Gwyn Griffiths G3ZIL and Nigel Squibb G4HZX • **E-mail: gxgriffiths@virginmedia.com**

Improving HF Band SNR

Gwyn Griffiths G3ZIL and Nigel Squibb G4HZX describe their quest to understand and improve signal-to-noise ratio (SNR) on the 40m band.

Man-made noise on the HF bands is a topic that often crops up in *PW*, to the extent that Paul Burgess G3VPT recently asked in the *Letters* pages, *"Is this the end of Amateur Radio?"* While man-made noise is certainly troublesome – we both have suburban locations, **G3ZIL** in Southampton and **G4HZX** in Beckenham, South East London – our answer is a resounding *"No"*. Furthermore, our answer is not based on using costly commercial receivers or antenna arrays but on the simple 40m WSPR direct conversion receiver described in the April 2016 issue of *PW* and with straightforward dipole and vertical antennas.

We've realised, not surprisingly, that it is the antenna and local noise and not the simplicity of the homebrew receiver that were limiting the receiver's performance. This article is the story of our quest to understand and improve HF band signal-to-noise ratio (SNR) using information derived from WSPR spots while along the way seeing textbook antenna and propagation characteristics appear in practice.

Starting Points

At G3ZIL the garden offers reasonable scope for wire antennas, being about 19m wide by 17m deep. The initial antenna for 40m was a sloping-V dipole with its apex at the eaves of the house at 6m and sloping to stub masts at the east and west boundaries. A common-mode choke balun was at the feedpoint and the coaxial cable, with a long loop against the back of the house, had a 14m run to the shack across the attic among crossing electrical cables. G3ZIL initially used a Raspberry Pi 2 to run the WSJT-X software and an Alesis iO2 USB sound card.

At G4HZX the garden is long (about 65m) and narrow (10m), backing on to playing fields. While this would appear to be ideal for longwire antennas, the presence of large mature trees along the boundaries and a mighty oak in the centre make running such wires challenging. For many years the antenna has been a Hustler 5-BTV five-band trap vertical situated at the extreme end of the garden, with a 95m run of coax into the shack. The Hustler is used with a ground spike connection, without radials, and is at least 65m from the nearest house. WSJT-X software was running on an Apple Mac Mini using its microphone input. The Mac was also being used as a server for a number of low volume websites. This machine was located in a small 19" rack of other servers and network hardware. The WSPR receiver is powered by a linear regulated 12V PSU.

40m WSPR Performance

G3ZIL began comparing the number of spots received to those of others using the WSPR Challenge site of **Remco PA3FYM** and **Rob PE1ITR** (URL below). Calculating the ratio of spots received to those of a reference station reduced the effects of day-to-day propagation variations in that they would affect both stations. The chosen reference station was **Erich DK6UG**. Erich's receiver (a Kenwood TS-480) operates 24 hours a day and is consistently in the WSPR Challenge top five. Mostly he uses a quarter-wave vertical hanging from a tree but at times uses his 5/8-wave 10m antenna. His rural QTH is an old farm outside a village and the antennas are on a small hill about 110m from the house.

http://wspr.pe1itr.com

The graph, **Fig. 1**, shows the ratio, G3ZIL to DK6UG, of the number of unique callsigns received each day on WSPR on 40m over 12 months. Each month has a colour, there are a few gaps when one or other station was off-air and there are a few spikes when there were antenna or other problems for part of a day. For problems at DK6UG the ratio spikes high, for example at the end of February 2017, while for G3ZIL the ratio spikes low such as at the end of September 2016 and early February 2017.

There are many tales and attempts at improvements within this graph with its day-to-day fluctuations of varying amplitude and a number of longer-term variations, some of which are steps. The early results of April 2016 were to prove untypical. From May to early August perhaps the drop was a shift to summer conditions. But the further decline later in August and a steep and unexplained fall in mid-September led to these investigations. Unplugging the numerous sources of interference within the house showed no obvious dominant source but recall G3ZIL's suburban QTH, including several student halls of residence within 500m.

