

# Waves & Wires: My RF Homebrew Adventures

Dhiru Kholia (VU3CER) - 2024

# Agenda

- Motivation
- Preview
- Custom Quartz
- Beacons
- Amplifiers
- Receivers
- A well-kept HAM secret
- New ideas and current work
- Tips and tricks
- Questions

# Motivation

- Enable everyone to experience the joy of HF (high frequency, shortwave) and homebrewing
- We have to reduce the 'cost of entry into the hobby' by producing cost-effective (VFM), high-quality, modern, sustainable, reproducible and rugged FOSS RF projects

# Sneak peek (preview) of my talk

- Build a Custom Variable Quartz / VFO / LO **WITHOUT** using Si5351 in 300 INR
- Build the most cost-effective ~10mW and ~250mW beacons
- Build a 1W to 10W+ FT8 / WSPR / CW beacon in 500 INR more
- Build a cost-effective HF receiver and transceiver

# Custom Quartz - 1

- Are you tired of searching for and sourcing quartz crystals for custom frequencies? 7.023 MHz anyone? What about 7.040 MHz? What about other bands?
- Such as <https://www.kenselectronics.com/lists/cbxtal.htm>



# Custom Quartz - 2

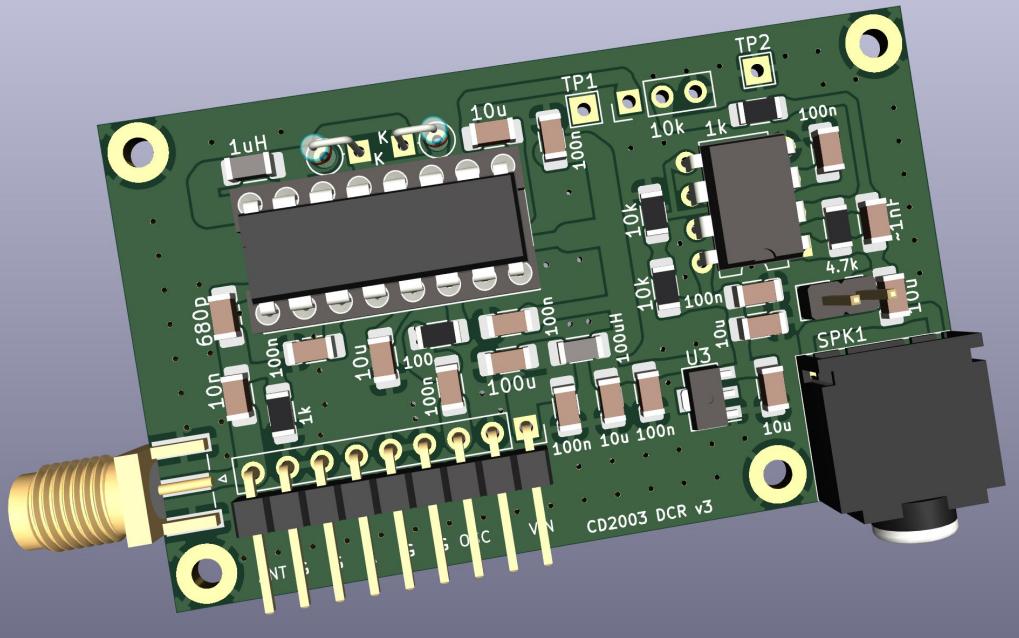
- In many cases, these ‘weird’ crystals can be replaced by the ‘Custom Quartz’ project
- <https://github.com/kholia/pico-hf-oscillator/tree/CUSTOM-QUARTZ>. On Google, search for “**GitHub kholia**”
- Covers all HF with mHz resolution!
- Superb work from R2BDY (Roman)!
- <https://qrp-labs.com/synth/synthnoise.html> (excellent read on this topic)

# Any-Quartz (LO) for 290 INR

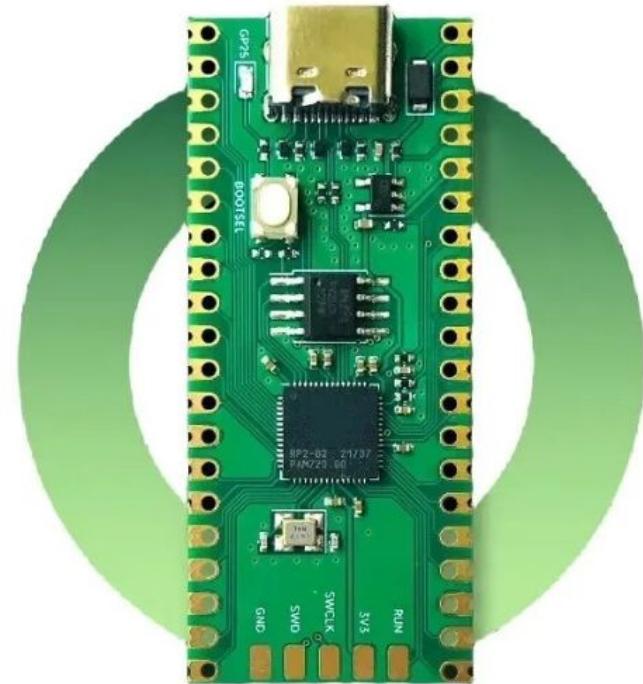
## RP2040 Development Board



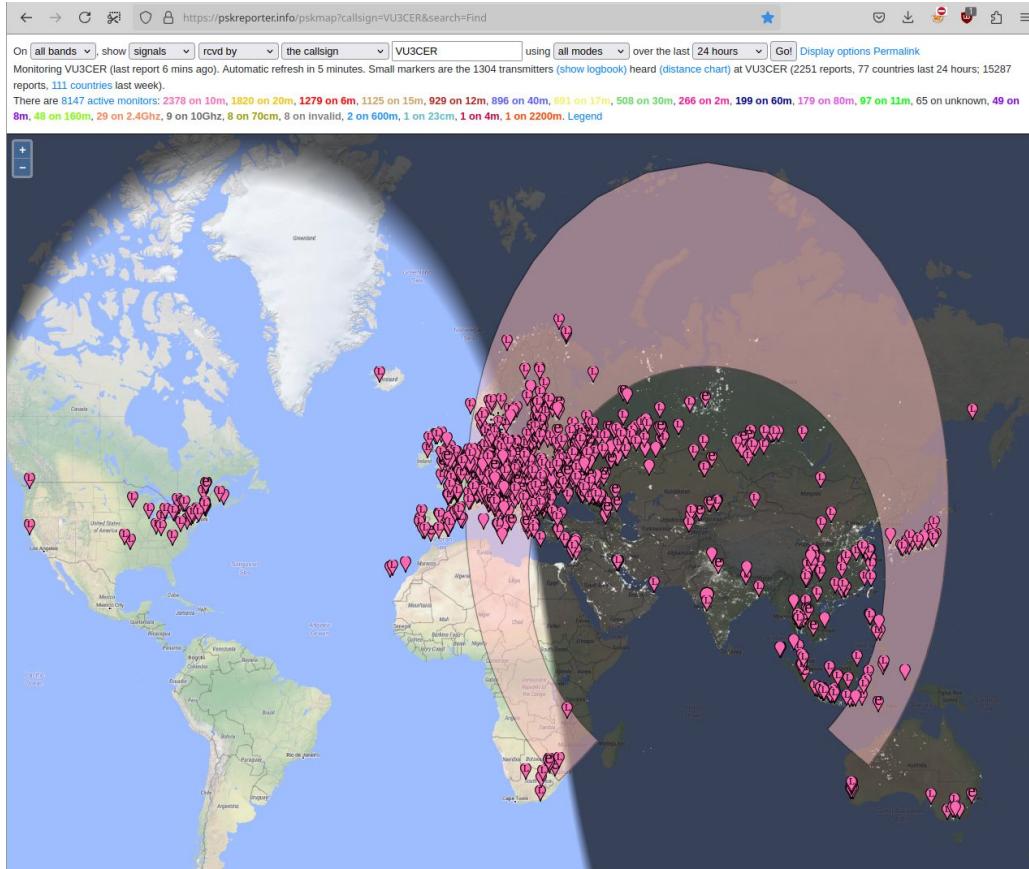
# How clean / good enough is this?



