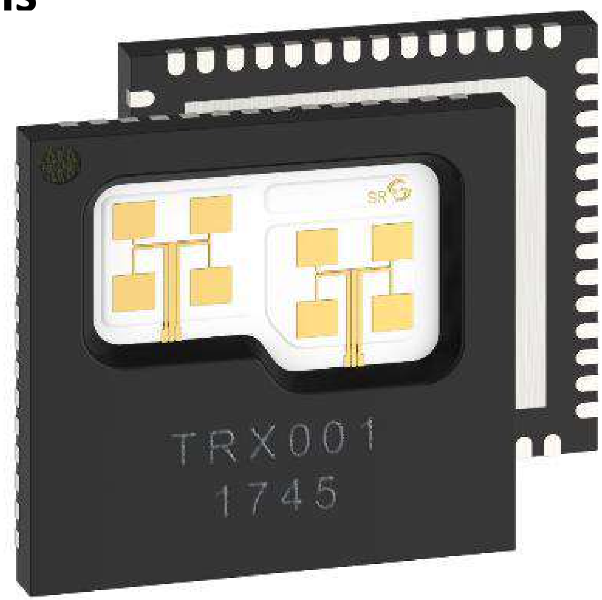
Building & Operating 122 GHz Radios

An update: What's new since BayCon 2018?

Mike Lavelle, K6ML
BayCon 2020

Silicon Radar TRX_120_001 Chip

- **Targets short range sensor applications**



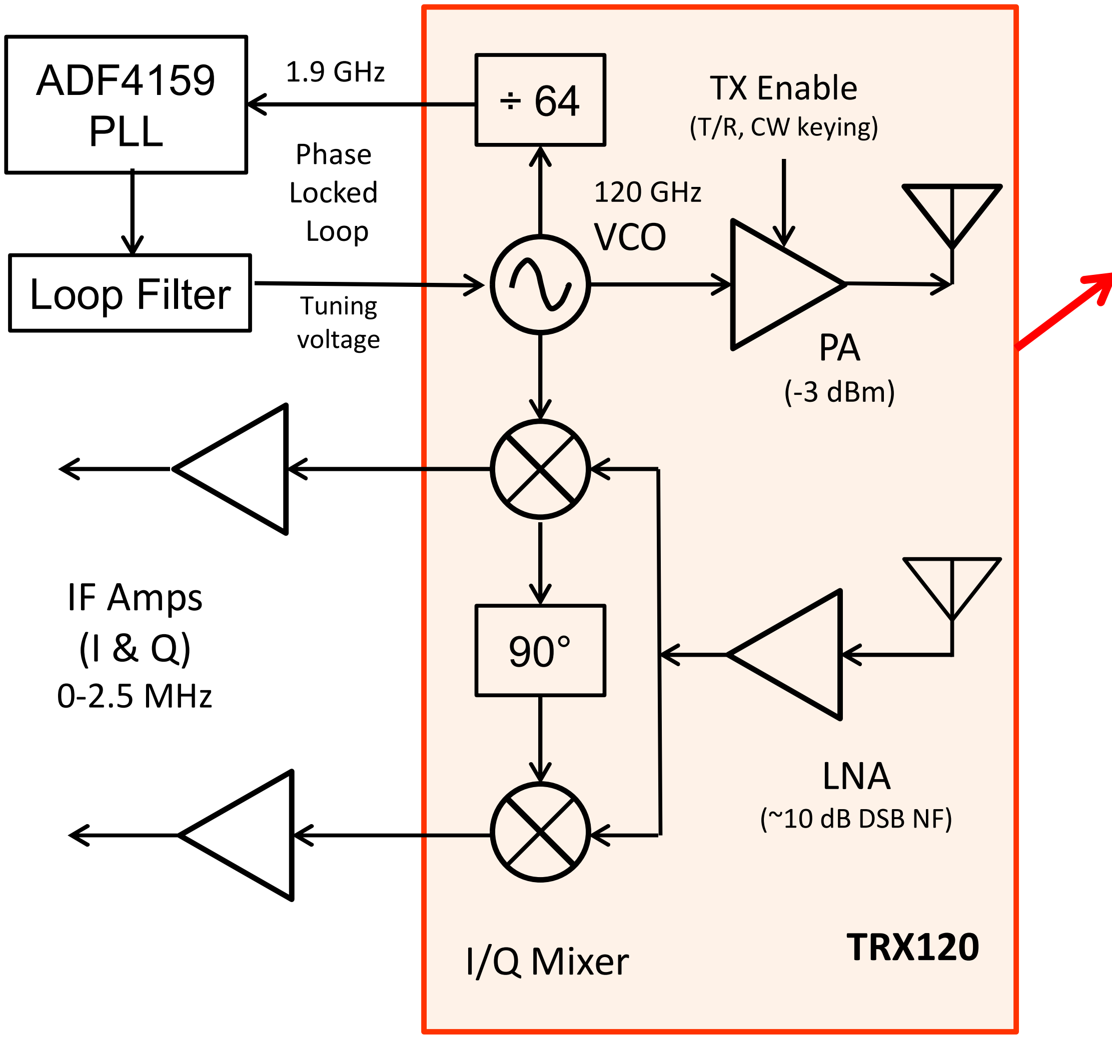
- **SiGe Technology**
- **120 GHz Oscillator**
- **0.5 mW Power Amp**
- **9 db NF Preamp**
- **Mixer to 0-200 MHz IF**

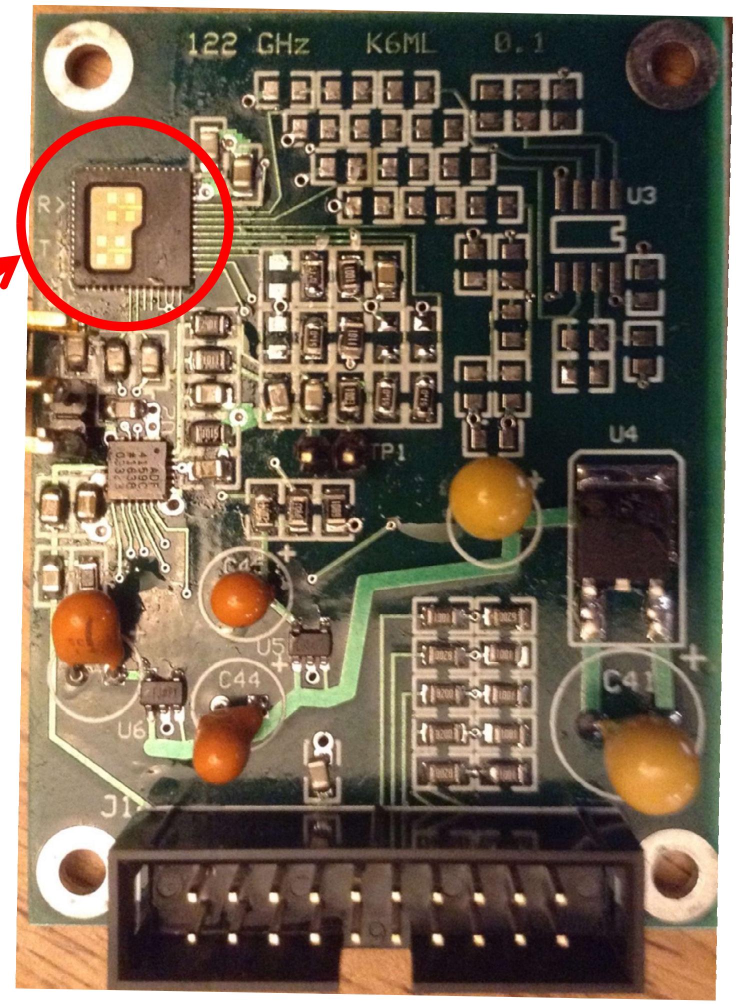
- **8x8mm QFN56 package includes internal Tx and Rx antennas**
- **Each is an array of 4 patch antennas**
- **This means no 122 GHz signal traces on my PCB**

K6ML 122 GHz Front End (2017)

