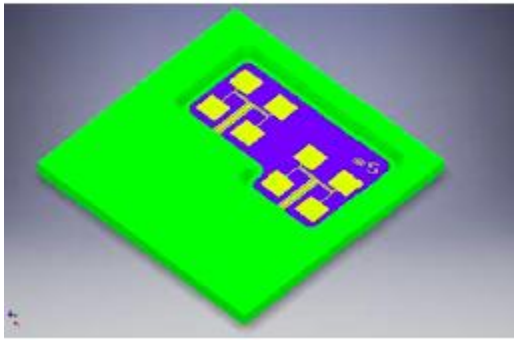
A Simpler 122 GHz Transceiver

Using the Silicon Radar TRX120 Chip



Mike Lavelle, K6ML

Microwave Update 2017

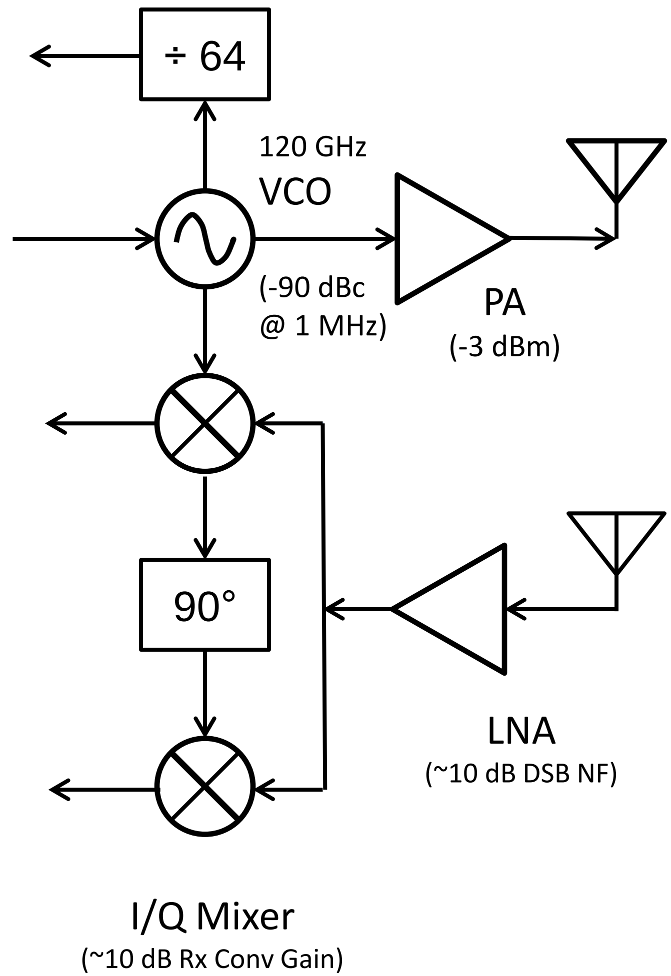
A New Way to Get on 122 GHz

- Hams have been getting on 122 GHz band using
  - diode multipliers and diode mixers
  - mounted in waveguide
  - with long frequency multiplier chains for the local oscillator.
- Perhaps there is an ‘easier’ way that could open up the band to more activity…
- Companies like Silicon Radar are now making low cost millimeter wave radar sensors for automotive, consumer and industrial applications…
  - Liquid level, tool depth and elevator shaft sensing
  - Target range and speed sensing (drones, bikes, golfers)

- TRX120 (and TRX024) ISM band radar sensors
  - SiGe microwave monolithic integrated circuit (MMIC)
  - FMCW chirp or CW Doppler radar
  - Homodyne architecture with some modern upgrades

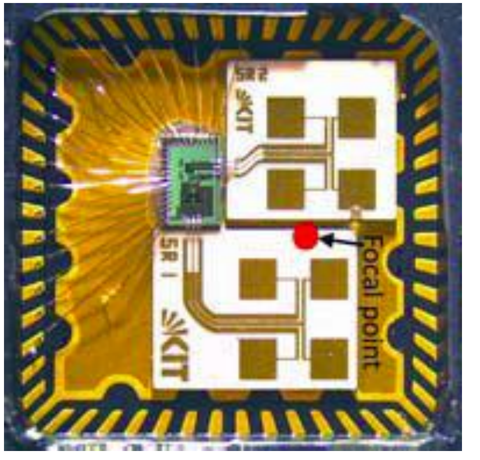
Silicon Radar TRX120 MMIC

- Lockable 120 GHz Local Oscillator
  - Coarse and fine voltage tuning
    - 3200, 1600, 800, 400 MHz/V
  - -90 dBc @ 1 MHz PN
- div64 PLL prescaler
  - 1.9 GHz to PLL
- Tx PA
  - 0.5 mW typ
- Rx LNA
  - ~10 dB DSB NF
- Phased IQ mixers
  - ~10 dB total RX Conversion Gain
  - IQ signal processing or image rejection
- DC-200 MHz IF out



