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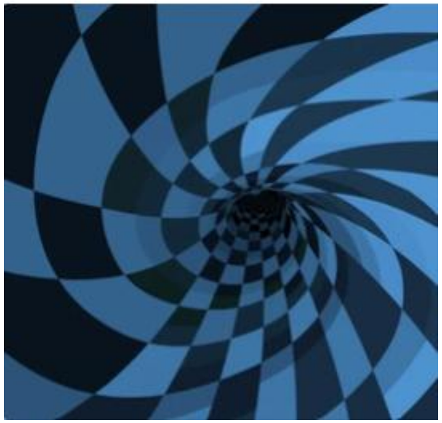
Automated beacon receivers Part 1

KM5PO – Jim McMasters

July 18, 2026

New Journey

- Why are automated beacon receivers needed?
- What would they need to do?
- Can they be made at relatively low cost?
- What is best way to calibrate & test the monitors?



Why?

- We built a propagation analysis/prediction tool with A.I. perfected algorithms.
  - This is a significant investment of IP and infrastructure.
  - We started with examining ~80,000 actual microwave contacts between 2 points.
  - New path link closures continue to be reported every day but at a very slow rate. Requires submission of contact info.
- Additional real path loss/gain is needed.
  - For different seasons of the year.
  - From different geographical areas.
- A monitor can measure *and report* results tirelessly.

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Why?

- Bell Burnell (1967) Pulsars discovered
  - A dumb, continuously running receiver caught something a scheduled or manual observation would not have found.
- Joe Taylor and Russell Hulse (1974) Binary Pulsar PSR B1913+16.
  - Nobel prize was awarded in 1993 but not for the discovery moment itself.
  - It was awarded for the years of precise, repeated timing measurements of the pulsar's orbital period, which showed the orbit decaying at exactly the rate general relativity predicts for gravitational wave emission.

What do they need to do?

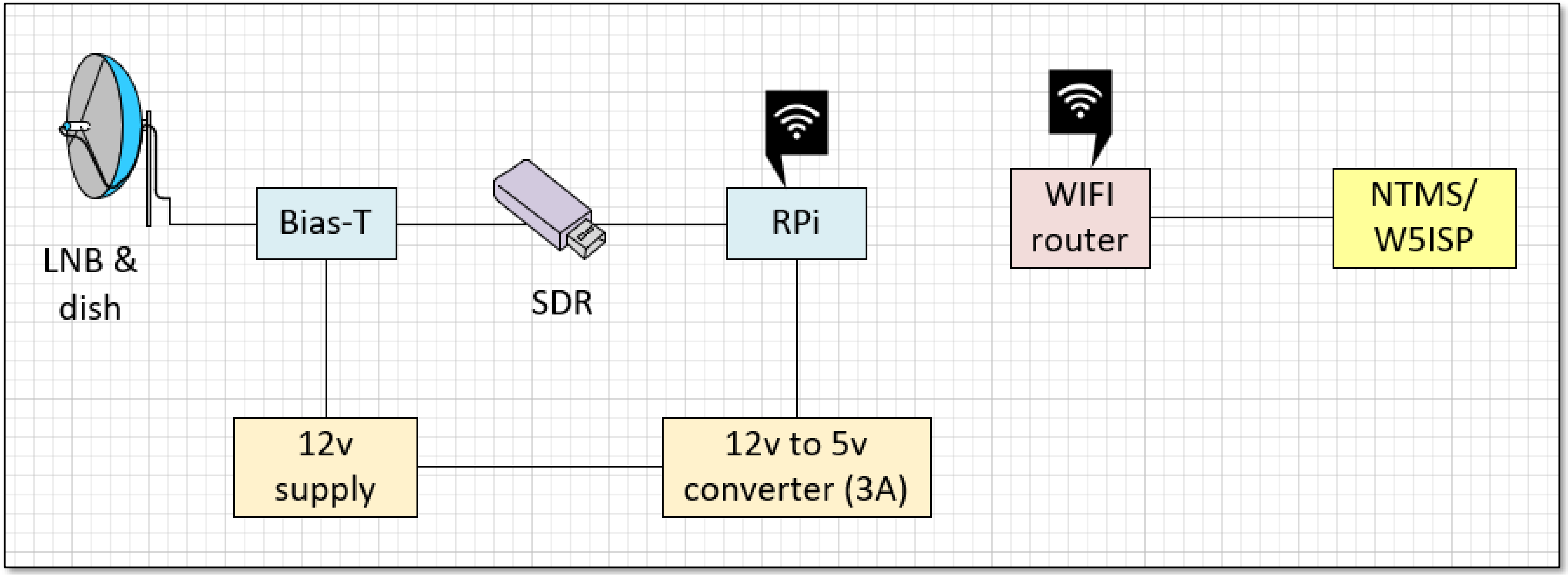
- Monitor a specific microwave band.
  - It's possible there could be more than one beacon on a band.
- Be located such that a beacon can be detected some percentage of the time.
- Report results to a central database.
  - NTMS/W5ISP propagation engine.
  - Other web accessible pages to display real time path/propagation status (HamSCI).

Can they be made at relatively low cost?

- Initial 10 GHz monitor prototype:
- Use a satellite LNB in combination with a surplus satellite dish.
- Use a low cost SDR dongle to process the LNB I.F. signal.
- Use a (headless) Raspberry Pi 4 to manage the SDR and report results.
- Use existing WIFI router at op QTH for reporting back to database.

Monitor Designs

- Model #1, indoor & outdoor version



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10 GHz Monitor Design

- Model #1, indoor & outdoor version, LNB IF = 618 MHz

Part	Description
Dish	Surplus
LNB	FTA Universal Ku Band LNB 0.1 dB Model 300101
Bias-T	Needs to pass 12v to LNB and IF freq. of ~618 MHz
SDR	NooElec NESDR Smart V5 or RTL-SDR
Processor	Raspberry Pi 4 B 2 GB
DC conv.	DC to DC converter like Amazon DROK 180080AFA
Coax/cable	Various short SMA male to SMA male coax and DC wiring
Software	Available on GitHub public repo: NTMS https://github.com/North-Texas-Microwave-Society/SDR-based-beacon-receive-systems

Model #1 -10 GHz Monitor

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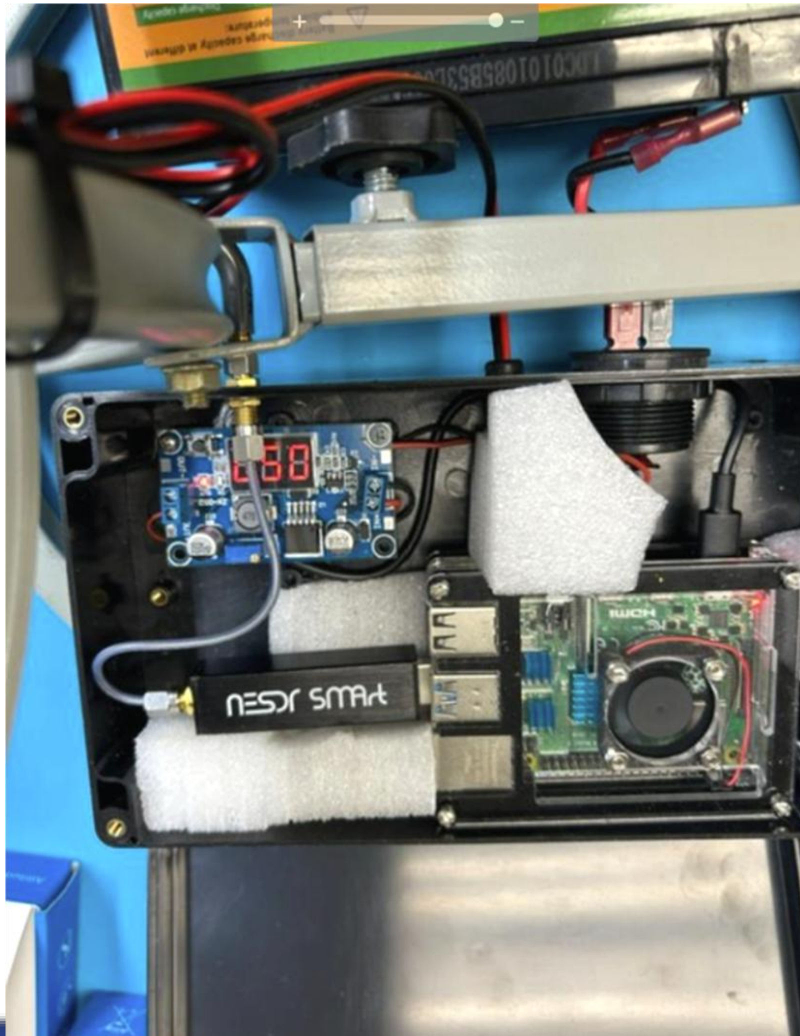

Monitor Designs

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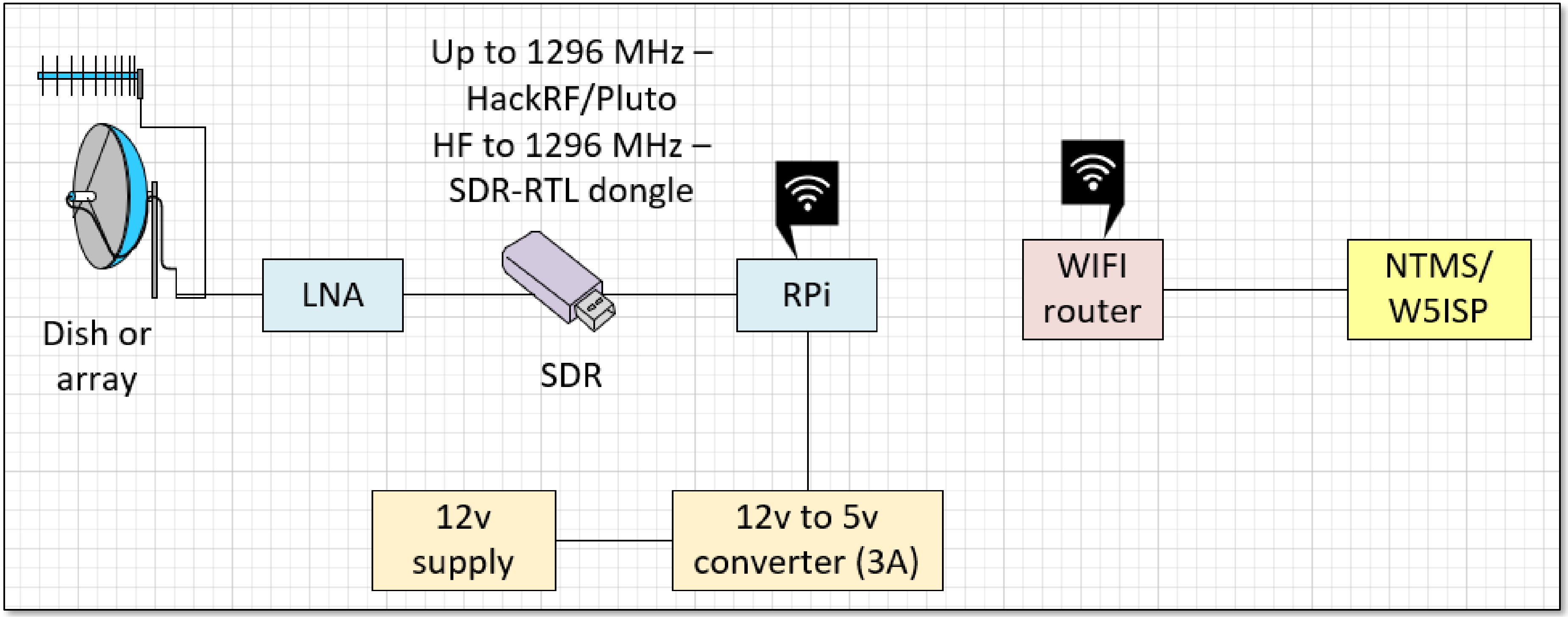
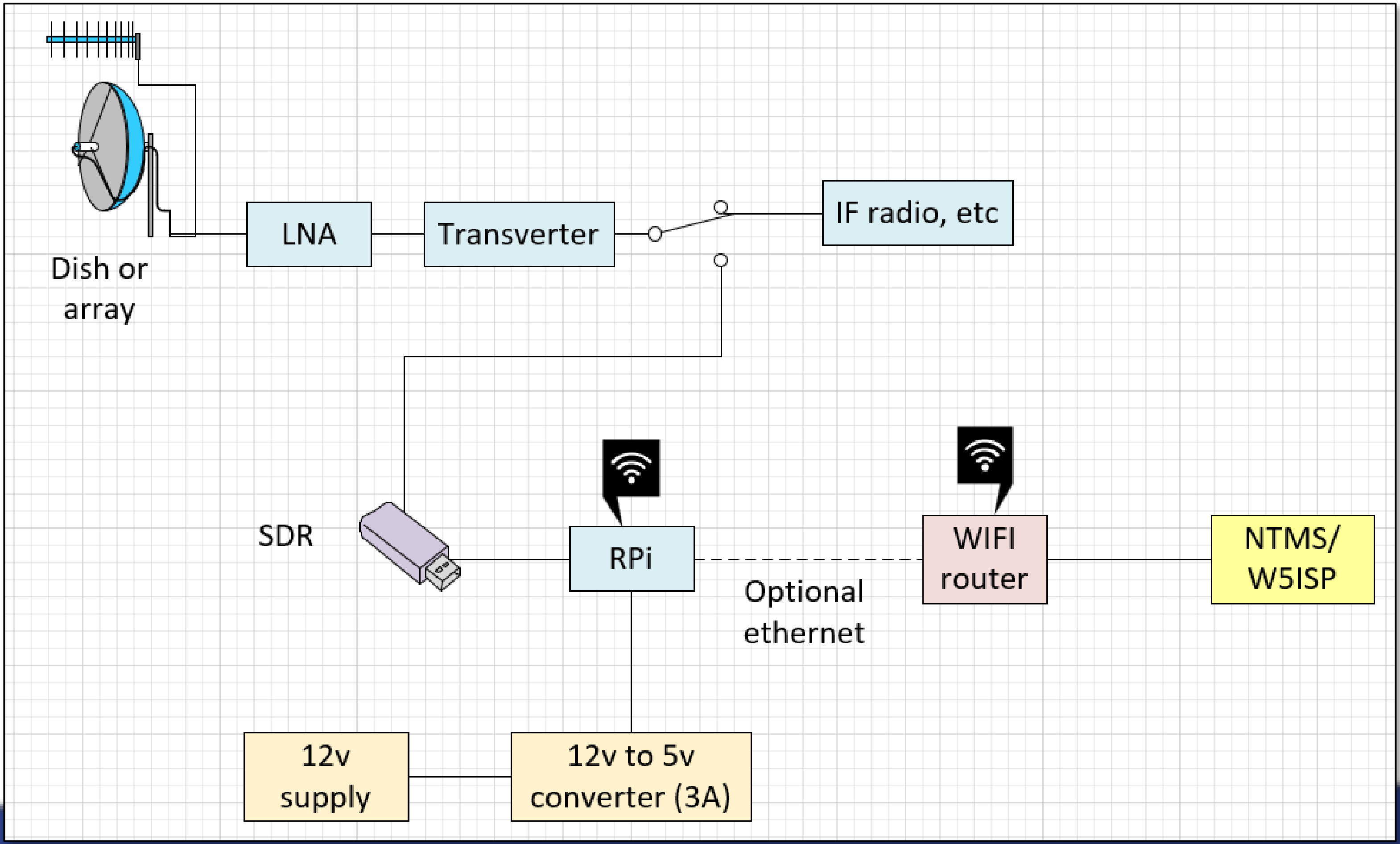
- Model #2, for bands < 10 GHz (HamSCI, others)



Monitor Designs

- Model #3, use existing equipment.



Monitor Designs

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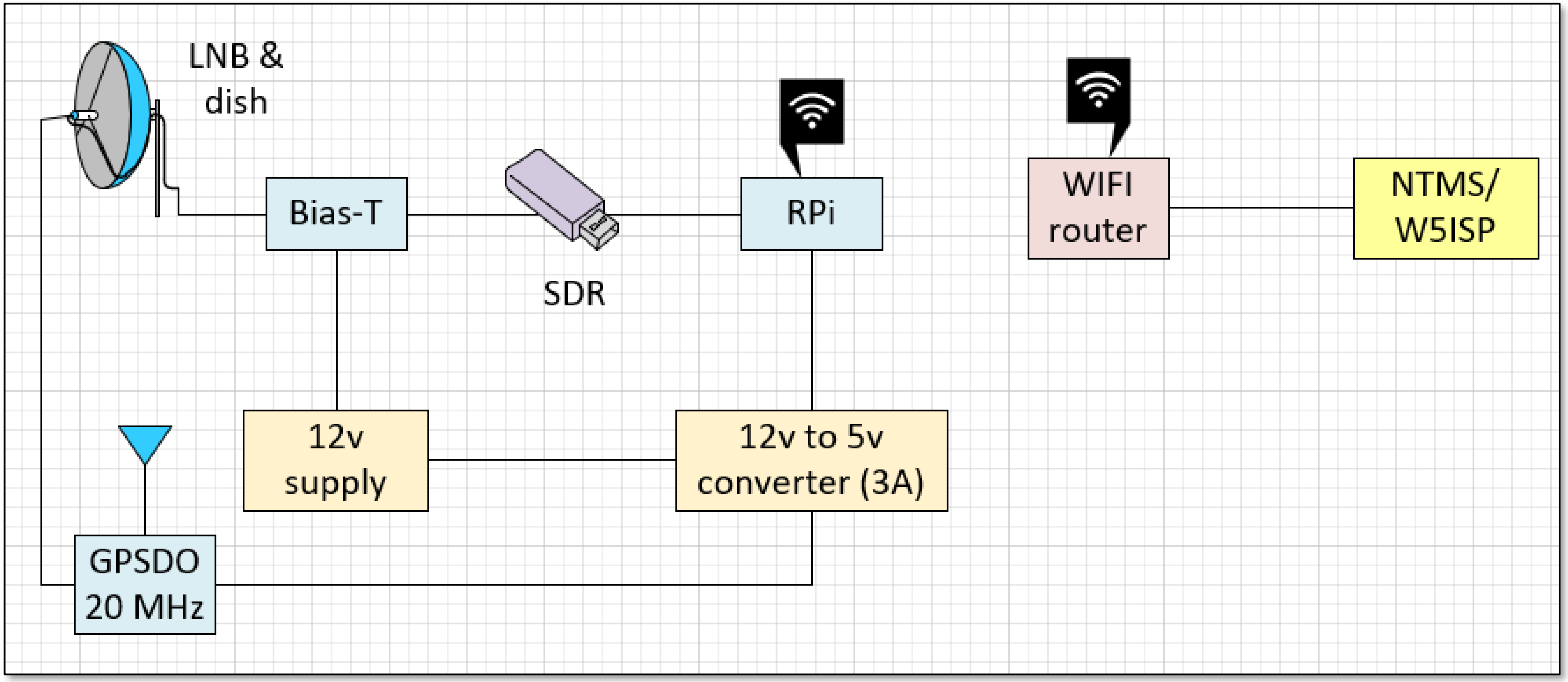
- Model #4, high stability – enables WSJT-X decode.