Diary of G3ZIL Tests

October 16th: Moved receiver and

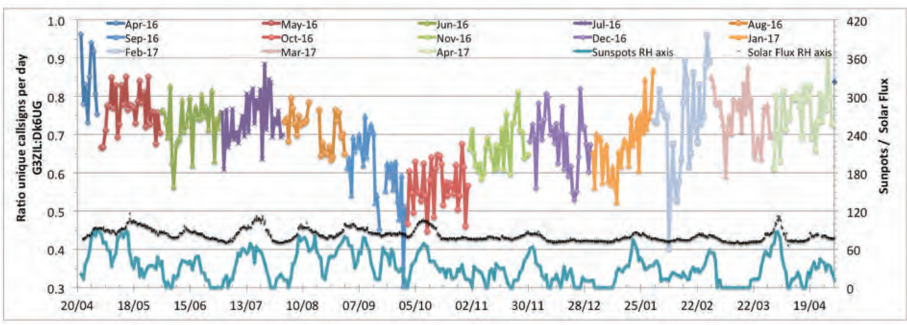


Fig. 1: Daily ratio of 40m WSPR unique callsigns received at G3ZIL to DK6UG. Sunspots from www.sidc.be/silso/datafiles Solar Flux from ftp.geolab.nrcan.gc.ca/data/solar_flux

Raspberry Pi out of the house, powered by batteries. Low dipole at 1.5m running north-south alongside then away from the side of the house – no improvement.

October 27th: Moved receiver and Pi to shed, as far as possible from the house, powered via separate linear regulators from 12V battery float-charged by DC supply via buried armoured cable. Low dipole running east-west parallel to house – improved for one day. 30m version of receiver installed in the shed with an inverted-V antenna some 2m away from the 40m low dipole.

November 2nd: Homebrew charge controller was oscillating, fixed, added common mode chokes on incoming and regulated DC supplies, added earth connection to coax screen at receiver input via 0.6m of wire to 1.2m earth rod of 15mm copper pipe – marked improvement. Raised centre of the low dipole to 4m, ends still at 1.5m – additional small improvement.

December 4th: Day-night temperature changes were resulting in crystal oscillator frequency changes of typically 25Hz. Changed the local oscillator to a QRP Labs Si5351A synthesiser with a Fox 924B 27MHz TXCO controlled over I2C by an Arduino Nano.

December 22nd: One leg of the dipole broke at the centrepiece during a storm, fixed on the 24th.

December 26th: Very strong E layer with many short-skip spots, best performance for five months.

December 28th: Changed from Raspberry Pi 2 to 3 – less noise on 30m, 40m no change.

January 7th: Added ferrite common mode choke to the power lead of (son's) recently acquired internet TV box.

January 20th: 20m version of receiver installed with delta loop antenna 3m from low dipole.

February 8th: Dipole damaged when G3ZIL away, one leg on ground.

February 14th: Repaired dipole, removed 20m WSPR receiver and its antenna. Two poor days due to interference – ARRL CW contest.

March 2nd: 30m WSPR receiver and antenna removed.

March 8th to 11th: Testing 60m WSPR receiver in shed with antenna with one leg parallel to 40m low dipole – added to noise.

March 18th: Quarter-wave vertical antenna with six radials over 180° in place 3m away from dipole, 4m to one side of centre. Sporadic tests with vertical and dipole via diplexer – worsened SNR.

April 8th: Retuned low dipole to resonance at 7.04MHz by adjusting length.

May 10th: Removed vertical.

Noise Measurements

From October 2016 occasional noise measurements were made at G3ZIL using a Rigol Spectrum Analyser DSA815 over a frequency range of 7.03 to 7.05MHz, averaging 50 scans with 100Hz resolution and a 10dB input attenuator. An encased Watson 50Ω dummy load showed ~53nV, well below the noise level with an antenna connected.

The noise from G3ZIL's sloping inverted-V, made mid-morning when the geomagnetic disturbance index at the Hartland Observatory, Devon was zero, was typically 2.5μV. For comparison, we can equate to an S-meter reading in a 2.5kHz bandwidth: 2.5μV in 100Hz is 12.5μV in 2.5kHz (square root of the ratio of bandwidths), which on an S-meter scale of S9=50μV and 6dB per division is S7.

