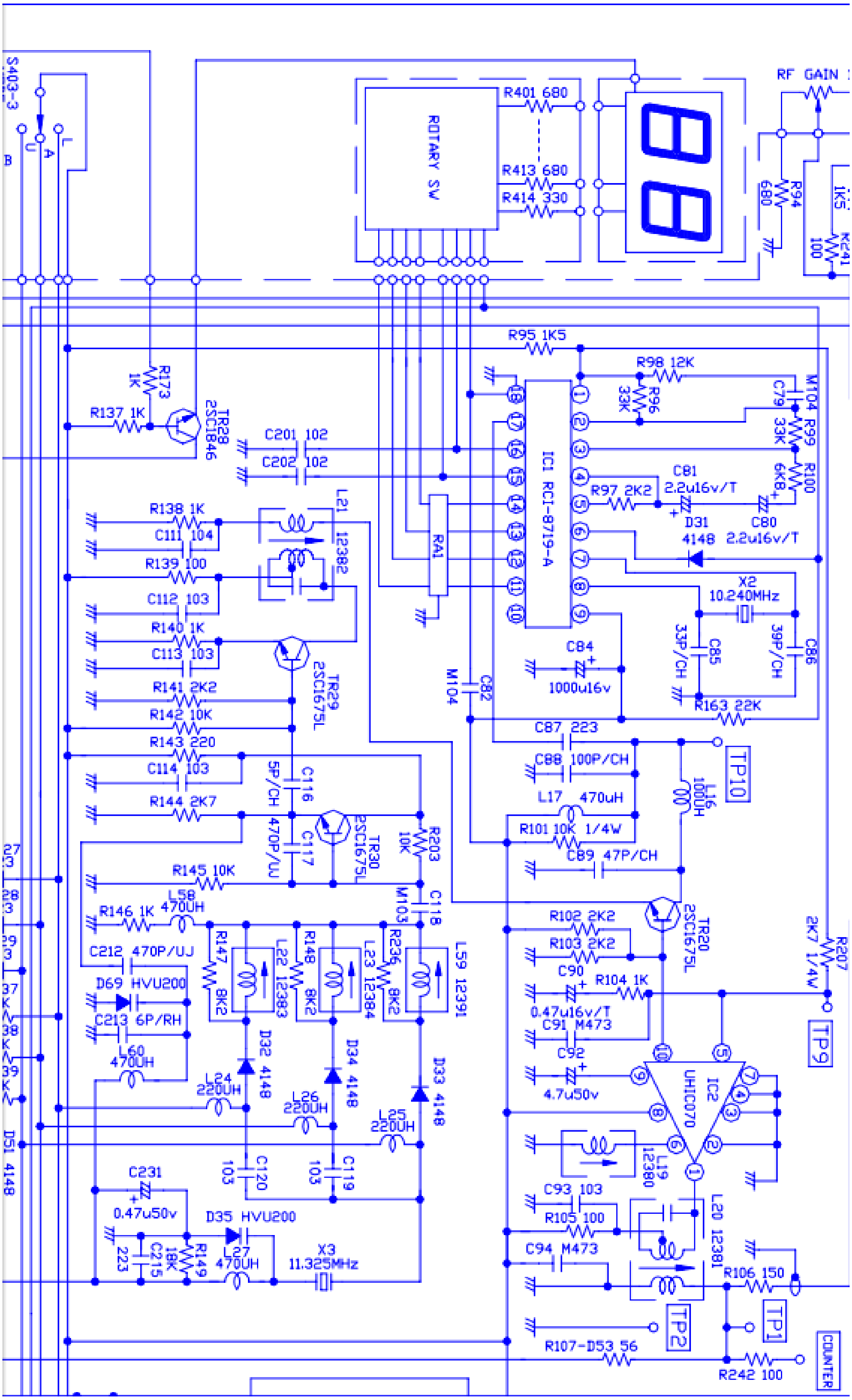
The transceivers Cobra 148 GTL for citizen band were manufactured by Uniden in Taiwan from 1977 onwards for the Dynascan group, being sold by Cobra brand and using the PC-412 board, which was a double conversion design that was also used on the Cobra 148GTL-F, Cobra 2000 GTL, Cobra 2010 radios GTL-WX, President Grant (latest version, PC-409 board), President Madison (latest version, PC-411 Board), Pearce-Simpson Super Bengal Mk II, Teaberry Stalker XX Export version, Uniden Grant, Uniden Grant LT, Uniden Grant XL, Uniden Madison, Handic 3505, Superscope Aircommand CB-140.

Due to its robustness, simplicity, low cost, reliability and excellent reception and transmission quality, the Cobra 148 GTL is one of the more versatile equipment for the radio amateur experimenter, as in addition to being able to be converted into an excellent QRP equipment for the 10 meter range, it can still be used as IF (intermediary frequency) for transverters and converters for other ranges, which makes it a unique piece of equipment.

Although launched in 1977, more than fifty years later the Cobra 148 GTL continues to be the most successful and most loved citizen band transceiver in the world.

