AC2YD 4-Square Transceiver

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4/16/2024 Presentation for David Sarnoff Radio Club

A “work in progress” …. hopefully not “vaporware”!!

Still fun, EVEN IF IT IS!!!! ;-)

Trying to finish “before I can’t”!!!

House rules: NO FUD!!!

What is a 4-Square *Antenna*?

- Array of 4 vertical antennas (“elements”) placed in a square footprint.
- Great low-takeoff radiation pattern for DX!!
- ***Typical*** characteristics:
  - 4 selectable directions, 90 degrees apart
  - (Narrow) single-band, 160m/80m/40m
  - 1/4-wavelength (electrical) element height
  - 1/4-wavelength (free space) element spacing
  - Single transceiver signal, split into 4 phased signals via transformers
  - Distributed using 1/4-wave tuned lengths of coax; these overcome antenna impedance variations caused by electromagnetic coupling between antenna elements
  - 4 directions selected via relays
  - Delicate balance of phase and signal amplitude
  - Needs good ground radial system

Why Do I Want One?

- This is my current antenna farm: The “Maple Tree Vertical”:
  - “Fan” vertical, with 4 separate 1/4-wave elements for 80/40/20/10m
  - 15m uses 3rd harmonic of 40m element
  - 32 radials, 16’ to 55’ long
  - “Rig-In-A-Box” at base, controlled via WiFi:
    - Radio (HW) + Raspberry Pi + Power Supplies

Why Do I Want One (cont'd)?

- I love my Maple Tree Vertical! Great radiation pattern for DX!
- WAS/WAC/DXCC(132 confirmed)/Contests, all using <= 5 watts
- BUT … I want more!! :-)
  - TX: It's currently hard to "run" in contests, N3P, etc.
  - Rx: Directional antenna pattern reduces noise and QRM
- BUT!!! My wife hates towers or visible antennas (e.g. beams)!
- My wife wants my antenna farm to look like THIS!
- Well, hey, I can enjoy a good challenge!

What If:

- I could build a multi-directional, multi-band 4-square antenna in the woods?
- Low visual profile (maybe even camouflaged), with no moving parts?
- Rig-In-A-Box with 4 (cheap) synchronized Transceivers, Remote Control via WiFi?
- Phasing and Signal Level Balancing done via Computer DSP?
  - Maybe even automatically/instantly optimally combine 4 Rx signals, and aim Tx in direction of Rx by phasing/balancing the 4 Tx signals “in reverse”?
- No Coax or Relays, i.e. all antennas connect directly to central transceiver?
  - No coax may avoid (some) problems with varying impedance!
- Power via Solar Panels and Battery?
- Few/No Radials?

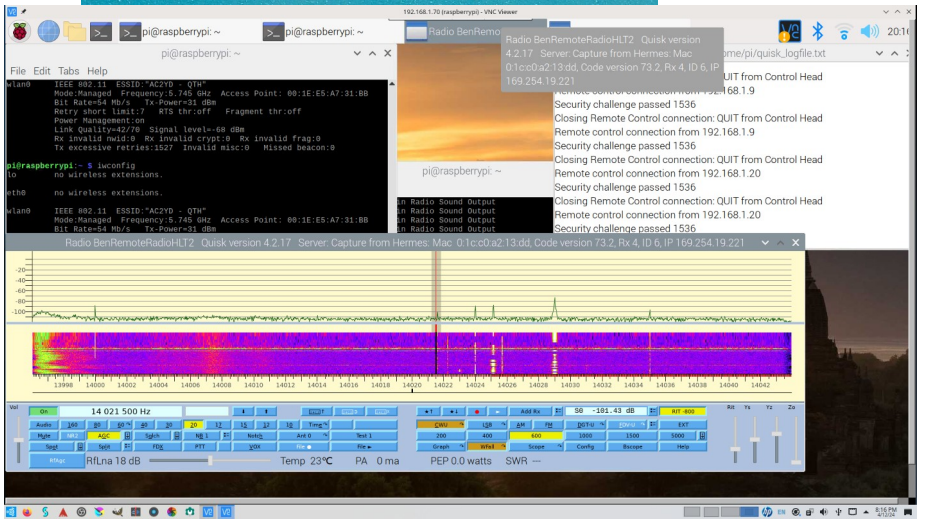
That would be cool!

