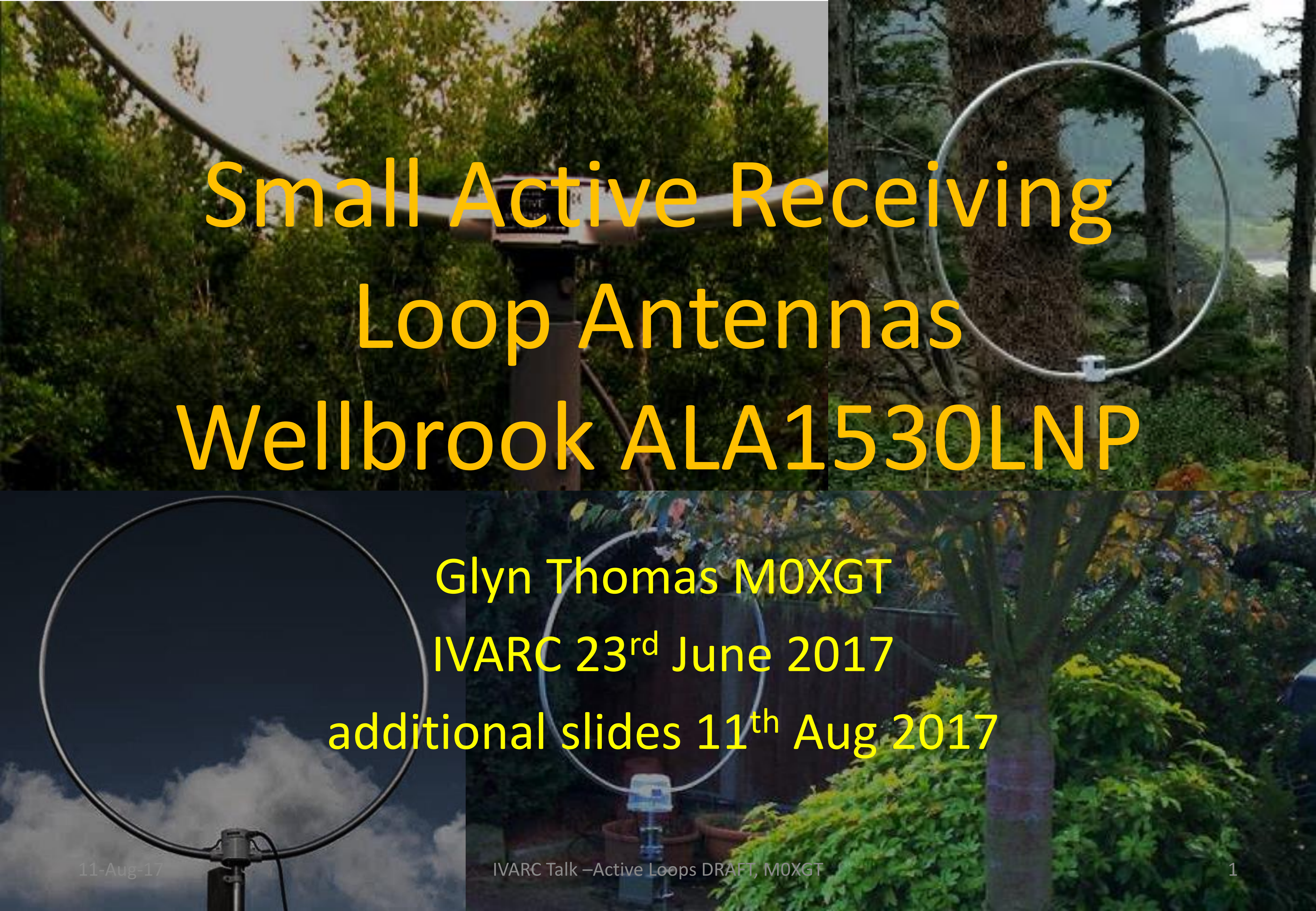


Small Active Receiving Loop Antennas Wellbrook ALA1530LNP

Glyn Thomas M0XGT

IVARC 23rd June 2017

additional slides 11th Aug 2017

Active Small Loop Antennas

Motivation

1. **Remote field strength measurement** - portable antenna, use calibrated or as a standard reference antenna.
2. **Urban noise** – can a loop help with near-field electric noise in cities?
3. **Compact** – need for small compact antennas in a city environment, use in garden, indoors or loft, portable.
4. **Wide-band response -** 50kHz to 30MHz with no tuning, good fit to wide-band SDR receivers. Competition use.
5. How does it **compare** with resonant wire antennas?

Small Active Rx Loop Antennas

Wellbrook ALA1530NLP
50kHz-30MHz Active Rx Loop
Loop + low-noise front-end (LNA) and bias-tee + preamp G=8.5dB, NF=3.5dB

Size
Loop diameter 0.950m
tube diameter 0.020m
Circumference 2.98m

LF/HF Noise

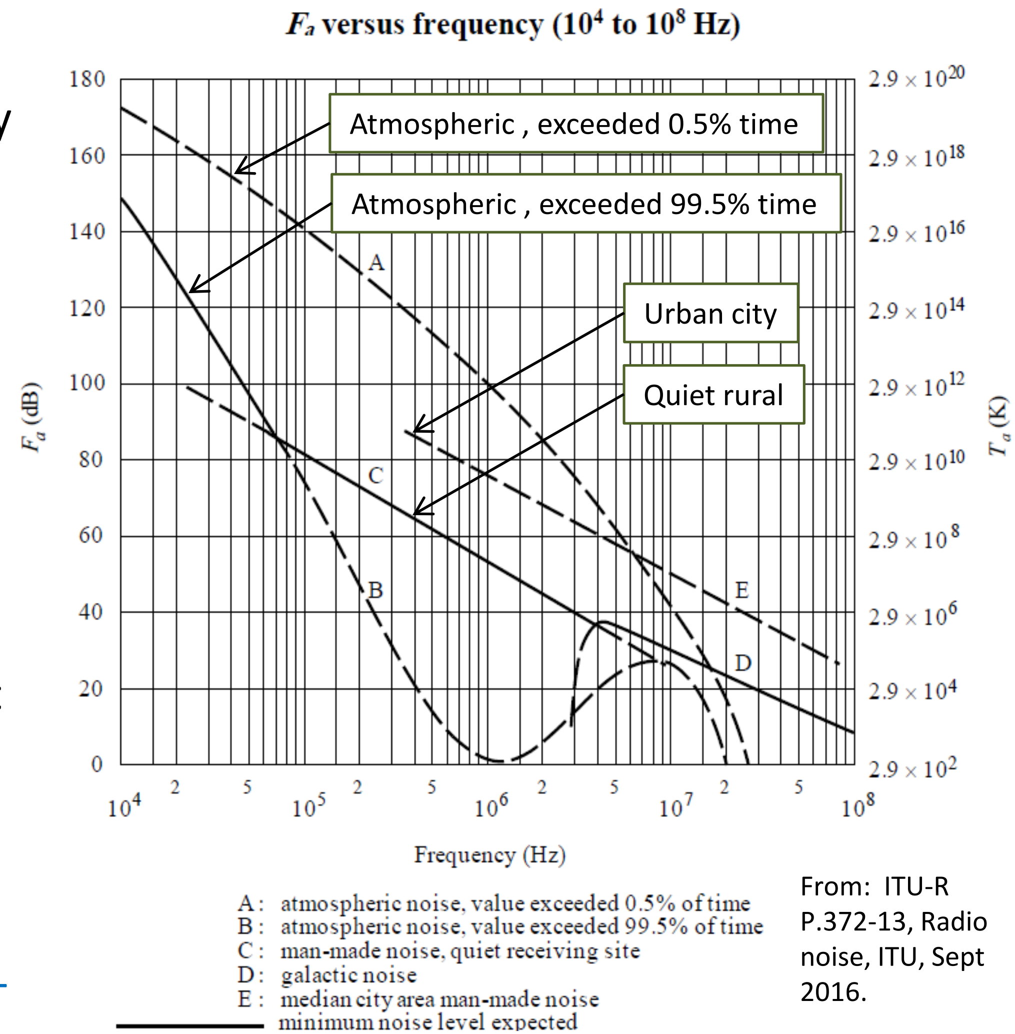
Atmospheric noise and man-made noise levels are very high at LF/HF and given by noise figure *Fa* in dB above terrestrial thermal noise @290K (*Fa* - 174dBm, ideal isotropic antenna, *G*=0dB)

Examples: median city noise (above thermal background) is about 70dB @ 1.8MHz (-104dBm) , and 55dB @7MHz (-119dBm).

Typical HF receiver noise figure NF about 10-15dB

⇒ weak signals limited by atmospheric noise, not RX NF,

⇒ scope to reduce antenna size (aperture and gain) paired with a low-noise system/LNA, NF < 1dB.



From: ITU-R P.372-13, Radio noise, ITU, Sept 2016.

Near-Field of Noise Sources

A city or urban environment will contain many local man-made noise sources that raise the noise level above the natural atmospheric *Fa* – Are there characteristics that can be used to mitigate them?

1. Direction – small loops have directivity and can be rotated to null noise.

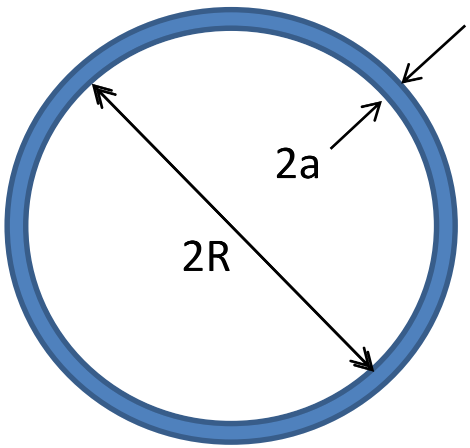
2. Near-field noise is due to E- and H-fields that are ‘bound’ to the radiator and decay faster than 1/r with distance – small loops can be moved, increase distance.

