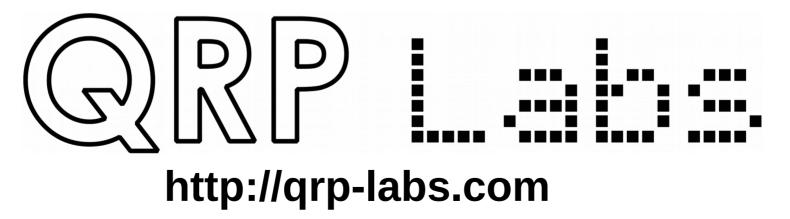
# Evolution in Radio Design: building the next

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



#### Start the story: New Year



• Make a \$million!



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





- Make a \$million!
- Lose 25 pounds!
- First SSB QSO!



- Make a \$million!
- Lose 25 pounds!
- First SSB QSO!
- Be nice to XYL!



- Make a \$million!
- Lose 25 pounds!
- First SSB QSO!
- Be nice to XYL!
- Be nice to kids!









- 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



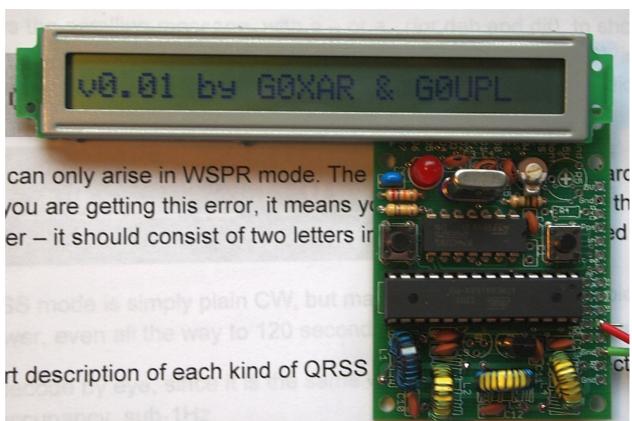


#### 100 kits sold out on vendor evening



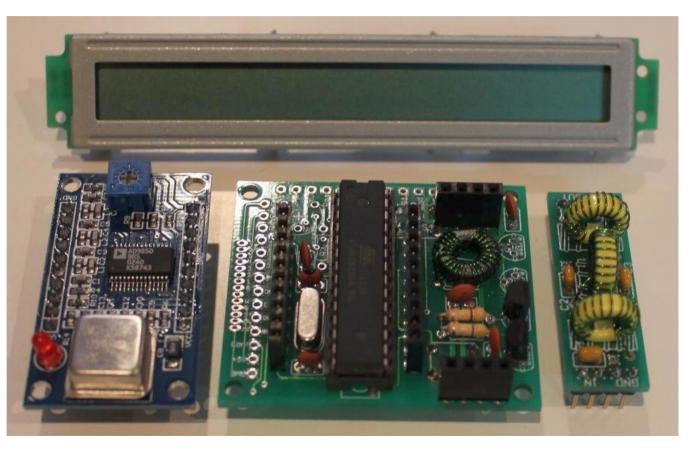
# Ultimate QRSS/WSPR beacon kit

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



## Ultimate2 QRSS/WSPR beacon kit

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



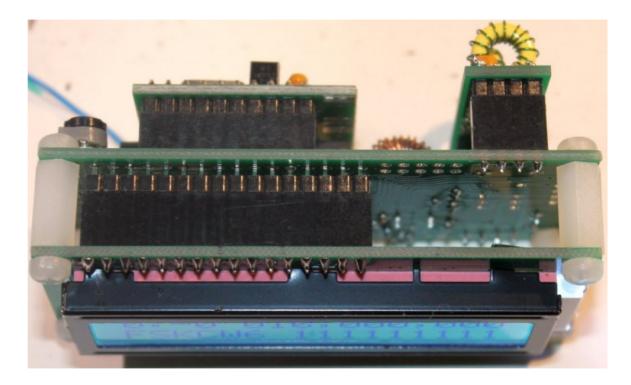
## Ultimate3 QRSS/WSPR beacon kit

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



### Ultimate3S QRSS/WSPR beacon kit

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

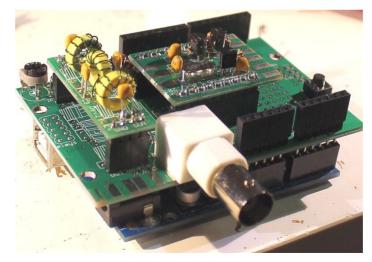


#### Other kits in the family

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



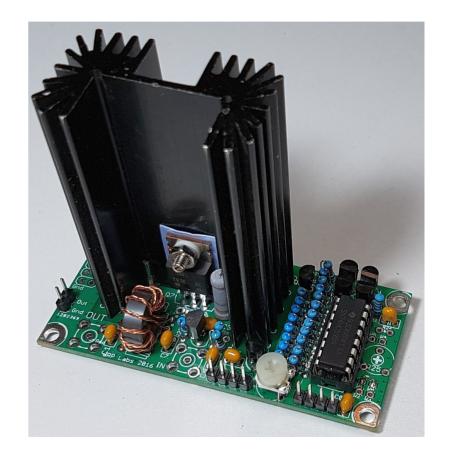




#### 5W PA kit for Ultimate3S

• DAC-controlled aplitude 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



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

#### QCX-mini



#### The three QCX





- 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: **Q**RP Labs **D**igital **X**cvr

