Technical Workshop

122 GHz
VK3CV
Transceivers

K6ML Intro, then Builders’ Roundtable
July 2020
122 GHz Radar Transceivers

- Andrew’s (VK3CV) design
- Tim’s (VK2XAX) Group Build
  - Shipped ~300 late May-June 2020 to ~130 hams worldwide
- Groups.io “The 122GProject”
  - Message List
  - Wiki
  - Original DUBUS Article & Dropbox
  - Construction and Operation Notes
  - PCB & Control Schematics
- Facebook “122 GHz and mmwave activity”
Mount + Ant + **Xcvr** + Ctrl + IF Rx

- **VK3CV Transceiver**
  - PCB = PLL + Complete Tx + Rx down conveter + IF amp
  - Choice of feed horns: Chaparral or Conical

- Need to add:
  - IF receiver (2M SSB/FM/CW), **DISABLE TX (no mic, no key)**
  - Key, Mic and/or PC “Soundcard” for desired modes
  - Dish antenna & mount
  - Power supply
  - Mode & Channel Switches
  - 1PPS GPS (or External Reference)
Packaging & Partitioning
All That Stuff

• Feed & Control Boxes
  – Radio PCB
    • At feed point
    • Minimum beam obstruction
  – Power/Controls/IF Rx
    • Under/behind dish, convenient to Op
  – Interconnect cables & remote controls

• All – in – One Box
  – Dishless rig or beacon
  – FM Handie-Talkies
  – Or behind a PF or Cass dish

• Let’s look at needed controls & I/Os...
## Channel Pairs

<table>
<thead>
<tr>
<th>Pair</th>
<th>Ch</th>
<th>Hex</th>
<th>8</th>
<th>4</th>
<th>2</th>
<th>A/B</th>
<th>Tx/Rx* Freq</th>
<th>Rx LO*</th>
<th>IF</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>A</td>
<td>0</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>122500.400</td>
<td>122356.000</td>
<td>+144.400</td>
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<tr>
<td></td>
<td>B</td>
<td>1</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>122356.000</td>
<td>122500.400</td>
<td>-144.400</td>
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<tr>
<td>2</td>
<td>A</td>
<td>2</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
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<td>122394.2004</td>
<td>-144.1005</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>122394.2004</td>
<td>122250.0999</td>
<td>+144.1005</td>
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<td>O</td>
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<td>O</td>
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<td>-144.2428</td>
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<tr>
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<td>B</td>
<td>5</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>122394.4828</td>
<td>122250.240</td>
<td>+144.2428</td>
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<tr>
<td>6</td>
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<td>O</td>
<td>O</td>
<td>O</td>
<td>122400.000</td>
<td>122256.000</td>
<td>+144.000</td>
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<td>B</td>
<td>7</td>
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<td>O</td>
<td>O</td>
<td>X</td>
<td>122256.000</td>
<td>122400.000</td>
<td>-144.000</td>
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<td>8</td>
<td>A</td>
<td>8</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>122950.000</td>
<td>122805.600</td>
<td>+144.400</td>
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<td>B</td>
<td>9</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>X</td>
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<tr>
<td>10</td>
<td>A</td>
<td>A</td>
<td>X</td>
<td>O</td>
<td>X</td>
<td>O</td>
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<td>122356.000</td>
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<td>B</td>
<td>X</td>
<td>O</td>
<td>X</td>
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<td>122500.400</td>
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<td>X</td>
<td>O</td>
<td>X</td>
<td>122356.000</td>
<td>122500.400</td>
<td>-144.400</td>
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<tr>
<td>14</td>
<td>A</td>
<td>E</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>O</td>
<td>User defined pair</td>
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<td></td>
<td>B</td>
<td>F</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>User defined pair</td>
<td>User defined pair</td>
<td>User defined pair</td>
</tr>
</tbody>
</table>

The original firmware has channel pairs 0 thru 6 as listed and pairs 8 thru 14 are just copies of pair 0.

* Tx & Rx on same freq and Rx LO at other half of pair, except for duplex mode (Rx LO = Tx freq; Rx Freq is other half of pair). Channel 0A (pair 0, A/B = open or hex switch = 0) is the highest frequency (lowest O₂ loss) & recommended.

**Andrew’s new firmware supports RS-232 entry and EEPROM storage of a user defined frequencies in pair 14.** I’m also suggesting that pair 8 (a new standard pair at the top end of the band) be added (even lower O₂ loss).

