Digital beacons, amplifiers, and transceivers

Dhiru Kholia (VU3CER) - 2023

About me

- Dhiru Kholia (VU3CER, WQ6W)
- Software security engineer by profession
- Electronics hobbyist, Love RF topics
- Fascinated by Hardware and RF security topics

Agenda

- Motivation
- Sneak peek
- Beacons
- Amplifiers
- Receivers
- Transceivers
- HOA / society restrictions
- My tips
- HF + homebrew as a gateway
- Questions

Motivation (Mine and Yours)

- Strongly motivated to reduce the “cost of entry of the hobby”
- Enable everyone to experience the magic of HF (high frequency) and homebrewing
- Experience ‘HF magic’ irrespective of financial, housing, and space constraints
- Push young folks towards problem solving. Develop engineering mindset and careers.
- Bring about a mental shift from being “consumers of knowledge” to being “producers of knowledge”
- Your part: Curious, open, positive, and resourceful mind is all I need to work with!

Sneak peek (Preview)

- How can I experience HF RX at NO cost?
- How can I experience HF TX (5 W) in ~1000 rupees?
- How can I experience own HF RX in ~300 rupees?
- How can I build a **rugged**, and **reliable** digital transceiver with a budget of 2000 INR in a day?
- Can a newbie get on air in a single day, and have a HF QSO with homebrew equipment?

HF RX (receive) at no cost!

- WebSDRs are awesome for general HF monitoring, and even debugging your own HF traffic!

- ‘Dip your toes’ in HF at no cost!

- http://websdr.ewi.utwente.nl:8901/ + plenty others out there.

- Interested in WSPR? First try decoding WSPR traffic from WebSDRs! (Virtual sound cards under Linux are free!)

- Tip: WSPR is much harder to work than FT8! I recommend working with FT8 for newbies.

HF TX (transmit) with a ~600 INR setup

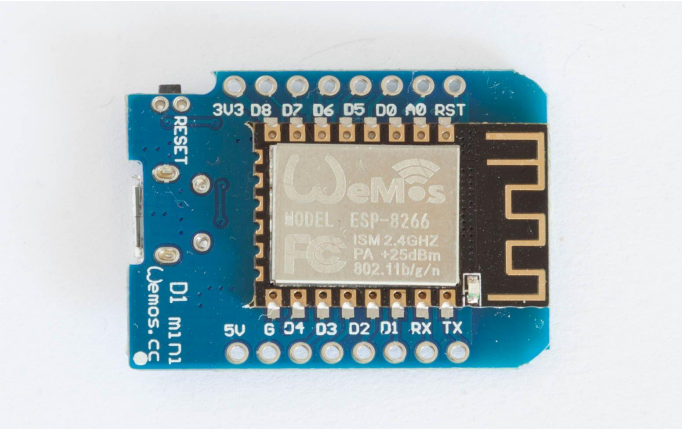
- Connect ESP8266 WiFi enabled MCU with a “RF Signal Generator” module (Si5351) using 4 jumper wires.

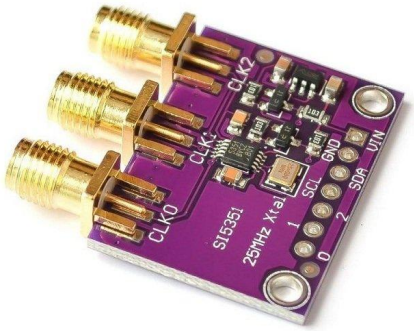
- Attach 5V USB power.

- Done already! Yes - in under 5 minutes!

- https://github.com/kholia/Easy-Digital-Beacons-v1
- https://github.com/kholia/Easy-Beacons-STEM

ESP8266 MCU + Si5351 module





Note: Si5351 (and MS5351M) is what enables all of the cheap digital brewing!

HF TX (transmit) with a ~1000 INR setup

- This gives us ~10 mW of RF power! How can I amplify this “small” RF output?

- https://github.com/kholia/Easy-Beacons-STEM (250 mW beacon)
- https://github.com/kholia/HF-PA-v10 (5 W)

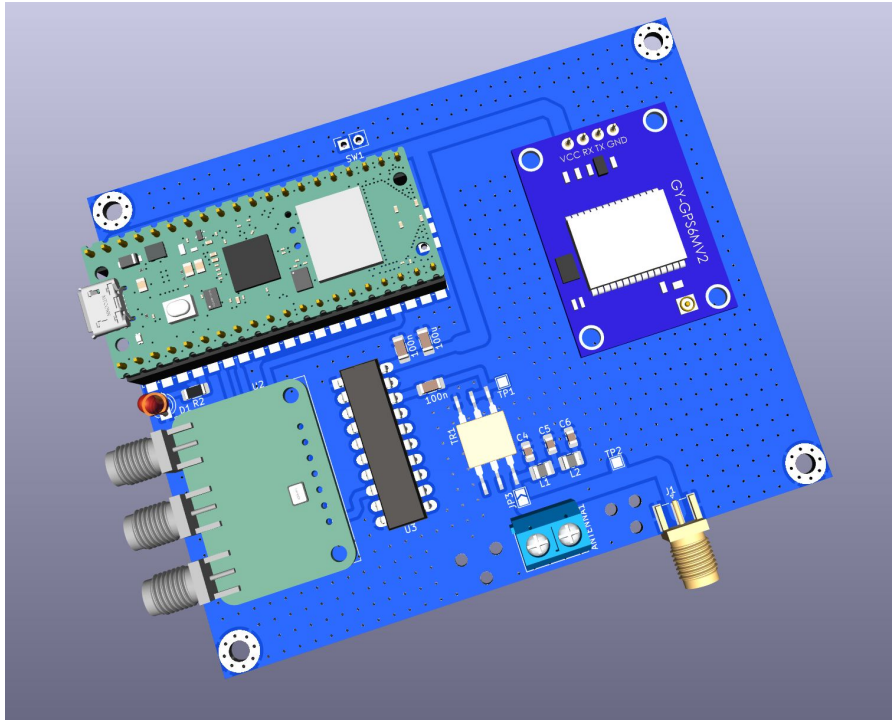
- Easy to build even for first timers (with some practice and supervision)!