RP2040 Development Board



# How clean / good enough is this?



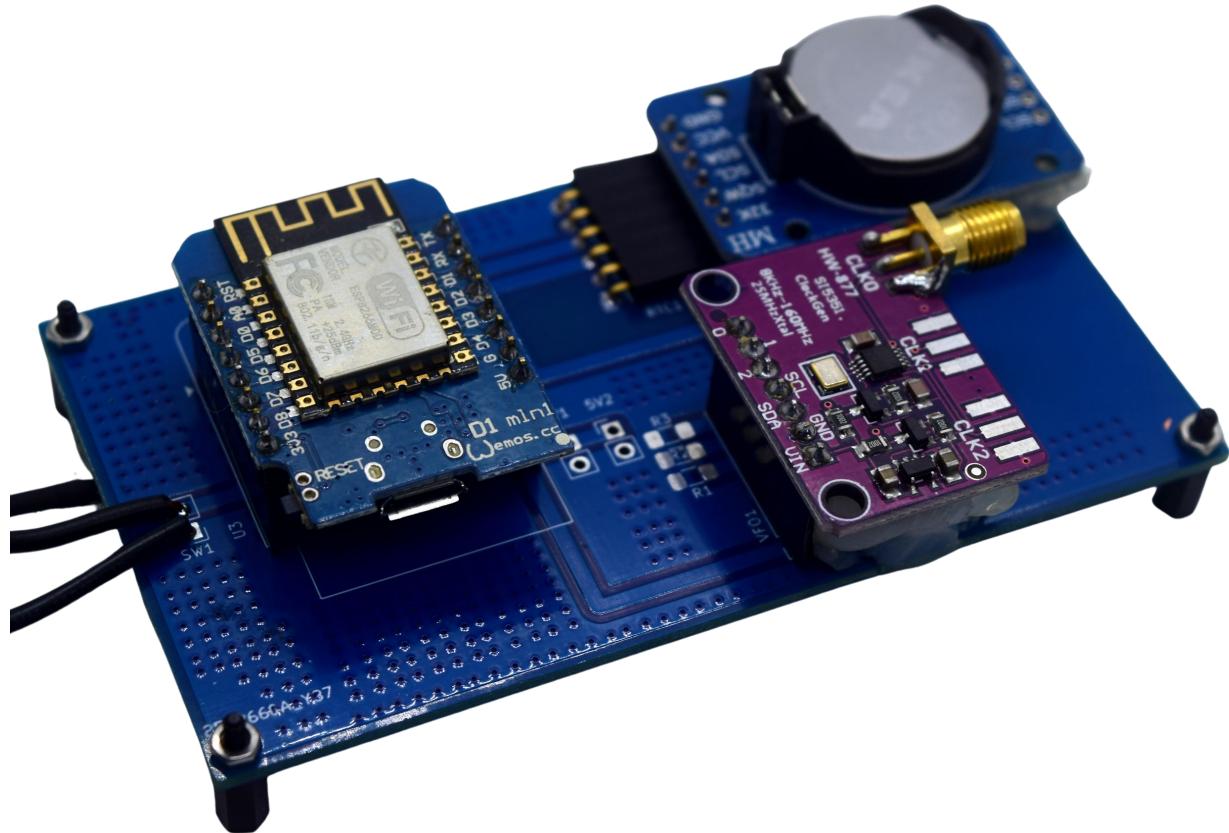
CD2003 receiver project is FOSS!

<https://github.com/kholia/ConsensusBasedTimeSync>

Modern “all-band” Pixie design anyone?

Of course, better designs are also possible!

# 10mW WiFi VFO + digital beacon (Last Year)



# WiFi VFO!



## Digital Radio Beacon

LED state **OFF**

**ON**

**OFF**

**LED Flash**

VFO OK **Yes**

RTC Lost Power **No**

Temperature **28.25 °C**

Time **14:39:15**

Current Delta **425.00**

**NTP Sync**

**Inc 25ms**

**Dec 25ms**

**Short Tune (7s)**

**Long Tune (30s)**

**Full-Power Tune (7s)**

Current Mode **FT4**

Time Delta Hack Enabled **Yes**

**FT8 Mode**

**FT4 Mode**

**WSPR Mode**

**Enable Time Hack**

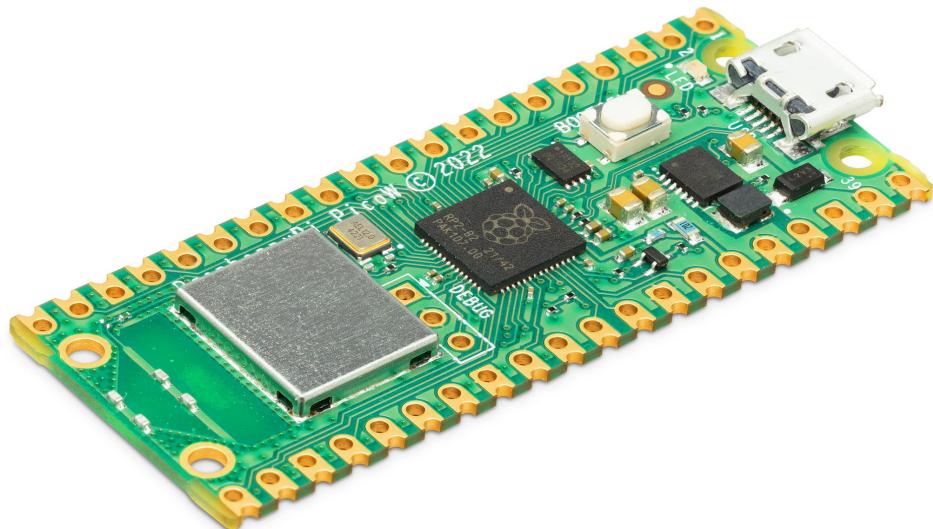
**Disable Time Hack**

Current FT8 Message **VU3CER VU3FOE MK68**

Frequency

**Change Frequency**

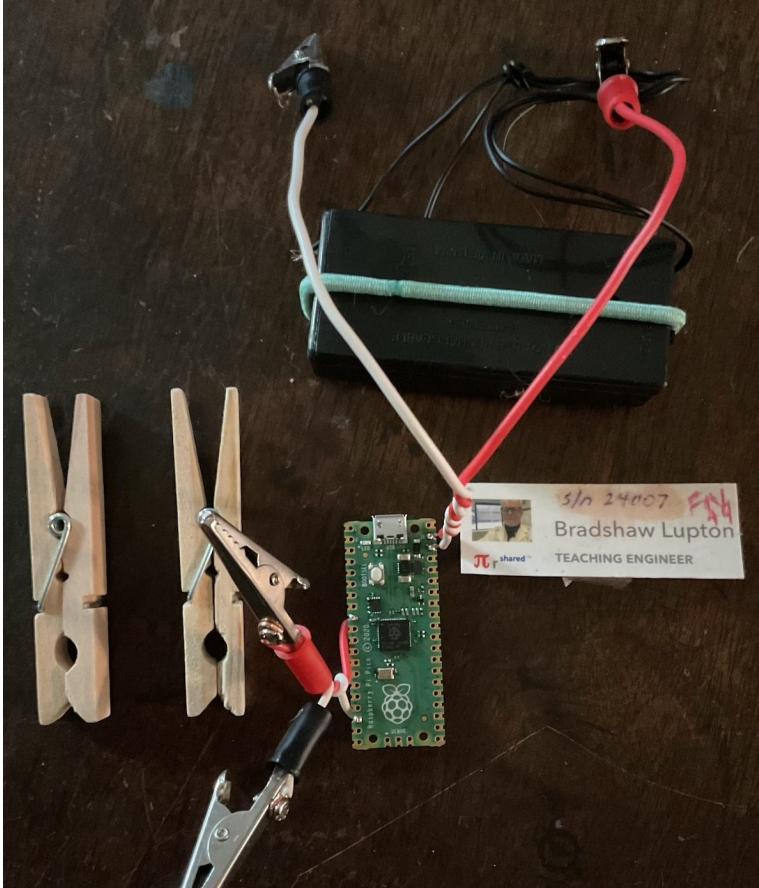
Pico W does ALL this by itself! (< 550 INR, R2BDY, This Year)