The screenshot, **Fig. 2**, shows typical measured noise with the low dipole in mid-April 2017 under similar conditions at 0.68μV, equivalent to S5 in a 2.5kHz bandwidth. In this plot the X-axis divisions are 200Hz, the peak between 7.0400 and 7.0402MHz represents the average level within the 100Hz bandwidth of the spectrum analyser of several 6Hz bandwidth WSPR signals at the time of measurement. Hence the noise measurement is made slightly outside the WSPR band where there were no signals. As a further comparison, the typical 100Hz bandwidth noise for a quarter-wave vertical with six radials over 180° in these conditions was 2.2μV.

Vertical and Dipole Comparisons

With G3ZIL and G4HZX using essentially the same *PW* receiver, we thought we could learn from comparisons between the performance of the low dipole at G3ZIL and the vertical at G4HZX. Spots from the two stations were downloaded from the online WSPR database into an SQLite database at G3ZIL and only those reports of the same station at the same time selected for analysis. So far we have looked at how the SNR difference varies with soil moisture, time of day, distance and with changes at each station.

SNR and Soil Moisture

The characteristics of a vertical monopole working with a ground spike depend on the electrical conductivity and permittivity of the surrounding area. Horizontal dipole antennas at low heights (<0.1 of a wavelength) are also affected by these ground parameters but to a lesser extent. A prolonged dry spell during April 2017

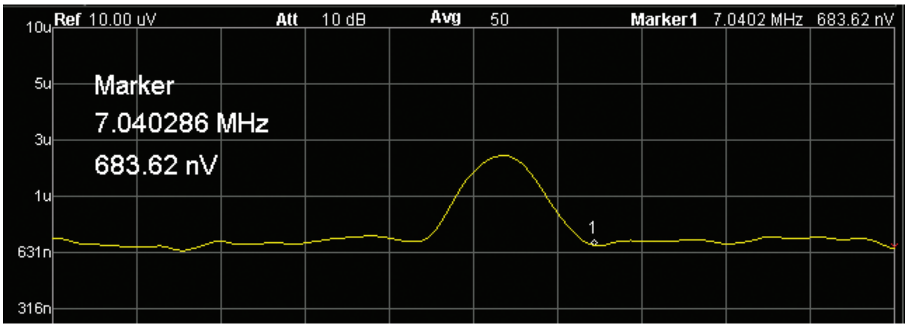


Fig. 2: Spectrum of signals at G3ZIL from 7.039 to 7.041MHz, average of 50 scans at 100Hz bandwidth for the low dipole.

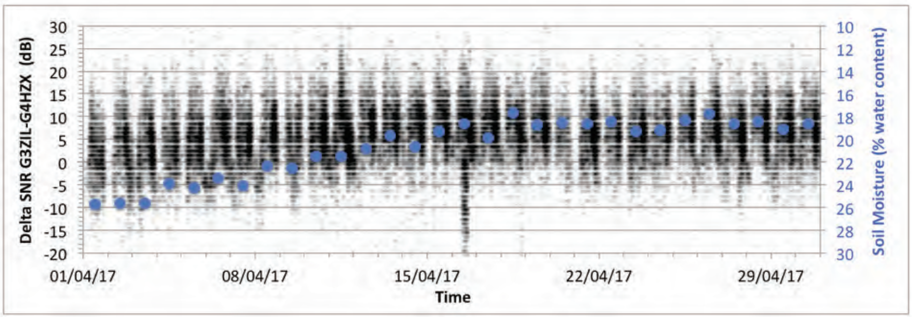


Fig. 3: SNR differences between G3ZIL (horizontal low dipole) and G4HZX (vertical monopole) on 40m with daily soil moisture at Rothamsted (blue squares).

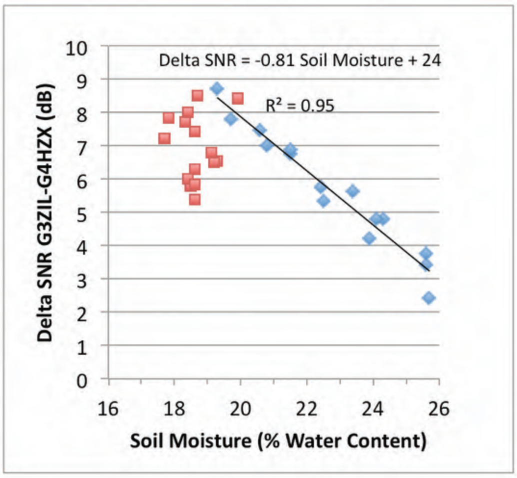


Fig. 4: SNR difference and soil moisture, blue April 1st to 15th, red April 16th to 30th.