Step 1: Remote Control (2021-2022)

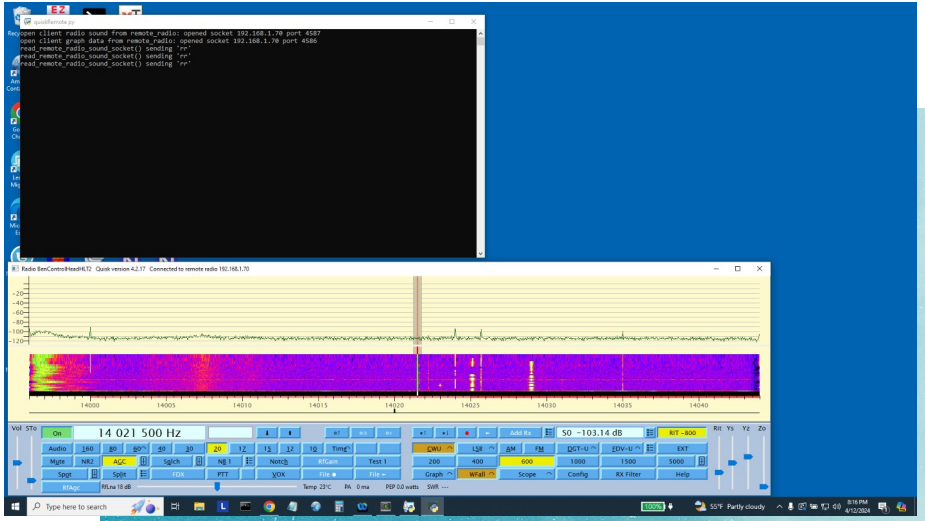
- Quisk Software Transceiver:
  - Open source Python/C
  - Written/maintained by Jim Ahlstrom, N2ADR, of Stirling, NJ(!!)
  - Runs on Linux/Win/Mac
  - Named after “QSK”; I wanted that!

- I wrote Remote Control Quisk “proof of concept” software in 2021 to control my Rig-In-A-Box over local WiFi.
  - Jim added this capability to Quisk in late 2022; “now used world-wide”, mostly for internet-based remote control.

- Learning Curves:
  - Reverse-Engineer Quisk (control/display hooks)
  - Network Programming
  - (Ham) WiFi Operation (BEWARE THE SCAN!!)
  - Gain Antenna for 5 GHz WiFi (homebrew horn)
  - Raspberry Pi



Quisk on Outdoor Raspberry Pi (Remote Radio)



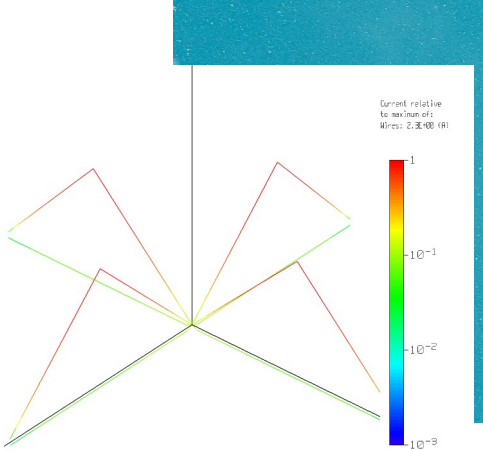
Quisk on Windows Laptop (Control Head)

Step 2: Antenna (2022)

