Designing a modern digi-mode transceiver

Development of the QDX 4-band QRP kit

QRP ARCI FDIM seminar

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http://qrp-labs.com

QDX Design

- What is a digital mode?
- Design motivations and goals – the **WHY**
- QDX summary – the **WHAT**
- Design explanation – the **HOW**
- Challenges – production, parts, etc. The **WHEN**

What is a digital mode

- Morse code is digital, 1’s and 0’s (key down’s and key ups, or if you prefer, dits and dahs)
- But normally a computer encodes and decodes them
- May use various modulation modes:
  - On/Off keying
  - Frequency shift keying
  - Phase shift keying
  - Spread-spectrum

What do digital modes send?

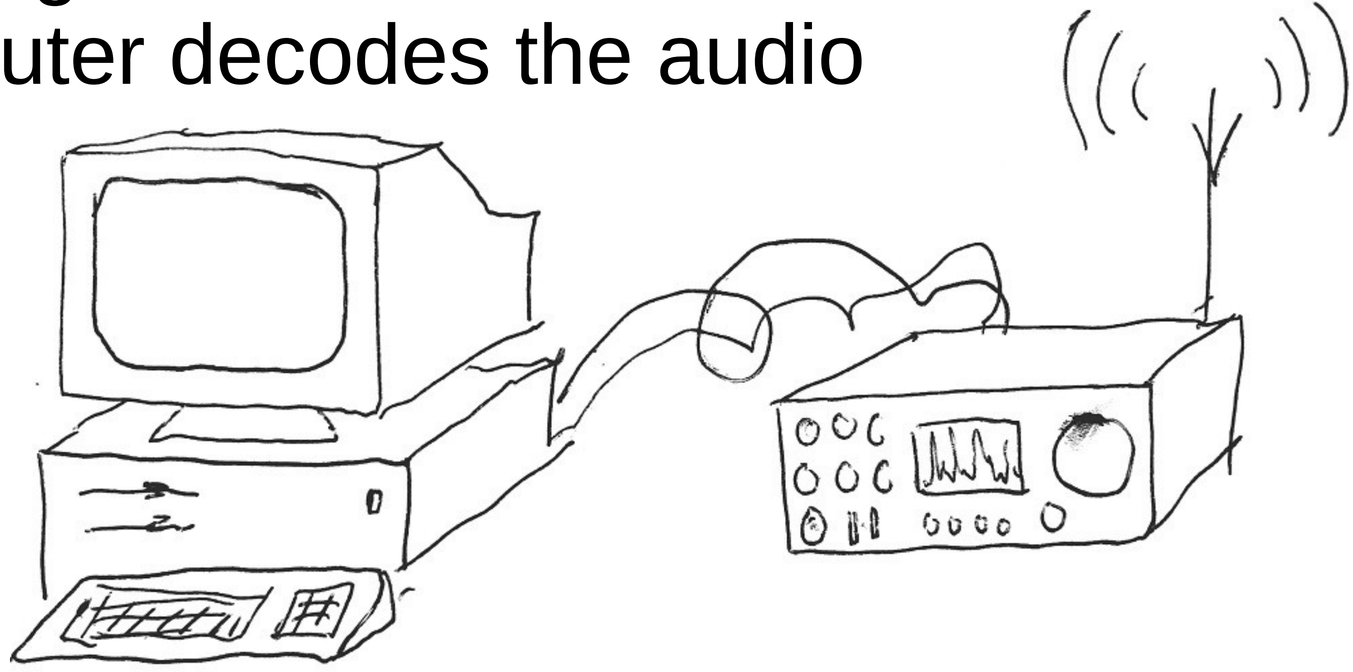
- Text messages, chat modes
- Computer QSOs – e.g. FT8
- Pictures
- Propagation testing – WSPR
- Balloon telemetry – QRP Labs U4B + WSPR

Other features

- Often narrow band
  - Lower bandwidth improves SNR at the expense of speed
- Often seen as low power, weak signal modes – though these are not necessarily the same thing
- May or may not include error correction
- Generally well-suited for QRP fanatics like us!

Typical set-up

- Computer generates and encodes audio, and SSB rig transmits and receives audio, the computer decodes the audio

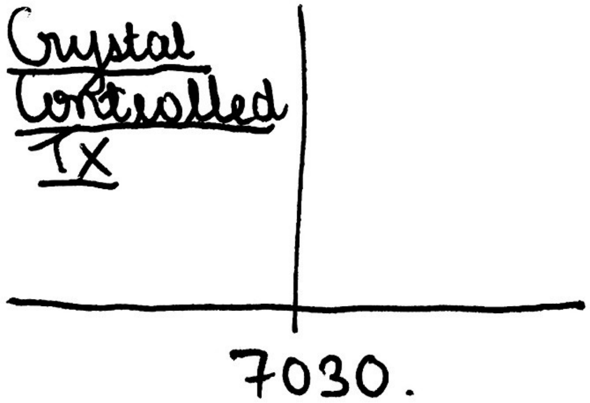


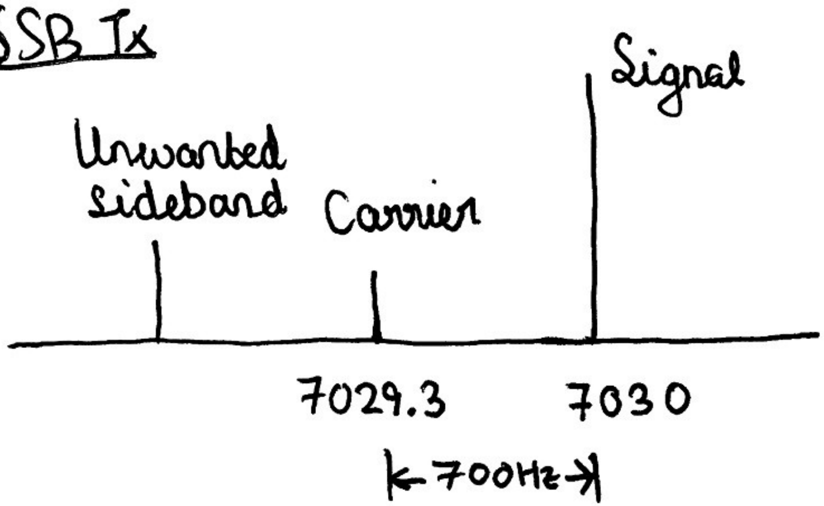
Digi mode software

- WSJT-X, the most popular
  - FT8, FT4, JT9, JT65, more
- JS8Call
  - JS8 (conversational variant of FT8)
- Fldigi
  - CW, PSK31, RTTY, Hell, more
- All send and receive audio tones to and from a sound card

A different way...

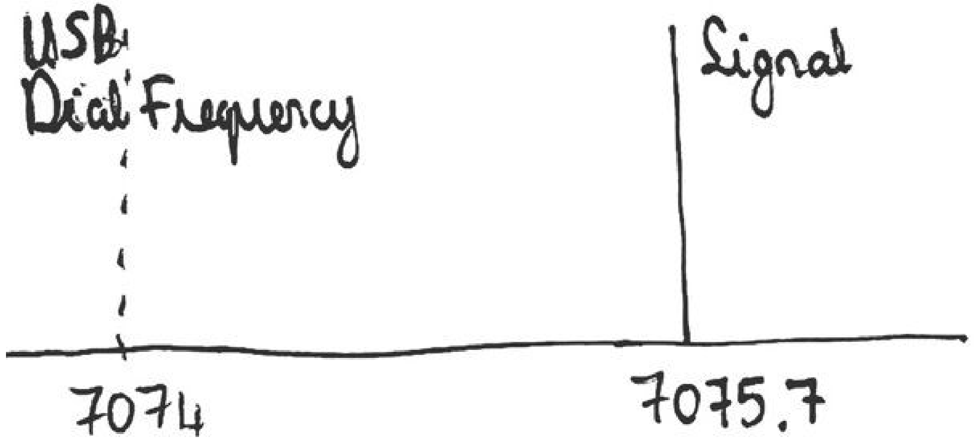
- Consider two ways of generating CW
  - A crystal controlled QRP transmitter
  - An audio tone generator connected to an SSB transmitter





Same with Digital…

- Audio via a SSB transciever
- Or generate it directly – clean, simple, cheap



7074 USB Dial Frequency
\+ 1700 Hz Audio
= 7075.7 kHz actual Tx freq.

2019 – motivations: doing better!

- Several FT8 kits
  - Direct conversion transmitters and receivers
  - Poor performance (receive and transmit) – low power
  - Crystal controlled, single band
  - Not even low cost!
- Recent improvements
  - Phasing SSB transmit
  - Si5351A Synthesis

Project goals

- A very high performance digi modes transceiver
- Multiple bands
- Full 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 USB soundcard and CAT, easy interface with software and single USB cable
- Built-in test and alignment tools

A look inside

Bottom side

Front

Rear

Design: USB connection

- QDX implements virtually:
  - USB sound card, 24-bit at 48ksps
  - Virtual COM serial port for CAT
  - All on ONE cable (so actually it also has to implement a “USB hub”)
- QDX bootloader:
  - USB Flash drive (firmware update)

Advantages of USB audio

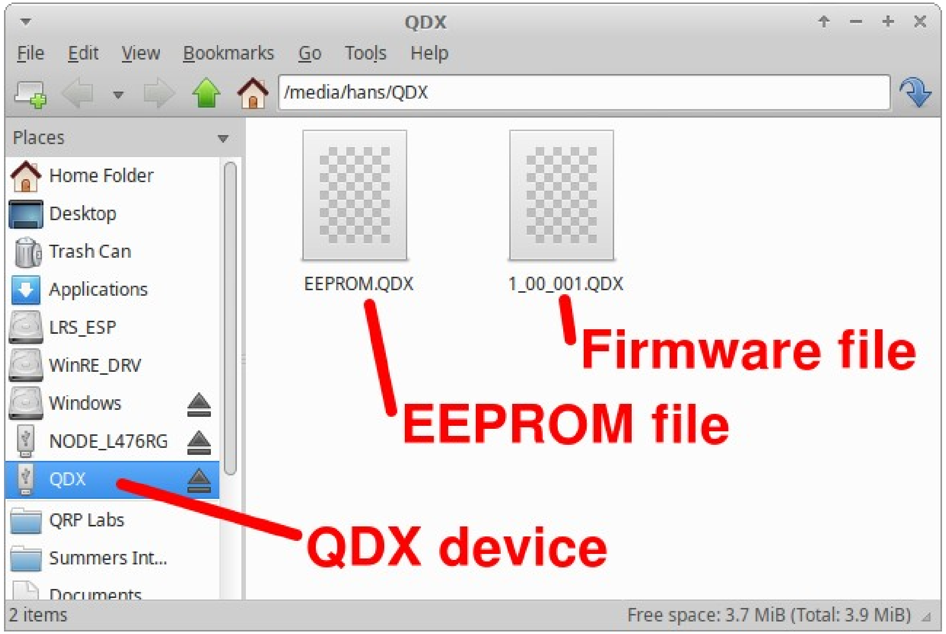
- Absolutely perfect sound transfer
  - Zero noise
  - Zero distortion
  - Zero loss
  - What WSJT-X generates as sequence of numbers, we get directly in QDX
  - No audio overload
- No audio cables
  - So no hum pickup possible

USB: Virtual COM serial

- CAT: PC gives commands to the radio
  - What frequency to operate on
  - When to transmit and receive (this is better than VOX – voice-operated-transmission)
- All digi modes software uses CAT to talk to the radio
- QDX pretends to be a Kenwood TS-480
- Terminal access for configuration, alignment