- Inspiration behind the 5W PA:

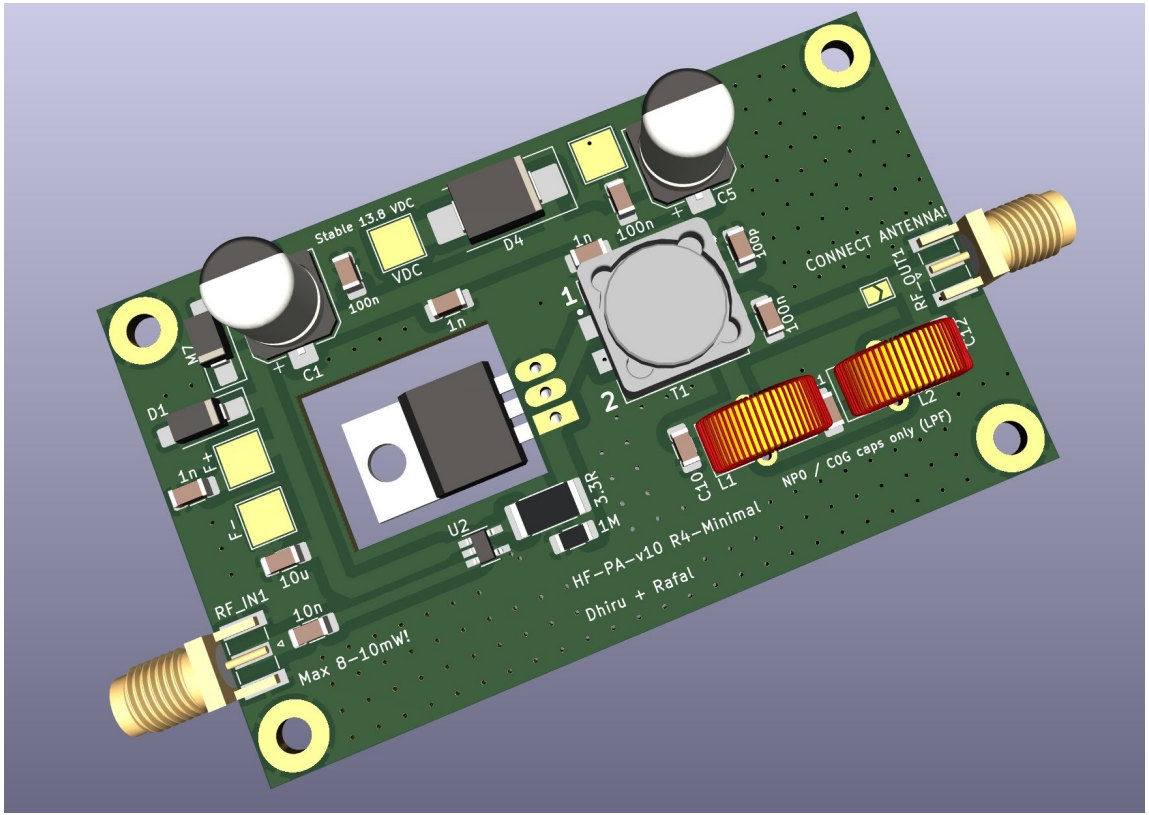
  https://www.youtube.com/watch?v=4r7wHMg5Yjg

250 mW digital beacon

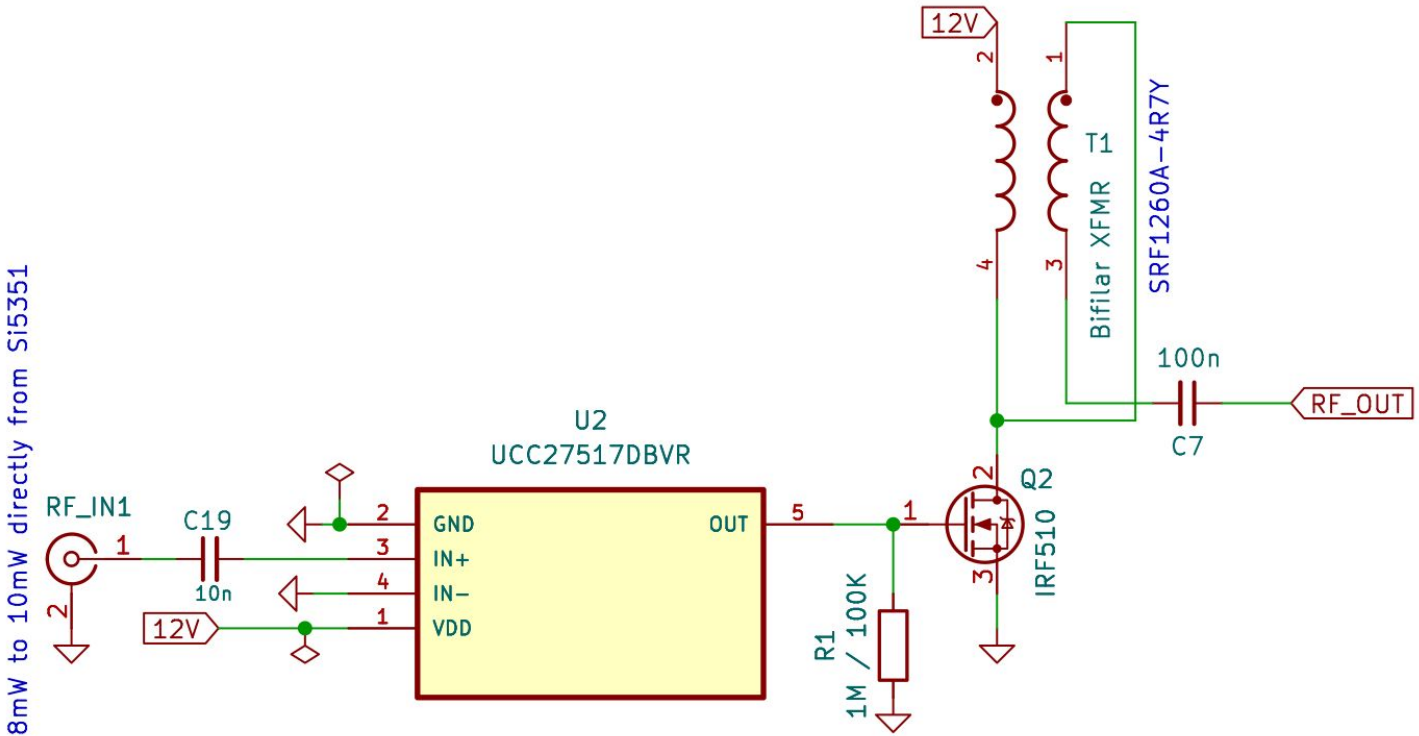
- “Cheap” clone of [Zachtek WSPR Transmitter](). Reached NASA Goddard Space Flight Center from MK68 (Pune) using a balcony dipole antenna!



