Assessment of HF Antennae using Doppler Analysis

Murray Greenman ZL1BPU
January 2020

Direct comparison of antenna behaviour at various locations over time

For at least 100 years, Radio Amateurs have relied on observations from other stations to assess the performance of their equipment, which is a haphazard method at best, and is of course highly subjective. A further problem is that each report represents only an instant in time from a single location. In recent years, receivers and calibration of their signal strength meters have improved, but there is still wide variation between receivers, and the level of received noise and receiver bandwidth selected also affect report reliability. In addition, signal reports still represent just a snapshot of reception, that on HF, due to ionospheric activity, is varying all the time.

While simulation can reveal quite a lot about antenna patterns, which can be confirmed in models on a radio range, neither method helps describe what the actual performance of a working antenna is when it interacts with the ionosphere.

This paper illustrates a method whereby, on low HF at least, detailed signal reports can be assessed over time, performance while interacting with the ionosphere can be recorded, and better still, two antennae can be compared directly.

Doppler Analysis

The author has been studying the behaviour of the ionosphere for about 30 years. While ionospheric propagation has been studied by the scientific community since the 1950s, using equipment such as the Rotating Interferometer, this study required specialised equipment, extensive manual measurement and mathematical analysis. Only a few well equipped laboratories with graduate student manpower could do this work, so for many years it was limited in scope and well outside the reach of the Amateur.[1]

While the complex mathematics required for Discrete Fourier Analysis (breaking down signals into their components in the frequency domain) has been understood for over 200 years, there was not the computing power available to achieve analysis in real time. The real breakthrough came for Amateurs in the late 1990s when real-time FFT first became available using specialised maths processors such as the Motorola DSP56002 EVM. The tool used back then was EVMSpec, written by Peter Martinez G3PLX. Peter published an important article on the use of FFT for studying radio propagation in May 1998.[2]

Computers have been equipped with sound cards since the late 1980s, but were no use for ionospheric analysis due to lack of processing power. This capability arrived for the average Ham in about 1999, when personal computers equipped with sound cards were finally fast enough to run audio analysis programs. Although not the first PC FFT software, the first really useful software for ionospheric study is still the best today – SBSpectrum, by Peter G3PLX.[3]

What sets this software apart from other Spectrogram programs before or since is that it is dedicated to Doppler Analysis of radio signals, and has very fine frequency resolution (it can resolve to 0.01 Hz). While the resulting *Dopplergram* is not perhaps as sensitive as Spectrum Laboratory or Spectran, and is only black and white, it allows very fine detail to be seen.

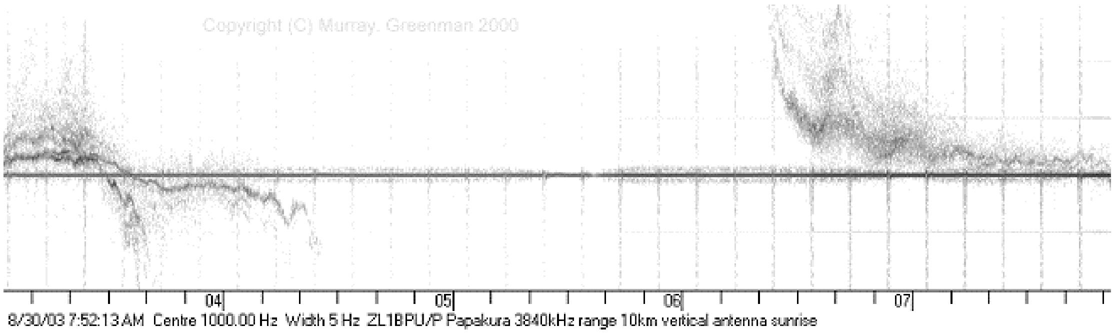


Fig 1. An SBSpectrum Dopplergram illustrating NVIS dropout

The first illustration is from an experiment performed back in 2003. A tiny CW transmitter was placed at a friend's place 10 km away, attached to his regular 80 metre dipole, and operated on 3840 kHz. The transmitter had CW ID every 10 minutes (hence the faint vertical lines). Using a very stable receiver on a dipole antenna, a recording was made overnight. SBSpectrum, which works with receiver audio, was used to make the graphical recording, with the receiver in USB mode, tuned 1 kHz lower than the carrier frequency.

