

Evolution in Radio Design: building the next

QRP ARCI FDIM seminar
Thursday 18-May-2023
Hans Summers, G0UPL

QRP Labs

<http://qrp-labs.com>

Start the story: New Year



Time for new year resolutions!

- Make a \$million!



Time for new year resolutions!

- Make a \$million!
- Lose 25 pounds!



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- First SSB QSO!



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- Be nice to XYL!



Dear Wife,
Love You



Time for new year resolutions!

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- Be nice to XYL!
- Be nice to kids!



Dear Wife,
Love You

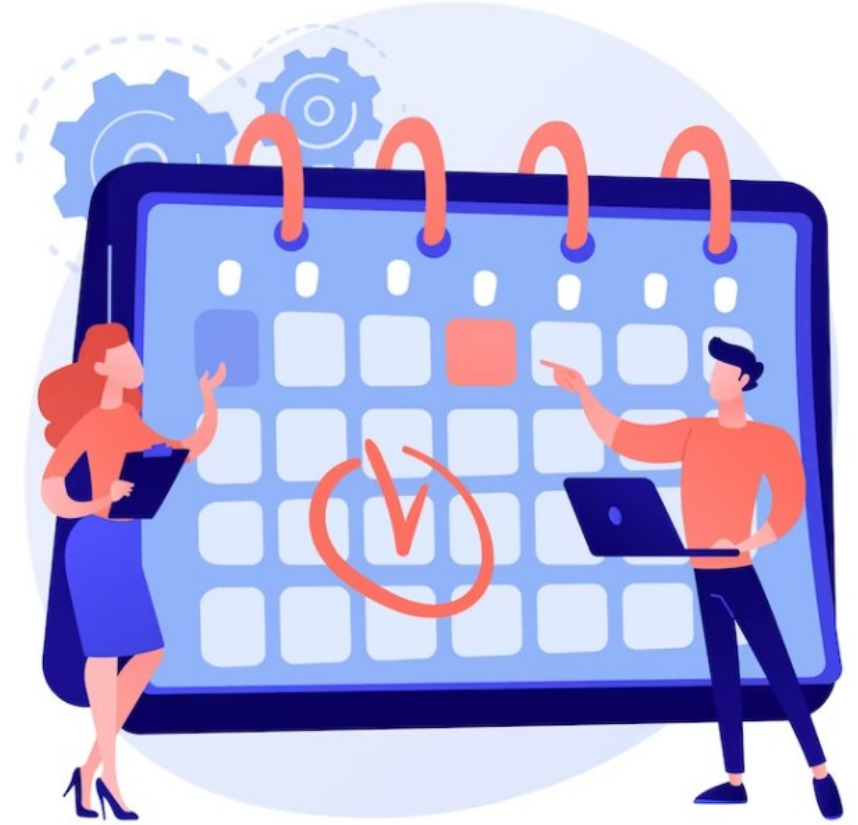


Time for new year resolutions!

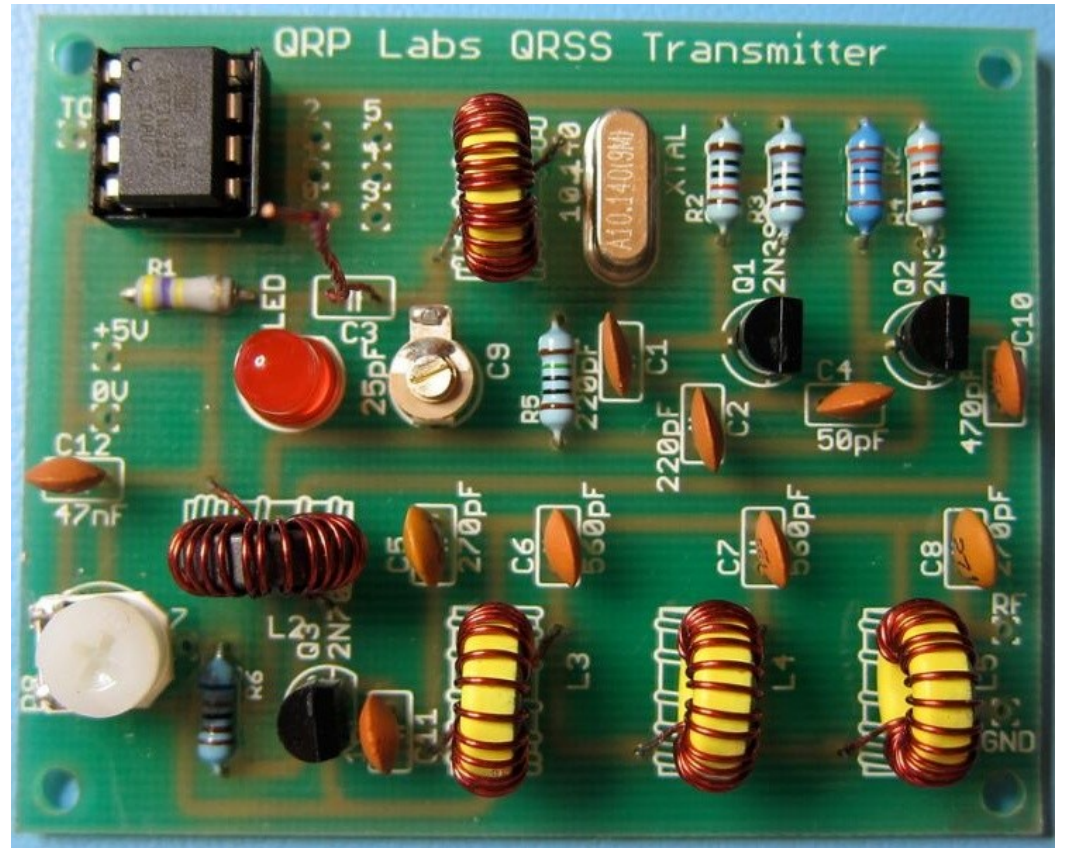
- Make a \$million!
- Lose 25 pounds!
- First SSB QSO!
- Be nice to XYL!
- Be nice to kids!
- Several other equally impossible goals...



A Dream vs a Plan



A short history of QRP Labs evolution

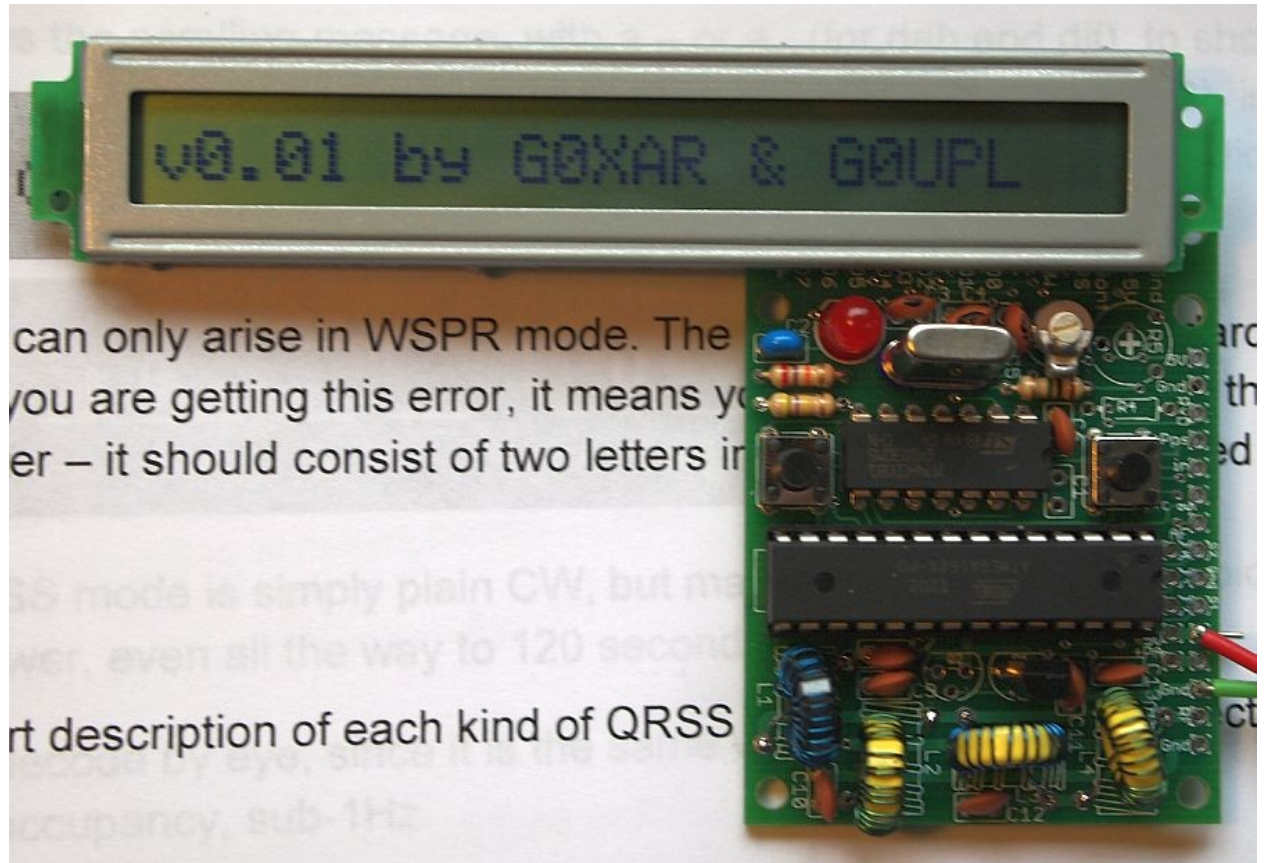


100 kits sold out on vendor evening



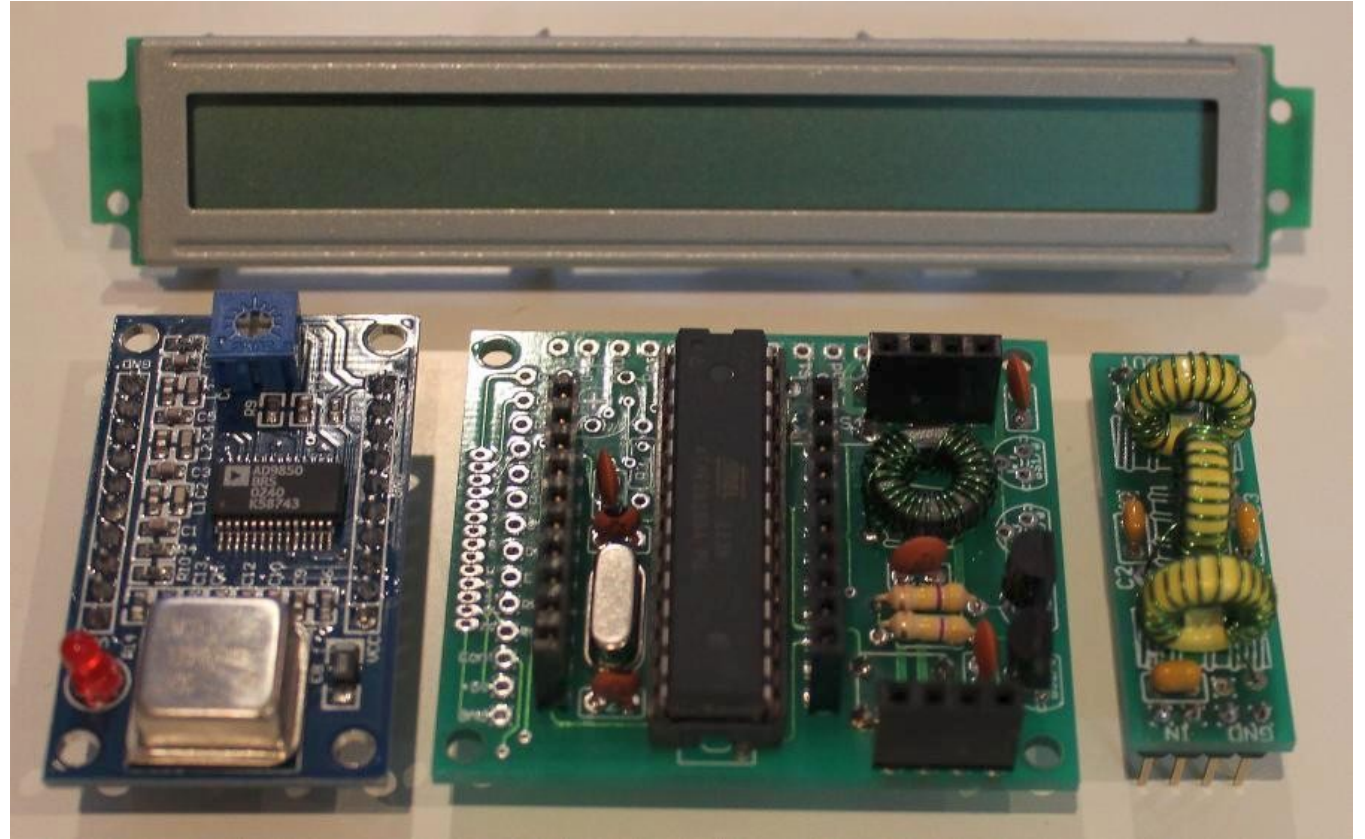
Ultimate QRSS/WSPR beacon kit

- WSPR
- CW
- QRSS
- FSKCW
- DFCW
- Hell
- Slow-Hell



Ultimate2 QRSS/WSPR beacon kit

- DDS
- Plug-in LPF
- More modes
- more...