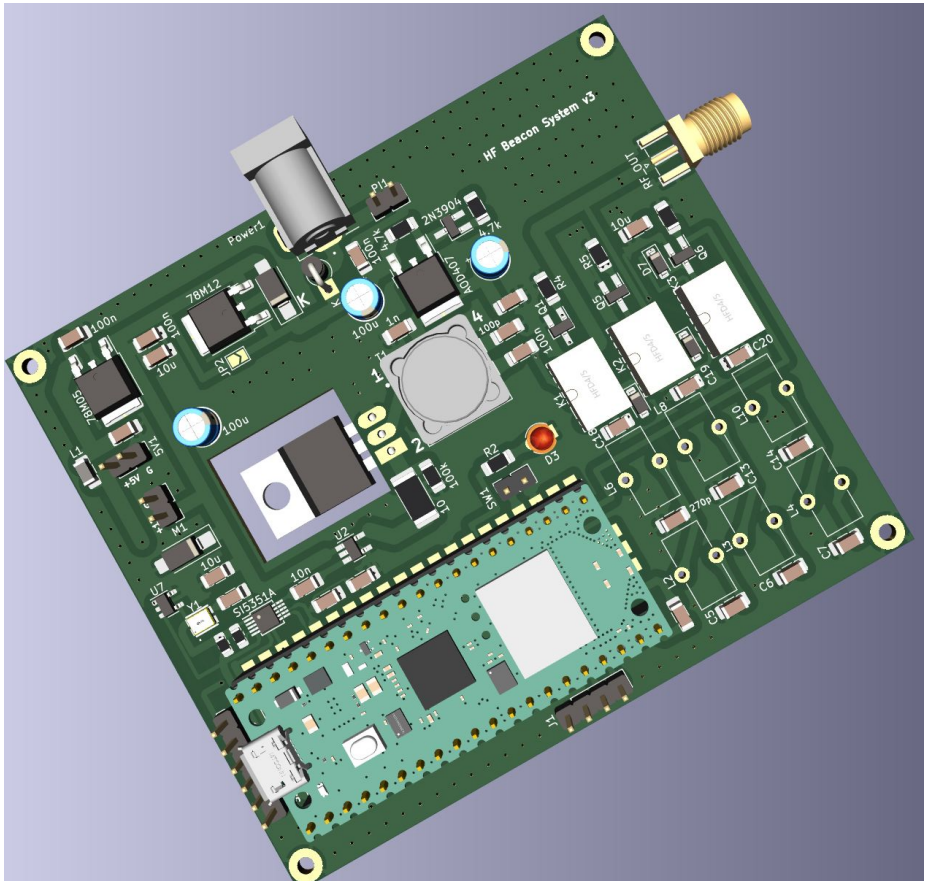
Modern digital RF power amplifier (~5W)



Core Schematic



We can do better but the complexity…



HF-PA-v10

- 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.
- ~5W output after LPF with 45 to 50% efficiency. Outputs ~2W even at 50 MHz with IRF510!
- MOSFET (“finals”) remains cool as a cucumber! Game changer!
- Based on designs and RF tricks from Henning Paul and Jim Veatch <3. No manual bifilar toroid winding required!

SMD coupled inductor FTW!

HF-PA-v10 - small / big wins

- http://www.carnut.info/WSPR_Tx/WSPR_Tx.htm - Expensive, MOSFET used can be hard to source + is widely faked, complex design, doesn't scale to higher bands easily, can blow up!

- https://www.dj0abr.de/english/technik/dds/pa.htm - Even more expensive, more complex too!

- BS170 based PA designs are NOT the most robust!

- The cost of the entire HF-PA-v10 system is less than the cost of the "finals" MOSFET(s) used in these amplifiers ;)

- Survives open, and short conditions but having protections in place is recommended (tested by Rafał)