Positive IF freq = low side LO & USB mixing; negative is reverse. This affects digital modes and image reject hybrids. Might want to wire an 8 position rotary switch (0,2,4,...,14) plus A/B toggle switch to remote the hex switch; set hex = 0.
## Operating Modes / Controls

O = open, X = grounded

<table>
<thead>
<tr>
<th>Mode</th>
<th>T/R</th>
<th>PTT_IN</th>
<th>KEY_IN</th>
<th>Chan A/B</th>
<th>IF Rx</th>
<th>I/O</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OOK CW</strong></td>
<td>Rx</td>
<td>O</td>
<td>O</td>
<td>O = A</td>
<td>CW</td>
<td>CW</td>
</tr>
<tr>
<td></td>
<td>Tx</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ear = sidetone out Rx audio from IF Rx</td>
</tr>
<tr>
<td><strong>FM Tone CW</strong></td>
<td>Rx</td>
<td>O</td>
<td>O</td>
<td>X = B</td>
<td>FM</td>
<td>FM</td>
</tr>
<tr>
<td></td>
<td>Tx</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ear = sidetone out Rx audio from IF Rx</td>
</tr>
<tr>
<td><strong>FM Voice</strong></td>
<td>Duplex</td>
<td>X</td>
<td>O</td>
<td>O = A</td>
<td>FM</td>
<td>FM</td>
</tr>
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<td></td>
<td>(1st radio Tx A/Rx B)</td>
<td></td>
<td>Mic → Mic in Rx audio from IF Rx</td>
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<td></td>
<td></td>
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<td></td>
<td>X = B</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>(2nd radio Tx B/Rx A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Q&amp;D Digital</strong></td>
<td>Rx</td>
<td>O</td>
<td>O</td>
<td>O = A or X = B</td>
<td>USB</td>
<td>Simplex (PTT) Mic → Mic in Rx audio from IF Rx</td>
</tr>
<tr>
<td></td>
<td>Tx</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td><strong>OOK CW Beacon</strong></td>
<td>Tx</td>
<td>X</td>
<td></td>
<td>O = A</td>
<td>n/a</td>
<td>Beacon Tx</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Ear = ID sidetone out)</td>
</tr>
<tr>
<td><strong>FM Tone Beacon</strong></td>
<td>Tx</td>
<td>X</td>
<td></td>
<td>X = B</td>
<td>n/a</td>
<td>Beacon Tx</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Ear = ID sidetone out)</td>
</tr>
</tbody>
</table>

Except for FM Duplex, transmits & listens on same frequency
Control Wiring
(schematic from groups.io wiki)

Controls and connectors

- (EAR)
- MIC
- A/B
- PTT
- KEY
- (LED+/-)
- Ch Pair
- 8 4 2
- ***OO (ext ref)

9600 N,8,1

RS IN

RS OUT

+ 12 V IN

GPS RS OUT

+ GND
Control Wiring Notes

• If two box partition (and GPS mounted at feed), how many wires?
  – Coax jack to IF Rx & shielded audio jack to mic
  – 5 minimum/essential wires: GND, +12V, A/B, PTT, KEY
  – 4 more likely wires: sidetone, ch8, ch4, ch2; really good idea to support remote chan switch
  – 2 more wires for LED (if not left to be seen on feed box)
  – 2 more if want RS-232 transceiver console (diagnostics, user def chan on the fly)
  – 1 more if want GPS RS-232 output
  – A DB15 conn can handle all, most could fit in a DB9 conn

• If GPS is used,
  – Need separate voltage regulator and 1 PPS, power & GND connected (RS-232 opt)
  – Good idea to have SPST switch on 1 PPS in: GPS out (use GPS) vs GND (don’t use GPS)

• If Ext Ref is used instead of GPS,
  – Should wire GPS 1PPS to gnd (to prevent interrupt on noise)
  – Add a coax jack to bring in 10 MHz ext ref, and (maybe) audio jack to send out modulation
  – Want clean regulated supply for ext ref

• A battery power supply is a good idea (quieter)
  – Transceiver only draws about 90 mA as shipped (220 if sub linear reg for switcher)
  – Don’t run below low voltage threshold (possible PIC loss of memory)
  – Don’t charge while power is on (same PIC issue); chg & pwr on LEDs & power switch per schem
Top Side PCB

CONTROL (UR): PTT_IN, KEY_IN
AUDIO (UR): MIC/GND, EAR/GND
IF OUT (COAX, R): IF RX
REF OUT (COAX, LR): use as REF IN if ext ref mod
GPS: use PPS/GND if GPS; don’t use PWR, RS232
DC IN: +12V & GND
CHAN PAIR, A/B: wire to back of switch, set switch to “0” (all open)

MAKE SURE ARROW IS HORIZONTAL for standard horizontal polarization!!!