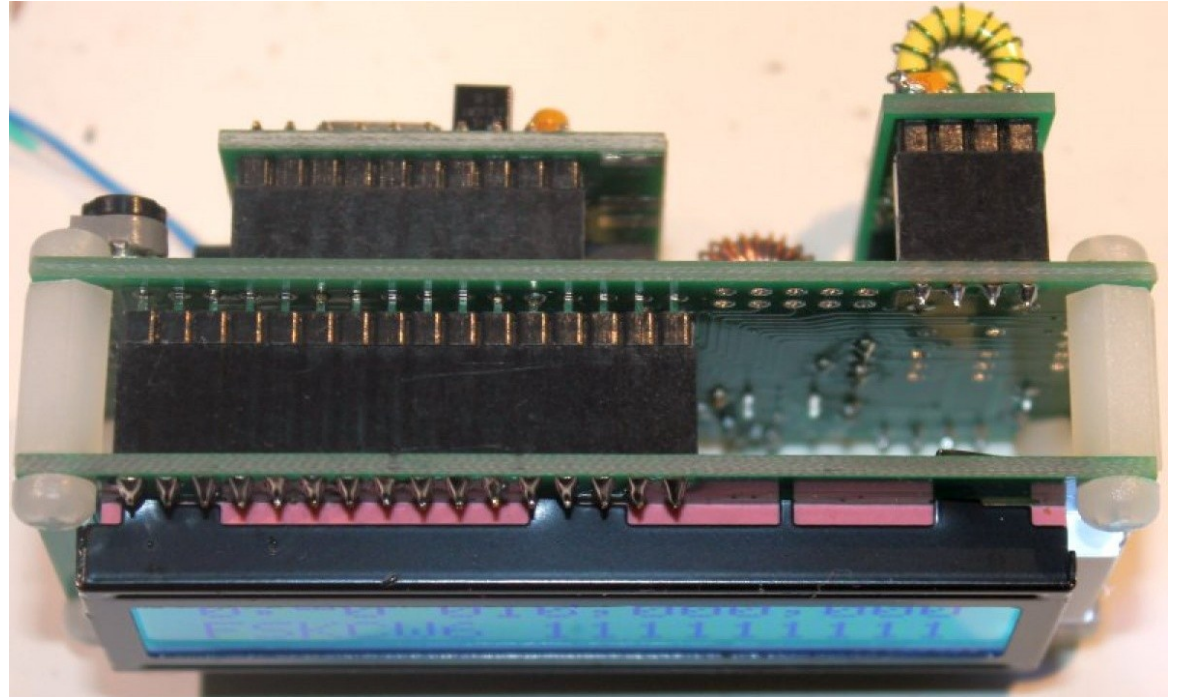
Ultimate3 QRSS/WSPR beacon kit

- 1602 LCD module
- 6-band relay-switched filter option



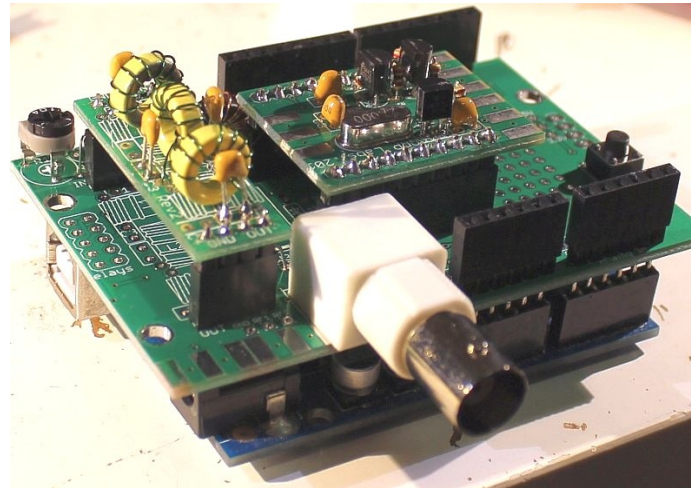
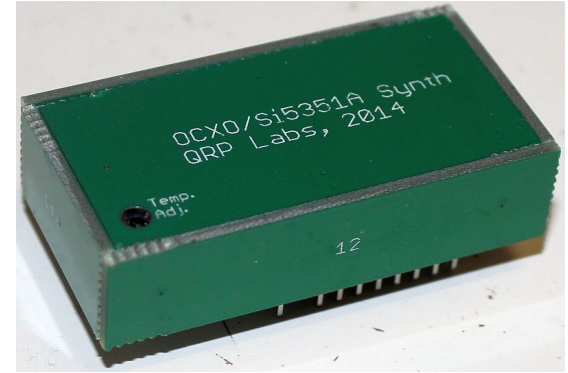
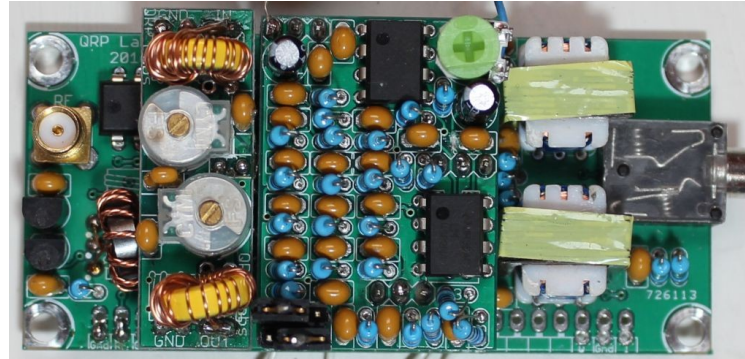
Ultimate3S QRSS/WSPR beacon kit

- Change to Si5351A Synth PLL chip
- Extends frequency range upward



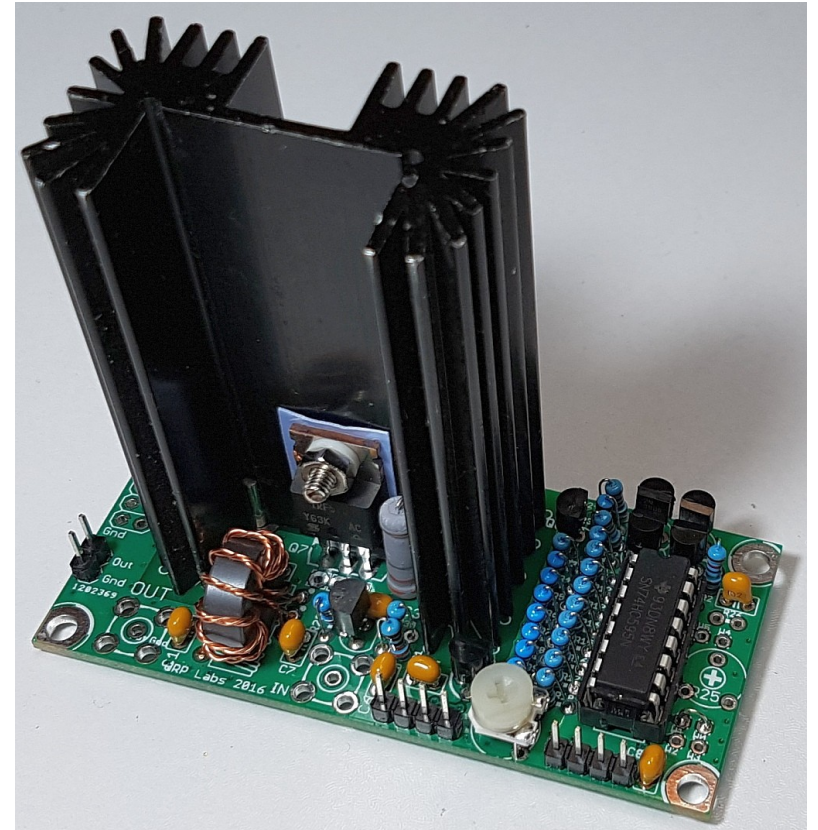
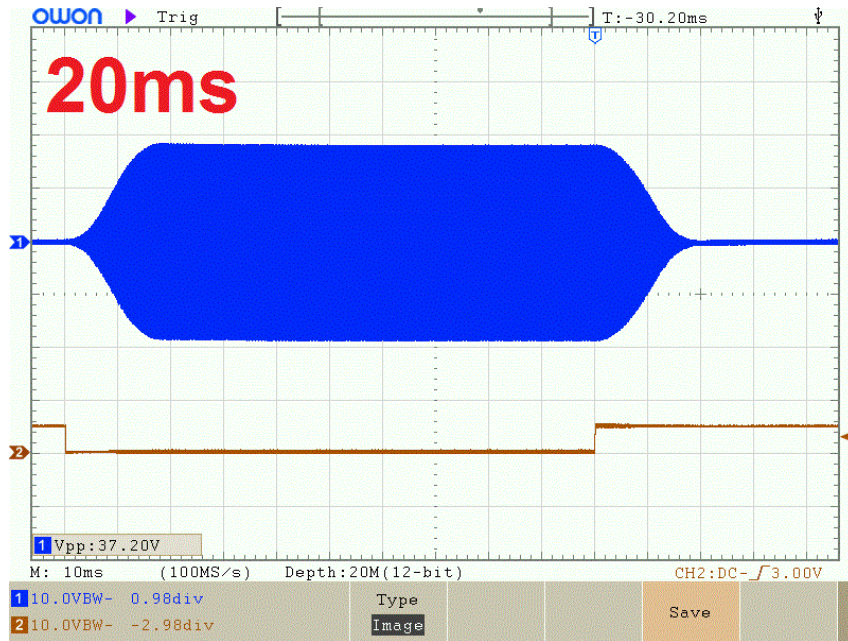
Other kits in the family

- OCXO
- Arduino-shield
- Receiver module
- Polyphase module
- ProgRock
- 5W PA
- QLG1 GPS
- LPF
- BPF
- VFO, Clock



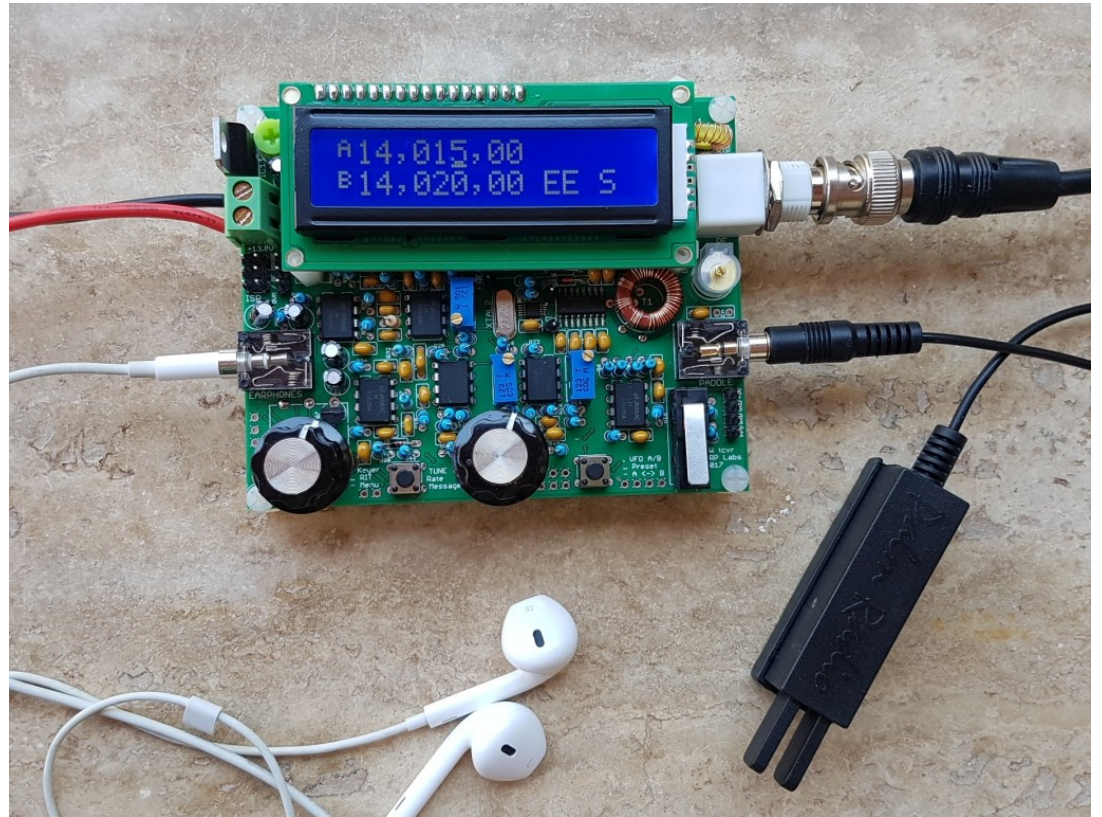
5W PA kit for Ultimate3S

- DAC-controlled amplitude modulation



2017: the first transceiver: QCX

- Single band, CW
- Analog
- Microcontroller assisted
- PLL Synth VFO
- Lots of features
- High performance
- Low \$49 price



2020: QCX+

- Same circuit, firmware, performance
- New mechanical design
- Nice extruded aluminium black enclosure
- TXCO option
- AGC option
- Dev board kit

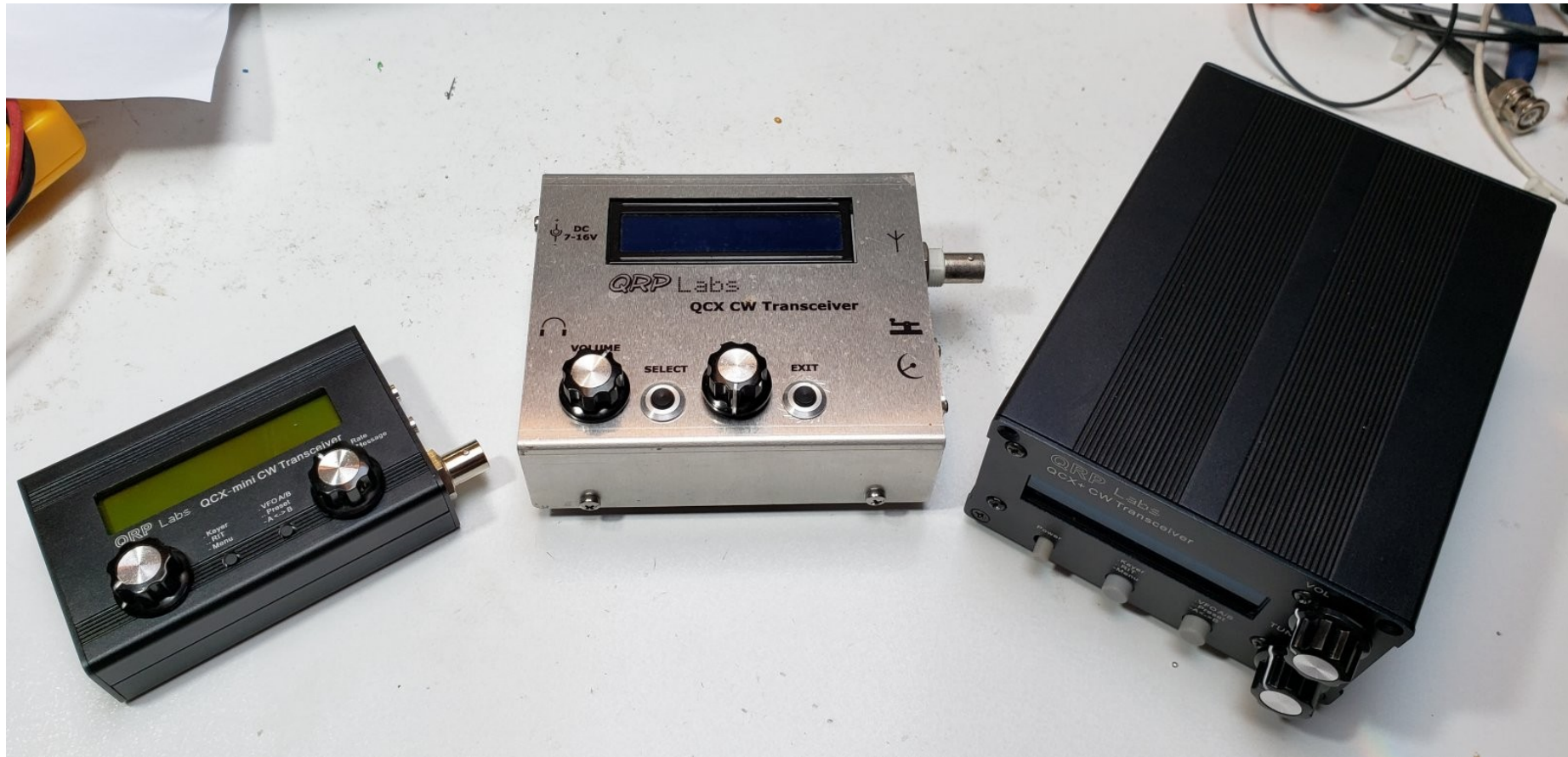


QCX-mini

- Miniature version of the QCX+
- As of May 14 2023, 19,771 QCX-series sold!