But, wait … that’s not all …

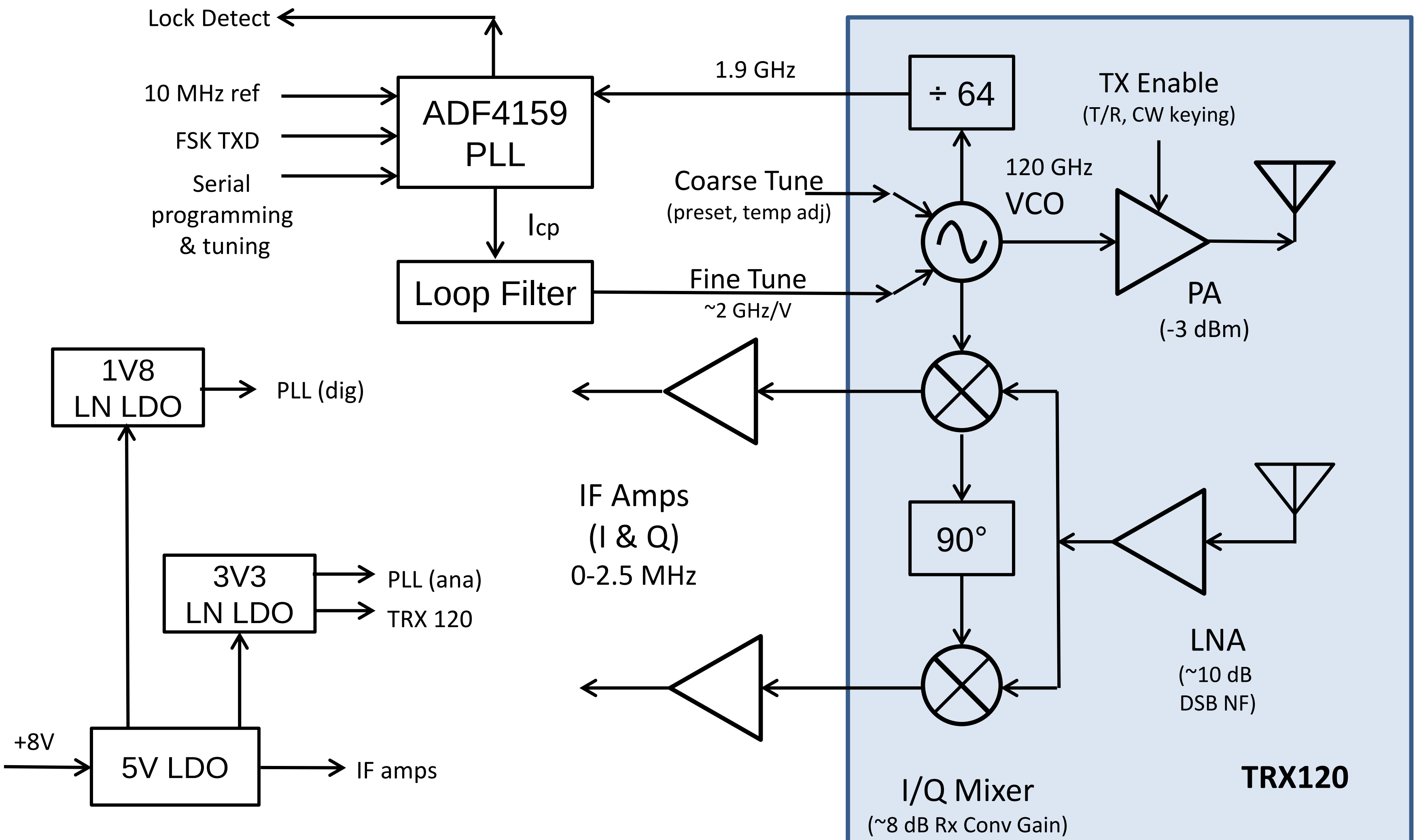
- 8x8mm QFN package includes dual internal Tx and Rx antennas
  - Each is a 2 x 2 array of patches on Rogers substrates
    - ~10 dBi gain
    - 65% efficient
    - > 20 dB return loss
    - > 35 dB Tx – Rx isolation



  - Can use barefoot, or place at the focal point of a lens or dish for higher gains
- This means that only 2 pins operate at more than tens of MHz
  - The div64 outputs are at 1.9 GHz
  - Can lay out a simple small FR4 PCB
  - Limited RF skills required: PLL and dish antenna design