3. Near-field E- and H-fields may be E-dominant or H-dominant depending on the nature of the radiator:
    a. electric dipole |E|/|H| >> 377 Ohm – typical of urban city / indoor environment.
    b. magnetic current loop, |E|/|H| << 377 Ohm
    c. radio waves and far-field |E|/|H| = 377 Ohm

Small loop reacts to dB/dt, $B=\mu H$, and is an H-field sensor

=> ideal if local |E|/|H| >> 377 Ohm – urban environment

Schematic: Loop and LNA



Loop inductance

$$L = R\,\mu\left[\ln\left(\frac{8R}{a}\right) - 2\right] = 2.45\mu H$$

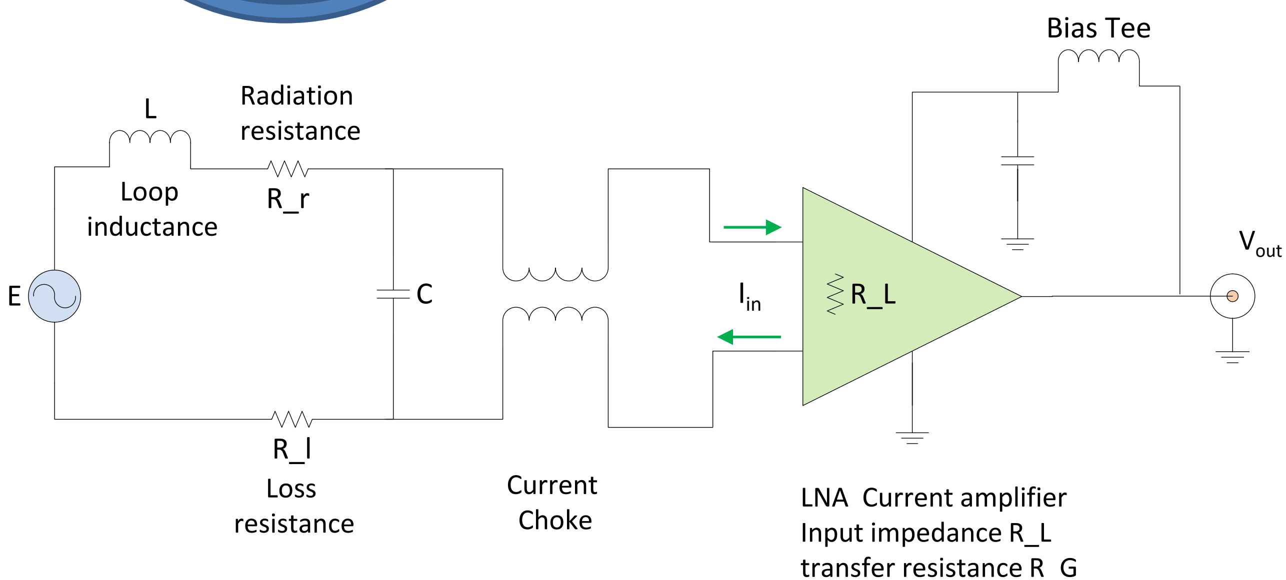
Agrees with value measured with Agilent LCR meter, and with tinyVNA impedance measurements.

Radiation resistance for a loop antenna

$$R_r = \eta\,\frac{8}{3}\pi^3\left(\frac{A}{\lambda^2}\right)^2$$

where

$$\eta = 120\pi$$
$$= 377\Omega$$
$$A = \pi R^2$$
$$\lambda = c/f$$



Loss resistance

$$R_l = \frac{2\pi R}{2\pi a} R_s$$

Surface resistance due to skin depth,

$$R_s = (\pi f \mu \rho)^{\frac{1}{2}}$$

$$\rho = 2.65 \times 10^{-8}\ \Omega/m$$
$$\mu = 4\pi \times 10^{-7}$$

Radiation and Loss Resistance

Radiation resistance

$$R_{rad} = \eta \frac{8}{3}\pi^3 \left(\frac{A}{\lambda^2}\right)^2 \quad \propto \ f^4$$

Loss resistance

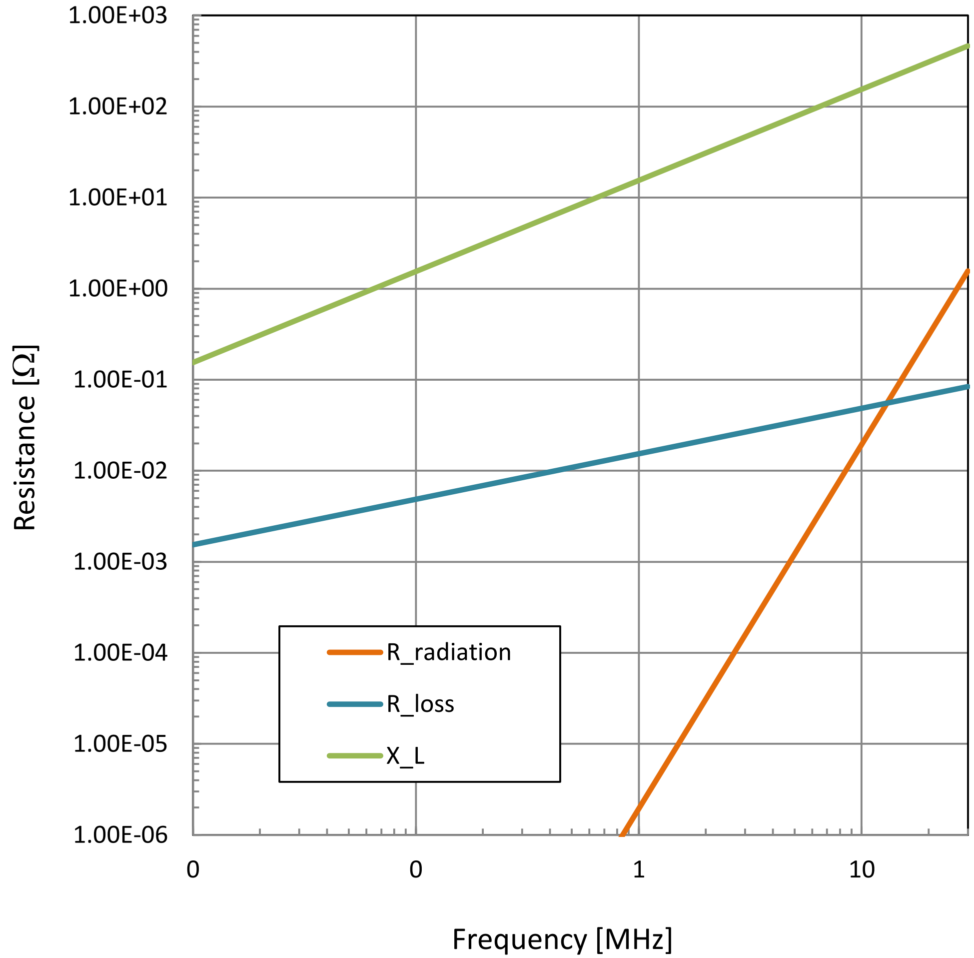
$$R_{loss} = \frac{C}{2\pi a} R_s \quad \propto \ f^{\frac{1}{2}}$$

$$R_s = (\pi f \mu \rho)^{\frac{1}{2}}$$

Loop reactance

$$X_L = 2\pi f L$$

Loop data	
loop radius R	0.475 m
tube radius a	0.010 m
circumference C	2.985 m
area A	0.709 m2
rho (aluminium), ρ	2.65x10^{-8} Ωm
loop Inductance, L	2.45 µH



Antenna Factors K_E & K_H

We need to relate the electric field strength E [V/m], or power density [W/m^2], of a radio wave to the voltage induced on the antenna terminals.

Antenna factor K_E [/m] gives the external E-field magnitude E_0 from the terminal voltage V_0

$$E_0 = K_E V_0$$

A radio wave has an electric field E_0 [V/m] and magnetic field H_0 [Am] which are proportional, so that $H_0 = E_0/\eta$ where $\eta=120\pi=377\Omega$ and if we measure K_H with a loop we can define an equivalent K_E as $K_E = K_H\eta$

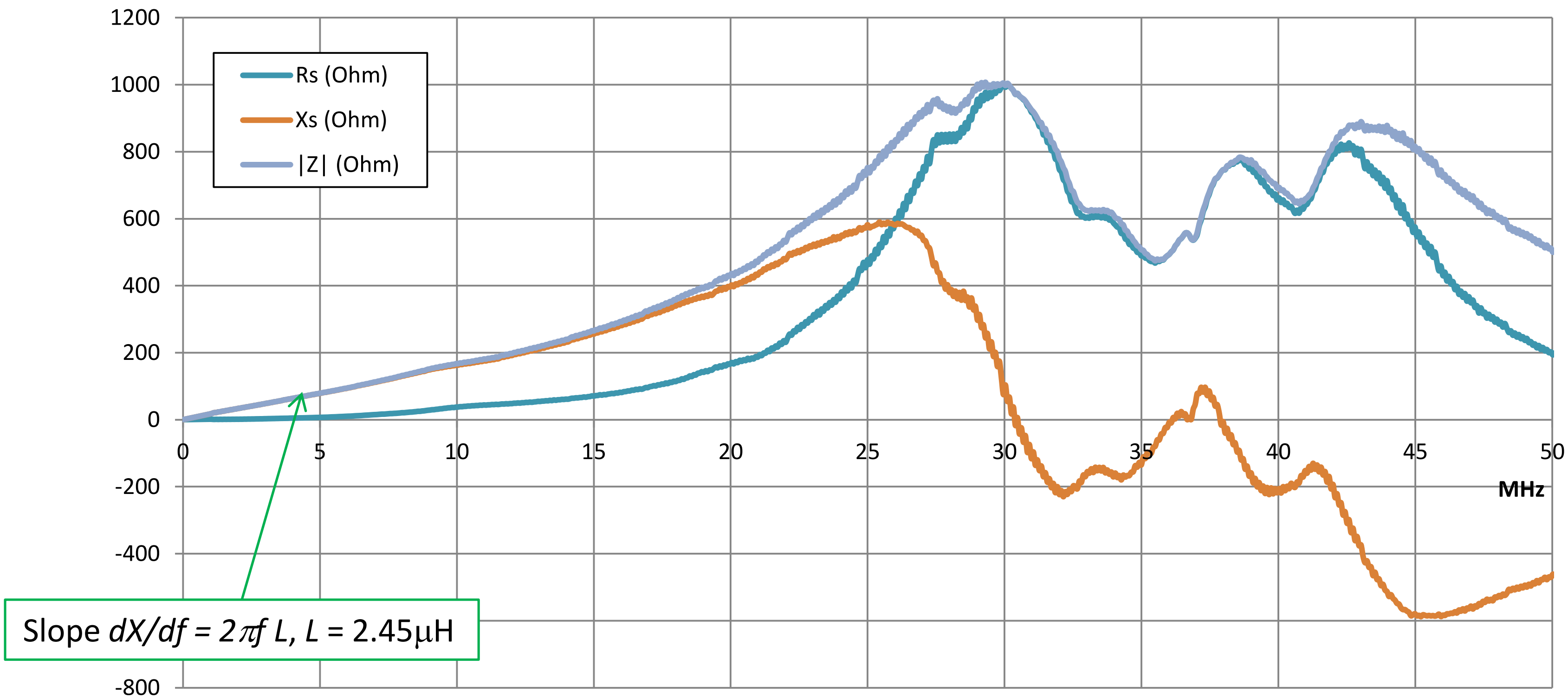
Loop induced voltage:

$$V_o = \frac{(2\pi f)\mu A}{\eta} E_0 = \frac{2\pi^2 R^2}{\lambda} E_o = \frac{1}{K_E} E_o \quad \text{and} \quad K_E = \frac{c}{2\pi^2 R^2}\frac{1}{f}$$

For small loops R << λ and terminal voltage scales as $V_0 \propto f$, hence need to flatten the response.