The three QCX



QSX

- QRP Labs SSB Transceiver
- SDR
- 160-10m
- 10W
- Ambitious!
- Still not finished...



2021: QDX

- QRP Labs Digital Xcvr
- A very high performance digital modes transceiver
- Multiple bands
- 5W QRP gallon
- And... LOW COST!



QDX: QRP Labs Digital Xcvr

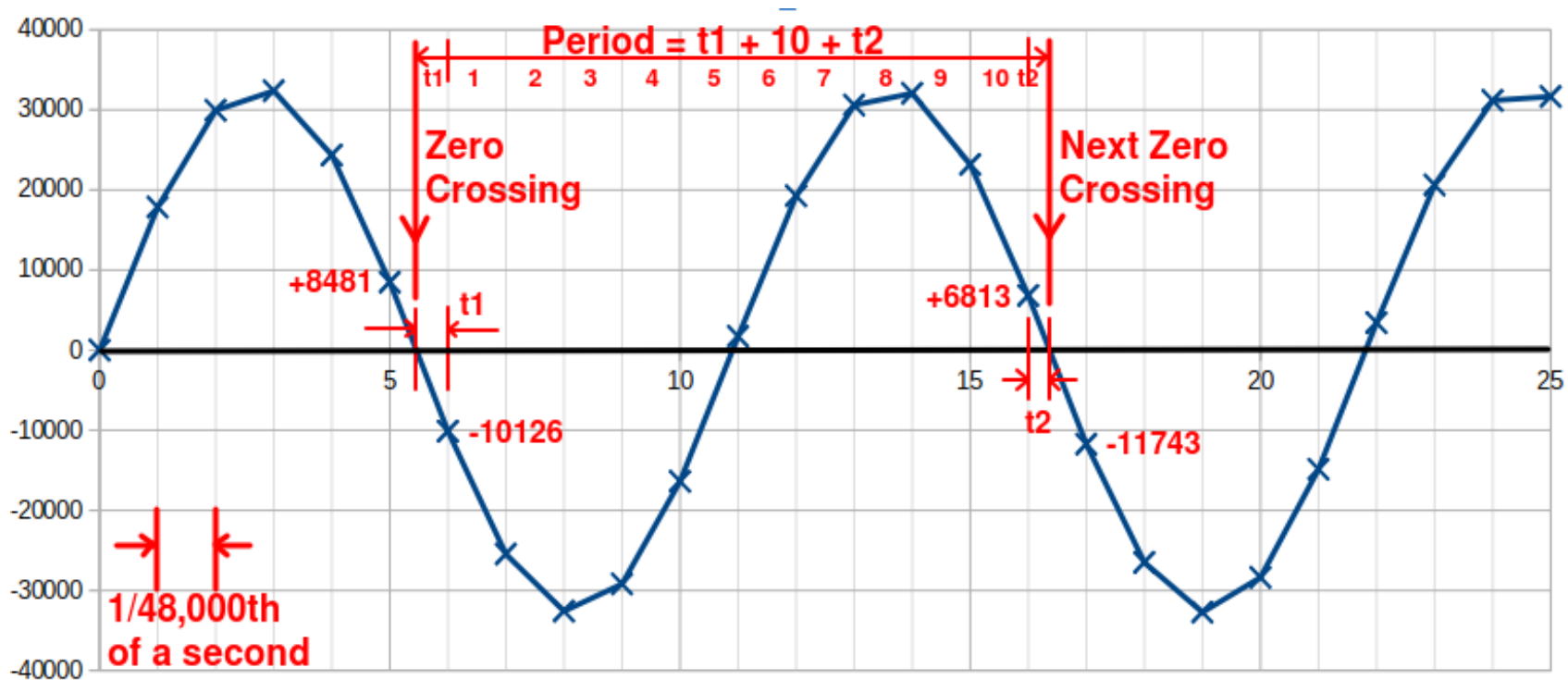
- 80, 40, 30, 20m PIN-diode band switched and transmit/receive switched
- Full 5W from 9V or 12V supply
- TCXO-referenced Si5351A synthesized LO
- Embedded high-performance SDR receiver with 24-bit 112dB ADC chip
- Single signal transmit
- Includes 24-bit 48ksps stereo USB soundcard and CAT, easy interface with software and single USB cable
- Built-in test and alignment tools

A look inside

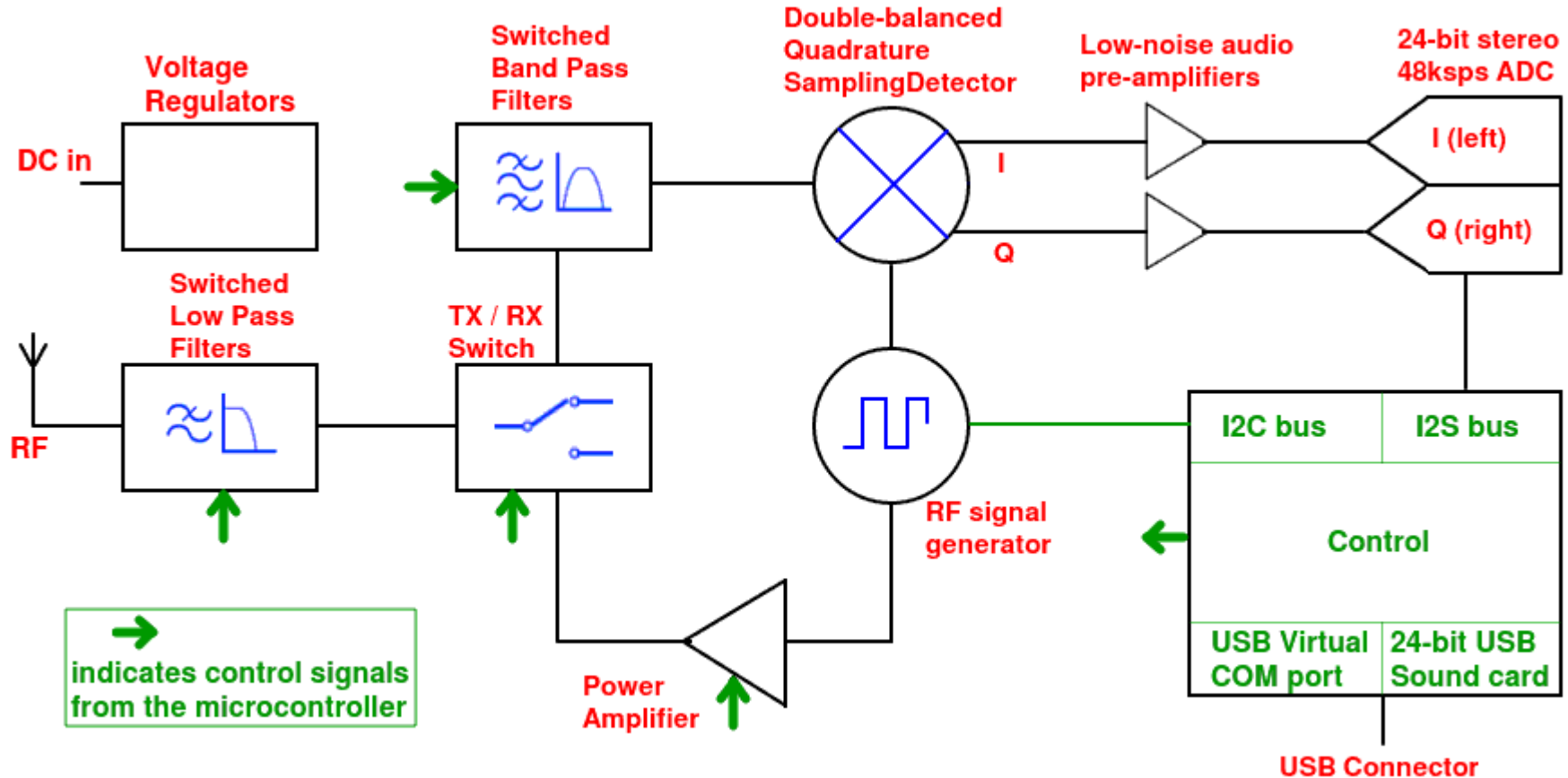


Measuring audio

- Normal frequency measurement too slow
- Cycle period is another way



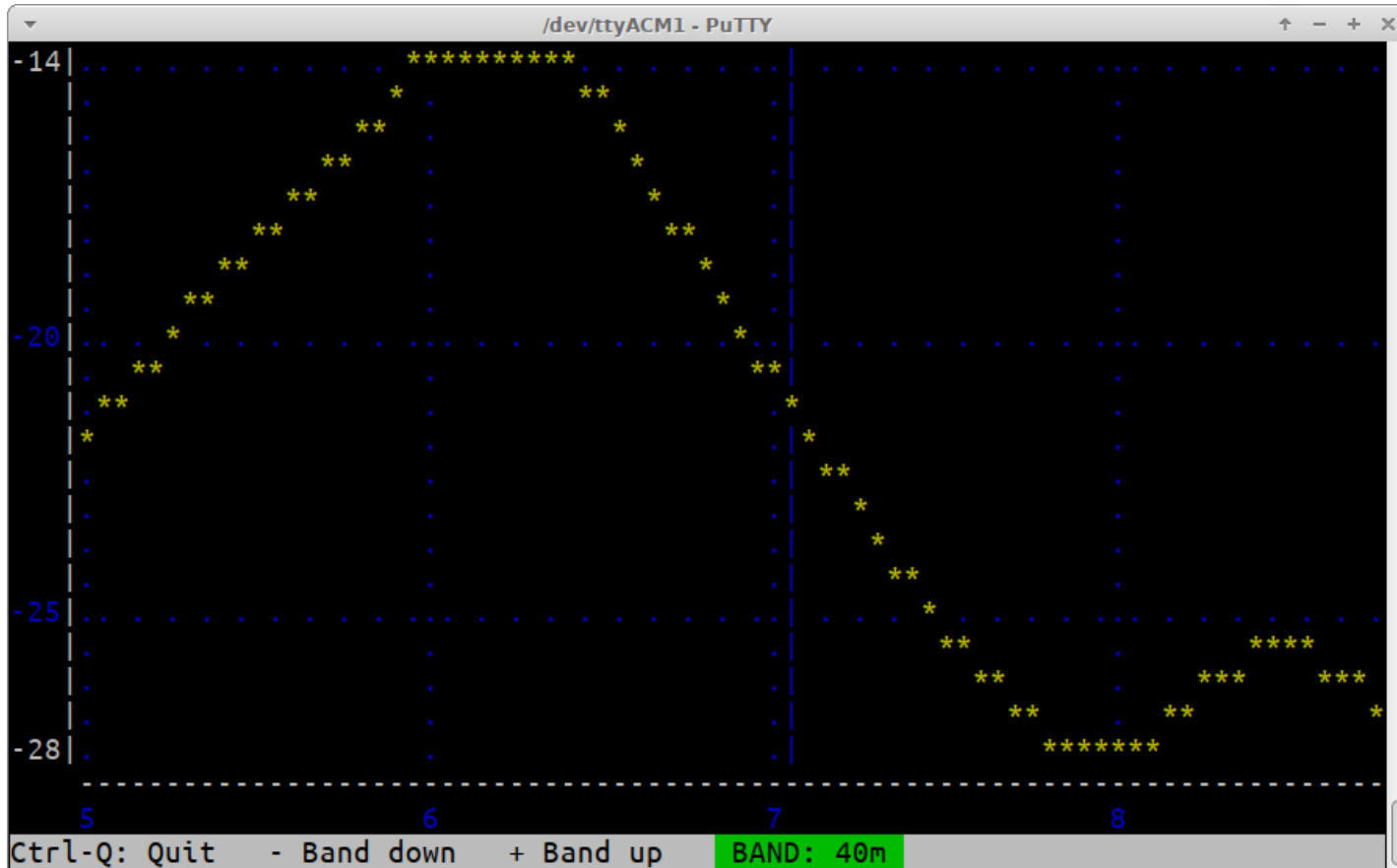
QDX design: block diagram



Design: Software Defined Radio

- Advantages
 - High performance, low cost
 - Digital Signal processing
 - Chance to update features in future by software
- QDX implements a superhet with 12 kHz IF
- All 32-bit floating point processing internally
- Provides 24-bit audio back to the PC

Terminal tool for BPF sweep etc



Designing the next...



The marriage of QDX and QCX-mini



80, 60, 40, 30 and 20m; CW and Digi

QRP Labs M... Xcvr. M is for:

- Marriage
- Merger
- Multi-band
- Multi-mode
- Magnificent
- Marvelous
- Etc...