Add PLL, IF Amp and Regulators

1.9”x2.5” FR4 PCB





Complete 2017 Radio

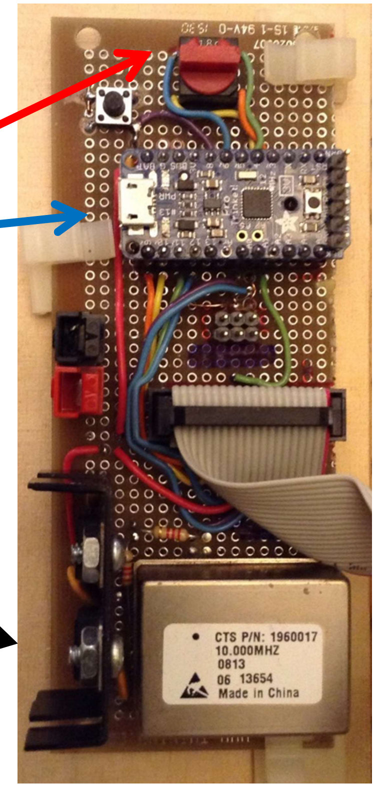
- **Tx**
  - Arduino Trinket controller
    - FSK keying for beacon
    - Tuning switch: 16 channels; 160 MHz steps
  - 10.000000 MHz ovenized crystal oscillator
  - Use the TRX120 10 dBi in-package antennas

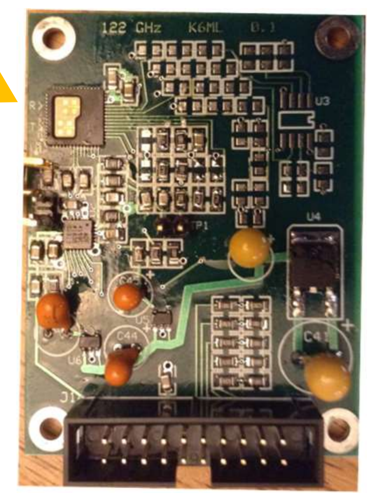
    -3 dBm PA + 9 dBi antenna = **+6 dBm EIRP**

- **Rx**
  - Same hardware plus a FT-817 or similar as 2.5 MHz IF

    -174 dBm + 12 dB (NF) + 35 dB (3 kHz) -9 dBi (ant) = **-136 dBm MDS**

- **System Gain** = 142 dB (in 3 kHz) without dishes
- **2 km max range for a pair of these radios**





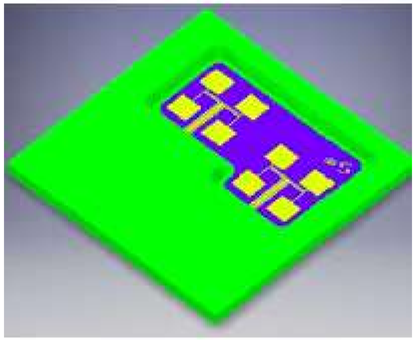
Boosting Range: Add Dish Reflector

← 150 foot Stanford Big Dish, operating at around 1 GHz

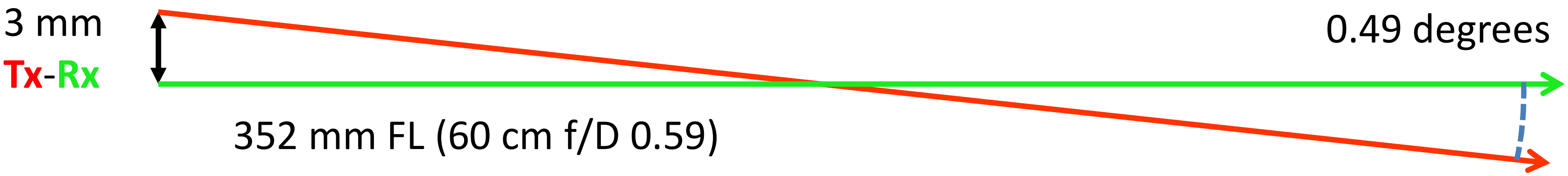
18” TV satellite dish, → operating at 122 GHz

Both have over 50 dB gain (and both have less than ½ degree beam)
Because both are about 200 wavelengths in diameter

Dish Antenna Beam Skew

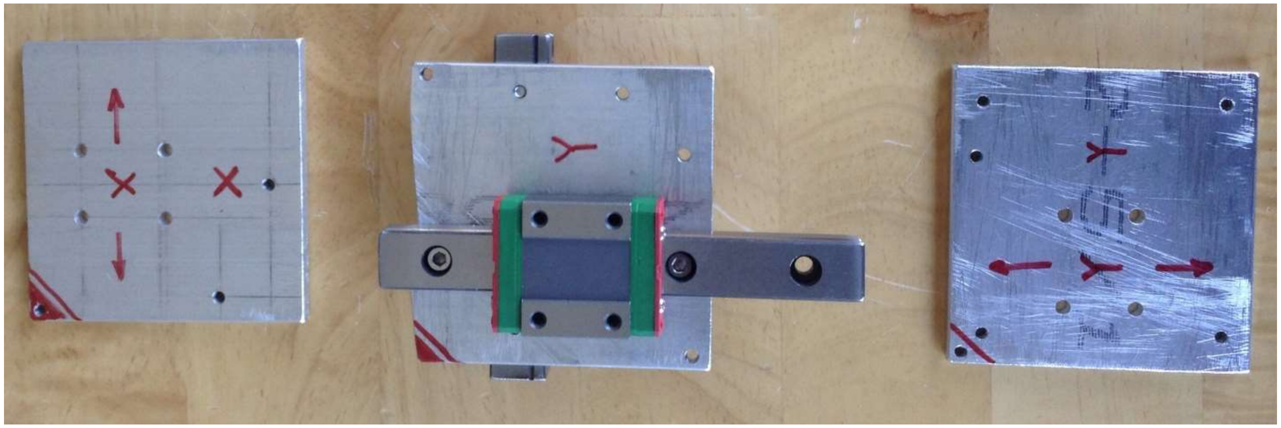


- TRX_120_001 TX and RX antenna sites are offset by:
  ~ 3 mm vertically and ~ 0.7 mm horizontally
- With **high gain** dish antenna
  - We get serious parallax between TX and RX beams
- Example: estimated beam shift is **half a degree**
  - But -3 dB half beam width is about **an eighth of a degree**
  - Tx beam is in the **first null or side lobes** of Rx pattern!!!
- I hear you, but you don't hear me



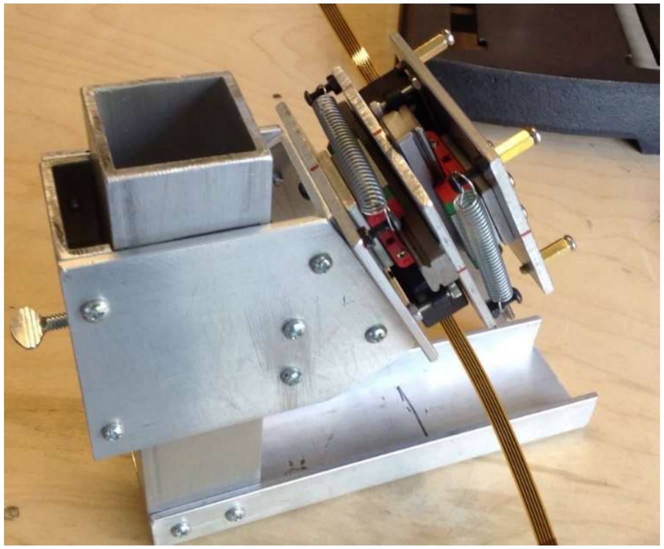
Solving TX/RX beam skew

- On every "over", linear actuators slide PCB & chip to focal point
- Supports band switching, too
- Firmware applies feed X-Y offsets when band or T/R switching



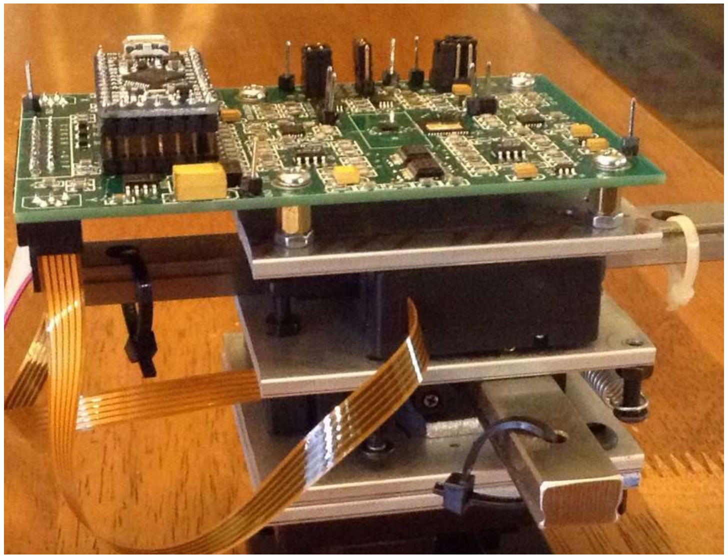
Actuonix PQ12
Mininature
Linear Actuator:
DC motor,
Lead screw
& position
feedback pot