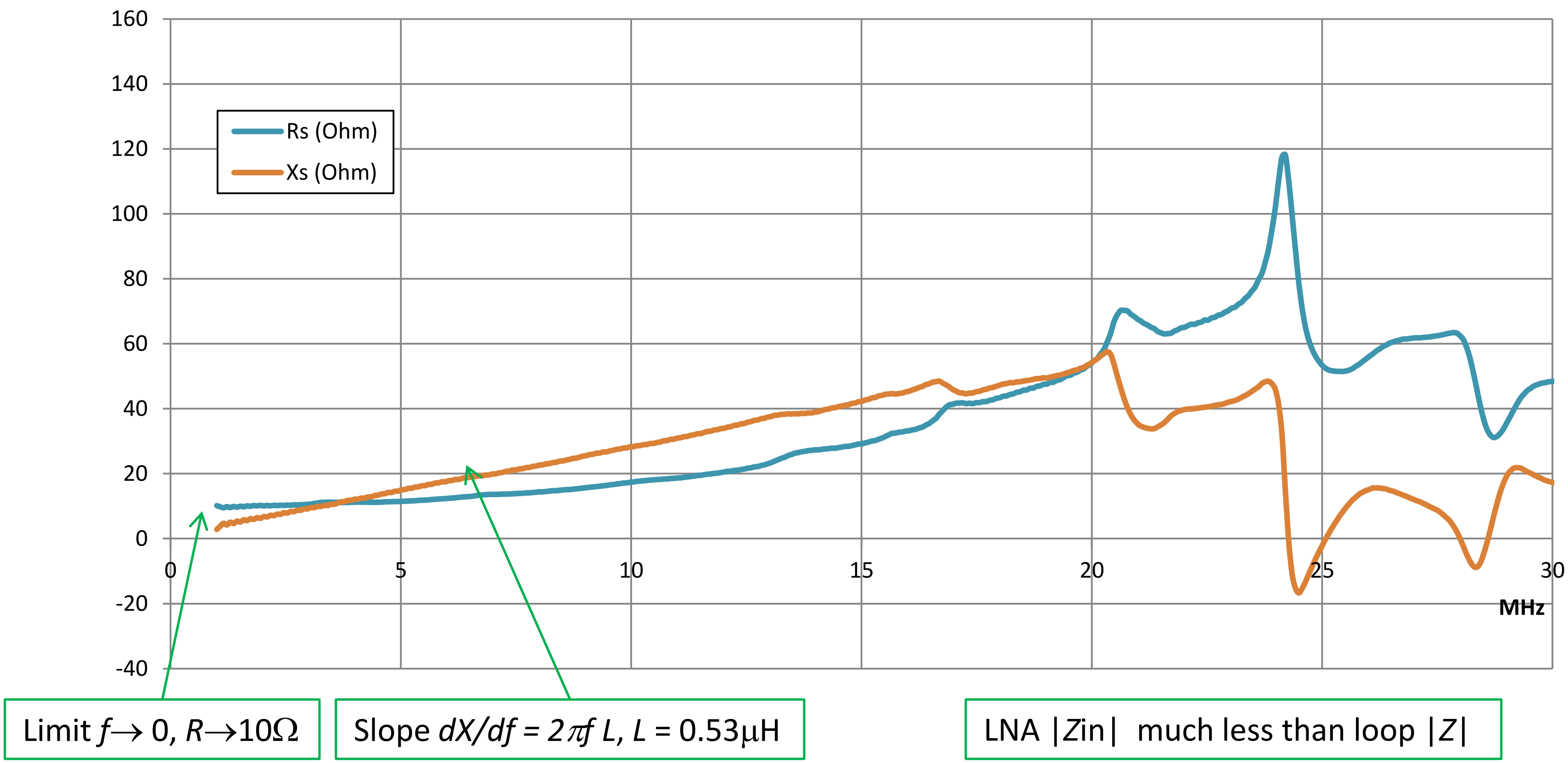
Loop Z = R + jX : 0 to 30MHz

Loop impedance $Z = R + j^*X$ and $|Z|$ over range 0 - 30 MHz measured using a tinyVNA.



LNA input Z_{in} = R+jX : 0 to 30MHz

Input Impedance of the front-end LNA, Z_{in} = R+jX over range 0 - 30 MHz.



Gain Flattening – LNA response

Given that the loop has a frequency response proportional to frequency we need to arrange for the LNA to have an inverse frequency response.

Choose the load impedance R_L to be small compared to loop inductance X_L and large compared to the radiation and loss resistances. The current into the load is then approximately $V_0/2\pi fL$ and the system gain including antenna factor and LNA is roughly

$$Vout = R_G \, 2\pi^2 R^2 \frac{f}{c} \, \frac{1}{2\pi f L} \, E_o$$

Output of LNA at bias-tee → $Vout$

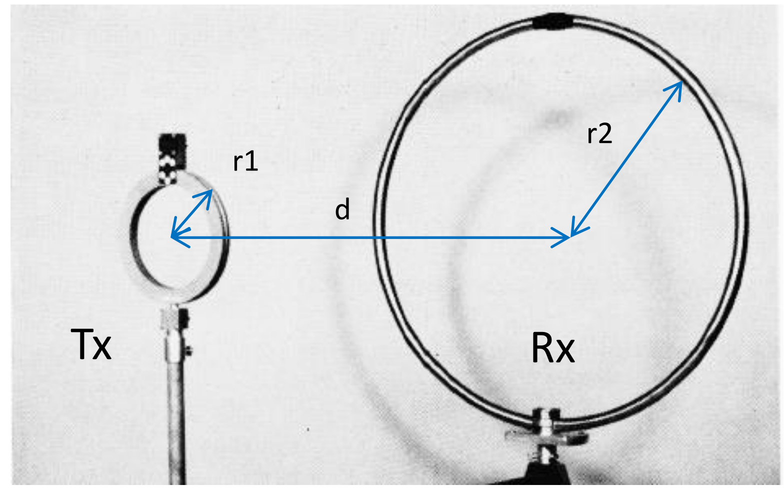
External E-field → E_o

which is flat wrto frequency. There is low frequency roll-off around 50kHz where X_L is not large and an upper limit imposed by the loop resonance around 30MHz.

Calibration – standard H-field

Calibration – basic idea

1. Use a small Tx loop to establish a defined H-field
2. Measure I_0 in Tx loop
3. Calculate equivalent E-field, E_{equiv}
4. Measure Rx loop terminal voltage V_0
5. Antenna factor K = E_{equiv}/V_0