8.1. Cobra 148GTL - PCB EPT014811Z – Electronic Circuitry

It's not the main goal here to talk about the whole electronic circuitry of this radio, but only the PLL/VCO part. Let's observe only this section of the radio:

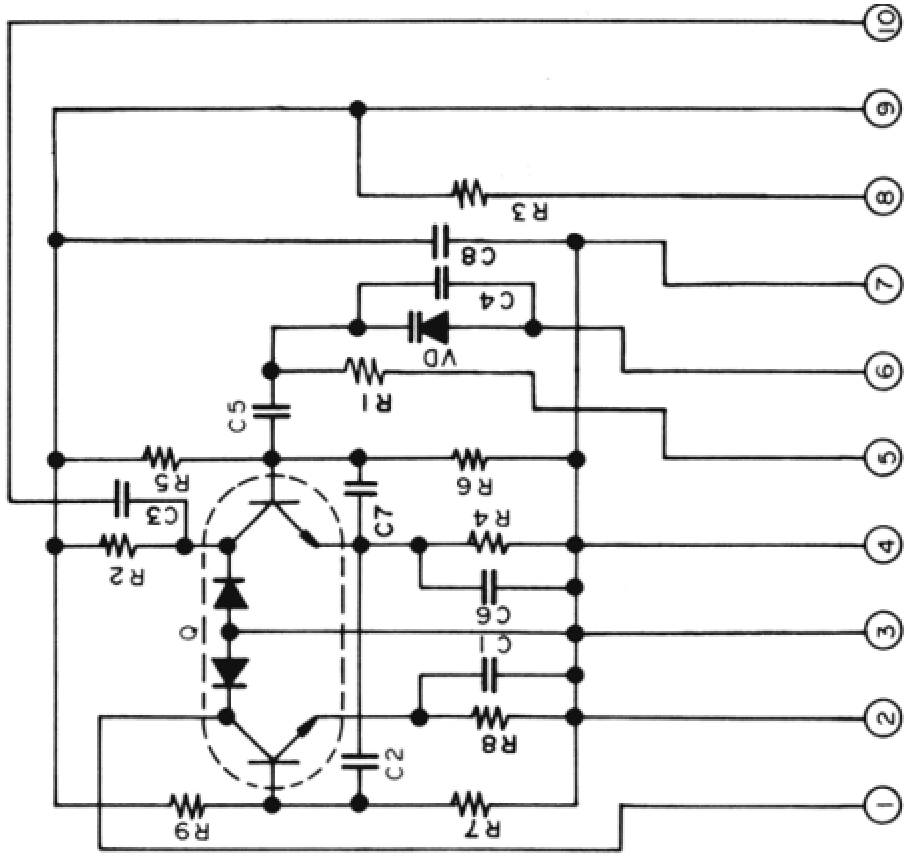


Cobra 148GTL - PCB EPT014811Z – PLL and VCO parts

Main points of interest:

- **IC1 RCI8719** (or MB8719 on the Uniden version of this radio) – This is the PLL and its main job is convert channel numbers from the rotary switch (ROTARY SW) to 40 distinct levels of voltage on his Analog Output 2 (Pin 1), which in turn, will feed varicap diode inside the VCO Circuitry (Pin 5, IC2 UHIC070);
- **TP9** – Test Point 9 – PLL Output

IC2 UHIC070 – This is the VCO Circuitry itself. Based on levels of voltage in its Pin 5, it will output at pin 1 the desired frequency for the CB radio operation;



UHIC 070 – VCO Integrated Circuit (Courtesy of Uniden).

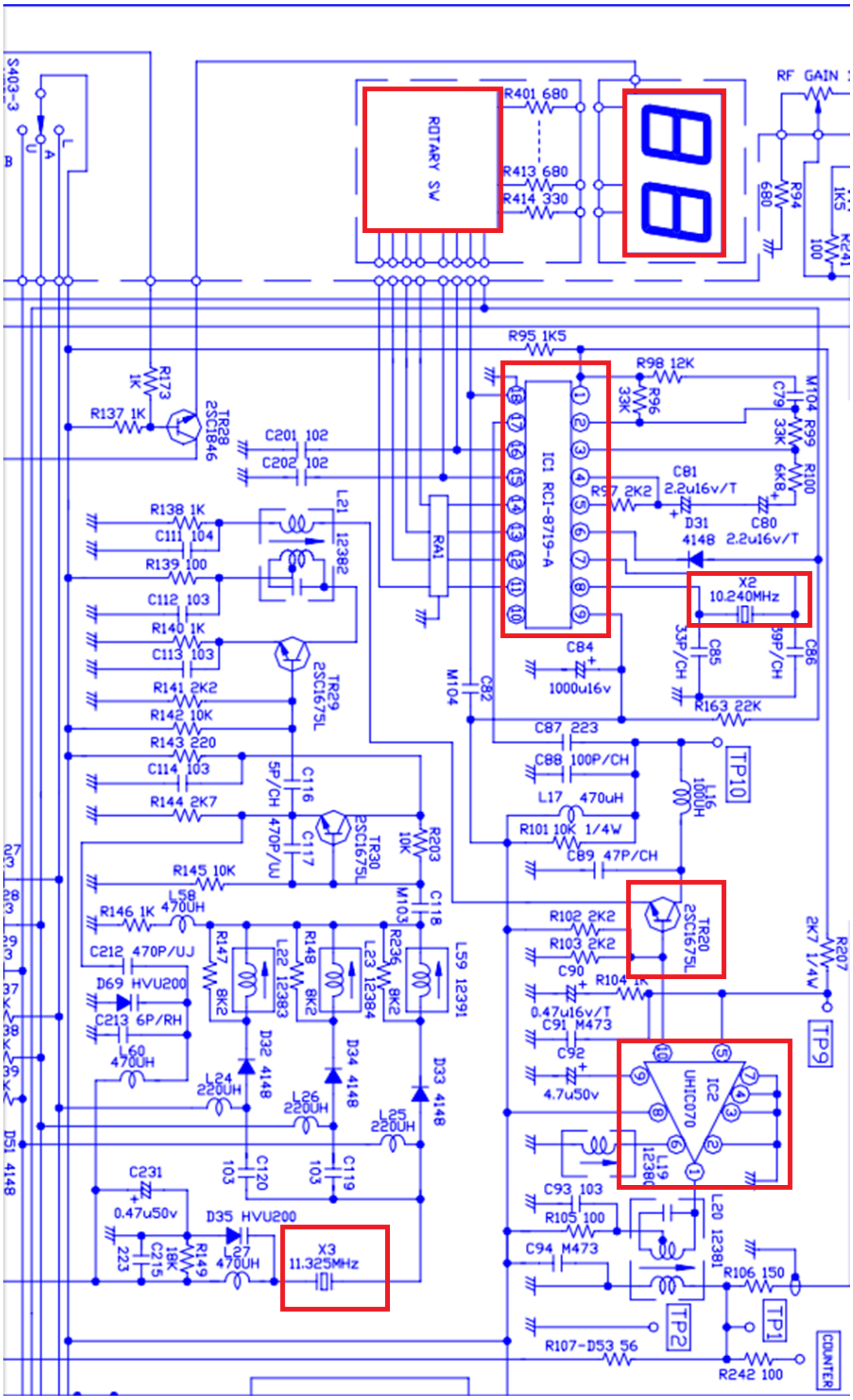
- **X3 –** Quartz Cristal. It's the main base frequency generator for radio channels;
- **Variable Inductors L59, L23 and L22 –** USB, AM and LSB, respectively, channel frequency shift adjustment;
- **TR29 and L21 –** Frequency Tripler. This is the place where the output frequency of **X3** is multiplied three times.
- **TR20 –** Loop Mixer. Returns a frequency reference for the PLL.
- **TP1 –** Test Point 1 – VCO Output. At his Test Point we will have, <u>considering AM Modulation</u>:
    - Channel 1 – 34.765 MHz
    - Channel 40 – 35.205 MHz