MORE OPTIONS:
ICSP (LL): to program PIC FW
RS232 (TOP): TX, RX pins
IQ OUT (R): image reject mixer (3 dB more sensitive Rx) and/or different IF freq
Bottom Side PCB

MAKE SURE ARROW IS HORIZONTAL!!!

ICSP: PIC firmware programming port
GPS: -, GND, - , - , 1PPS
SMA REF1 REF2: 2 copies ref out (or ref in if ext ref mod)
VCO TP: VCO/64 test pt (phase noise, spurs, lockin)
SMA IF OUT
-- IQ – (covered by C201): image reject mixer, other IF
DC IN -/+ 12V
8 4 2 B / G = chan pair, A/B/ gnd
(wire to remote switches; set hex = 0)
DB9 : RS232 tx, rx, gnd
AUDIO: G, mic, G, ear
CONTROL: GND, PTT_IN, - , KEY_IN, -
Another key ingredient: the Antenna

**Antenna Feeds**

- Needs 4 M2-6 screws & one M2 set screw to adjust feed WG depth in combiner

*Oh, did I mention? ... MAKE SURE that ARROW IS HORIZONTAL!!!*

Adjust feed WG depth in combiner 1.2-1.8 mm above chip (max Rx sig, 2 step cavity)

**VK3CV / VK2XAX feeds:**
- **Chaparral horn:** optimum dish f/D ~ 0.5 (70 deg HPBW)
  - Good for most dishes
- **Conical horn:** optimum dish f/D ~ 2 (8.5 deg HPBW)
  - Meant for *standalone (dishless) beacon (only 23 dBi gain)*
  - Not a good match for most dishes
  - One of us has a Cassegrain with the right subreflector shape

**G4DBN custom feeds:**
- **W2IMU horn:** optimum dish f/D ~ 0.7
  - Great for many offset dishes
Dish Antennas

12” = 48/0.55, 18” = 50/0.35, 24” = 52/0.27 dBi/deg

Match feed to dish f/D

- **Prime Focus dishes usually 0.25 to 0.4 f/D** (SHF Micro is 0.6!)
  - 0.5 Chap may slightly under illuminate, but **best choice** of above; some loss of gain
    - Might be able to make a lower f/D VE4MA/Kumar feed out of hobby tubing
  - Feed from front or thru waveguide from back
  - Mount radio for minimum dish blockage (2-3%):
    - 2-3” sq facing dish, long dimension parallel to beam
  - Note vertical vane, horizontal support beam (out of beam) in example

- **Offset** (TV satellite) **dishes usually 0.5 to 0.8 f/D** (Winegard is 0.59)
  - Choose Chap or IMU, depending on your dish; either will work well
  - Feed from front, feed arm support and most of radio well out of beam
  - Mount 2x2” radio at top edge of box, so less than 1X2” beam blockage (1%)

- **Cassegrain** dishes have **curved subreflector**
  - Fed from behind the dish (or just in front of a hole at dish vertex)
  - Subreflector “magnifies” horn illumination (reduces horn f/D)
  - **Desired feed f/D will vary depending on the subreflector design**
  - A suggestion:
    - Find one with a feed designed to match the two reflectors
    - If it is a lower band (39, 76-81 Ghz) dish, the waveguide will be too large...
    - Use telescoping metric hobby tubing to run from VK3CV combiner collar (4mmOD/2mmID) to an extender WG
    - Size extender WG OD to fit inside original WG, with a 2mm ID
    - Run the WG extension out to the original feed (maybe a lens/subreflector assembly)
Mounting & Pointing

With 0.27-0.55 degree beam widths, this is like mounting and pointing a telescope...