122 GHz Front End PCB Design

Add PLL, IF Amp and Regulators



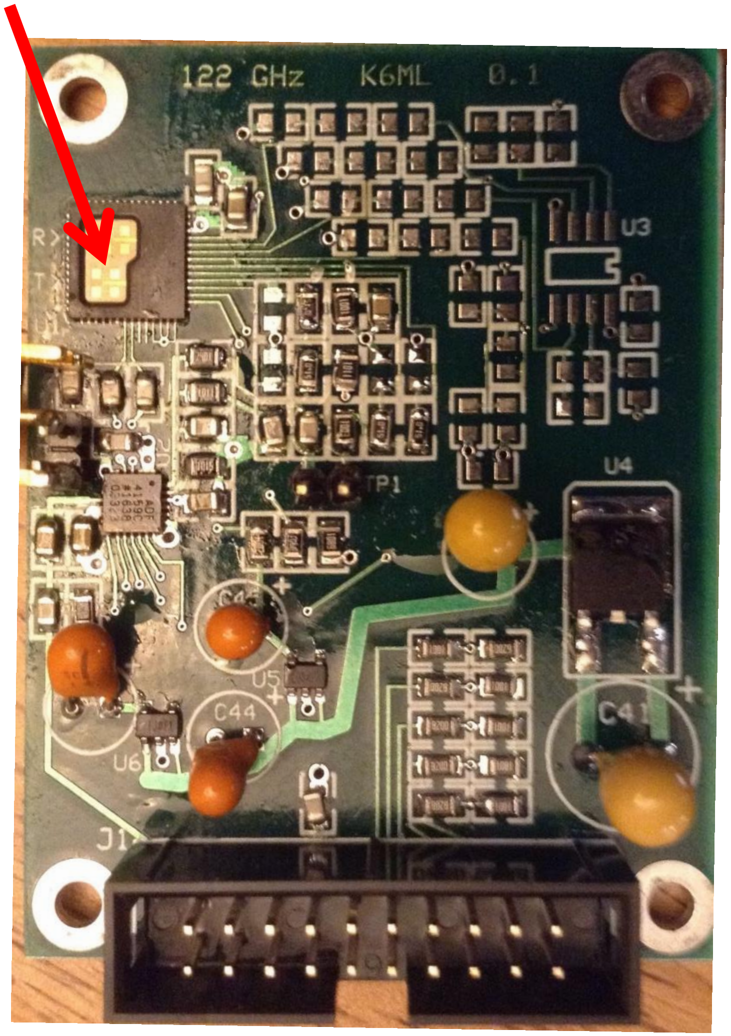
122 GHz Front End PCB

To be mounted at Dish Focal Point

TRX120 Rx Ant
Tx Ant

ADF4159 PLL
& Loop Filter

1v8, 3v3
Low Noise
LDOs



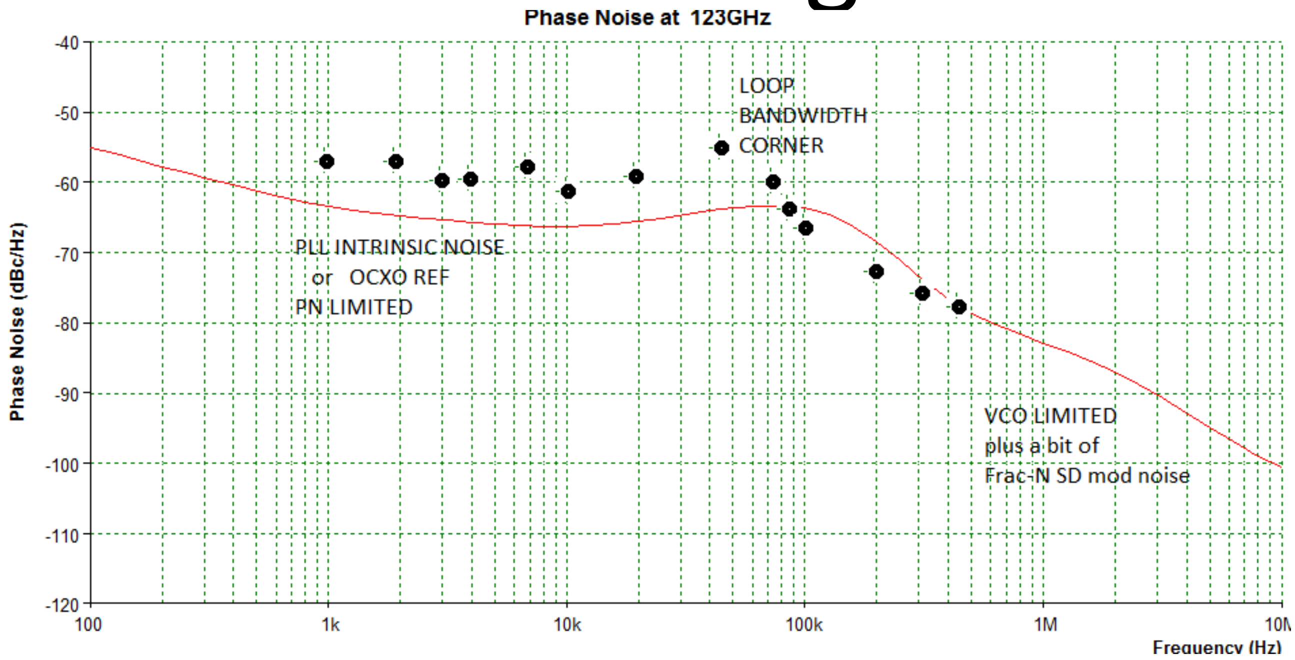
LT6231 IF Amp

5V LDO

Serial Bus
Level Shifters

The PCB layout uses 1.9” x 2.5”, one half of an ExpressPCB “MiniBoard”

PLL Design



- Frac-N PLL provides radio tuner (38 Hz steps) & mFSK deviations as small as 38 Hz
  - Supports FSK and PSK, as well FMCW chirp radar
- ~100 kHz loop bandwidth filters out LF VCO PN and allows ~20 kbaud max FSK
- Built 3 boards so far
- One board had serious (~1 GHz) VCO center freq. drift during (~2 minute) chip warmup
  - Similar shifts with temp (cold mountaintop vs hot valley), according to latest data sheet
  - Find best tradeoff of coarse (preset, temp) and fine (PLL loop lock range) gains
  - Add a digital pot for coarse preset to allow lower VCO gain? (lower PN?)