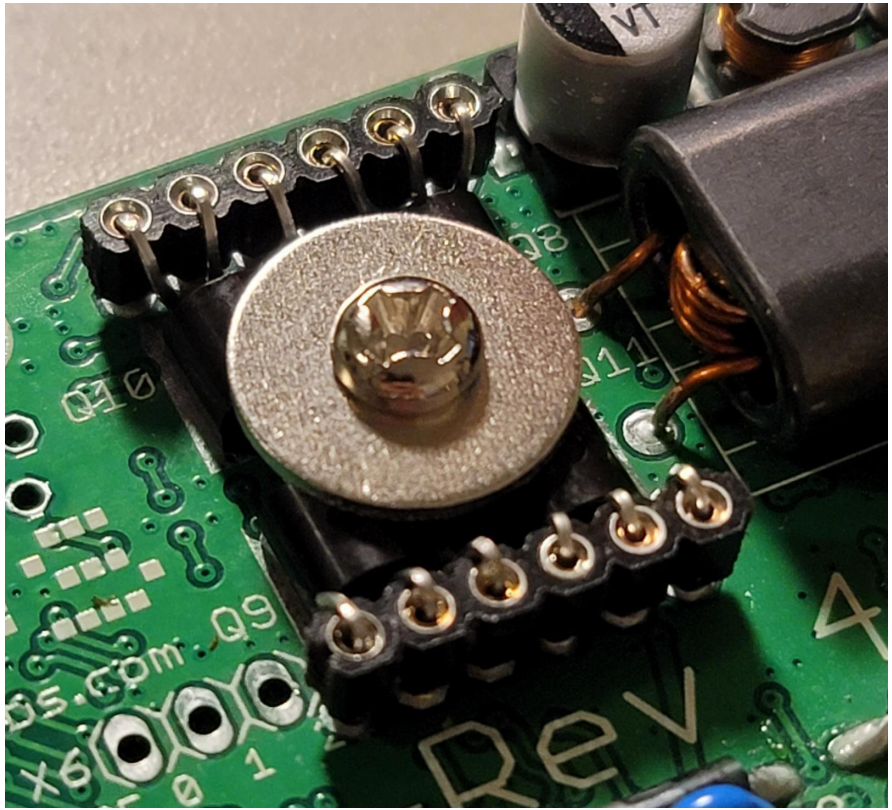
BS170 PA designs #1

- The “margin for error” is relatively less. Easier for things to go south…

- Replacing blown BS170 MOSFET(s) may not be expensive money-wise but it may be EXPENSIVE from a time, patience, tolerance, and energy perspective.

- Your EF(HR)W wire antenna may NOT have perfect SWR in the field. What happens then?

BS170 PA designs #2



Future PA goals

- A push-pull design gives us clean 10W easily but consumes much more space (designed and tested by Henning Paul originally).

- Ultimately, we want to operate our PA designs with random length wires - non-resonant antennas with no tuners and get a signal out! Keep MOSFET dynamically in **SOA** using MCU controlled DC-DC power supply!

- The PA designs must be able to survive any SWR mismatches (without a tuner?)!

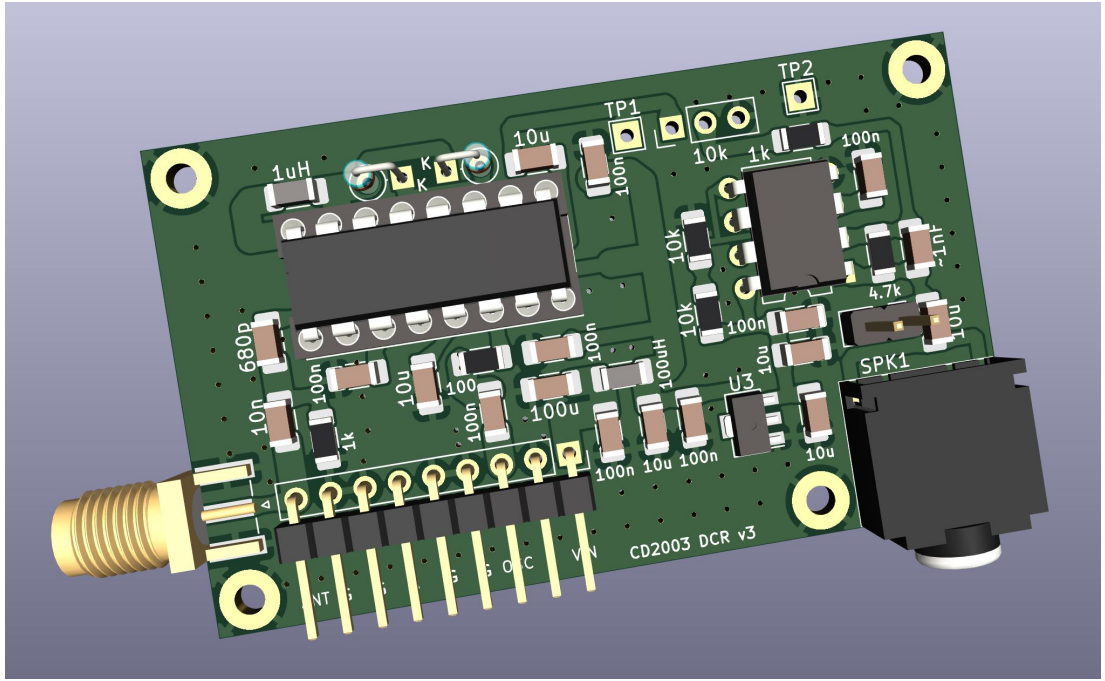
  Note: Even IC-9700 (priced > 1700 USD) can blow up with 100W FT8 ;)

- **“A radio PA design rugged and reliable enough to be operated from the trenches”**

Own HF RX setup at low cost

- https://github.com/kholia/ConsensusBasedTimeSync
- Any (cheap) MCU (<= 16 INR even) + Si5351 IC + TCXO + CD2003 board!
- WB2CBA (Barb) gave us this CD2003 DCR design via his ADX transceiver project!
- https://github.com/IOsetting/py32f0-template (Low cost MCU controlling Si5351)

CD2003 receiver



CD2003 receiver results

- https://github.com/kholia/ConsensusBasedTimeSync/tree/master/screenshots
- https://github.com/kholia/DDX/blob/master/screenshots/
- **Can receive FT8 traffic from 100+ countries in a single day with a modest 5m long EFHW antenna!**
- **We can reduce the cost of this RX to <= 300 INR, even with a TCXO!**
- **Add 50 to 250 INR for a BPF filter for ultra performance!**