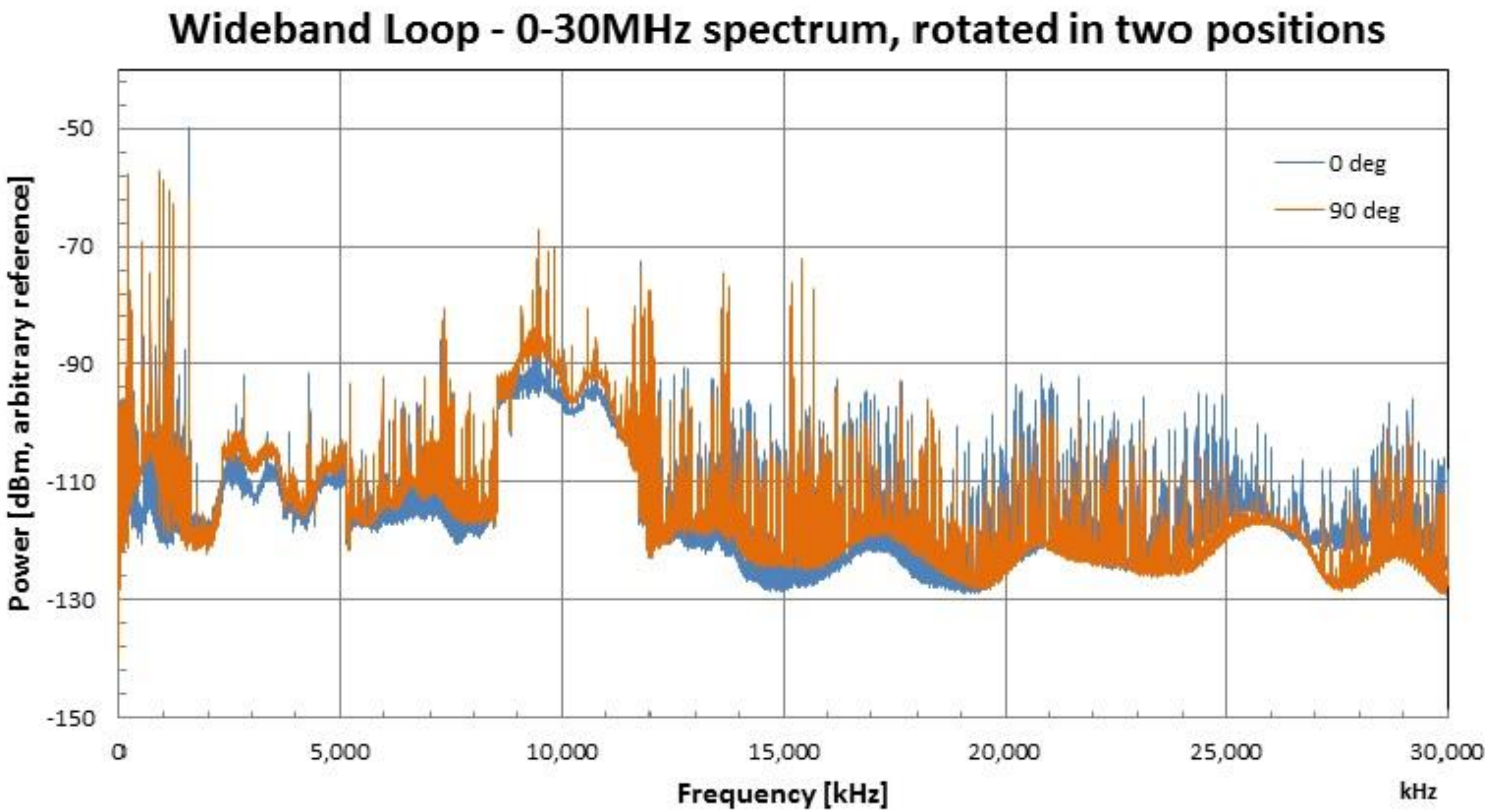


$$E_{equiv} = \frac{60\pi\, r_1^2 I_0}{(d^2 + r_1^2 + r_2^2)^{\frac{3}{2}}} \left[1 + \left(\frac{2\pi d}{\lambda}\right)^2\right]$$

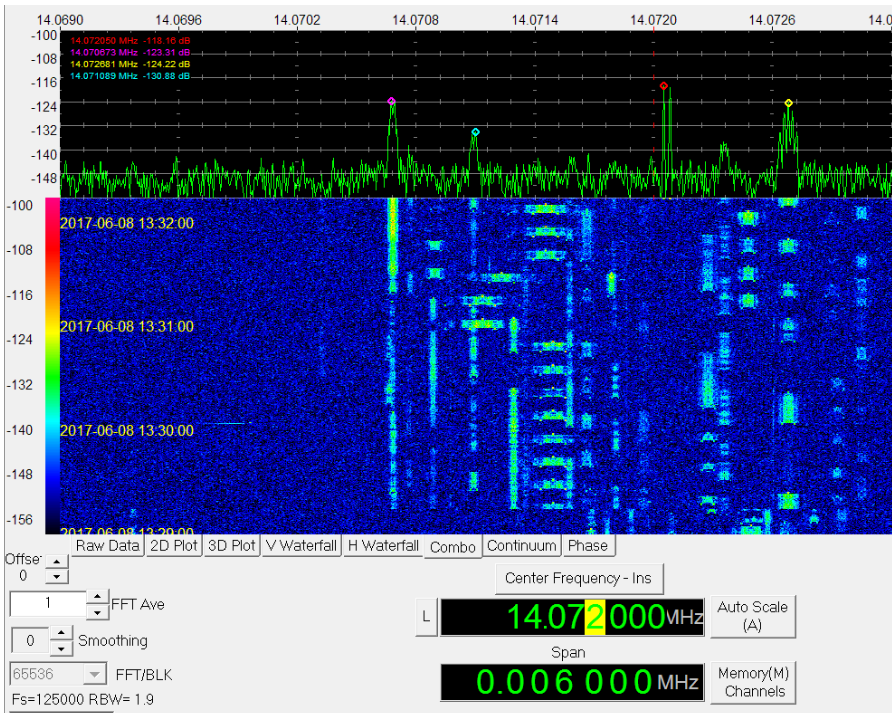
Small Tx loop with current I_o, equivalent E-field induced in Rx loop

See, Taggart & Workman (1969), Calibration principles and procedures for field strength meters 3Hz to 1GHz. Technical note 370, US National Bureau of Standards.

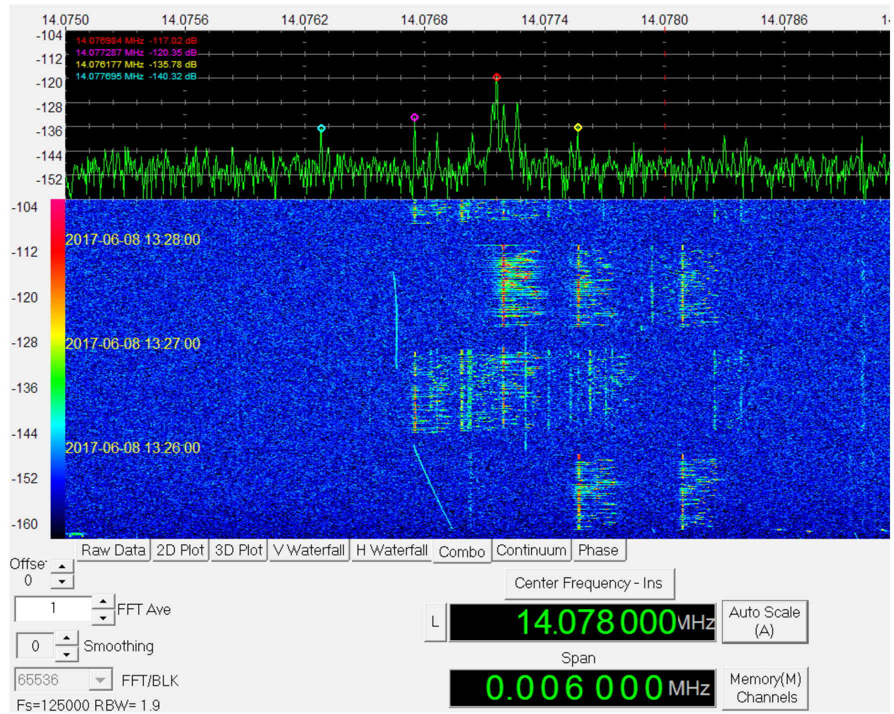
Wideband Spectrum 0-30MHz



NetSDR screen grabs (20m)