Tx Modulation

- Does not support AM, SSB
  - There is a Tx enable pin which might be used for CW OOK or T/R
- So we are left with angle modulation
  - FM Audio Modulate the PLL Reference for NBFM
  - PLL FSK data pin supports
    - FSK CW
    - BFSK RTTY/data
    - BPSK
  - PLL serial interface can support slow MFSK modes
    - JT, FT modes
    - Domino, etc

Duplex vs Simplex

- Full Duplex “SiGePlexer”
  - Along the lines of the venerable Gunnplexer:
  - Can talk and listen at same time
  - **Station A: LO at F, transmits at F, listens at F+IF**

    vvvvvvvvvvvvvvvvv ^^^^^^^^^^^^^^^^^^^^^^^^^^
  - **Station B: LO at F+IF, listens at F, transmits at F+IF**
  - A 455 kHz or 10.7 MHz FM IF strip/chip could hook up directly to RX IF out

- Simplex
  - Tx enable pin (probably) supports simplex T/R
  - When T/R switching, shift PLL/VCO frequency up by the IF frequency
  - Lower desense floor should enable better DX
  - Current efforts are simplex

Receiver IF

- TRX120 has DC – 200 MHz I and Q IF Outputs
- LT6231 dual low noise op amp has 215 MHz GBW product
- Direct conversion (zero IF) often has problems with LO leakage and with local reflections … ***Doppler shift at 122 GHz is 370 Hz per mph***
- So, decided to use a 2.5 MHz IF
  - Avoids Doppler up to 6750 mph (nothing moves that fast nearby)
  - Gets away from Tx carrier PN and leakage
- Just connect I or Q amp output to any old HF QRP receiver

  ---OR---
- Add a 2.5 MHz dual channel downconverter to a IQ phasing SDR

But Is It a Radio?

(Demo)

- Tx Beacon
  - Using the TRX120 10 dBi in-package antennas
  - 10 MHz OCXO and Arduino Trinket controller
    - FSK keying
    - 16 channels; 160 MHz steps
    - -3 dBm PA + 10 dBi antenna = +7 dBm EIRP

- Rx
  - Same hardware plus a FT-817 as 2.5 MHz IF
  - -174 dBm + 10 dB (DSB NF) + 3 dB (SSB) + 34 dB (2.7 kHz) -10 dBi (ant)

    = -137 dBm MDS

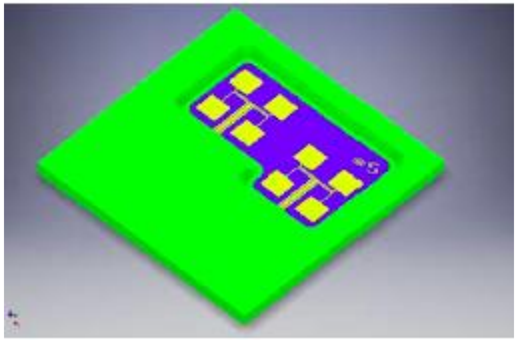
But Is It a Radio?

(Field Tests)

- Range with the 10 dBi antennas
  - +7 – (-137) = +144 dB system gain (pre-detector)
  - 1 km: 135 dB path loss works easily, calc. det. S/N +9 dB
  - 2.1 km: 143 dB path loss works, calc. det. S/N +1 dB
  - 6.5 km: 156 dB path loss not working, calc. det. S/N -12 dB

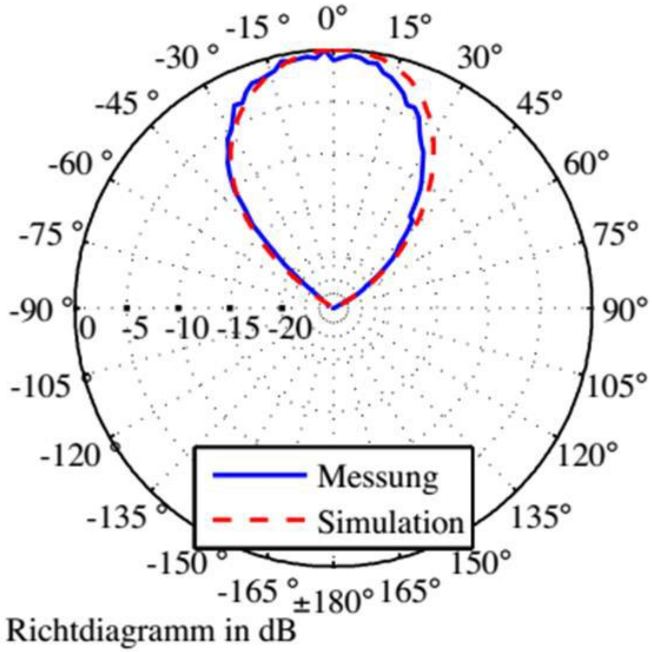
  - Observation: This is definitely a “line of sight” band
  - More gain will give more range …