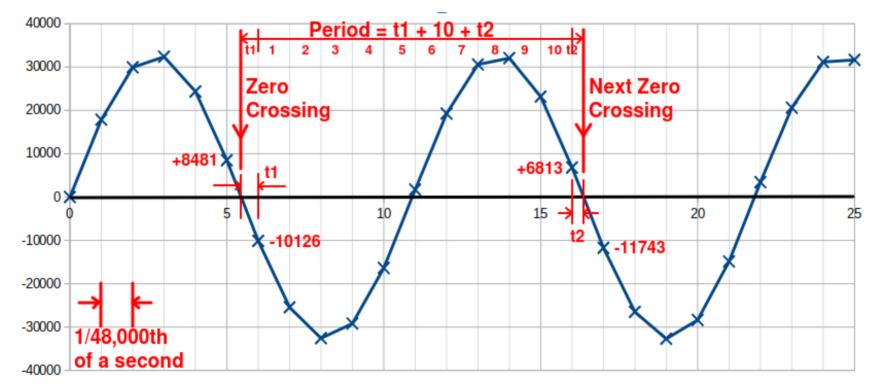
- 80, 40, 30, 20m PIN-diode band switched and transmit/receive switched
- Full 5W from 9V or 12V supply
- TCXO-referenced Si5351A synthesized LO
- Embedded high-performance SDR receiver with 24-bit 112dB ADC chip
- Single signal transmit
- Includes 24-bit 48ksps stereo USB soundcard and CAT, easy interface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