Motorized X-Y Stage for Feed Positioning uses linear slide bearings



Assembled stage
on feed arm insert

Radio PCB on
moving stage



K6ML 24/122 Dual Band Rig

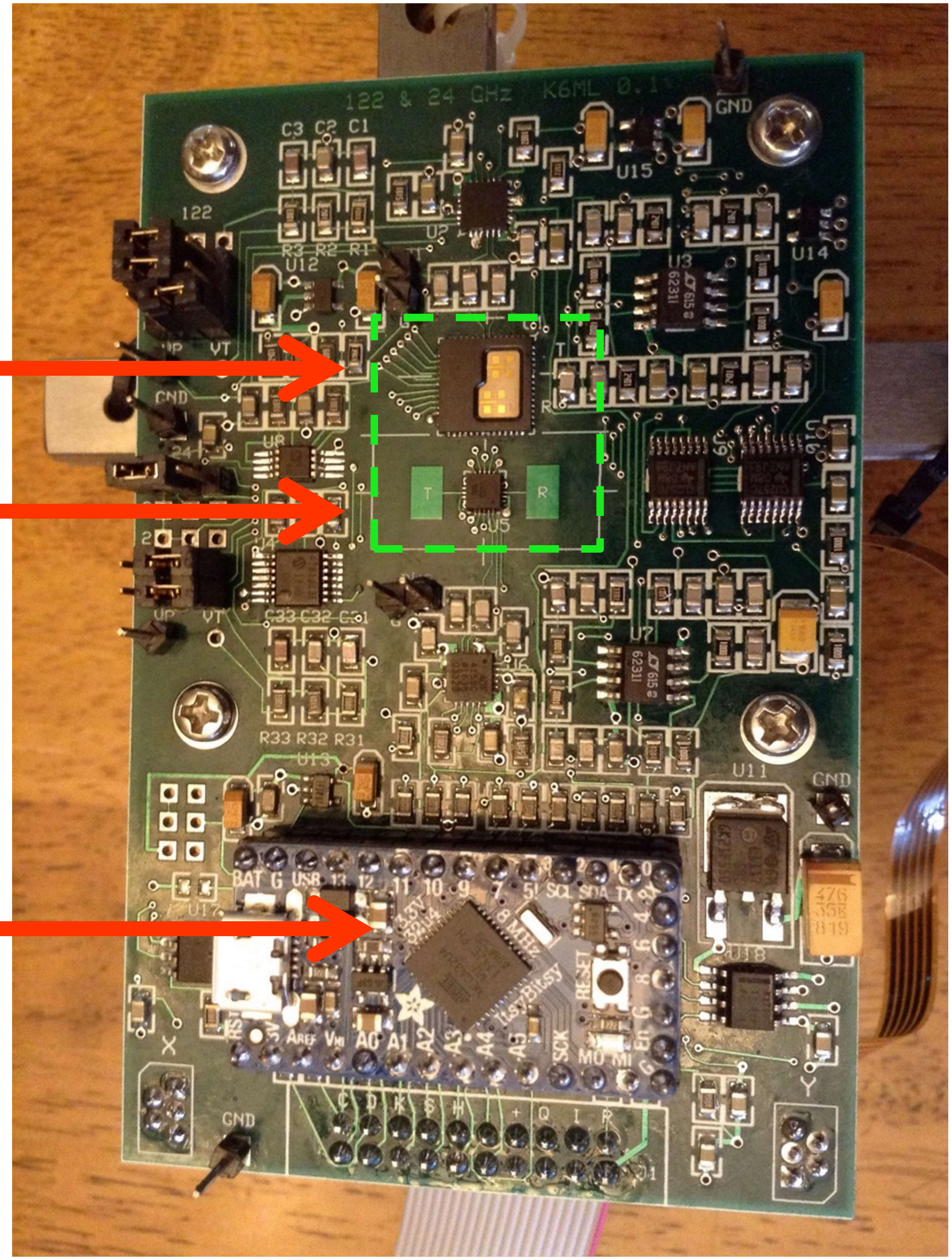
- Use motorized X-Y stage to move desired feed to focus
- Add a 24 GHz front end that shares the dish & IF Rx
  - Make a copy of TRX_120 design using the TRX_024 chip
  - Use the X-Y stage to focus on 1 of 4 feeds (24/122, Tx/Rx)
- Extra 'pilot' band is a tool for easily finding your partner on 24 GHz before switching to 122 GHz:
  - Higher power & lower NF at 24 GHz using TRX_024
  - Much lower water vapor loss (and no O_2 loss) at 24 GHz
    - 24 GHz link budget is 50-60 dB better at 100 km
  - Dish pointing is 5x easier in both azimuth and elevation at 24
  - 5x easier to find operating frequency at 24 GHz
    - Can scale up freq. ref. error to 122, so 'spot on'

K6ML 122/24 Dual Band Radio

(2.5” x 3.8” PCB)

TRX 120

TRX 024



Itsy Bitsy Arduino

- Tunes PLL
- Drives X, Y Motors

Motorized Dish Mount

Dish arm on see saw pivot & lazy susan rotor
Linear Actuators for El & Az (+/- 5 deg, ~0.02 deg res)
I^2C bus links radio, dish & hand controller

Hand controller menus:

- Pointing the dish
- Tuning the radio
- Calibrating feed offsets
- Radio settings

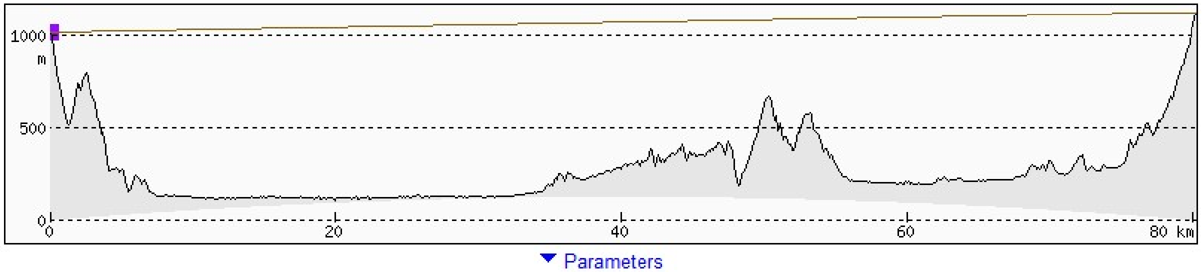
PLL and motor status display

System Gain – Path Loss = Signal/Noise

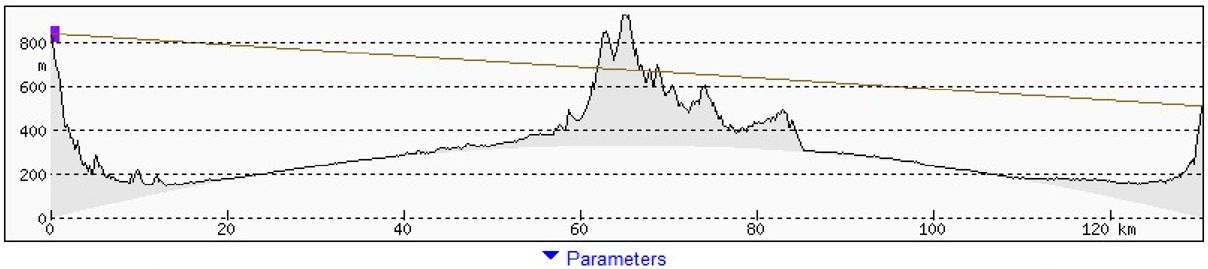
- System Gain = 213 dB *improvement:*
  + Tx Power <0.5 mW *power amp*
  + Tx Antenna 60 cm *bigger/smoother dish*
  + Rx Antenna 60 cm *bigger/smoother dish*
  – Rx Noise Figure 9 dB *low noise preamp*
  – Rx Bandwidth 2500 Hz *narrower mode/filter (FM->CW->dig)*
- Path Loss
  – Free Space (spreading; **6 dB** loss for **2x range**)
  – Obstructions, rocks, trees, clouds, other stuff that gets in the way
  – Atmospheric (**dB per km**; each step of the way)