TRX120 Antenna Pattern

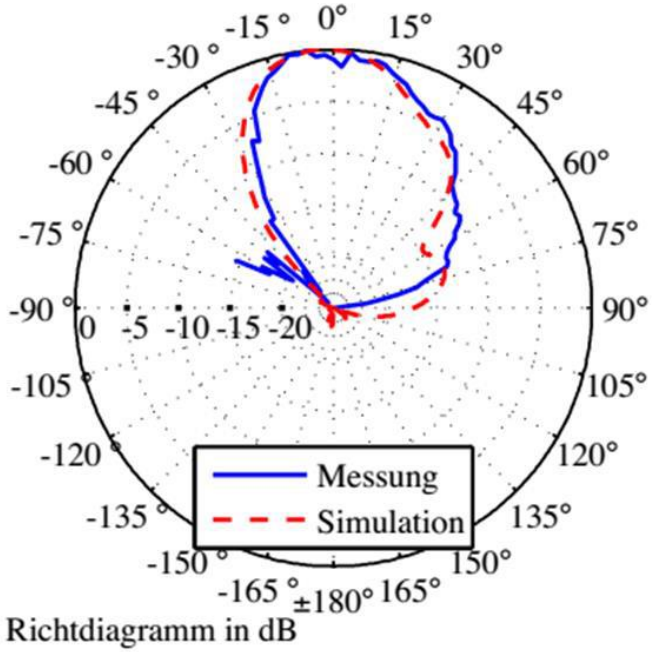


THE GOOD NEWS: Integrated antennas means highest frequency outside the package is under 2 GHz, can use ordinary PCB!
THE NOT SO GOOD NEWS: Antenna design is driven by radar sensor application, may not be an ideal dish feed
MORE NOT SO GOOD NEWS: Two antennas is one more than we need.

~10 dBi Gain, ~30-40 deg HPBW, ~80 deg dish illumination



H-Plane



E-Plane

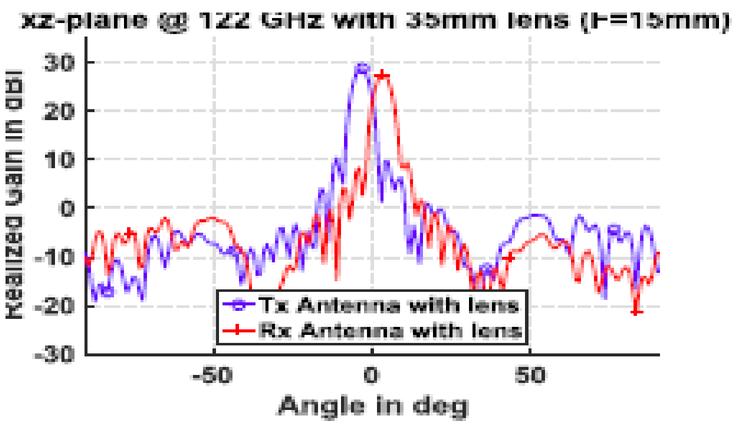
red – simulated, blue - measured

Dish Antenna Feed Considerations

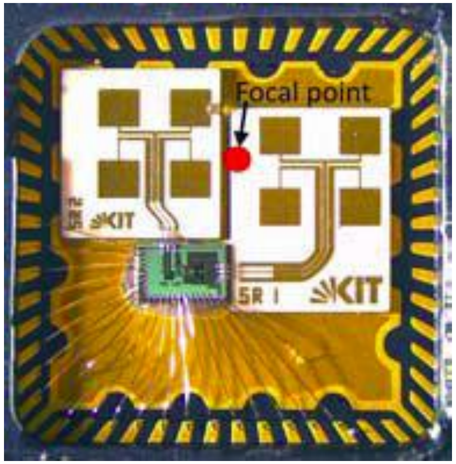
- Using the TRX120 as the dish feed
  - Slightly over-illuminates an offset dish
  - Seriously under-illuminates a prime focus dish.
  - Most offset dishes are designed for lower frequencies
  - Prime focus & Cassegrain more common at mm waves
- 12” dish has 49.8 dBi gain & 0.55 degree HPBW
  - Why? Because 1 foot is 123 wavelengths at 123 GHz
  - Assumes 123 GHz and 65% efficient feed
- 24” dish has 55.8 dBi gain & 0.27 degree HPBW
  - That’s about 45 dB more than the internal patch antennas!
  - For two rigs with 2 ft dishes, an extra 90 dB system gain

Effect of Increasing Gain on Antenna Pattern

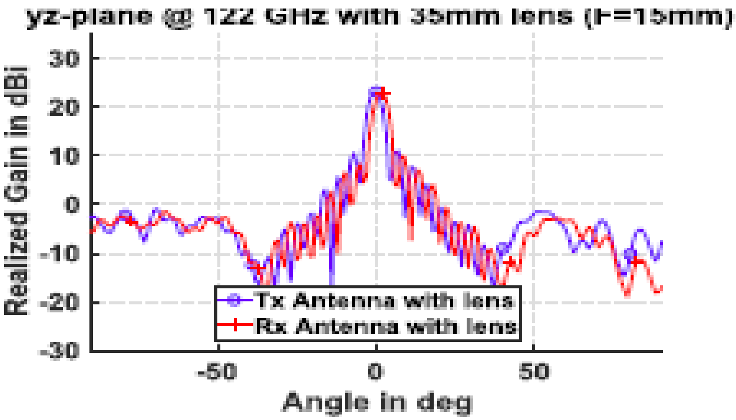
(~20 dB extra gain from a plastic lens)



(a)



Note that TX and RX beams are offset due to differing antenna sites, even for a low gain lens antenna



(b)

Dish Antenna Parallax / Beam Shift

- TX and RX antenna sites are offset by:
  ~ 3 mm (~ 1.23 wavelengths) vertically
  ~ 0.7 mm (~ 0.28 wavelengths) horizontally

- With a **high gain dish**, we can expect serious beam shifting between TX and RX:
  – Beam shifts by **one or more dish beam widths**
  – **Tx null** can even fall on **Rx peak**

- For correct pointing we need to either:
  – Move the dish (rotate and tilt), or
  – Move the feed (X-Y, *preferred solution*).