Monitor Designs

Model	Basic config	Function	Pro/Con
1	Indoor/Outdoor 10/24/47/? GHz	Microwave propagation	Low cost to high cost based on freq.
2	Indoor/Outdoor Less than 10 GHz	VHF/UHF propagation	Low cost to high cost based on freq.
3	Use existing (ops) equipment	Any frequency – our demo used this model	Low cost
4	Hi stability – can decode WSJT-X	Very weak signal	Higher cost

Model #4 Hi res system

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- Bullseye modified to use external reference.
- Bodnar or other programmable GPSDO ref.
- Other components the same as Models 1 – 3.

Install the monitor

- Choose a location.
  - Consider how the device will be powered.
  - Needs to be in-range of the WIFI connection or use an ethernet cable.
    - Indoor units in plastic case use WIFI antenna printed on Rpi PCB but can be fitted with external WIFI antenna.
    - Outdoor units in metal casing use external WIFI antenna.

Software load and configuration

- For volunteer ops, NTMS can perform the configuration. We will use a short info form.
- For others:
  - Establish connection with Rpi.
  - Pull code from NTMS GitHub.
    - This will download the latest code.
  - Run calibration script (optional).
  - Update monitor script to use gain/threshold values from calibration recommendation.
  - Start the monitor.
  - Validate the beacon is being received.

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Calibrate options

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- Here is the internal code for monitor_calibrate.sh

```
# --- RF chain ---
FREQ=618.245          # IF center frequency (MHz) after Bullseye LNB
LO=9750.0             # LNB LO frequency (MHz)
PPM=0                 # PPM correction

# --- Calibration sweep settings ---
DWELL=2.0             # Seconds of IQ data collected per gain step
SETTLE=0.5            # Seconds to wait after each gain change
EXCLUDE=500           # Exclusion zone (kHz) around center when measuring noise
MARGIN=10.0           # dB above noise floor for suggested threshold
GAINS=all             # 'all' for full R820T2 sweep, or e.g. '28.0,29.7,32.8,33.8,36.4'

# --- Output ---
# Timestamped CSV saved automatically if --output not specified

sudo $PYTHON $SCRIPT \
    --freq    $FREQ \
    --lo      $LO \
    --ppm     $PPM \
    --dwell   $DWELL \
    --settle  $SETTLE \
    --exclude $EXCLUDE \
    --margin  $MARGIN \
    --gains   $GAINS
```

Identify gain and threshold (one time calibration)

- While pointed to cold sky, step through all SDR gain values (29 steps, 0-49.6 dBFS).
- Take n FFT sweep at each step, averaging each.
- Compute noise floor as median power across spectrum centered on beacon frequency (+/- 500 kHz)
- Print a table: gain_dB | noise_floor_dBFS | delta_from_previous_step.
- Identify the knee and recommend gain & threshold.
- Also create .csv file for comparison across stations/LNBs.

dBFS

- **dBFS = "decibels relative to Full Scale."**
- It's not an absolute physical unit (not watts, not volts at an antenna)
- it's purely a statement about how "loud" a digital sample is *relative to the maximum value the file format can represent*.
- For 16-bit PCM audio (what all WSJT-X WAV files are), the full-scale reference is the largest representable sample value, 32768. The formula used:
- dBFS = 20 * log10(RMS_amplitude / 32768)
- 0 dBFS is the ceiling, not a target.
- RMS vs. peak matters.
- It is a property of the digital recording, not the RF signal.

Cold sky measurement

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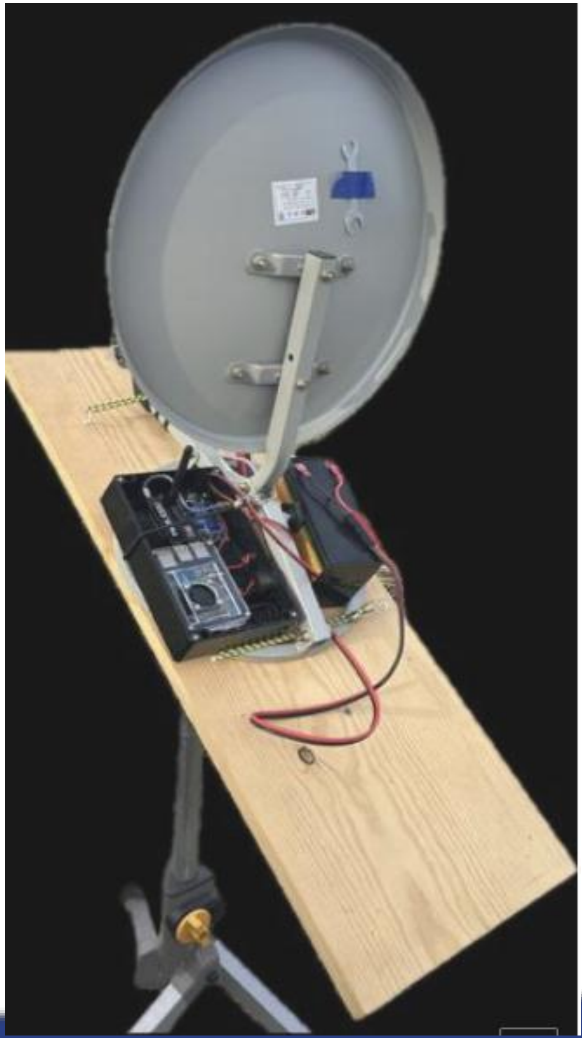
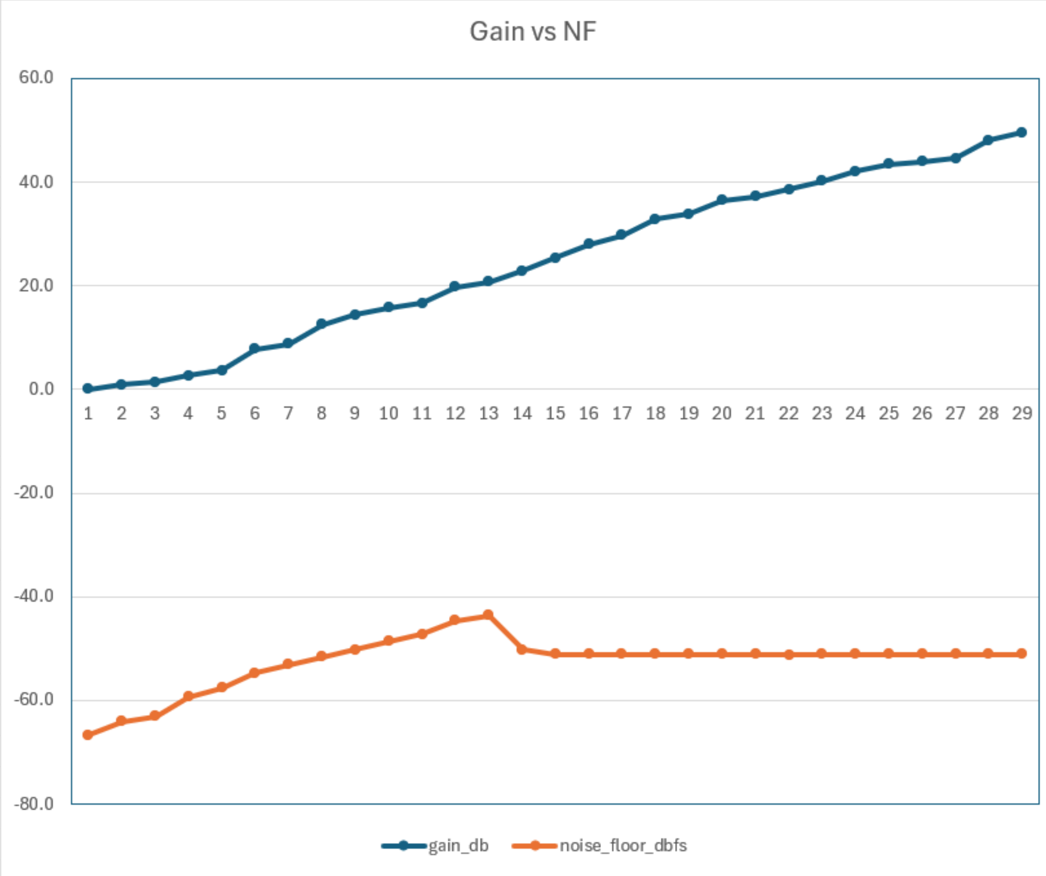


Calibration results (cold sky)

	A	B	C	D	E
1	gain_db	noise_floor_dbfs	delta_noise_db	delta_gain_db	ratio_dn_dg
2	0.0	-66.6476			
3	0.9	-64.1394	2.5082	0.9	2.7869
4	1.4	-63.0632	1.0762	0.5	2.1524
5	2.7	-59.3000	3.7632	1.3	2.8948
6	3.7	-57.5733	1.7267	1.0	1.7267
7	7.7	-54.7358	2.8375	4.0	0.7094
8	8.7	-53.1367	1.5991	1.0	1.5991
9	12.5	-51.6749	1.4618	3.8	0.3847
10	14.4	-50.2569	1.4180	1.9	0.7463
11	15.7	-48.5849	1.6720	1.3	1.2862
12	16.6	-47.2329	1.3520	0.9	1.5022
13	19.7	-44.6296	2.6034	3.1	0.8398
14	20.7	-43.6507	0.9789	1.0	0.9789
15	22.9	-50.2418	-6.5912	2.2	-2.9960
16	25.4	-51.1705	-0.9286	2.5	-0.3714
17	28.0	-51.0765	0.0940	2.6	0.0362
18	29.7	-51.1171	-0.0407	1.7	-0.0239
19	32.8	-51.0916	0.0256	3.1	0.0083
20	33.8	-51.1288	-0.0372	1.0	-0.0372
21	36.4	-51.1598	-0.0309	2.6	-0.0119
22	37.2	-51.0990	0.0608	0.8	0.0760
23	38.6	-51.1805	-0.0816	1.4	-0.0583
24	40.2	-51.1767	0.0038	1.6	0.0024
25	42.1	-51.0816	0.0951	1.9	0.0500
26	43.4	-51.1199	-0.0383	1.3	-0.0294
27	43.9	-51.0594	0.0605	0.5	0.1211
28	44.5	-51.1115	-0.0521	0.6	-0.0868
29	48.0	-51.1114	0.0000	3.5	0.0000
30	49.6	-51.1022	0.0092	1.6	0.0058



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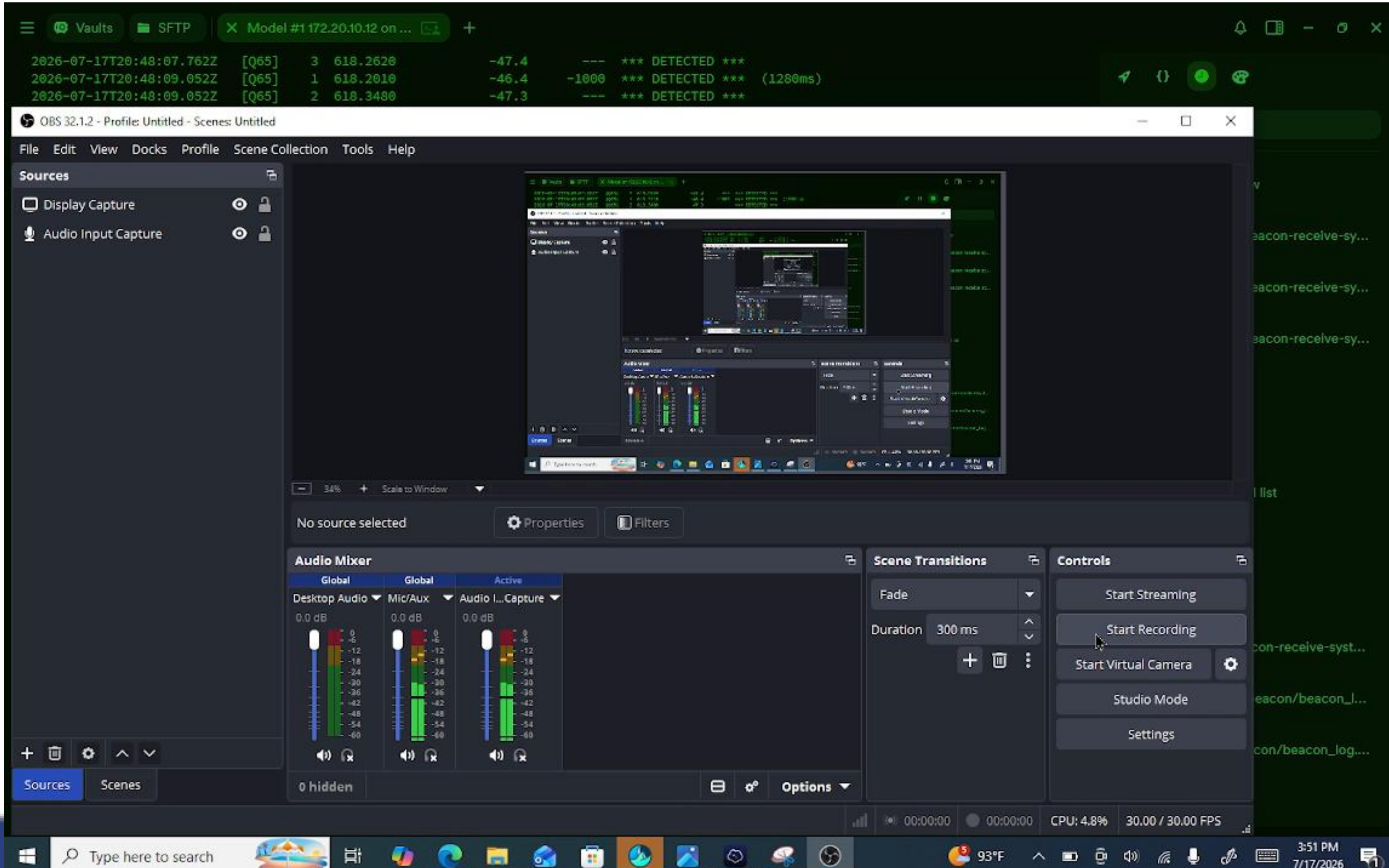
Calibration run



```
km5po@raspberrypi2:~/SDR-based-beacon-receive-systems $ sudo ~/SDR-based-beacon-receive-systems/run_calibrate.sh

NTMS Beacon Station Calibrator
================================
  IF center   : 618.245 MHz
  LNB LO      : 9750.000 MHz
  RF (approx): 10368.245 MHz
  FFT size    : 4096 bins  (500 Hz/bin)
  Dwell/step  : 2.0 s  (4,096,000 samples, 1000 frames)
  Settle time: 0.5 s
  Exclude     : ±500 kHz around center
  Margin      : 10.0 dB above noise floor → threshold
  Gain steps  : 29  (0.0–49.6 dB)
  Estimated   : ~72 s (1.2 min)
  Output      : beacon_cal_20260717_205153.csv

Point dish at cold sky, then press Enter to begin (Ctrl+C to abort)...
```

```
Opening SDR... Found Rafael Micro R820T/2 tuner
OK

   Gain  Noise floor   Δ noise   Δ gain   Ratio  Note
     dB        dBFS         dB       dB   dN/dG
 ------  ----------  --------  -------  ------  -------------------
    0.0      -66.53       ---      ---     ---
    0.9      -64.01     +2.52     +0.9    2.80  *** KNEE ***
    1.4      -62.91     +1.10     +0.5    2.19
    2.7      -59.18     +3.73     +1.3    2.87
    3.7      -57.42     +1.76     +1.0    1.76
    7.7      -54.56     +2.86     +4.0    0.71
    8.7      -52.94     +1.62     +1.0    1.62
   12.5      -51.39     +1.55     +3.8    0.41
   14.4      -50.00     +1.40     +1.9    0.73
   15.7      -48.36     +1.64     +1.3    1.26
   16.6      -47.04     +1.32     +0.9    1.47
   19.7      -44.49     +2.55     +3.1    0.82
   20.7      -43.53     +0.96     +1.0    0.96
   22.9      -50.12     -6.59     +2.2   -3.00
   25.4      -50.94     -0.81     +2.5   -0.32
   28.0      -51.01     -0.07     +2.6   -0.03
   29.7      -50.95     +0.06     +1.7    0.03
   32.8      -50.99     -0.04     +3.1   -0.01
   33.8      -50.95     +0.04     +1.0    0.04
   36.4      -51.02     -0.08     +2.6   -0.03
   37.2      -50.95     +0.08     +0.8    0.09
```