#### A look inside

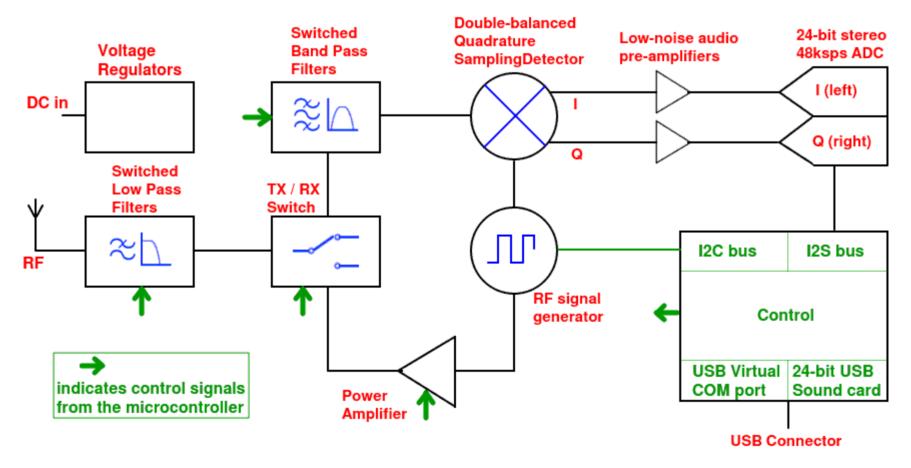


## Measuring audio

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



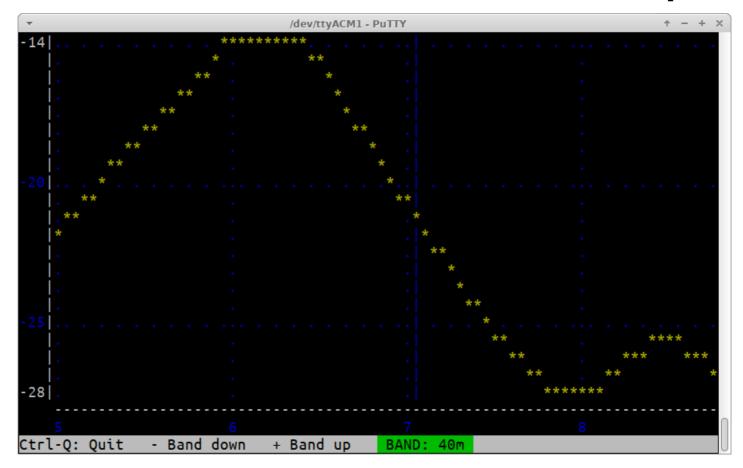
# QDX design: block diagram



# 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

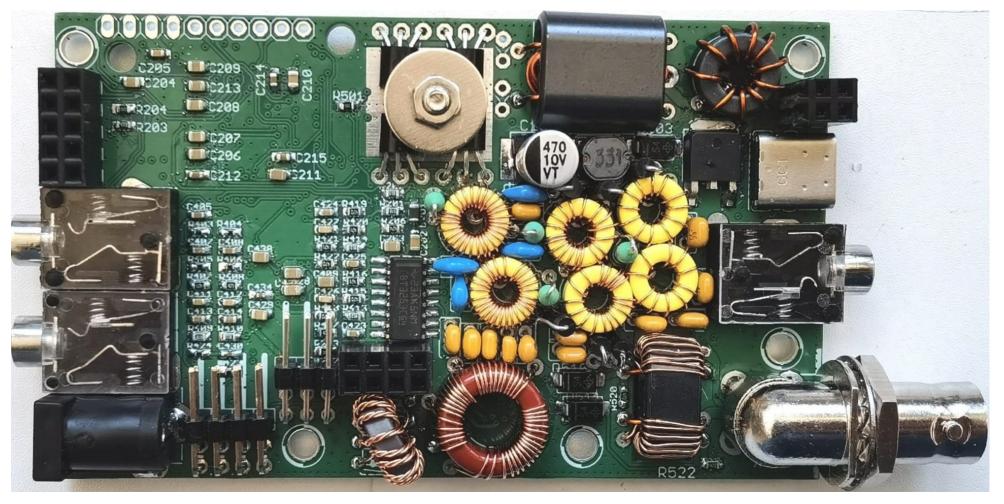


#### **USB-C** connector

- 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 SMPS and Controls



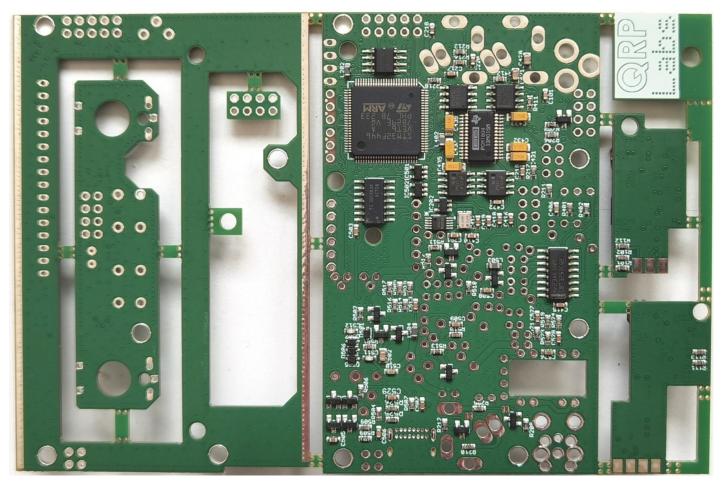
## Plugged-in LCD board



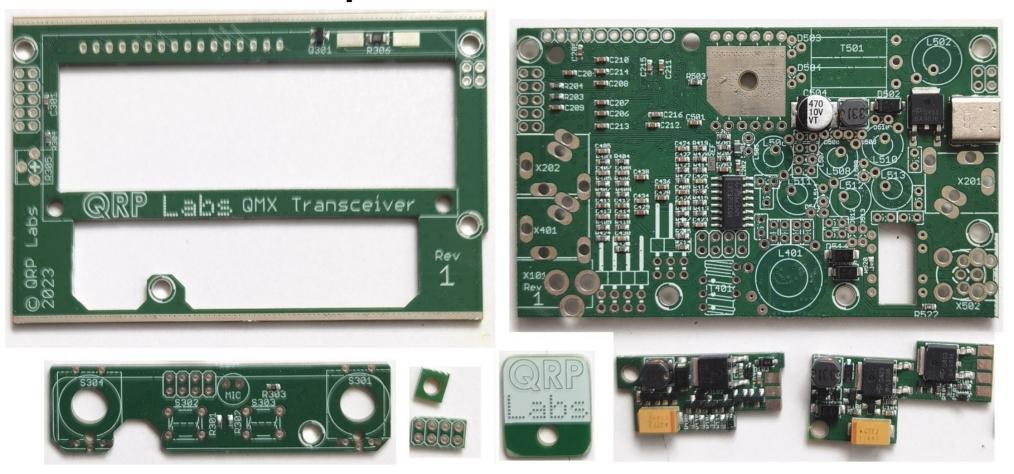
#### PCB design: 5.5 x 3.6 inches



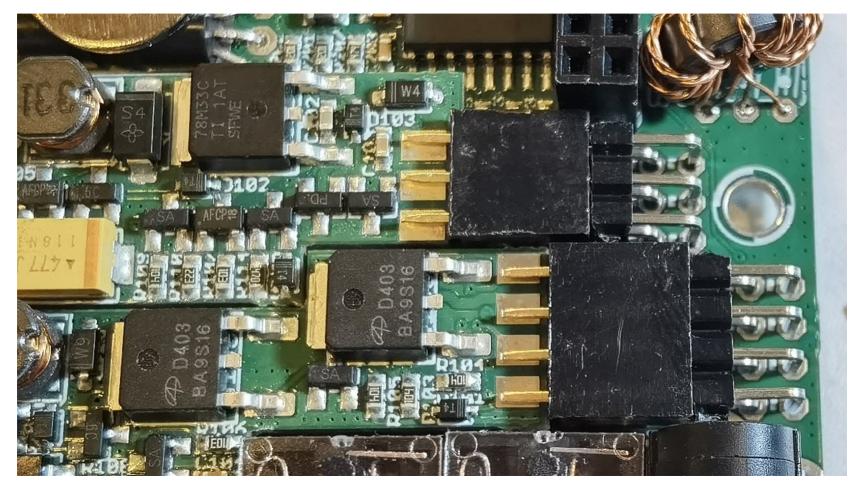
#### PCB bottom side



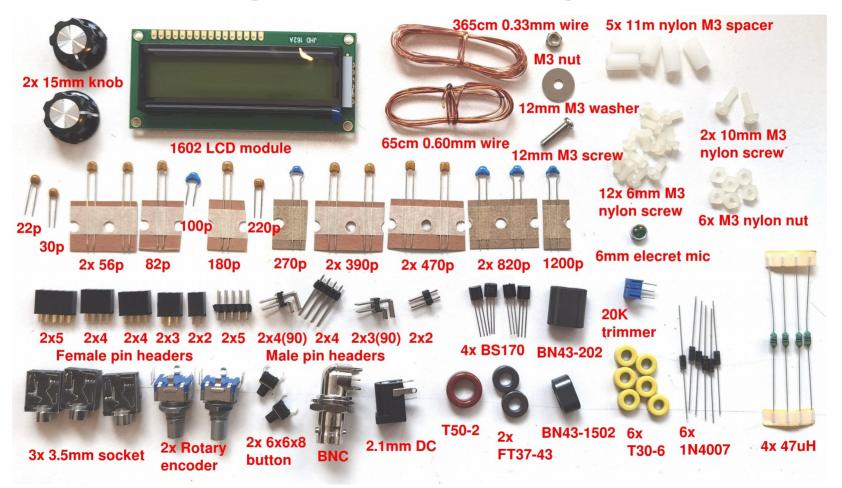
#### Separated boards



## Power supply boards close-up

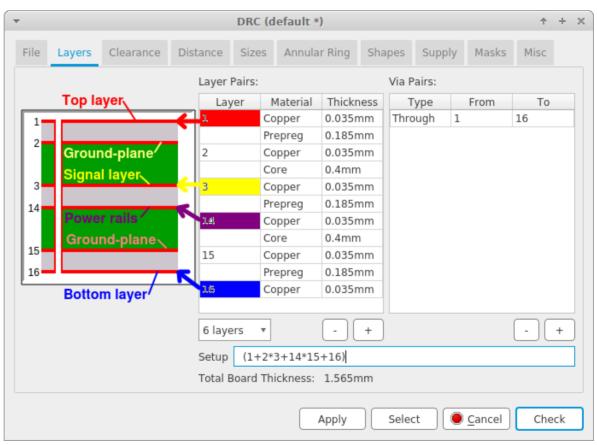