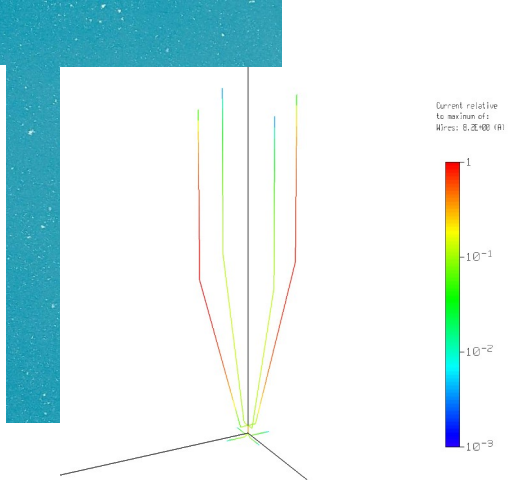
- Speculation: Could 4 symmetrical Half-wave (vertical?) Dipoles be end-fed directly from a central 4x-transceiver?
  - No coax; less picky about impedance!
  - High impedance; few/no radials needed!

- Tool: NEC5 Antenna Simulator (newer than NEC4)
  - Wrote Python code to control NEC5:
    - Search for best antenna geometry for good DX patterns, via layered iterative computing loops.
    - Display results (graphics) automatically.

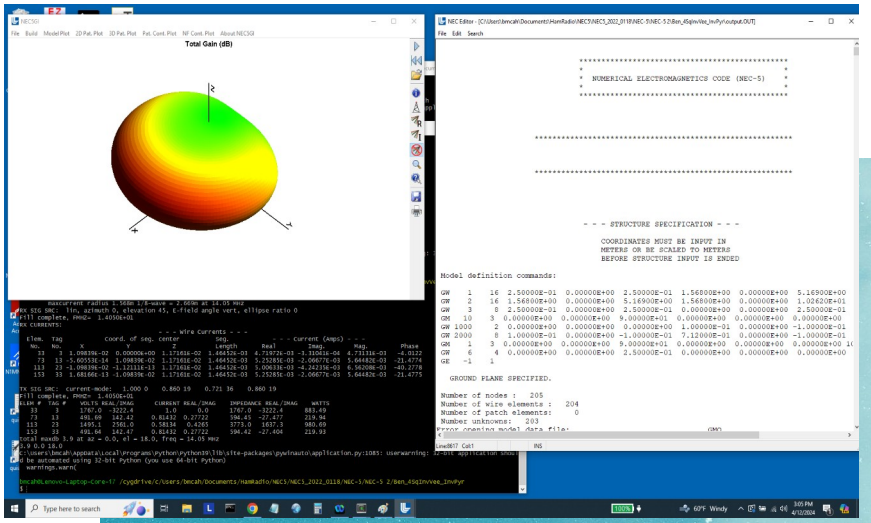
- Experiments/Results:
  - Began with 4-square of Inverted Vees, inspired by ARRL book “Antenna Physics: An Introduction”.
  - Ended up with 4-square “Inverted Rocket”; great low-takeoff-angle radiation pattern for DX!!
  - Affirmed that 4-square could be arbitrarily directed towards many more than 4 Azimuth directions!
  - Rx/Tx directional experiments showed that ***reversing*** relative phasing of 4 Rx signals, while ***maintaining*** their relative amplitudes, works well for Tx back to Rx source for Azimuth, somewhat even for Elevation!