The horizontal axis is local time, marked in hours. The vertical axis is received frequency, and has a span of just 5 Hz. The steady line across the graph is the ground wave signal. In places there is some 'furriness', which may be an E-layer response. F-layer returns are Doppler shifted by vertical movement of the ionosphere, and are easily visible up to 0430, and again after 0625. Between those times, there was no F-layer propagation available at the receiving site since the high-angle rays were not returned due to insufficient ion density (above the MUF).

In Figure 1 the F-layer signal fades out at two independent points, at 0350, and again at 0425. Affected by the earth's magnetic field, at higher latitudes electron spin in the upper ionosphere is elliptical, rather than circular, and this results in two refractive indices. For signals of mixed polarisation, two return rays are the result, called the Ordinary and Extraordinary (O&E) rays. These fade out independently with different Doppler shift. These rays are quite well defined because, with the sun on the other side of the earth, the ionosphere is very stable, just slowly losing ionisation.

The fade-out occurs because the F layer no longer supports the high-angle refraction necessary for such short paths. In other words, the receiving station is in the 'skip zone'.

Approaching sunrise at 0640, the ionosphere re-ionises as the sun again bombards it, causing more charged particles, with density increasing with time from the top down, which causes Doppler shift in the radio returns in an up-frequency direction. The rays are much more scattered than at night, as the sun causes considerable disturbance. As time goes by, the vertical shift drops off. If you look closely, between 0640 and 0650 you will see that there are several similarly shaped returns stacked on top of each other, with increasing Doppler shift. These are the direct F-layer return, and returns involving one or more bounces off the earth and again from the ionosphere. The increased Doppler shift occurs because the signal is refracted by the moving F layer more than once.

So, as illustrated, the Dopplergram can reveal ground wave, E-layer and F-layer propagation, allowing a radio path to be assessed in great detail. The Dopplergram can also reveal other effects not discussed here, including Sporadic E, returns from meteorites, aircraft and ionospheric scatter.

Application to Antenna Behaviour

Applying this propagation analysis technique, an understanding can be developed of what the various products mean with regard to the antennae used. Because the F-layer, E-layer and ground wave returns may involve different antenna radiation mechanisms, it is possible to learn about the practical performance of a transmitting or receiving antenna, especially if you can compare one antenna with another.

The author’s first experiment in this field was stimulated by a friend’s need to know how he could achieve 24/7 telemetry reports from his holiday home, 30 km away. Being outside VHF range, but within 80 metre ground wave range, he expected that this band would be the best bet, using the well established FSQCall telemetry capability.[4] But initially this proved not to be so, as there were times, especially around sunrise and sunset, when message reception was intermittent. He asked for help to understand what was going on.

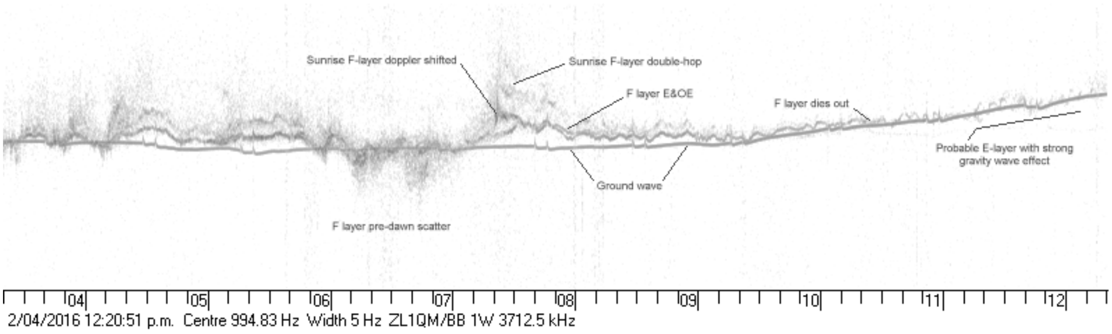


Fig. 2. 80 metre Doppler study from holiday home

Figure 2 shows the preliminary study. Again, a small CW transmitter was used at the remote site, with a low dipole antenna. The chart has been annotated to show the various effects that were observed through the morning hours. While this transmitter was not as stable as desired, it served the purpose, and at least seven different propagation products were identified. It was clear that, much of the time, the sky-wave was as strong as the ground wave, which was the likely cause of the problem, as the two products would have quite different timing and frequencies on arrival at the receiver, making decoding of digital modes, even FSQCall (designed specifically for NVIS), less reliable.