Since we're dealing with a new kind of frequency generation, we can strip out some components from the radio so we can put our new DVFO to work.

Remember: If you are no familiarized with Electronics and all that I presented till now means nothing to you, I suggest you to stop reading this at once. Put your radio at a safe place and forget about these modifications.

If you decided to go along, take a look at the next pictures: **All red squared components must be desoldered from the main PCB, removed and stored at a safe place** (you can even earn a few bucks on e-bay with them).

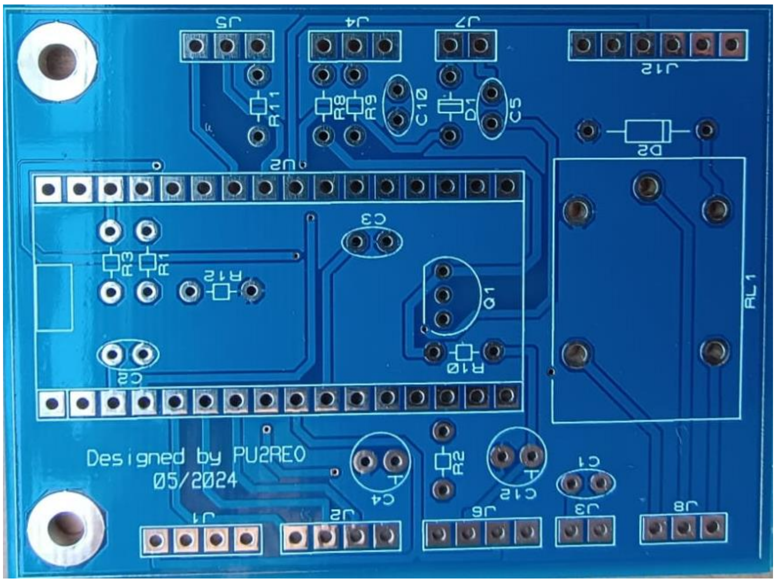
If want to go further, you can remove all components related to PLL and VCO, since they won't be used anymore, but I would call it an unnecessary preciosity.



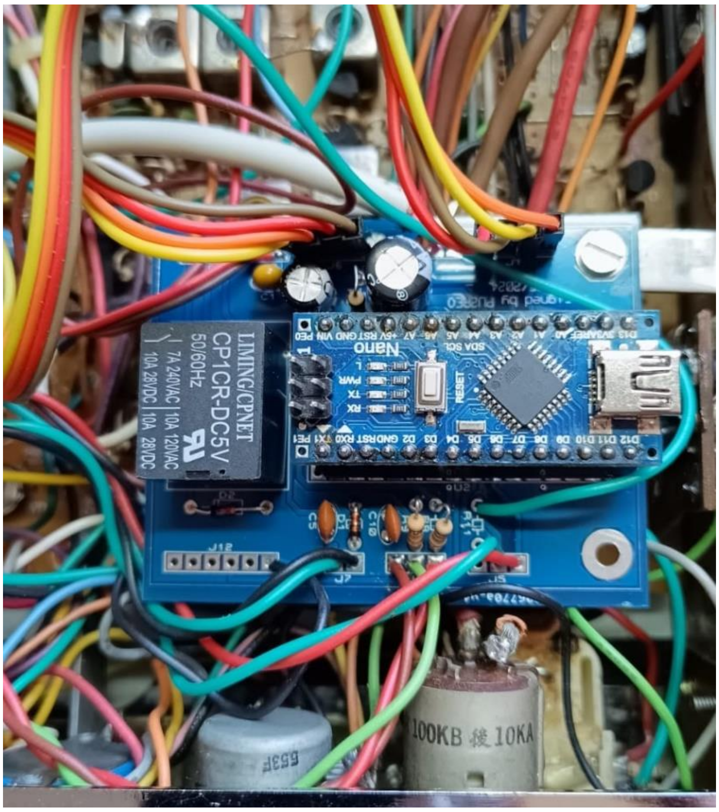
Cobra 148GTL - PCB EPT014811Z – "Red Squared" PLL and VCO parts to be removed

8.2. Putting DVFO to Work

First of all, assemble DVFO into a Universal PCB board, following schematics to the letter, to test it and see if you like it. After that, you can send PCB cad files to some PCB manufacturer of your liking. That’s the steps I’ve followed and now I can present you the final PCB board crude and assembled:



DVFO Crude PCB board.