Digital Transceivers

- Transceiver => Transmitter + Receiver + T/R switch

- https://github.com/kholia/Easy-Beacons-STEM (RF source)
- https://github.com/kholia/HF-PA-v10 (Amplifier)
- https://github.com/kholia/ConsensusBasedTimeSync (Receiver)
- https://github.com/kholia/Simple-TR-Switch (T/R switch)

- Done! ;)

DDX-1

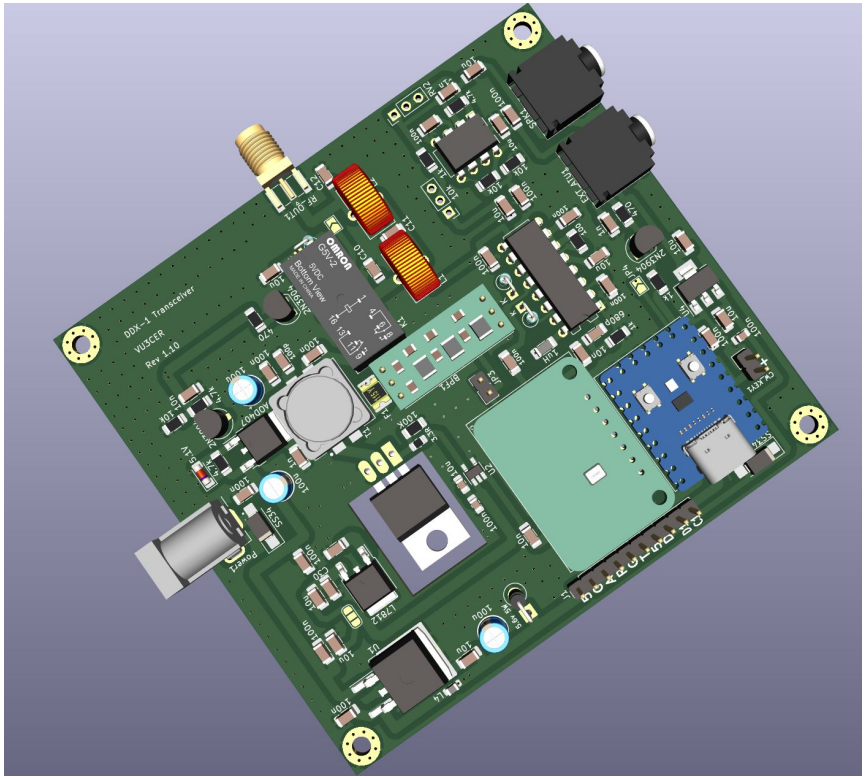
DDX-1 - Digital Transceiver in ~2000 INR

- Transceiver == RF generator + amplifier + Receiver + T/R switch

- This is exactly what we did in https://github.com/kholia/DDX.

- BOM cost estimate: 20 to 30 USD. Around ~2000 INR.

DDX-1



DDX-1 features

- Rugged and reliable PA
- Reliable CAT + audio over a single USB cable - a first for homebrew systems!
- We have a plan to upstream major components of the DDX-1 firmware!
  https://github.com/hathach/tinyusb/pull/2105
- Motivation: Enable others to build reliable, next-generation radios!
- No calibration required, fuss-free operation in all conditions!

DDX-1 wins

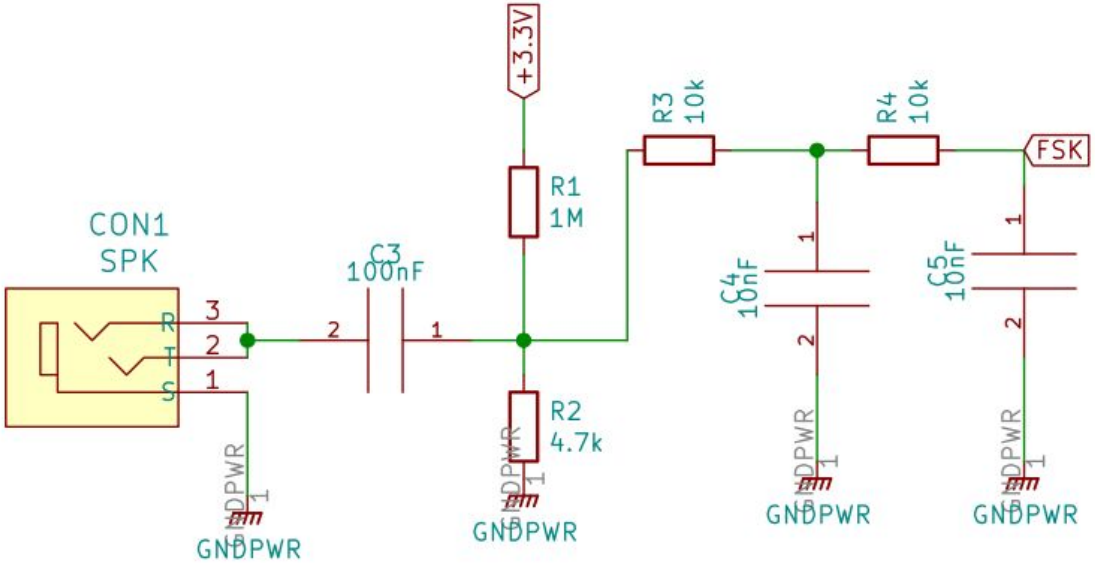
- Bit perfect output with fine timing.

- ADX can handle all FSK modes without even knowing what they are (!) but this comes at a cost. ADX's RF output can suffer from artifacts (non-bit-perfect and non-perfect-timing).

- DDX is flexible - It can do F + T derivation digitally or it can derive F + T via native digital mode encoders! Two audio output modes: Audio over USB or Audio over 3.5mm jack!

- We have published a WSJT-X patch to further help other radio designs with this stuff.

ADX re-derives frequency + timing from input audio!



This can be problematic in non-perfect operating conditions!

What if we need more power at times?