Below ~25km, spreading dominates, above, atmospheric dominates

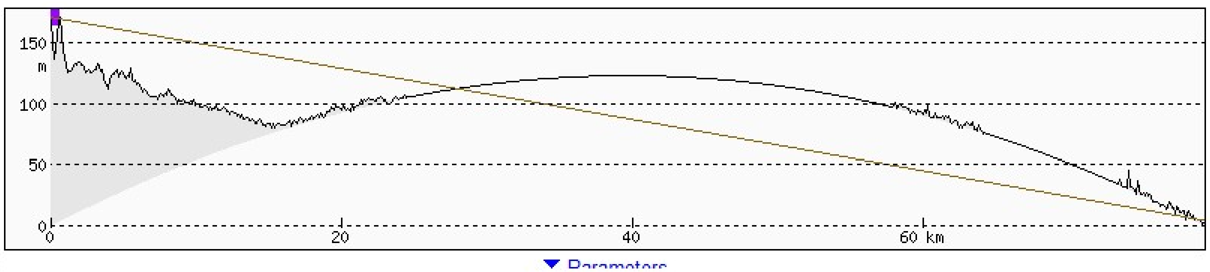
Start with a Line Of Sight (LOS) Path



YES! Both ends high



NO Obstructions



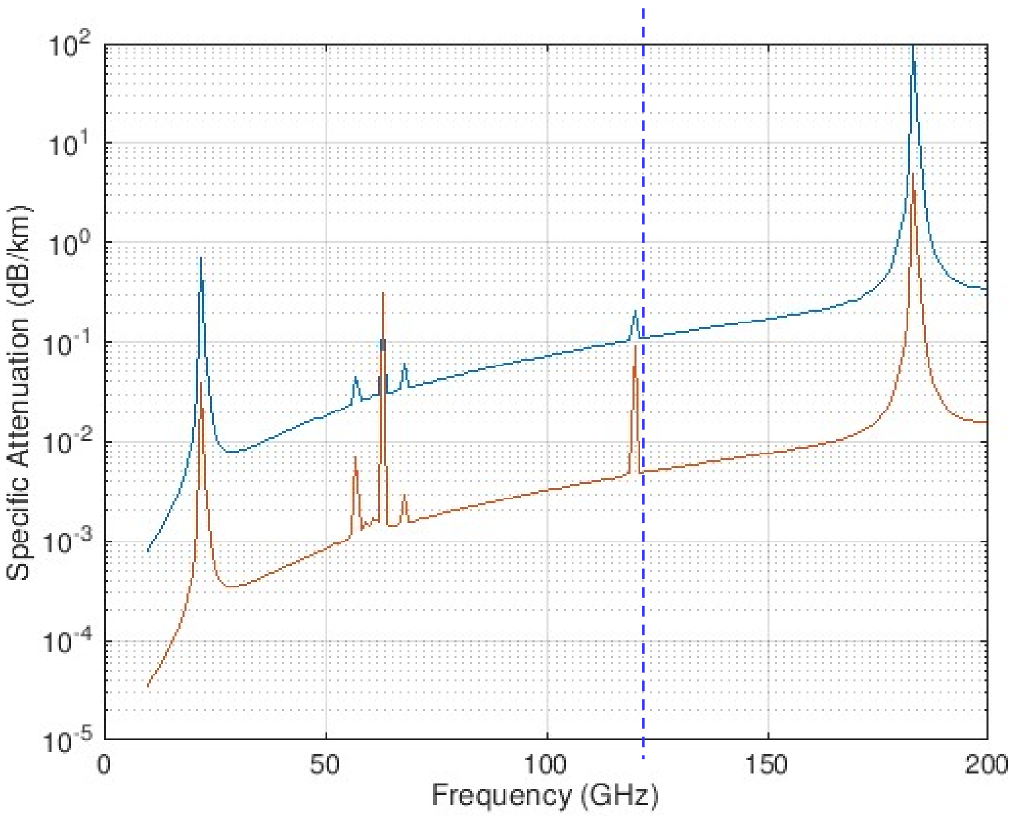
NOT below horizon

Again, each 2x distance costs 6 dB free space loss

Atmospheric Losses

Start to kick in above 20 GHz

and every km adds xxx dB loss



- Water Vapor is Public Enemy #1
  - Blue is damp, orange is dry
  - Trend: Increasing w/frequency
  - Resonances at 22, 183, … GHz
- Oxygen is #2
  - Resonances at 60, ***119***, … GHz
- At even higher freqs …
  - CO_2
  - N_2
  - etc
- At 122 GHz band (122.25-123.0) …
  - Water vapor is 2/3 or more of loss
  - Oxygen can be 1/3 of loss when dry

International Telecommunications Union P.676 Atmospheric Gas Loss Model equations depend on distance, frequency, abs water vapor, air temp, air pressure.

Reducing path loss

in descending order of importance (1 > 2 > 3 > 4)

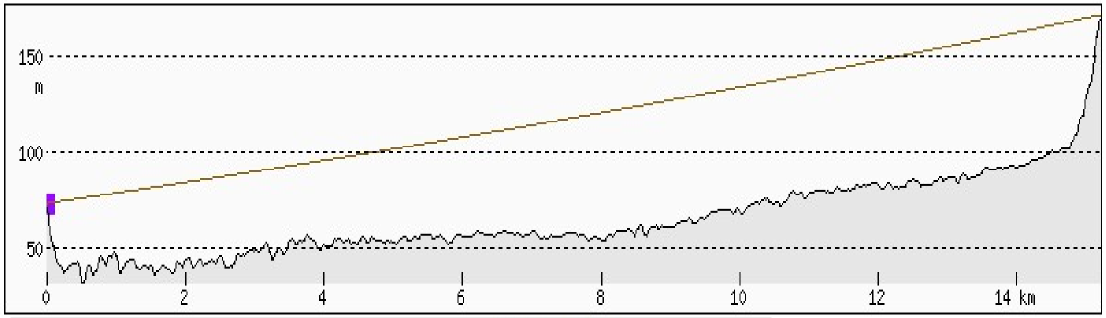
1. Find two mountains with LOS … the higher the better …
   - More distant horizon
   - Lower water content
   - Lower (oxygen) pressure

2. Look for a ***very low dew point*** day (T_{dew} < **-20 ºC**)
   - *Dew point* is the air temp at which water saturation (dew, fog, mist, rain) occurs
   - Dew point is a *direct* (*absolute*) measure of how much water vapor is in the air
   - Looking for a **dry air duct** between the two mountains
   - Beware: path "sags" in middle (usually wetter)

3. Look for high dew spread ($T_{air} – T_{dew}$) or low *relative* humidity (RH)
   - RH (or dew spread) measures how close we are to saturation at current air temp (*not* how much water)

$T_{air} – T_{dew}$	RH	Weather
0 ºC	100%	Dew/frost/rain…
10 ºC	~45%	Everyday
20 ºC	~22%	Pretty Dry
30 ºC	~11%	Verrrrrry Dry
40 ºC	~6%	Bone Dry

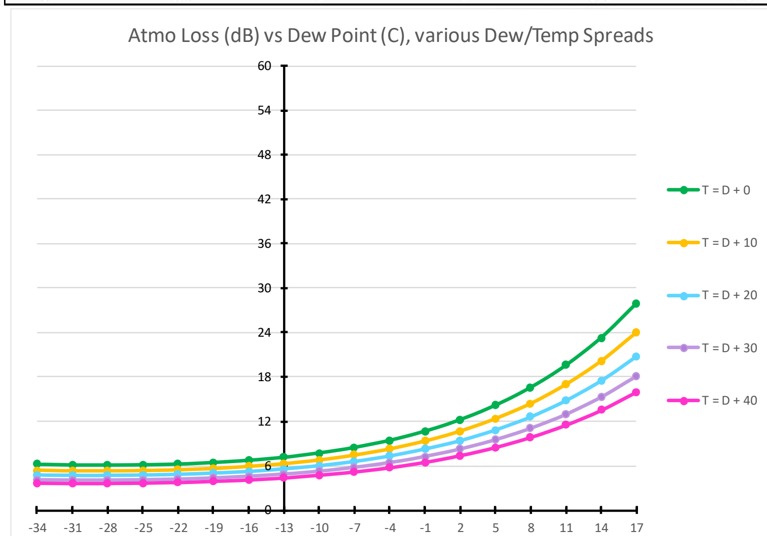
4. Use the top end of the band to get away from the 119 GHz O_2 absorption line.