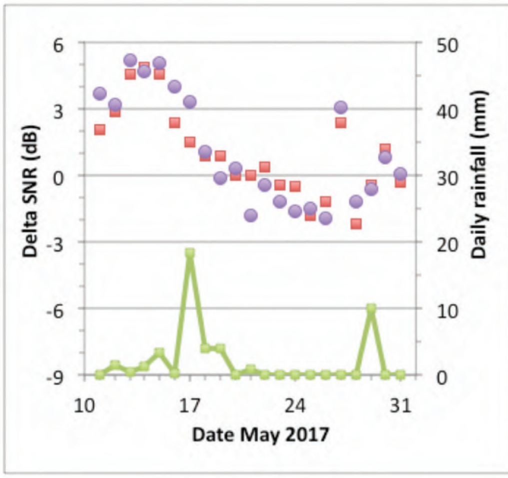


Fig 5: SNR difference G3ZIL-G4HZX (red) and G4CPD-G4HZX (purple) with daily rainfall (green).

provided a good opportunity for us to study the SNR difference of G4HZX on London clay and G3ZIL, Southampton, also on clay, with soil moisture as a proxy for conductivity/permittivity. Soil moisture data is from Rothamsted, Hertfordshire where the ground is clayey loam [Acknowledgement: The soil moisture data is owned by NERC – Centre for Ecology & Hydrology and is used here under licence. © Database Right/Copyright NERC – Centre for Ecology & Hydrology. All rights reserved.]

The plot, **Fig. 3**, shows the SNR difference with date/time based on our WSPR reports on 40m. On average there are some 2,000 spots each day, mostly from Europe during the day and from North America during the night. The daily soil moisture, as a percentage of water content, is shown as blue squares.

There is a trend for the SNR difference to increase over the first two weeks of April and our hypothesis is that this was because reduced soil moisture adversely affected the performance of the vertical antenna at G4HZX. The trend from April 1st to 15th is very clear when the SNR difference is averaged over a day and plotted against soil moisture, the blue points in **Fig. 4**. For April 16th to 30th, the relationship had altered – see the red points in Fig. 4. We surmise that while Rothamsted soil moisture was a good proxy for soil conductivity in Kent during April 1st to 15th as the soil was drying out with essentially no rain, patchy rain across the South East on April 16th made the Rothamstead data a poorer proxy.

A good test of a hypothesis is whether it can explain the converse – in our case whether the SNR difference between dipole and vertical decreases after it rains and the soil moisture increases. We have taken average daily rainfall data from St James' Park and Northolt, London and

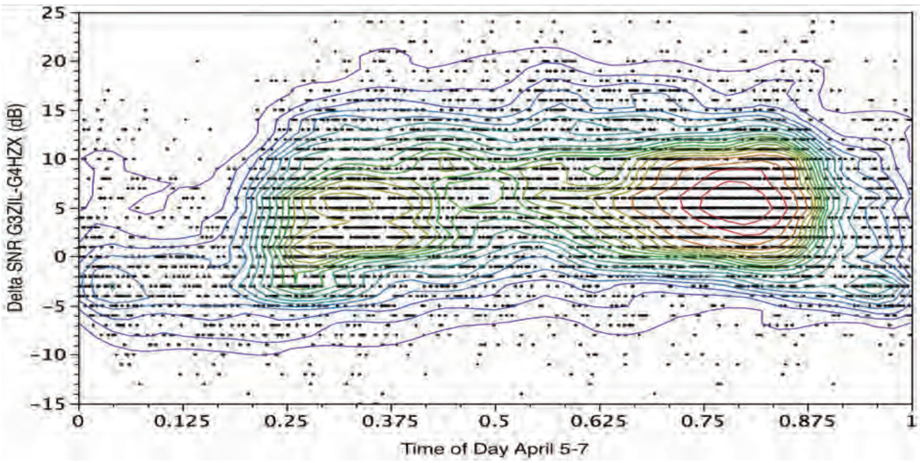


Fig. 6: Density contours of SNR difference G3ZIL–G4HZX April 5th to 7th 2017.