QMX consists of:

- QCX-mini mechanical design and enclosure
- QDX inside, plus:
 - LCD, buttons, encoders
 - Audio headphones output
 - Paddle connector
 - SWR bridge
 - Switching power supplies
 - RF envelope shaping

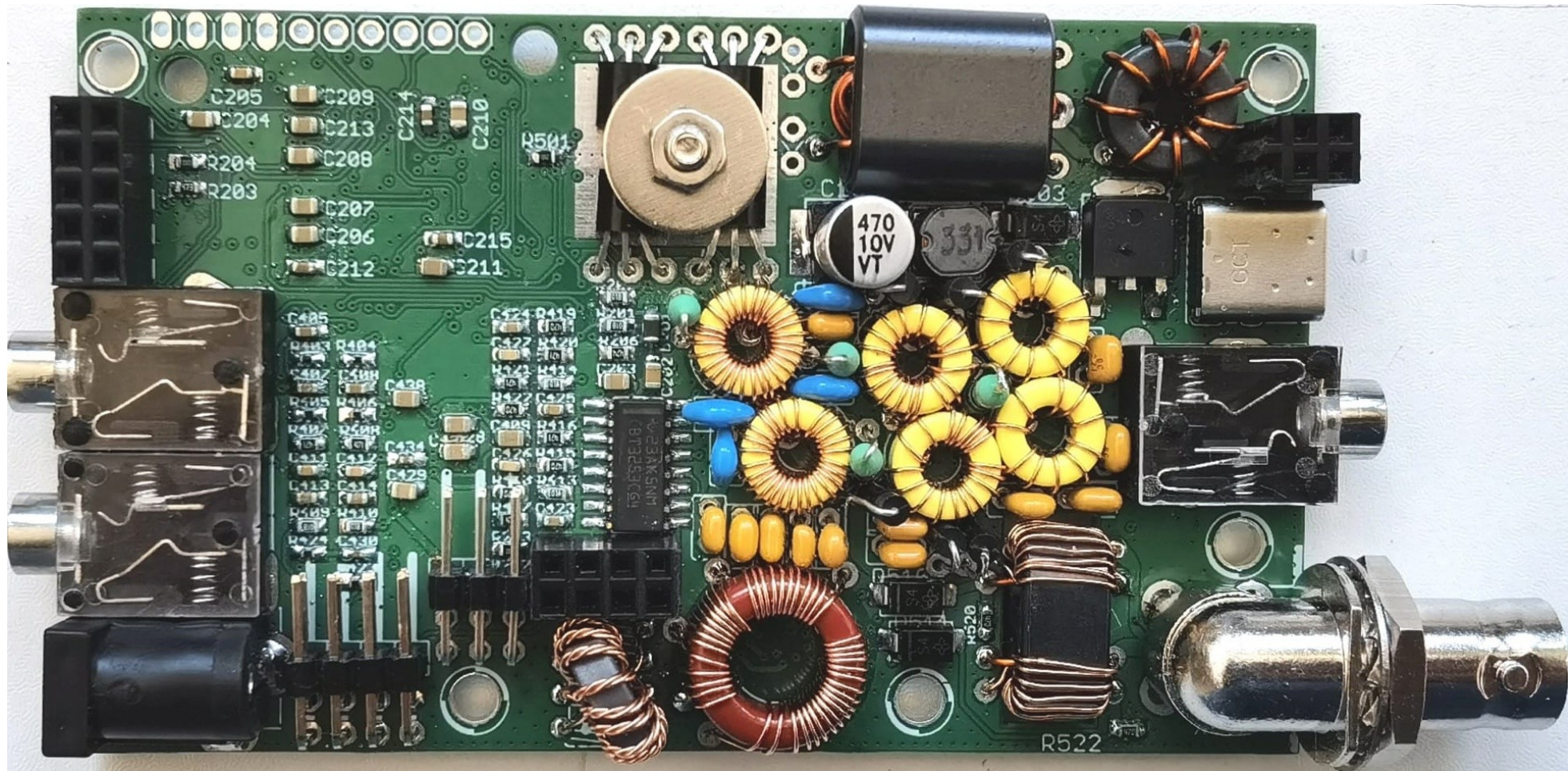


USB-C connector

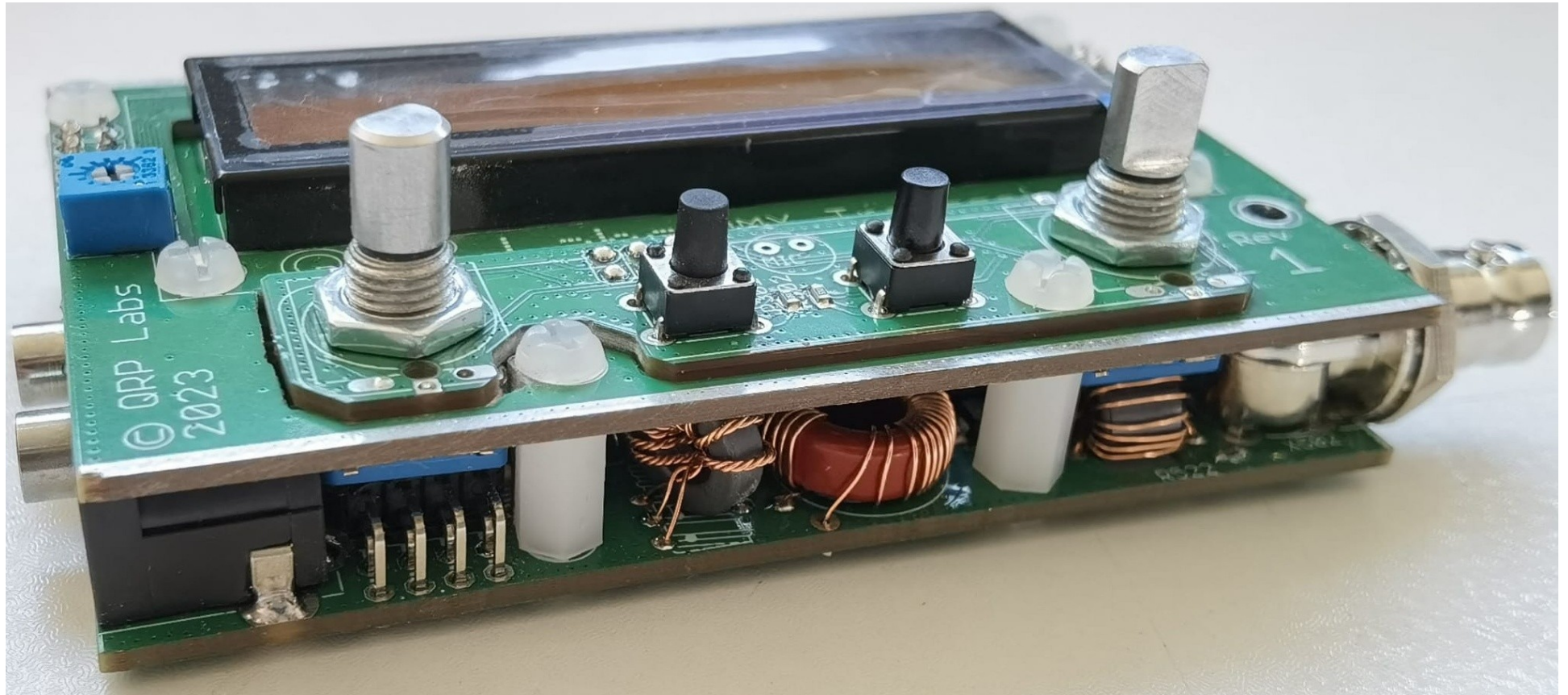
- Replaces the QCX-mini 3.5mm serial jack connector
- Not for power supply!
- Provides USB connection for:
 - 24-bit 48ksps USB sound card
 - Two Virtual COM serial ports (CAT, terminal access)
 - Firmware update: radio appears as Flash drive