It seemed therefore pertinent to test an antenna with reduced sky wave capability, and so for the second test, a trapped vertical was studied along with the dipole. So that both transmissions could be seen in nearly the same time frame, a timer and relay was added to the transmitter, so that it would alternately spend 12 minutes connected to the dipole, for reference, and then 35 minutes connected to the vertical. The results of this next experiment showed clearly that the assumption was correct – there was almost no sky-wave signal from the vertical antenna, and in fact the ground wave signal was even stronger than on the dipole – see Figure 3.

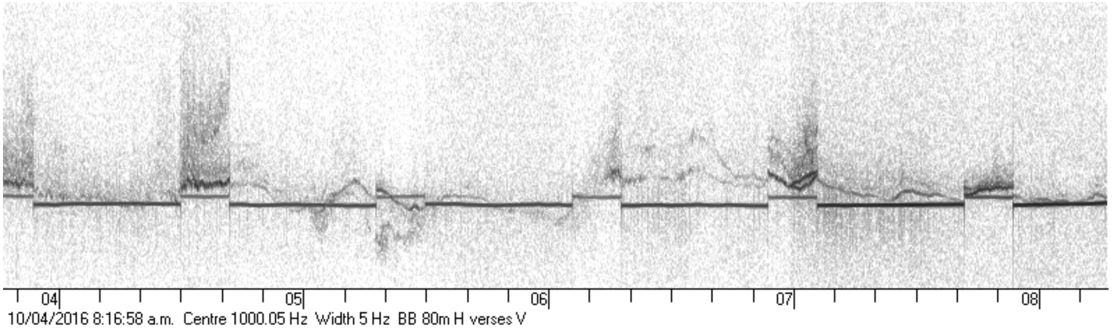


Fig 3. Time multiplexed signals from two antennae

It can be seen in this spectrogram that the shorter (dipole) segments show spectacular F-layer returns with marked Doppler shift, and that they are mostly much stronger than the ground wave. In contrast, the longer segments from the vertical antenna have strong ground wave and much reduced sky wave. The ground wave shows a carrier shift between segments, due to power supply loading by the relay affecting the carrier frequency of the very simple crystal-controlled transmitter.

This study was made in 2016. As far as is known, this was the first ever use of Doppler analysis to study and compare the performance of two antennae.

Dual Transmitter Analysis

More recently there has been a need to study the performance of a Magnetic Loop antenna, in particular to dispel the misinformation (and frankly, much ‘pixie dust’) which accompanies reports relating to this antenna. Everyone spoken to gave different reports, so to dispel any myth, the earlier antenna comparison scheme was repeated, but with technical improvements.

These new tests commenced with a single transmitter and a relay switch, as before, but it was clear that it was easy to miss some of the effects from one antenna, while connected to the other. So a method was evolved that did not require an antenna switch, just two very stable transmitters. The signal sources used were Rubidium Synthesisers, although for all practical purposes a commercial TCXO multiple output DDS synthesiser (such as the the Novatech 409B), or a homebrew multiple output synthesiser, such as the QRPLabs OCXO/Si5351 kit, would suffice.

Two separate power amplifiers, loafing along at 1 Watt output, were connected to a Kenwood SW-200 power meter with two SWR heads (in order to check the power), two appropriate antenna tuners, and the two antennae. Tests were made on an Army Loop and on a short centre loaded vertical, comparing them to a reference Inverted Vee Dipole.

The two transmitters were operated just 10 Hz apart, so that their signals would be together within the receiver pass band, and close enough that selective fading effects would be almost coincident. Placing the signals closer than 10 Hz would result in their received products overlapping, and could also result in AGC pumping and intermodulation due to the beat note. This type of analysis is of course best performed with professional grade receivers, with AGC off.