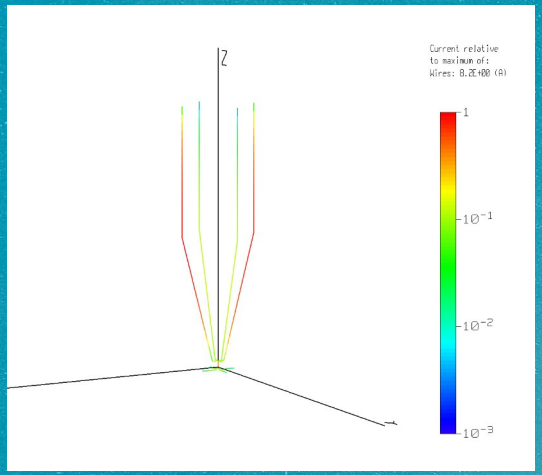
4-Sq Inverted Vee

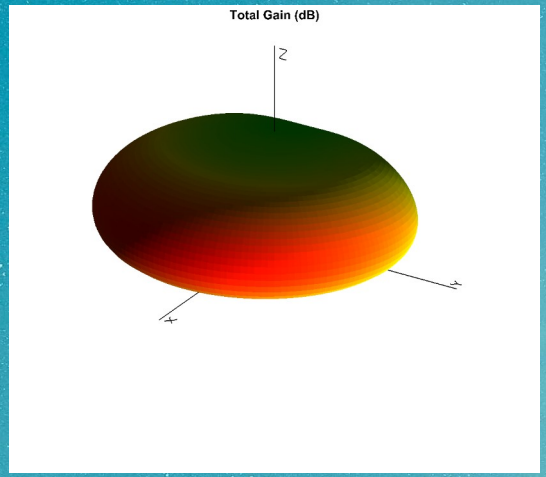


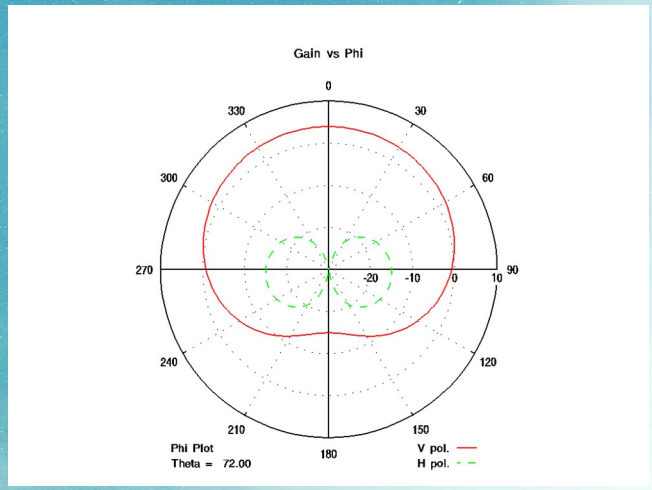
4-Sq “Inverted Rocket”