Kenley, Surrey as a fair measure of rainfall at Beckenham. To be sure that our findings relate to the performance of the vertical at G4HZX, **Fig. 5**, shows the SNR differences between G4HZX and two stations, G3ZIL and **Graham G4CPD** in rural Yorkshire using the ZS6BKW version of the G5RV antenna at 30ft (9.2m). Our interpretation of Fig. 5 is that with no rain since May 4th, the initial rise in SNR difference is from drying out at G4HZX, 3mm of rain over the three days May 12 to 14th halted this drying out, 3.5mm of rain on May 15th reversed the trend, with SNR difference declining further following rain on May 17th to 19th. The subsequent dry spell led to a plateau from May 24th, with the SNR difference increasing from May 28th before declining after the rain on May 29th.

In mid-June three radials placed on the soil surface were added to the vertical at G4HZX. In stark contrast to the clear relationship between daily average SNR difference and Rothamsted soil moisture between April 1st and 15th, Fig. 4, there was no significant correlation during the dry spell June 13th to 27th (the correlation coefficient squared was 0.063). Adding even three radials has effectively removed the dependence on soil moisture for good performance from the vertical.

SNR and Time of Day

Seen as a banding of the mass of data points in Fig. 3 is a daily pattern to the SNR difference. This reflects the different elevation angle responses of the vertical and horizontal antennas as WSPR spots from stations at different distances are received. **Fig. 6** draws out this pattern, showing the SNR difference against time of day for April 5 to 7th (where 0.5 is midday). The contours give a good representation of the density of points from mauve for sparse to red for the highest concentration of points. Note that we should wrap this flat plot into a cylinder so that 0 meets 1 (both being midnight).

From about 0.9 (2130UTC) a minor rise with two peaks appears and wraps round to the early hours – here the SNR difference is negative. These two peaks, at about −3dB, show the vertical at G4HZX to be outperforming the dipole at G3ZIL. This is understandable given that most signals are from North America during this time and the vertical has a better low angle response than the dipole. The

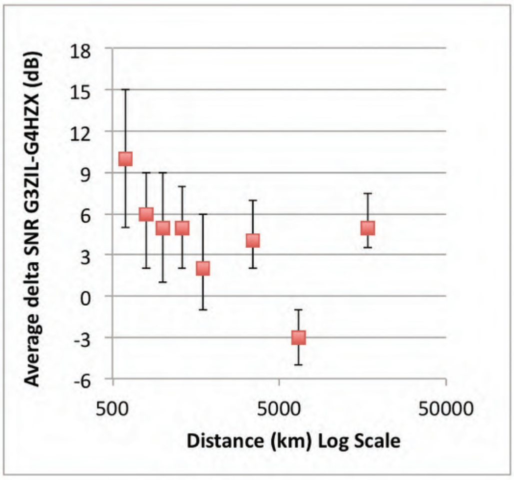
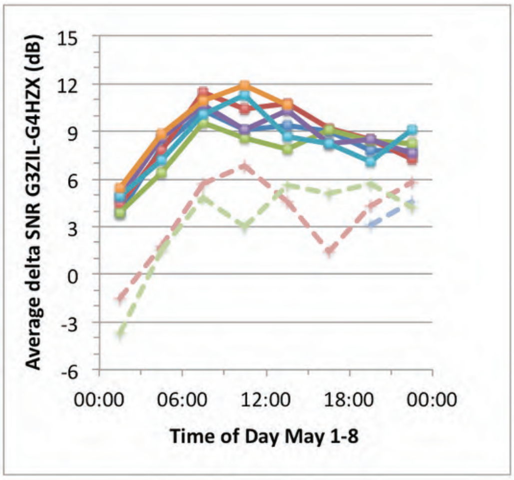


Fig. 7: Average SNR difference in distance bins with bars showing upper and lower quartiles.