#### **Through-hole components**



## A 6-layer board

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

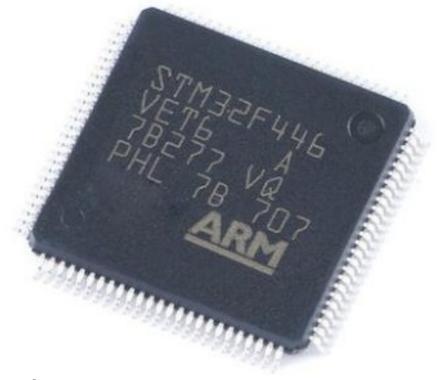


## QDX + design increments = QMX

- 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!



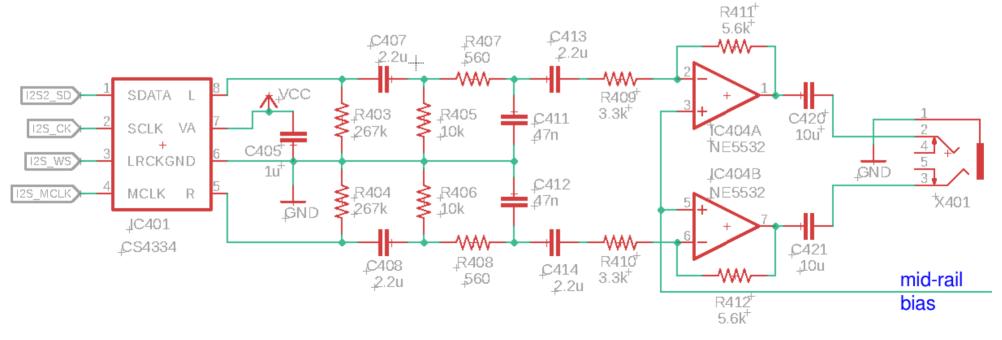
## LCD, buttons, encoders

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



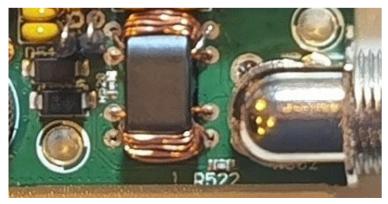
## Audio headphones output

- 24-bit stereo I2S DAC chip
- Two op-amps drive left and right

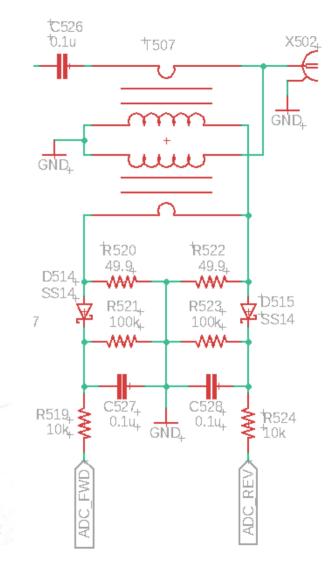


# SWR bridge

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





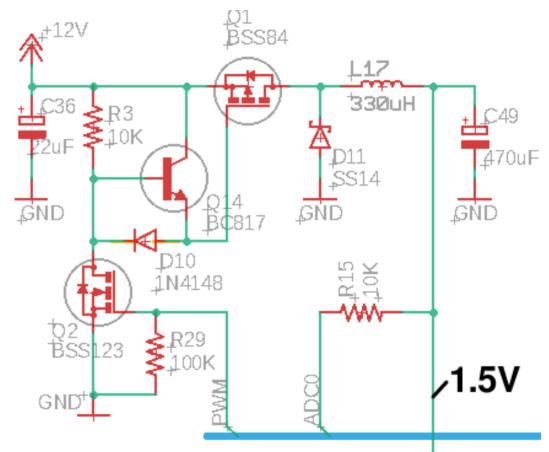


# Switching power supplies

- WHY switching? Receive current consumptionm 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



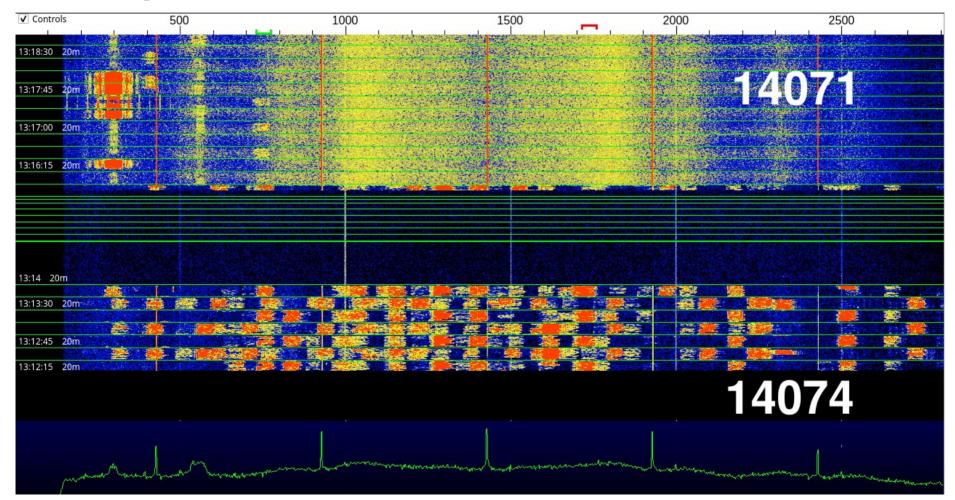
# Why are SMPS noisy?