Vaults | SFTP | Model #1 172.20.10.12 on ...


```
     dB        dBFS         dB       dB   dN/dG
 ------  ----------  --------  -------  ------  -------------------
    0.0      -66.53       ---      ---     ---
    0.9      -64.01     +2.52     +0.9    2.80  *** KNEE ***
    1.4      -62.91     +1.10     +0.5    2.19
    2.7      -59.18     +3.73     +1.3    2.87
    3.7      -57.42     +1.76     +1.0    1.76
    7.7      -54.56     +2.86     +4.0    0.71
    8.7      -52.94     +1.62     +1.0    1.62
   12.5      -51.39     +1.55     +3.8    0.41
   14.4      -50.00     +1.40     +1.9    0.73
   15.7      -48.36     +1.64     +1.3    1.26
   16.6      -47.04     +1.32     +0.9    1.47
   19.7      -44.49     +2.55     +3.1    0.82
   20.7      -43.53     +0.96     +1.0    0.96
   22.9      -50.12     -6.59     +2.2   -3.00
   25.4      -50.94     -0.81     +2.5   -0.32
   28.0      -51.01     -0.07     +2.6   -0.03
   29.7      -50.95     +0.06     +1.7    0.03
   32.8      -50.99     -0.04     +3.1   -0.01
   33.8      -50.95     +0.04     +1.0    0.04
   36.4      -51.02     -0.08     +2.6   -0.03
   37.2      -50.95     +0.08     +0.8    0.09
```


```
   38.6      -50.96     -0.01     +1.4   -0.01
   40.2      -50.96     -0.01     +1.6   -0.00
   42.1      -50.98     -0.01     +1.9   -0.01
   43.4      -50.96     +0.01     +1.3    0.01
   43.9      -50.95     +0.02     +0.5    0.04
   44.5      -50.92     +0.03     +0.6    0.04
   48.0      -50.99     -0.07     +3.5   -0.02
   49.6      -51.00     -0.00     +1.6   -0.00

============================================================
Results saved to: beacon_cal_20260717_205153.csv

Optimal gain        : 0.9 dB
Noise floor @ knee  : -64.0 dBFS
Suggested threshold: -54.0 dBFS  (noise + 10 dB margin)

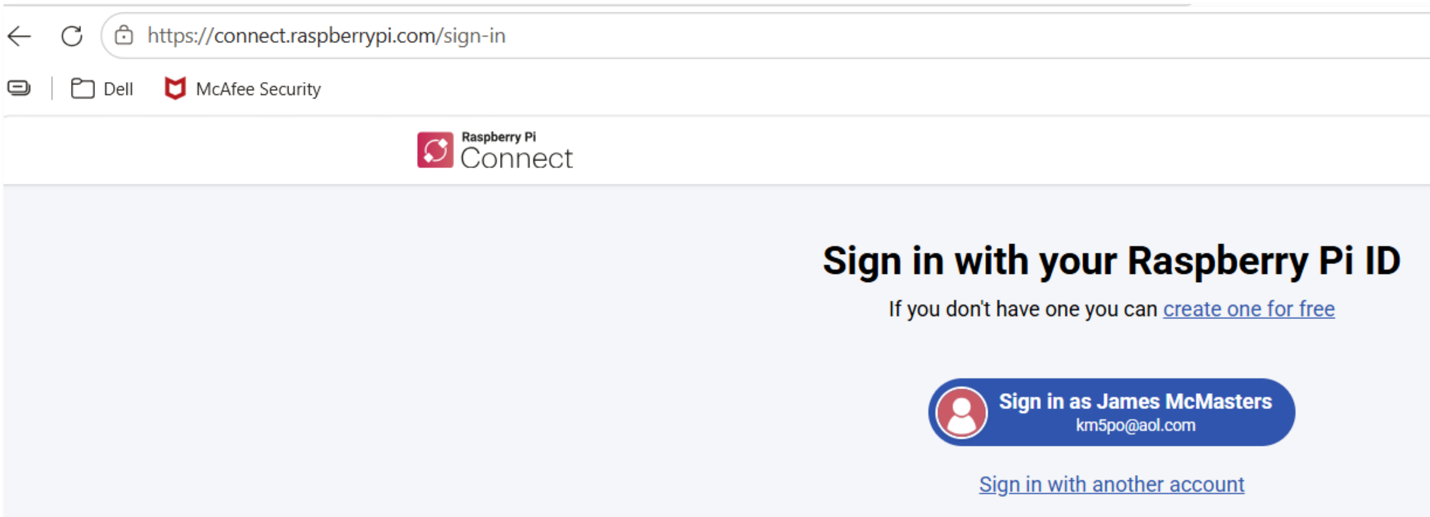
Add to your beacon_monitor.py command line:
  --gain 0.9 --threshold -54.0
============================================================
```

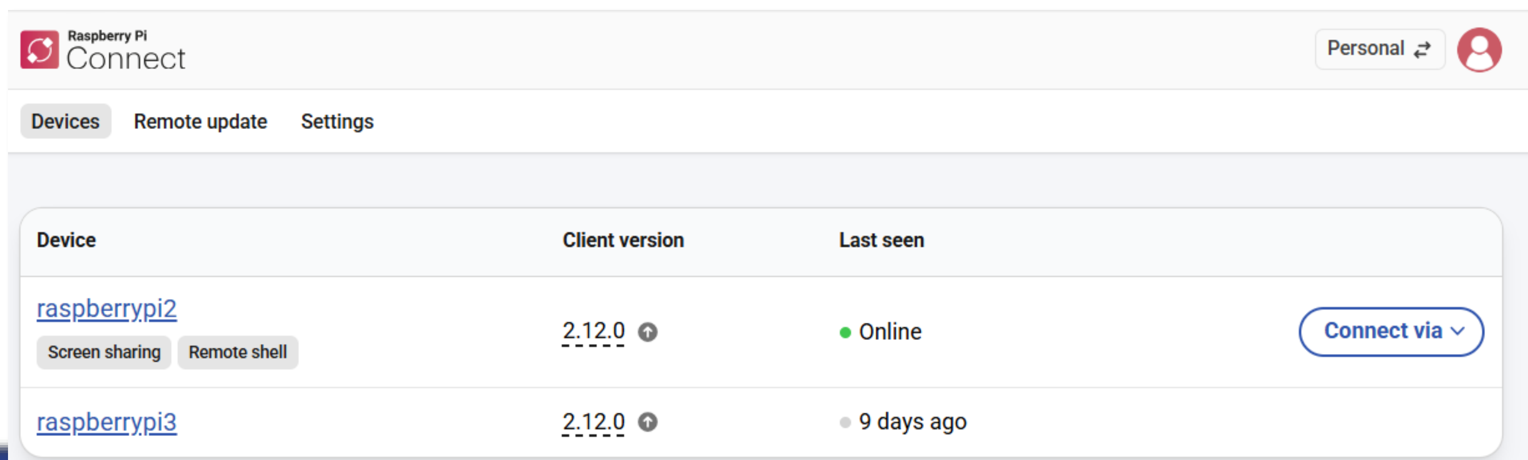
Rpi connectivity options

- Headless operation
  - Rpi ***Connect***
    - Create account at Raspberrypi.com.
    - Register your device.
  - Internal network
    - Home WIFI, all devices attached to local WIFI.
    - Field operation, all devices attached to cell phone hot spot
  - Other options exist.
- Add monitor and keyboard if necessary!

Raspberry Pi *Connect*

- Create an account for free, list devices.





Raspberry Pi *Connect*

- Open a “remote Shell”

raspberrypi2 remote shell – Raspberry Pi Connect - Personal - Microsoft Edge

https://connect.raspberrypi.com/devices/1789bfa2-789a-4d74-8732-f346789ef6f0/remote-sh...

```
km5po@raspberrypi2:~ $ tail -5 /var/lib/ntms-beacon/beacon_log.csv
2026-07-16T13:01:07.664Z,KM5PO-10G-BURLESON,CW,2,144360000,-23.53,,,1,144360000,9750.000,
9894360000
2026-07-16T13:01:07.664Z,KM5PO-10G-BURLESON,CW,3,144378000,-39.34,,,1,144360000,9750.000,
9894378000
2026-07-16T13:01:12.664Z,KM5PO-10G-BURLESON,CARRIER,1,144354000,-10.38,0,,1,144360000,975
0.000,9894354000
2026-07-16T13:01:12.664Z,KM5PO-10G-BURLESON,CARRIER,2,144360000,-23.33,,,1,144360000,9750
.000,9894360000
2026-07-16T13:01:12.664Z,KM5PO-10G-BURLESON,CARRIER,3,144378000,-38.51,,,1,144360000,9750
.000,9894378000
km5po@raspberrypi2:~ $
```

Raspberry Pi *Connect*

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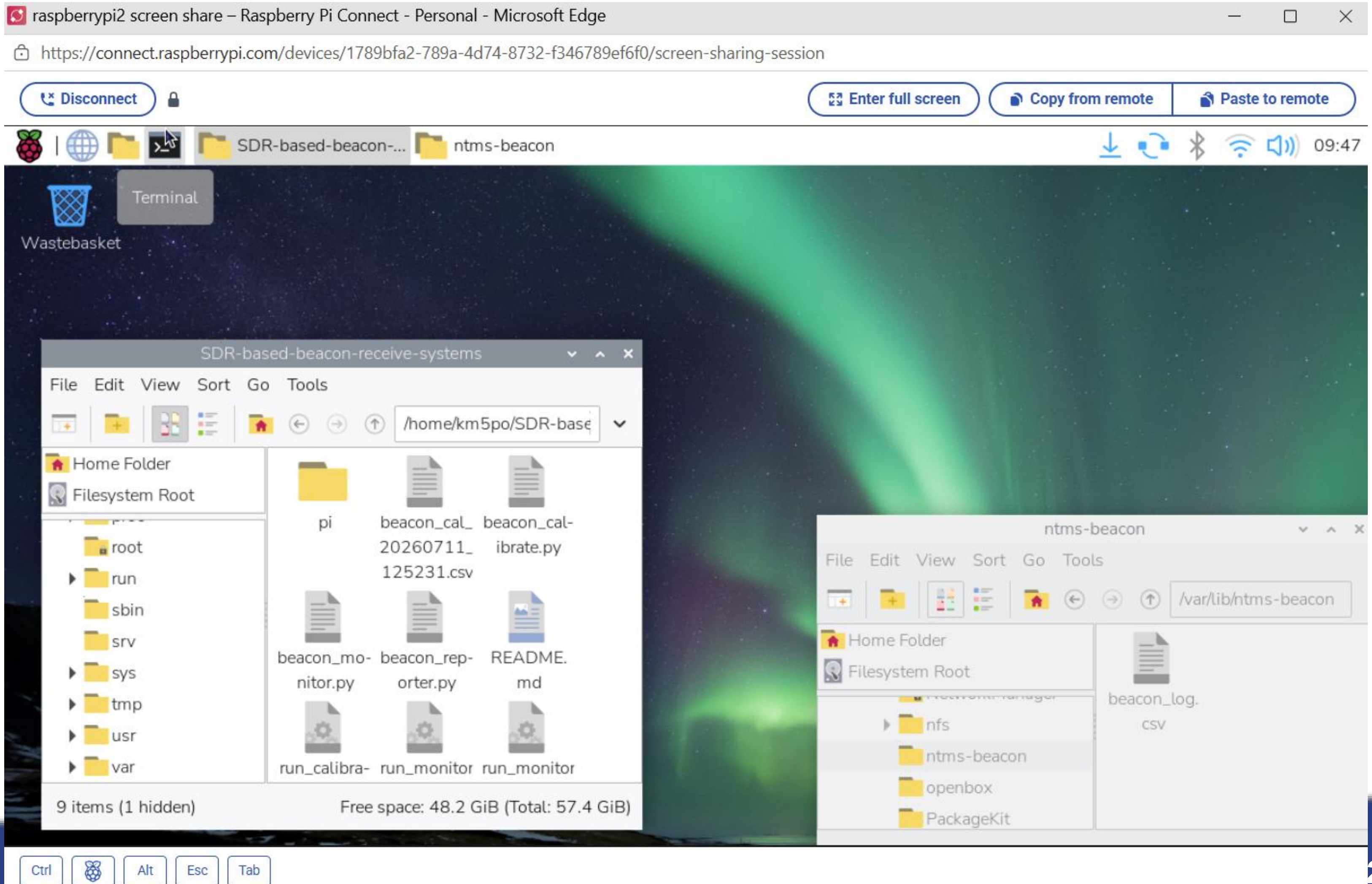
- Open "desktop sharing"



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Terminal tools – you can always use a CMD terminal

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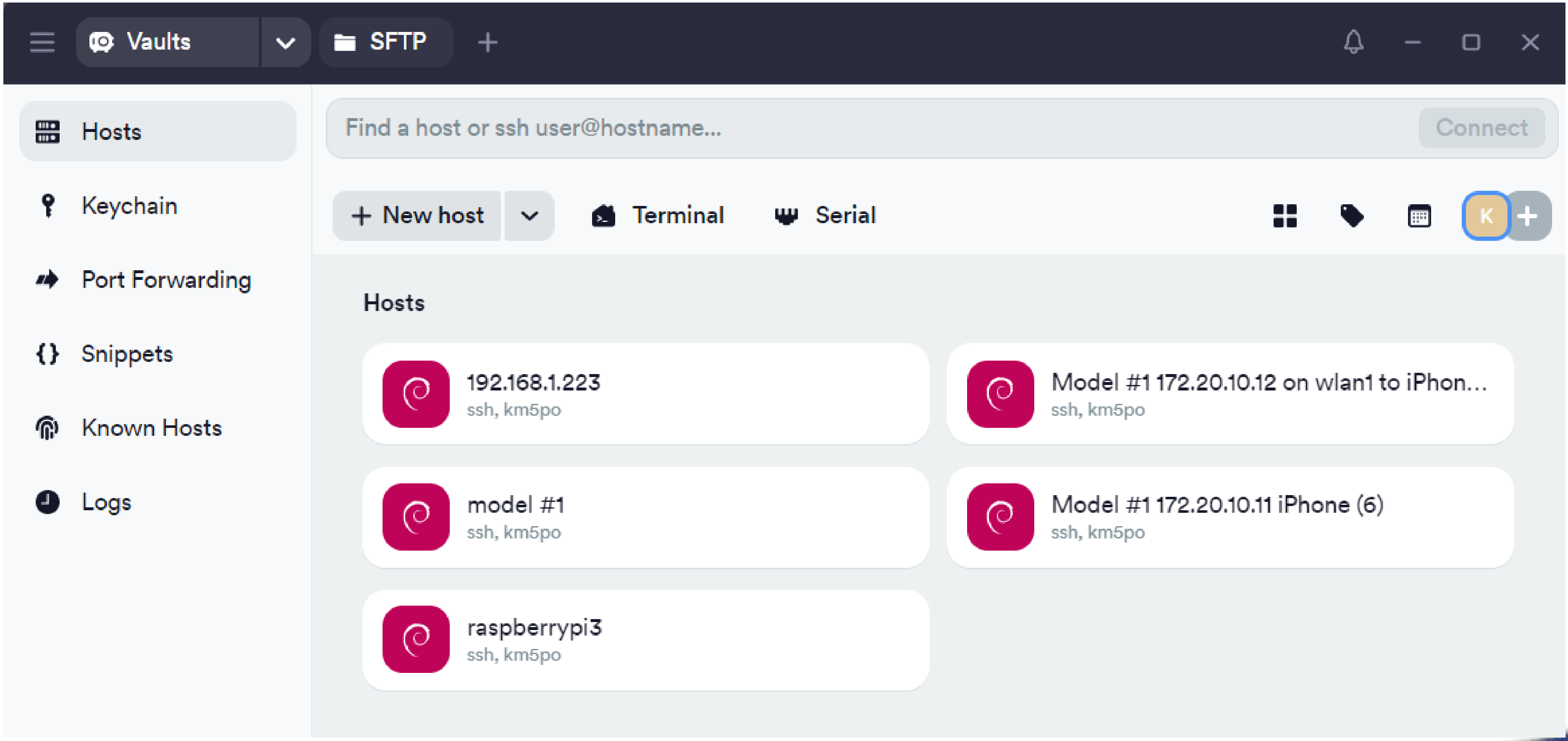
- “Termius” on laptop, after creating devices, double-click!



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Rpi connectivity

- Termius terminal on Laptop

```
Presentation last saved: Just now
Vaults   SFTP   192.168.1.223

Linux raspberrypi2 6.18.34+rpt-rpi-v8 #1 SMP PREEMPT Debian 1:6.18.34-1+rpt1 (2026-06-09) aarch64

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Wed Jul 15 12:05:37 2026 from 192.168.1.195
km5po@raspberrypi2:~ $ ls
Desktop    Downloads  Music     Public                            Templates
Documents  librtlsdr  Pictures  SDR-based-beacon-receive-systems  Videos
km5po@raspberrypi2:~ $
```

```
km5po@raspberrypi2:~ $ cd ~/SDR-based-beacon-receive-systems
km5po@raspberrypi2:~/SDR-based-beacon-receive-systems $ ls
beacon_cal_20260711_125231.csv  beacon_monitor.py   pi         run_calibrate.sh  run_monitor.sh.save
beacon_calibrate.py             beacon_reporter.py  README.md  run_monitor.sh
km5po@raspberrypi2:~/SDR-based-beacon-receive-systems $
```

Termius in use


```
Vaults   SFTP   192.168.1.223

GNU nano 8.4                          run_monitor.sh
#!/bin/bash
# NTMS Beacon Monitor — manual start script
# Edit the options below, then run:  bash ~/SDR-based-beacon-receive-systems/run_monitor.sh

PYTHON=/opt/ntms-beacon/venv/bin/python3
SCRIPT=/opt/ntms-beacon/beacon_monitor.py

# --- Site ---
LOCATION="KM5PO-10G-BURLESON"

# --- RF chain ---
FREQ=144.360 #618.245        # IF center frequency (MHz) after Bullseye LNB
LO=9750.0           # LNB LO frequency (MHz)
PPM=0               # PPM correction (0 for TCXO; 1-2 for standard crystal)

# --- SDR gain and detection ---
# Run beacon_calibrate.py to find optimal values for your setup.
GAIN=36.4          # R820T2 gain in dB (or: auto) was 36.4
THRESHOLD=-50 #-35.0     # Detection threshold in dBFS

# --- Sweep ---
INTERVAL=5          # Sweep interval in seconds
MAX_SIGNALS=3       # Max signals to detect per sweep (1-5)
SPAN=100 #2000          # Analysis span in kHz (2000 = full 2 MHz capture)

# --- Output ---
                                   [ Read 40 lines ]
^G Help        ^O Write Out   ^F Where Is    ^K Cut         ^T Execute     ^C Location    M-U Undo
^X Exit        ^R Read File   ^\ Replace     ^U Paste       ^J Justify     ^/ Go To Line  M-E Redo
```