Still to Do

- Test various surplus dish antennas
  - Feed vs. F/D, feed focus, beam pattern, gain
  - Use 10 dBi beacon as antenna range source
  - *Find max range using one dish*
- T/R (and band) switching
  - Mount front end PCB on a X-Y slider stage with linear actuators to maintain focus
  - Firmware calibrates, remembers and applies feed X-Y offsets when band or T/R switching
  - *Find max range for 2 way QSOs, dishes on both ends*

More to Do: Dual Band Rig

- Add a 24 GHz front end & share the back end & dish
  - Use the slider stage to focus on either band’s front end
- Has several operational advantages:
  - Higher power & lower NF at 24 GHz using TRX024 in similar design
  - 5x easier to point the dish in both azimuth and elevation at 24 GHz
    - Don’t move the dish when switching from 24 to 122 (except for fine trimming)
  - 5x easier to establish operating frequency at 24 GHz
    - Once delta is found at 24, 122 GHz delta can be calibrated out (common reference)
  - Much lower path loss at 24 GHz
    - 24 GHz atmospheric loss at 25F dew point is ~10 dB lower per 20 km
    - 24 GHz link budget is ~30 dB better at 60 km, ~50 dB better at 100 km
  - QSY up to 122 GHz when 24 GHz path approaches S9 signals

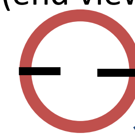
24 GHz Front End PCB

Only significant difference: TRX024 does not have on chip antenna

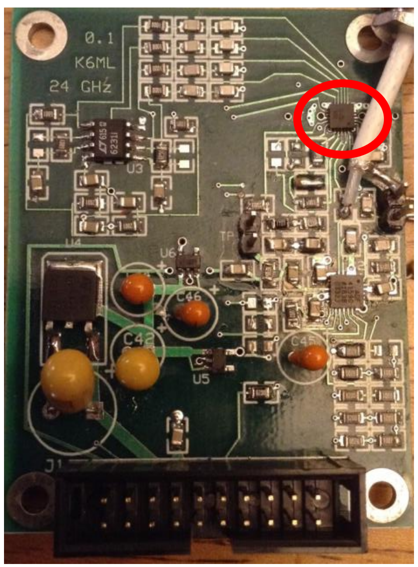
The PCB layout uses 1.9” x 2.5”, the other half of an ExpressPCB “MiniBoard”

It’s a **mirror image** of 122 FE PCB Layout, so that we can **flip it over** and then **solder on** a ½” diameter **horn antenna** with current loop coupling thru the PCB from the TRX024 Rx in and Tx out pads …

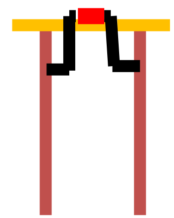
½” horn
(end view)



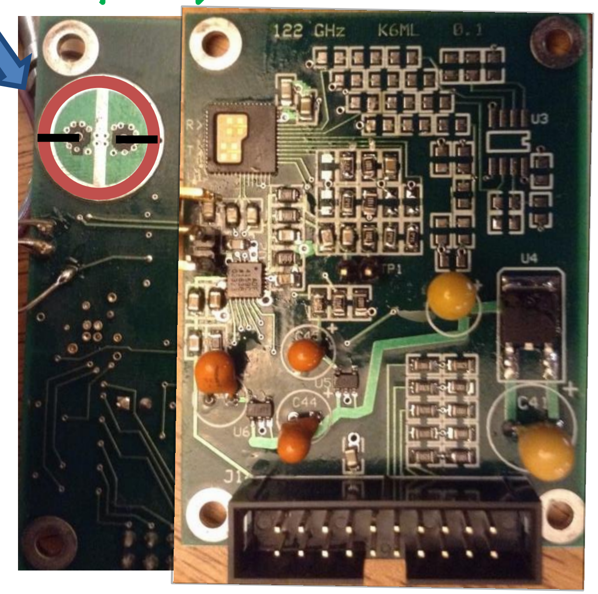
… placing the 24 FE under the 122 FE, staggered alongside, so that a small translation can slide either the 24 FE or the 122 FE antenna to the focal point to switch bands