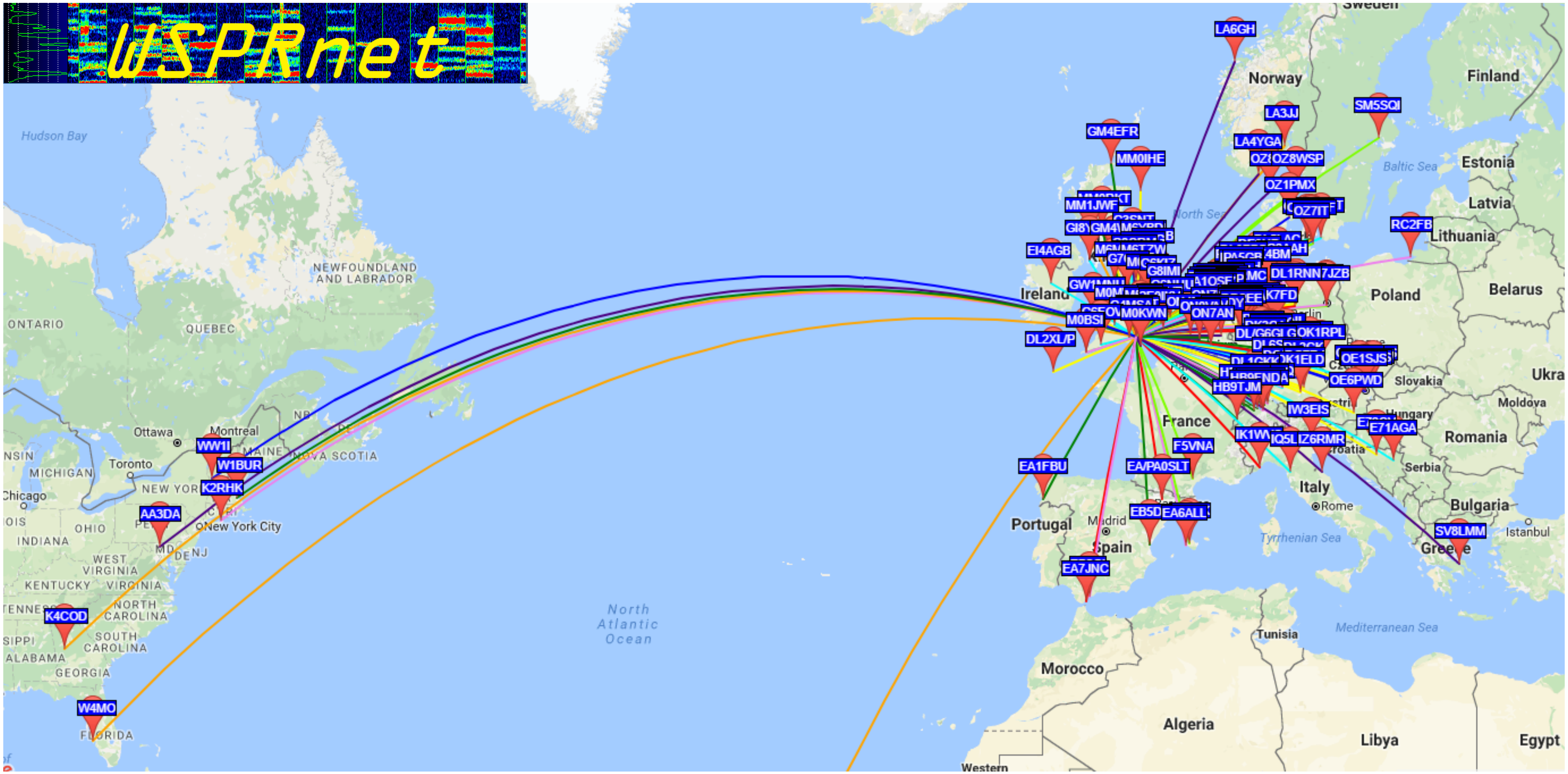


PSK and friends

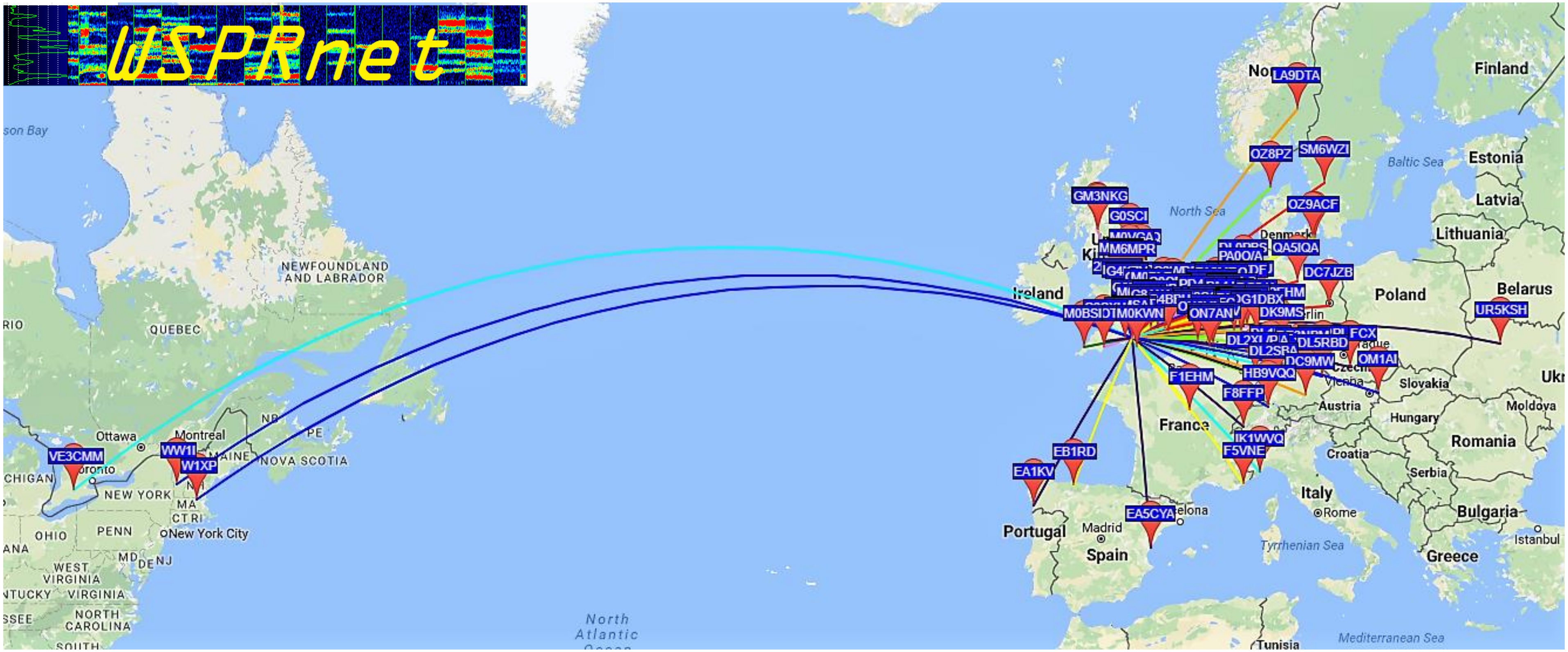


JT65 and

WSPRnet received spots (20m)



WSPRnet received spots (40m)



24hr collection, loop located indoors

Further Adventures with Wideband RX Loops

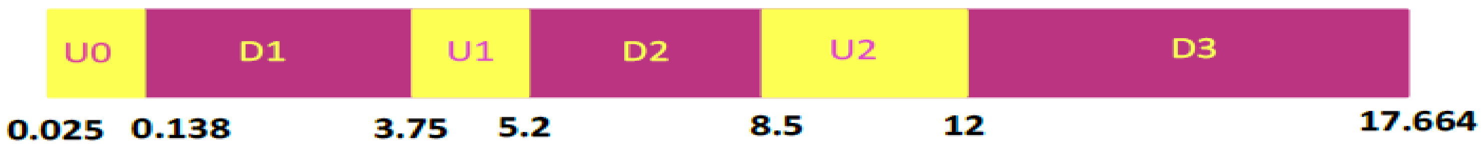
1. Identifying VDSLx interference from wideband spectra

2. Reverse Engineering the Wellbrook – some low cost alternatives

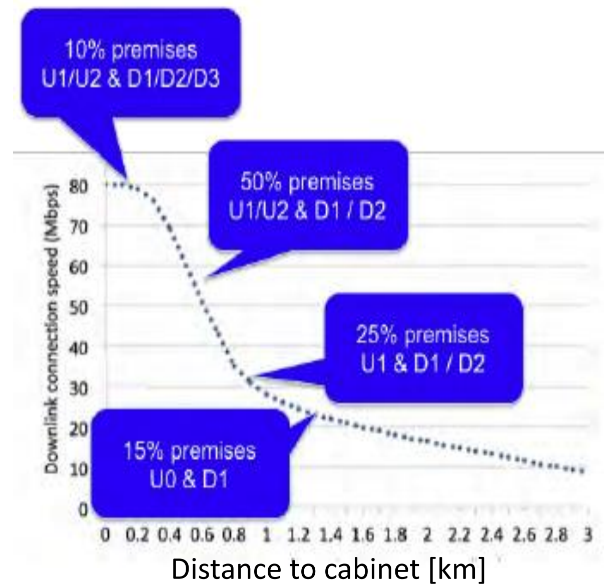
3. Comparing the LZ1AQ loop amplifier with the Wellbrook

Identifying Interference: VDSLx bands

VDSL Band	U0		D1		U1		D2		U2		D3	
Frequency MHz	0.030	0.133	0.143	3.700	3.800	5.150	5.250	8.450	8.550	11.950	12.050	17.664

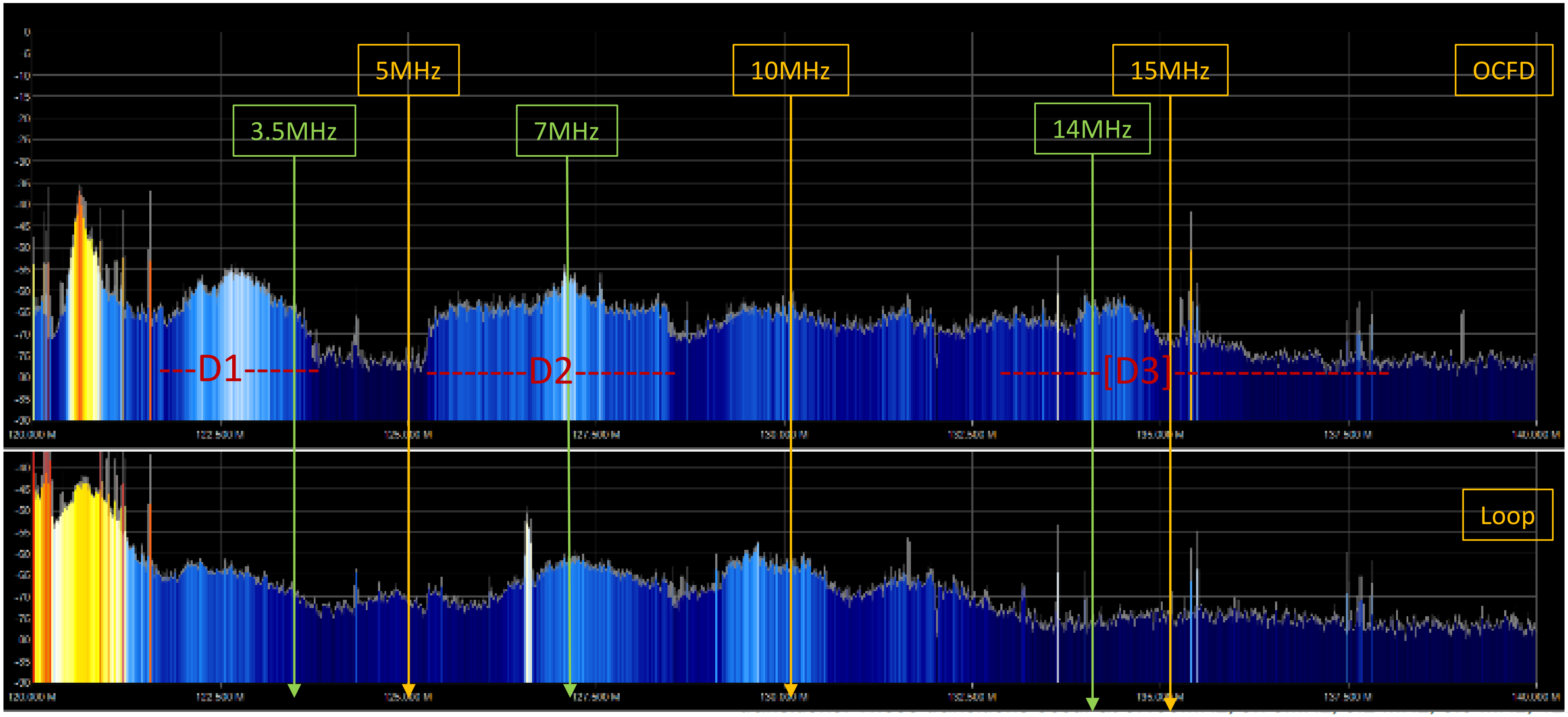


1. VDSLx Spectum is allocated into UPSTREAM U0, U1, U2 and DOWNSTREAM D1, D2, D3 bands separated by 50-100kHz guard bands.
2. Band edges are a good way to identify the presence of local VDSLx interference. Near the house the UPSTREAM is stronger, further away at the street cabinet the DOWNSTREAM will dominate.
3. On longer wires and lower data-rate service higher bands U2 & (D2) D3 are not used.