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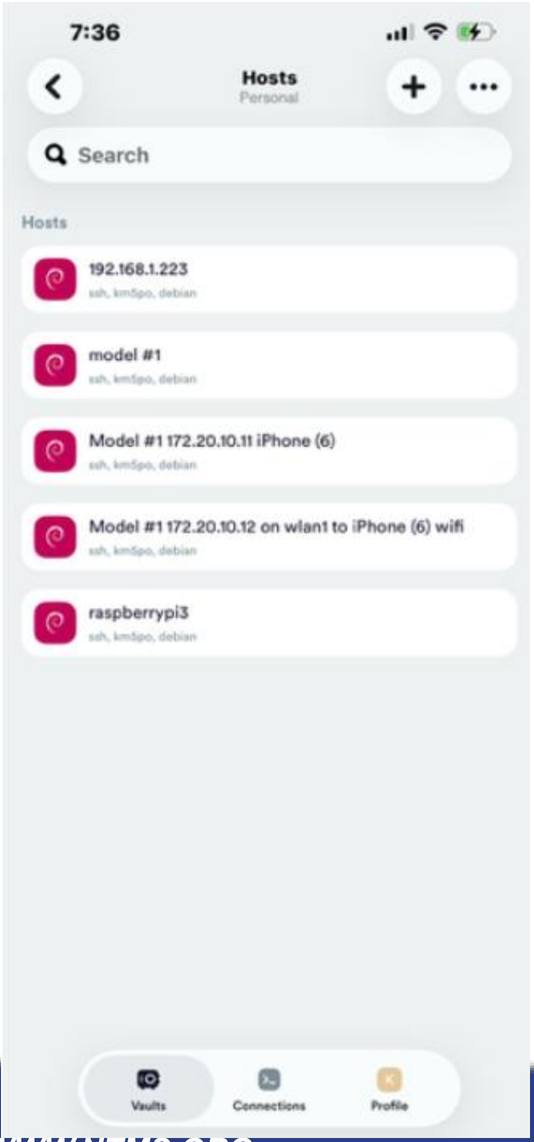
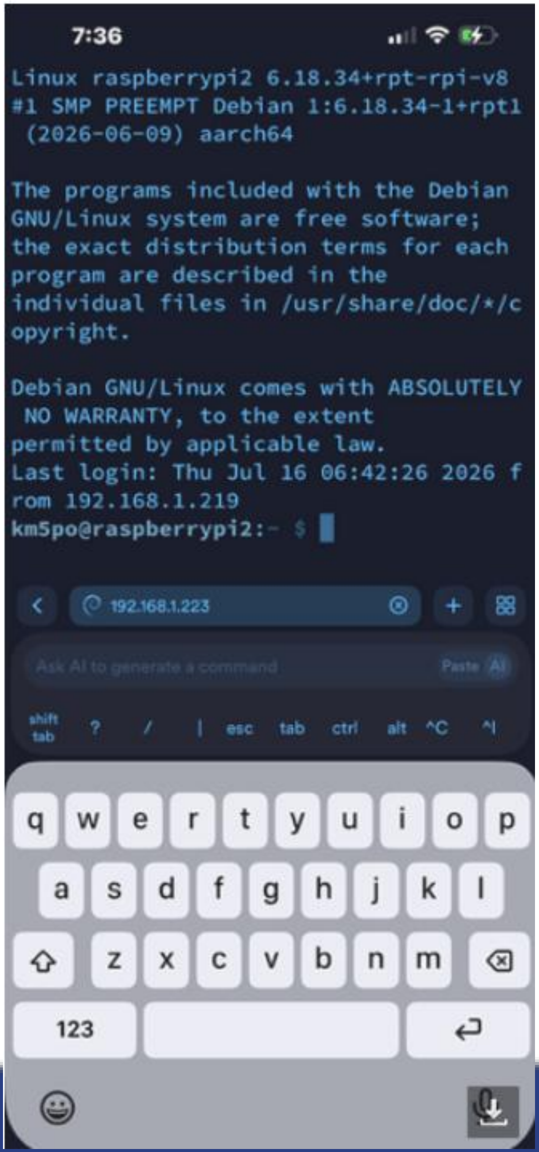
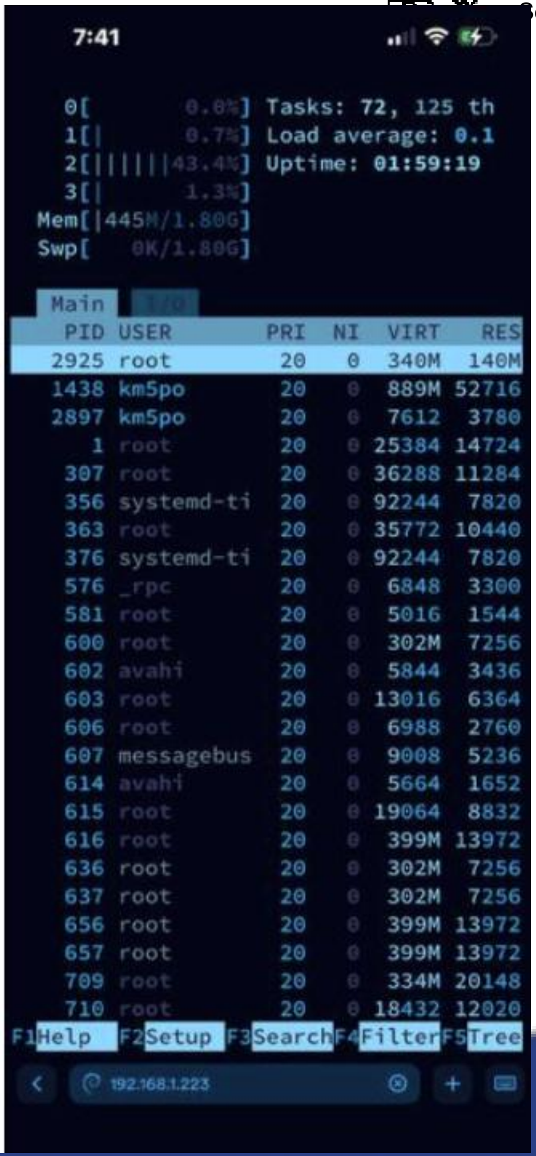
Termius on cell phone







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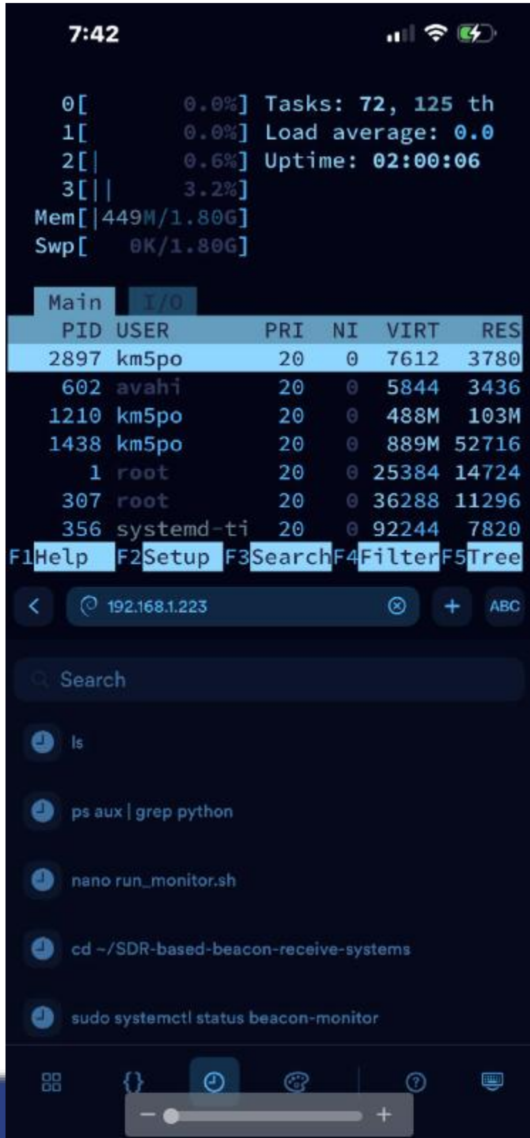

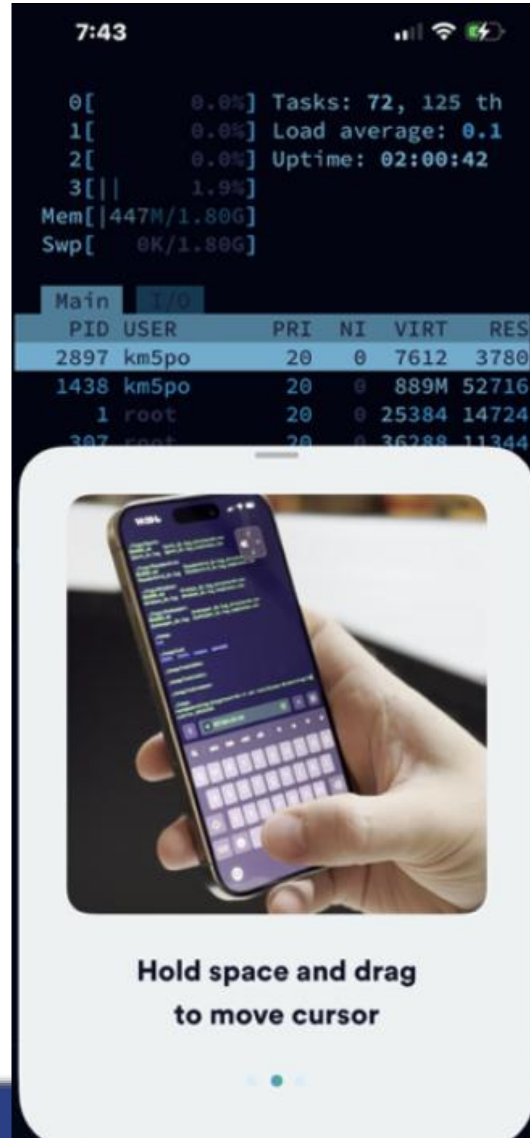

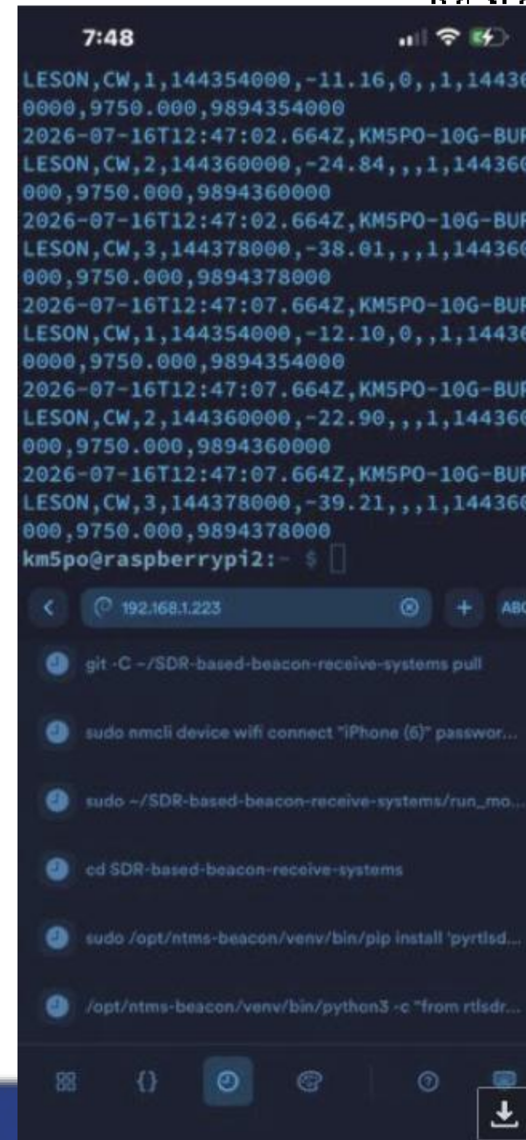

Test setup for demo

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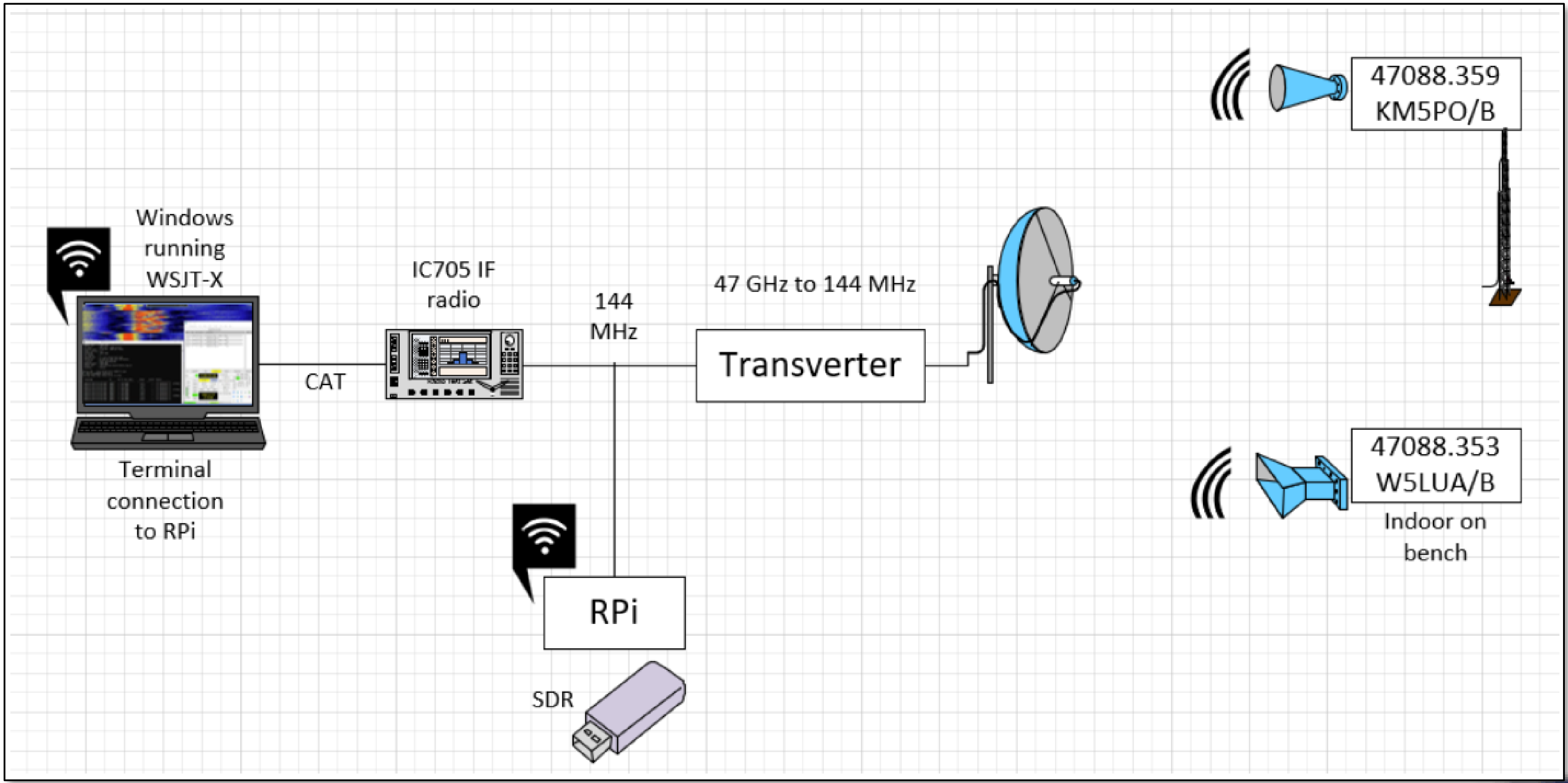
A splitter was used to feed transverter output two directions



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The two 47 GHz beacons

- Outdoor KM5PO/B 47088.359
- Indoor W5LUA/B 47088.353

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Demo

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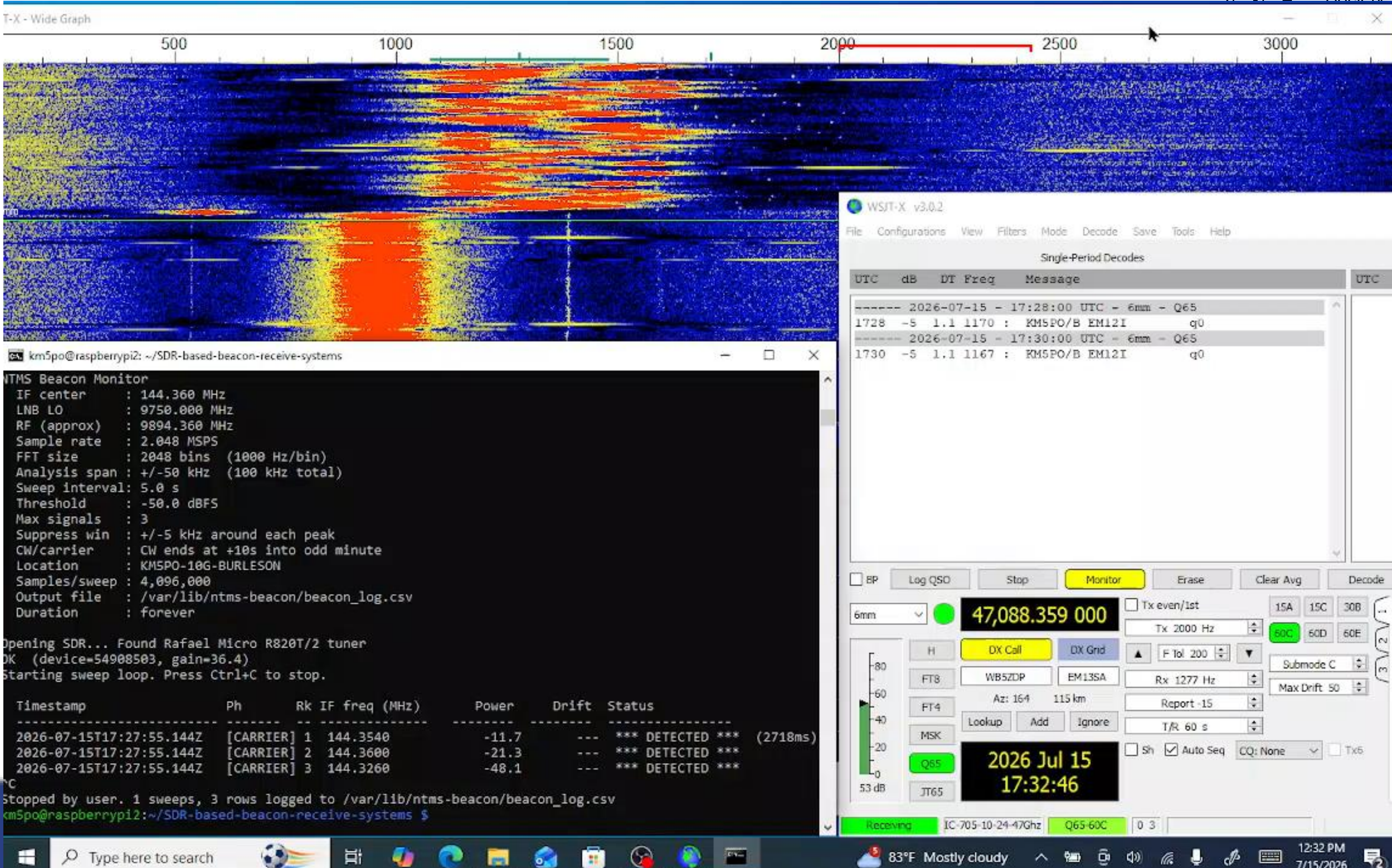

Beacon monitor options

- From the beacon_monitor.sh shell script
- Pre-configured by NTMS – ready to go

```
# --- Output ---
OUTPUT=/var/lib/ntms-beacon/beacon_log.csv

# --- Run ---
sudo $PYTHON $SCRIPT \
    --location   "$LOCATION" \
    --freq       $FREQ \
    --lo         $LO \
    --ppm        $PPM \
    --gain       $GAIN \
    --threshold  $THRESHOLD \
    --interval   $INTERVAL \
    --max-signals $MAX_SIGNALS \
    --span       $SPAN \
    --output     "$OUTPUT"
```