- Use a https://github.com/kholia/HF-PA-v10 board (at low power setting) to drive another https://github.com/kholia/HF-PA-v10 board fitted with IRF530.

- 20W+ is possible @ 14 MHz with a single IRF530 but I tend to use 9 to 12W to compensate for coax losses (which is 50 meters long in my case!).

- https://github.com/kholia/HF-PA-v10 has more details. Push-pull gets us 15W+ easily!

- If you are targeting lower bands, we also have IRFP140N MOSFET PCB option to put out more power.

- We also have a MRF101 based HF PA project to put out ~25 to 50W which is overkill ;)

Getting on air?

- ARRL's Small Antennas for Small Spaces - a decent resource!

- Magloops VS EFHW antennas

  https://github.com/kholia/HF-Balcony-Antenna-System

- Key tip: Target the highest band you can! 10m (28 MHz) is superb when it is active. 15m is competitive but quite fun. The antenna lengths for these bands is very manageable!

Getting on air?

- Bottom line: DO NOT WAIT FOR TOMORROW TO COME!

- Life’s biggest trap: Waiting to get started on the “right foot” at “the right time”.

- The most terrible antenna is better than a rotable 128-element HF beam which doesn’t get installed in this lifetime ;)

- So, start right now. Throw a piece of wire outside and see what all you can catch.

HOA / Housing society restrictions?

- https://github.com/kholia/HF-Balcony-Antenna-System

- Bottom line: Any piece of wire out there is better than the one sitting in the shelf. All antennas work ;) You will succeed 100% eventually, and consistently with practice.

- All we need is a resourceful (reproducible “jugaad” / “hacker”) mindset to overcome restrictions.

- Reach out to other HAMs to get tips, ideas, and help!

- Operate a field, portable setup - super fun and great for health! Our VU license explicitly allows this!

What about SSB?

- Possible even with Digital (“Class C / Class D”) amplifiers!

- We (Rafał and me) have a basic demo working on RPi Pico + Si5351 combination!

- http://pe1nnz.nl.eu.org/2013/05/direct-ssb-generation-on-pll.html (Guido’s magic) - Change phase (via FM!) and amplitude (via ‘drive levels’) at a very high speed to get SSB compatible output!

- https://github.com/F5OEO/rpitx is super easy to use!

- PoC code -> https://github.com/kholia/Si5351-Pi-Pico/tree/v3

The importance of ‘perspective’

- Folks say that FT8 and other digital modes “make them **bored** / **sleepy**”.

- Yep, 100% true!

- Other folks claim that FT8 makes them **super excited**!

- Also, 100% true!

How can conflicting views be equally true?

- It all depends on our own perspectives - the ways we view things.

- Operators using 100W commercial rigs with 1.5 KW amps with rotatable beam antennas with no interest in Information Theory and Coding, homebrewing, or operators chasing external validations may find FT8 very boring after a while.

- But a homebrewer with even a slight interest in Information Theory and Coding, or a tinkerer who is intrinsically motivated might develop a lifelong fascination for such things!

Choosing a perspective

- We all are free to choose our perspective (PoVs).

- We can even influence other people perspectives!

- How to choose then?

- Choose something which allows a deeper sense of understanding, enjoyment, and appreciation for you and others - be an enabler and not a gatekeeper.

The “FT8” app on Play Store

- By being interested in FT8, we were able to develop the “FT8” app for Android.

- The modest commercial success of this app has enabled us to release lot of our other projects for free!

- We thanks our app users, and GitHub contributors for enabling our work!

Standing on the shoulders of giants - ‘**New APRS**’

- We can easily build a global, reliable **APRS** network at close to zero cost by building on top of FT8!

- Combine JS8Call like framing with https://en.wikipedia.org/wiki/Geohash

- TX 1 (Offset 1250): CQ VU3CER MK68

  TX 2 (Offset 1250): U09TUNQUC9ZH

  https://www.movable-type.co.uk/scripts/geohash.html + http://geohash.co/

  https://github.com/kgoba/ft8_lib/pull/39

- Super handy for emergencies, and communicating outwards (< +- 30 meters is good enough!)

‘New APRS’ - RescueBox

- Emergency HF beacon that can be activated from anywhere!

- Multiple WebSDRs can be monitored for reception on the “other side”. Generate mobile alerts (WhatsApp / Telegram / SMS)

- Upstream “SOS” mode to all “WebSDR software” out there.

- We can produce the **RescueBox** for 1500 INR or perhaps even less!

WSPR Balloons - another useful and fun idea

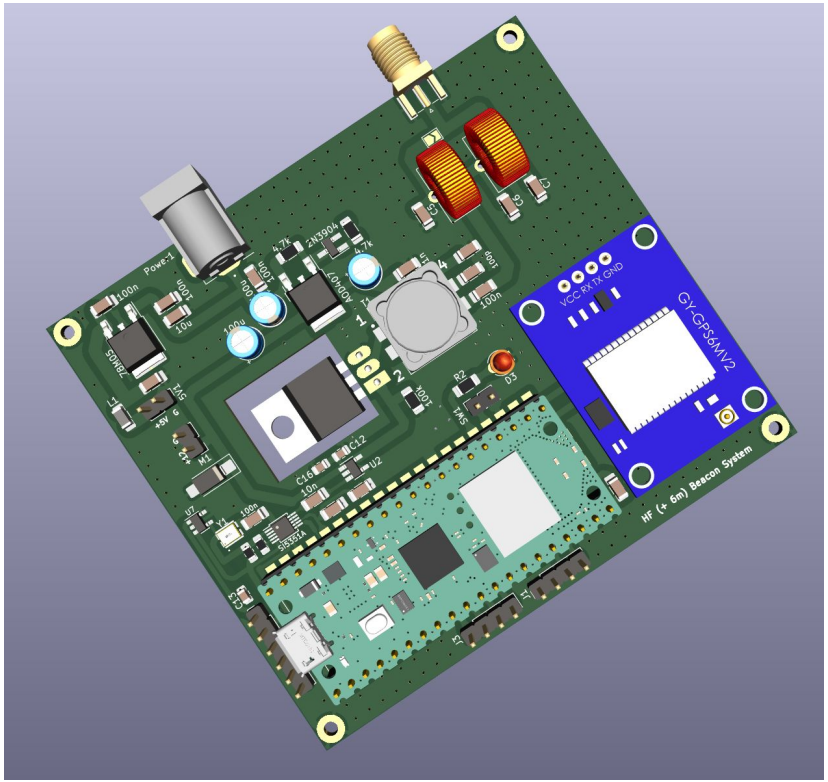
- https://traquito.github.io/tracker/

- Can we reduce the price by half?