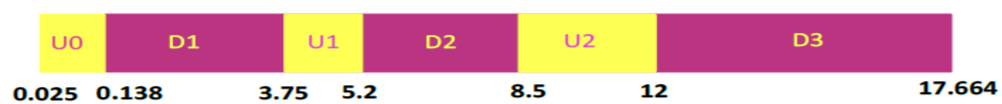


See RSBG publication: EMC Leaflet 15 - VDSL Interference to HF radio, http://rsgb.org/main/files/2012/11/VDSL-Interference-v3b-.pdf

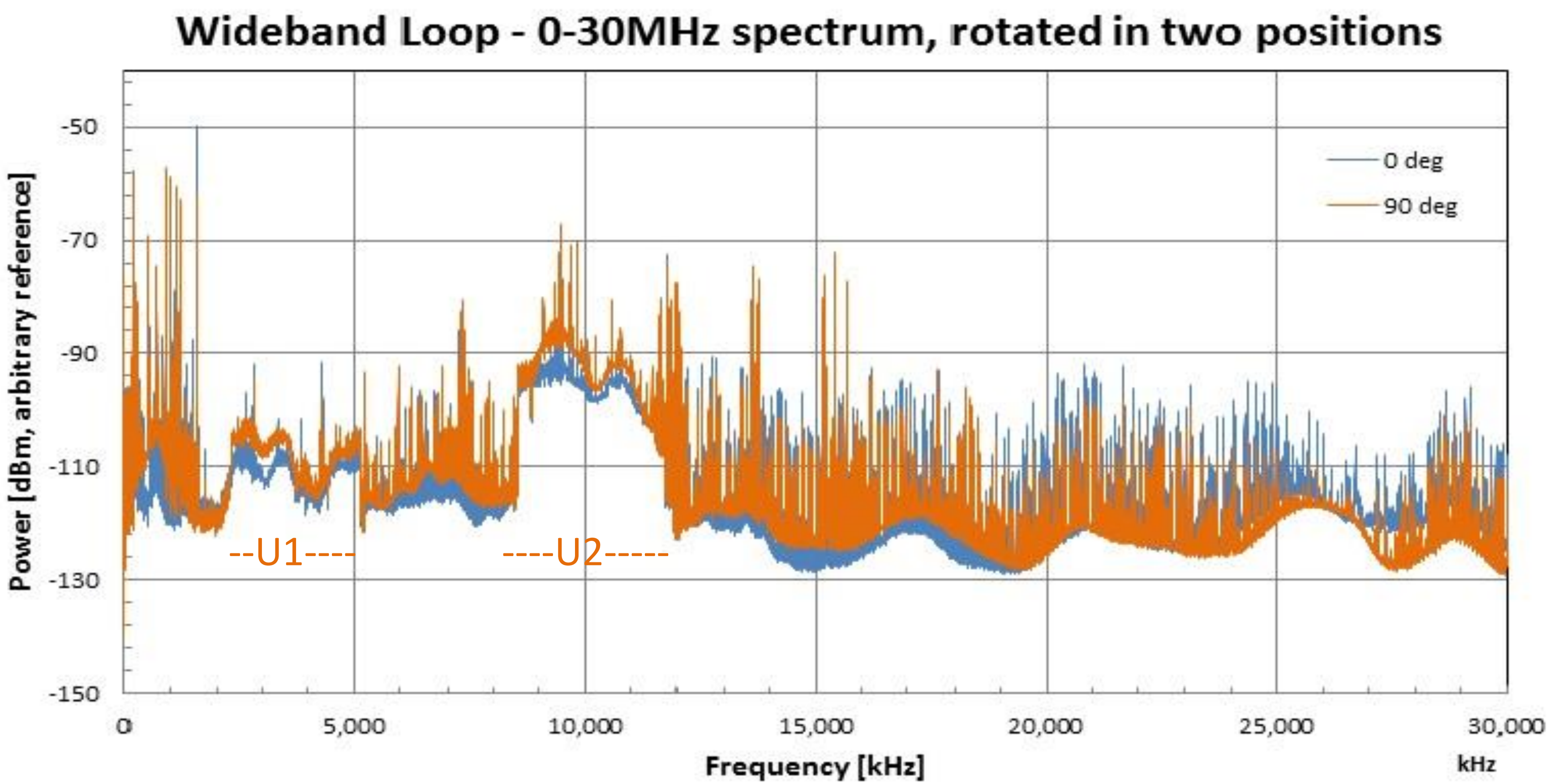
Spectra at M1CNK's location 0-20MHz OCFD dipole vs. Wellbrook Loop



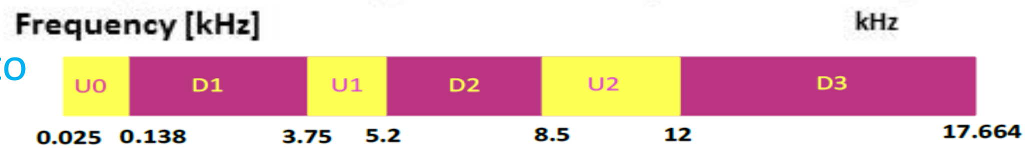
Strong D1 + D2 (and possibly D3), away from house towards cabinet end. OCFD tuned to 7MHz.



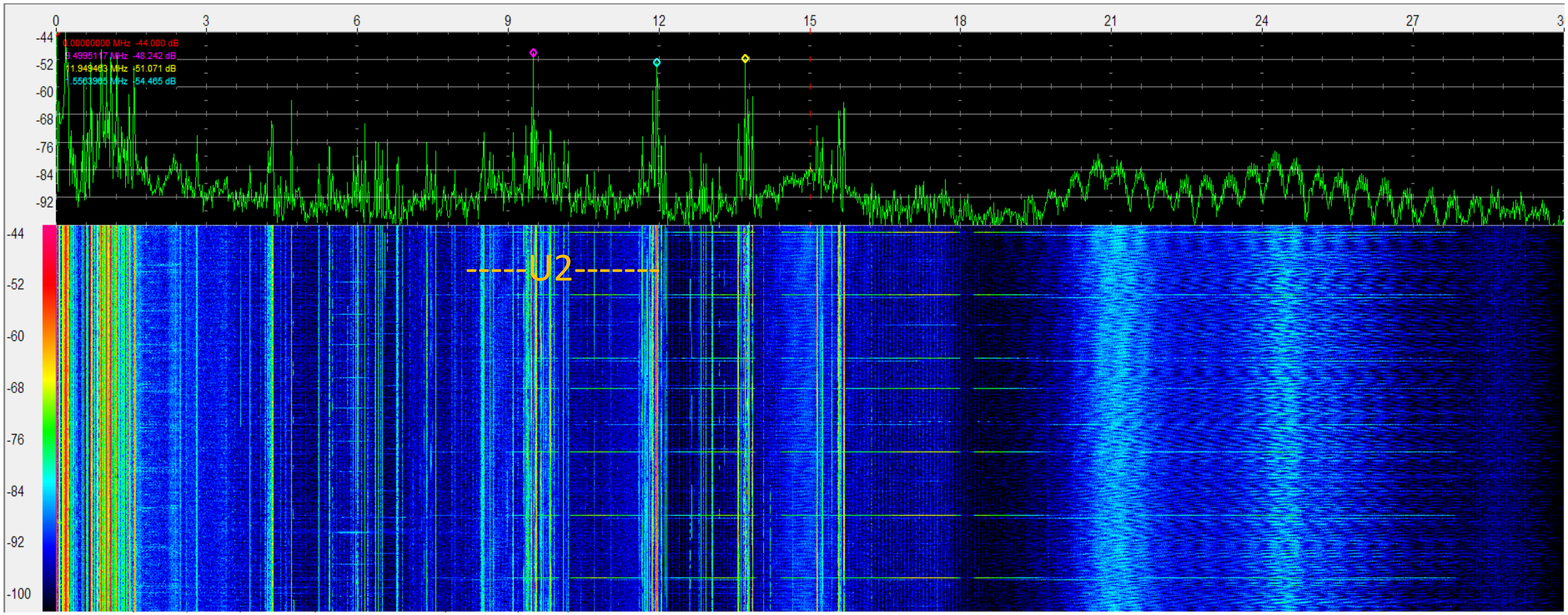
Spectra at M0XGT's location, 0-30MHz



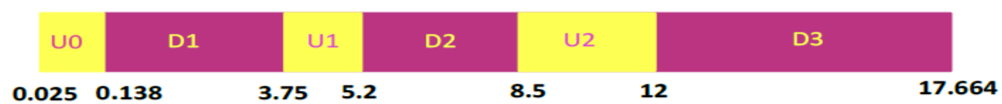
Strong U1 + U2. Inside house (loft) near to telephone pole and away from cabinet.



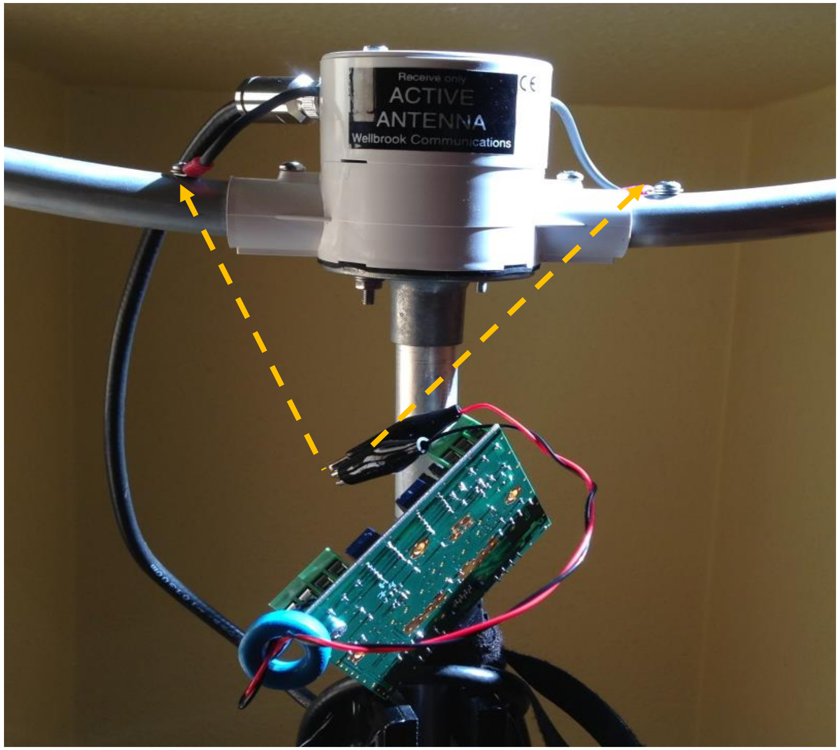
Spectra at G3ROG's location 0-30MHz Wellbrook Loop