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Beacon monitor options

- Shell script options are printed to screen output at startup

Administrator: Command Prompt

```
km5po@raspberrypi2:~/SDR-based-beacon-receive-systems $ sudo ~/SDR-based-beacon-receive-systems/run_monit
or.sh
NTMS Beacon Monitor
  IF center      : 144.360 MHz
  LNB LO         : 9750.000 MHz
  RF (approx)    : 9894.360 MHz
  Sample rate    : 2.048 MSPS
  FFT size       : 2048 bins  (1000 Hz/bin)
  Analysis span  : +/-50 kHz  (100 kHz total)
  Sweep interval: 5.0 s
  Threshold      : -50.0 dBFS
  Max signals    : 3
  Suppress win   : +/-5 kHz around each peak
  CW/carrier     : CW ends at +10s into odd minute
  Location       : KM5PO-10G-BURLESON
  Samples/sweep  : 4,096,000
  Output file    : /var/lib/ntms-beacon/beacon_log.csv
  Duration       : forever

Opening SDR... Found Rafael Micro R820T/2 tuner
OK  (device=54908503, gain=36.4)
Starting sweep loop. Press Ctrl+C to stop.

  Timestamp                  Ph       Rk IF freq (MHz)       Power     Drift   Status
  -------------------------- -------  -- -------------    --------  --------  ----------------
  2026-07-15T17:32:49.765Z   [Q65]    1  144.3540           -12.3       ---   *** DETECTED ***   (2713ms)
  2026-07-15T17:32:49.765Z   [Q65]    2  144.3600           -22.9       ---   *** DETECTED ***
  2026-07-15T17:32:49.765Z   [Q65]    3  144.3270           -48.7       ---   *** DETECTED ***
  2026-07-15T17:32:54.765Z   [Q65]    1  144.3540           -11.8       ---   *** DETECTED ***   (2713ms)
```

SDR programmed IF frequency
Not important
SDR span to sweep
Sweep trigger
Sensitivity, max sigs, suppress window

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Beacon monitor display

Administrator: Command Prompt

```
OK  (device=54908503, gain=36.4)
Starting sweep loop. Press Ctrl+C to stop.

  Timestamp                 Ph      Rk IF freq (MHz)       Power     Drift  Status
  ------------------------- ------- -- -------------     ---------  -------- ---------------
  2026-07-15T17:32:49.765Z  [Q65]    1 144.3540            -12.3       ---  *** DETECTED ***  (2713ms)
  2026-07-15T17:32:49.765Z  [Q65]    2 144.3600            -22.9       ---  *** DETECTED ***
  2026-07-15T17:32:49.765Z  [Q65]    3 144.3270            -48.7       ---  *** DETECTED ***
  2026-07-15T17:32:54.765Z  [Q65]    1 144.3540            -11.8       ---  *** DETECTED ***  (2713ms)
  2026-07-15T17:32:54.765Z  [Q65]    2 144.3600            -22.0       ---  *** DETECTED ***
  2026-07-15T17:32:54.765Z  [Q65]    3 144.3260            -48.0       ---  *** DETECTED ***
  2026-07-15T17:32:59.765Z  [Q65]    1 144.3540            -12.2       ---  *** DETECTED ***  (2650ms)
  2026-07-15T17:32:59.765Z  [Q65]    2 144.3600            -21.9       ---  *** DETECTED ***
  2026-07-15T17:32:59.765Z  [Q65]    3 144.3480            -41.9       ---  *** DETECTED ***
  2026-07-15T17:33:04.765Z  [CW]     1 144.3540            -14.1       ---  *** DETECTED ***  (2660ms)
  2026-07-15T17:33:04.765Z  [CW]     2 144.3600            -18.6       ---  *** DETECTED ***
  2026-07-15T17:33:04.765Z  [CW]     3 144.3480            -42.4       ---  *** DETECTED ***
  2026-07-15T17:33:09.765Z  [CW]     1 144.3540            -13.0       ---  *** DETECTED ***  (2660ms)
  2026-07-15T17:33:09.765Z  [CW]     2 144.3600            -20.4       ---  *** DETECTED ***
  2026-07-15T17:33:09.765Z  [CW]     3 144.3480            -42.0       ---  *** DETECTED ***
  2026-07-15T17:33:14.765Z  [CARRIER] 1  144.3540            -14.3       ---  *** DETECTED ***  (2665ms)
  2026-07-15T17:33:14.765Z  [CARRIER] 2  144.3600            -19.4       ---  *** DETECTED ***
  2026-07-15T17:33:14.765Z  [CARRIER] 3  144.3480            -40.9       ---  *** DETECTED ***
  2026-07-15T17:33:19.765Z  [CARRIER] 1  144.3540            -11.9        +0  *** DETECTED ***  (2680ms)
  2026-07-15T17:33:19.765Z  [CARRIER] 2  144.3600            -21.8       ---  *** DETECTED ***
  2026-07-15T17:33:19.765Z  [CARRIER] 3  144.3260            -48.1       ---  *** DETECTED ***
  2026-07-15T17:33:24.765Z  [CARRIER] 1  144.3540            -11.8        +0  *** DETECTED ***  (2618ms)
  2026-07-15T17:33:24.765Z  [CARRIER] 2  144.3600            -22.2       ---  *** DETECTED ***
  2026-07-15T17:33:24.765Z  [CARRIER] 3  144.3260            -48.0       ---  *** DETECTED ***
```

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Excel beacon log

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/var/lib/ntms-beacon/beacon_log.csv

	A	B	C	D	E	F	G	H	I	J
1	timestamp_utc	monitor location	phase	rank	IF frequency	Actual	dBFS	over thresh		
2	2026-07-15T00:00:01.586Z	KM5PO-EM12IL56EI	Q65	1	144360000	144.353	-29.41	1		
3	2026-07-15T00:00:01.586Z	KM5PO-EM12IL56EI	Q65	2	144366000	144.359	-48.63	1		
4	2026-07-15T00:00:01.586Z	KM5PO-EM12IL56EI	Q65	3	144334000	144.327	-56.62	0		
5	2026-07-15T00:00:06.586Z	KM5PO-EM12IL56EI	Q65	1	144360000		-30.94	1		
6	2026-07-15T00:00:06.586Z	KM5PO-EM12IL56EI	Q65	2	144366000		-48.58	1		
7	2026-07-15T00:00:06.586Z	KM5PO-EM12IL56EI	Q65	3	144328000		-56.83	0		
8	2026-07-15T00:00:11.586Z	KM5PO-EM12IL56EI	Q65	1	144360000		-28.87	1		
9	2026-07-15T00:00:11.586Z	KM5PO-EM12IL56EI	Q65	2	144366000		-49.06	1		
10	2026-07-15T00:00:11.586Z	KM5PO-EM12IL56EI	Q65	3	144328000		-56.80	0		
11	2026-07-15T00:00:16.586Z	KM5PO-EM12IL56EI	Q65	1	144360000		-30.31	1		
12	2026-07-15T00:00:16.586Z	KM5PO-EM12IL56EI	Q65	2	144366000		-49.06	1		
13	2026-07-15T00:00:16.586Z	KM5PO-EM12IL56EI	Q65	3	144335000		-56.95	0		
14	2026-07-15T00:00:21.586Z	KM5PO-EM12IL56EI	Q65	1	144360000		-30.20	1		
15	2026-07-15T00:00:21.586Z	KM5PO-EM12IL56EI	Q65	2	144366000		-48.35	1		
16	2026-07-15T00:00:21.586Z	KM5PO-EM12IL56EI	Q65	3	144380000		-56.82	0		
17	2026-07-15T00:00:26.586Z	KM5PO-EM12IL56EI	Q65	1	144360000		-29.85	1		
18	2026-07-15T00:00:26.586Z	KM5PO-EM12IL56EI	Q65	2	144366000		-48.27	1		
19	2026-07-15T00:00:26.586Z	KM5PO-EM12IL56EI	Q65	3	144334000		-56.78	0		
20	2026-07-15T00:00:31.586Z	KM5PO-EM12IL56EI	Q65	1	144360000		-28.24	1		
21	2026-07-15T00:00:31.586Z	KM5PO-EM12IL56EI	Q65	2	144366000		-48.26	1		
22	2026-07-15T00:00:31.586Z	KM5PO-EM12IL56EI	Q65	3	144392000		-56.84	0		

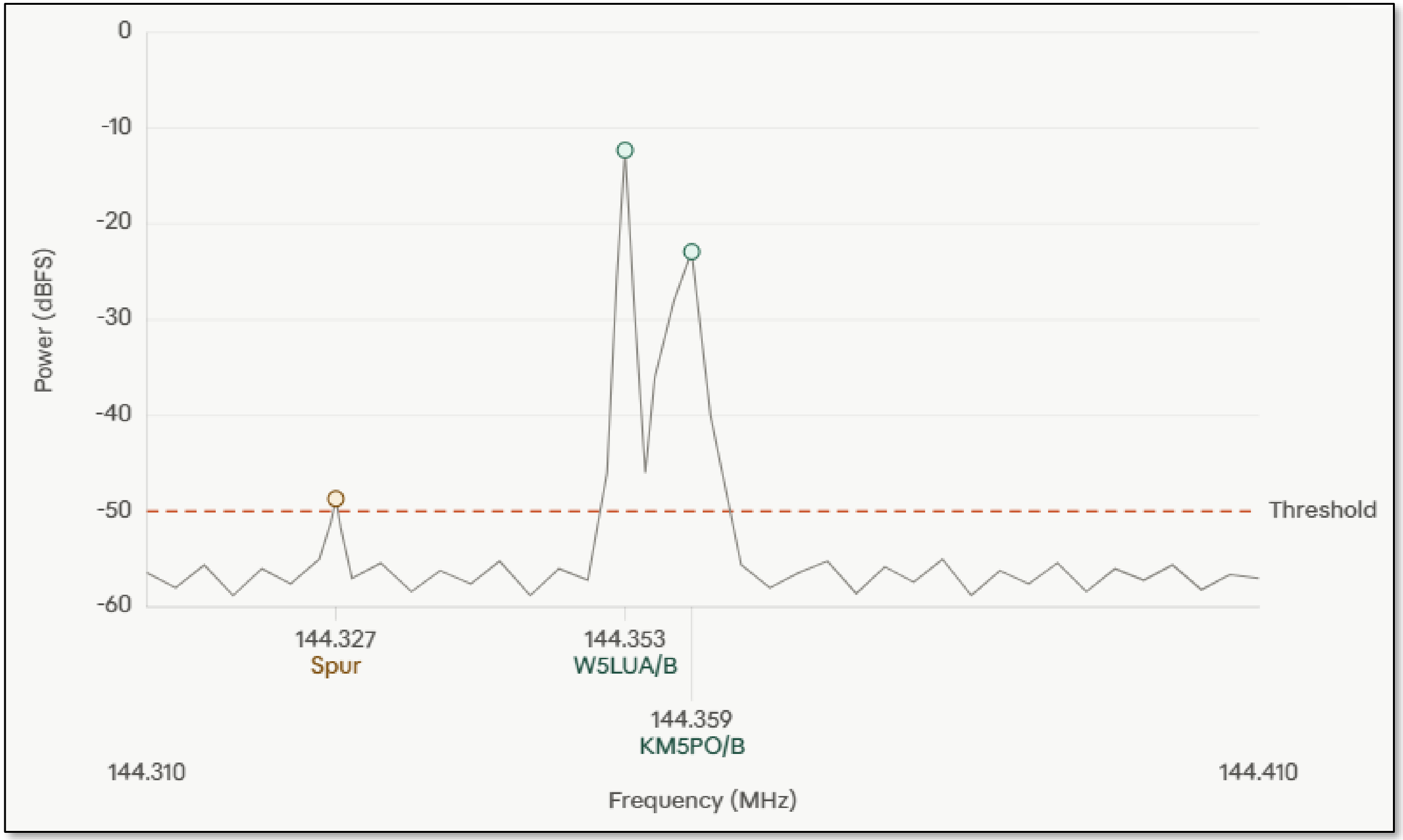
Transfer beacon log to PC

Open Power Shell window on PC

scp km5po@raspberrypi2.local:/var/lib/ntms-beacon/beacon_log.csv C:\Users\km5po\Downloads\beacon_log2.csv

```
PS C:\Users\km5po\q65analysis> scp km5po@raspberrypi2.local:/var/lib/ntms-beacon/beacon_log.csv C:\Users\km5po\Downloads
\beacon_log2.csv
km5po@raspberrypi2.local's password:
beacon_log.csv                                                                          100%  308KB   3.8MB/s   00:00
PS C:\Users\km5po\q65analysis> |
```

How it sweeps spectrum



How it sweeps spectrum

- Step 1 Compute averaged power spectrum from IQ samples.
  - Splits the sample buffer into non-overlapping FFT frames, windows each, computes magnitude squared, and averages across frames.
- Returns:
  - freqs_offset: array of frequency offsets from center (Hz), FFT-shifted. power_db: array of power values in dBFS (dB relative to full scale).

- Step 2 Find up to max_signals peaks within +/-(span/2) of center using iterative peak suppression.
- Algorithm:
  - 1. Find strongest peak in span.
  - 2. Suppress +/-suppress_hz bins around it (zero them out in a copy).
  - 3. Repeat up to max_signals times.
- Returns:
  - list of (peak_freq_hz, peak_power_dbfs) tuples, strongest first. Always returns at least one entry.

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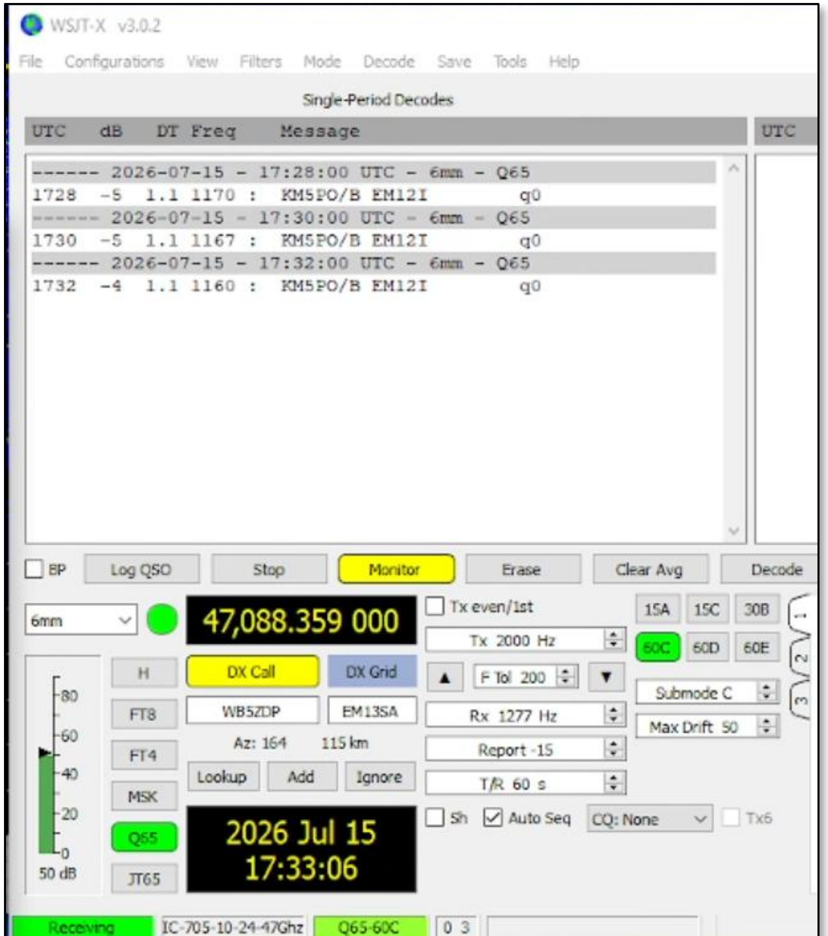
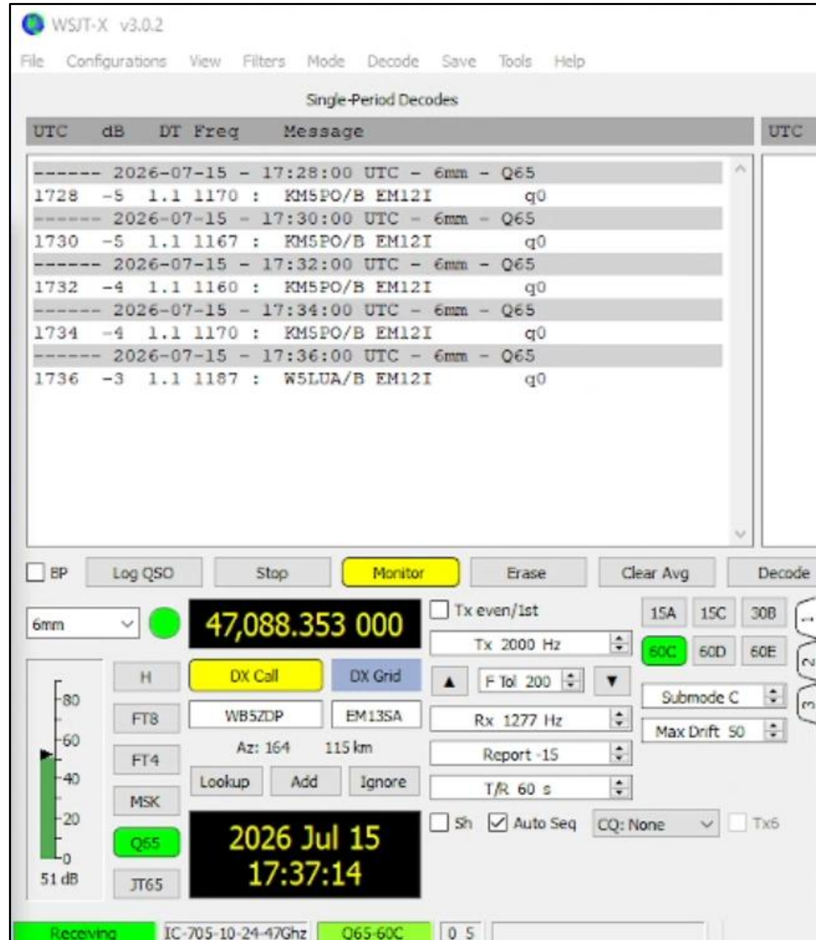
Decodes from demo





Beacon field observations

- Estimated beacon coverage vs observed.
- Estimated coverage from Radio Mobile
  - VE2DBE tool set
- NTMS/W5ISP propagation predictions revealed upcoming conditions.
- We saw normal and enhanced conditions.
- Rover reception vs. beacon monitor observations.