# Pico or Pico W + R2BDY's magic

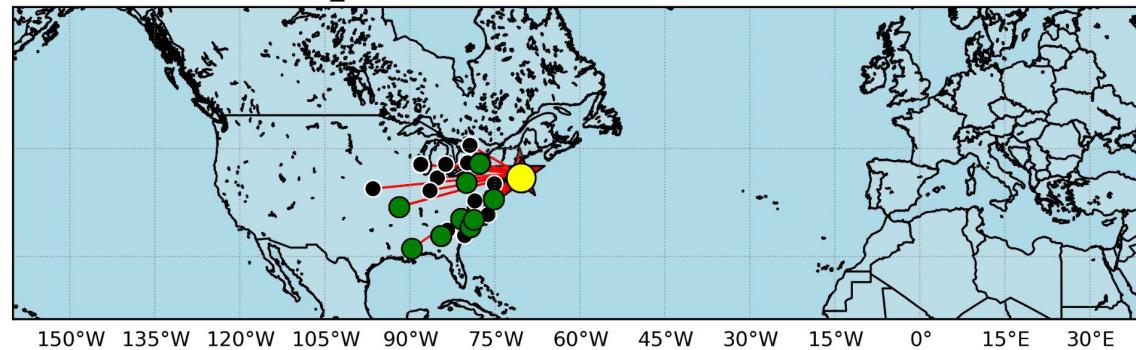
- <https://github.com/kholia/Pico-FT8-TX>
- WSPR beacon (Roman)
- FT8 beacon (our addition)
- CW beacon (our addition)

# Brad's K1TE - 'Teaching Beacon'

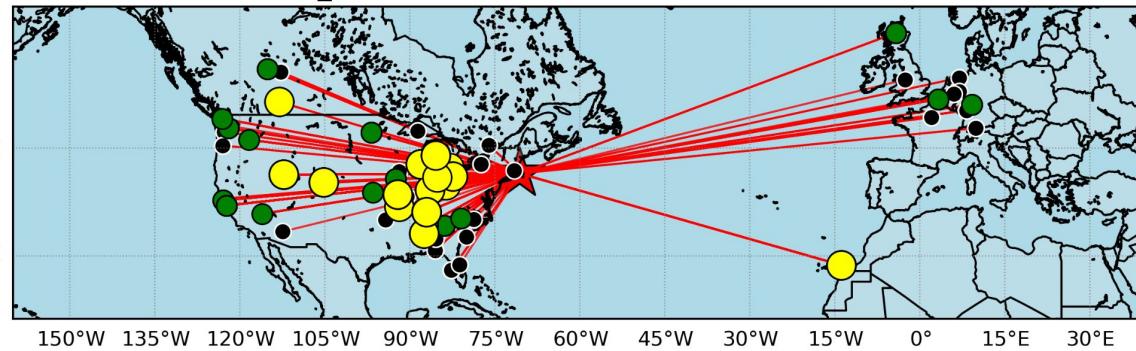


# Brad's (K1TE) beacon results

**WSPR Spots - 241208-09:49**  
**TX\_SIGN: K1TE BAND: 14 HOURS: 24**



**WSPR Spots - 241208-09:52**  
**TX\_SIGN: WQ6W BAND: 18 HOURS: 24**



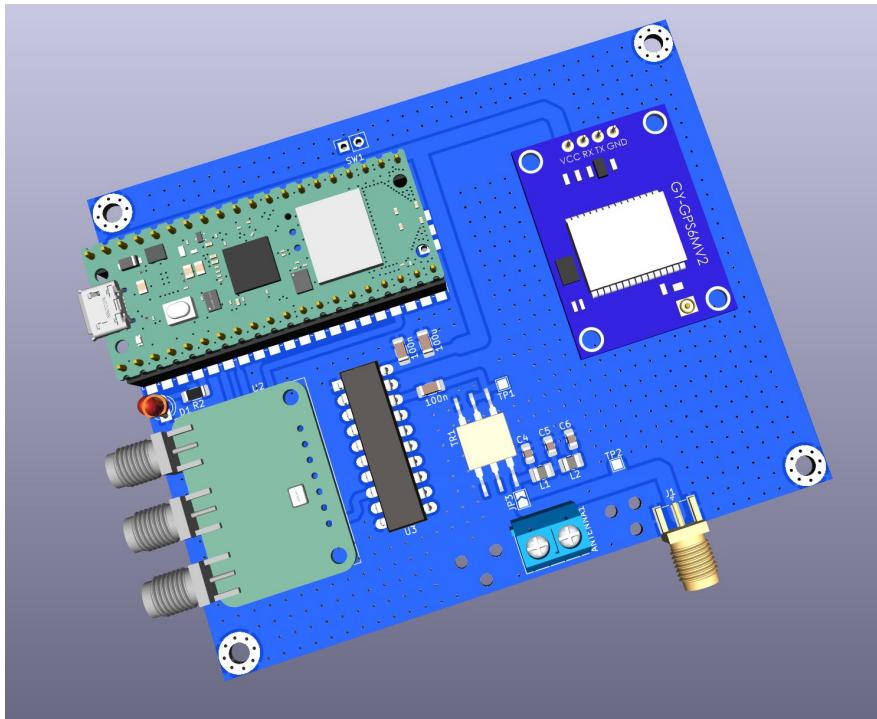
# Self-reliance (Brad - K1TE)

Brad wants us to build solutions which do NOT rely on centrally / controlled governed infrastructure - like USA's GPS or even NTP or mobile networks (for that matter)

**We want to build self-reliant, and robust systems!**

# 250 mW digital beacon (Last Year)

- Cost-effective clone of [Zachtek WSPR Transmitter](#). Reached NASA Goddard Space Flight Center from Pune using a 1st-floor balcony dipole antenna!



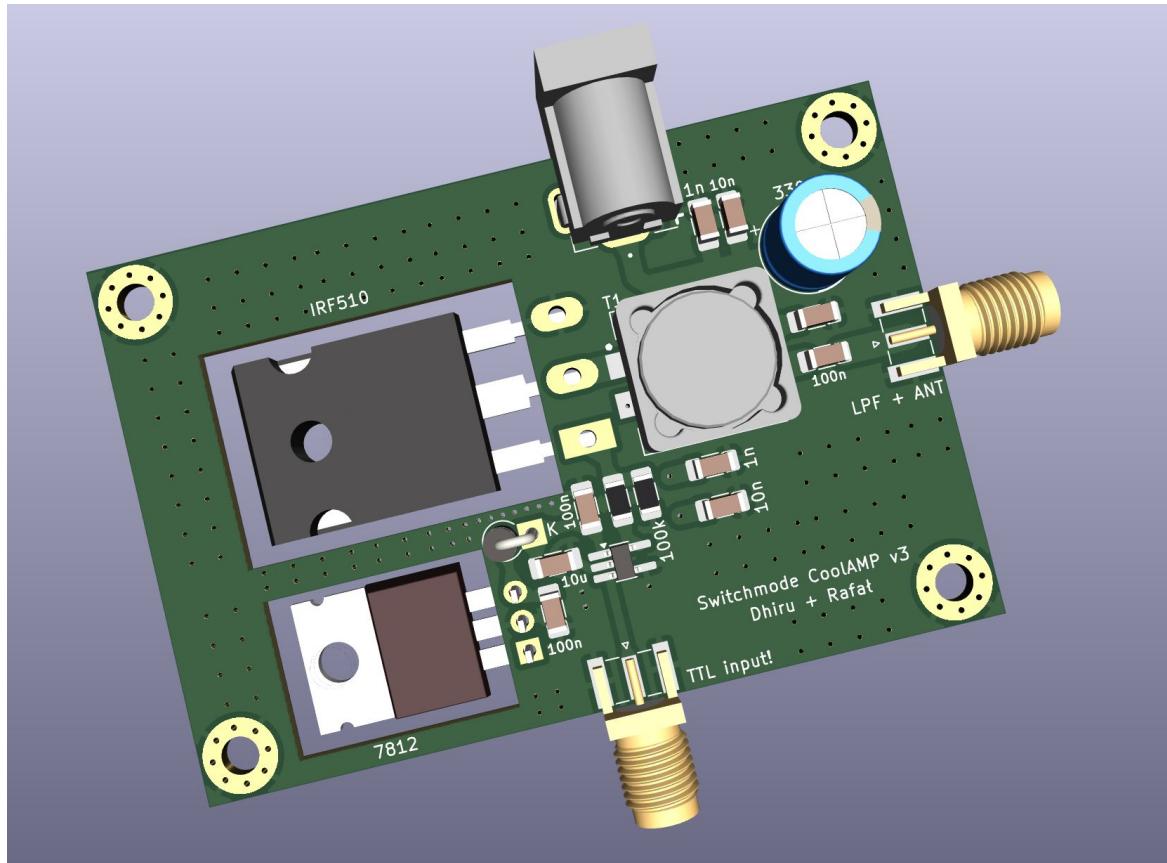
## Further reduce this '15 USD' cost?