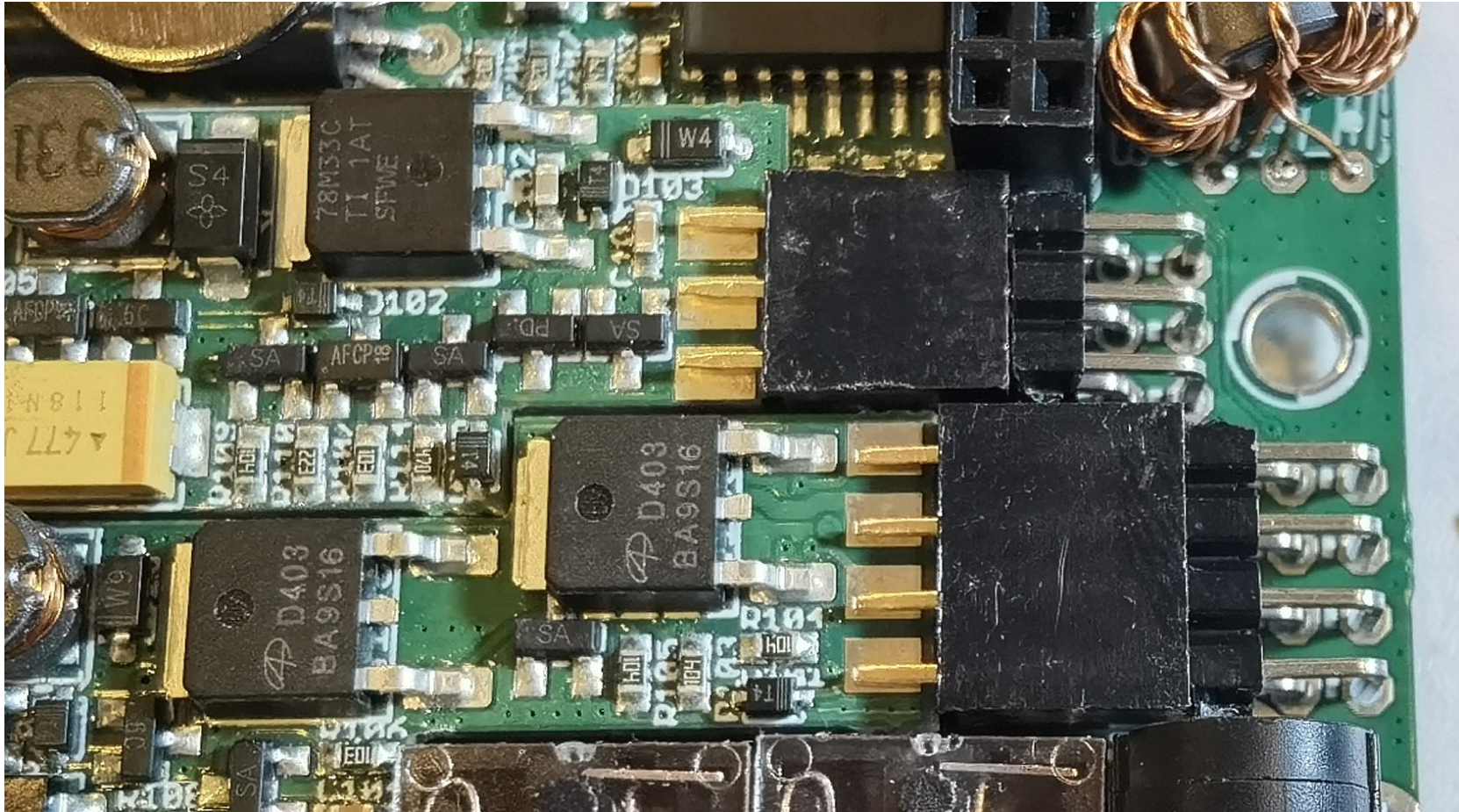
QMX main board



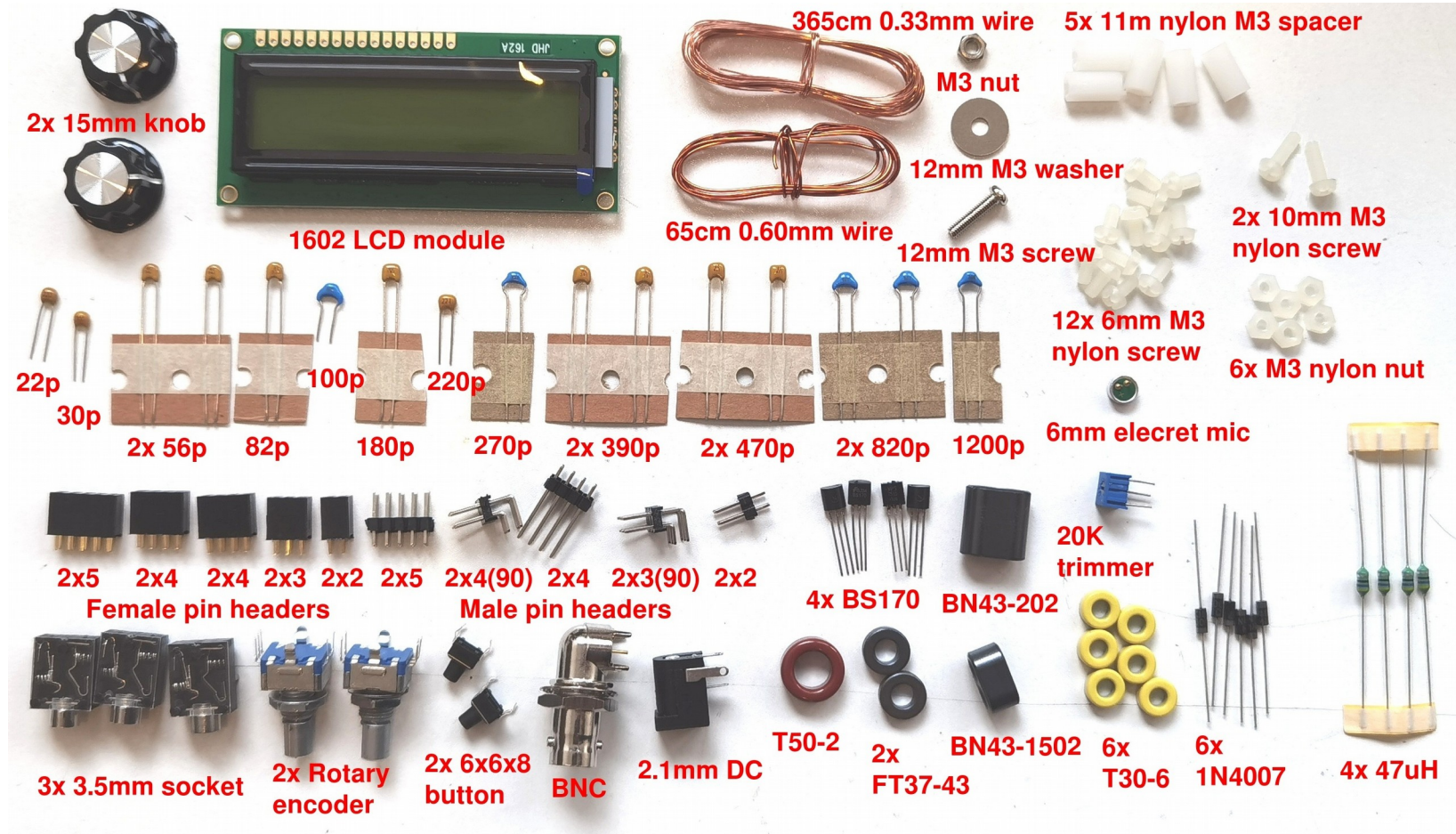
Plugged-in LCD board



Power supply boards close-up

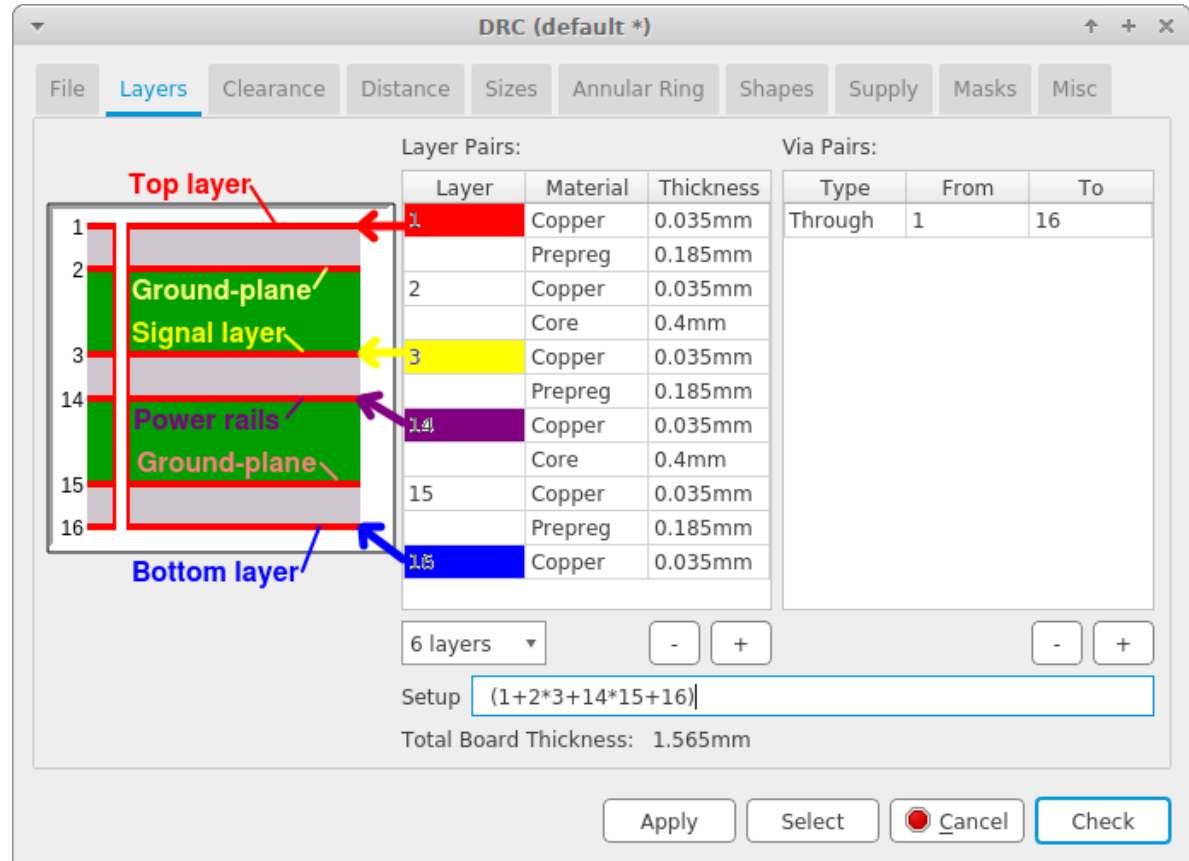


Through-hole components



A 6-layer board

- Necessary to achieve complex compact circuit
- No blind or hidden vias!
- Two internal layers are ONLY ground-plane



The screenshot shows the 'DRC (default *)' dialog box with the 'Layers' tab selected. The 'Layer Pairs' table is as follows:

Layer	Material	Thickness
1	Copper	0.035mm
2	Prepreg	0.185mm
3	Copper	0.035mm
4	Prepreg	0.185mm
5	Copper	0.035mm
6	Core	0.4mm
7	Prepreg	0.185mm
8	Copper	0.035mm
9	Prepreg	0.185mm
10	Copper	0.035mm
11	Prepreg	0.185mm
12	Copper	0.035mm
13	Prepreg	0.185mm
14	Copper	0.035mm
15	Prepreg	0.185mm
16	Copper	0.035mm

The 'Via Pairs' table is empty. The 'Setup' field contains the formula $(1+2*3+14*15+16)$ and the 'Total Board Thickness' is 1.565mm. The '6 layers' dropdown is set to 6 layers. The 'Apply', 'Select', 'Cancel', and 'Check' buttons are visible at the bottom.

QDX + design increments = QMX

- Bigger CPU
- LCD, buttons, encoders
- Audio headphones output
- Paddle connector (no further detail needed)
- SWR bridge
- Switching power supplies
- Transmit RF envelope shaping

STM32F446VET6 microcontroller

- 100-pin LQFP: lots of I/O
- 180 MHz CPU (run at 168 MHz)
- 512K Flash program memory
 - 16K used for QFU bootloader
- 128K RAM
- I2S, I2C, USB peripherals
- 12-bit ADC with loads of channels
- Two 12-bit DAC
- Plenty of power and space for expansion!



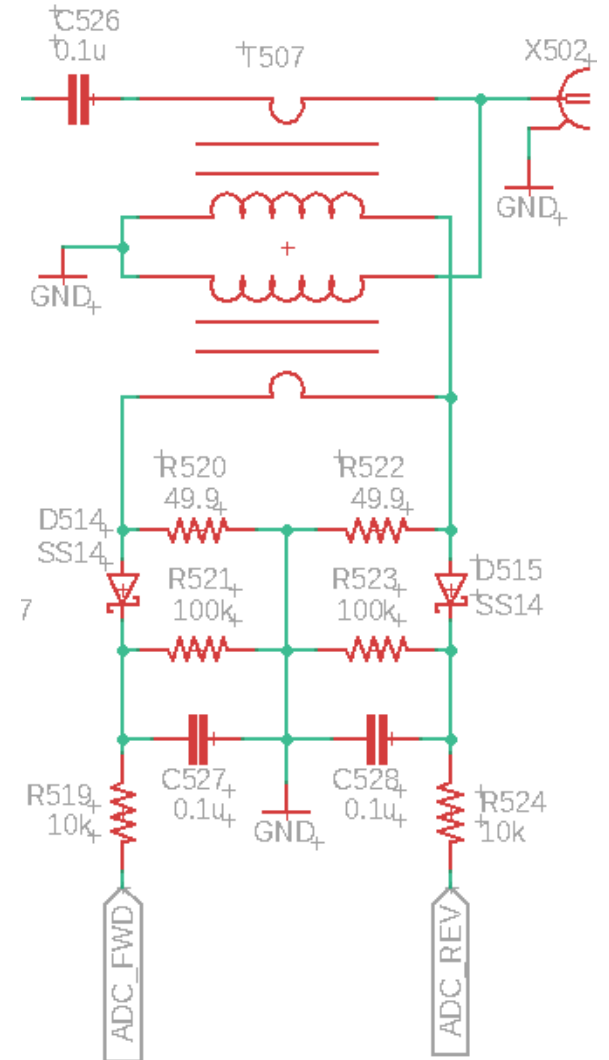
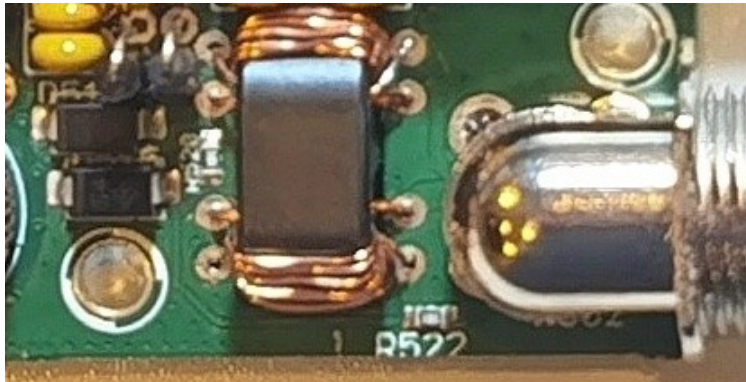
LCD, buttons, encoders

- Same as QCX-mini – but two rotary encoders
- Left rotary encoder is audio gain, and press for On/Off, band change, and mode change



SWR bridge

- Standard in-line coupler
- Feeds two ADC inputs
- Constructed on single binocular

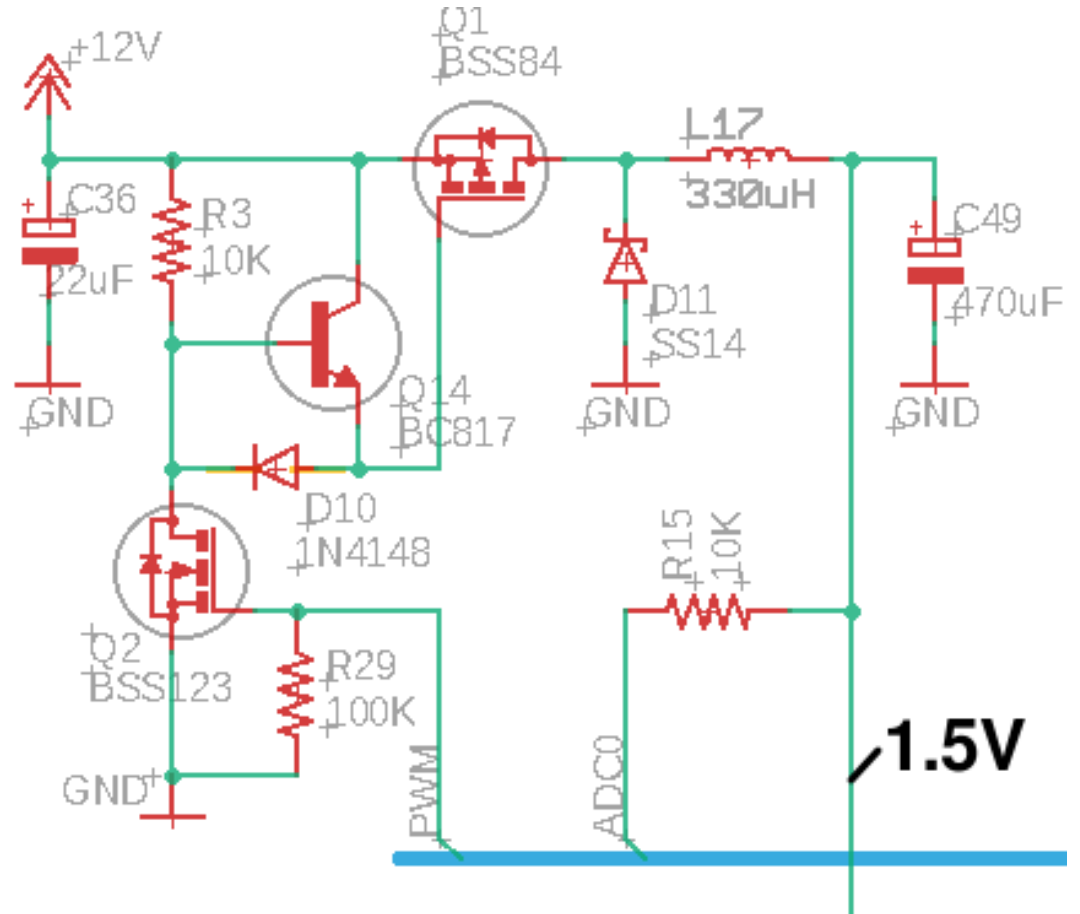


Switching power supplies

- WHY switching? Receive current consumption at 12V:
 - QCX+: 112mA
 - QCX-mini: 72mA
 - QDX: 150mA
 - QMX: 220mA on a linear supply
- Three supplies
 - PIN diode fwd bias during transmit (as on QDX > Rev 4)
 - 5V supply
 - Main 3.3V supply
- Challenge: NOISE! Develop a unique approach...