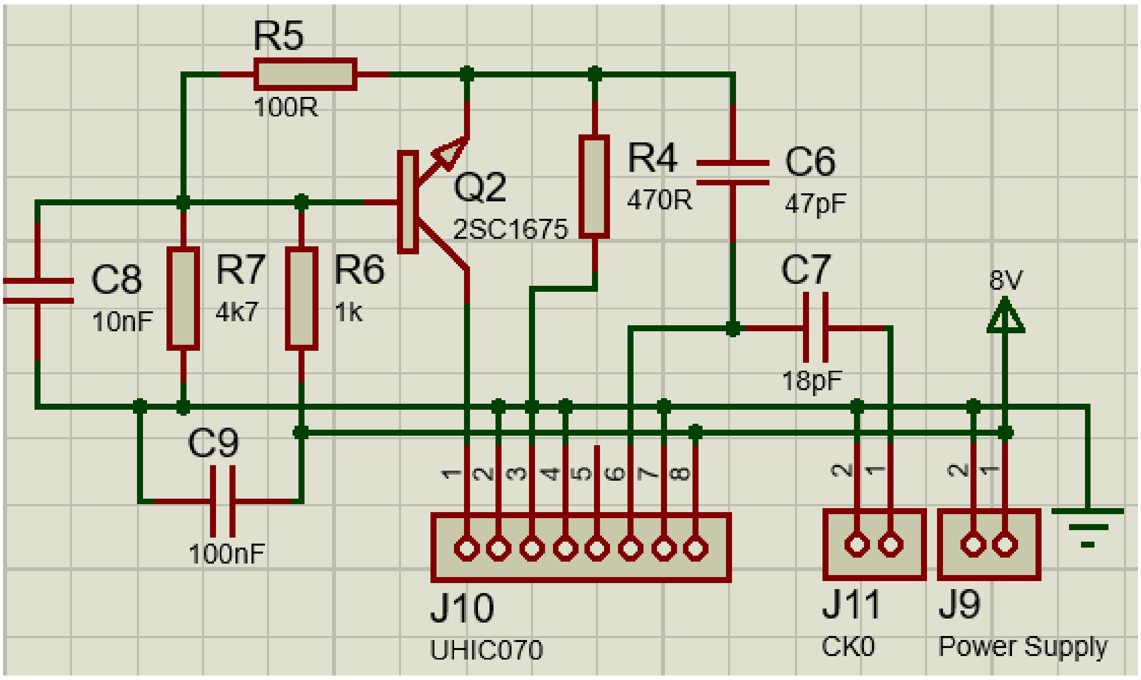


DVFO Assembled PCB board.

Let's get back into business: after removing "red squared" radio components marked into radio schematics, it's time to put DVFO to work.

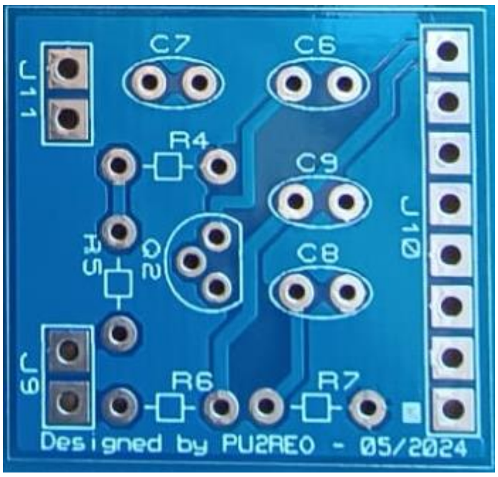
If you took a look at radio schematics, it's easy to identify that **Pin #1 from IC2 (UHIC 070)** is the output of the analogic VFO. So, it's right there we will enter our new generator.

After a couple of tests, I've found Si5351 is not suitable to be direct coupled to L20, due to its low output current and voltage, among other 2 or 3 reasons that are beyond the scope of this manual. There's the point where a small signal amplificatory goes in:

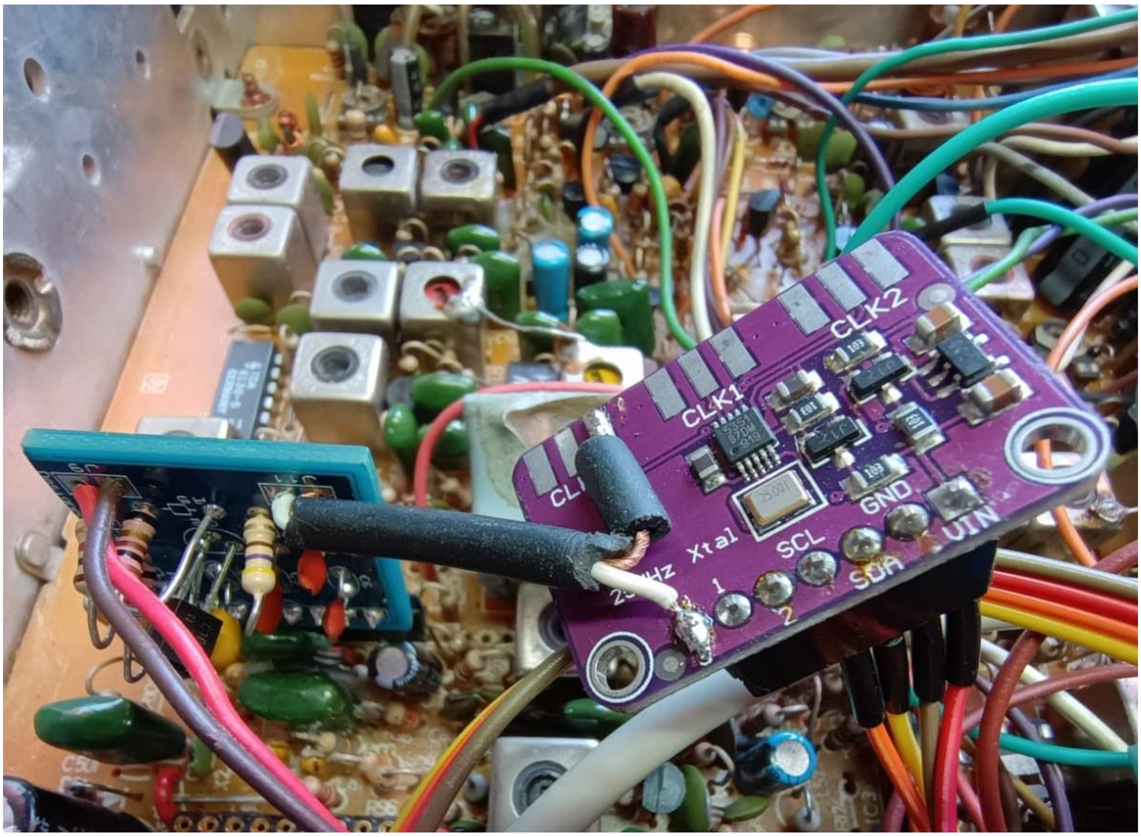


Small-Signal Amplificator (or simply "Buffer") Schematic

To construct this buffer, I used TR20 from the own radio. You can use a BC547 that it would do fine too. The final version of this buffer was assembled into PCB an soldered in the same place where once was UHIC-070.



Buffer's crude PCB



Assembled Buffer and Si5351 Module fitting UHIC-070 place in the main board.

After our DVFO buffer is in place and running, it's time to adjust our DVFO parameters.

9. PU2REO 's DVFO Screens

9.1. Splash Screen

Shows for 1 second when DVFO is turned ON. Shows my call sign and software version.

9.2. Main Screen

or


These are the 2 possible main screens for the DVFO. On the left, showing CB Channel Number and Frequency, and on the right, showing only frequency. How to choose between both screens will be treated later.

In both screens, we can see:

- Signal Strength Indicator (Yellow);
- Channel Indicator (6, on the left);
- Multiple Movement Selector (x 1);
- Modulation Mode (AM);
- Roger Beep ON (RB);
- Channel Frequency (27025.5 kHz)

When in main screen and pressing the encoder button, it will be treated as follows:

- **1 quick press** – Change Multiple Movement Constant (x1, x10, x100 and x1000);
- **1 press and hold for 500ms or more** – Enter DVFO parameters setting mode. To exit Setting Mode, press and hold encoder button once more at any parameter screen;
- **Turning encoder to the Left/Right** – Will decrease/increase Channels/Frequencies at the ratio indicated by the Multiple Movement Constant.

9.3. Parameters Setting Mode

When in main screen and pressing the encoder button, it will be treated as follows:

- **1 quick press** – Change Multiple Movement Constant (x1, x10, x100 and x1000);
- **2 quick presses** – Change from one parameter screen to another;
- **1 press and hold for 500ms or more** – Exits DVFO parameters setting mode.
- **Turning encoder to the Left/Right** – Will decrease/increase parameters values at the ratio indicated by the Multiple Movement Constant.

9.3.1. Display Type

Choose:

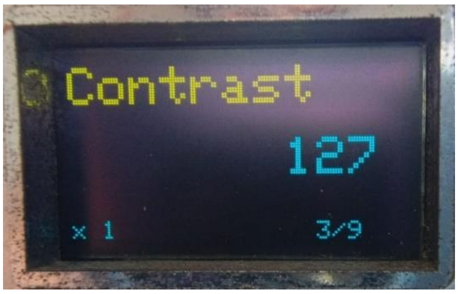
- 0 – To display only frequencies
- 1 – To display channel numbers and frequencies

9.3.2. Roger Beep

Choose:

- 0 – To deactivate Roger Beep when releasing PTT key;
- 1 – To activate Roger Beep when releasing PTT key.

9.3.3. Contrast



Choose:

- Towards 0 – To a darker LCD.
- Towards 255 - To a brighter LCD.

9.3.4. Correction Factor Adjustment Si5351

Use this parameter to set the Si5351 oscillator correction factor.

This value is a signed 32-bit integer of the parts-per-billion value that the actual oscillation frequency deviates from the specified frequency.