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Denton 10 GHz beacon

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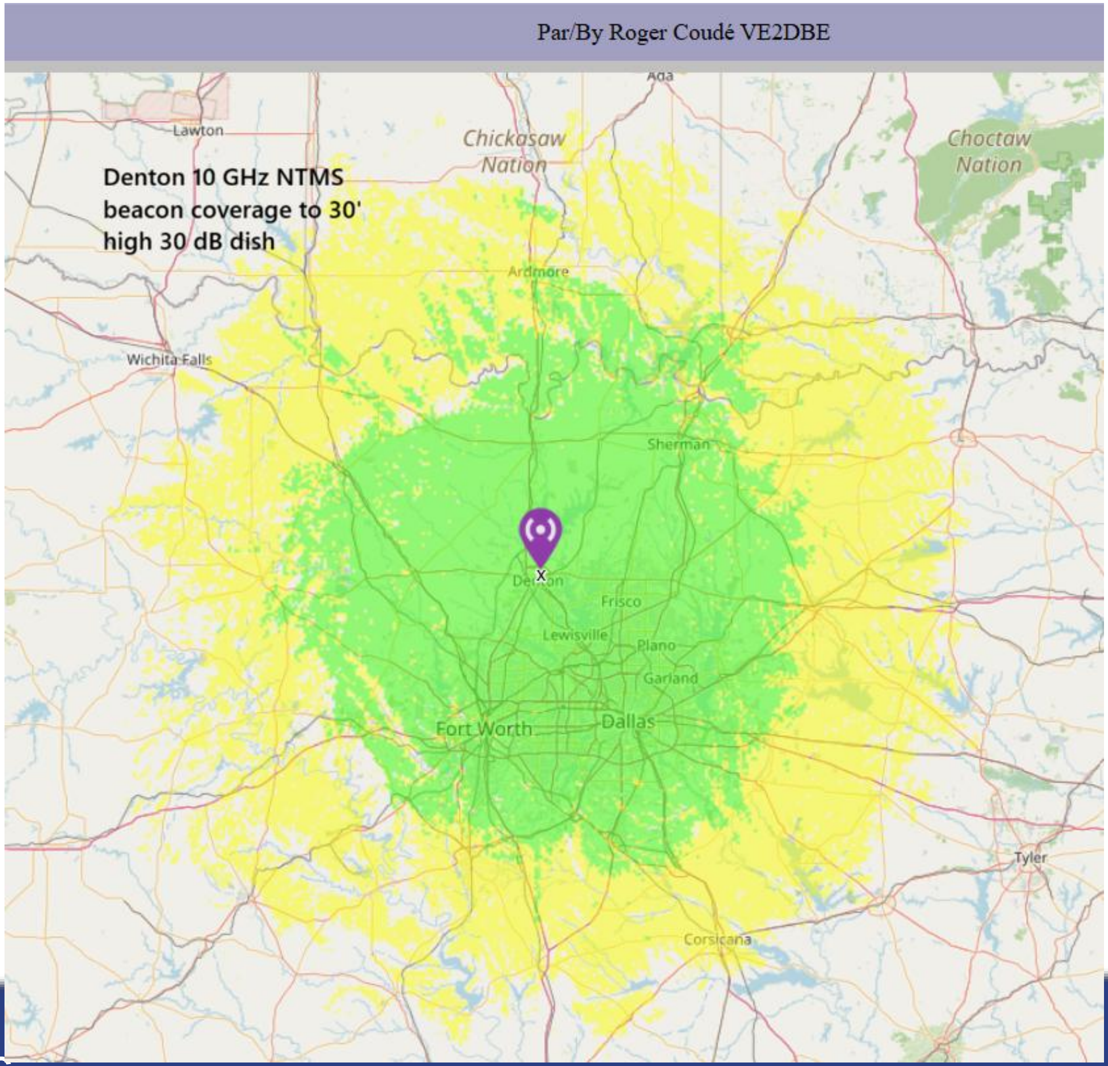

Observations – normal conditions

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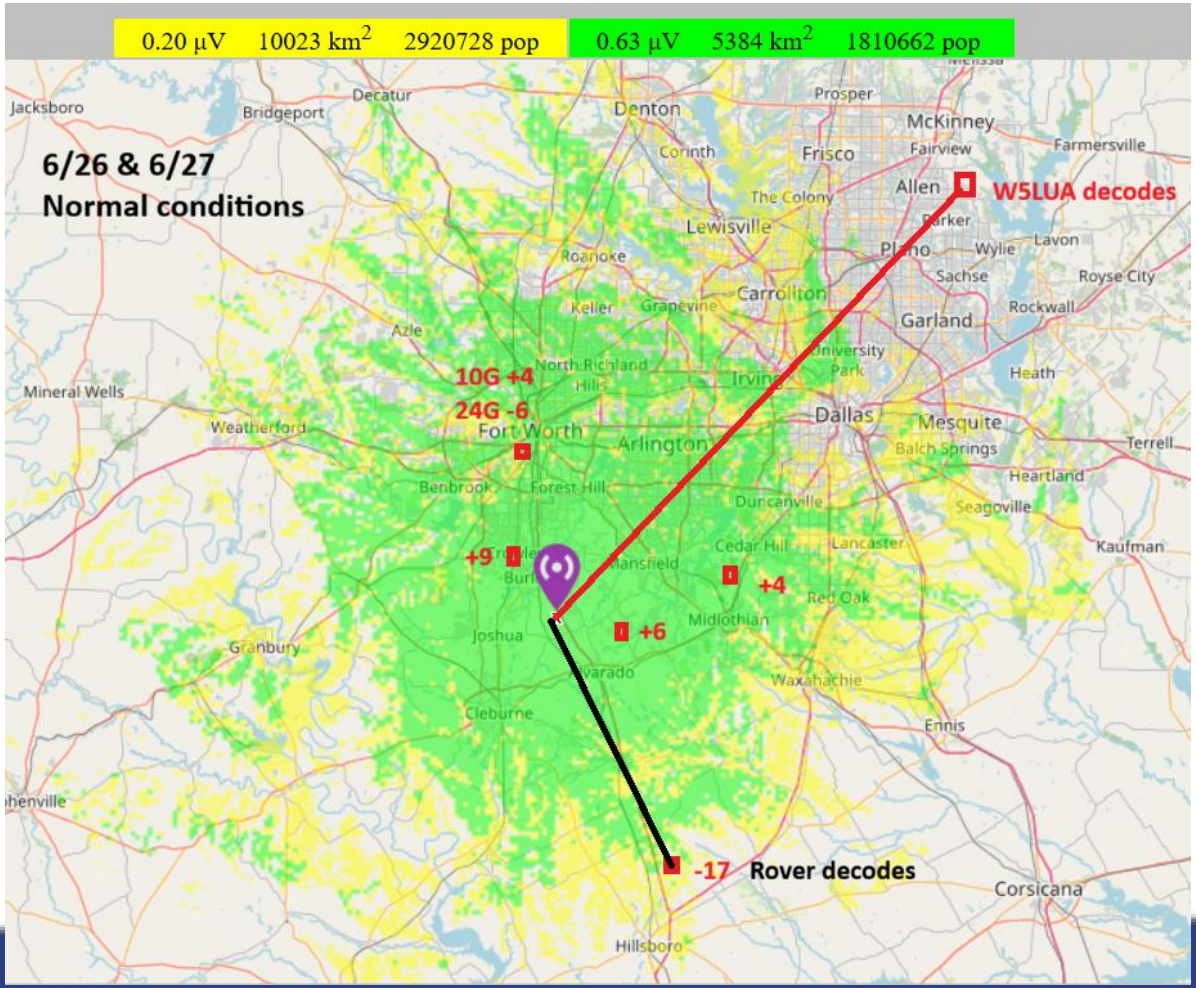
- 6-26 and 6-27 - ***Normal conditions***, W5LUA best -21



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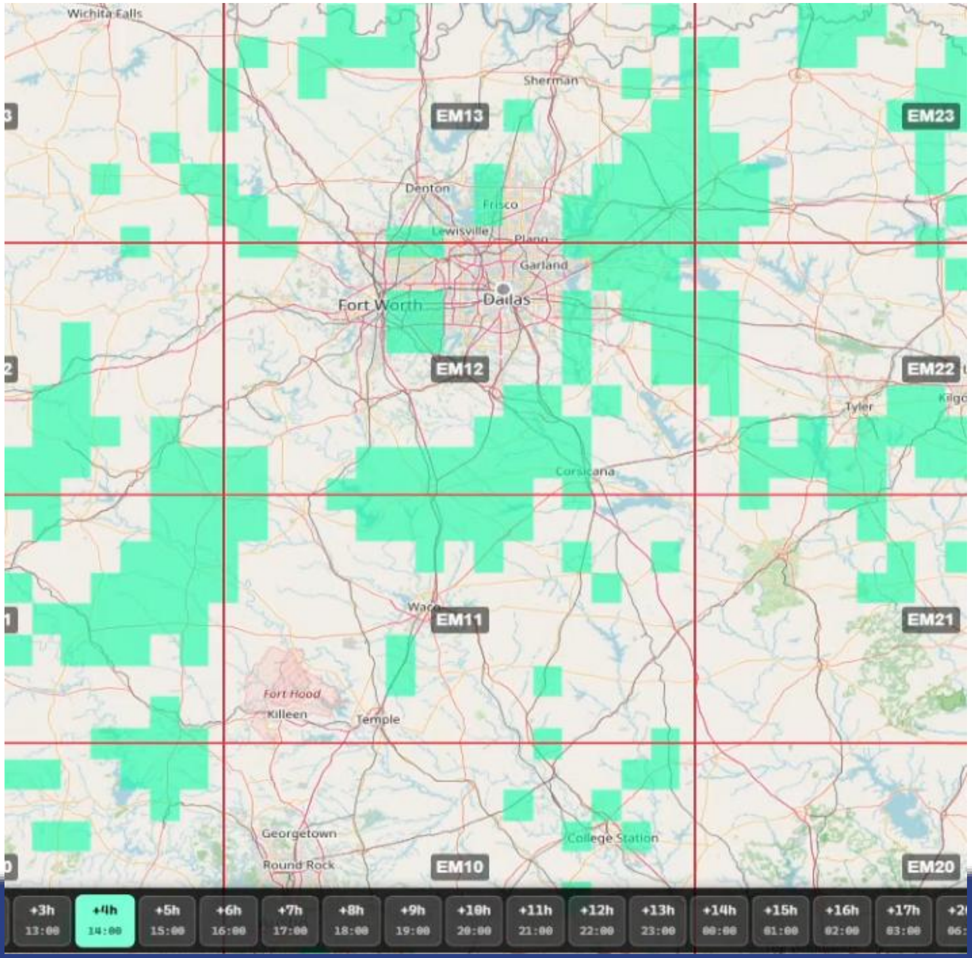
NTMS/W5ISP prediction –June 30 4:45 am current for + 4 hours

- Ducting metrics predicted at approx. 9:00 am CDT



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NTMS/W5ISP prediction –June 30 4:45 am current for + 4 hours

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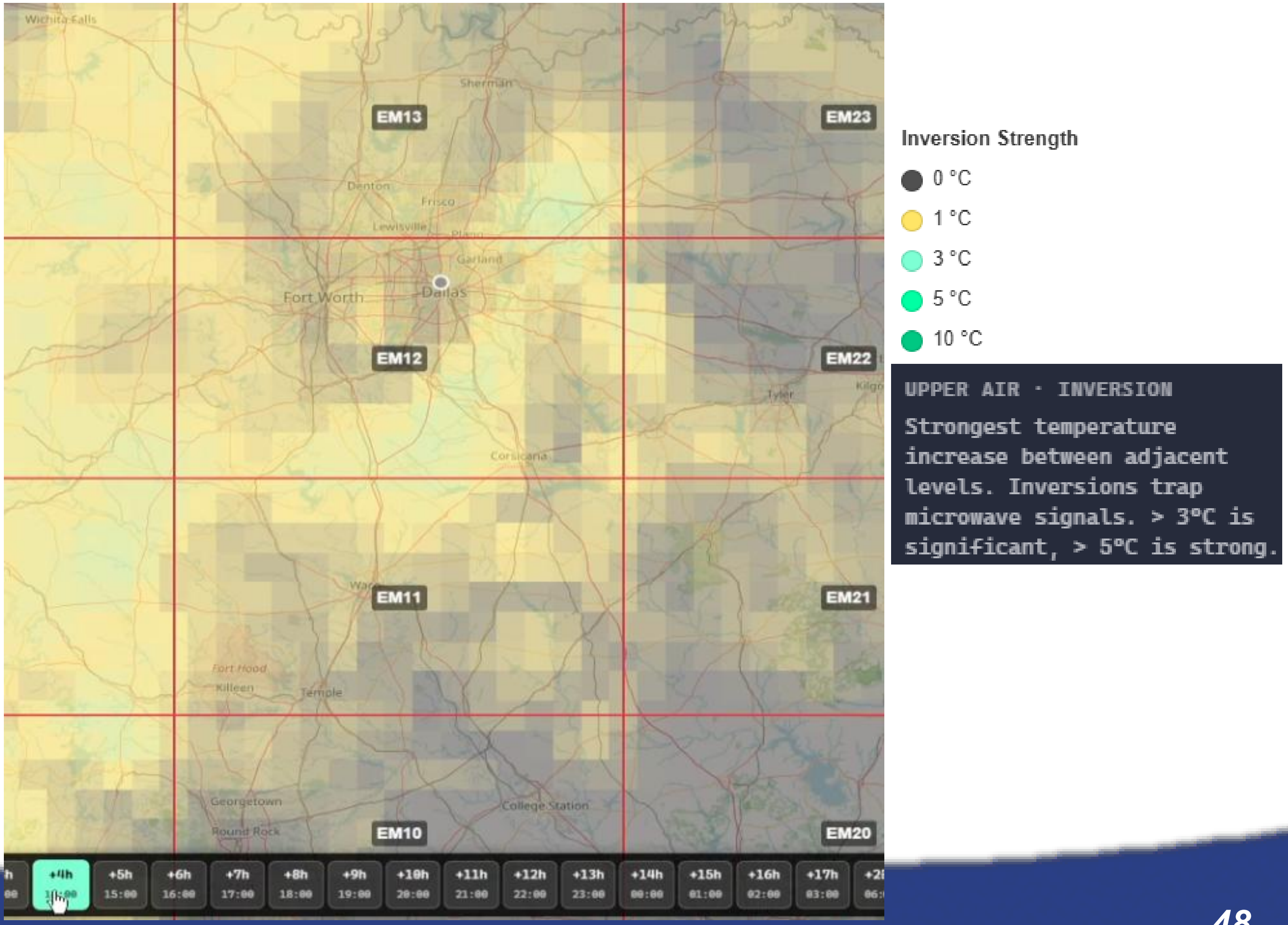
- Inversion strength metrics predicted at approx. 9:00 am CDT



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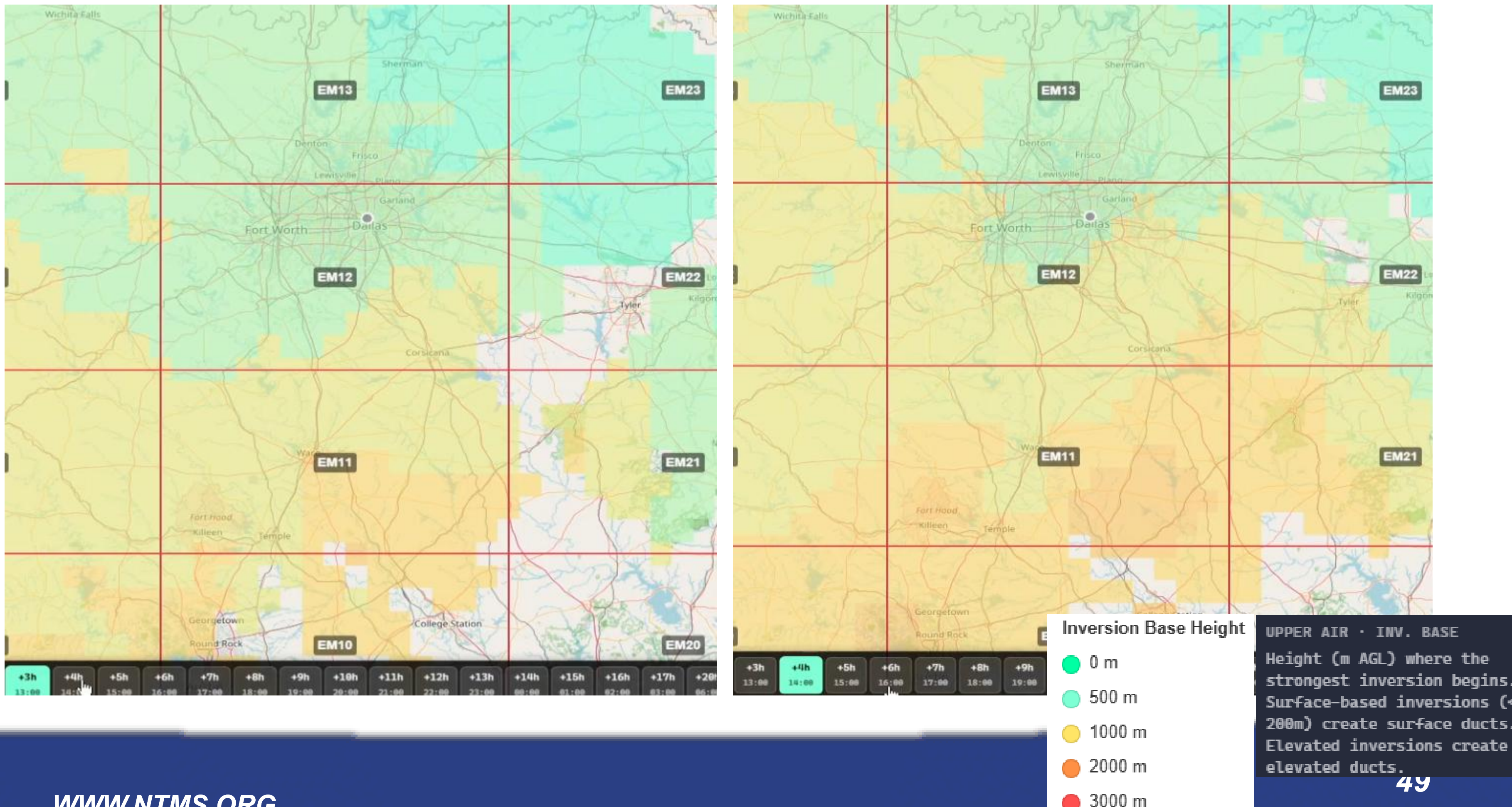
NTMS/W5ISP prediction –June 30 4:45 am current for + 4 hours