Because of a need to understand the characteristics of these antennae at different distances, receiving stations at various locations were recruited, each equipped with a stable receiver and the SBSpectrum software. KiwiSDR receivers, also used, are really handy for such tests, except that they time out after a while. Figure 4 shows returns for the Dipole (reference) antenna, upper trace, and the 4 metre centre-loaded vertical, received at Marahau KiwiSDR,[4] some 500 km away. Transmissions were on ~3560 kHz.

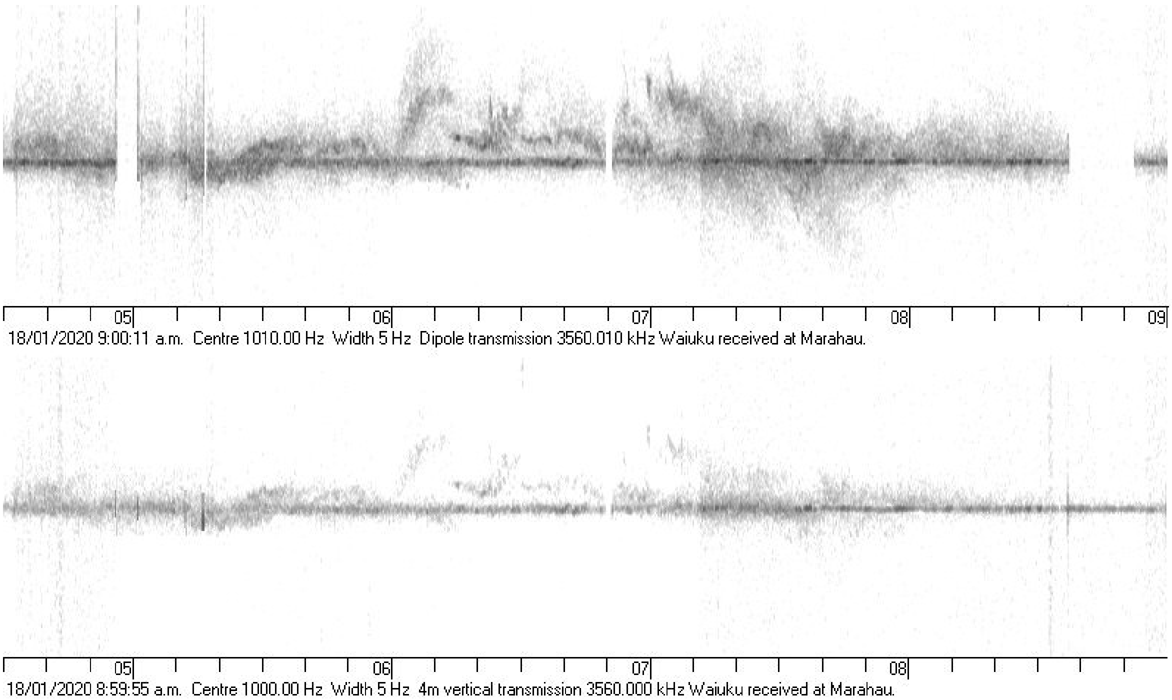


Fig. 4. Dipole and Short Vertical comparison at 500 km

Two instances of SBSpectrum were used, set 10 Hz apart, to analyse audio from the same receiver, the KiwiSDR web application. In the time frame shown, sunrise occurred at about 0610. The Dipole signal is quite strong (blacker), while the signal from the Vertical is much weaker. There is also more scatter on the Dipole signal, which is typical since it has strong high-angle radiation, invoking NVIS propagation. Both traces show almost continuous E-layer reception, the straight-line but fuzzy product with slight wiggles. You might not expect this, but E layer propagation on 80 metres is there (although weak) 24 hours a day, even over 500 km, and is usable for weak signal modes such as FSQCall or WSPR most of the time.

Dual Receiver Comparison

Similar tests can be performed using a single transmitted carrier, and at the receiving station two antennae, and two reasonably similar high performance receivers, tuned 10 Hz apart. Two instances of SBSpectrum can be used with different sound cards, or the audio from the receivers can be combined and fed to the computer together.