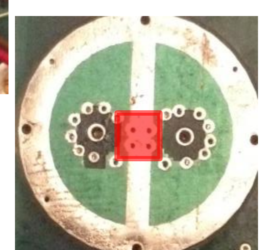


TRX024
3x3 QFN



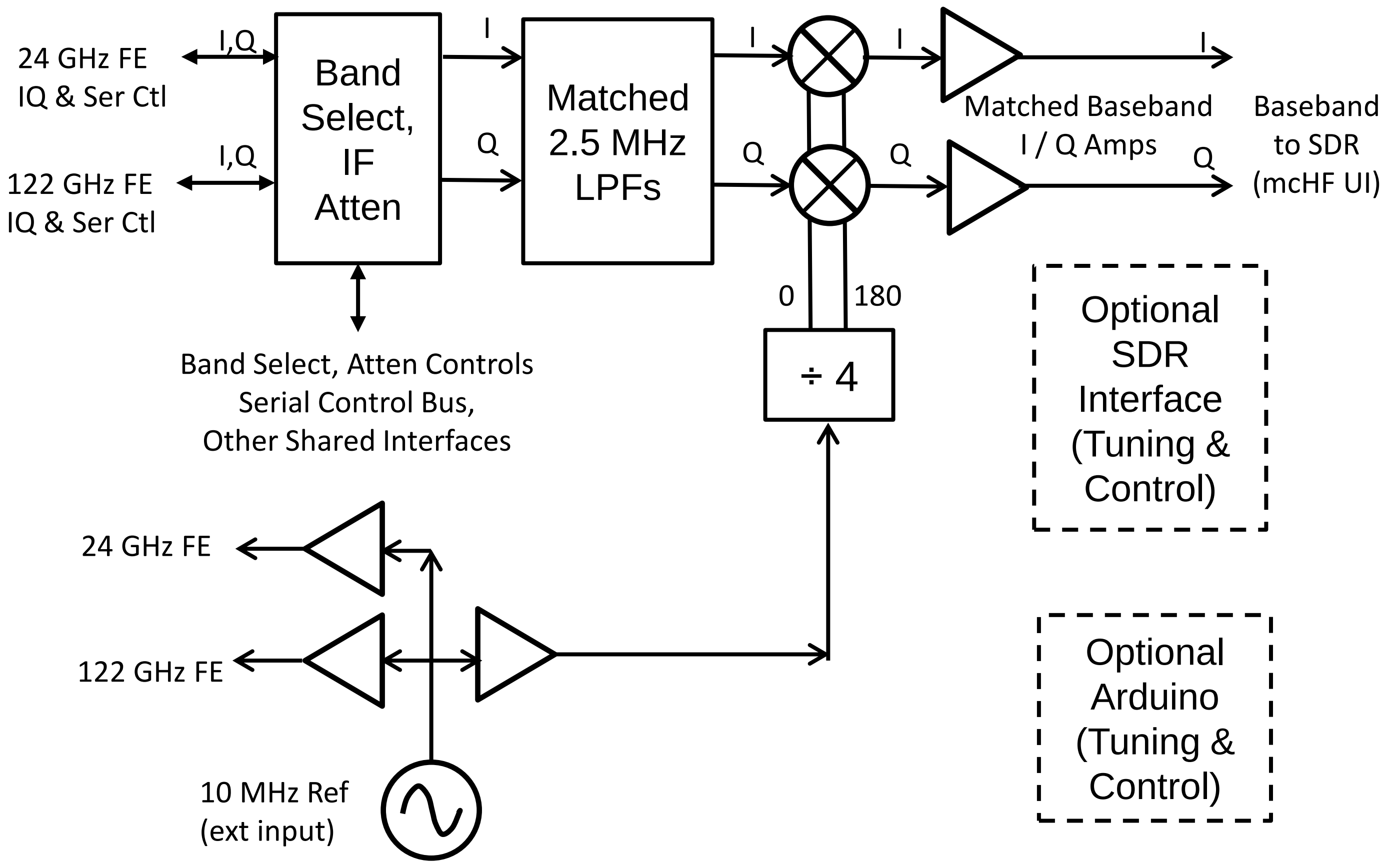
½” horn
(side view)





Common IF Board (in design)

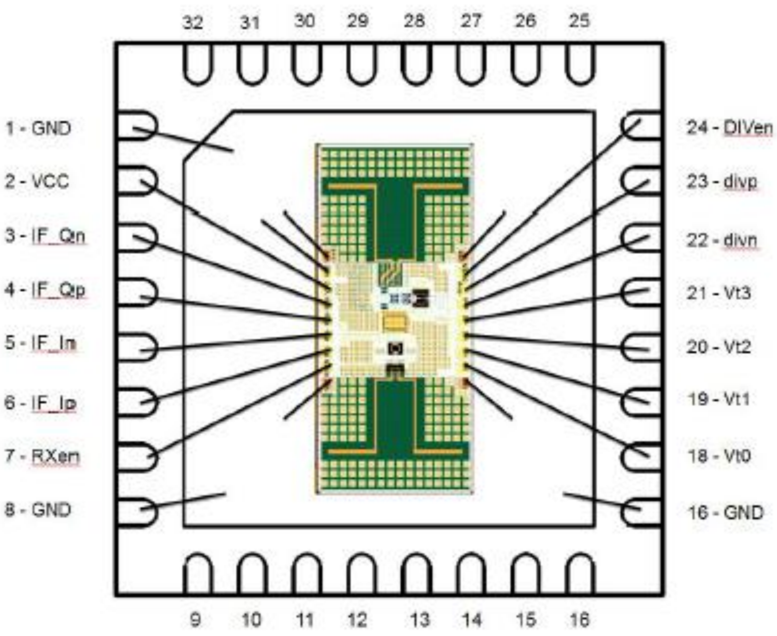
Reference buffers, band switch, downconverter



Matched LPFs, sampling downconverter and matched BB amps preserve IQ phase & amplitude so that a Weaver method SDR can be used to reject SSB image noise

Even More to Do

- Mod/Demod for FSK, MFSK modes
- Corrective optics (Cassegrain) to match feed to dish
  - see Michelle's paper
- Or try TRXA122 next gen chip?
  - Single die
  - On chip dipoles
  - Wider beam?
  - Better for prime focus dish?