USB: Firmware update

- QDX appears as a USB Flash drive
- Simply download the file and drag it across
- Benefits:
  - No hardware
  - No software
  - No drivers
  - Easy, anyone can do it
  - 256-bit AES encryption

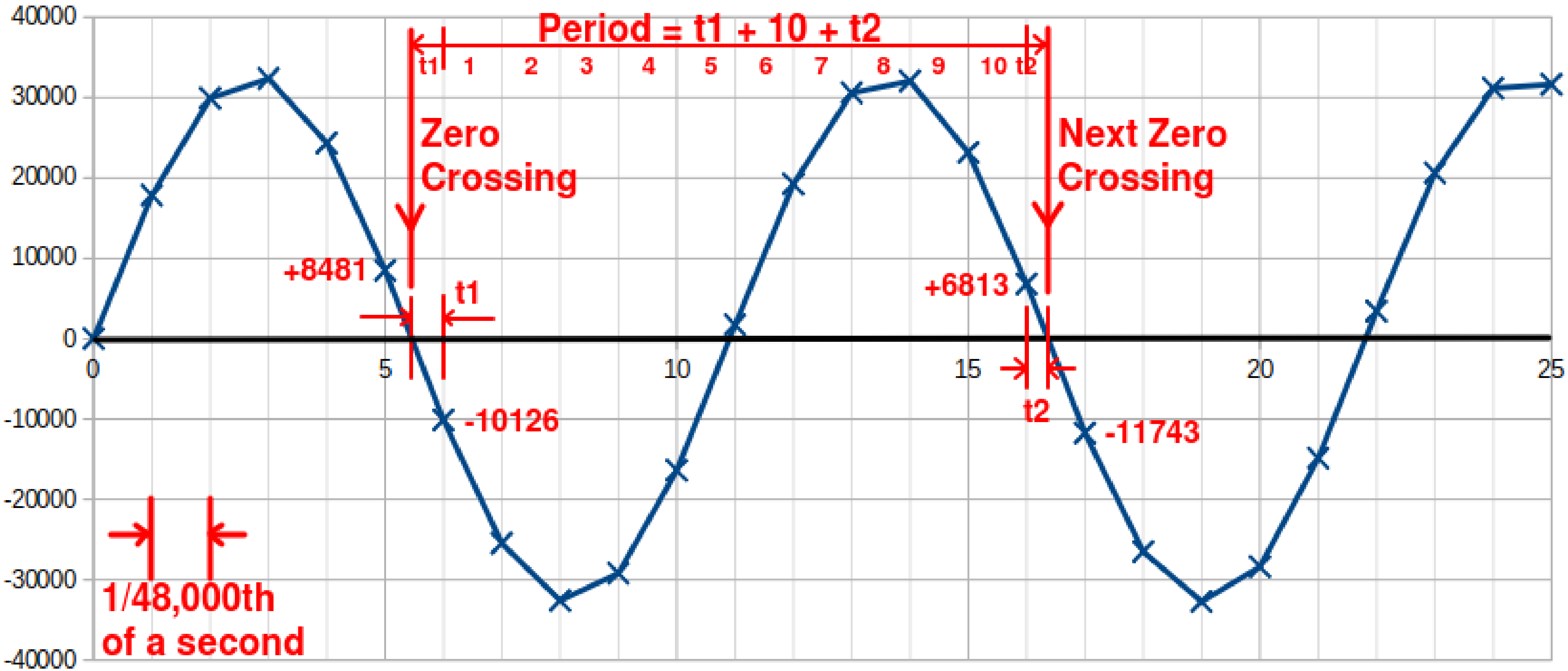


Design: transmit signal strategy

- The PC digimode software will tell us the “USB Dial frequency” via CAT
- QDX measures the audio tone frequency coming from the host PC
- Add tone frequency to USB dial frequency, and tell the synth to produce it
- The PA transmits it

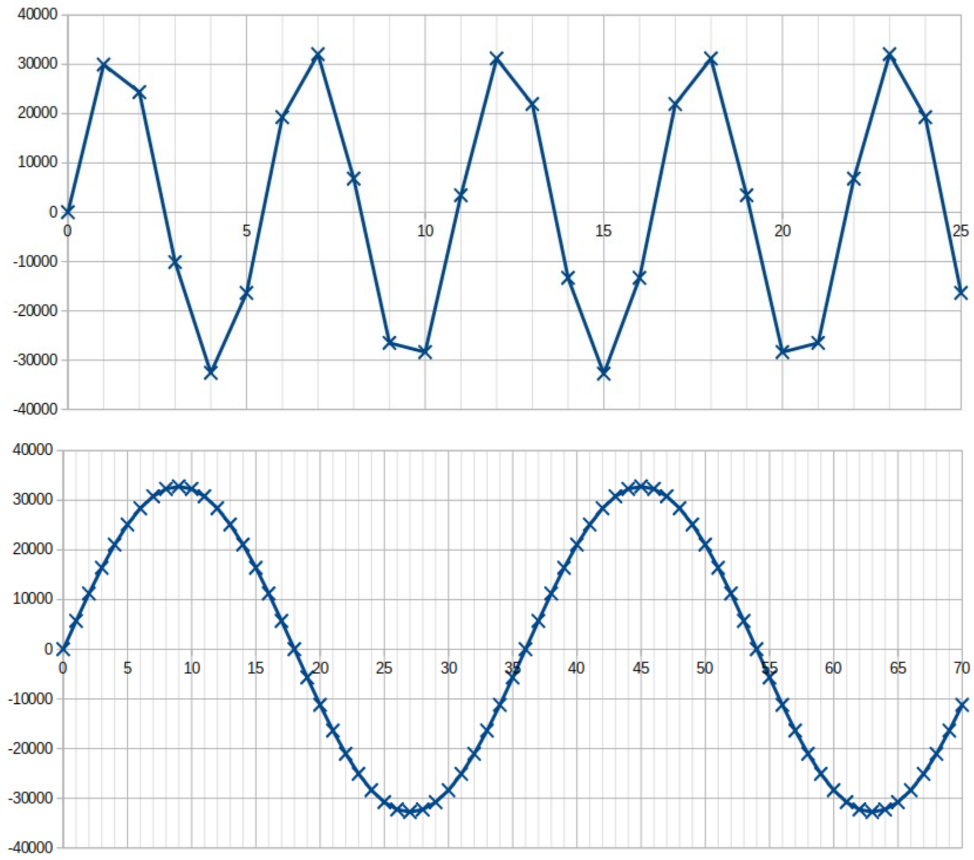
Measuring audio

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



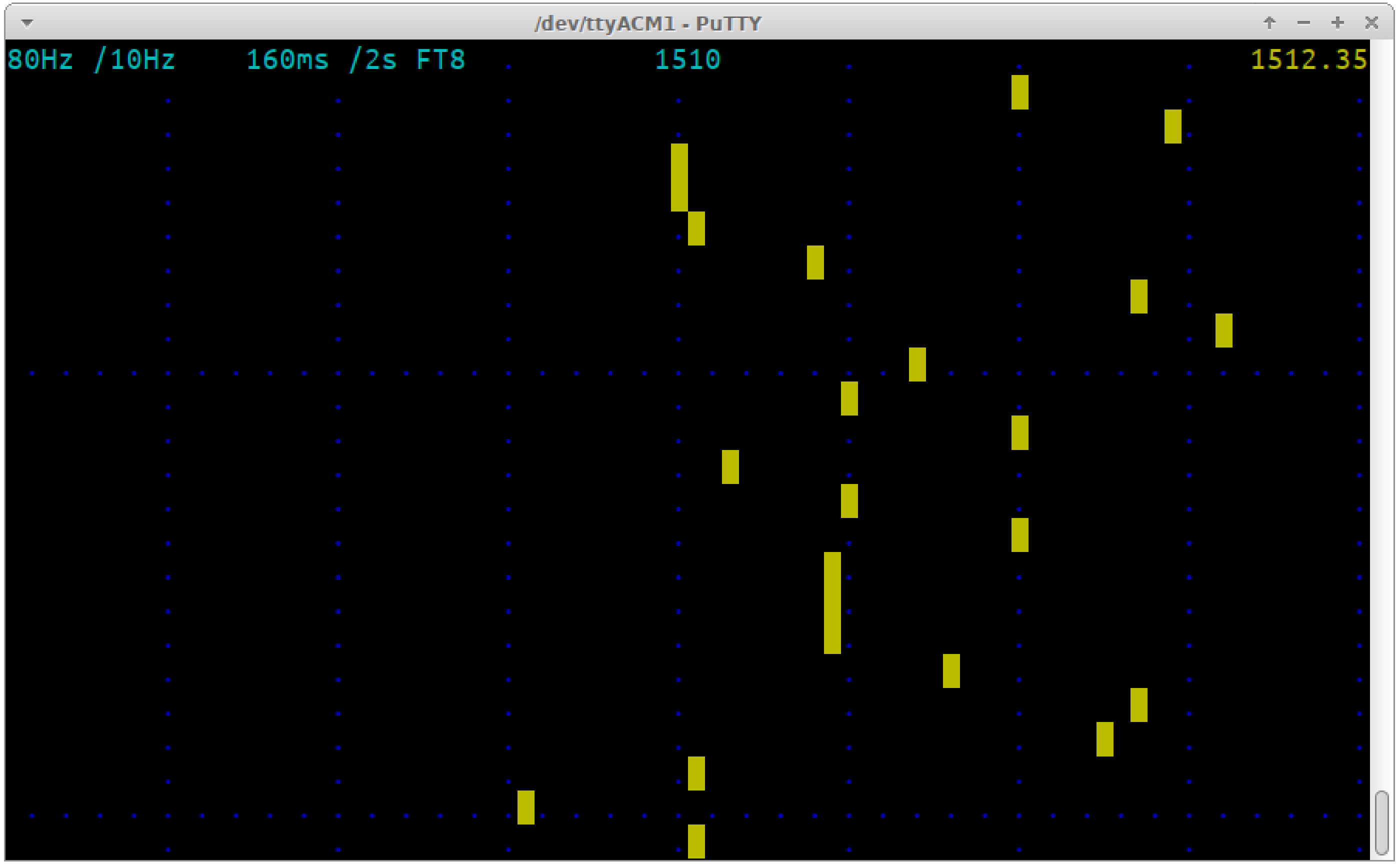
Low vs high audio

- Straight-line linear interpolation
  x = sin(x)
  (for small x)
- At high frequencies "x" is no longer small – there are few samples per cycle
- Still PLENTY aaccurate!