This reverse method highlights an important factor not previously mentioned – the assessments you make of course depend on the receiving antenna performance as much as the transmitting antennae, and this needs to be recognised in assessing the results.

Army Loop Comparison
Now to the main purpose of this latest experiment – to dispel some of the prevalent misinformation and myth about the Magnetic Loop Antenna, and specifically the Army Loop, which is a simple, small and very effective NVIS antenna for portable and emergency applications on 80, 60 and 40 metres. It was originally developed for the US Army. As a portable antenna, the Army Loop (as envisioned here) is just 6 metres high, uses just 10 metres of wire, and has a very small footprint (16 m^2), compared with a full-sized dipole and all its support structures, with a 9 metre mast and much larger footprint (typically 100 m^2). An Army Loop will easily fit within a typical campsite.

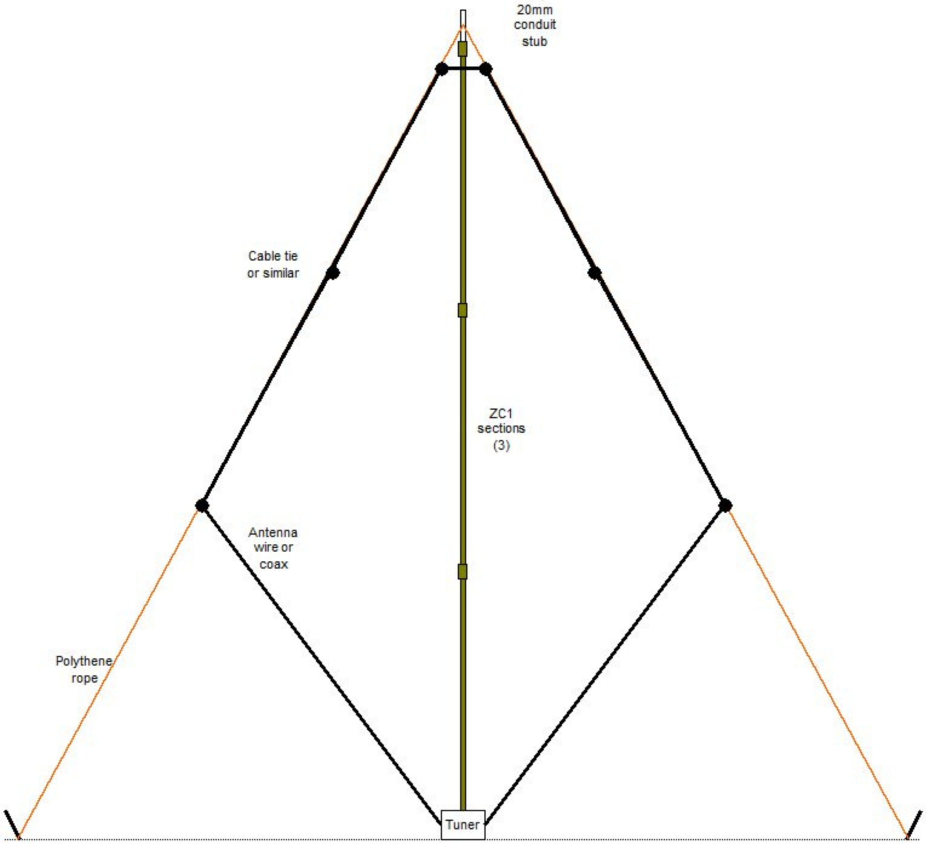


Fig. 5. Diagram of a simple 80/40 Army Loop

As can be seen in the diagram (Figure 5), this version of the Army Loop requires three 2 metre poles, four nylon guy ropes, and a 10 metre length of heavy DC cable or the braid of coax cable. Apart from the mast sections, this antenna packs easily into a small box. It is this antenna that was used for the next series of tests.

As mentioned earlier, signal reports from QSOs might be useful, but the reports will be highly variable. So the best solution is to make comparisons directly, at the same time, over a suitable time frame, and with stations at distances that are of interest.