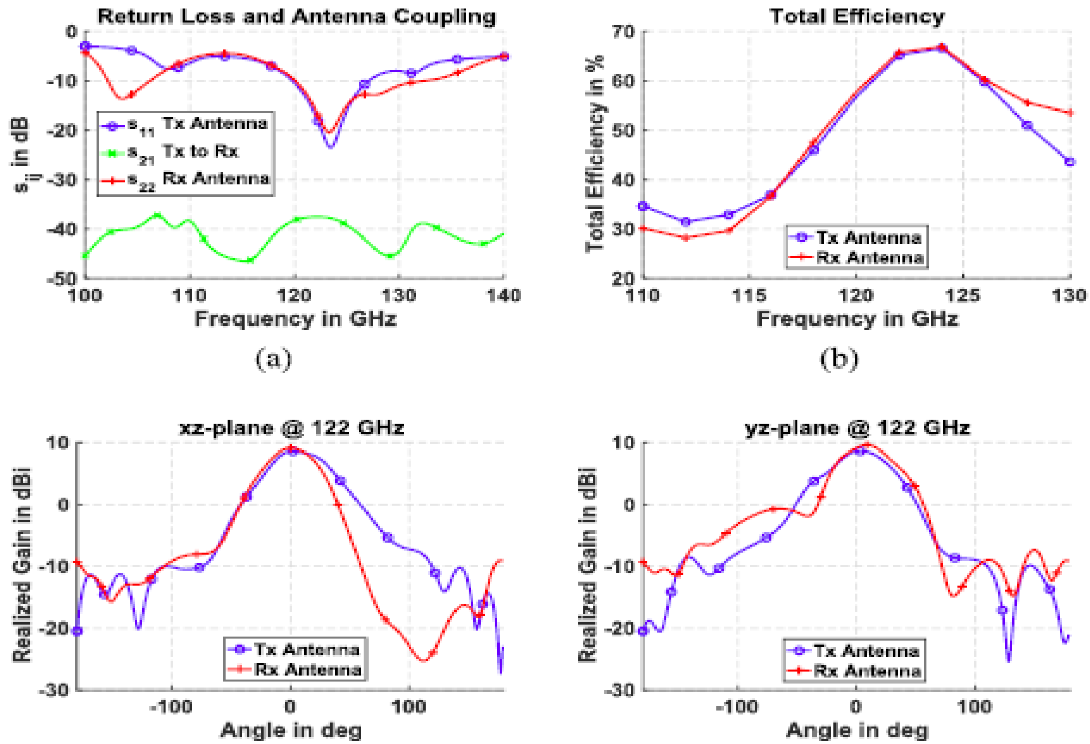


TRXA_120_02 QFN-package outline with signal indication (top view)

Thank You

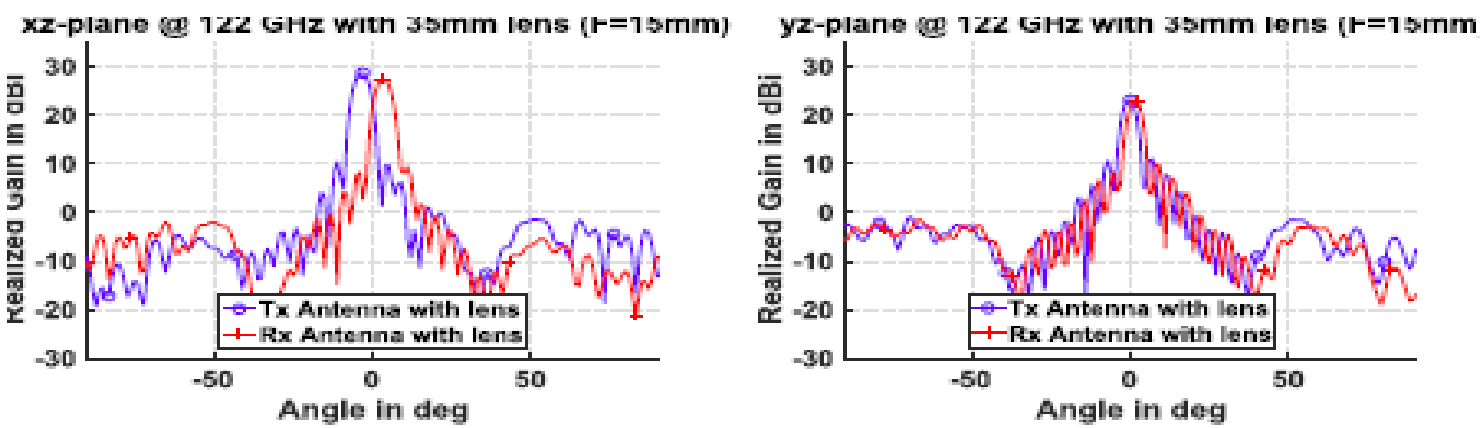
Any Questions?

TRX120 Antenna Measurements



(a) (b) (c) (d)

__Note that TX and RX beams are offset due to differing antenna sites, even for a low gain lens antenna →__



(a) (b)

24 GHz Front End PCB

Only significant difference: TRX024 does not have on chip antenna