- Remove the expensive Mini-Circuits transformer - Use the Bourns coupled inductor
- Remove the Octal Driver IC @ 5v - Use a Fast Gate Driver chip instead at 9v or 10v!
- Finally, remove the Si5351 module - Use bare Pico!

# 250mW to 10W+ amplifier (HF-PA-v10)

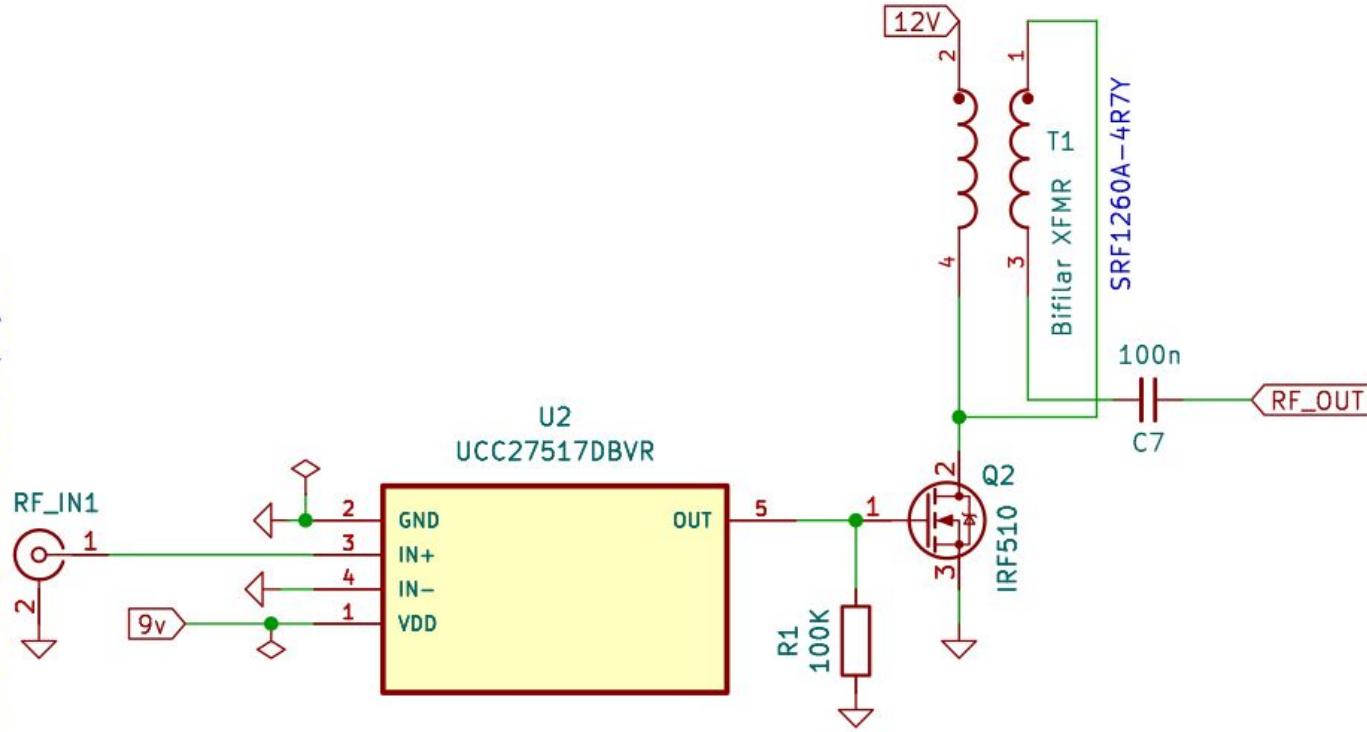
- <https://github.com/kholia/HF-PA-v10>
- Easy to build even for first timers
- Inspiration behind the 5W PA:  
<https://www.youtube.com/watch?v=4r7wHMg5Yjg>

## 250mW to 10W+ amplifier (HF-PA-v10)



# Core Schematic

Custom Quartz / Pico-FT8-TX projects



# HF-PA-v10 (Latest Developments)

- Almost flat gain from 3.5 to 30 MHz.
- The main trick is to use a ‘Stiff constant RF source’ (Fast Gate Driver) to drive the finals.
- 250mW to 10W+ output after LPF with 45 to 50% efficiency.
- MOSFET (“finals”) remains cool as a cucumber - Class D operation - Game changer!
- Another improvement: Bringing SiC MOSFETs to the hobby!

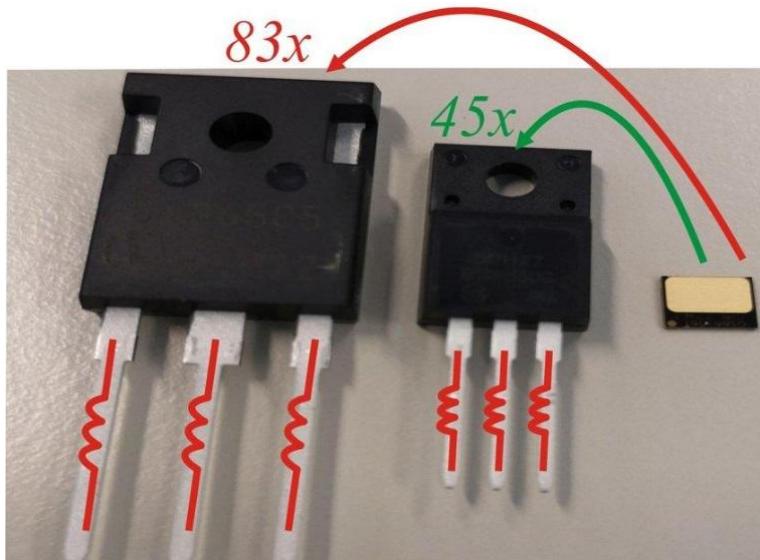
# Stop worrying about the Class - C / D “drive”

- Texas Instruments UCC27517ADBVR
- SOT-23-5 package - tiny but possible to hand solder without magnification\*

# Why SiC MOSFETs?

- TO-247 - larger package. Easier heat dissipation with more surface area!
- Massive V<sub>ds</sub> rating (can handle bad mismatches better) - Infinite SWR protection?
- $\geq 900$  V<sub>ds</sub>!
- Some CREE - Wolfspeed / SUPSiC models are quite fast enough even in the larger package! (C<sub>iss</sub> of 204 pF only)