- 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



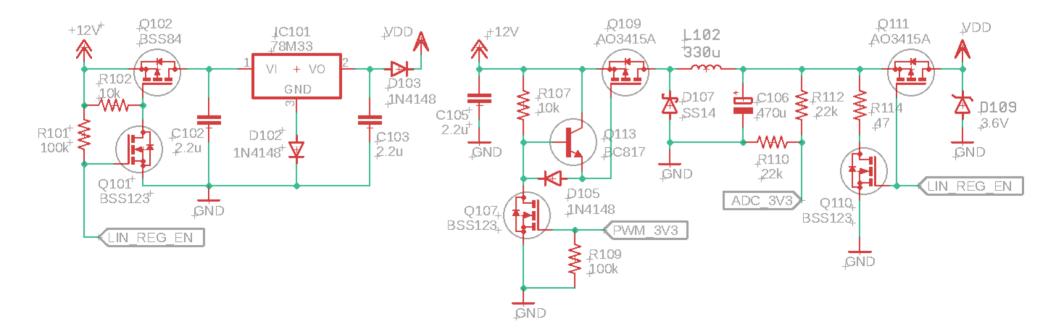
Considering of the by my wind of the appropriate of the and the second provide the the second of the se

## The chicken and egg problem

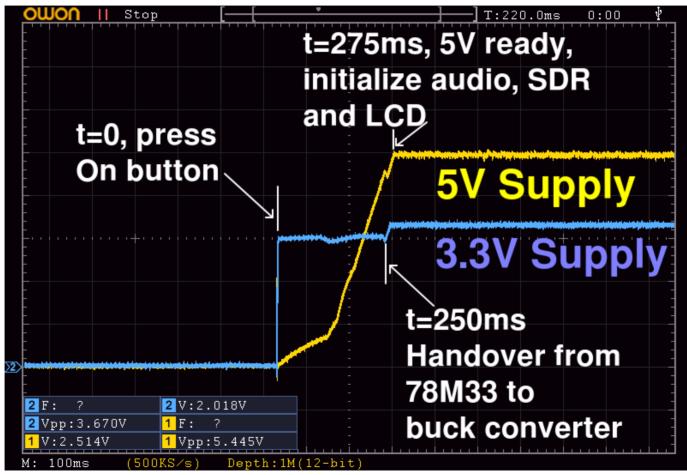
- The microcontroller is the control loop for all three power supplies (PIN diode bias, 3.3V, 5V)
- But the microcontroller is supplied by the 3.3V supply...

## Solution:

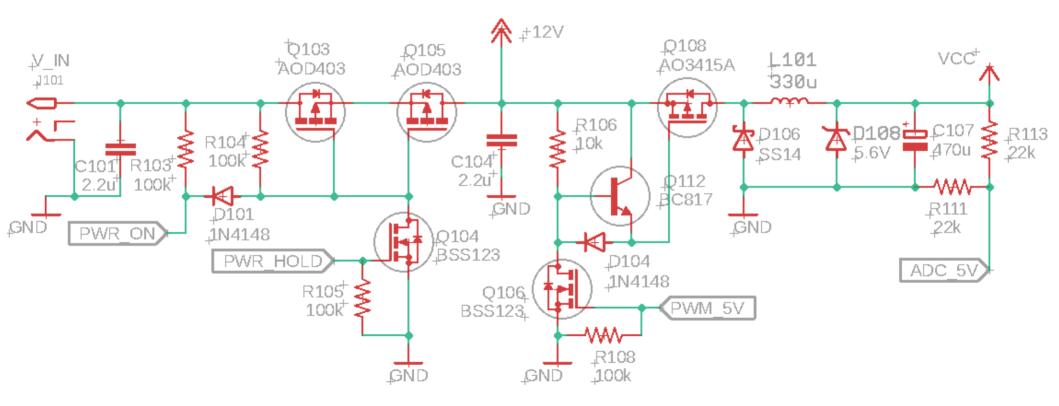
- 78M33 linear regulator
- Switch to 3.3V buck converter when ready...



#### In practice: power-up sequence

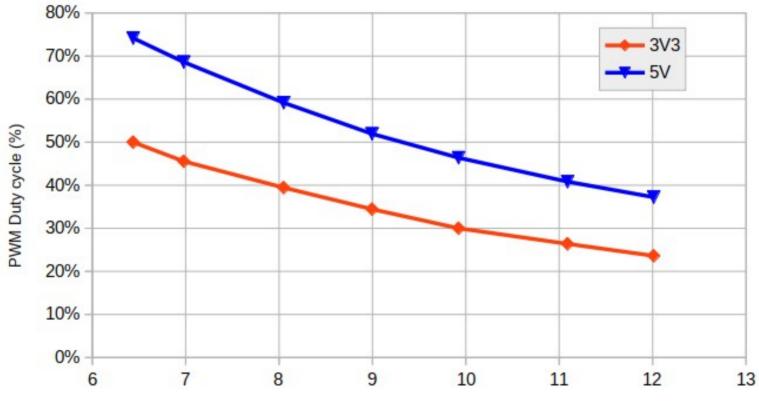


## 5V, soft power, reverse-polarity-prot



#### In practice: duty cycle

Buck converter duty cycle vs Supply voltage



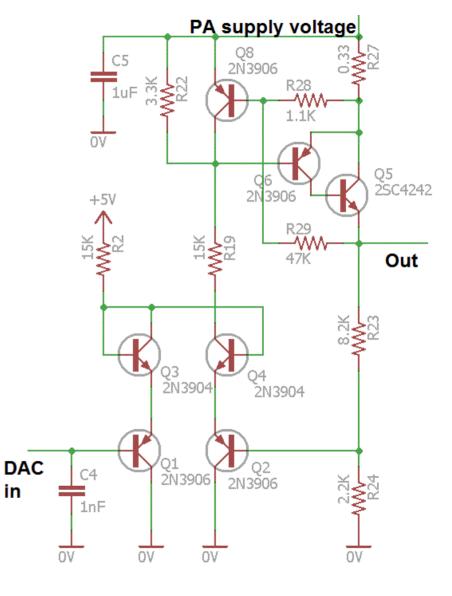
Supply voltage (V)