Basic idea from QDX PIN bias

- Discrete components
- P-channel MOSFET Switch
- Micro generates PWM at 100kHz
- Micro reads ADC, adjusts PWM



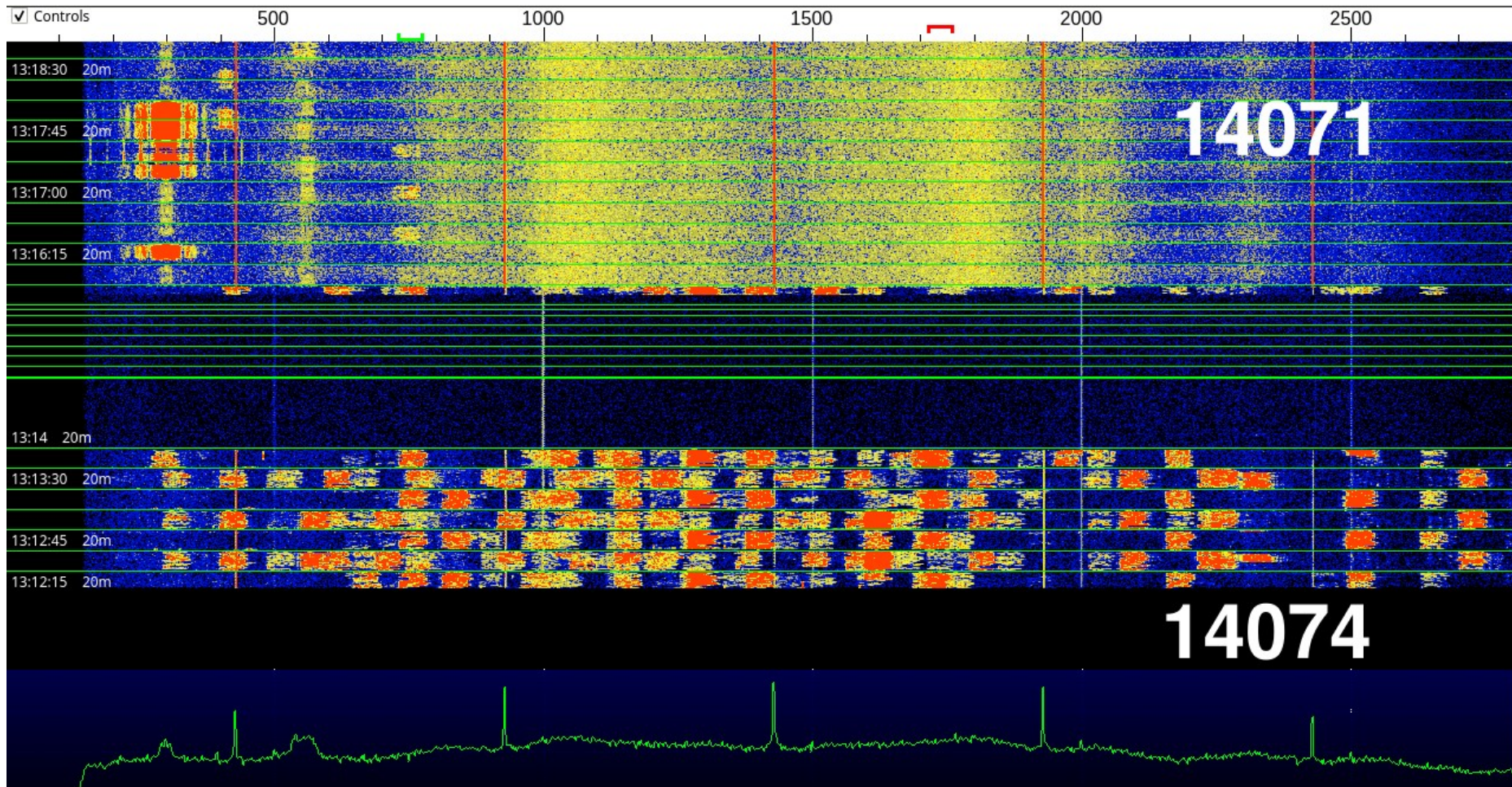
Why are SMPS noisy?

- Linear regulator is like a controlled variable resistor
- A buck converter switches power on and off with a sharp switch
- Harmonics to daylight
- Hard to filter out completely!
- Inexpensive SMPS have free-running RC oscillator
 - Drifts!
 - Phase noise
- Doesn't matter in QDX: TX-only! But in QMX...

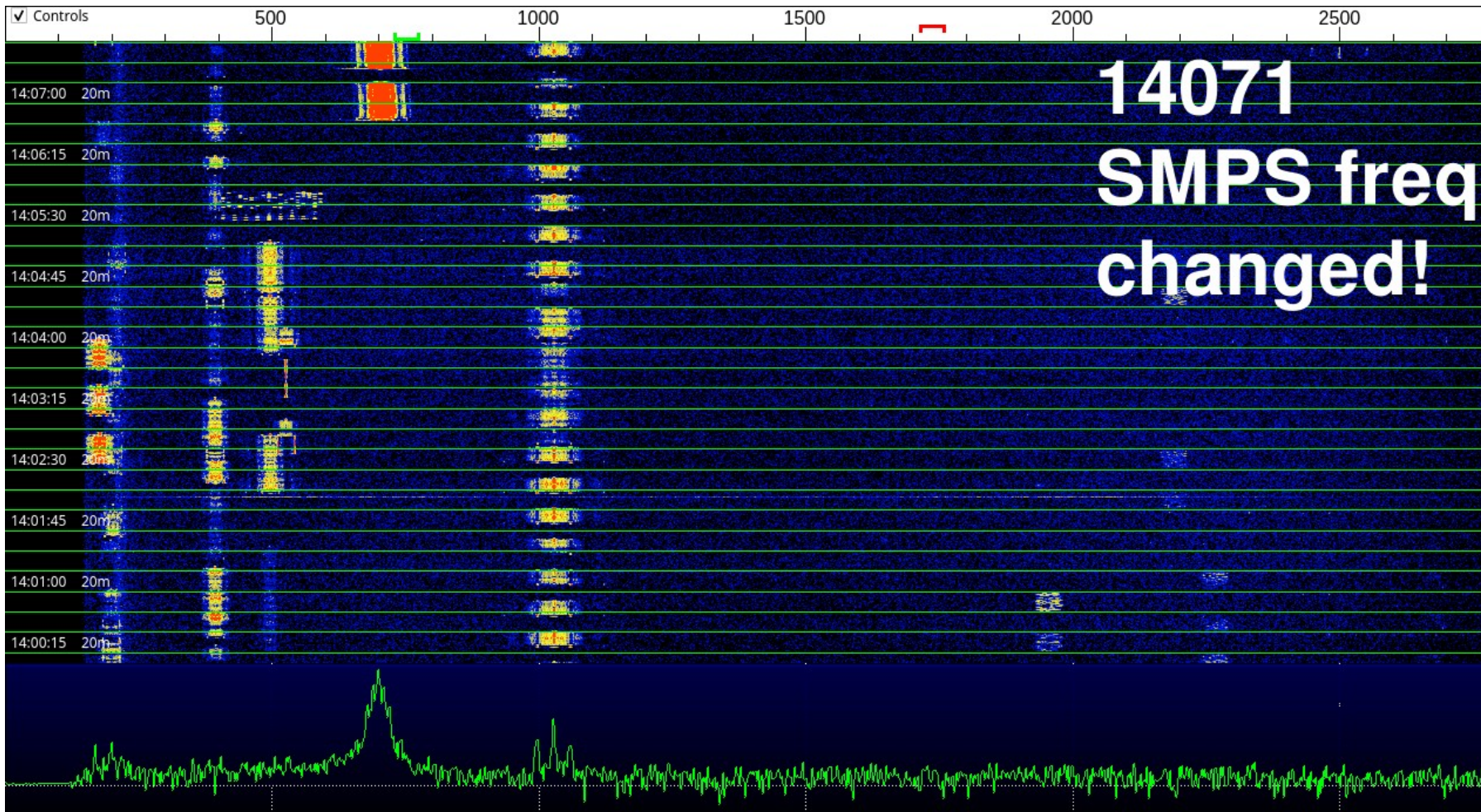
Don't try to eliminate; **control** the noise!

- In QMX everything derives from single 25 MHz TCXO
- Microcontroller generates PWM
- Microcontroller knows the operating frequency
- So... Tadaaaaaahhhh

In practice: tuned to a harmonic



In practice: micro moves PWM freq

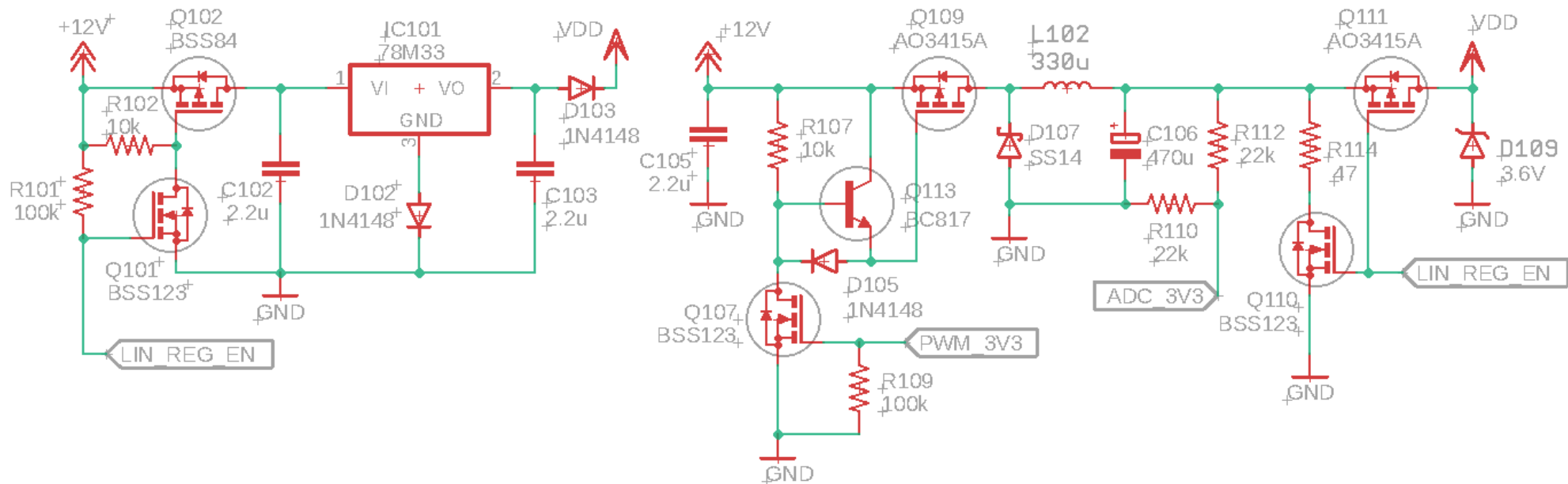


The chicken and egg problem

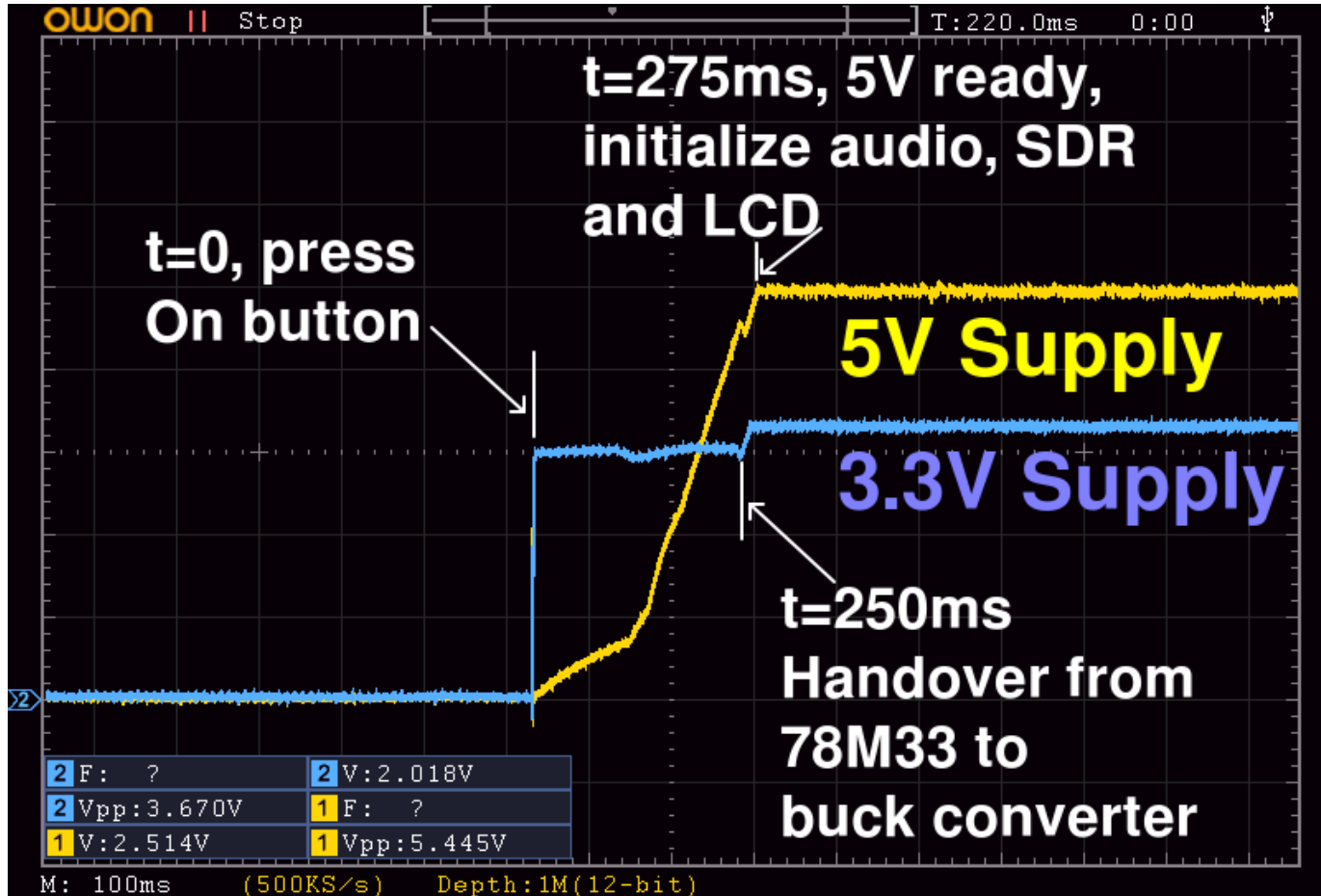
- The microcontroller is the control loop for all three power supplies (PIN diode bias, 3.3V, 5V)
- But the microcontroller is supplied by the 3.3V supply...

Solution:

- 78M33 linear regulator
- Switch to 3.3V buck converter when ready...