- Can we reduce the weight by half?

- https://www.n2wu.com/2021-05-07-10m-hf-wspr-beacon-for-hab/ - fun!

‘New APRS’ - RescueBox



“U09TUNQUC9ZH”

Movable Type Scripts

Geohashes

A geohash is a convenient way of expressing a location (anywhere in the world) using a short alphanumeric string, with greater precision obtained with longer strings.

Geohash

Enter latitude, longitude & precision to obtain geohash; enter geohash to obtain latitude/longitude.

Latitude / Longitude 48.858411 , 2.29449

Precision 9 characters

Geohash u09tunquc

Neighbours:

u09tunqv0 u09tunqv1 u09tunqv4
u09tunqub **u09tunquc** u09tunquf
u09tunqu8 u09tunqu9 u09tunqud

My tips

- Use quality tools! They needn't be very expensive.

  Use a temperature controlled soldering iron (~330 INR for Oswal branded one).

  The best micro-soldering specialist I know personally uses a 400 INR Hiko Micro Soldering Iron Station!

- Use the best quality jumper wires (from https://projectpoint.in/) - this will save you weeks of hair-pulling!

- Review https://learn.adafruit.com/adafruit-guide-excellent-soldering/. Use 'Chemtronics' wick (desoldering braid) with extra flux for removing soldering bridges!

- Liquid soldering flux (Soldron, Max Gold) is magical, and makes things much easier.


SOLDERING STATION
ON
OFF
OUTPUT


TUBE 125°C VW-1 H 20135

My tips 2

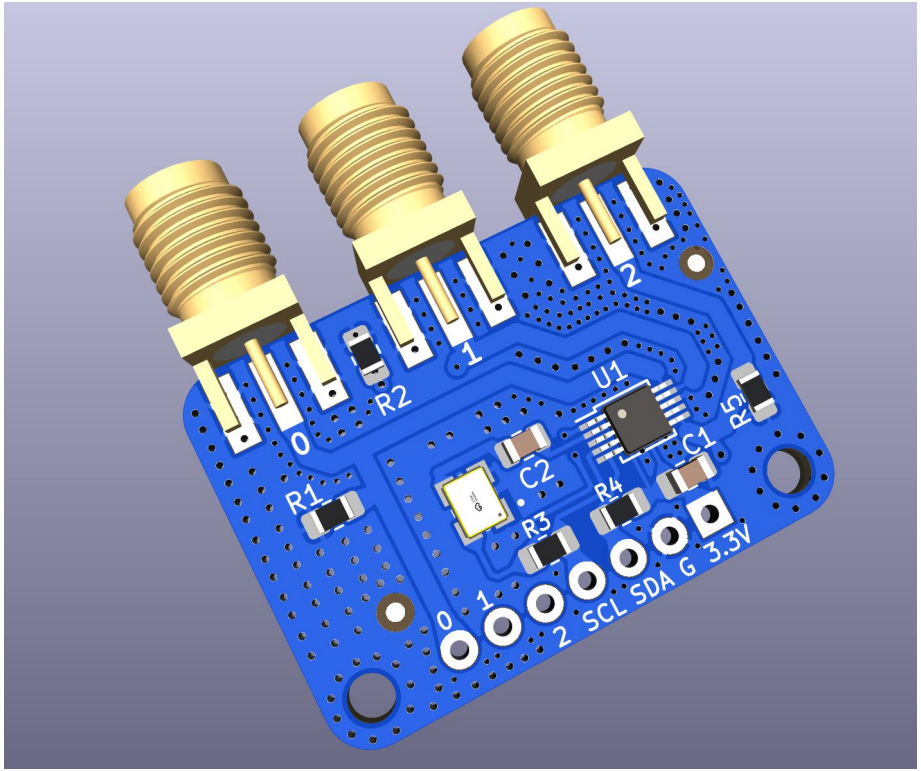
- Use IRFI510G (TO-220FP) - It is IRF510 with an insulated tab (!), whenever possible. It saves time, and energy for other things.

- Use a trusted supply chain to procure ‘critical’ components (LCSC, Semikart for India, TME, DigiKey, Mouser and others) - Save time and money!