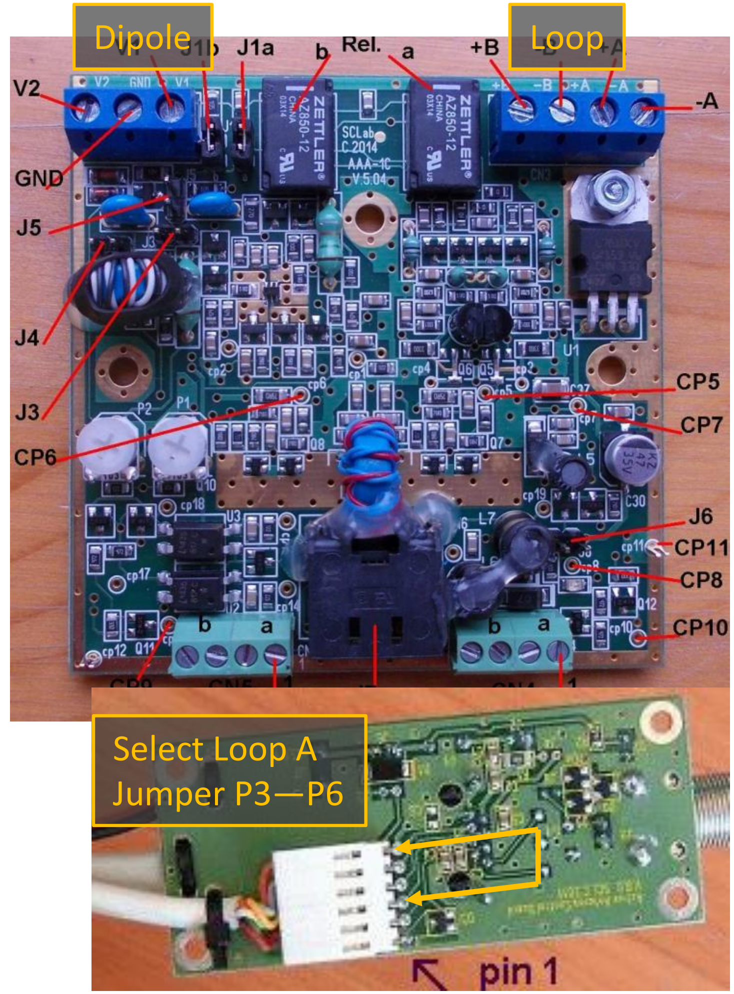


Strong wideband signals 21-25MHz *above* VDSL range , U2 edges at 8.5MHz & 12MHz.



Commercial LZ1AQ Loop Amplifier





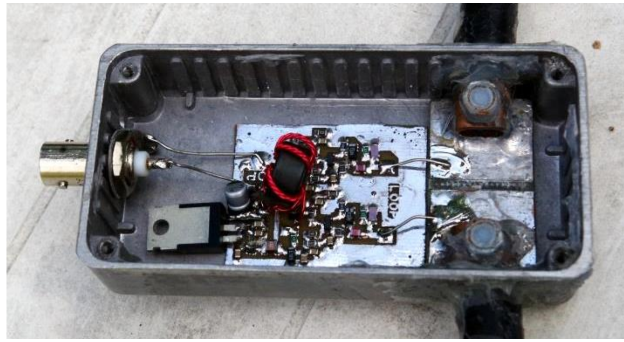
Both E-field (dipole) and H-field (current loop) signal paths with remote controlled relay switching to select / combine the inputs.

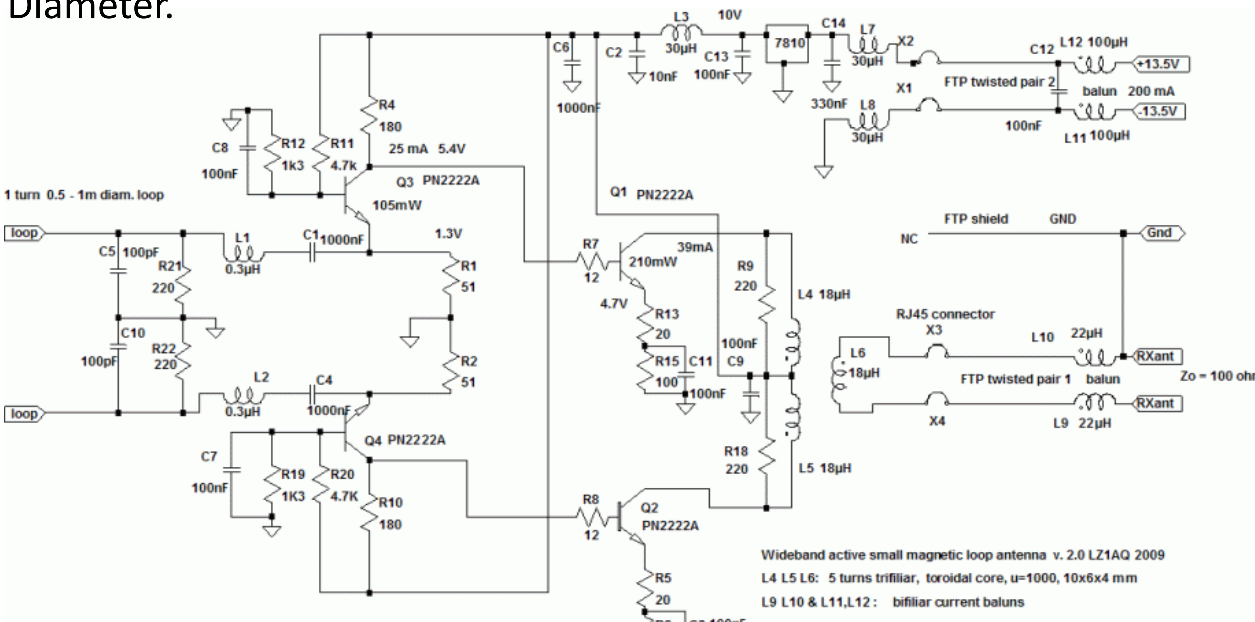
Dual loop diversity system.

Andy G4JNT modified LZ1AQ LNA

Low Z_{in} LNA with internal bias-T.

Original LZ1AQ design feeds 100Ω twisted pair Ethernet cable, G4JNT mod'd for 50Ω coax and lower power consumption. 60cm loop Diameter.