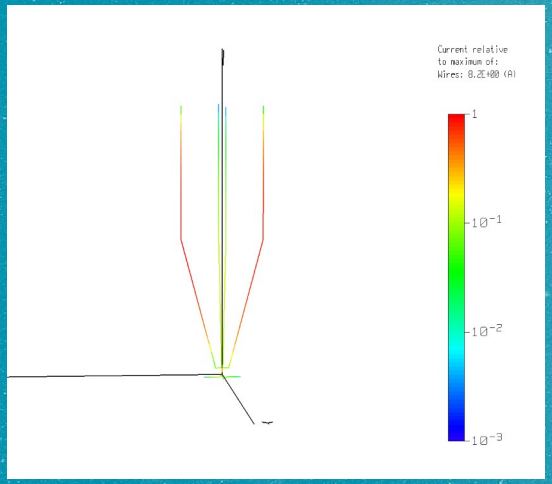


Screen Shot: NEC5 Output


Z
Current relative
to maximum of:
Wires: 8.2E+00 (A)
1
10^-1
10^-2
10^-3


Total Gain (dB)
Z
Y
X


Gain vs Phi
0
30
60
90
120
150
180
210
240
270
300
330
-20
-10
0
10
Phi Plot
Theta = 72.00
V pol.
H pol.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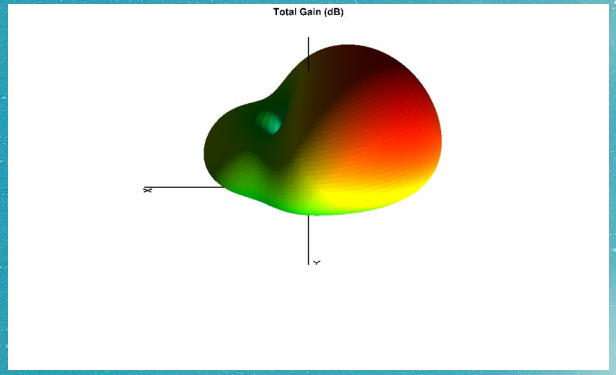
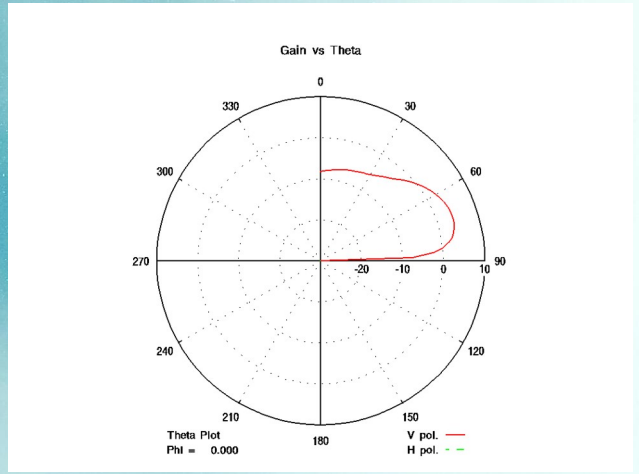
to maximum of:
Wires: 8.2E+00 (A)
1
10^-1
10^-2
10^-3


Total Gain (dB)
Z
X
Y


Gain vs Theta
0
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60
90
120
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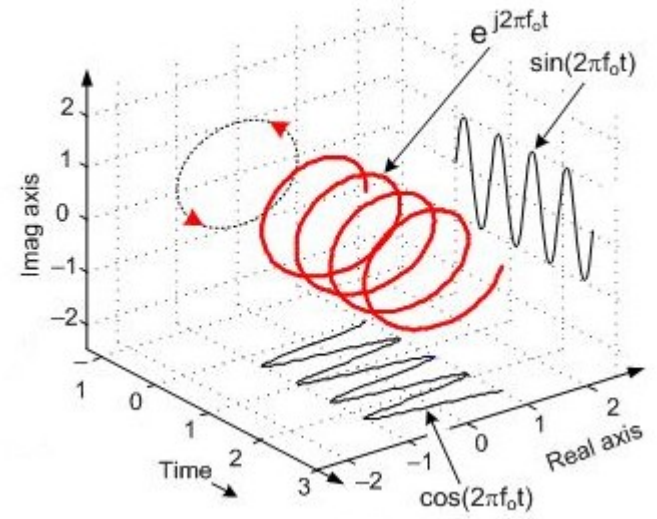
180
210
240
270
300
330
-20
-10
0
10
Theta Plot
Phi = 0.000
V pol.
H pol.

Step 3: Review/Learn (some) DSP (2022)

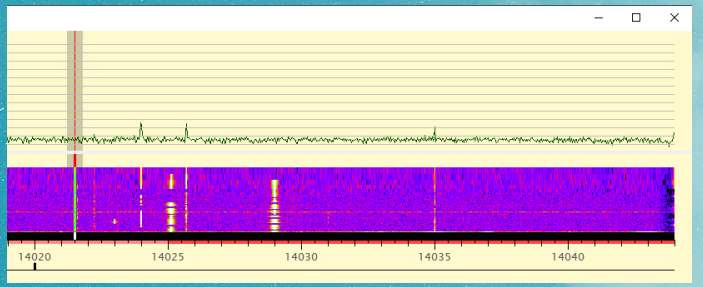
- SDR (Software Defined Radio) relies on DSP (Digital Signal Processing)!
  - "I/Q" (In-phase / Quadrature signal sampling)
  - Heterodyne (Tayloe Mixer does this in hardware)
  - Digital Filters
  - Modulation/Demodulation
  - Fast Fourier Transform (think "Waterfall Display")

- Resources:
  - Quisk source code
  - www.dspguide.com … "The Scientist's and Engineer's Guide to Digital Signal Processing"
  - www.dsprelated.com … Many great articles

- Experimented with DSP using Python code:
  - Captured some I/Q samples via Quisk
  - Played with I/Q filtering, etc., using Python's "`numpy`" and "`matplotlib.pyplot`"



The diagram that shed light on "I/Q"!