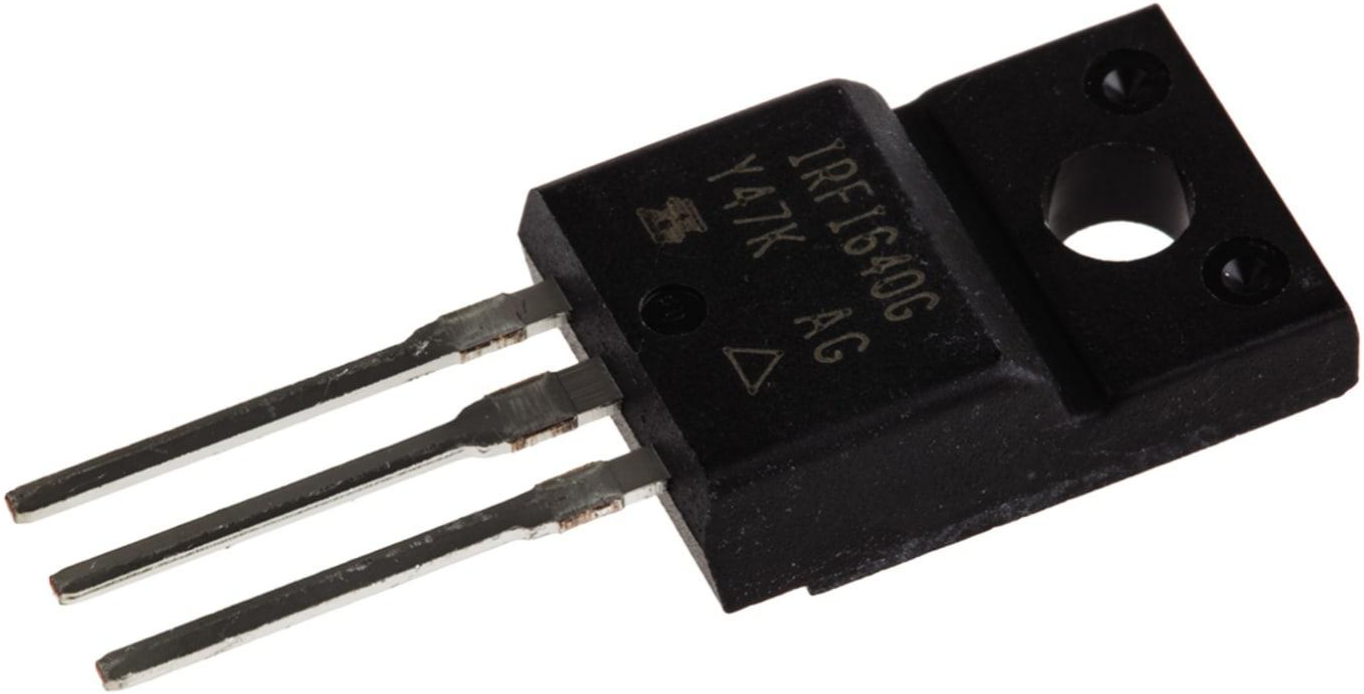
- Use a TCXO everywhere you can! 0.5 ppm 26 MHz TCXO cost less than 0.6 USD (< 50 INR)! Super required for 28 MHz and higher bands.

  My WSPR reports on 28 MHz went from under 20 to thousands after using a TCXO (with the 250 mW beacon version).

Si5351 module with TCXO!



“IRF510” with insulated tab (from Vishay)!



Trusted Supply Chain is CRITICAL!

- There are even sellers who can't tell a 100% proper IRF510 from knockoffs!

- Avoid AliExpress or other "cheap" sites to source proper RF components!

- Link to NASA resource on this topic - "Counterfeit Electronic Parts"

My tips 3

- A hot plate makes SMD soldering really convenient, and reliable (NOT 100% essential though).

- MSOP-10 ICs like Si5351 and tiny TCXOs can be soldered easily with a hot plate.

- **Don’t shy away from software hacking opportunities.** Yes, software really did eat the world! It is everywhere - from your bread toaster to fridge to radios!

- Move forward (and even ahead of) with the time, and NOT backwards! Stop asking newbies to build radios with unobtanium components! ;)

Hot plate > Reflow oven!

My tips 4

- A quality “debugging capable” CC + CV power supply needn’t be expensive.

  RuiDeng DPS3005 (and more powerful models) are superb!

DC-DC module - DIY power supply

My tips 5

- **Positivity**: Now is the best time to be alive, and homebrew stuff ;). Modern, production-grade MCUs cost less than 20 INR now!

- Everything is available easily (in India and other place) - you just need to learn the tricks of the trade. Same thing applies to life, in general ;)

- Don’t believe in the pessimism and defeatism of others! The self-imposed limitations of others are NOT your problem ;)

- **Resourcefulness** (**reproducible** “j**ugaad**” - “hack”) really works wonders!

The future (SDR receiver)

- By spending around ~3000 INR, we can get a 8-to-14 MHz BW capable SDR (“RSP1 SDR”).

- This 8-to-14 MHz spectrum slice enables us to monitor 2 or even 3 consecutive FT8 bands at the same time *__theoretically__*.

- Not even IC-7300, and IC-705 can boast of such a feature!

- We need more **open** systems, solutions, researchers and engineers to build the next generation of radios! Your contributions are welcome!

The future receiver

The future (CD2003 receiver)

- We can implement a 2 band or 3 band solid-switched BPF filter bank on the PCB itself.

Homebrewing and HF as a gateway

- World’s greatest hobby - Yes, for sure! It enables curious minds to practice, and develop problem solving and communication skills.

- These skills translate very well into exactly what the industry needs!

- The hardware and software skills you develop while hambrewing will lead you to better and highly rewarding career paths!

- A sense of urgency, and earnestness will take you anywhere!

Shoutouts

- The ‘HAMBREWERS’ group on Telegram. Sandeep Da, Rafał, Ismo, Daniel and ton of other folks <3. Absolutely the best resource for homebrewers!

- K1TE (Brad) and piRshared.org team for all the fun ideas, directions, unconditional support, and discussions!

- WB2CBA (Barb) and Hans - for creating awesome radios and for all the support!

- PHARC radio club members and my elmers there. My family and friends for supporting me. LARC (Lamakaan) members for doing all they do!

- A lot of other folks who are part of this journey - you know who you are <3

Questions!

- Can a newbie get on air in a single day, and have a HF QSO with homebrew equipment with active help, and guidance of elmers?

- Can we enable and drive such “HF-In-A-Day” bootcamps for newbies?

- How can HAM clubs enable and nurture newbies in a positive, liberating way?

Resources

- https://github.com/kholia ;)

- https://rf-tools.com/lc-filter/ - super practical, realizable filters

- https://github.com/kholia/Si5351-Module-Clone-TCXO/ - High performance Si5351 module

Thanks!

- Thank you for your time and attention today.