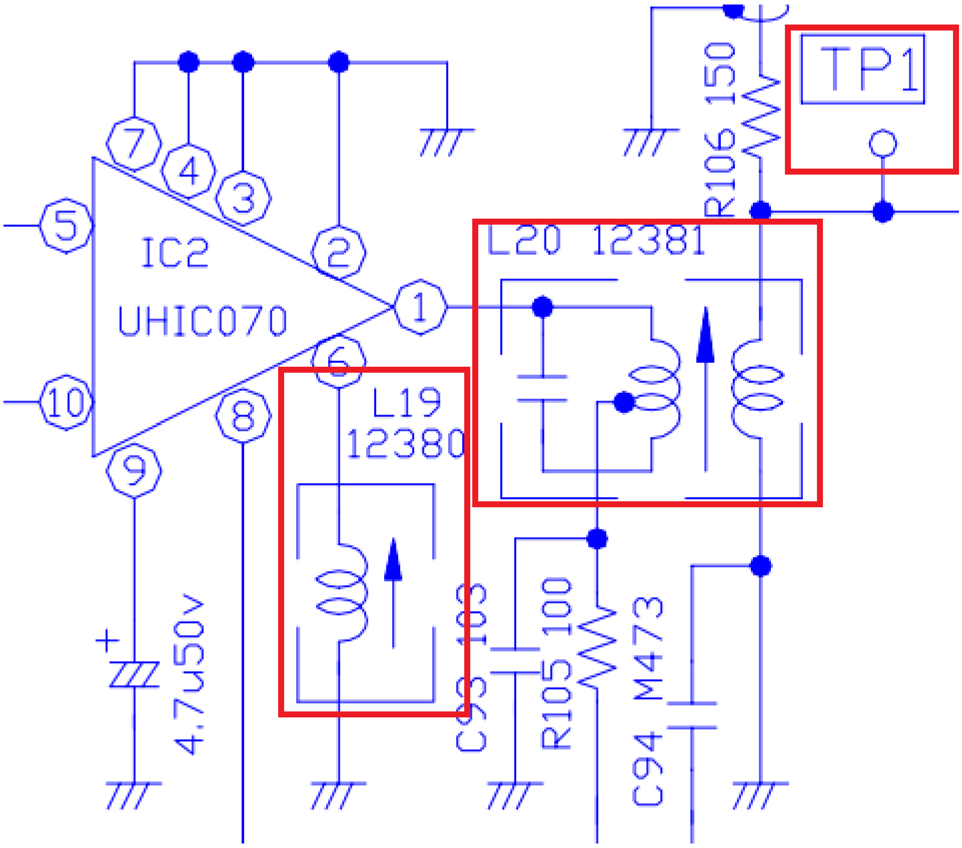
The frequency calibration is done as a one-time procedure.

Any desired test frequency within the normal range of the Si5351 should be set, then the actual output frequency should be measured as accurately as possible, with a frequency meter or an oscilloscope. The difference between the measured and specified frequencies should be calculated in Hertz, then multiplied by 10 in order to get the parts-per-billion value.

Since the Si5351 itself has an intrinsic 0 PPM error, this correction factor is good across the entire tuning range of the Si5351. Once this calibration is done accurately, it should not have to be done again for the same Si5351 module.

9.3.4.1. How to proper set this value

Assuming all the soldering/unsoldering stuff is done, and our DVFO is properly installed accordingly to the schematics provided, set up a Frequency Meter or an Oscilloscope and attach a test probe into TP01, the original VCO output and now, our DVFO buffer output:



Cobra 148GTL - PCB EPT014811Z – L19, L20 and Test Point #1

For calibration purposes, let's assume DVFO is running on CB **Channel 40, i.e., 27.4055 MHz.**

Considering:

- **Intermediate Frequency of the Radio:** 7.8 Mhz;
- **SSB Shifiting:** +1500 Hz (USB) and -1500 Hz (LSB);
- **AM** - no shifting, i.e., 0 (zero).

That said, we just have to do some math:

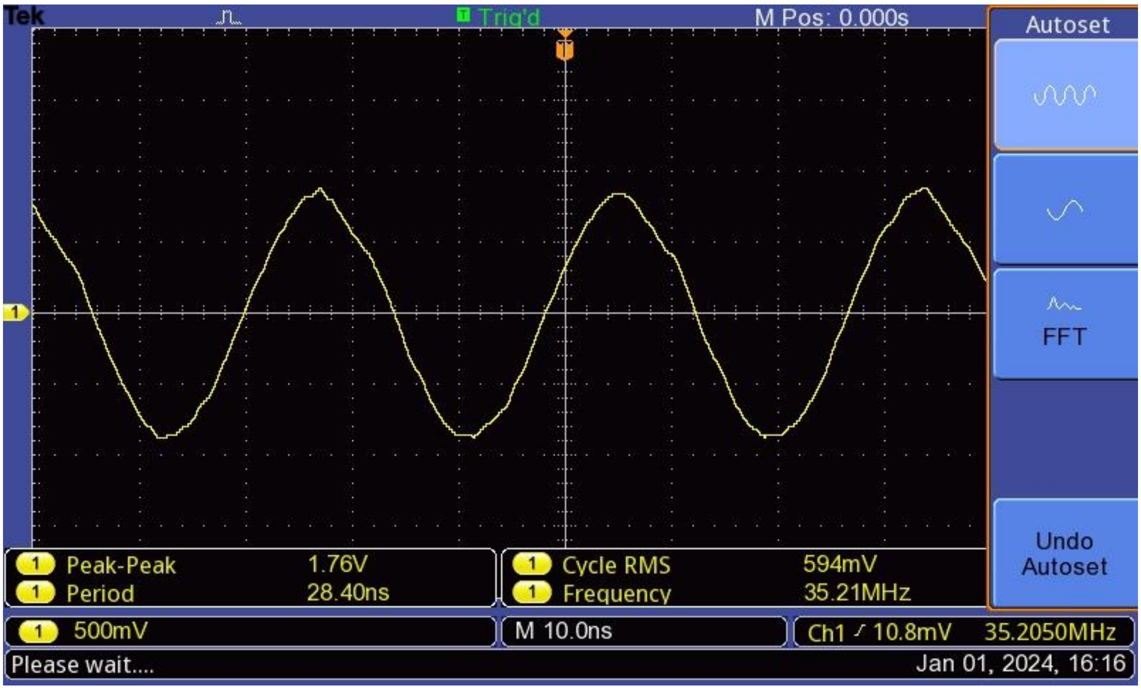
$$Si5351_{Output\ Frequency} = Ch_{Frequency} + IF_{Frequency} + SSB_{Shifting}$$