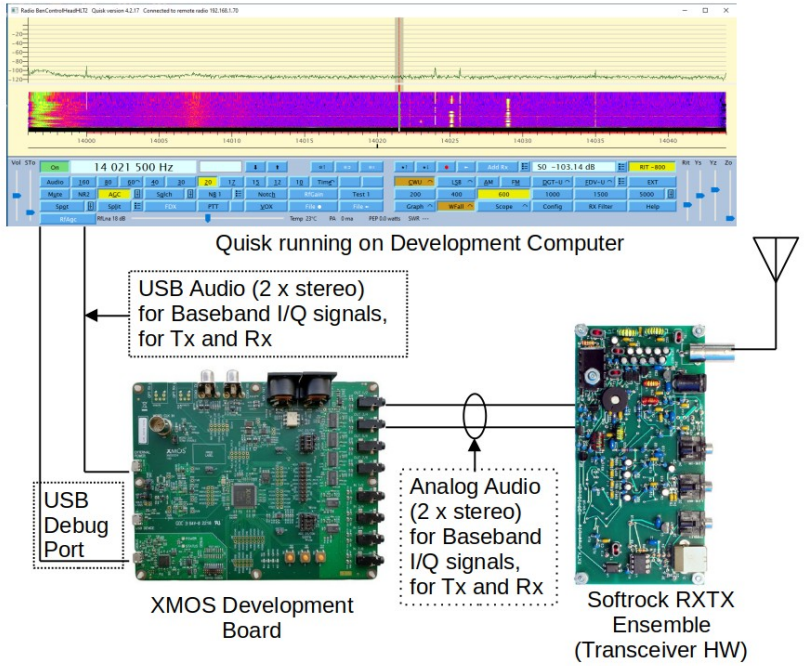
Part of Quisk Graph/Waterfall

Step 4: USB and Processor (2022/23)

- Quisk runs on a computer, and uses USB audio devices for radio signal (I/Q) input/output (I/O).
- So, 4-square transceiver hardware should ideally “look like” an audio USB interface, with some sort of additional “standard” control interface (e.g. HID).

- XMOS (Inmos Transputer legacy) makes great hardware-multi-threaded processors for USB audio:
  - Multi-channel USB audio capabilities
  - Control logic for audio Analog<->Digital Converters
  - Lots of DSP processing capability!
  - Used in many modern audio mixing consoles.

- Took me 1+1/2 Years(!) to:
  - Learn XMOS architecture
  - Learn USB architecture (oof!)
  - Learn XMOS code (C) for USB, mixing, A<->D control
  - Modify XMOS code to do Radio Rx, using Quisk and a Softrock SDR transceiver as prototype setup.

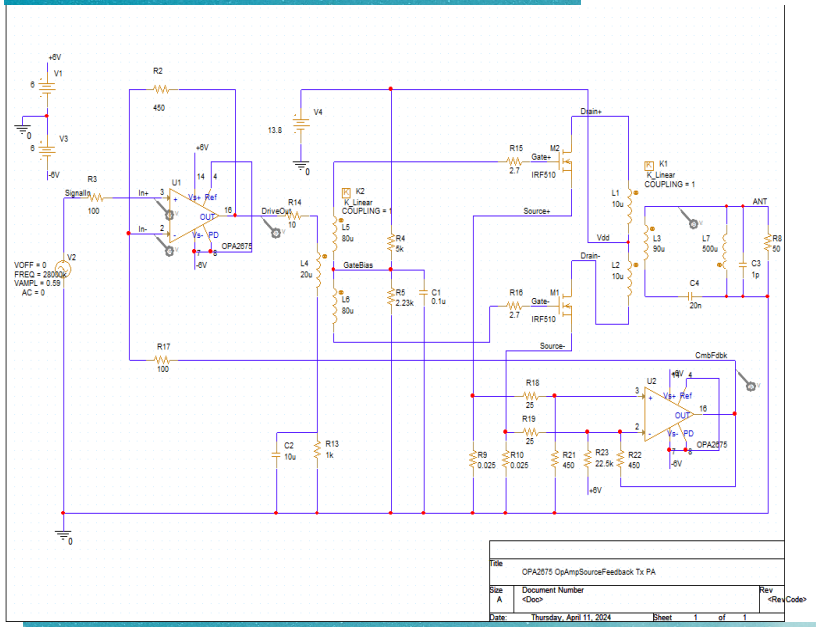


Prototype Development Setup,
with ***only 1*** transceiver/antenna.
4-square will need ***4*** transceivers/antennas!
XMOS chip will phase/combine 4 Rx sigs,
or distribute/phase 4 Tx sigs.