- Inversion base (height) metrics predicted at approx. 9:00 am CDT



Observations – 6/30/26 *enhanced* conditions

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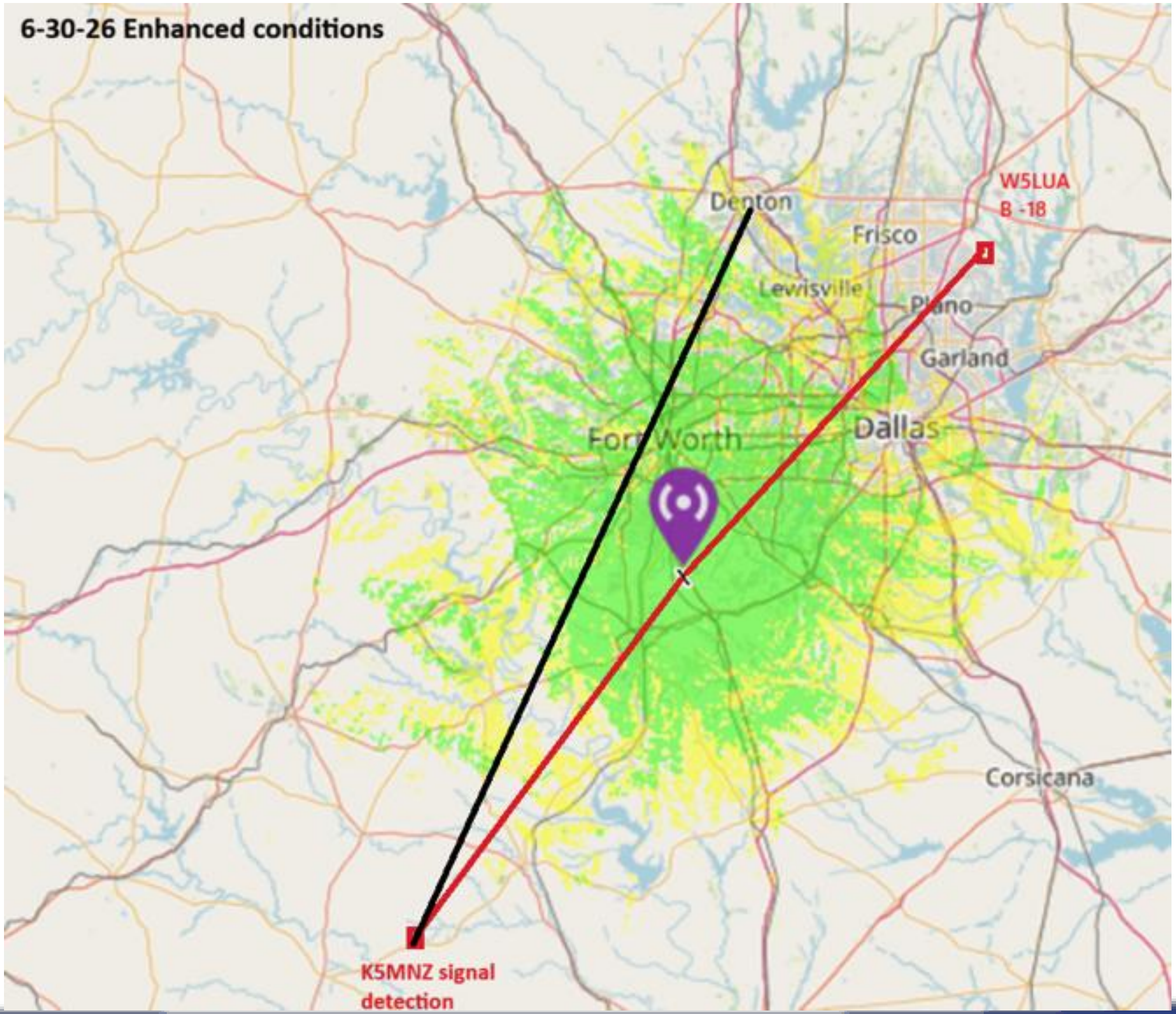

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Original algorithm NTMS findings for W5LUA obs.

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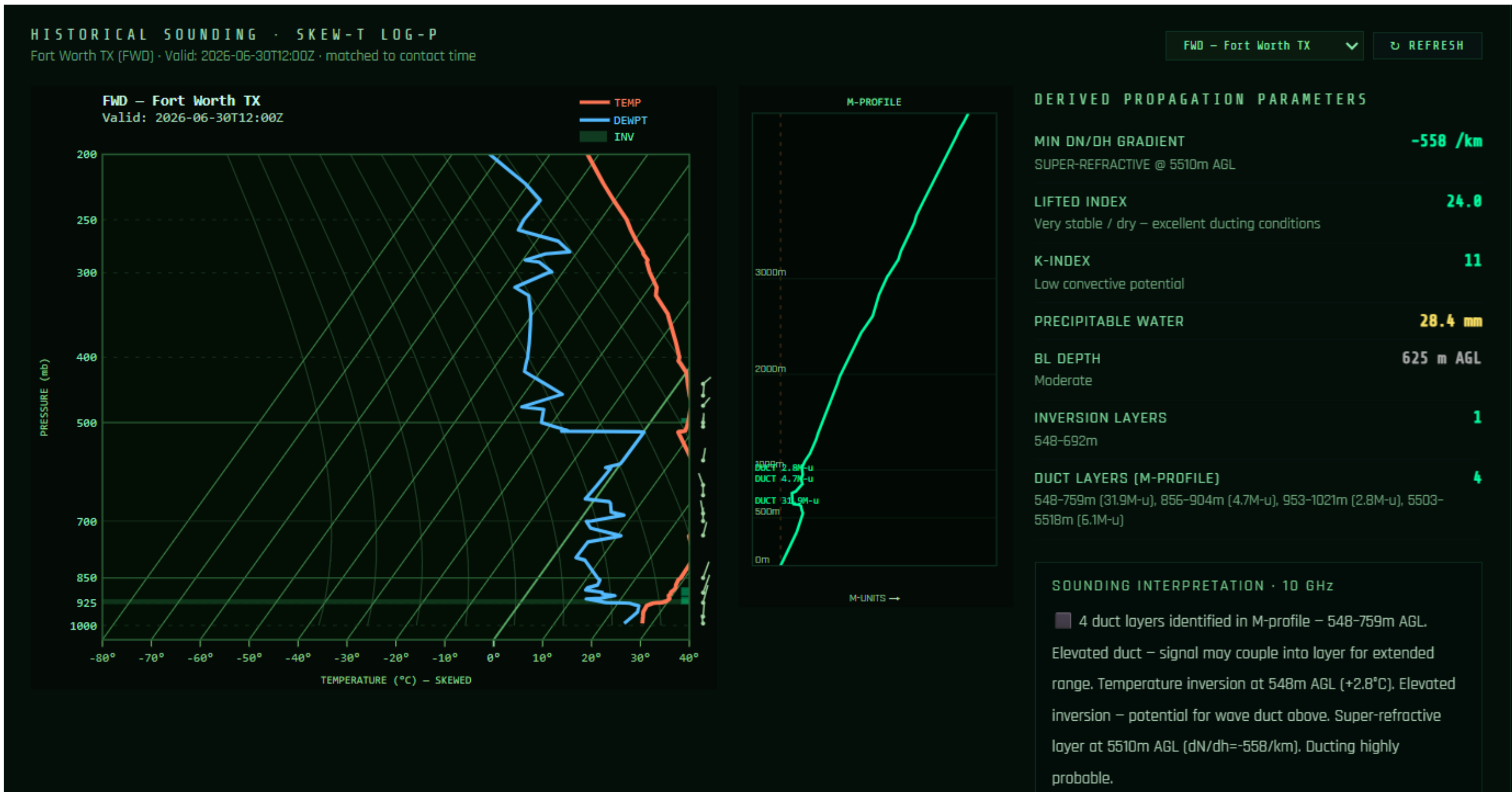


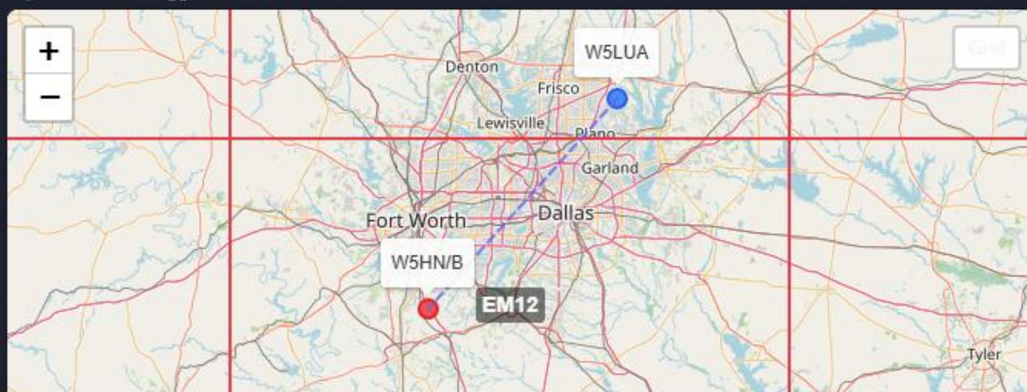
“Contact” analysis in NTMS tools (W5LUA)

W5LUA / W5HN/B

10 GHz · Q65 · 2026-06-30 14:10 UTC

Edit | Flag as Invalid | Delete | Open in Path Calculator | ← Back to Contacts

Locations approximate, in the center of the grid squares. Have more detailed position information? Suggest an edit



10 GHz · Q65 · 59 mi (95 km) · EM13QC68IL → EM12IL56EI

W5LUA → W5HN/B Az: 357.8° El: -0.29°
W5HN/B → W5LUA Az: 002.3° El: -0.35°

Obstructed at 0.9 mi (1.5 km)

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“Contact” analysis in NTMS tools (W5LUA)

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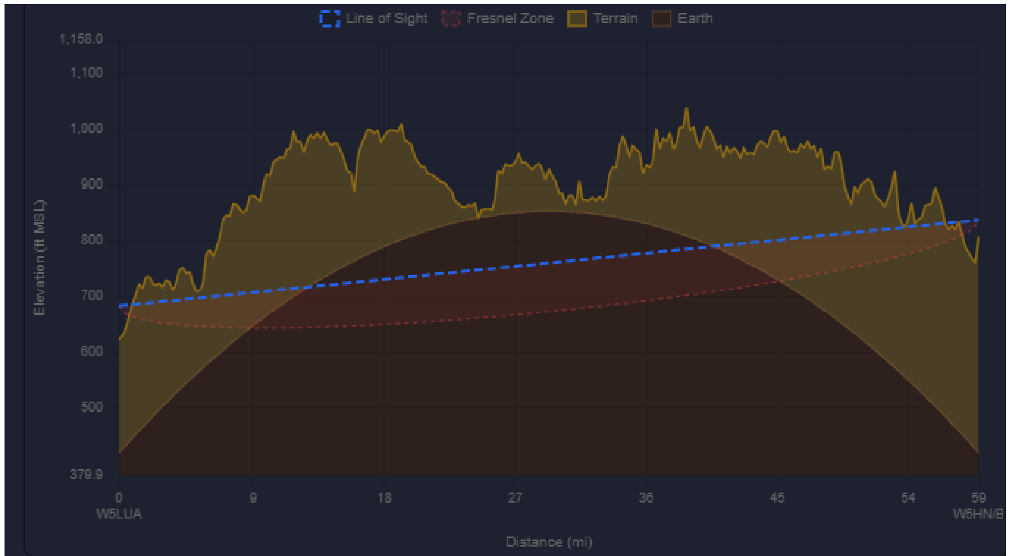

Propagation Analysis

Path is terrain-obstructed at 0.9 mi (1.5 km) from W5LUA. Signal likely propagated via atmospheric ducting (sounding-detected layer at 2480-4034 ft, 31.9 M-units), bending over the terrain obstruction. At 10 GHz, the elevated moisture (PWAT 31.2 mm) enhances refractivity and ducting potential.

Antenna heights: W5LUA @ 60 ft AGL, W5HN/B @ 30 ft AGL.

Refractivity gradient: -159 N-units/km (ducting).

Boundary layer depth: 564 m.

Tropo duct detected at 1/3 HRRR samples along the path.

Ducting detected by soundings at: Fort Worth Area -- KFWH KFWD, Fort_worth TX/US.

Most likely propagation duct: sounding-detected layer at 2480-4034 ft, 31.9 M-units.

"Contact" analysis in NTMS tools (W5LUA)

Factor	Score	Weight	Contribution	Notes
Rain	100/100	14%	14.3	None
Humidity	88/100	13%	11.1	19.9 g/m^3 (beneficial at this band)
Season	90/100	11%	10.2	Jun (summer peak band)
Refractivity	92/100	10%	9.1	dN/dh = −159 (ducting)
T-Td Depression	85/100	10%	8.6	T-Td = 8.7°F (moderate)
PWAT	70/100	11%	8.0	32.0 mm (refractivity aid)
Pressure	82/100	10%	7.9	989.4 mb (low)
Sky Cover	50/100	8%	4.2	–
Wind	50/100	8%	4.2	–
Time of Day	100/100	4%	3.8	Solar hour ~8 (morning)
Composite	81/100		EXCELLENT	

Propagation Mechanism

Tropospheric Duct

HRRR profile shows a trapping layer (refractivity gradient below −157 N/km) at one of the endpoints.

Common volume: 427089 km^3 Max reflectivity: 58.1 dBZ Heavy-rain pixels: 3

Radar coverage: 1% Frame: 2026-06-30 14:10 UTC

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"Contact" analysis in NTMS tools (W5LUA)

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Atmospheric Profile

HRRR (3 km) 33.1°, -96.6° 14:00 UTC HPBL: 564.2 m PWAT: 31.2 mm
N: 371.7 dN/dh: -159.0 Ducting

IEMRE Gridded Reanalysis

Grid point: 33.1°, -96.6° — 2026-06-30 hour — UTC

Temp: 84.5°F **Dewpoint:** 72.2°F **Sky Cover:** 1.0% **Wind:** 11.6 kts **Precip:** 0.0"
Soil Temp: 96.1°F

Surface Observations

Station	Time	Temp	Dewpt	RH%	Wind	Pres (mb)	Sky
DALLAS/LOVE FIELD	08:53	81.0	72.0	74.2	190° @ 7.0 kts	1015.3	FEW
DALLAS/LOVE FIELD	09:53	80.0	73.0	79.3	180° @ 6.0 kts	1015.2	FEW
DALLAS/LOVE FIELD	10:53	80.0	72.0	76.7	180° @ 7.0 kts	1015.6	BKN
DALLAS/LOVE FIELD	11:53	79.0	72.0	79.2	180° @ 9.0 kts	1015.8	FEW
DALLAS/LOVE FIELD	12:53	80.0	73.0	79.3	170° @ 9.0 kts	1016.1	SCT

Data Sources

HRRR Model
3 path profiles
13 pressure levels each
Valid: 2026-06-30 14:00 UTC
Grid: 33.12, -96.61

Elevation Profile
257 samples along path
59 mi (95 km) path distance
Source: SRTM 1-arcsecond
2 duct layers detected

Terrain Analysis
65 profile samples
Verdict: BLOCKED
Max elevation: 246 m
Diffraction: 86.6 dB

Surface Observations
5 stations
08:53 – 12:53 UTC

Soundings (RAOB)
5 profiles
KSPS (0 levels), _FWD (152 levels), KSEP (0 levels), KFWD (152 levels), KFWH (0 levels)
2 with ducting

Solar Indices
SFI: 202.6
SSN: 138
Ap: 18

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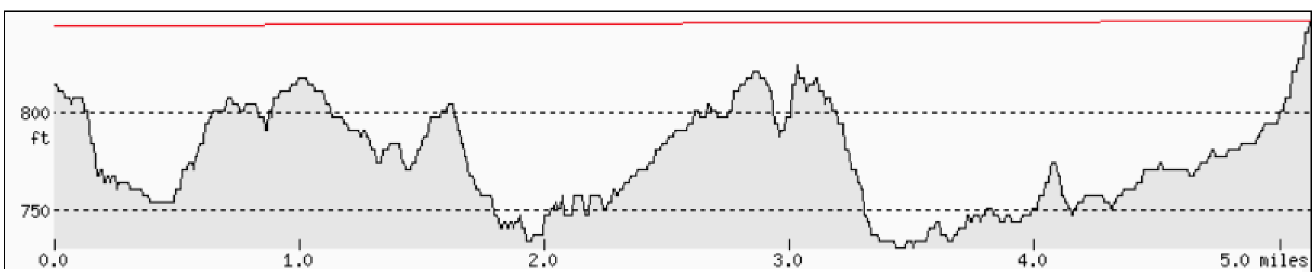
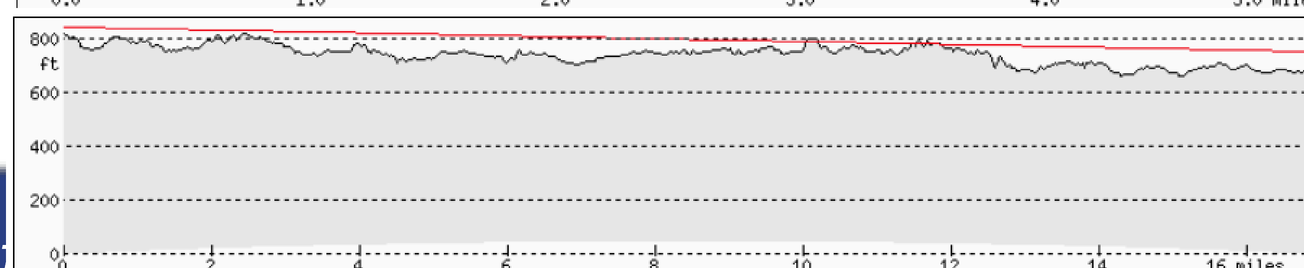
Contact analysis delta between W5LUA and K5MNZ

	W5LUA	K5MNZ
DX	95 km	106 km
Time	14:00 utc	12:00 utc
Duct layer	2480-4034 ft,	2921-4474 ft
N units	-159	-152
BL depth	564 m.	286 m.
Common Volume	427089 km²	418196 km²
Heavy Rain Pixels	3	15

Beacon monitor dx
7-17-26

Distance/height	Avg noise dBFS	Best signal strength dBFS
100’ from beacon	-33.4	-5.7
100’ but beacons OFF	-47.3	
8.5 km dx - 100’ above surrounding ground	-47.7	-27.7
28 km dx – 60’ above surrounding ground	-45.0	-18.7