So, taking into consideration Channel 40 frequency, we will have to set at Si5351 output at these frequencies, and inject them at the output point of the removed VFO into the radio:

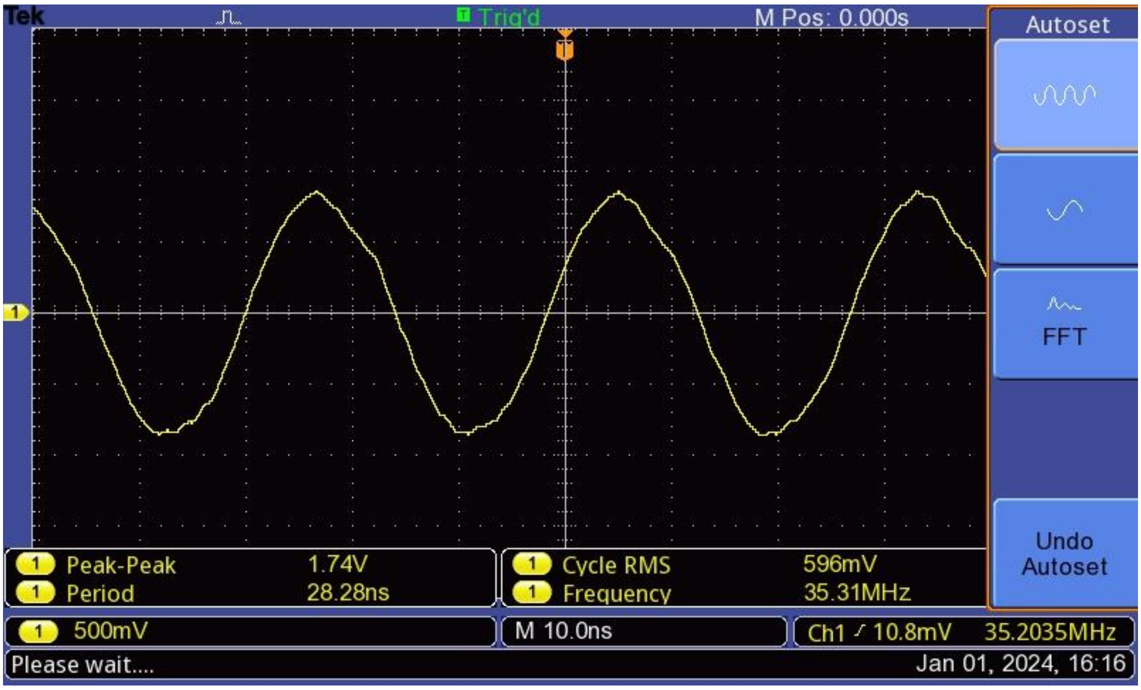
- **AM Modulation:** 35.2055 MHz;
- **LSB Modulation:** 35.2040 MHz;

- **USB Modulation:** 35.2070 Mhz.

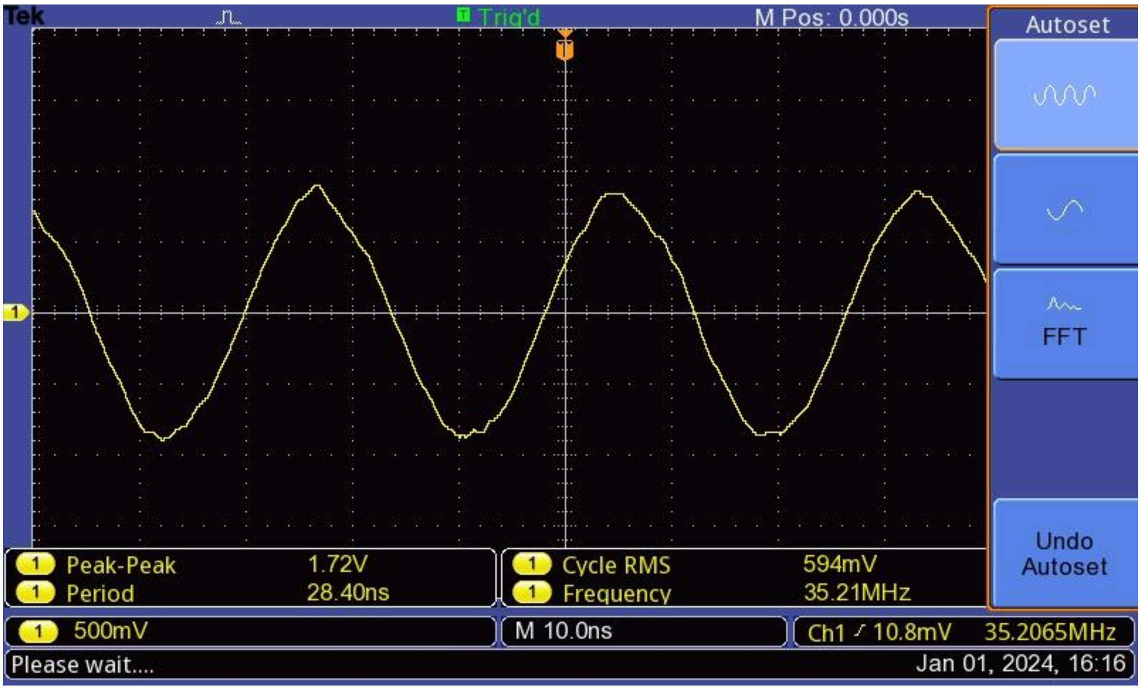
So, for the **Correction Factor Parameter**, we must choose a value (negative or positive) that makes the DVFO output matches the equation and values presented above, as shown in the following pictures:



CH40-AM – DVFO Output Frequency (TP #1)

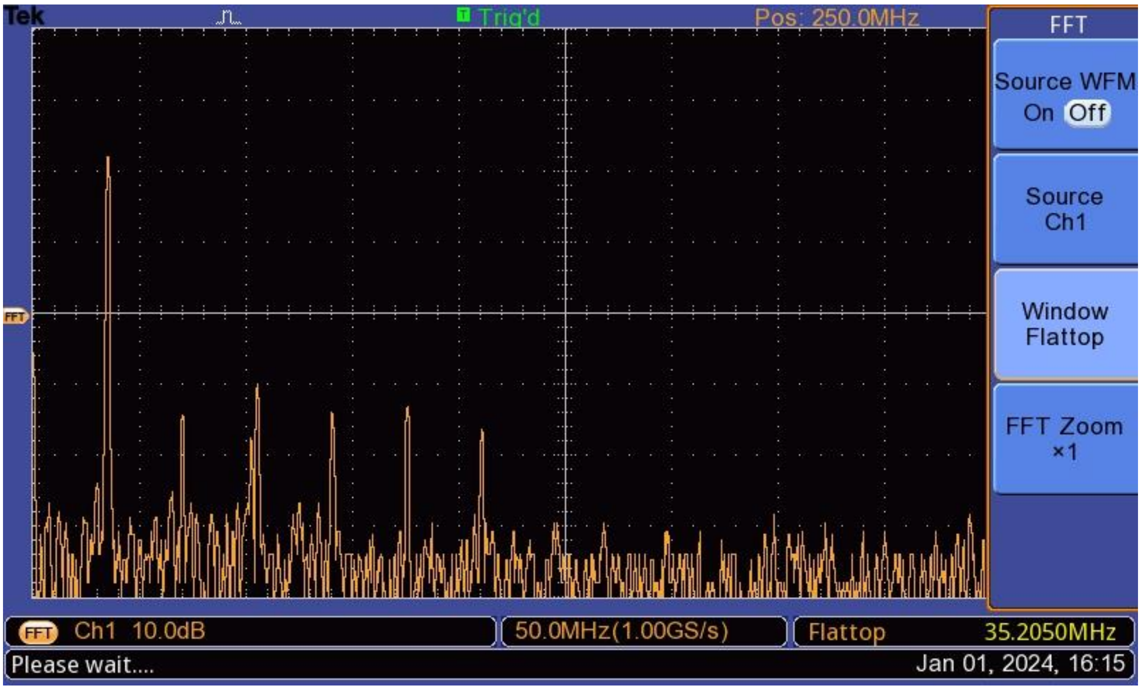


CH40-LSB – DVFO Output Frequency (TP #1)



CH40-USB – DVFO Output Frequency (TP #1)

After set the proper value for the **Correction Factor Parameter,** we can use L19 and L20 to maximize fundamental frequency parameter, and minimize harmonics.



Fundamental Frequency at Ch40-AM and its 5 harmonics

9.3.5. Intermediate Frequency

Intermediate Frequency of the Radio being used.

In communications and electronic engineering, an intermediate frequency (IF) is a frequency to which a carrier wave is shifted as an intermediate step in transmission or reception. The intermediate frequency is created by mixing the carrier signal with a local oscillator signal in a process called heterodyning, resulting in a signal at the difference or beat frequency. Intermediate frequencies are used in superheterodyne radio receivers, in which an incoming signal is shifted to an IF for amplification before final detection is done.[8]

Refer to you radio Service Manual to find out the value of this parameter.

9.3.6. Lower Side Band frequency shifting

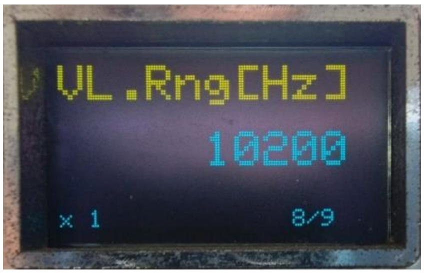
Sets the value, in Herts, of frequency shifting when modulating in LSB mode.

9.3.7. Upper Side Band frequency shifting

Sets the value, in Herts, of frequency shifting when modulating in USB mode.

[8] Wikipedia, The Free Encyclopedia. Intermediate Frequency, Accessed on 01/01/24, 17:23 (UTC).

9.3.8. Voice Lock Range



Sets the value, in Herts, of voice lock control range.

9.3.9. Signal Meter Calibration

This value must be manually tested for each radio, accordingly to S-Meter readings.

10. History

- 1.0 – Initial version
- 1.0.1 – New pictures into the manual, minor correction to the schematics.
- 1.1 – Improvement on EEPROM savings routine