Step 5: Hardware Design (2024)

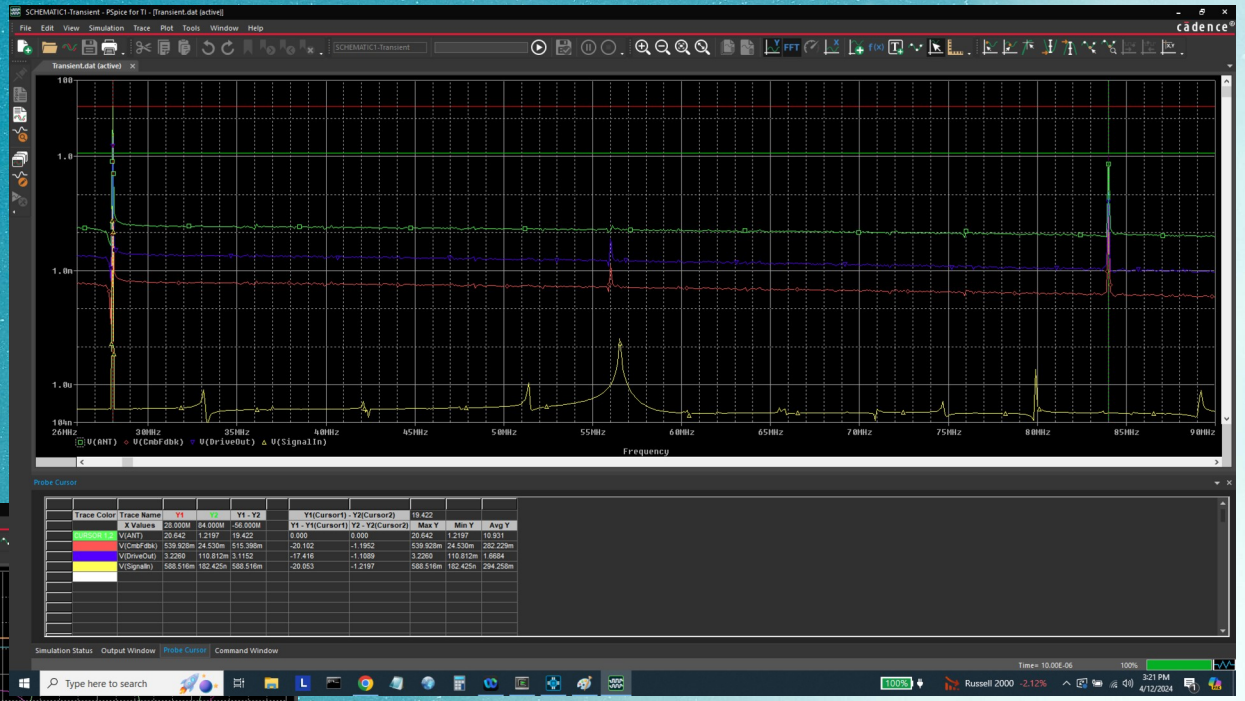
- Trying (with a few exceptions) to copy/paste as much as possible from other designs (XMOS, Softrock, Hermes Lite 2):
  - XMOS chip
  - VFO Clock chip (Si5351A)
  - 8 channels A/D (Rx I/Q), 8 channels D/A (Tx I/Q)
  - 4 Tayloe Demodulators, 4 Tayloe Modulators
    - These are really cool; intuitive for I/Q!
  - 4 (bandpass?/lowpass?) filters
  - 4 Tx Power Amplifiers
    - Trying something special with these; pre-distortion via op-amp feedback loop, to avoid output filtering!
  - Connectors