Astonishingly accurate

- +/- 0.05Hz midband
- More accurate at lower freqs, worse at higher
- Averaging improves it further

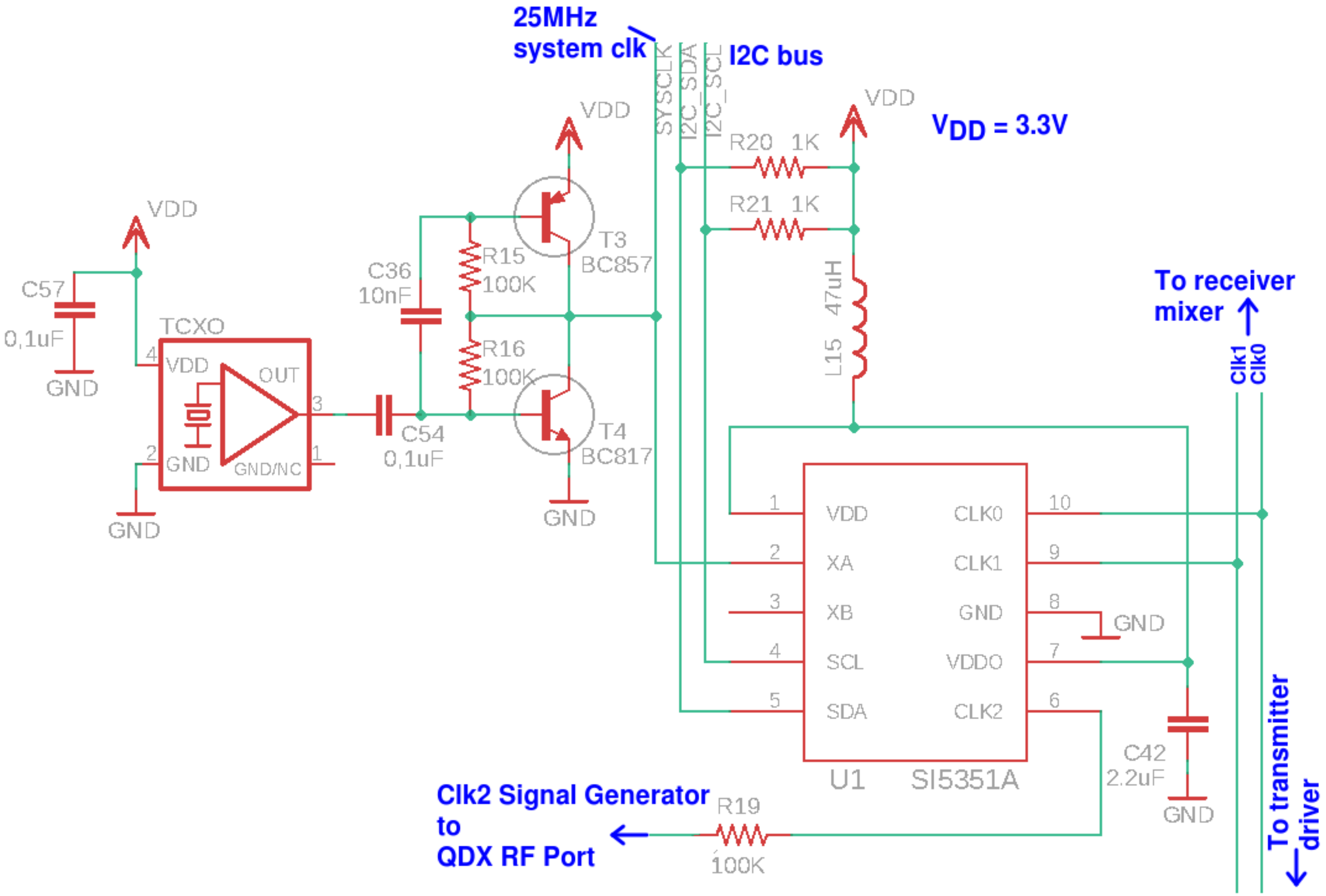


Defaults to 100 per second

- WSJT-X slides from one tone to the next
- QDX follows it

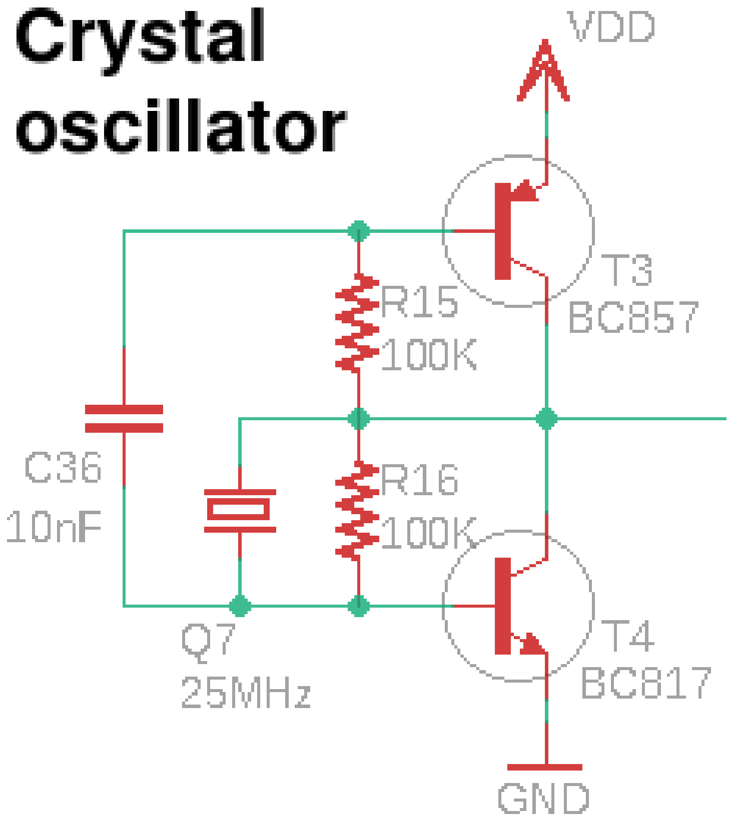
Design: Synthesizer

- Old friend: Si5351A
- 25MHz TCXO – also system clock
- NPN/PNP buffer



An aside: push-pull crystal osc

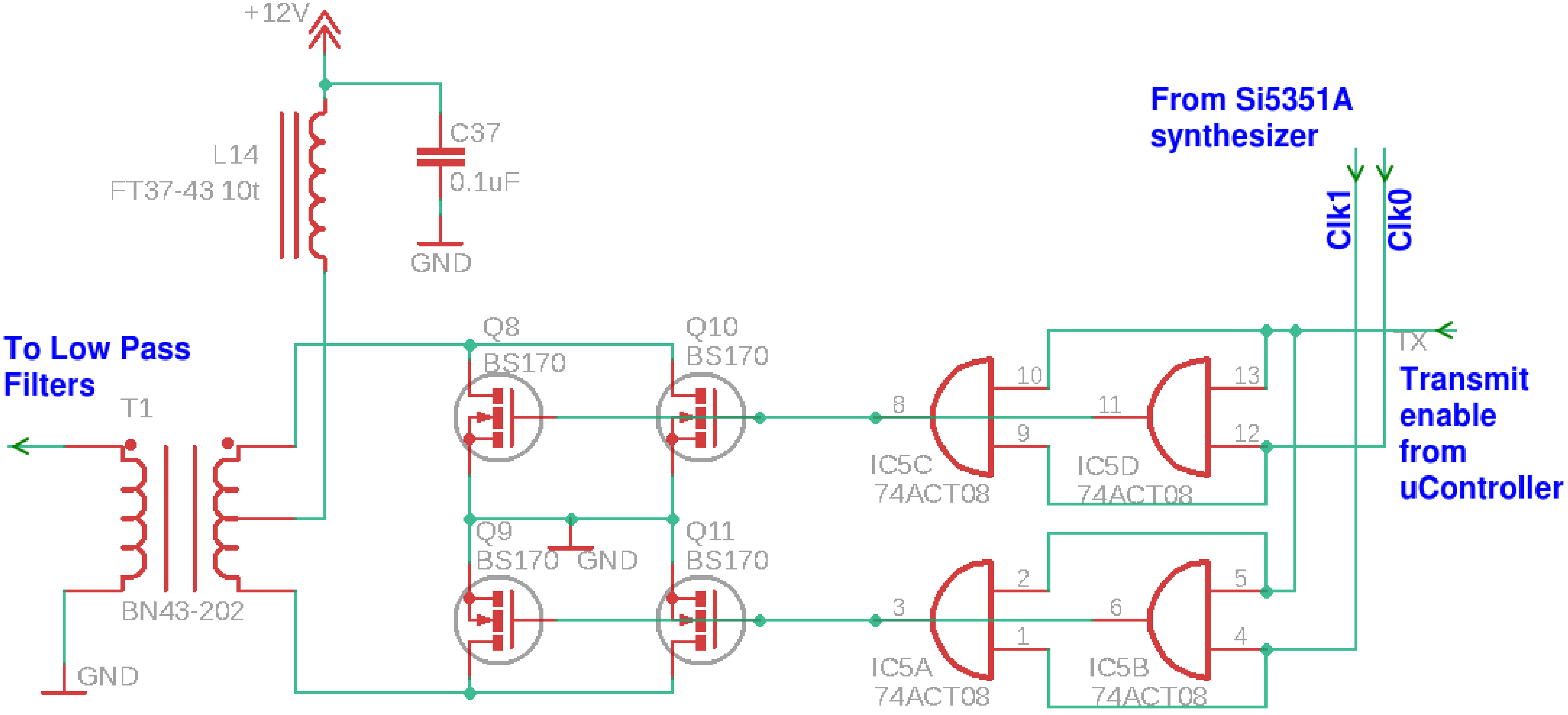
- NPN/PNP transistors
- Low impedance output
- Rail-to-rail square-ish
- Works with every crystal I've tried
- Works as amplifier too



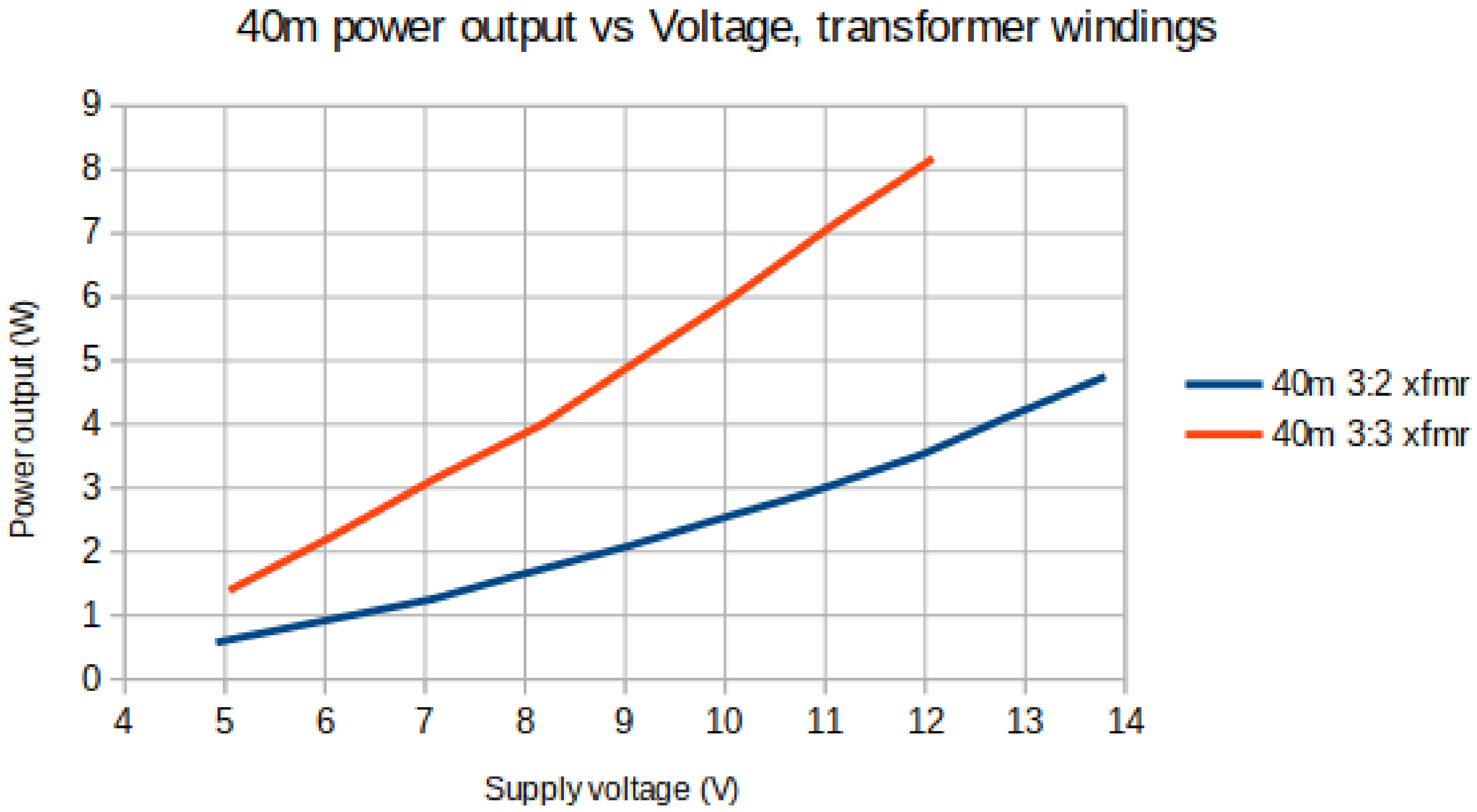
Design: Power amplifier

- Class-D Push-Pull
- Very low even harmonics (I measured -70dBc)
- High efficiency (not as high as Class-E)
- Broad-band (unlike Class-E)
- Works great with low cost BS170 transistors and a 74ACT08 as driver
- Needs antiphase drive
- 5W from 9V supply (3:3) or 12V (3:2 O/P transformer)