# Why SiC MOSFETs?



# SUPSiC GC3M0280090D

$R_{DS(on)}$	Drain-Source On-State Resistance		320
			416
$g_{fs}$	Transconductance		3.6
			3.6
$C_{iss}$	Input Capacitance		204
$C_{oss}$	Output Capacitance		26
$C_{rss}$	Reverse Transfer Capacitance		3
$E_{oss}$	$C_{oss}$ Stored Energy		5.5
$E_{ON}$	Turn-On Switching Energy (Body Diode FWD)		80
$E_{OFF}$	Turn Off Switching Energy (Body Diode FWD)		6
$t_{d(on)}$	Turn-On Delay Time		5.3
$t_r$	Rise Time		25
$t_{d(off)}$	Turn-Off Delay Time		8.5
$t_f$	Fall Time		6.4
$R_{G(int)}$	Internal Gate Resistance		23.5
$Q_{gs}$	Gate to Source Charge		3.0
$Q_{gd}$	Gate to Drain Charge		2.9
$Q_g$	Total Gate Charge		9.7

# SMD coupled inductor FTW (Bourns)!



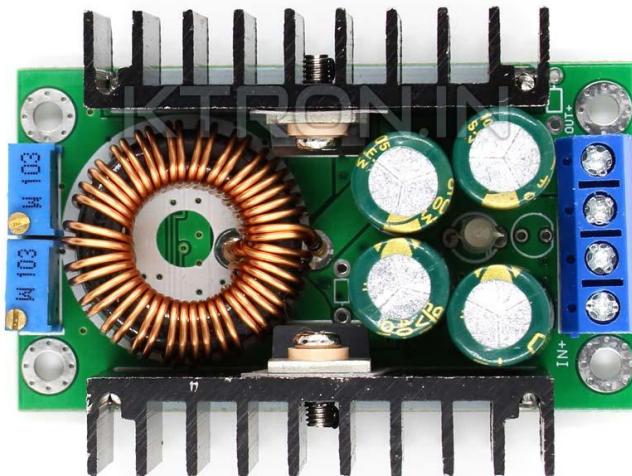
Bigger SMD coupled inductors are available too!



# PA goals (Last year)

- The PA designs must be able to survive any SWR mismatches without a tuner!
- Keep MOSFET dynamically in **SOA** using MCU controlled DC-DC power supply!
- **“A radio PA design rugged and reliable enough to be operated from the trenches without a tuner...”**

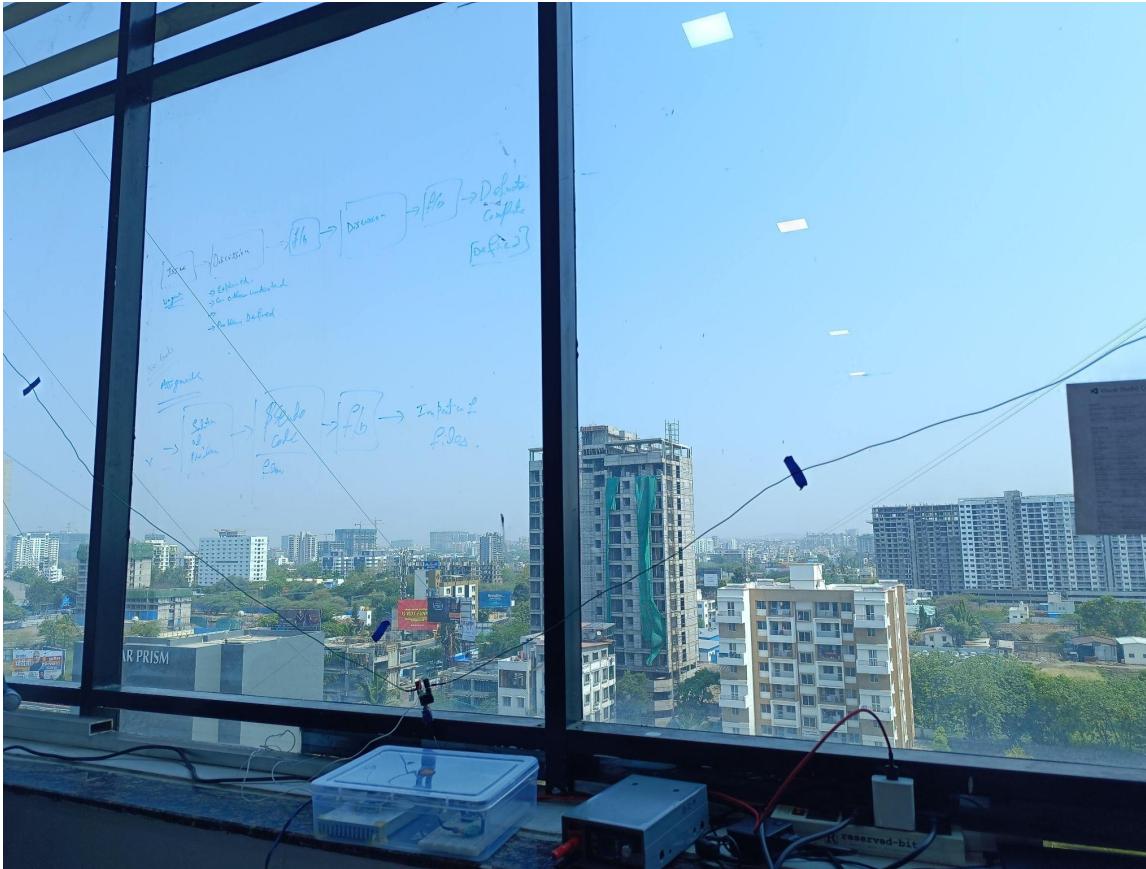
# CC CV Buck Module -> SOA implementation!



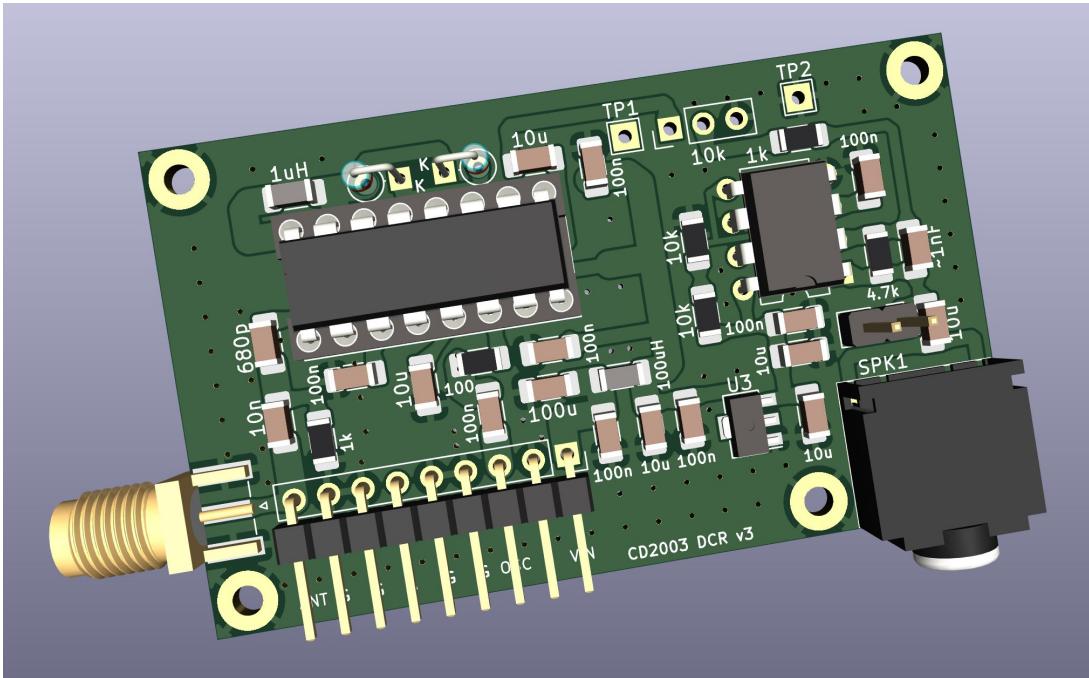
# PA goals tested!

- We were able to test our “MOSFETS SOA operating” theory in practice.
- The PA survived operations under 10:1 SWR condition and even made a QSO with Russia (from MK68) just fine!

# PA goals tested!



# CD2003 receiver (Last Year)



# Own HF RX setup at low cost (Last year)

- <https://github.com/kholia/ConsensusBasedTimeSync>
- Any cheap MCU (PY32 @ < 16 INR even) + Si5351 IC + TCXO + CD2003 board!
- WB2CBA (Barb) gave us this CD2003 DCR design via his ADX transceiver project!