## 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"

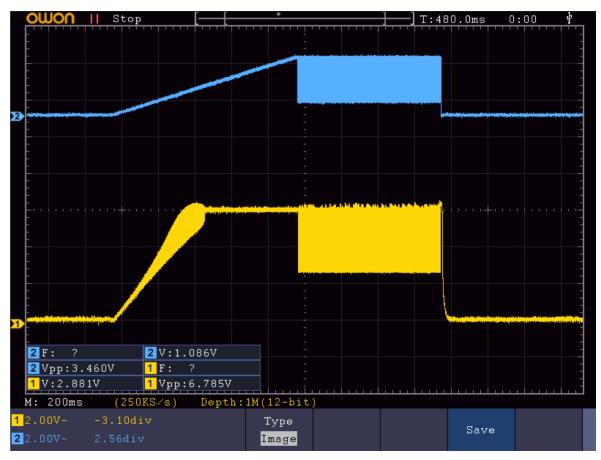
## RF envelope shaping

- Circuit from earlier 5W PA kit
- In QMX: unstable! OUON > Trig **20ms** Vpp: 37.20V 10m⊂ (100MS/s) Depth:20M(12-bit) CH2:DC-\_\_3.00V .0VBW- 0.98div Type Save 210.0VBW- -2.98div Image



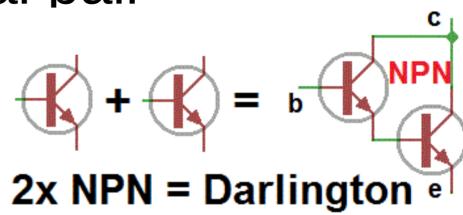
- Slow ramp
- At some point.. OSCILLATION
- Could not be tamed!

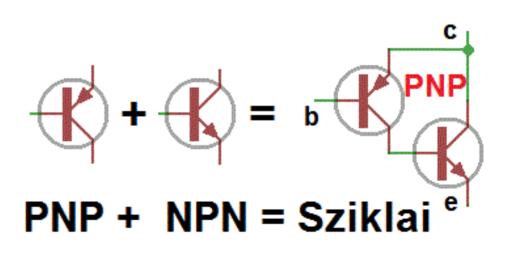
## Instability



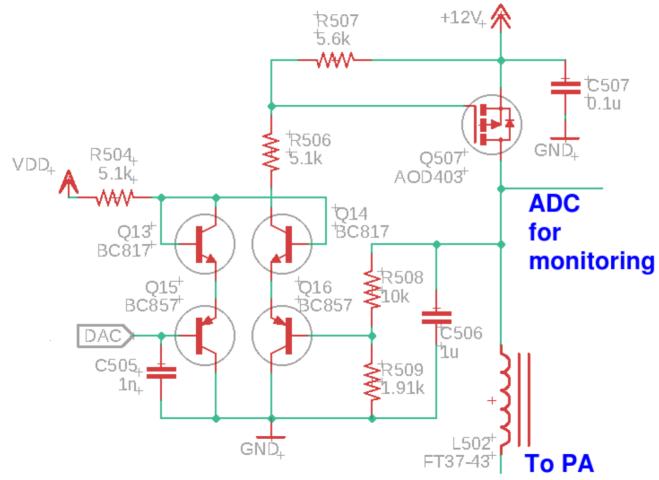
## Sziklai pair

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



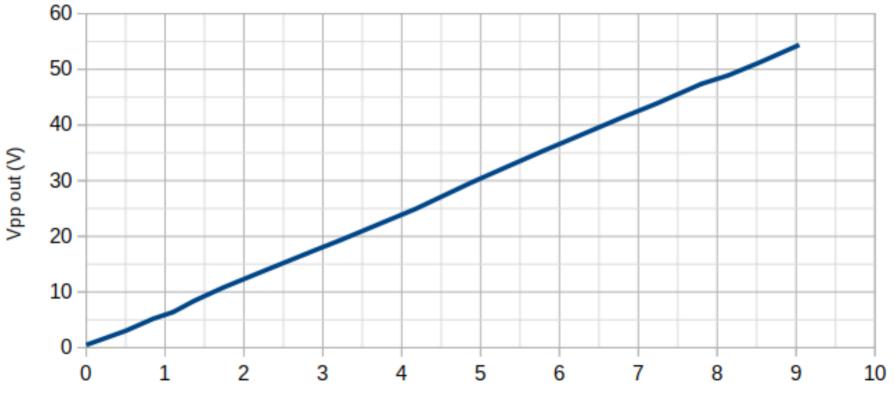


#### Solution: P-channel MOSFET!



#### In practice: 37dB control range

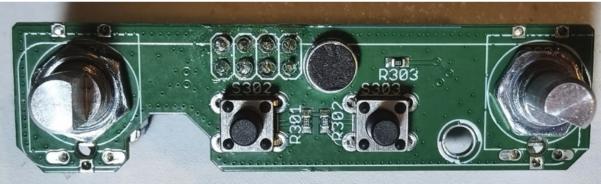
#### Vpp vs PA Supply voltage



Supply voltage (V)