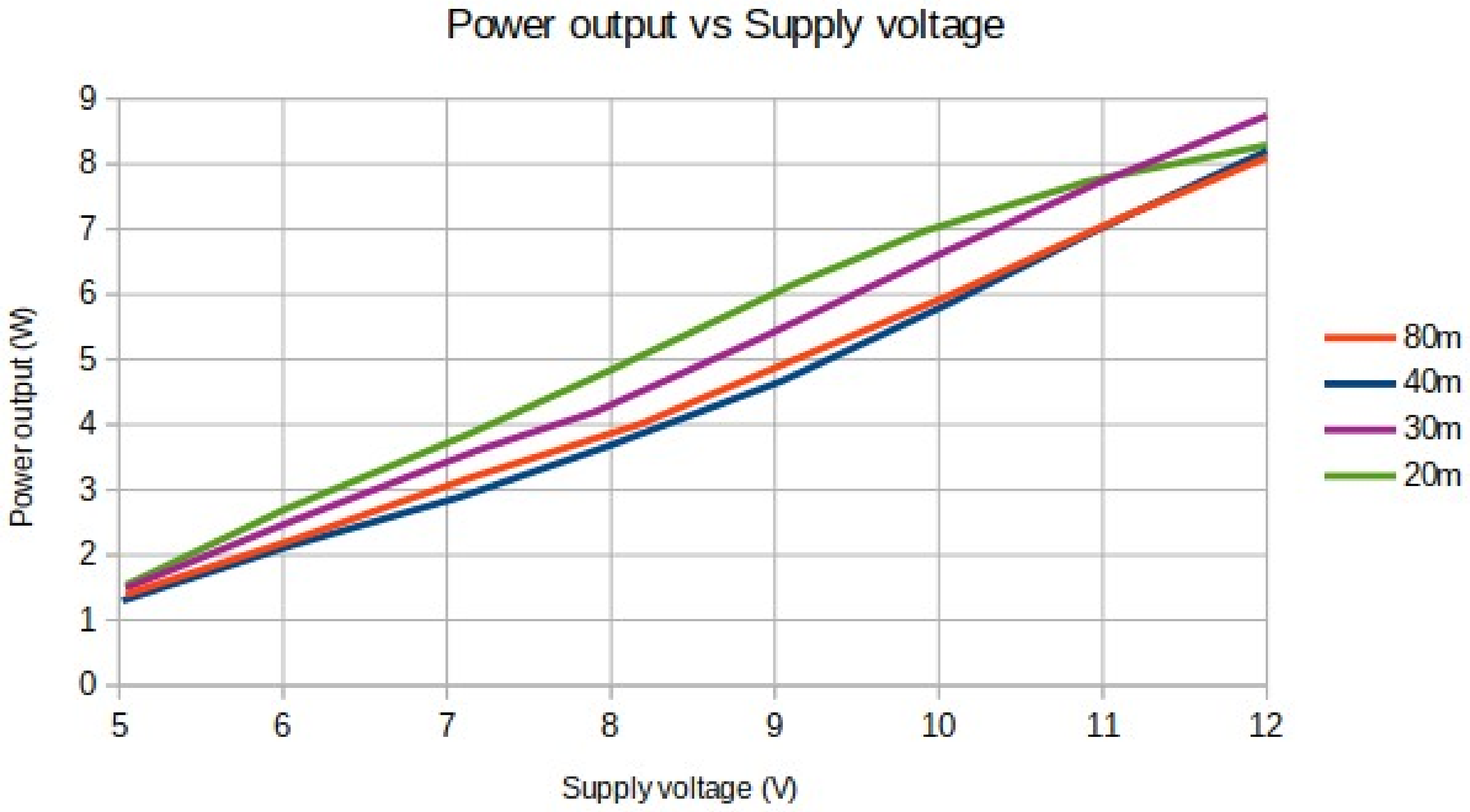
PA schematic



Build for 9V or 12V supply

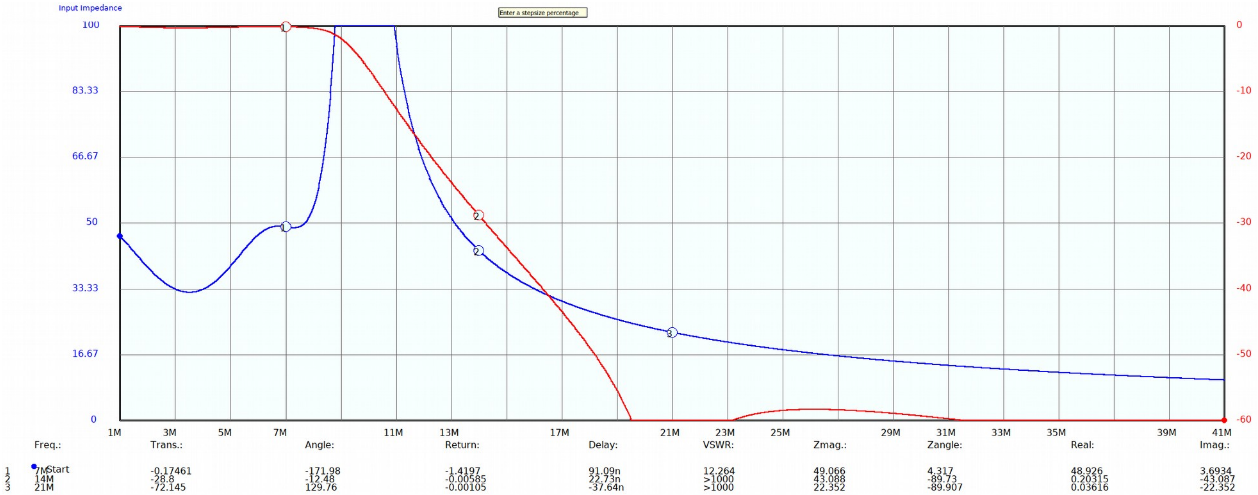


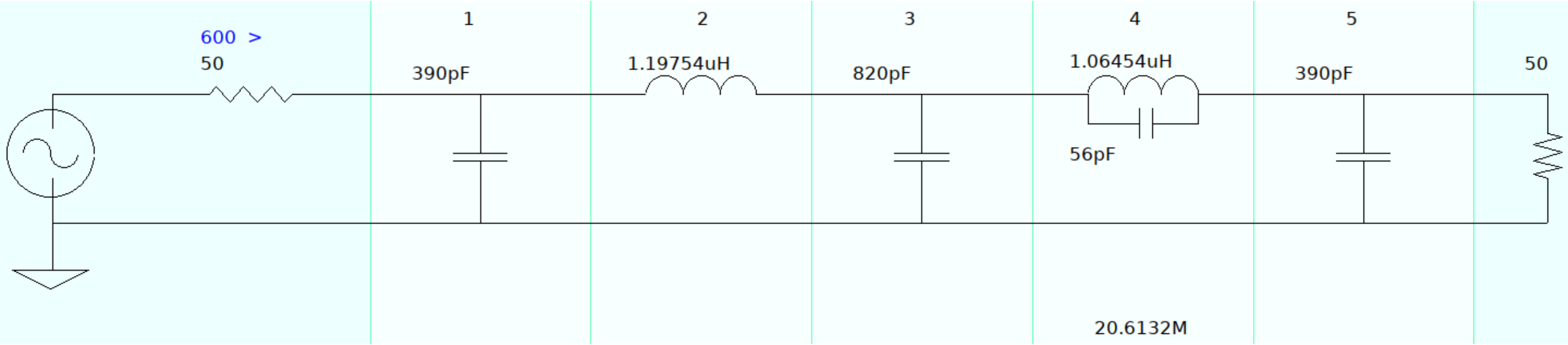
5W on each band



Design: simpler LPFs

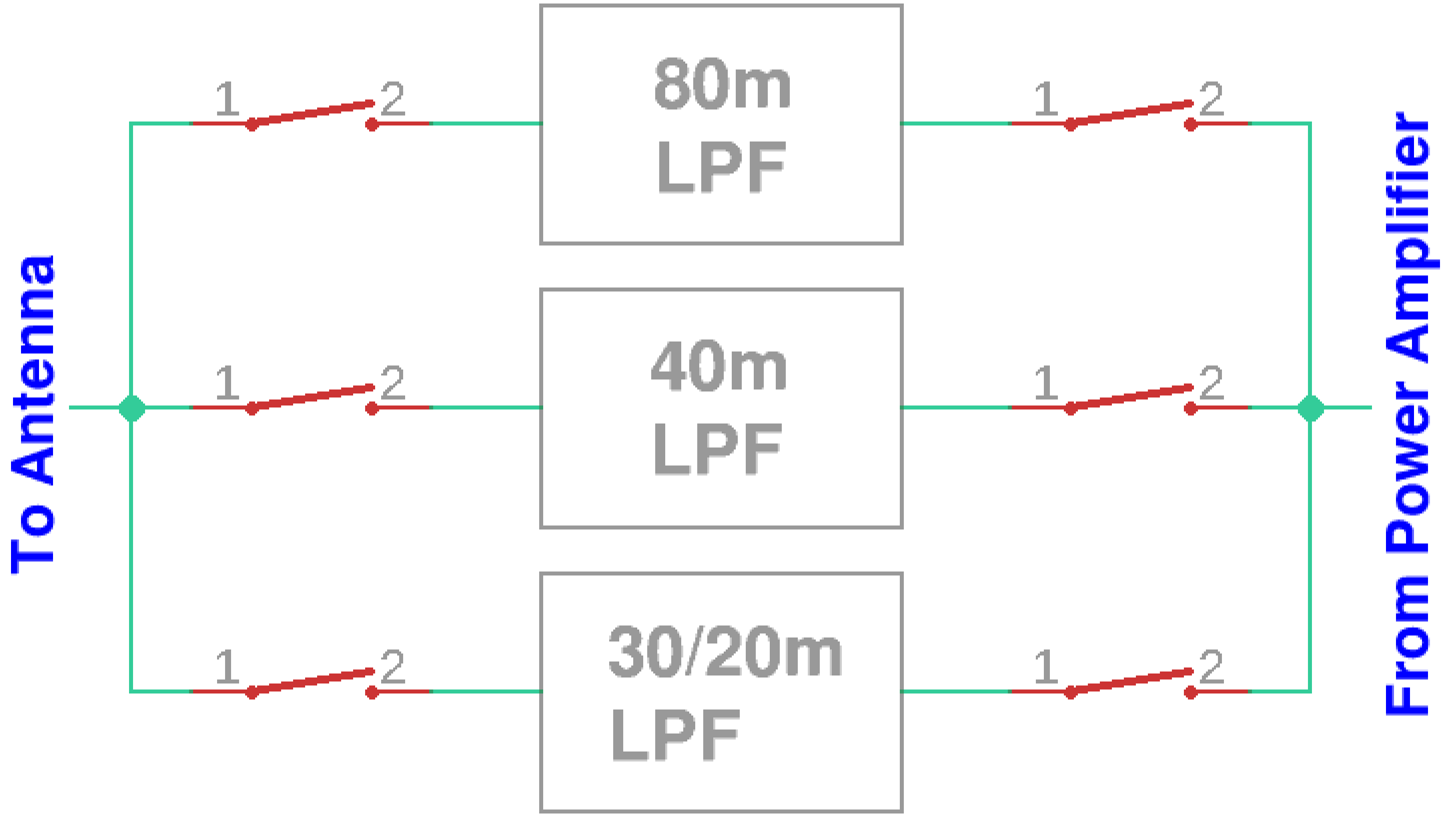
- Due to low 2nd harmonic
- 3rd harmonic trap