# Own HF RX set up (This year)

- <https://github.com/kholia/ConsensusBasedTimeSync>
- Pico (clock source) + CD2003 board - that's it!

Also mentioned towards the beginning of this talk

- Much more compact and cost-effective!

# CD2003 receiver's results

- Can receive FT8 traffic from ~80 to ~120 countries in a single day with a modest 5m long EFHW antenna for the 10m band!
- BPF filter is required for great performance!
- Not-too-bad **given the price** (only 25 INR for the workhorse IC) when compared against the results of excellent receivers like Airspy HF+ Discovery or even the latest PDSDR (Pavel Demin SDR).

# Why not Si473X?

Si4732 drifts quite a bit (even with a TCXO clock source) and has trouble staying still enough to receive WSPR

Availability has been a problem / concern in the past.

A bit expensive and fragile (CD2003 is a 'tank' in comparison)!

Suggestion(s): Accept a High-MHz clock signal instead of the low 32.768 kHz one!

# Why not QSD?

We are getting there (slowly)...

Let's see how the actual on-air performance is first!

# TX-BPF filters are for everyone!



# BCI filters

<https://vk3il.net/projects/broadcast-band-filter/>

80m + 40m decimated even on IC-7300 due to AM BCI!

# Homebrew TX-BPF challenge?

We are trying to homebrew TX-BPF filters (10 to 25W continuous maximum) as well but this has proved to be challenging so far.

In our next version of the TX-BPF, we will have a tunable element (trimmer capacitor) for easier adjustments.

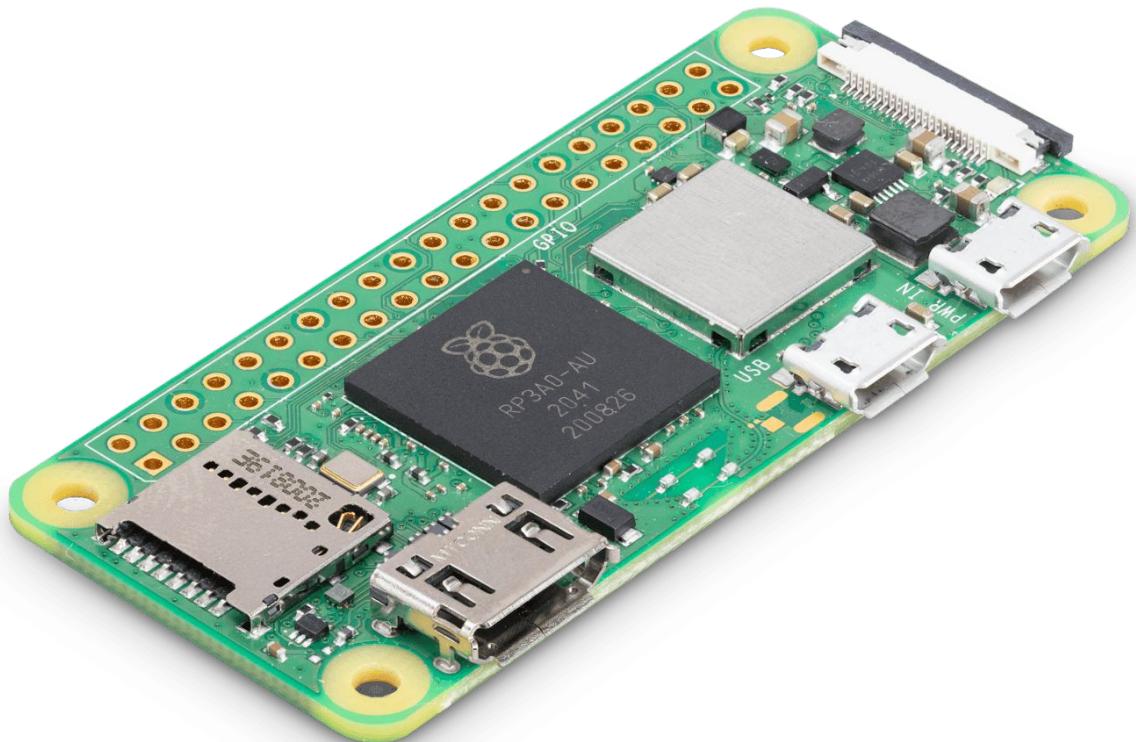
Inspired again by <https://w7zoi.net/pft.pdf> work.

It might even work (TM)!

# SSB RF source

- How can I build a SSB RF source in 10 minutes without touching the soldering iron?
- While NOT an optimal SSB source, this can be pretty useful for quickly testing things.
- Cost: 1550 INR.

# SSB RF source - RPi Zero 2 W + rpitx!



# SSB RF source - RPi Zero 2 W

<https://github.com/kholia/rpitz> - supports microphone input!

The SSB quality is quite reasonable for the amount of work involved (close to none!)

The spectrum produced also looks fairly OK!

Give it a try today! ;)

# Universal flight-safe battery pack

- Use a PD 3.0 capable USB battery bank (Amazon India)
- Along with a PD trigger decoy module (12v / 15v / 20v)
- <https://punoscho.in/product/usb-qc-pd-afc-trigger-decoy-board-module-15v/>  
(Make In India product)

# Universal flight-safe battery pack - 2



# My current work

- Enable R2BDY precise (mHz) clock to work along with ‘dawsonjon’ low-jitter imprecise-steps clocks, thus enabling a 100% Pico powered transceiver. No Si5351 needed anymore!
- R2BDY has TX working, ‘dawsonjon’ has RX working - combining both would be awesome!
- R2BDY clock consumes 1 core by itself!
- <https://github.com/dawsonjon/PicoRX>
- <https://github.com/kholia/pico-hf-oscillator>