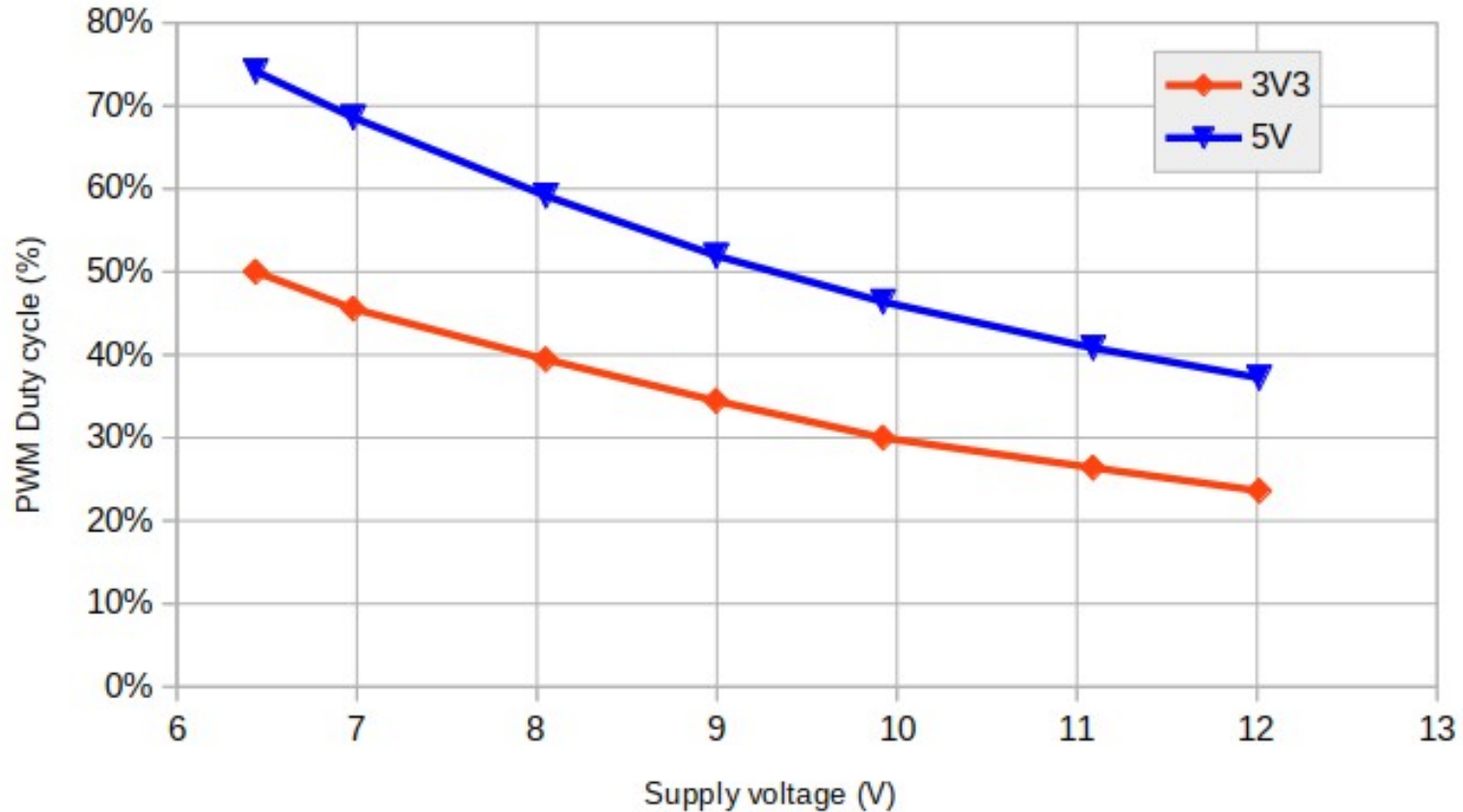


In practice: power-up sequence



In practice: duty cycle

Buck converter duty cycle vs Supply voltage

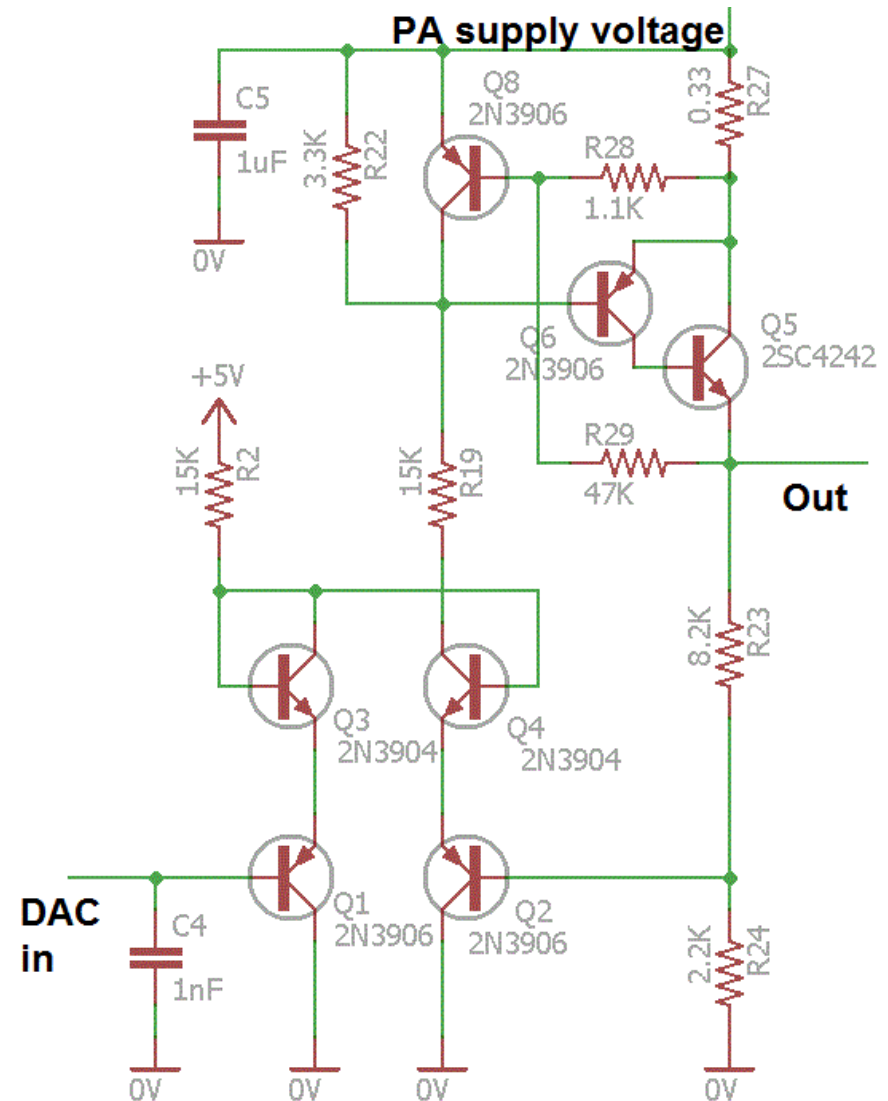
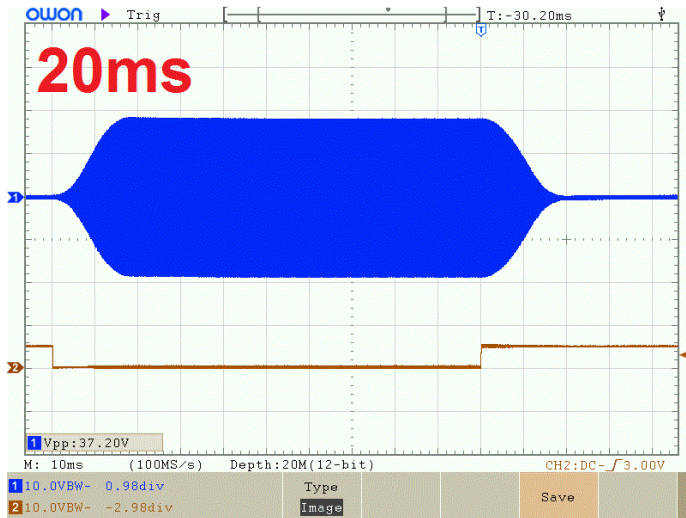


In practice: Current consumption

- Receive current at 12V supply:
 - 80 mA (LCD backlight off)
 - 86 mA (LCD backlight on)
- Big improvement from the 220mA measured on linear regulators (1.0 vs 2.6W heat)
- Elecraft KX3 (an embedded SDR of comparable performance) – website says: “Receive current as low as 150mA”

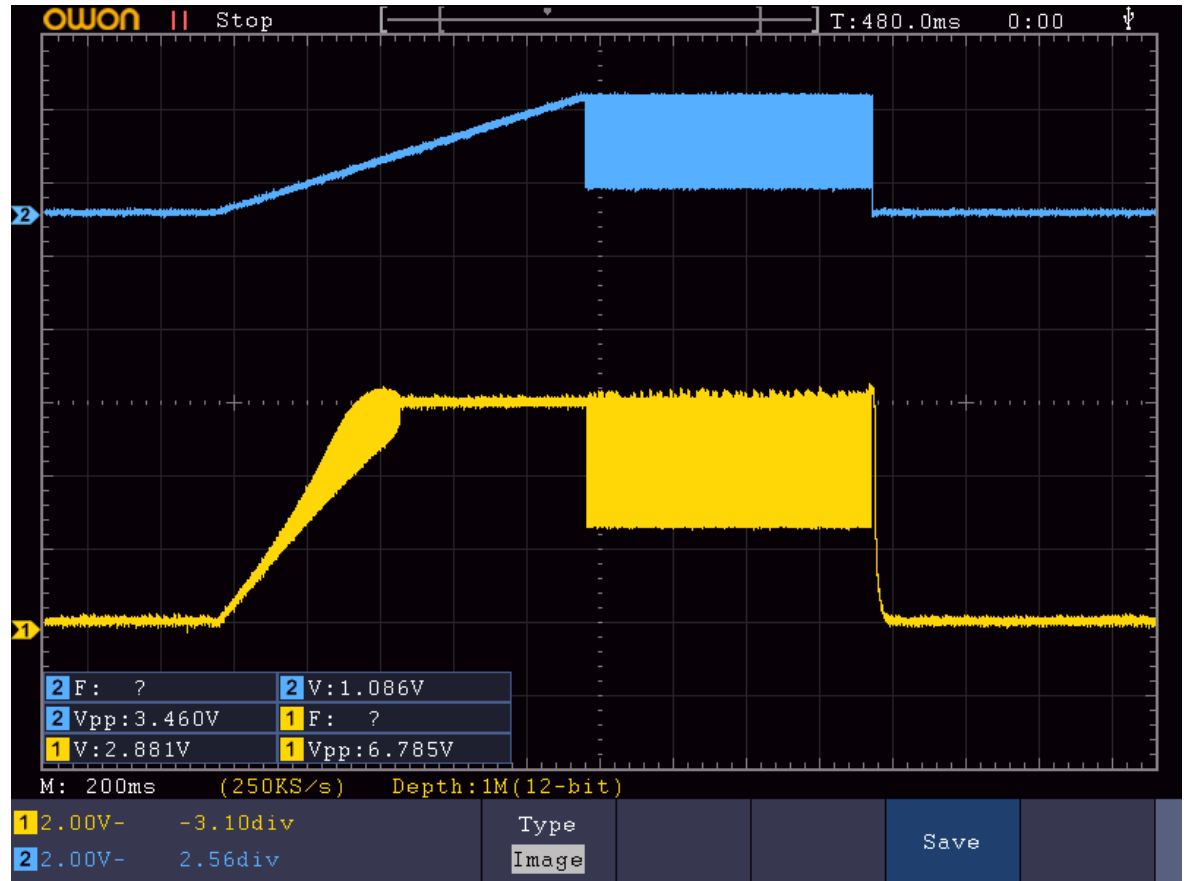
RF envelope shaping

- Circuit from earlier 5W PA kit
- In QMX: unstable!



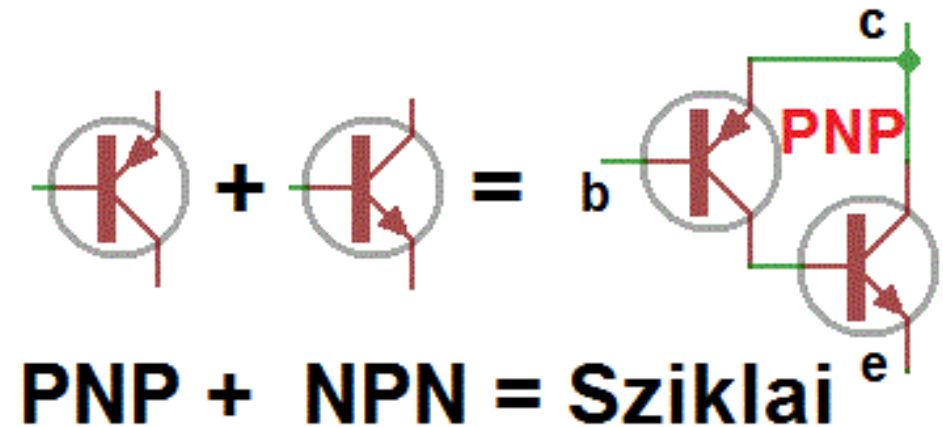
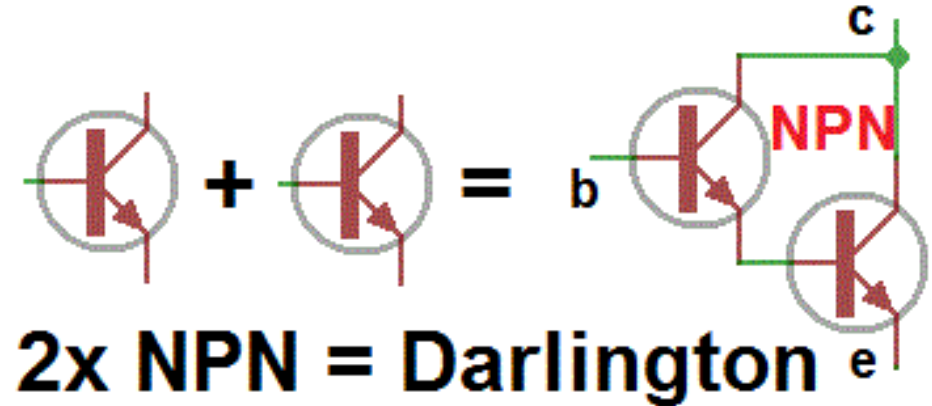
Instability

- Slow ramp
- At some point..
OSCILLATION
- Could not be tamed!