## 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



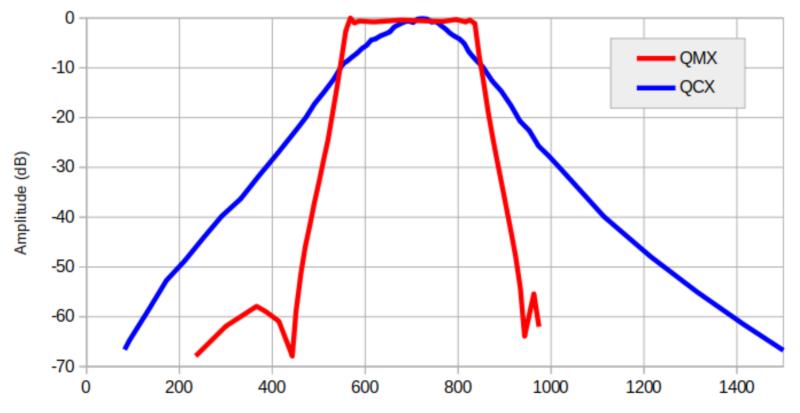
- 168 MHz 32-bit ARM Cortex M4 with floating point unit and DSP instructions
- 512K Flash
   128K RAM
- 12-bit high bandwidth DAC
- 37dB of linear control

#### 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



Freq (Hz)