15 km Test Path

(Saratoga-Ironwood)

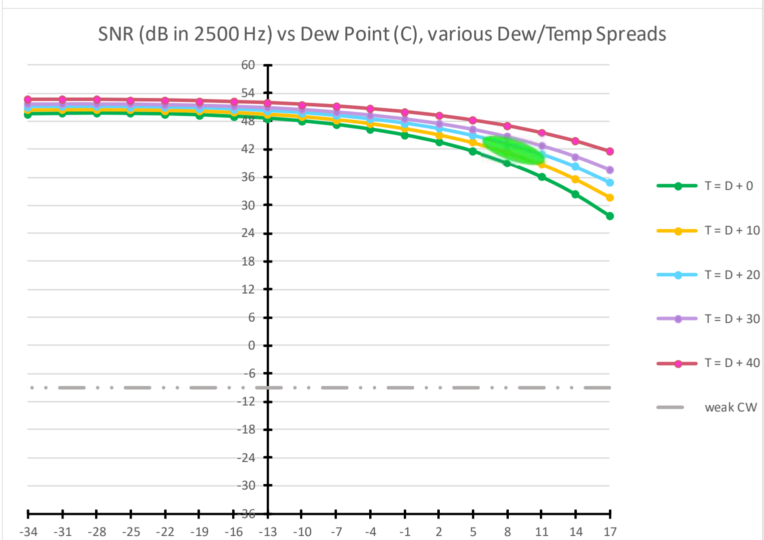
K6ML <-> KB6BA



Atmospheric Loss (in 1 “S” unit steps) vs Dew Point (in 3 ^{o}C steps) for various Dew/Temp spreads (in 10 ^{o}C steps)

- ~ 6 dB / 15 km below approx. -10 ^{o}C T_d
- Over 30 dB when not dry

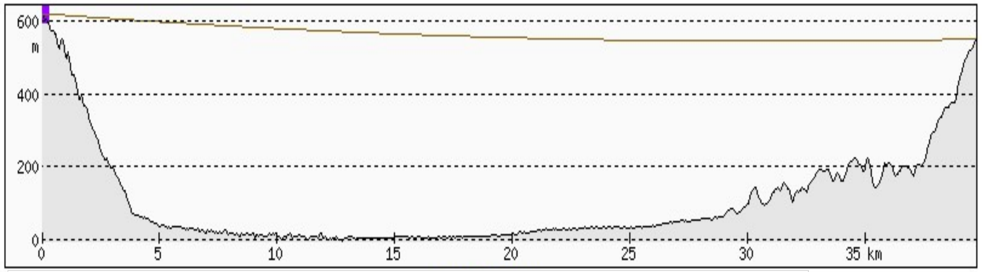
- But FSPL dominates (158 dB)



SNR (dB), assuming a 213 dB system gain

(without the +71 dB dish gain this path is impossible)

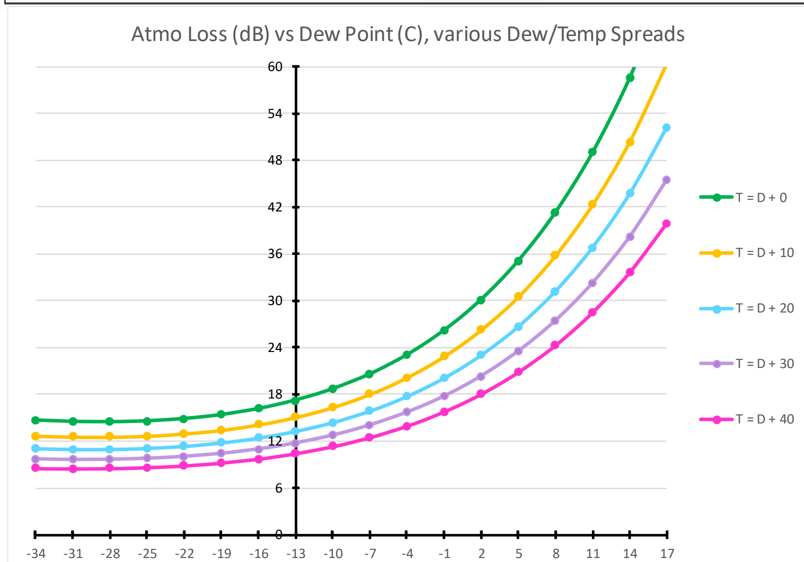
- 60 cm dish, TRX120, 2500 Hz BW
- Dashed grey line is weak CW copy
- Driest days are “S9” copy
- It would take a very wet day
  plus clouds to shut this path down



40 km QSO

(Sierra Rd – Windy Hill)

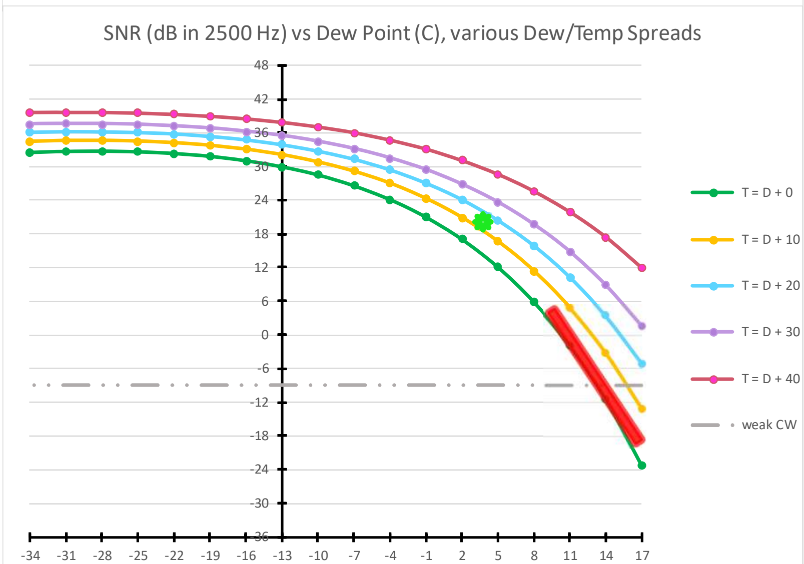
K6ML <-> KB6BA



Atmospheric Loss (in 1 “S” unit steps) vs Dew Point (in 3 ^{o}C steps) for various Dew/Temp spreads (in 10 ^{o}C steps)

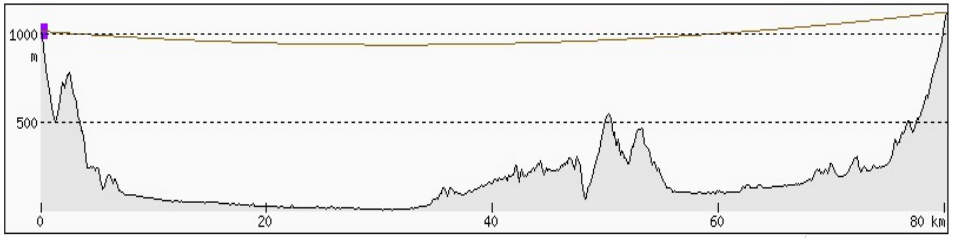
- 2 S units for < -13 ^{o}C T_d & 20 ^{o}C spread
- Over 10 S units when not dry

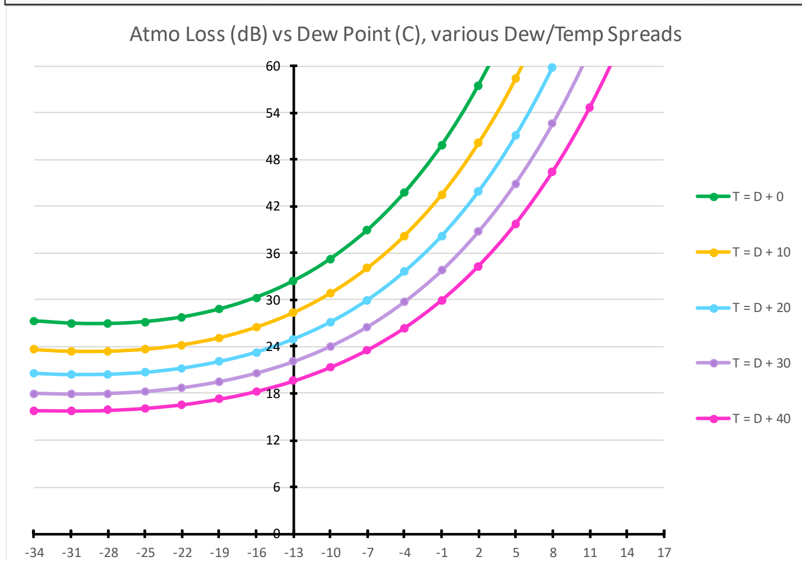
- But FSPL only went up **8** dB (166 dB)
- Atmospheric loss went up **6** to **60** dB!