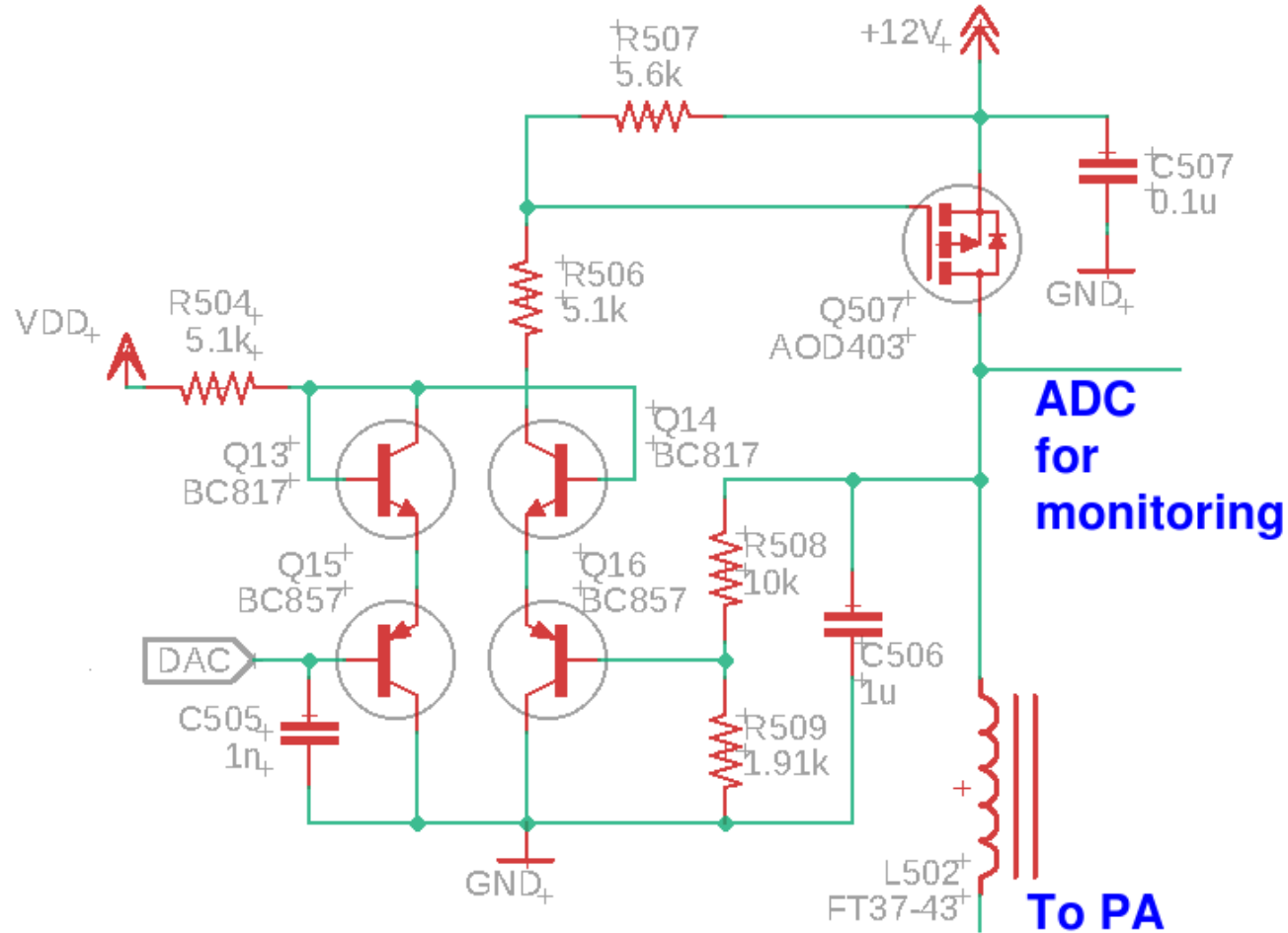


Sziklai pair

- Originally NPN signal + PNP power = Sziklai
- Like a Darlington: gain = product of transistor hFE's
- Huge gain → instability

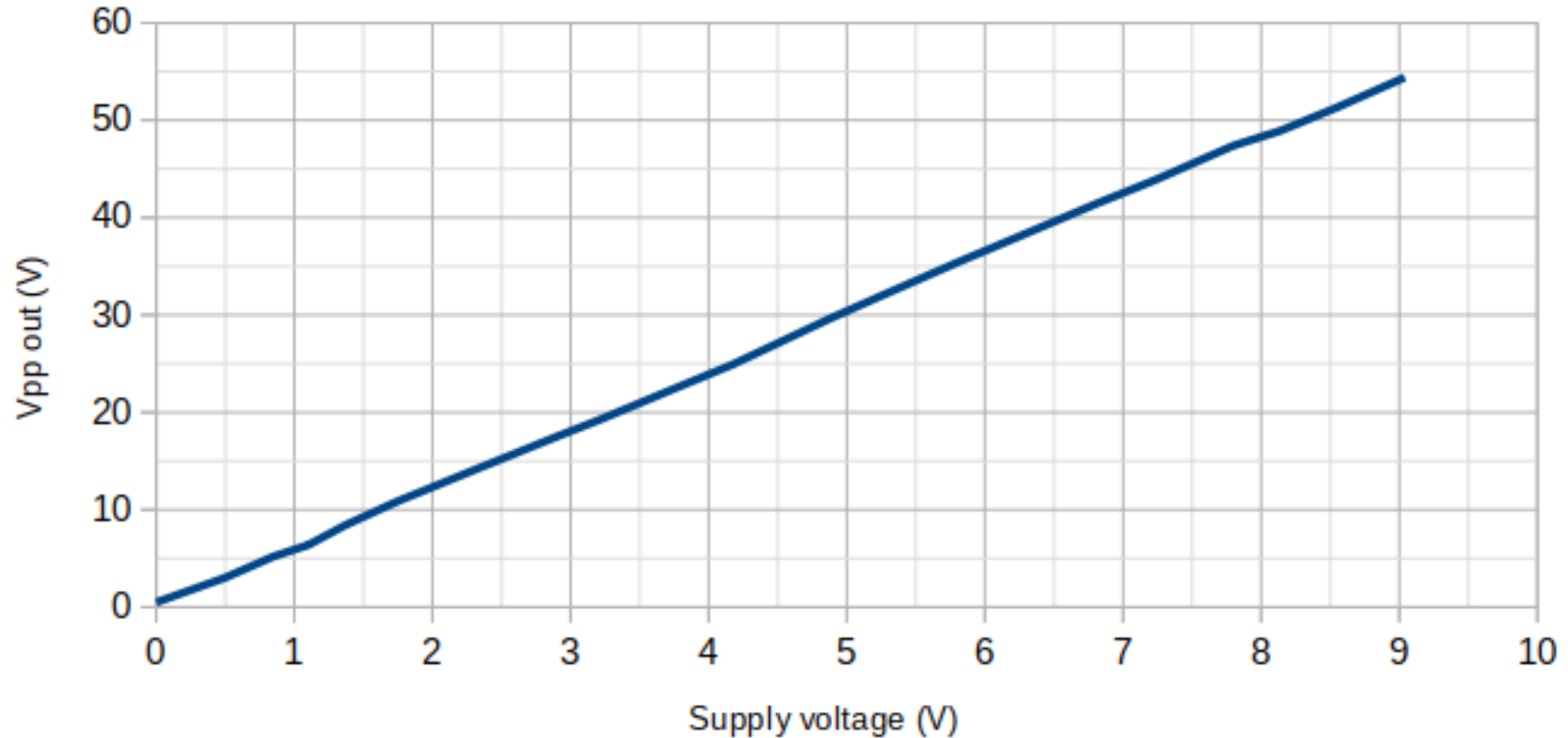


Solution: P-channel MOSFET!



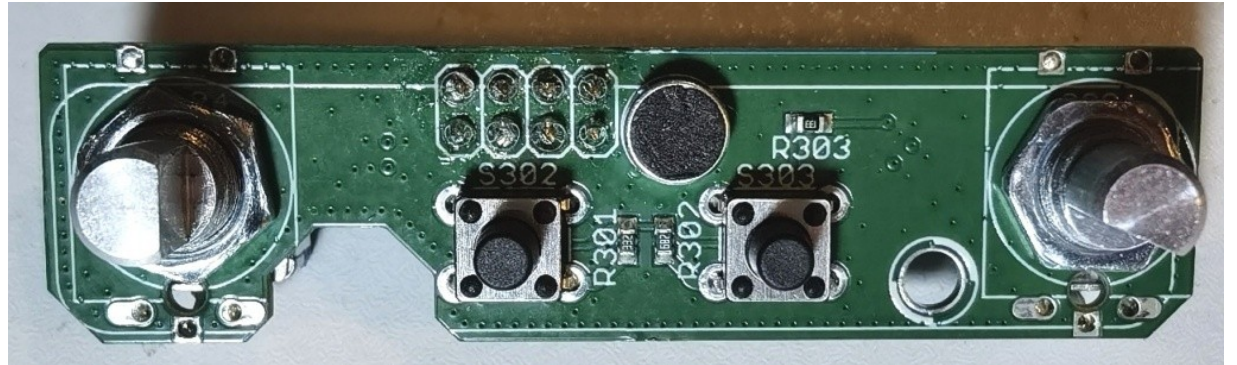
In practice: 37dB control range

Vpp vs PA Supply voltage



SSB on QMX

- A future goal via a firmware update
- QMX has an electret mic!
- And plug-in mic, PTT capability
- EER:
Envelope
Elimination and
Restoration
- USDX
(PE1NNZ/DL2MAN)



USDX vs QMX on transmit

USDX:

- 8-bit 20MHz AVR (ATmega328)
- 32K Flash
2K RAM
- 10-bit PWM
- 20dB of non-linear control

QMX:

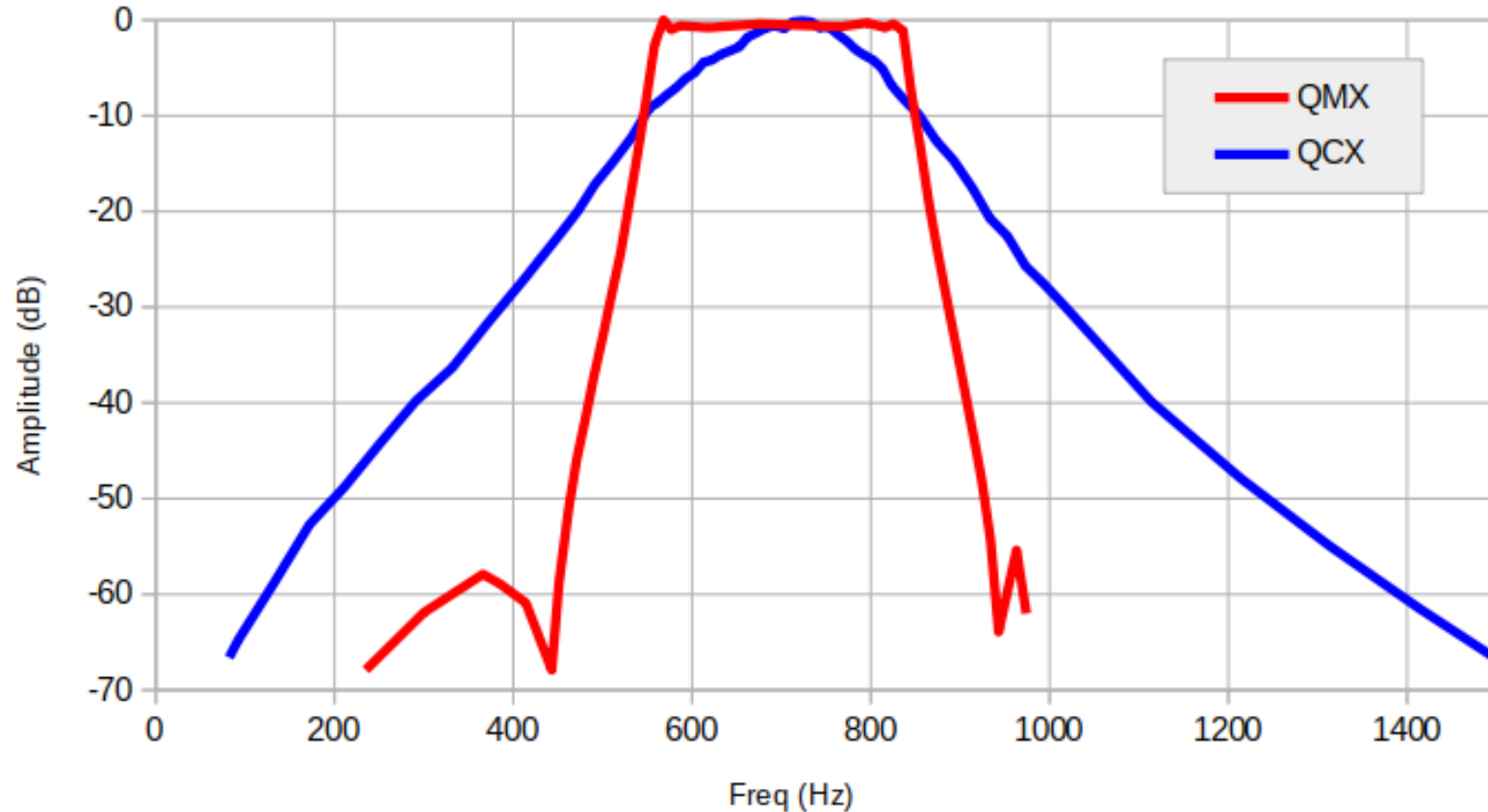
- 168 MHz 32-bit ARM Cortex M4 with floating point unit and DSP instructions
- 512K Flash
128K RAM
- 12-bit high bandwidth DAC
- 37dB of linear control

Firmware

- Currently, basic QDX and QCX-mini functionality – consider it beta
- Well under 25% of Flash and even less RAM are utilized – massive scope for future features
- Trivially easy firmware update procedure

QMX CW filter comparison

QMX cs QCX CW filters



First QSOs: 20m band FT8, 1W

- LZ2MP, DL1BBO, YO6OGJ, 4O4DB, UR7ED

The screenshot displays the WSJT-X v2.1.0 software interface. The main window is split into several sections:

- Band Activity Log:** A table showing received QSOs with columns for UTC, dB, DT, Freq, and Message. The log includes stations from Kazakhstan, Denmark, Norway, Netherlands, Italy, EU Russia, Poland, and Sardinia.
- Wide Graph:** A spectral display showing signal activity across the 20m band (14.000 to 14.500 MHz). The graph shows a dense cluster of signals between 14.070 and 14.100 MHz.
- Controls:** A panel on the right side of the wide graph showing various settings like Bins/Pixel, Start 0 Hz, Palette, and Cumulative.
- QRP Labs Chat:** A chat window at the bottom right showing a message from 'My QRP Labs friends' with the text 'Muhsin: https://youtu.be/w5wZhc5Cst' and a timestamp of 4:59 Am.
- Bottom Panel:** A control panel for the 20m band, showing the current frequency (14.074 000), TX/RX frequency, and various settings like 'Tx even/1st', 'Hold Tx Freq', and 'Generate Std Msgs'.

QMX is available now

- Fully tested hardware, beta firmware
- **\$95** kit
\$20 enclosure
\$50 assembly, calibration
and testing option

QRP Labs

<http://qrp-labs.com/qmx>