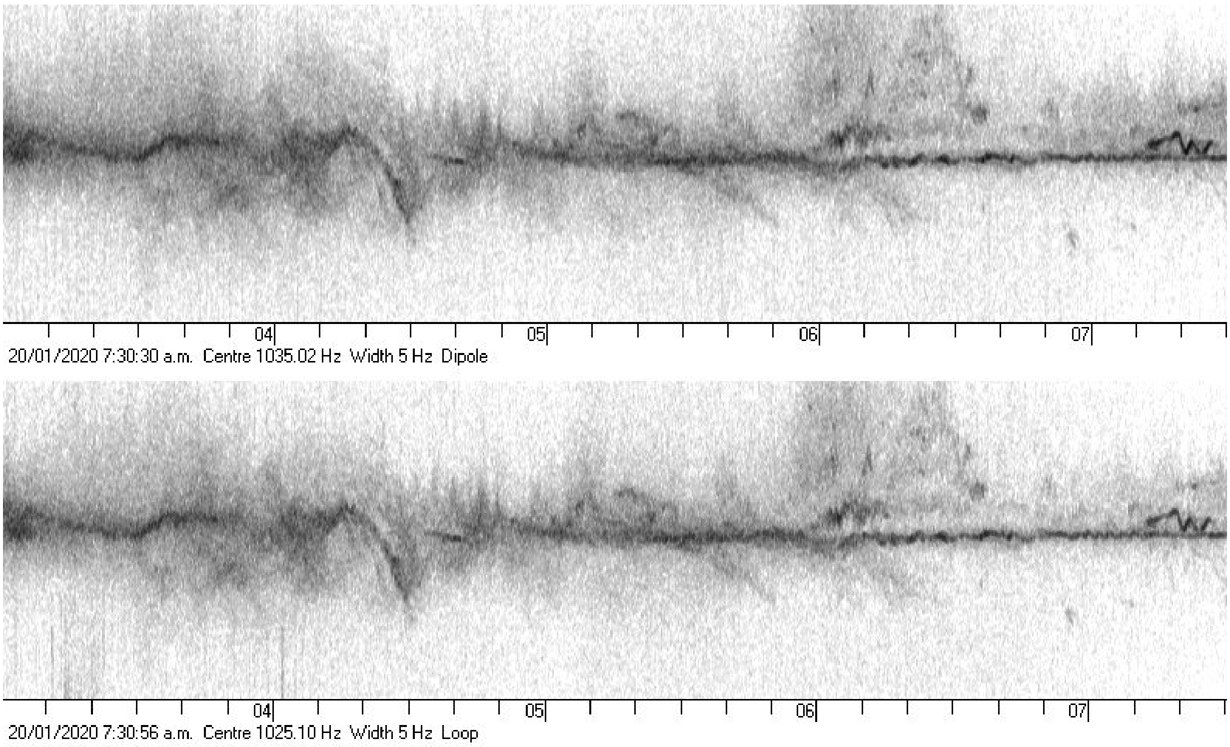


Fig. 6. Dipole & Army Loop morning at 300 km

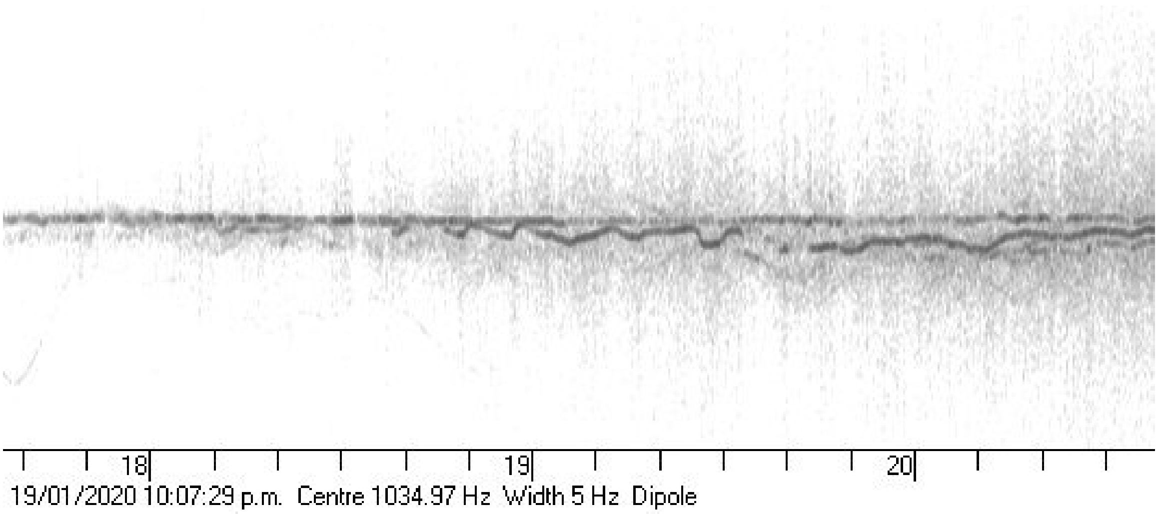
Now is the time to dispel all the hype about the Army Loop! Figure 6 is a comparison of the Dipole in the upper trace, and the Army Loop in the lower one, recorded in Gisborne, 300 km to the southeast, over the sunrise period. The traces are remarkably similar!

There is an E-Layer return clearly visible from about 0610, both of similar strength. There is of course no visible ground wave. But the F-layer returns are also of generally similar strength, throughout the measurement period. Taking instantaneous measurements, differences between the two signals of 10 dB or more might be observed, but overall the recordings are nearly identical. Although not so obvious here, as it is a sunrise recording and there is considerable scatter (looks like noise) throughout the measurement period, it has been observed that at other times there is a little less F-layer scatter on the Loop signal than on the Dipole, implying that it is perhaps not as effective for very long paths.