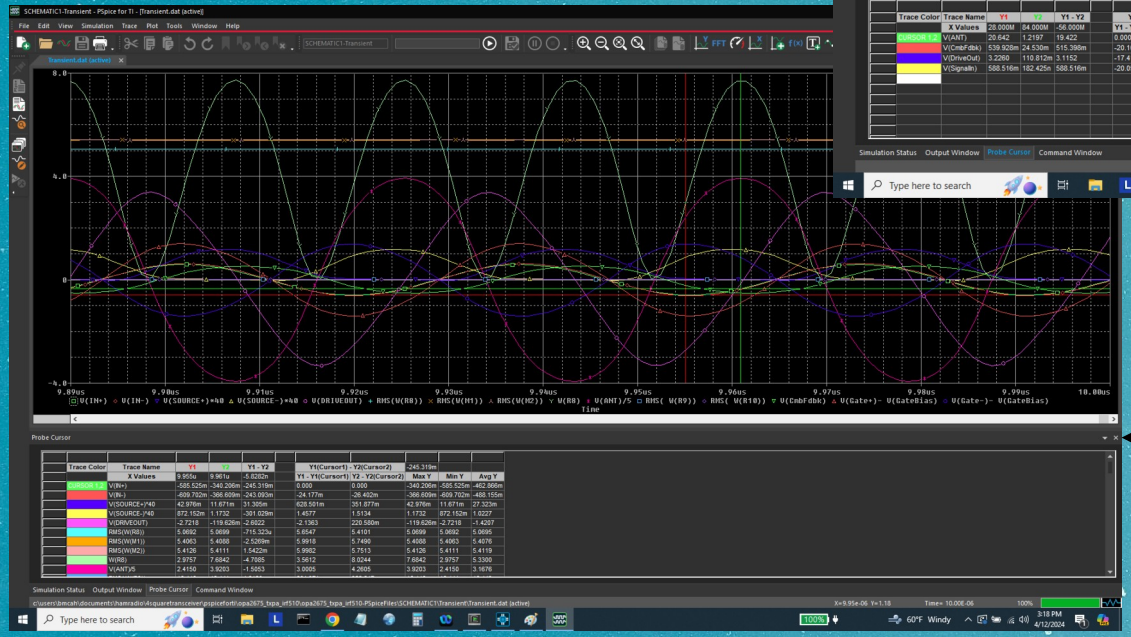
- Tools:
  - KiCad:
    - Schematic Capture
    - Circuit Board Layout
  - Pspice for TI (Texas Instruments)
    - Schematic Capture
    - Analog Simulation



Pspice Schematic for simulating one Tx Power Amplifier with op-amp feedback

Fourier Transform output of Pspice simulation of Tx PA at 28 MHz 5 Watts, showing fundamental, 2nd and 3rd harmonics. 2nd is great, but 3rd is only ~24 dB below fundamental; not good enough!





Waveform output of Pspice simulation of Tx PA at 28 MHz 5 Watts

Future Steps:

- Finish Tx PA design and simulations (faster MOSFET?)
- Finish KiCad schematics for:
  - Common/shared devices (XMOS, Clock, D/A, A/D, etc.)
  - Rx module (1x)
  - Tx module (1x); add Tx metering (SWR, temp, etc.)
- Design Circuit Board(s?)
- Buy Parts
- Assemble and Test Prototype
- Refine XMOS code (C) for Rx, write for Tx
- Develop “hardware” file for Quisk (Python)
  - Add human interface “widgets” to Quisk
- Build “real” antennas at site in woods
  - Review simulations first … Still some questions!
- Install Rig-In-A-Box (4sq-Xcvr + Rasp Pi) at site in woods
- Get WiFi link working well
- Design and install Solar/Battery power supply
- Have fun on the air!!!

- But wait, there’s more!! (there always is!!)

Wish me luck!!!!

73/72, Ben AC2YD