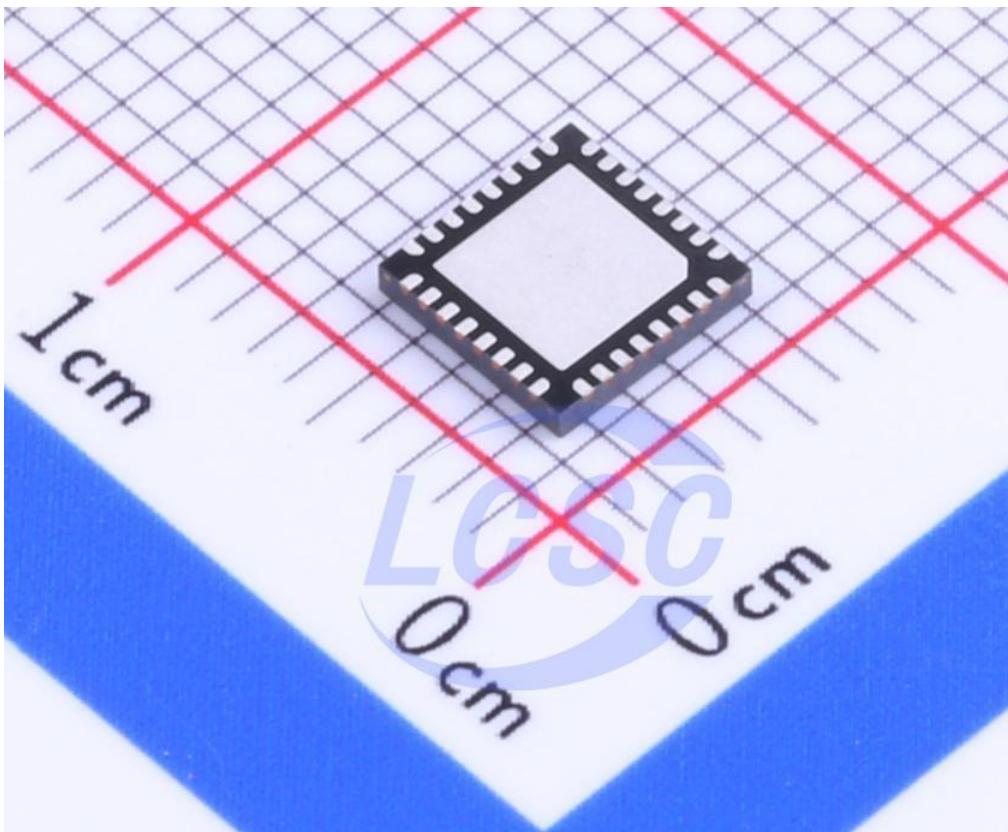
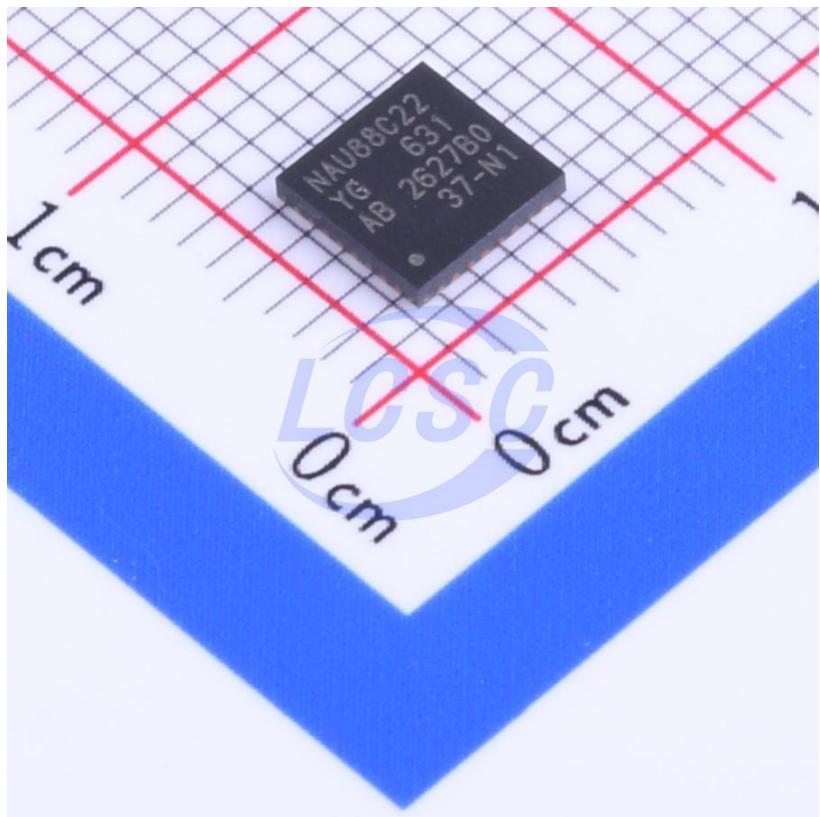
# My current work - CWX CW rig

- 5W+ CW rig
- Has DSP filters
- Might have AF AGC or at least tunable audio gain
- CD2003 based, might try QSD later
- Trying to eliminate Si5351, if possible

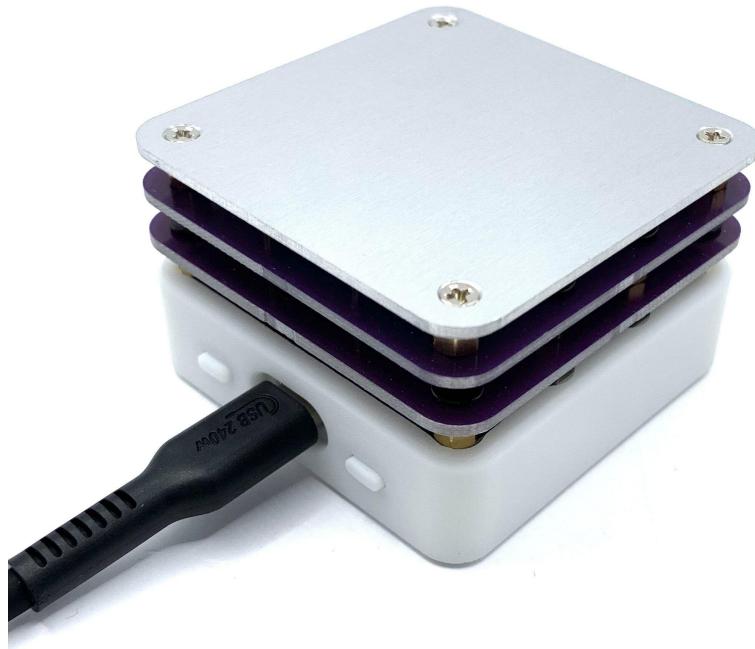
# Current work

- WM8731 CODEC is dead. What now?
- Stereo CODEC chip NAU88C22YG from Nuvoton
- Superb specs for 60 INR!
- Only catch - QFN packages can take some practice to solder ;(

## NAU88C22YG Stereo Codec



# Ideas and tips - PD 65W Mini Hot Plate - Banggood



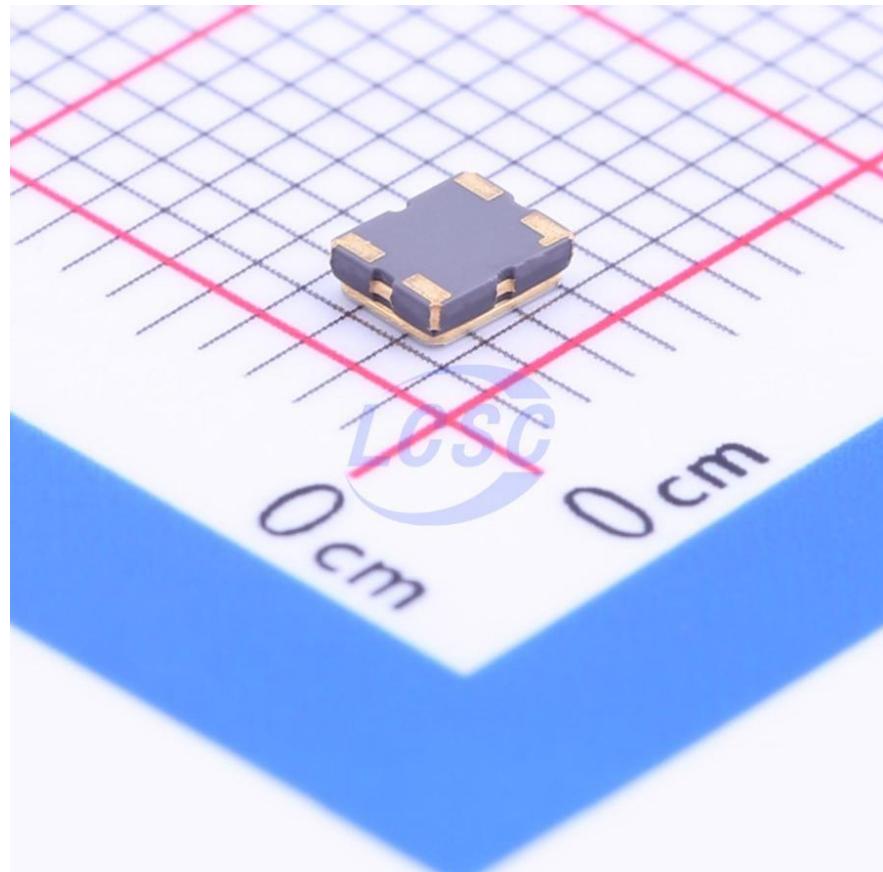
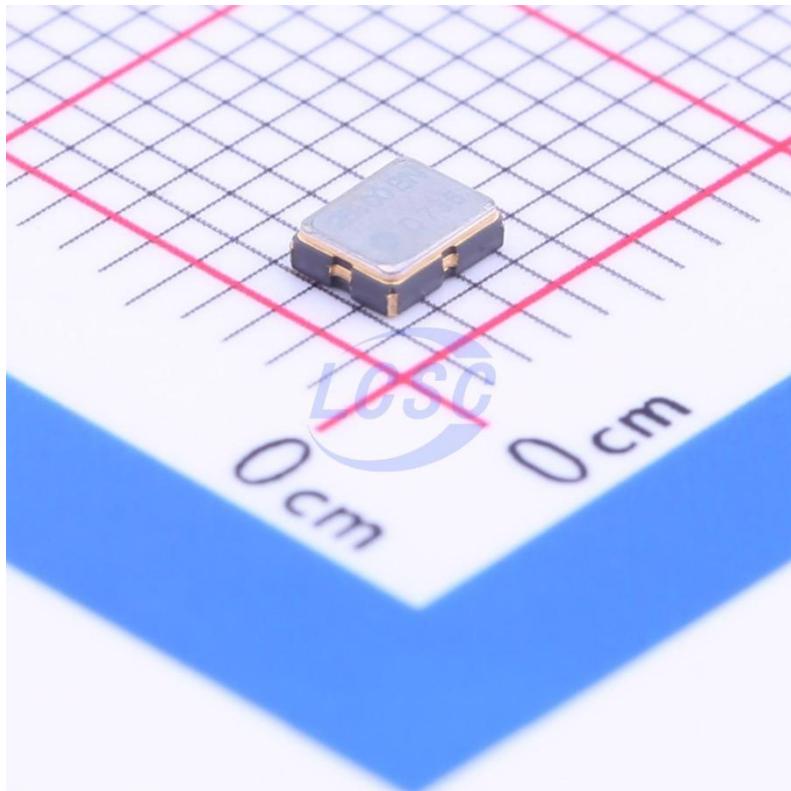
# 2UUL 183 degrees solder - “Low melt solder” - G2MARK