Fig. 8: Average SNR difference G3ZIL–G4HZX over three hour intervals before and after the move.



vertical has the edge until about 0500UTC as dawn presages an increase in the F2 layer critical frequency and European signals from 2,000km and closer start to dominate. The advantage is now with the low dipole with its better high elevation angle response. This advantage, on average about +6dB, persists until about 2130UTC. Note the two peaks in spot density, morning and evening, reflecting fewer WSPR spots being received during the middle of the day when D layer absorption is greatest.

SNR and Range

To look specifically at SNR difference with range the April 5th to 7th SNR difference data were binned into range intervals centred on 600, 800, 1000, 1300, 1750, 3500, 6500 and 17000km with 989, 2053, 1502, 974, 249, 69, 539 and 15 spots respectively, **Fig. 7**. The dipole had the advantage out to 1,750km and the vertical a clear advantage at 6,500km. We have no definitive explanation as to why the dipole had the advantage for the two bins centred on 3,500km and 17,000km; perhaps multiple skips, chordal-hop or whispering gallery modes meant that signals were arriving at higher elevation angles?

Placement in the Shack

At 1600UTC on May 6th the Mac Mini in the equipment rack at G4HZX was replaced by a standalone low-end Mac Mini located close to the WSPR receiver, on the other side of the shack – about 3m away from the rack. This resulted in an immediate improvement of about 5dB in SNR. The plot, **Fig. 8**, shows the average SNR difference between WSPR spots at G3ZIL and G4HZX over three hour intervals before and after the move. Solid lines are from May 1st to 6th with the equipment at the original position at G4HZX, dotted lines are at the revised position. While there is some day-to-day variation, the broad cyclic patterns within a day are clear and the biggest improvement after the move, an average of 7dB, is between 0000 and 0300UTC. Our supposition is that RF noise from the rack was getting back into the WSPR receiver via the 5m of audio cable, although there may have been a decrease in AF noise as well. A short test with a cheap external USB audio converter showed a dramatic increase in audio noise, with 50Hz hum bars clearly visible on the WSPR waterfall display, so this was immediately abandoned.

The improved SNR at G4HZX from May 6th enabled a dramatic rise in spots from North America, red squares in **Fig. 9**, from fewer than at G3ZIL (blue and black) on and before the 6th to at least 12 more each night after the move. The black G3ZIL spots are for four days when a quarter-wave 40m vertical antenna with radials was being tested, some 3m offset from the dipole. While clearly affecting reception adversely (average daily SNR was 3dB lower), further investigations are needed to find out why.

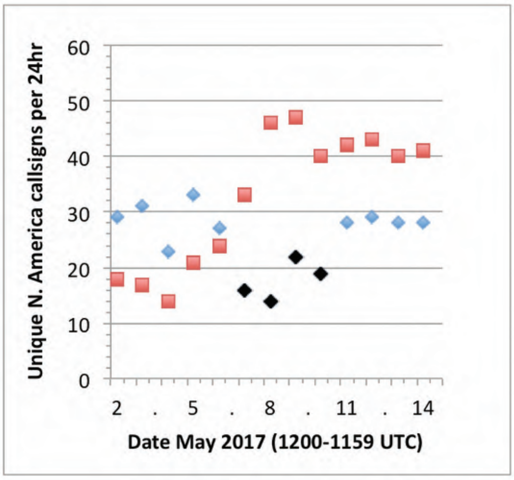


Fig. 9. Unique North America callsigns each day for G3ZIL (blue and black) and G4HZX (red).

Summary

While there's no magic solution to the problem of man-made noise on the HF bands we've described a number of practical actions that may help:

Siting antennas as far as possible from the house, even if, as at G3ZIL, this means a height of only 0.1 wavelength. Indeed, the low height may improve SNR.

See if you can site your receiver so that you have as short a wire as possible to a good earth.

Especially if you have a homebrew receiver, ensure you have good common mode filtering for its power supply and use linear regulators.

If you've a vertical antenna with no radials, your SNR may vary by 7-8dB, as at G4HZX, depending on soil moisture.

Your own equipment could contribute to the problem; try different locations within the shack.

The close proximity of a second, unconnected, antenna for the same band decreased average SNR by 3dB.

Finally, our thanks to the WSPR community for a very useful tool for checking propagation and antenna performance and for the transmissions that made this analysis possible.