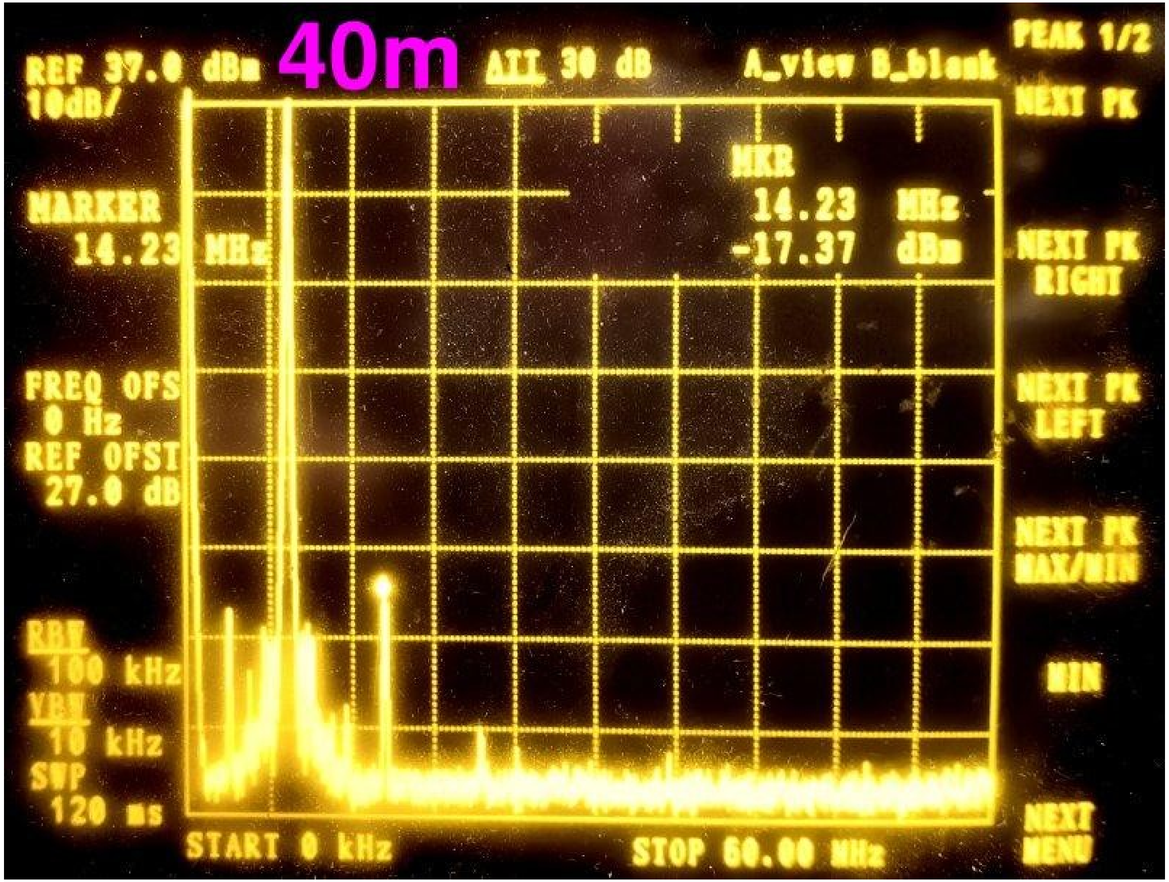


Three LPFs are enough

- 80m
- 40m
- 30/20m



Very low level harmonic output

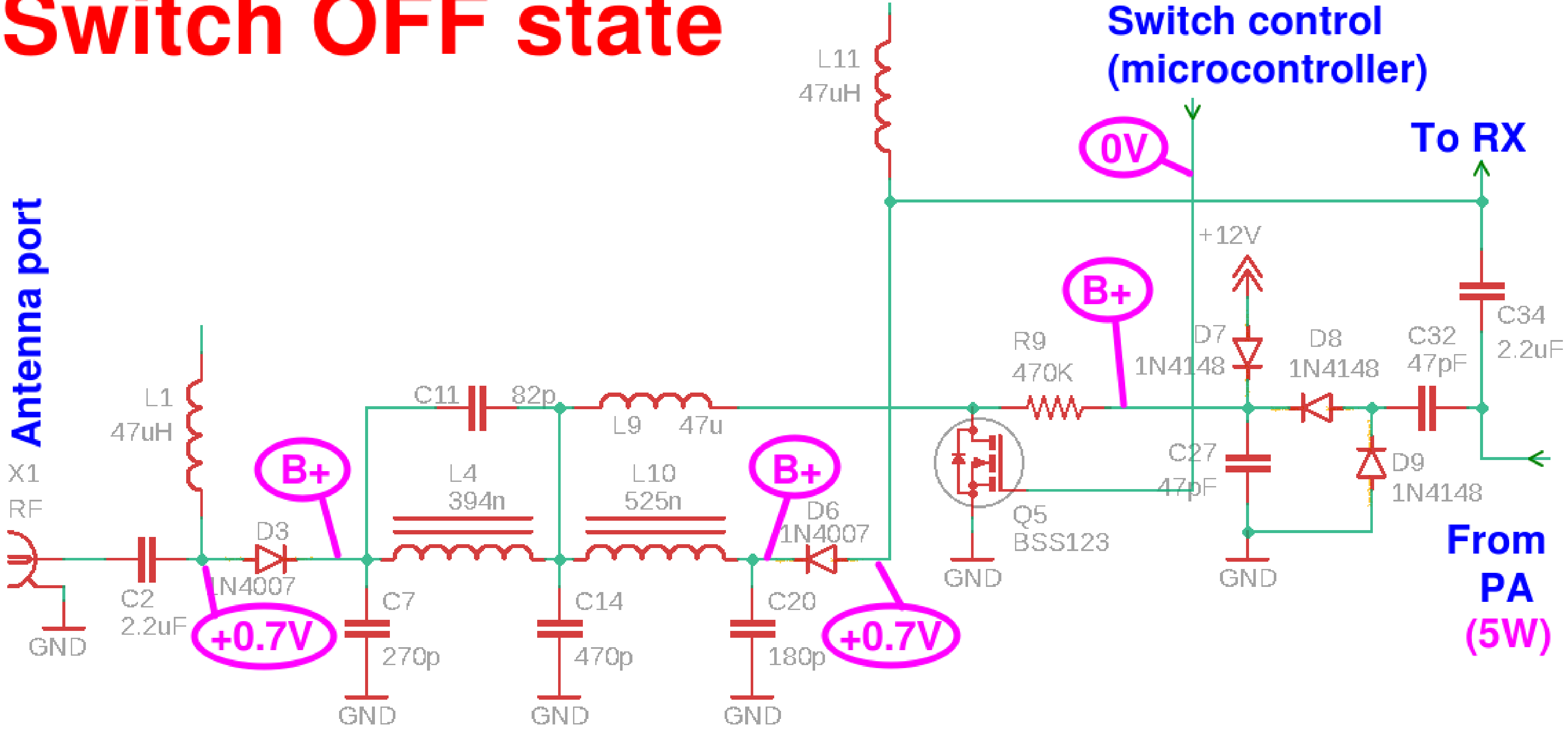


Design: band switching PIN diodes

- Relays are expensive. Heavy. Mechanical. Noisy. Slow.
- 1N4007 makes an excellent HF PIN diode!
- Rules:
  - ON: pass a bias current – more power, needs more mA of bias current to avoid distortion
  - OFF: reverse bias voltage larger than the signal being blocked