By the way, the strange little wiggle at 0720 on both traces was caused by a meteorite impact event. There is an initial burst and a trail lasting many minutes. These impacts are common in the morning, and cause intense short-term ionisation in the F Layer. The frequency shift is caused by air movement (wind) in the ionised area.

The downward-sloping fuzzy effects at around 0540 and 0615 are believed to be caused by passing Sporadic E clouds off to one side of the direct path.

Now let’s look at what happens in the evening:



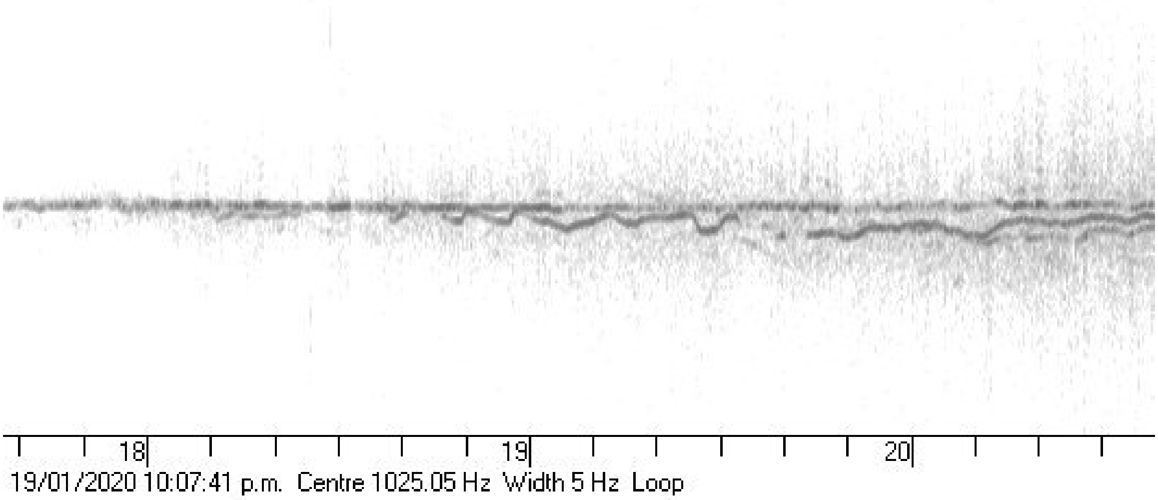


Fig. 7. Dipole & Army Loop evening at 300 km

Figure 7 was recorded by the same station during the early evening, and you can see E-layer propagation (straight but fuzzy line), and the onset of F-layer rays *below* the nominal frequency. While the signal strength is similar from both transmitters, there is noticeably less scatter on the Loop signal.