Beacon monitor dx

DX 100 feet.

```
Timestamp                  Ph       Rk IF freq (MHz)      Power     Drift   Status
-------------------------- -------  -- --------------   --------  --------  ----------------
2026-07-17T20:42:58.109Z   [Q65]    1  618.3160            -5.7       ---   *** DETECTED ***   (1341ms)
2026-07-17T20:42:58.109Z   [Q65]    2  618.2360           -33.4       ---   *** DETECTED ***
2026-07-17T20:42:58.109Z   [Q65]    3  618.3960           -33.5       ---   *** DETECTED ***
```

DX 8.5 km.

```
2026-07-17T17:26:10.025Z   [Q65]    1  618.3220          -27.7        +0  *** DETECTED ***   (1335ms)
2026-07-17T17:26:10.025Z   [Q65]    2  618.2070          -47.5       ---  *** DETECTED ***
2026-07-17T17:26:10.025Z   [Q65]    3  618.2760          -47.7       ---  *** DETECTED ***
```

DX 28 km.

```
2026-07-17T18:22:40.111Z   [Q65]    1  618.3190           -18.7        +0  *** DETECTED ***   (1276ms)
2026-07-17T18:22:40.111Z   [Q65]    2  618.3960           -44.0       ---  *** DETECTED ***
2026-07-17T18:22:40.111Z   [Q65]    3  618.3900           -45.7       ---  *** DETECTED ***
```

Next steps (Part 2 updates)

- Deploy beacon monitors in DFW area.
- Current planned beta monitor sites:
  - WA5WCP - G. Paul, EM12JO88PM
  - W5ISP - Graham, EM13SF88TX
- Build hi-stability beacon monitor for Q65 decode reporting.
- Resolve psk reporter feed issue.
  - Separate internal Rfzero config elements
  - Expand Rfzero WSJT string > 13 characters

W5HN

HamSCI

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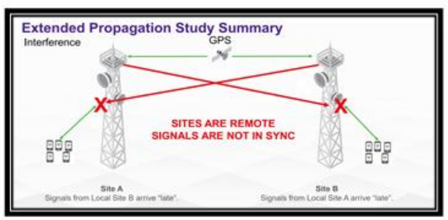
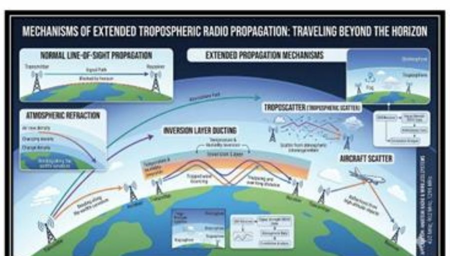
Starting a Low-Cost SDR Beacon Receiver Project for Studying Extended Tropospheric Propagation on 144/432/902/1296 MHz

Declan Reavy (KD3BMA), Brett Hoey (KD3CIJ), Josephine Coffey (KD3CPF), Katie Martinez (KD3CHR), Navid Shahrouzi, Nathaniel A. Frissell (W2NAF), J. Gordon Beattie, Jr. (W2TTT)
University of Scranton, VIAVI Solutions

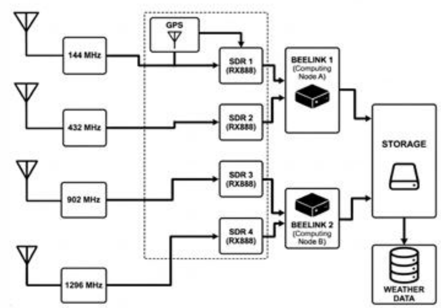
Abstract

In this project, we will build and test a low cost SDR-based receive system to study extended tropospheric propagation on 144 MHz, 432 MHz, 902 MHz, and 1296 MHz, with the primary goal of understanding how radio signals travel far beyond normal line of sight. This can be caused by atmospheric or other tropospheric conditions such as refraction, inversion layer ducting, tropospheric scatter, and aircraft scatter. These extended propagation events are important not only for amateur radio operators who monitor weak signals, but also for synchronized wireless systems where late arriving signals can create interference or affect timing.





SYSTEM ARCHITECTURE



Method

1) Deploy:
   - A receiving station using an RTL SDR class device
   - A low-noise preamplifier
   - Band appropriate antennas
2) Monitor known beacons and signals of opportunity
3) Collect time stamped RSSI values, CW and WSJT mode to decode results including WSPR, FT8, and Q65
4) Concurrently, gather atmospheric data on 15 to 60 minute intervals along/near propagation path
5) Compare signal behavior against weather patterns such as fog, temperature inversions, humidity changes, or pressure gradients

Since this is the first year and this project is just now starting, the primary focus of the project is on building a stable receive chain, confirming consistent beacon reception, and creating a data pipeline, that supports long-term propagation studies.

When we have stable data, we plan to analyze the signatures of extended propagation events and explore which atmospheric features are most responsible for them, and later we plan to attempt an initial machine learning model to predict "event vs. no event."

Applications

The end goal of this project is to create an AI algorithm based in large datasets in order to forecast signal propagation under specific atmospheric, tropospheric, and topographic circumstances for the cellular wireless industry, particularly in 5G. Additional applications exist in the military, reducing communication interception rates and improving communications clarity between allied forces. This research will also carry significant advantages for reducing interference in VHF/UHF radio.

[1] 

References

[1] https://vhf.dxview.org/

Acknowledgements

The project is a new collaboration between the University of Scranton, HamSCI, VIAVI Solutions, and the Texas A&M MTT-S student group. We also plan to create simple documentation and deployment guides so students, clubs, and under resourced schools can reproduce this low-cost system and join the research effort over time.

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VIAVI SCRANTON HamSCI NSF

HamSCI Workshop 2026

Preview for future meetings

- Rfzero modulation = see the CW/Carrier signal before decodes occur. +2.1 dB SNR
- Understanding the decode threshold.
- Tweaking the receive chain.
- Lab tools created:
  - Q65 Toolkit – Creates synthetic Q65 files
  - Q65 Analysis – Performs analysis on wav files

W5HN

CW/Carrier but no Q65 decode

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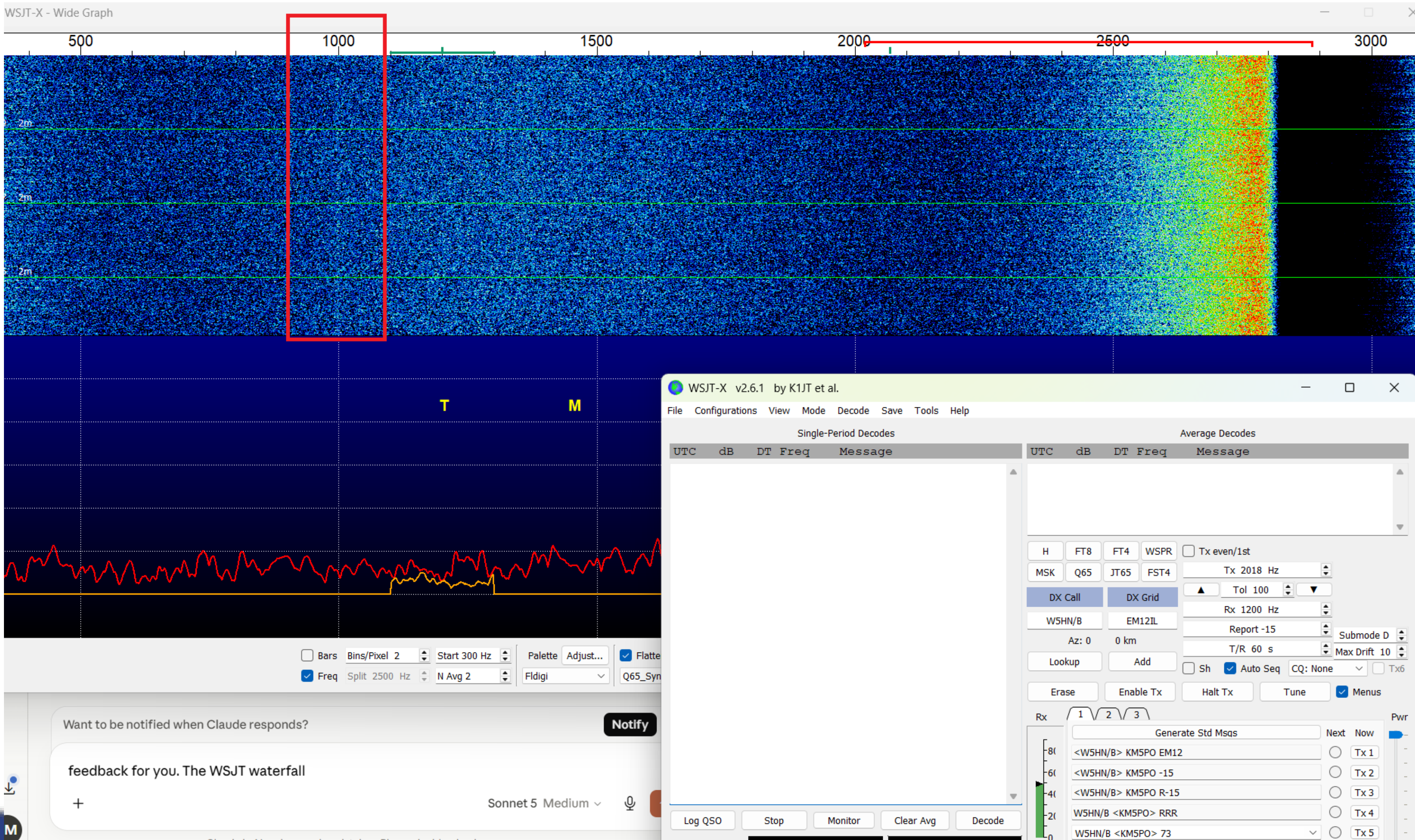

Beacon decode limit is approximately -27 / -28

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Beacon message cannot enter the AP pipeline

Basic parameters of Q65 for each of the five T/R sequence lengths and their minimum tone spacings ("A" submodes) are summarized in the table below. Threshold sensitivities (SNR in 2500 Hz bandwidth yielding 50% probability of decode) were measured for each submode using simulations over the additive white Gaussian noise (AWGN) channel. As with other recently developed modes in *WSJT-X*, a feature called *a priori* (AP) decoding improves sensitivity by several additional dB as information is accumulated during a standard minimal QSO.

50% decode probability

T/R Period (s)	Symbol Length (s)	"A" Tone Spacing (Hz)	"A" Occupied Bandwidth (Hz)	Transmission Duration (s)	SNR (dB)	Max AP SNR (dB)
15	0.150	6.667	433	12.8	-22.2	-23.7
30	0.300	3.333	217	25.5	-24.8	-26.6
60	0.600	1.667	108	51.0	-27.6	-30.2
120	1.333	0.750	49	113.3	-30.8	-32.5
300	3.456	0.289	19	293.8	-33.8	-37.4

Ordinary noise floor improvements

	0	1	2	3	6	10	14
-26 dB	–	50%	100%	100%	100%	100%	100%
-27 dB	0%	0%	50%	100%	100%	100%	100%
-28 dB	0%	0%	0%	50%	100%	100%	100%
-29 dB	0%	0%	0%	0%	0%	0%	0%
-30 dB	0%	0%	0%	0%	0%	0%	0%

Broadband noise dip depth (dB) →

Why “AP adds ~3 dB” does not apply here

Actual message W5HN/B EM12IL

i3=0 (free text). Structurally cannot enter Q65's AP candidate list -- confirmed directly from WSJT-X source.

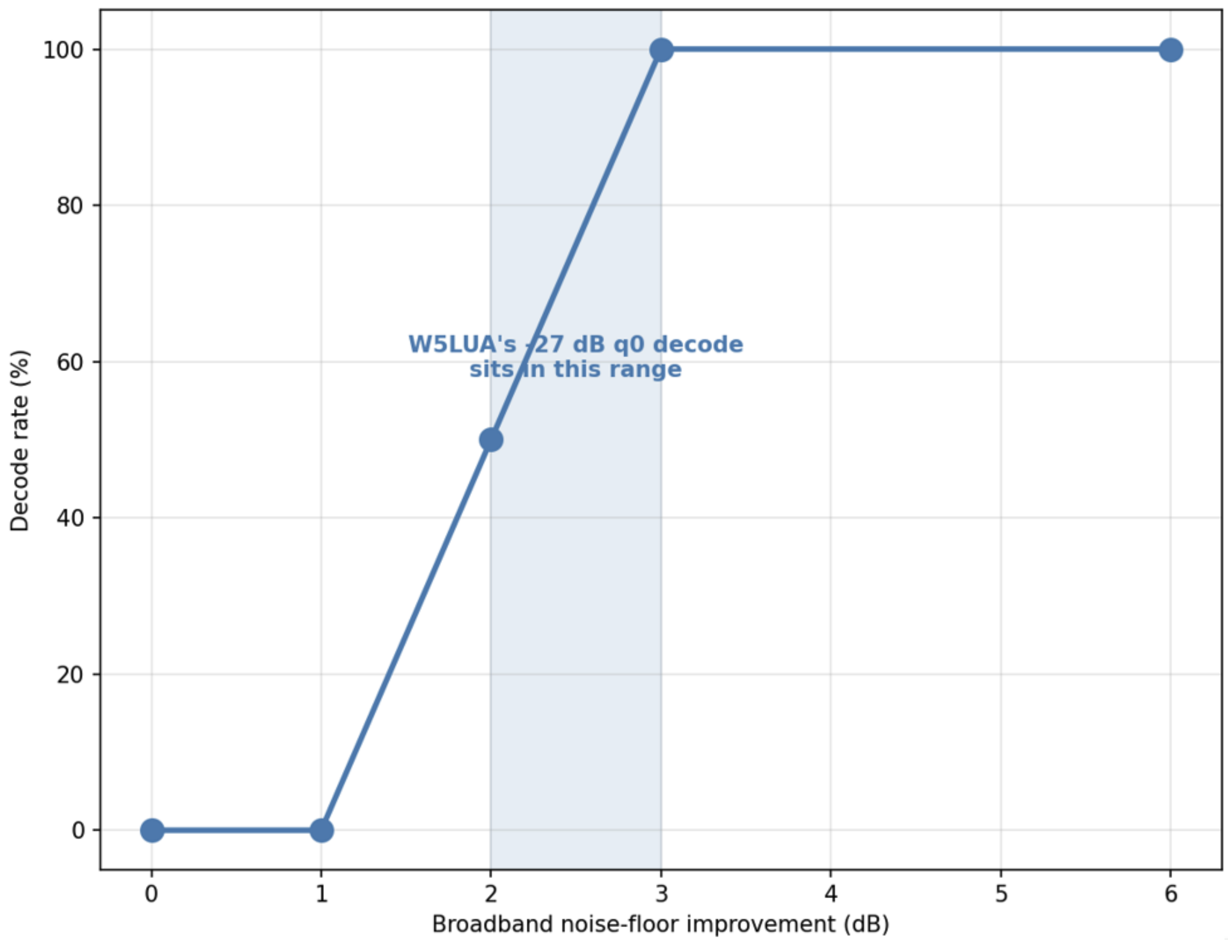
AP-eligible format CQ W5HN EM12

i3=1, tested directly with AP hints across the full threshold range. Zero measurable benefit found at any SNR.

Quick-Start Guide "Max AP" figure

Comes from a full escalating QSO exchange (q2->q3->q4), a scenario this beacon's message format never enters.

A 2 dB improvement makes possible a -27 dB decode



Optimize receive chain

- Gain levels of receive stages.
  - The system noise floor is dominated by the fixed noise figure of the LNB so by the time the signal hits the SDR, the LNB thermal noise is well above the SDR's internal noise at moderate gain.
  - Need to find the SDR “knee”.
  - Below the knee, then ADC quantization noise dominates – noise floor in dBFS appears artificially low and flat.
  - Past the knee, LNB noise dominates – noise floor in dBFS rises 1 dB per 1 dB of added gain (good-seeing real noise, not ADC artifacts)
  - Too high: ADC clips.
  - We want to be just above the knee. The threshold then sits some margin (6-10 dB?) above the noise floor.

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Q65Toolkit

- Runs under Ubuntu (Linux).
- Generates synthetic WSJT-X Q65 .wav files

q65_synth.py ×

C: › Users › km5po › Downloads › q65_synth.py

```
Q65 TIMING (confirmed against WSJT-X source, lib/qra/q65 and map65/libm65):
    - Tone spacing depends on submode: dfgen = 2**(mode65-1) * 12000/7200 Hz
        mode65=5 -> E -> 26.67 Hz
    - Tone for symbol j: f = f0 + itone(j)*dfgen, itone in [0,64].
      itone==0 marks a sync symbol (transmitted exactly at f0).

Usage:
    python3 q65_synth.py "W5HN/B EM12IL" --submode D --snr -18 \
        --f0 1200 --out beacon_test.wav

    # Batch-generate a set spanning a range of SNRs for calibration:
    python3 q65_synth.py "W5HN/B EM12IL" --submode C --snr-sweep -30 -10 5 \
        --out-dir calibration_set/

    # With channel impairments -- accelerating drift, spreading that
    # changes twice, and a slowly-fading signal:
    python3 q65_synth.py "W5HN/B EM12IL" --submode D --snr -14 \
        --drift-start 0.01 --drift-end 0.05 \
        --spread-min 2 --spread-max 8 --spread-changes 2 \
        --fade-mode varying --fade-range-db 6 --fade-timescale 5 \
        --out spread_test.wav

See q65_channel.py for the full design rationale and caveats on the
drift/spread/fade models.
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Q65Analysis

- Runs under Windows.
- Batch .wav file processor
- Deep_dig .wav file processor

q65_deep_dig.py

C:\Users\km5po\q65analysis\q65_deep_dig.py

```python
#!/usr/bin/env python3
r"""
q65_deep_dig.py
----------------
Deep analysis of marginal/sub-threshold Q65 recordings:
  1. Blind decode (jt9, no AP hints)
  2. AP-assisted decode (jt9, with expected callsign/grid supplied as hints)
  3. Sync-correlation curve extraction (red.dat) regardless of decode outcome,
     so we get a quantitative "was there a sync tone" answer even on total
     decode failures.
  4. Cross-file stacking of the sync curves (since a GPS-locked beacon won't
     drift file-to-file, incoherent averaging across the whole series adds
     real integration gain).

IMPORTANT jt9 quirk this script works around: red.dat/decoded.txt/avemsg.txt
are written to the *temp-path* (-t), which defaults to the current working
directory -- NOT the data-path (-a). If you run jt9 repeatedly from the same
cwd without isolating each run, later runs silently clobber earlier runs'
red.dat. This script runs every jt9 invocation in its own temp directory.

Usage:
    python3 q65_deep_dig.py /path/to/wavs --submode D --period 60 \
        --his-call "W5HN/B" --his-grid "EM12IL" --out-dir results/
```

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Links

youTube Beacon demo – two 46 GHz beacons

youTube Beacon calibration run demo

Questions?