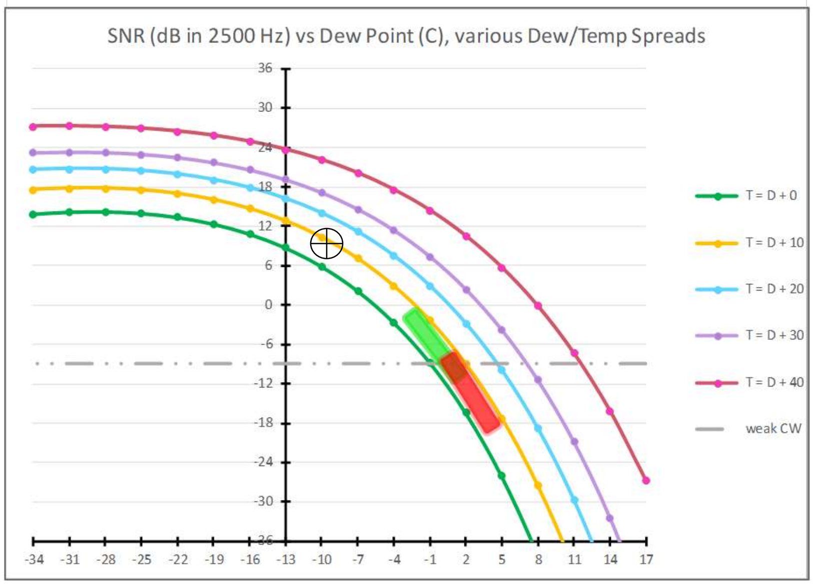


SNR (dB), again assuming a 213 dB system

- Dashed grey line is weak CW copy
- Dry days are “S6-S7” copy
- A wet day can shut this path down
  - Our first attempt failed (eve. dew)
  - Next day was dry and strong signals







80 km QSO

(Umunhum - Diablo)

Best DX so far!

K6ML <-> KB6BA

Atmospheric Loss (in 1 "S" unit steps) vs Dew Point (in 3 ^{O}C steps) for various Dew/Temp spreads (in 10 ^{O}C steps)

- 4 S units for -13 ^{O}C T_d & 20 ^{O}C spread
- Well over 10 S units when not dry

- 2x distance, FSPL goes up **6** dB (172 dB)
- Atmospheric loss went up **12** to **>100** dB
- The weather can easily shut us down

SNR (dB), again assuming a 213 dB system

- Dashed grey line is weak CW copy
- Dry days are "S3" copy…
- Even a bit of moisture drifting across any part(s) of the path shuts us down

Haze/moisture rising at mid path

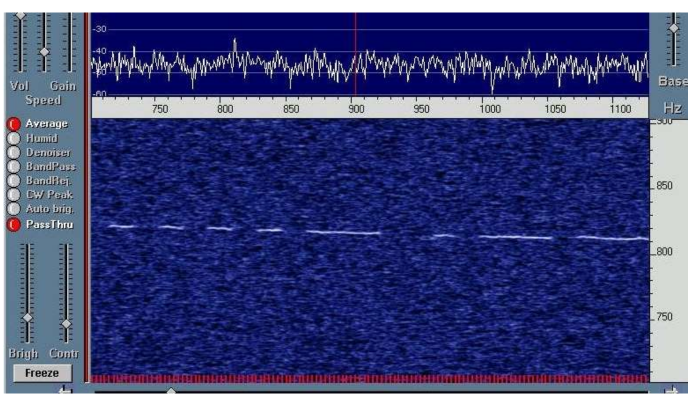
(Sunol Ridge, caused QSB and dropouts)

80 km QSO

KB6BA (Mt Umunhum) <> K6ML (Mt Diablo)

122 GHz DX

Year	Km	Mode	Callsigns, Dew/Air ^{0}C		Rigs
2004	**25**	**CW?FM?**	**W0EOM**	**KF6KVG**	**30cm?, µW, diode mixer**
2019	60	CW	VK3CV -8/?	VK3NH -9/?	60 cm, 0.5 mW, TRA120
2019	70	SSB	VK4CSD -4/+26	VK4FB -4/+26	Diode mixer
2019	80	CW	K6ML -4/+3	KB6BA -3/+4	60cm, 0.5 mW, TRX120, ~15 NF
2019	92	FT8	VK4CSD -5/+19	VK4FB -5/+19	Diode mixer
2005	**114**	**QRSS* CW**	**WA1ZMS -23/-12**	**W4WWQ -21/-18**	**30 cm, 5 mW, diode mix**
2013	**132**	**CW**	**OE5VRL ? -2/+12 ?** *"250 km visibility"*	**OE3WOG ? -13/+2 ?**	**120cm, 0.5 mw, ~25 NF 47cm, 1.2 mw, ~25 NF**

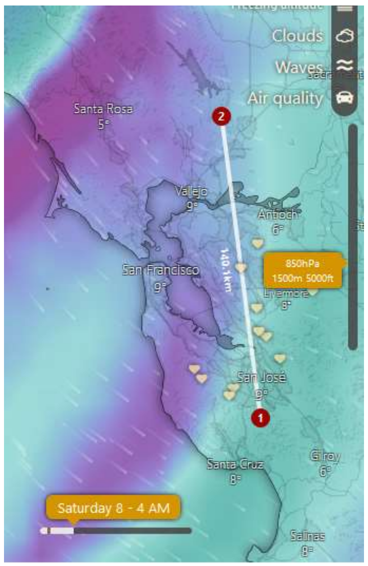


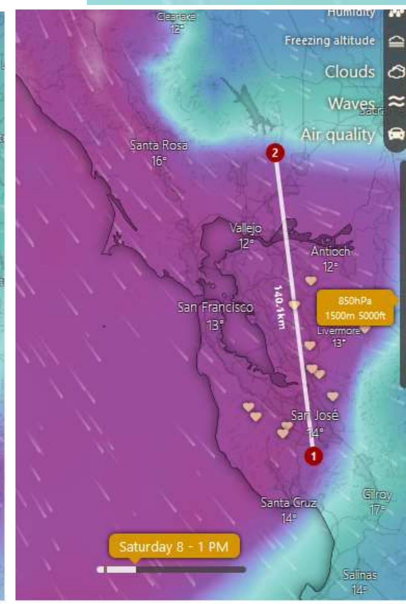
*QRSS: super slow CW, 6 sec per dit, 0.2 WPM in this case, and a super stable frequency reference allow 0.5 Hz bandwidth. Using SPECTRAN SW, you can "see" the signal even when you can't hear it.