- Need a stable mount with smooth, repeatable, fine pointing
- Need a stable tripod, too
- Need an aligned spotting scope/landmarks to point
  - Riflescope, Peak Finder app, heywhatsthat.com
- An aligned lower band radio helps a lot...
  - Example: 24 GHz is 5x less critical in Az, El and kHz, so 125x easier 😊
  - Lower path loss, stronger signals easier to find
  - With a common ref osc, can scale any freq error by 122500/24192
  - Use **sliding feed stage** or **flip mirror** to change bands without losing aim
Possible Improvements

1. Radio is OK as is (60 km QSOs already); no need to tear into it
   - A lot to be said for just getting it working as is

2. Replace 280 ppB TCXO with external 5 ppB OCXO for better temp stability?
   - GPS only has 1PPS updates, provides long term accuracy, not short term stability
     - Either way, thermally insulate your reference for better temp stability
   - TCXO OK for FM, maybe CW, QSOs; more stability helps WS CW & digital QSOs
     - Can use GPS to find freq, then turn off 1 PPS for slow drift/no jumps during QSO
   - Latest ext ref mod in July Construction Notes (remove r200, not c200)
   - Will need some work to restore FM
     - Restore FM audio using “V” link or by routing FM audio to similar Vtune pin on ext ref
     - Will lose FM tone CW

3. FM deviation / limiter / mic preamp?
   - Designed for electret mic modulating the TCXO
   - G4EML suggests dev adj + preamp for fuller voice modulation

4. Image Reject Hybrid?
   - VK3CV built IQ phase shifter to reject the image freq and get 3 dB better Rx NF

5. Reduce Noise & Spurs?
   - Under investigation (shared 3.3v power, RS232, sidetone, other PIC main loop activities)
   - 12V to 5V Murata switcher vs linear 7805 (efficiency vs possible noise)
Quick & Dirty WSJT using FM tones

- WSJT & other MFSK digital mode transmitters are meant to frequency shift the carrier just a few Hz (ppt), which is difficult at this high freq (but I’m working on it).
- **Meanwhile, here is an easy ‘cheat’... use FM audio tone modulation to produce a carrier + multiple sidebands**
  - The cost: wasted Tx power & spectrum
- Connect 1st PC sound output to FM audio input of 1st (Tx) radio and use **FM voice mode** to FM tone modulate carrier
  - Or, if using ext ref, connect directly thru a blocking cap (2-4 kHz HPF) to Vtune pin of OCXO
- Connect 2nd PC sound input to audio output from IF Rx of 2nd (Rx) radio, running in **USB mode**. Tune to carrier freq & use WSJT spectrum display.
- Choose a mode with tone spacing wider than your typical reference carrier drift rate (as seen on Rx spectrum), perhaps JT4D (38 Hz / 1min) or maybe FT4 (21 Hz / 15 sec).
  - If your ref is stable you may be able to work down to progressively narrower spacings (JT4C, JT65C, QRA64C, FT8 .. QRA64A); if not, you may have to go to wider spacings (JT5E, JT4F, JT4G)
- Choose a low Tx base audio frequency (400-500 Hz), but higher than the bandwidth of the selected mode (so 1st & 2nd sidebands don’t overlap)
- Enable Tx message sending. **Adjust the Tx PC sound output level to maximize the first upper sideband** of message
  - At zero sound level, only the carrier will be visible and full power
  - As the sound level is increased, the first upper and lower sidebands (spaced above and below the a carrier by the Tx audio base freq) will start to grow as the carrier starts to fall

- Maximum 1st USB/LSB signal will occur when the carrier and 2nd USB/LSB are approximately equal, but weaker than the 1st USB/LSB.
- The Rx PC should decode the first upper sideband signal; it will not decode any other signals.
coming soon …

Mt Allison Beacon
CM97bl59

OCXO external ref, linear regulators
VK3CV board
Tedlar tape over Chaparral feed
-48V to +12V DC-DC inverter

122400.000 GHz (Ch “6A”), CW ID
70 degree beam width aimed ~SW
Approximately 1 milliwatt EIRP

Expect about 10-15 km range to a rough focused 12” dish (Alviso Marina)
Maybe 25-40 km to a well tuned 2’ dish (Cupertino hills, Stanford, Skyline Dr)
VK3CV Builder’s Roundtable

• Please introduce yourself
• Show & Tell Us what you’ve done/are doing
• Questions, answers and comments
Roundtable

• Introduce yourself

• What’s new?
  – Projects
  – Contacts (DX, Contests, EME, other activity)
  – 10 Ghz and Up contest in the COVID era?
  – Activity Days for microwaves, mmwaves?
  – Feedback on meetings/nets