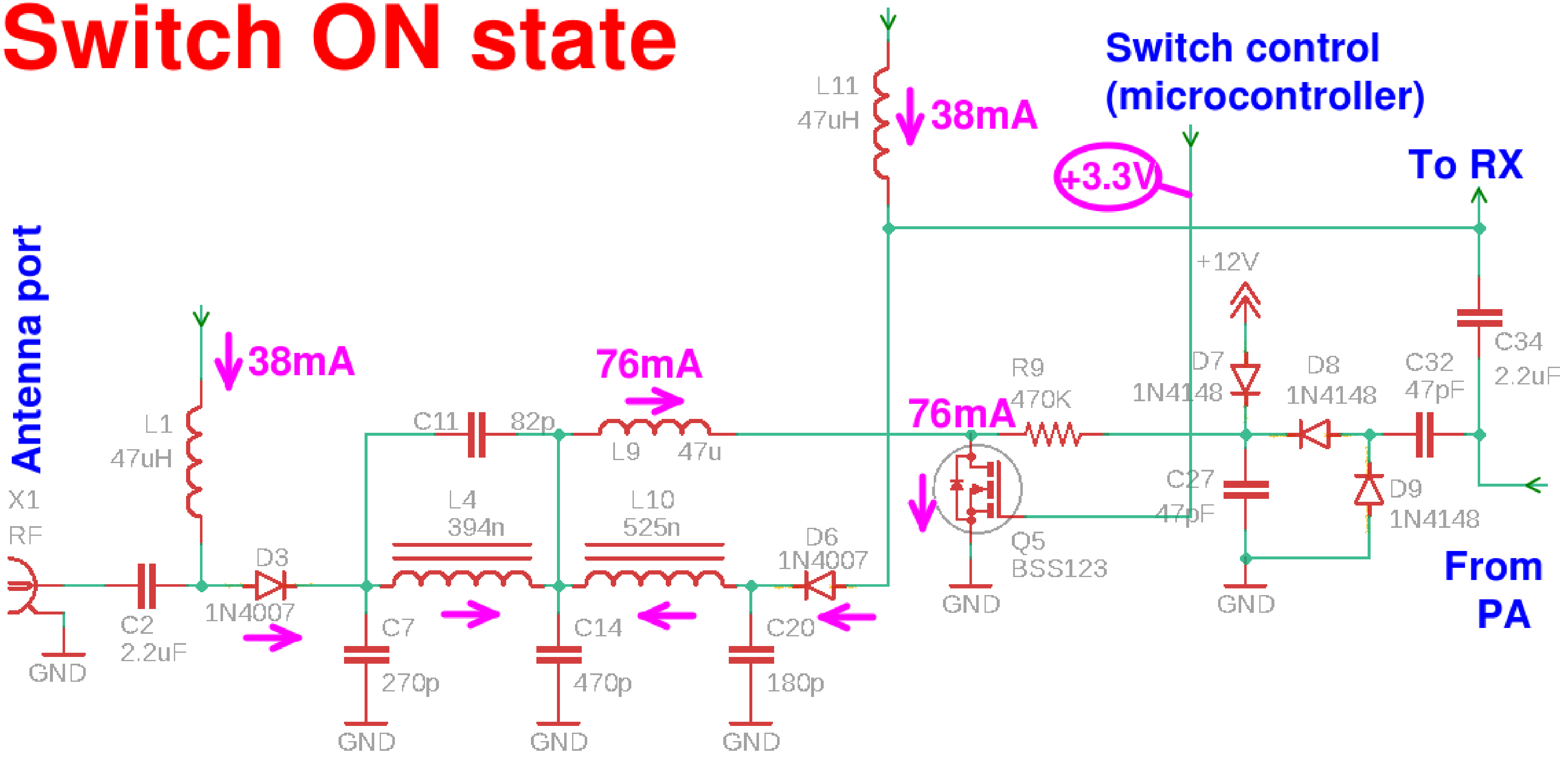
PIN diodes OFF

Switch OFF state

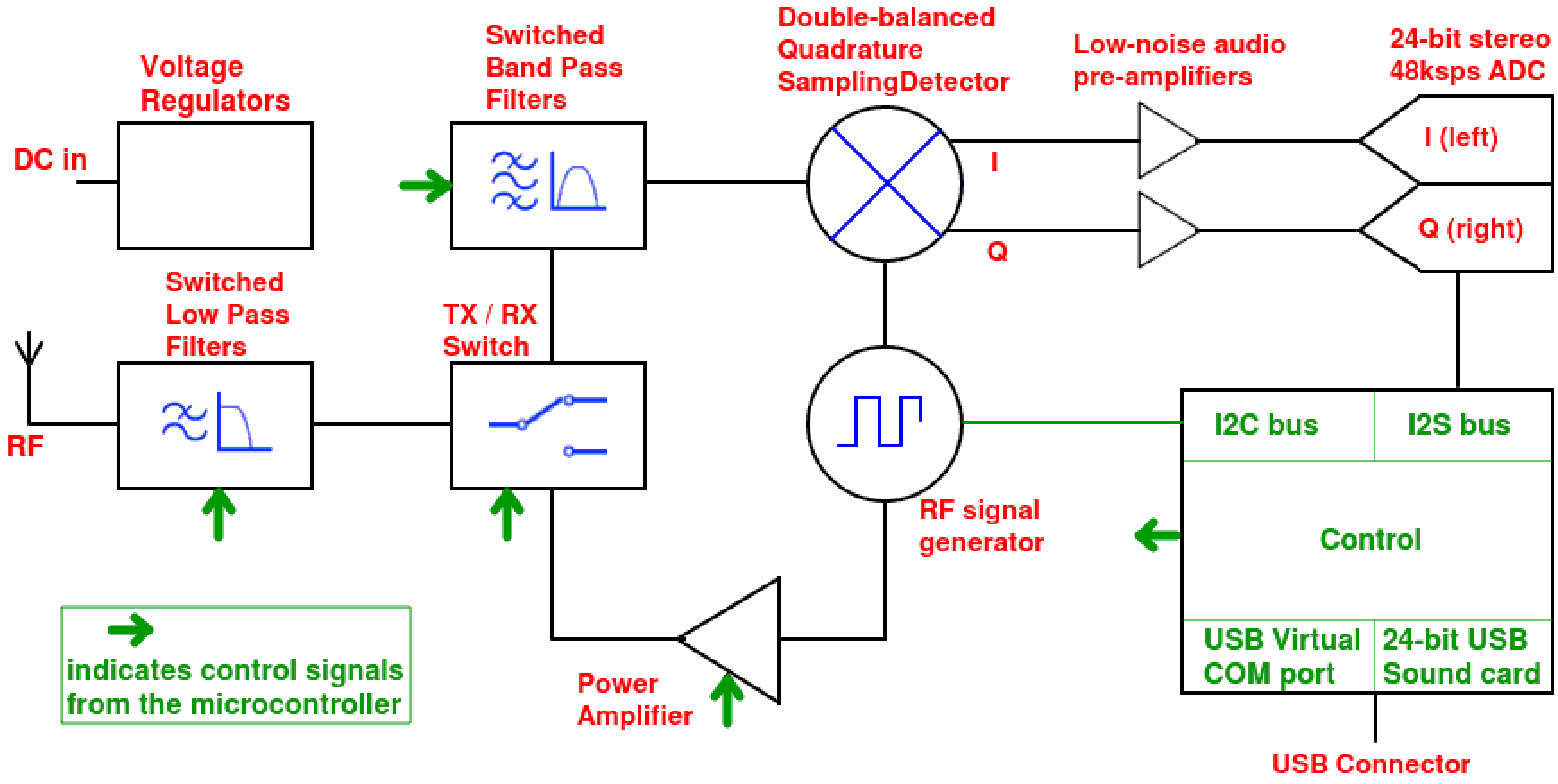


PIN diodes ON

Switch ON state

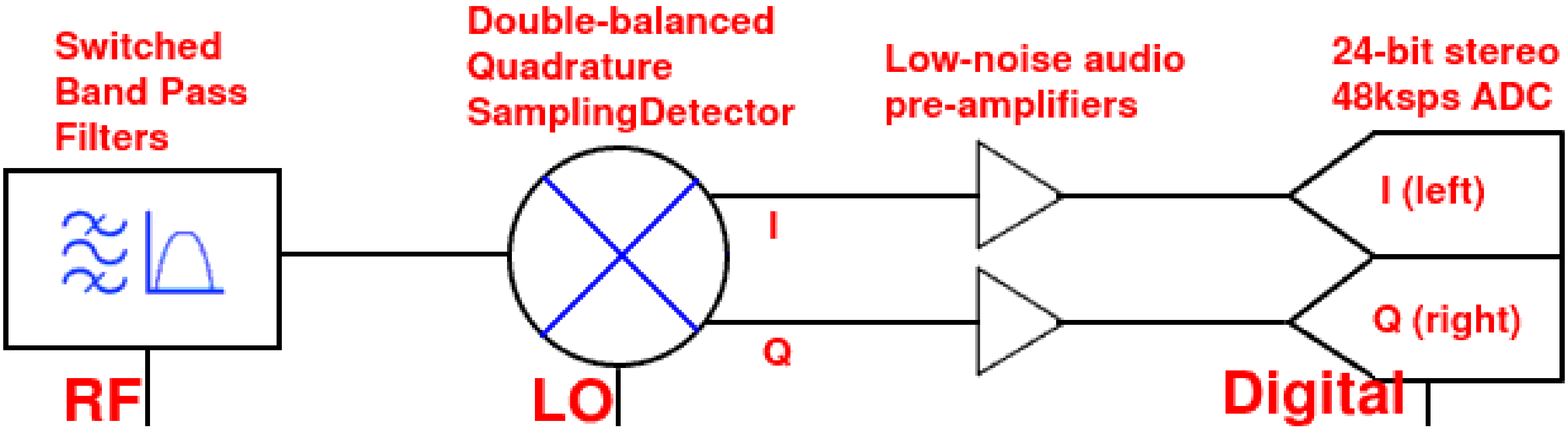


Design: block diagram



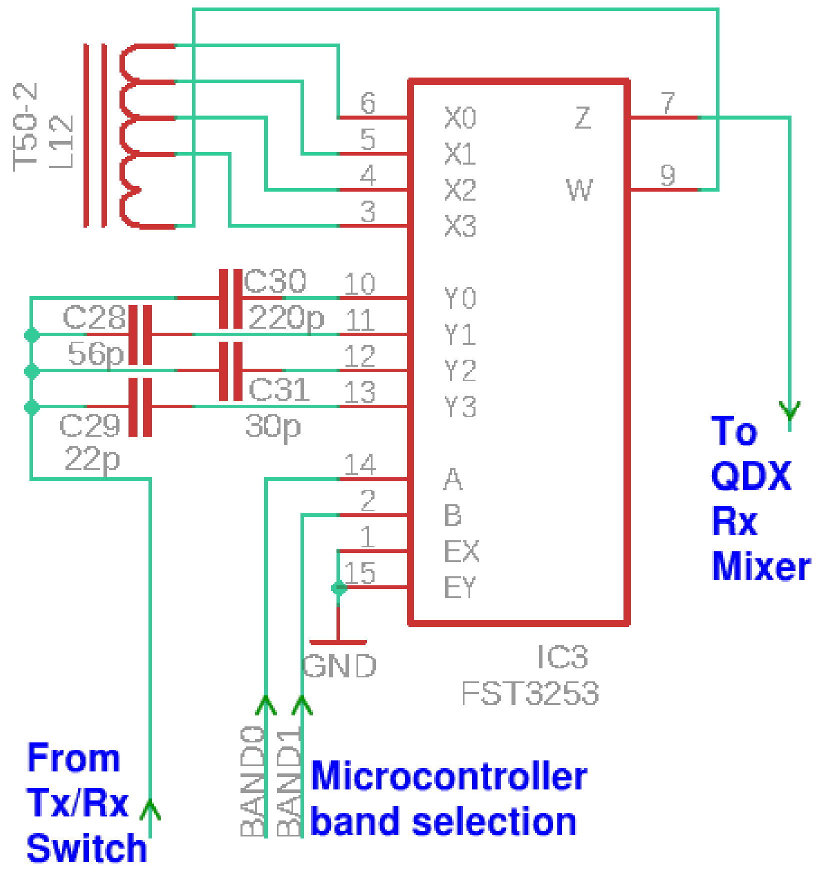
Design: Receiver

- Band Pass filters
- Detector
- I & Q amplifiers
- Analog to Digital Conversion

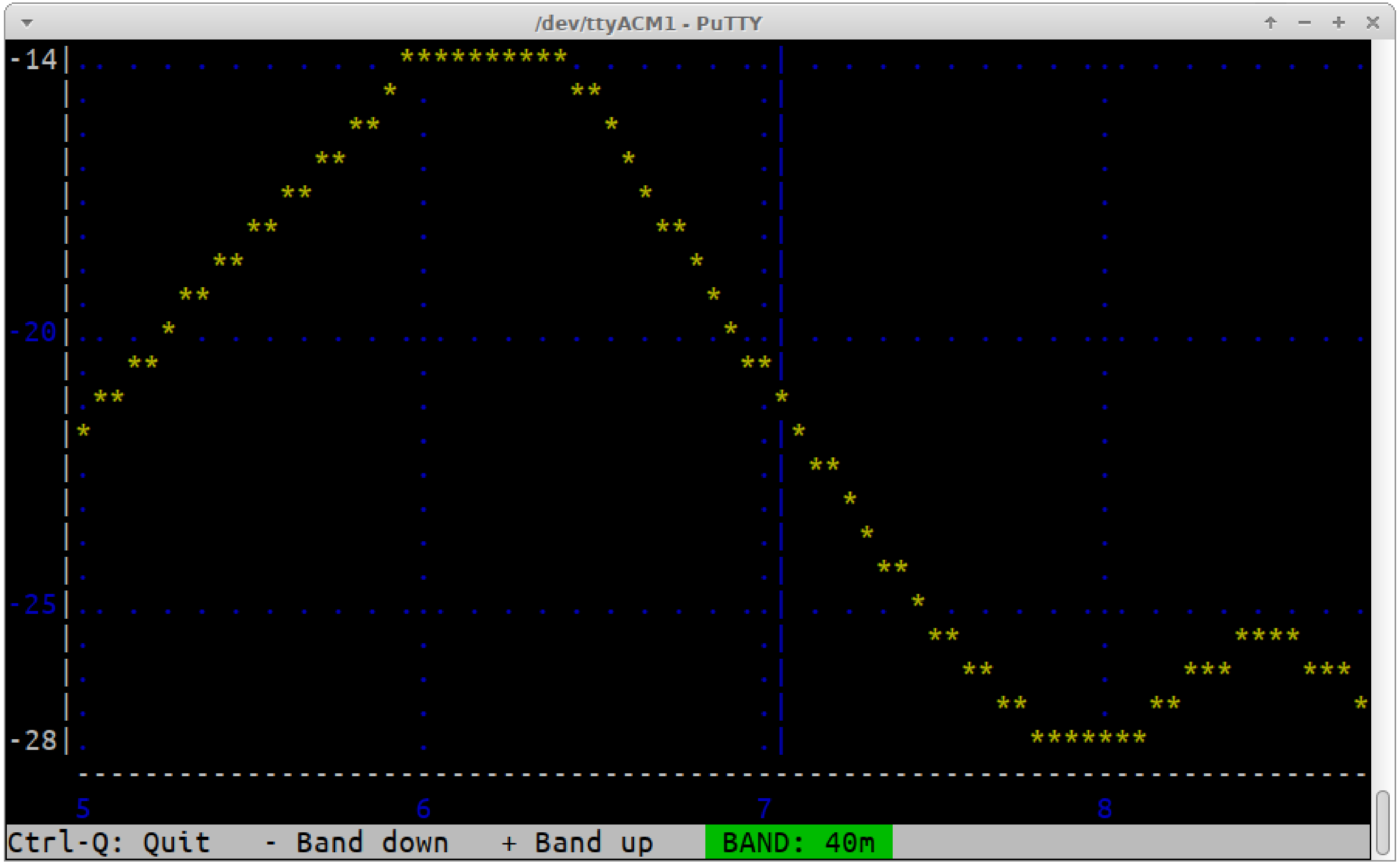


Design: Band Pass Filter