Searching for the perfect wave …

Searching in time & 2-D space

Dew Point forecasts, Fri 1 pm thru Sat 4 pm





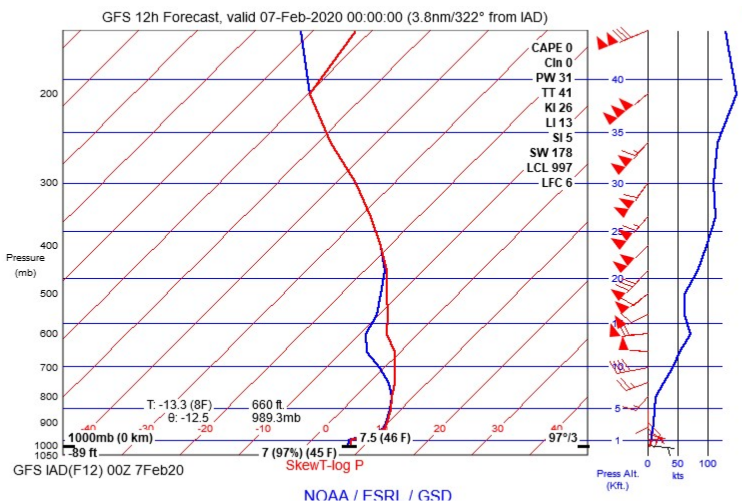
Fri 1300 Sat 0400 Sat 1000 Sat 1300 (now!) Sat 1600

We want purple (close to -20C dew point) OVER THE ENTIRE PATH if possible…
Doesn't happen very often or for very long

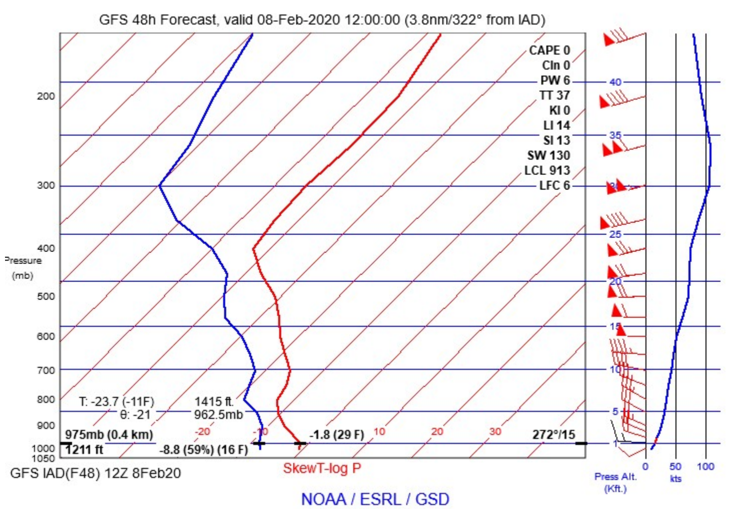
Searching for the perfect wave in 4-D

moisture varies with elevation, too

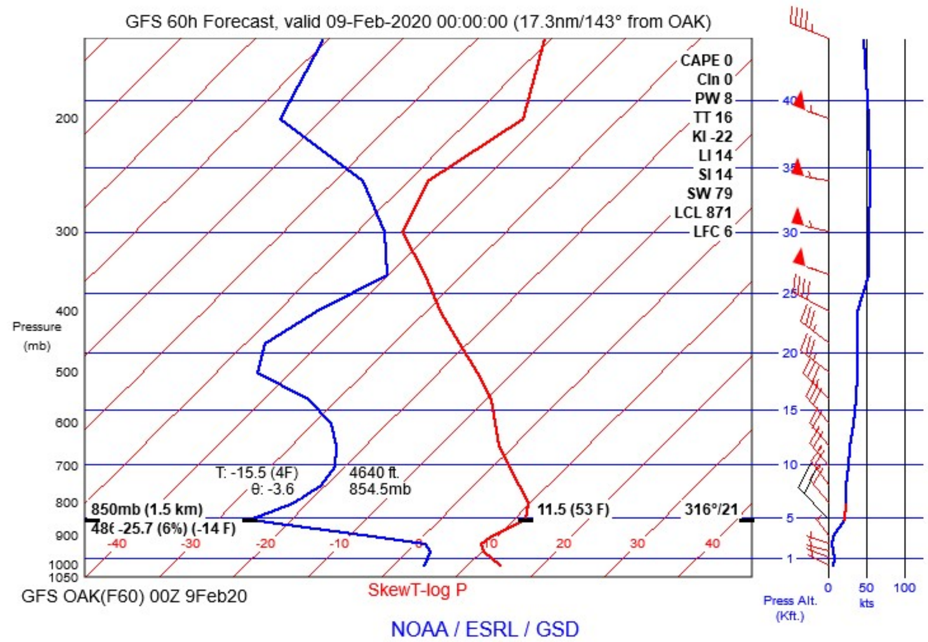
“Skew-T” plots show dew (blue) and temp (red) vs elevation



Wet: Rain, clouds



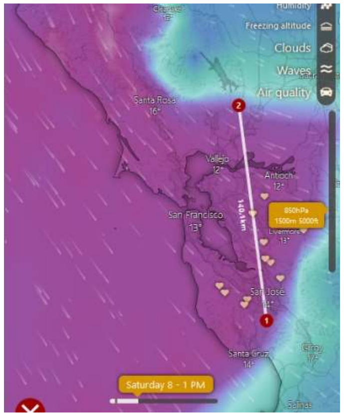
typical



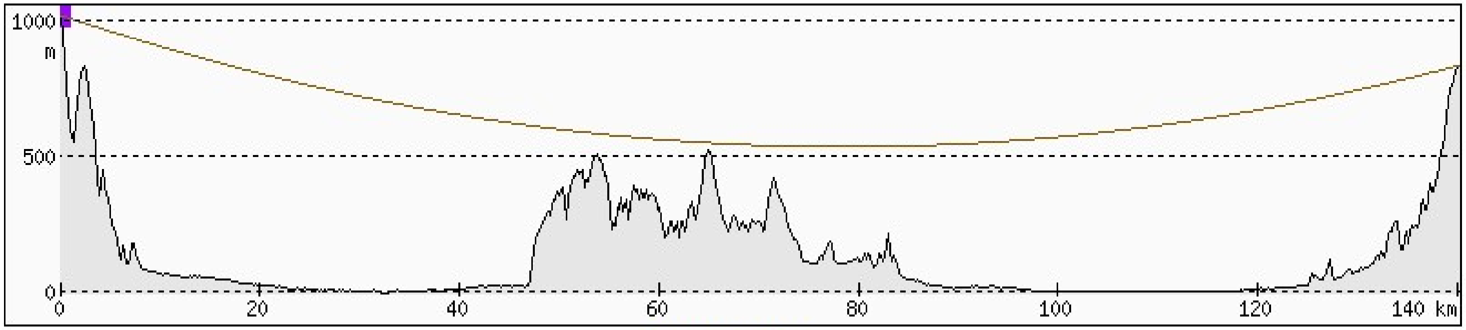
“dry duct” at elevation
(-26C / +12C / 4600 ft)

Searching for the perfect wave…

at the correct *heights along the path*



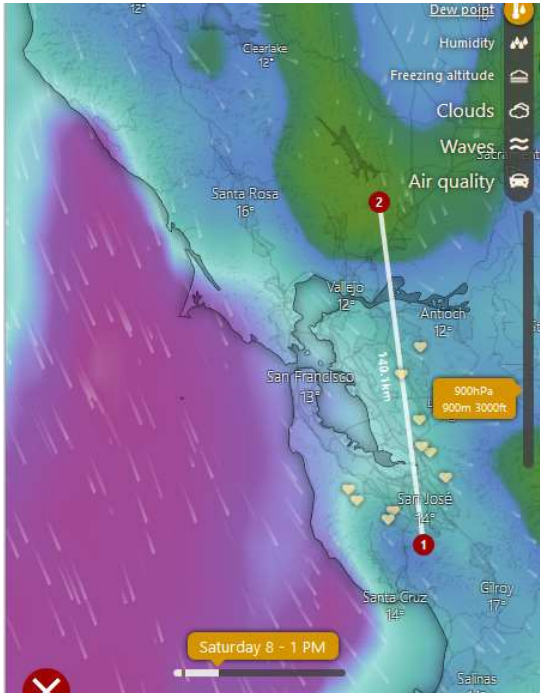
1500m (too high)