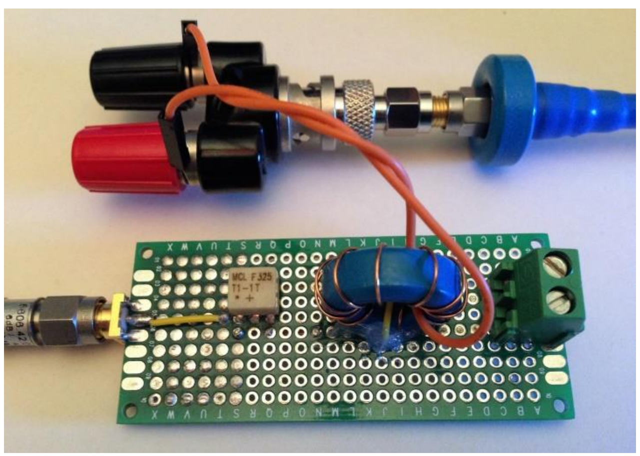


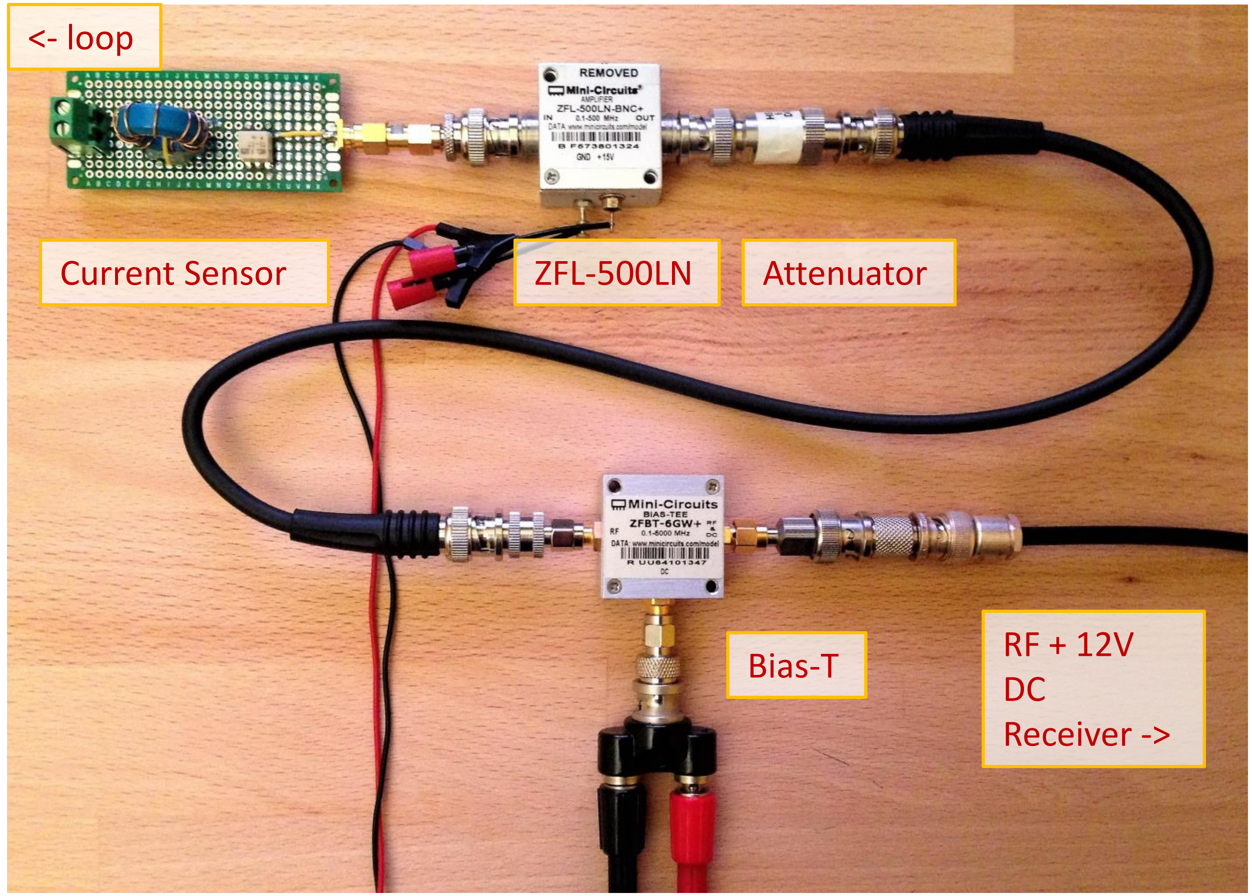
Original LZ1AQ schematic

Current Sensor
Mini-Circuits LNA + Bias-T

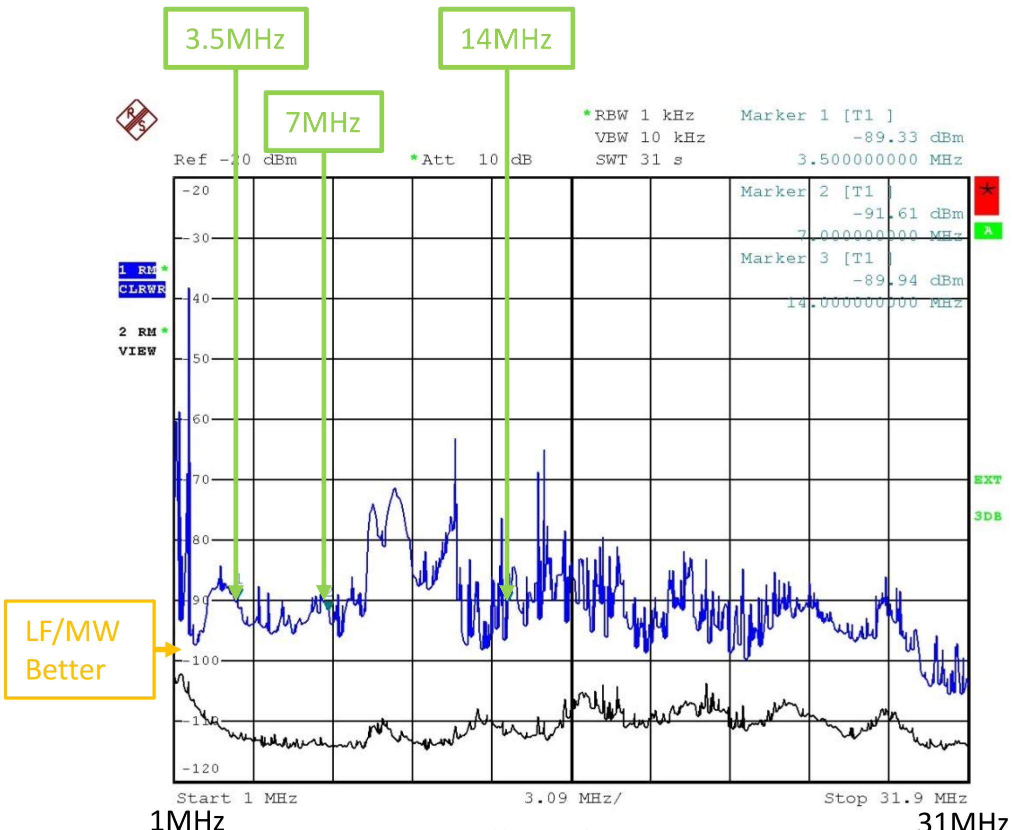
Current Sensor: 1:10 turns ratio + current choke. Input impedance – R~1-3Ω, X~2πfL, L=0.15μH (tinyVNA)

LNA: Mini-Circuits ZFL-500LN
G=24dB, NF<3dB, 0.1-500MHz
Bias-T - ZFBT-6GW
Can be used either as loop RX or to calibrate a TX loop.





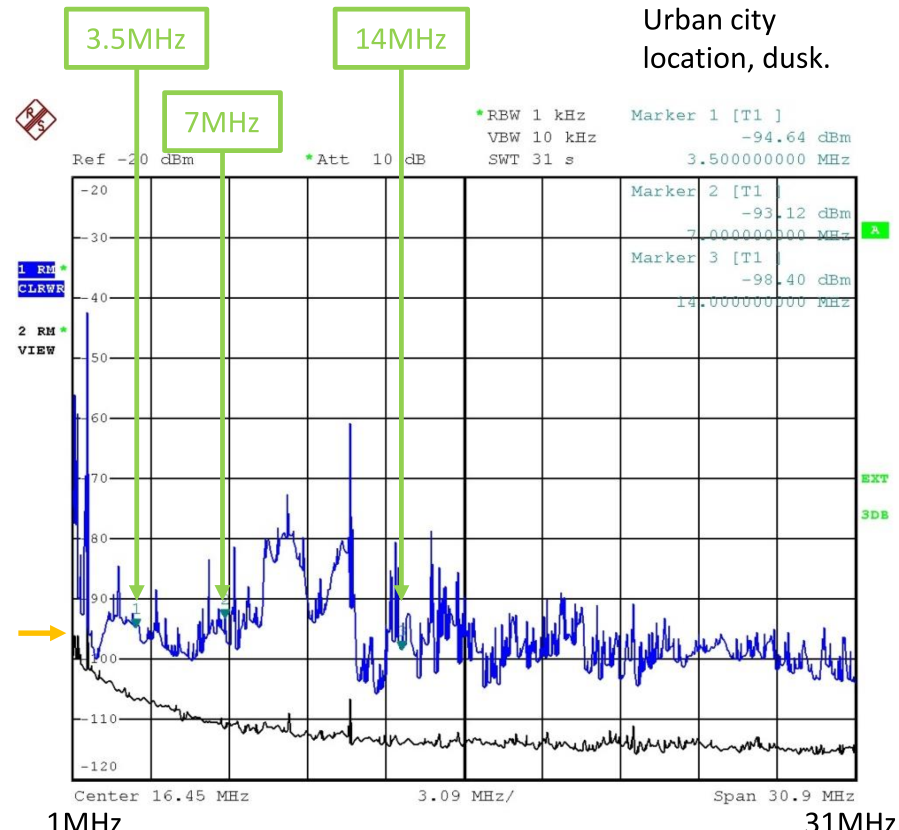
Compare Wellbrook & LZ1AQ Noise floor and Signals 1 to 31MHz



Loop + Wellbrook LNA

blue = signals, black = noise floor

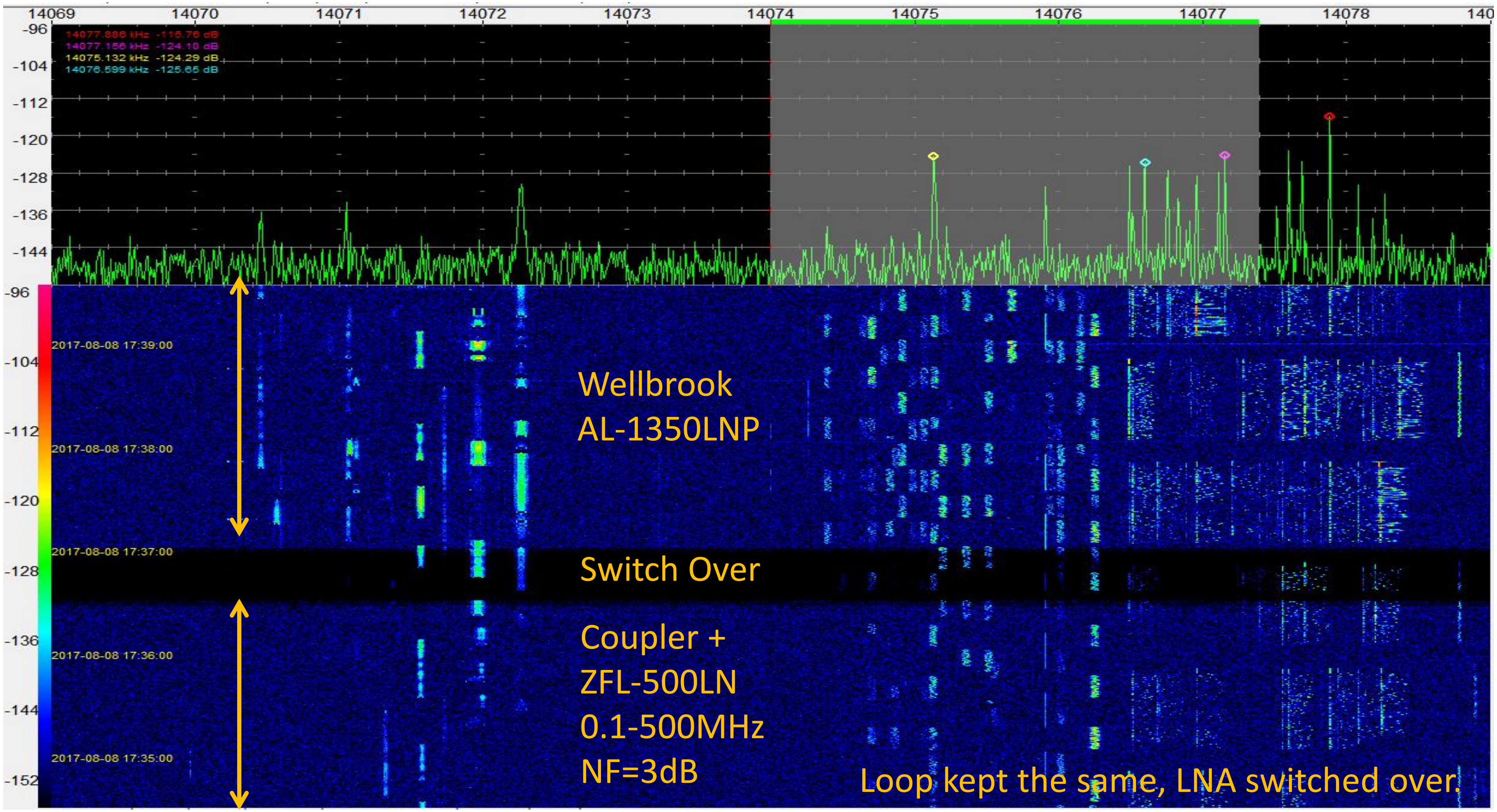
Urban city location, dusk.



Loop + LZ1AQ LNA

blue = signals, black = noise floor

Wellbrook LNA versus ZFL500LN/Coupler 14MHz/|BW10kHz PSK, FT-8, JT-65



Wellbrook LNA versus ZL1AQ loop LNA 14MHz/10kHzBW PSK, FT-8, JT-65