## First QSOs: 20m band FT8, 1W

#### • LZ2MP, DL1BBO, YO6OGJ, 4O4DB, UR7ED

• W5JT-X v2.1.0		♥ WSJT-X - Wide Graph	÷ - +
File Configurations View Mode Decode Save Tools Help		Image: W controls         500         1000         1500         2000	2500
Band Activity UTC dB DT Freq Message	Rx Frequency UTC dB DT Freq Message	145345 20m 20 20 20 20 20 20 20 20 20 20 20 20 20	
145345 -16 0.2 2015 ~ D1AW UB0AMB R-05	▲ 14445 -7 0.1 2280 ~ GOUPL LZ2MP KN23		<b>*</b> * <b>*</b> *
145345 -7 -0.4 2207 ~ CQ UN7IN L080 Kazakhstan	144500 Tx 2340 ~ LZ2MP GOUPL -07		
145345 3 0.2 2277 ~ CQ R0AX NO56 CQ Zone 18 145345 -2 0.2 2386 ~ DS4FWI UT6MAH KN98	144515 -8 0.0 2281 ~ GOUPL LZ2MP R-02 144530 Tx 2340 ~ LZ2MP GOUPL RR73		
145345 -10 0.1 2575 ~ G8KUZ SQ8RMX R-05	144545 -5 0.0 2281 ~ GOUPL LZ2MP 73		
145345 -16 0.0 2350 ~ TA4/GOUPL <ur7ed> 73 145345 -9 0.1 522 ~ CO 5P10T J066 Denmark</ur7ed>	144545 -16 0.1 835 ~ GOUPL DL18B0 J043 144692 Tx 2348 ~ C0 GOUPL KM46	1450.45 2010 2010 2010 2010 2010 2010 2010 201	
145345 -9 0.1 664 ~ CQ LA26CA J049 Norway	144606 Tx 2340 ~ DL1BBO G0UPL -16		
145345 -15 0.8 797 ~ UN7PNF SP3RAT J082 145345 -7 0.0 1478 ~ YB1GDL UN7BFY M043	144615 -12 0.1 835 ~ GOUPL DL1880 R-21 144630 Tx 2340 ~ DL1880 GOUPL RR73	144915 20m	
145345 -18 0.6 2580 ~ R3PLN M0YGH I092	144645 -18 0.1 835 ~ GOUPL DL1880 73 144780 Tx 2348 ~ CO TA4/GOUPL	1449:15 20m	
145345 -11 0.1 501 ~ F6HSJ F5TMJ JN03 20m	144700 Tx 2340 ~ CQ TA4/G0UPL 144715 -5 0.1 2340 ~ <ta4 g0upl=""> YO6OGJ KN26</ta4>		
145415 -4 0.3 173 ~ UA0QNI UA2FGQ R-15	144730 Tx 2340 ~ Y060GJ <ta4 goupl=""> -05</ta4>	144745 20m 🚟 👘 👘 👔 👔 👔 👘 👘 👘	
145415 -3 0.0 234 ~ BG7SFE DG7MHR JN57 145415 -13 0.2 393 ~ CQ PCGR JO22 Netherlands	144745 2 0.1 2337 ~ S56B0 UR5EUY RR73 144745 -6 0.1 2339 ~ <ta4 gbupl=""> Y060GJ R-12</ta4>	14:47:15 20m	
145415 -8 0.1 522 ~ R9UIQ 5P10T -11	144880 Tx 2348 ~ <yo60gj> TA4/GOUPL RR73</yo60gj>	144615 20m	
145415 -3 0.1 568 ~ BG1URZ DB1BDL J031 145415 -2 0.1 687 ~ <is0fap i7=""> DJ0MAB JN49</is0fap>	144815 4 0.1 2337 ~ S56B0 UR5EUY 73 144815 -1 0.1 2339 ~ TA4/G0UPL <y060gj> 73</y060gj>	144615 20m 25 25 25 25 25 25 25 25 25 25 25 25 25	
145415 -12 0.1 878 ~ CQ IK4RVY JN64 Italy	144830 Tx 2348 ~ CQ TA4/G8UPL 144980 Tx 2348 ~ CO TA4/G8UPL	144515 20m	
145415 -6 0.1 1050 ~ CQ R566 K092 EU Russia 145415 -3 0.2 1095 ~ IK4LZH DM4MS JN69	144980 Tx 2340 ~ CQ TA4/G0UPL 144930 Tx 2340 ~ CQ TA4/G0UPL	14:44:45 20m	
145415 -4 0.3 1132 ~ UA9AAE UA6CN R-09 145415 -16 0.1 1190 ~ KJ4MCT DG1FBG J040	144945 -2 0.1 2339 ~ <ta4 g0upl=""> 404DB JN92 144945 -1 0.2 238 ~ <ta4 g0upl=""> F1NOP JN19</ta4></ta4>		
45415 -18 0.1 1239 ~ CQ SP9MZU KN09 Poland	144945 -1 0.2 238 ~ <ta4 g0upl=""> F1NQP JN19 145080 Tx 2340 ~ 404DB <ta4 g0upl=""> -02</ta4></ta4>		
45415 -13 0.1 1290 ~ CO DX PE1PIX J023 Netherlands 45415 7 1.0 1442 ~ PD1PTT 0E8DDX 73	145015 -5 0.1 2339 ~ <ta4 g0upl=""> 404DB R-17</ta4>	144245 20m	
45415 -5 0.2 1615 ~ UT3UV DL5YCL J031	145015 -10 0.2 346 ~ <ta4 goupl=""> F1NQP JN19 145030 Tx 2349 ~ &lt;404DB&gt; TA4/GOUPL RR73</ta4>		
145415 -7 0.3 1692 ~ LZ86IV DL2CBB 145415 -7 0.0 1847 ~ 4X4ZP UN7BFY R-16	145045 -4 0.1 2339 ~ TA4/GOUPL <404DB> 73 145045 -8 0.2 346 ~ <ta4 goupl=""> F1NOP JN19</ta4>		
145415 -7 0.0 1847 ~ 4X42P UN78FY R-10 145415 -9 0.1 1930 - CQ IS0YHV JM49 Sardinia	145180 Tx 2348 - F1N0P <ta4 g0upl=""> -08</ta4>		
145415 -20 0.2 2016 ~ D1AW UB0AMB RR73 145415 -3 0.1 2207 ~ CQ UN7IN L080 Kazakhstan	145130 Tx 2340 ~ F1N0P <ta4 g0upl=""> -08 145200 Tx 2340 ~ F1N0P <ta4 g0upl=""> -08</ta4></ta4>	14:40:45 200	
145415 4 0.2 2277 ~ CQ R0AX N056 CQ Zone 18	145200 Tx 2340 ~ CQ TA4/G8UPL		
145415 -1 0.2 2386 ~ DS4FWI UT6MAH R-13 145415 -12 -0.1 2736 ~ SA4CFJ LA7MTA JP77	145230 Tx 2340 ~ CQ TA4/G0UPL 145245 -12 0.1 2349 ~ <ta4 g0upl=""> UR7ED KN78</ta4>		
45415 -15 0.1 501 ~ F6HSJ F5TMJ R-01	145300 Tx 2340 - UR7ED <ta4 g0upl=""> -12</ta4>		
145415 -13 0.1 664 ~ CQ LA2GCA J049 Norway 145415 -6 0.2 1469 ~ YB1GDL R4HHM L053	145315 -15 0.0 2349 ~ <ta4 g0upl=""> UR7ED R-19 145330 Tx 2348 ~ <ur7ed> TA4/G0UPL RR73</ur7ed></ta4>		
45415 -7 0.1 1612 ~ UT3UV F6GCB JN26	145345 -16 0.0 2350 ~ TA4/GOUPL <ur7ed> 73</ur7ed>		
45415 -7 0.7 1815 ~ YD9HJD EUGKA R-04 45415 -14 0.4 1930 ~ EA4GM IZ50VP JN53	145400 Tx 2340 ~ CQ TA4/G0UPL ▼ 145430 Tx 2340 ~ CQ TA4/G0UPL ▼		
CQ only Log QSO Stop Monitor Erase	Decode Enable Tx Halt Tx Tune ✓ Menus	Manual Contract and more thank that the second that	
0m - 14.074 000	▼ Tx even/1st		hand harmong they may my
	Generate Std Msgs Next Now Pww		
DX Call DX Grid			
80		Bins/Pixel 3 D Start 0 Hz Palette Adjust Flatten Ref Spec	Spec 30 %
-60	NX 2349 HZ V	[165 2500 JT9 ] N Avg 3 ♀ Default ▼ Cumulative ▼	
-40	Report -15 \$		
Lookup Add	✓ Auto Seg ✓ Call 1st	My QRP Labs friends 4:59 Am	
20	<ul> <li><ur> <li><ur> <li><ur> <li><ur> <li><ur> <li><ur> <ur> <li><ur> <ur> <li><ur> <ur> </ur></ur></li> <li><ur></ur></li></ur></ur></li></ur></ur></li></ur></li></ur></li></ur></li></ur></li></ur></li></ul>	Muhsin: https://youtu.be/wt5wZhC5crl 🙂 🖉 Type a message	
د 2023 Apr 04 14:54:40	CQ TA4/GOUPL   TX 6		
0 dB 14:54:40		13 03-04-2023 e arsjivv.xlsx 🔺	
Tx: CQ TA4/G0UPL FT8 Last Tx: CQ TA4/G0UPL	10/15 WD:99m		
🖞 Applications Menu 🛛 💂 manual 📕 Control 👼 2 Board 📴 1 Schem 🐻 Orders 🚳 1	pa_asse 🌀 Snap Cir 🚳 https://w 🧿 WhatsA 🧧 STM32 🧾 QRPlabsJ 📓 Calculator 💼 Dow	nloa 🛅 Order Ph 🛅 Inc 👘 STM32C 🧧 (1)]586aa. 💼 WSJT-X 🔲 🔍 WSJT-X- V2.1.0 by K11T 🔍 17:54:39 🐼 🔂 🚺 👘 😡 Hans Summers 🜒 🔲	

## QMX is available now

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