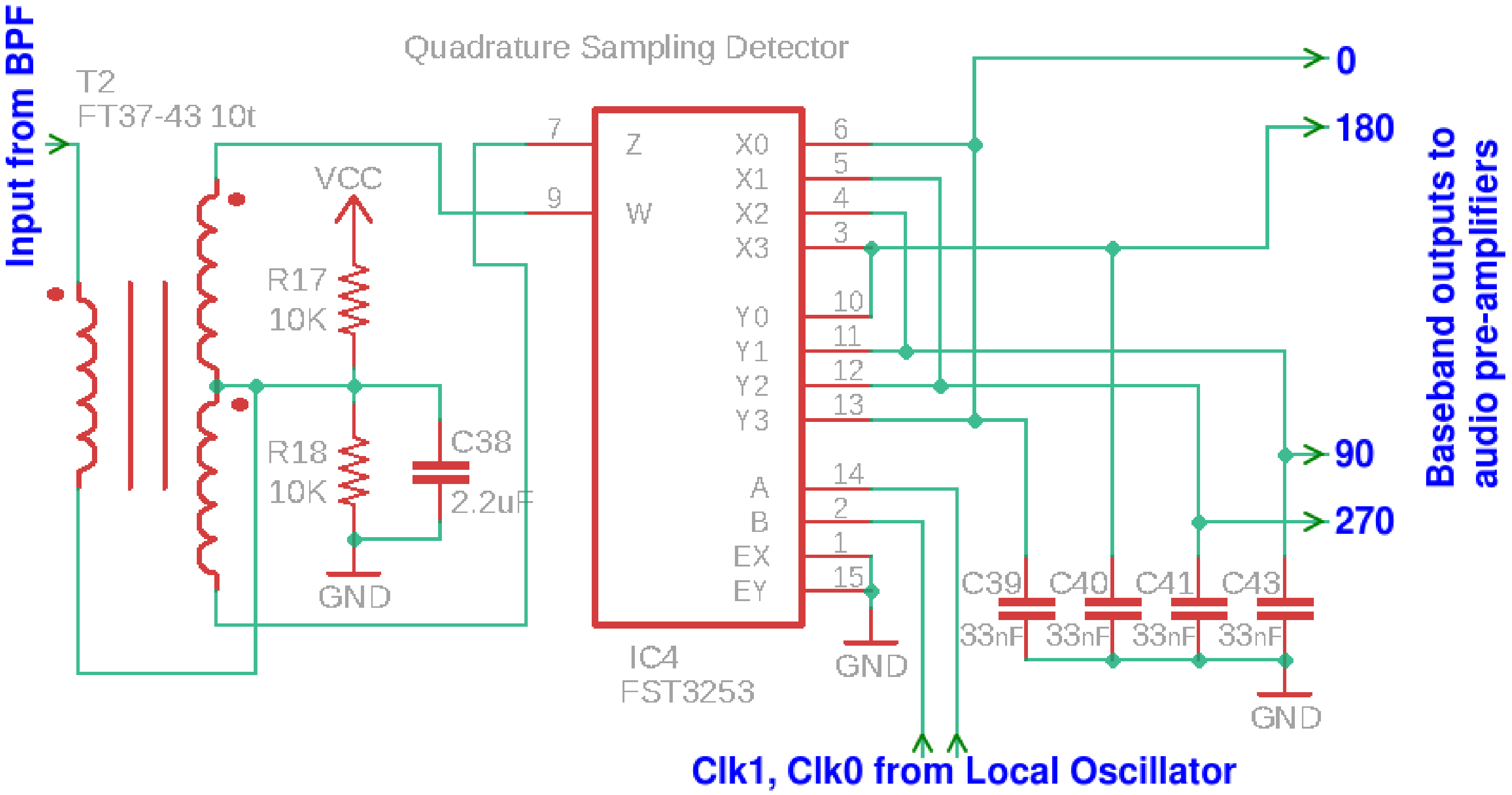
- Series L-C resonant circuit
- Tapped inductor
- Four capacitors
- 1:4 dual MUX to select one capacitor and one inductor tap



Terminal tool for BPF sweep

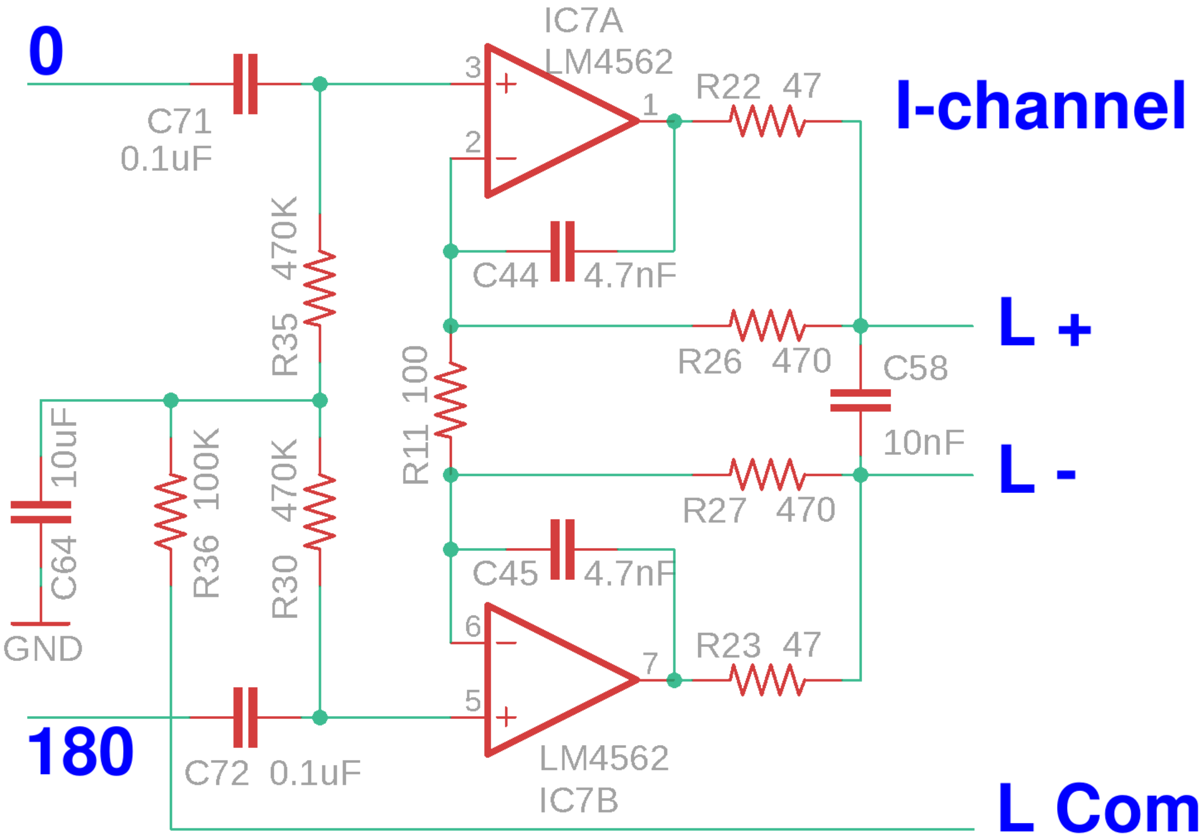


Quadrature Sampling Detector



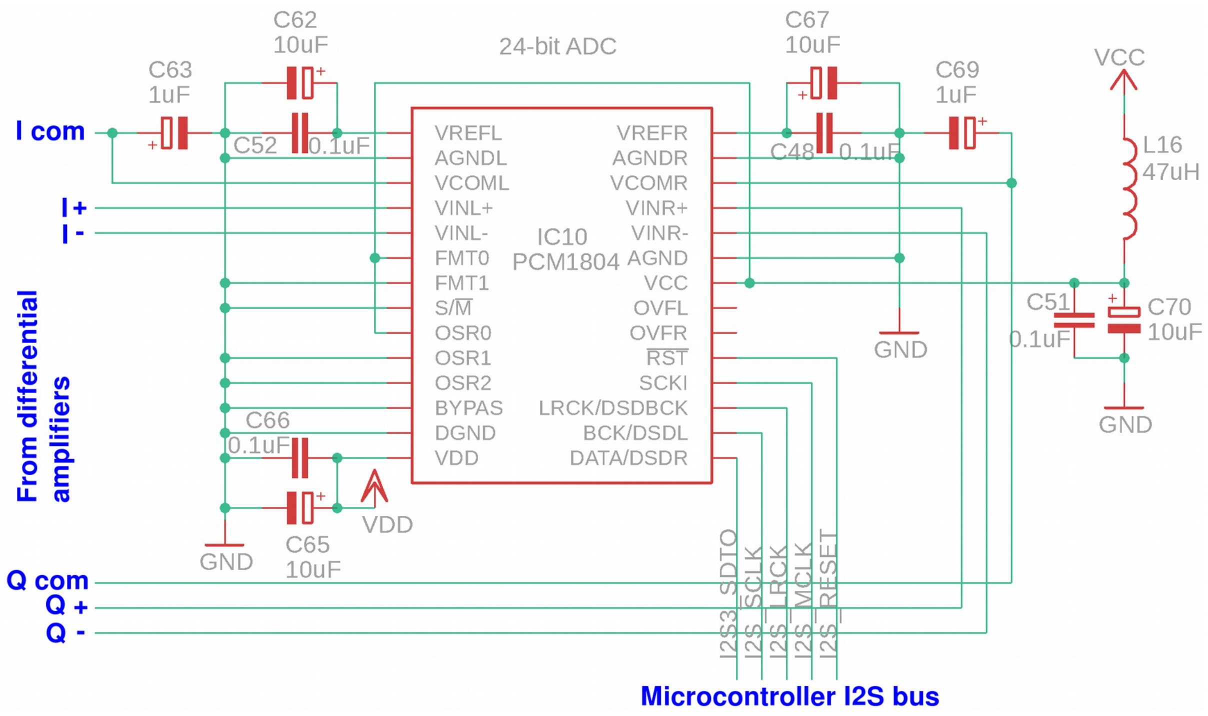
Differential amplifier

- Low-noise op-amps
- ADC has a differential input
- Needs differential drive
- Instrumentation amplifier