# Ideas and tips - Chemtronics Wick - Otovon



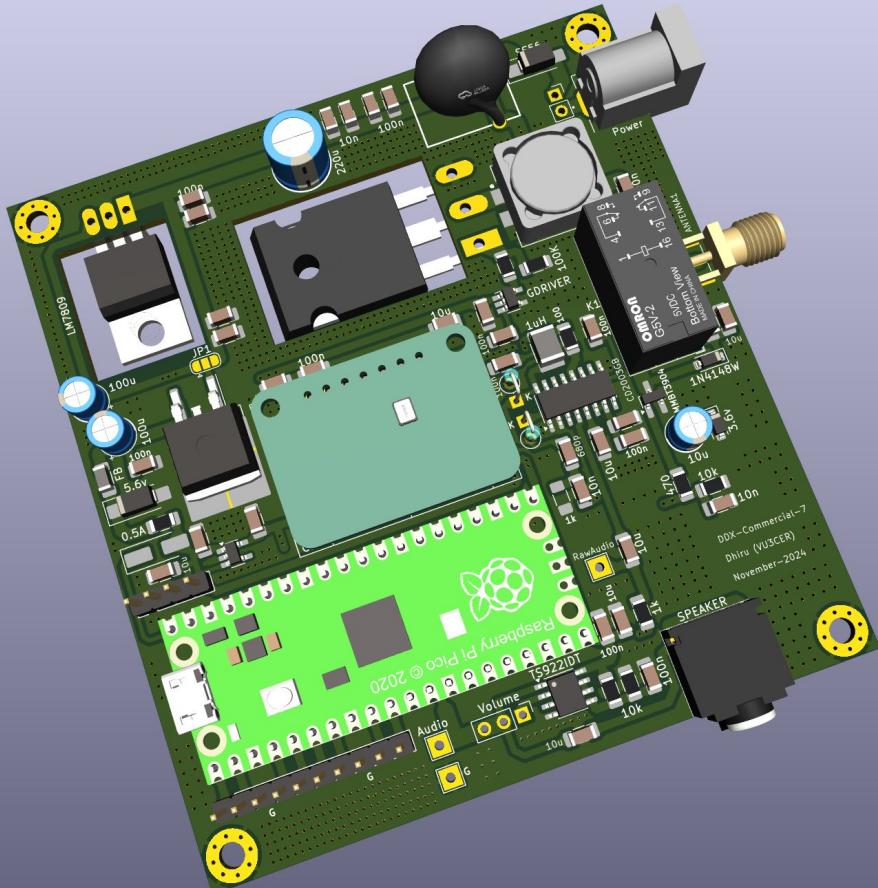
# Soldering QFN / 3225 packages is easier + reproducible now!



## Current work - Easier ADCs and DACs

- ESHINE CJC5340 (and other ESHINE ADCs @ LCSC) - TSSOP packages can be hand soldered!
- ESHINE CJC4334 DAC
- There are already projects using these parts out there!

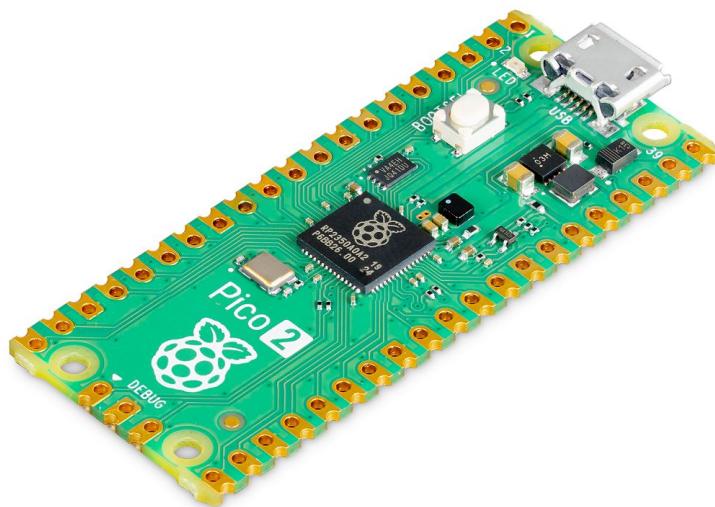
DDX is ready to ship now!



# DDX - Operate from anywhere!



# Raspberry Pi Pico 2 is here!

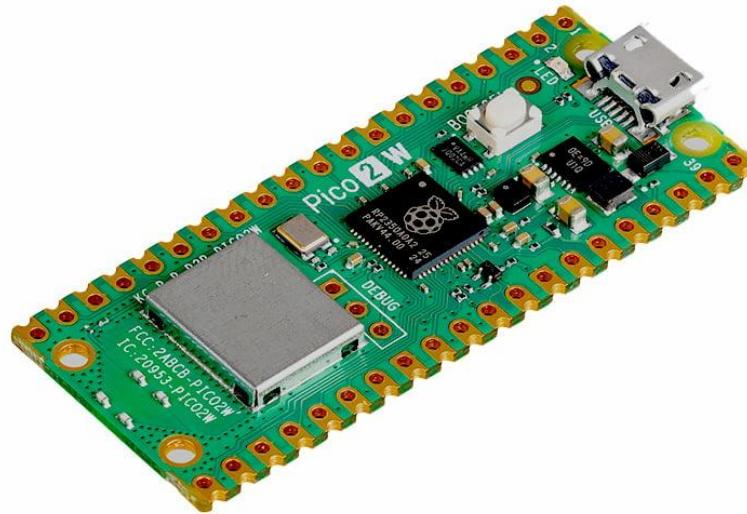


## Pico 2

- A lot more powerful! (Dual-core Cortex-M33), FPU
- Same pinout, porting efforts are next to none!
- The ADC bug is fixed!
- Best feature: It is very well supported and loved by the community around it!

# Raspberry Pi Pico 2 W (fresh release)

- Pico 2 with WiFi!



# Tip - Trusted Supply Chain is CRITICAL!

- Most shops and sellers can't tell a 100% proper IRF510 from knockoffs! LCR-T4 meter is your friend here (< 400 pF for IRF510).
- Avoid AliExpress or other “cheap sites” to source proper RF components!
- [Link to NASA resource on this topic](#) - “Counterfeit Electronic Parts”
- “You (might) get what you pay for!”
- Even famous old-time local electronics shop in Pune are affected by fake components problem!

# Resources

- <https://github.com/kholia> - starting point
- <https://www.qrz.com/db/VU3CER/>
- <https://github.com/kholia/Pico-FT8-TX>
- <https://github.com/kholia/DDX>
- <https://github.com/kholia/ConsensusBasedTimeSync>

Thanks!

That's all folks!

Thank you for your time and attention today.