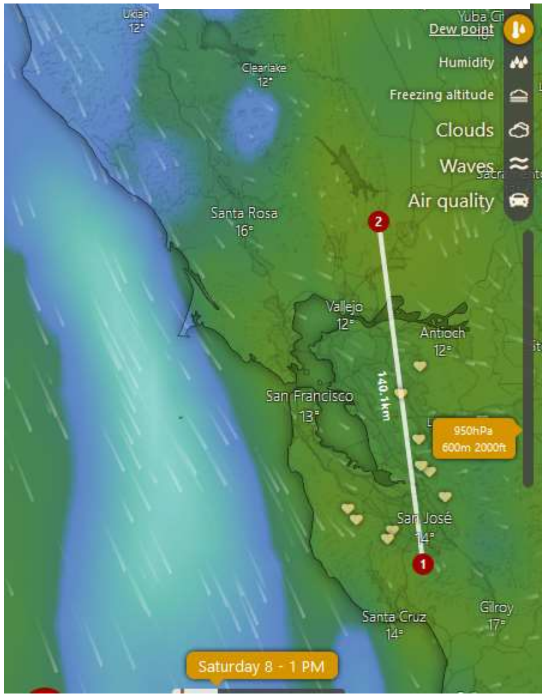


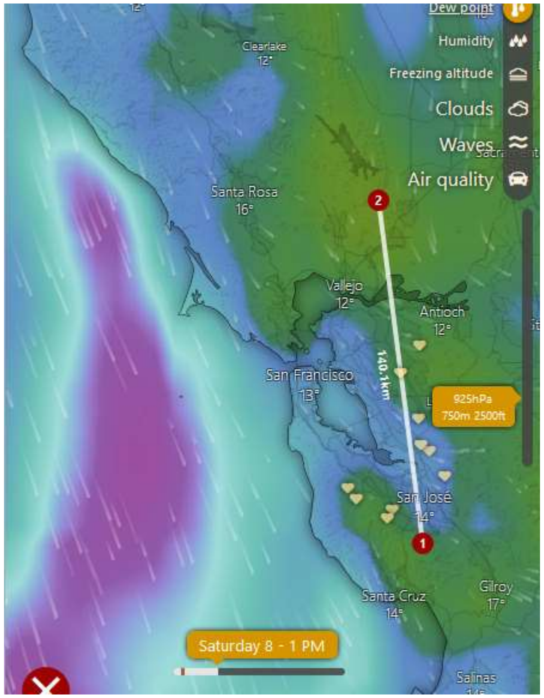
900m (Mt Um)

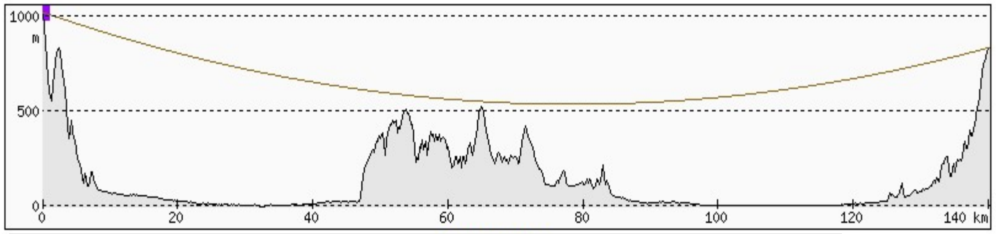
600m (midpoint)

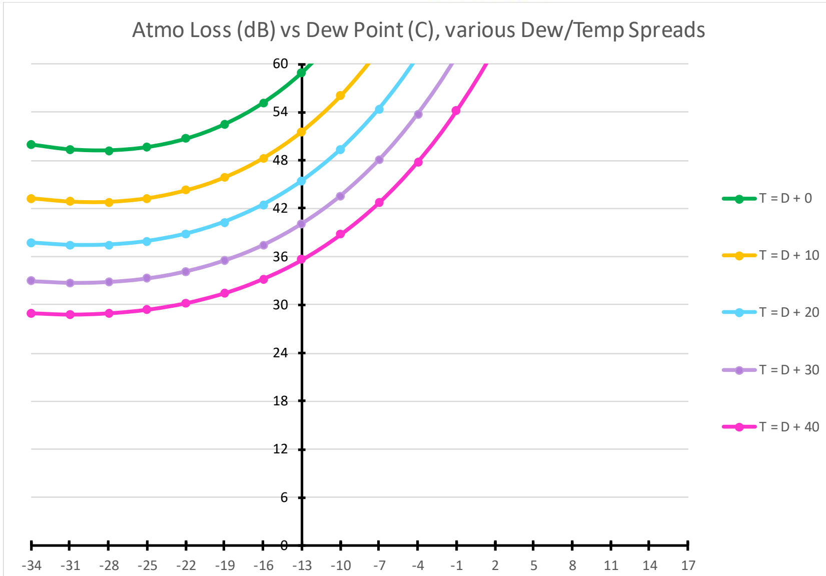
750m (Mt Vaca)

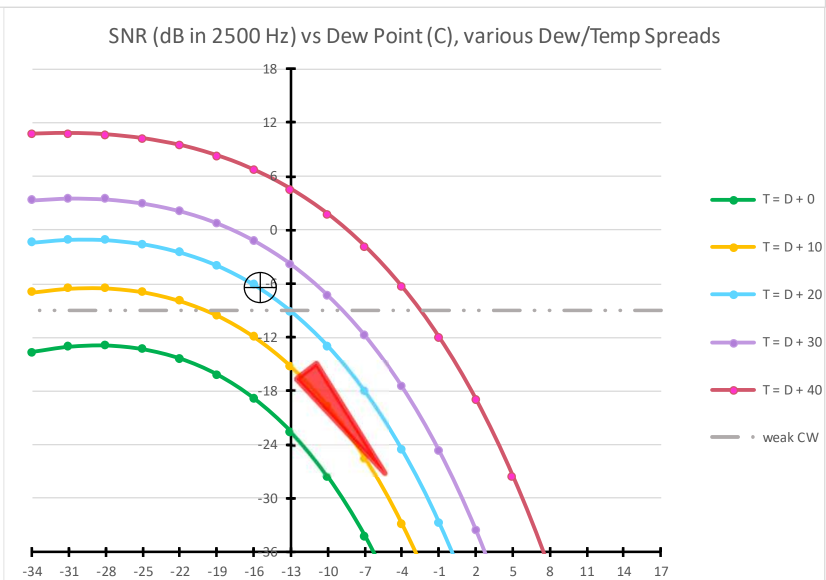












140 km Attempt

(Umunhum - Vaca)

K6ML <-> KB6BA & N9JIM

Atmospheric Loss (in 1 “S” unit steps) vs Dew Point (in 3 ^{o}C steps) for various Dew/Temp spreads (in 10 ^{o}C steps)

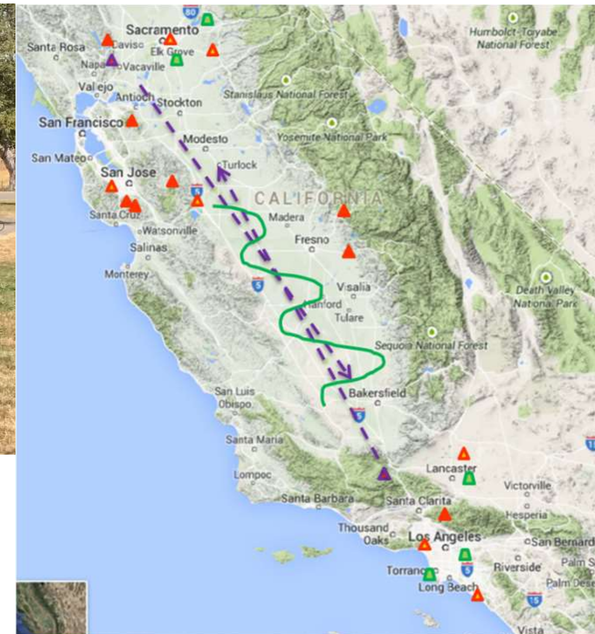
- 7.5 S units for -13 ^{o}C T_d & 20 ^{o}C spread
- Well over 10 S units when not dry

- FSPL goes up **5** dB (177 dB) from 80 km
- Atmospheric loss went up **21** to **>100** dB
- The weather is **THE** critical factor…
- First attempt (Tuesday) failed

SNR (dB), again assuming a 213 dB system

- Dry days are “weak CW” copy…
- Even if we can get dry endpoints,
  It’s way too easy for points along the path to be wetter

We loaded up our boards,
headed out to Mavericks and…
wiped out !!!



Getting into Microwaving

- Mountain topping, weak signals, roving, contesting
- **10 GHz** is the most popular band *(mostly SSB)*
  - Can homebrew or buy a transverter
  - Use an FT-817, KX-3 or other QRP rig as IF
  - 18” satellite dish: > 30 dB gain & 4 deg beam
  - Stick it on a tripod, use your smartphone to navigate and power it all with a 12V battery
- **www.50mhzandup.org** group meets first Tuesdays
  - We’ll help you get on the air

www.50mhzandup.org

Thank You

Mike K6ML