Analog to Digital Conversion

- PCM1804 112dB 24-bit differential ADC
- I2S (Inter-IC Sound Bus)
- I & Q channels to micro

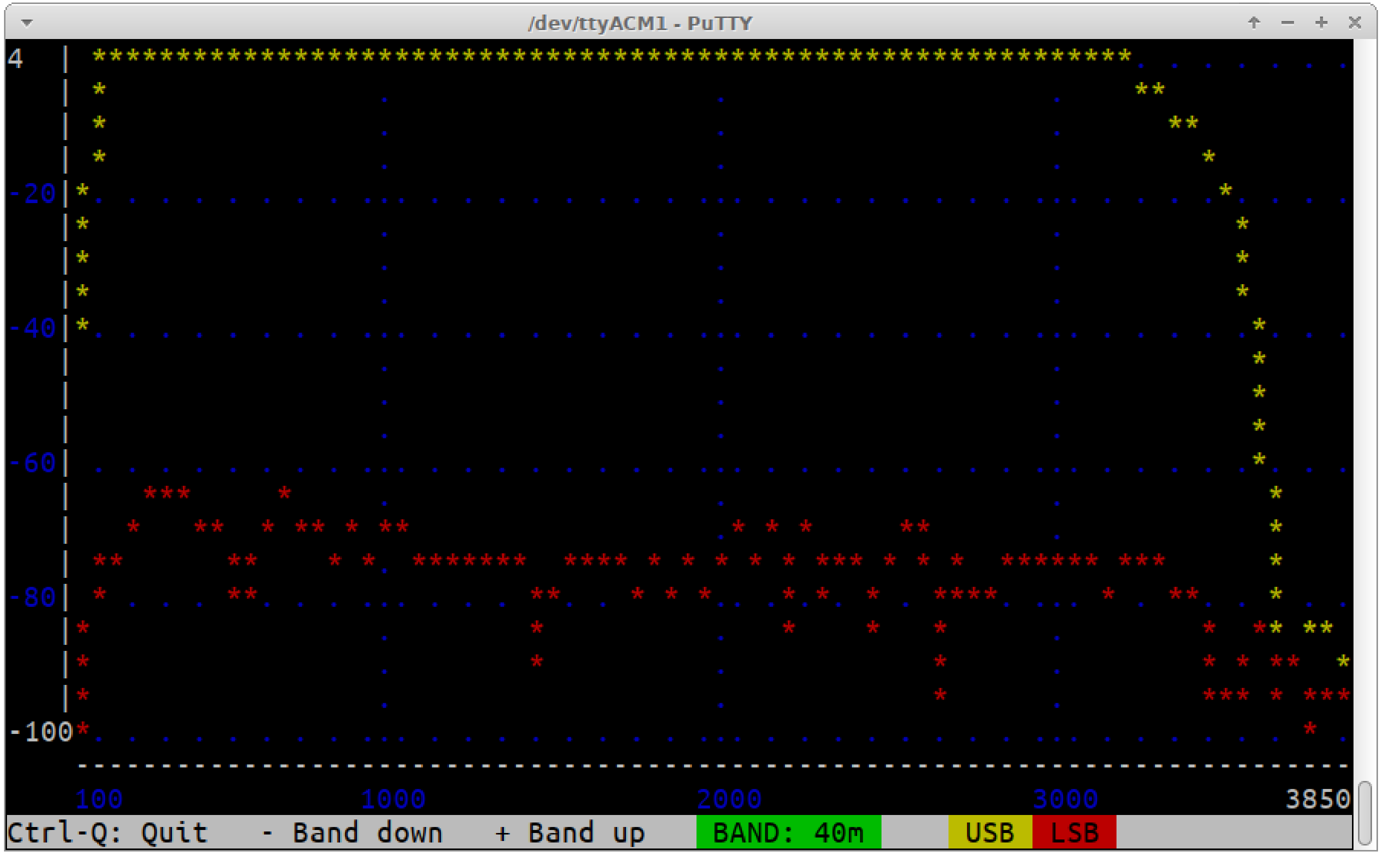


Design: Software Defined Radio

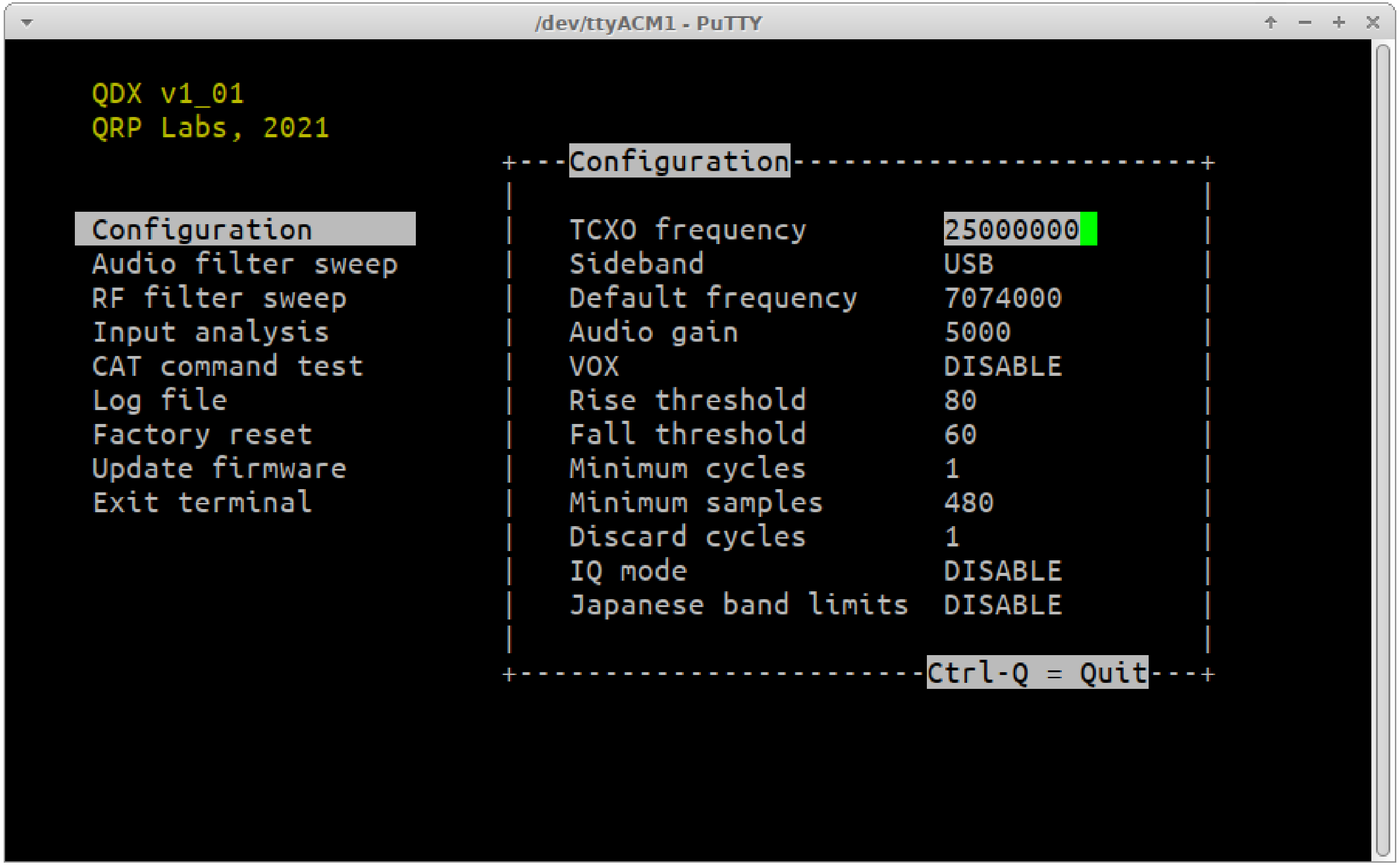
- Advantages
  - High performance, low cost
  - Digital Signal processing
  - Chance to update features in future by software
- QDX implements a superhet with 12 kHz IF
- All 32-bit processing internally
- Provides 24-bit audio back to the PC

Terminal tool for AF sweep

- Audio 150Hz to 3.2kHz
- 60-70dB unwanted sideband
- 40dB image rejection typical

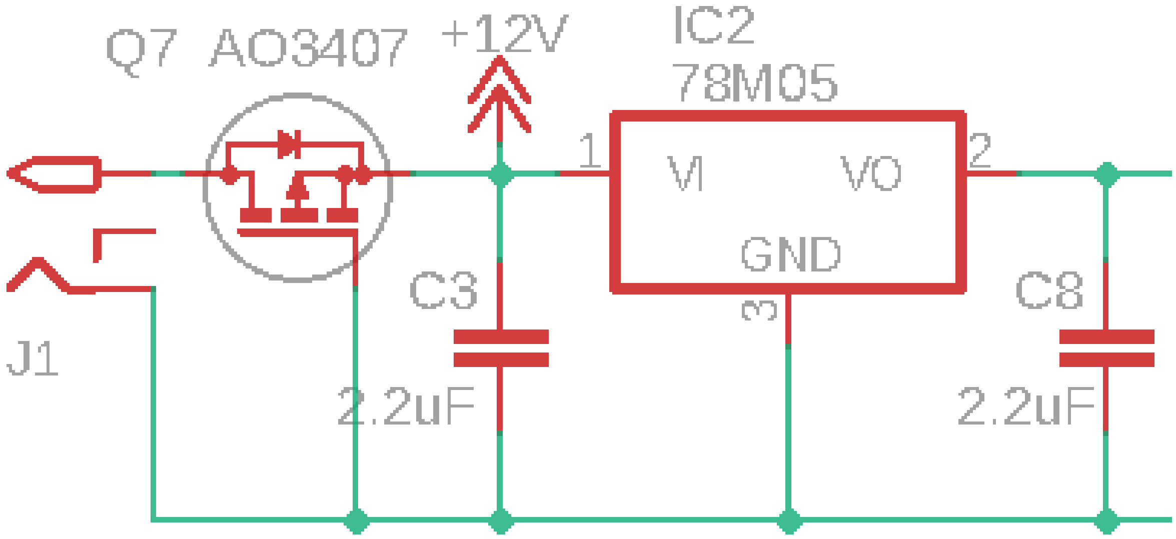


Terminal configuration etc



Reverse polarity protection

- Use a P-channel MOSFET
- “Connected backwards”
- Very low voltage Drop



Production challenges

- The first 500 sold out in 15 minutes in October
- The next 385 sold out in 5 minutes in December
- Global semiconductor shortage
- Change ADC chip AK5386 to PCM1804
- Buy before you even design!
- Slow board manufacture, logistics

Frequently Asked Questions

- Can it do CW?
- Can it to PSK?
- Can it to blah-blah mode?
- Do you have some with yc

- Is the firmware OpenSource?
- Will it work on other bands than 80/40/30/20m?

QDX project complete

- Performance
- Features
- Affordable ($66 rig, $20 enclosure)
- More at: http://qrp-labs.com/qdx