Conclusions

It has been clearly shown from Figures 6 and 7 that the small Loop (10 metre circumference) performs essentially as well on 80 metres as a full-sized Inverted Vee Dipole of modest elevation, over a 300 km path. It was also learned from other receiving stations that the Army Loop is not as good over shorter paths. Can we say that this dispels all the hearsay and general lack of scientific evidence of previous reports? Maybe not, but at least it has been shown with some reliability how the antenna performs over a specified path.

Tests have also shown that on 40 metres, while propagation is at present poor due to low solar activity, over medium distances the Loop as nearly as good as the Dipole, with less scatter. Over short distances (inside skip) the Dipole is superior, while at 2441 km (to VK2OB) the Loop is some 10 - 12 dB worse, although directionality could be a significant factor in this case.

That the Army Loop performs this well under these circumstances is remarkable, considering its much smaller size and capture area. It is also a much more suitable portable antenna for NVIS applications than any vertical, especially the short one whose results are shown in Figure 4.

Summary

This paper has demonstrated how practical signal measurements can be made using Doppler techniques, allowing different ionospheric products to be assessed. Through the use of two simultaneous transmissions, we have also shown how direct comparison of reception from two different antennae can be made in real time, and accurate conclusions formed about their relative performance. This can be done with relatively simple equipment, through the use of remote receivers or by recruiting friends to make recordings.

Appendix

Equipment used for these tests:

Transmitter A

Frequency Electronics Inc FE-5650A Rubidium Synthesiser
Homebrew 100 W amplifier (based on Codan 8525A power module)
Homebrew T-type antenna tuner
80/40 Fan dipole, deployed east-west as an inverted vee
Power 1 Watt out, 3560.010 kHz

Transmitter B

Frequency Electronics Inc FE-5680A Rubidium Synthesiser
Homebrew 100 W amplifier (based on Codan 7727)
Homebrew Army Loop tuner (for loop)
Kenwood AT-130 antenna tuner (for vertical)
10 m circumference loop, deployed in an east-west plane
4 m centre loaded whip, base 2m above ground
Power 1 Watt out, 3560.000 kHz

Receiver

Marahau KiwiSDR, or various receivers at friends' locations
G3PLX SBSpectrum Dopplergram software
Welbrook ALA1530S+ loop deployed N-S (at Marahau)
Full-sized dipoles at other sites

Footnotes

[1] *Effects of Ionospheric Scattering on Very-Long Distance Radio Propagation*, H.A. Whale, Plenum Press, New York, 1969.
[2] *Using Doppler DSP to Study HF Propagation*, Peter Martinez, RadCom, May 1998.
[3] Available from Peter.Martinez@btinternet.com (or zl1bpu@nzart.org.nz)
[4] www.qsl.net/zl1bpu/MFSK/TELEMweb.htm
[5] kiwisdr2.owdjim.gen.nz:8075
[6] *Down-to-Earth Army Antenna*, Patterson, Electronics, August 1967.
[7] webclass.org/k5ijb/antennas/Small-magnetic-loops-Army-loop.htm

Glossary

Army Loop
A type of magnetic loop antenna, characterised by a loop circumference of about 1/8th wavelength, tuned and matched to frequency by a simple capacitive network at the bottom of the loop. The Army Loop was developed for the US Army by Kenneth H. Patterson, and described in 1967.[6],[7]

Doppler
An effect caused on audio or radio waves by movement compressing or expanding the wave front. The change in apparent pitch of a race car engine as the car passes by is a common example. With radio waves it can be caused by vertical movement of a refracting layer in the upper atmosphere.

E Layer
A low altitude region of the ionosphere (about 50-100 km up) which provides refraction of radio signals day and night.

F Layer
A higher altitude region of the ionosphere (about 200-300 km up) which provides strong refraction of radio signals during the day. At night this region separates into two areas (higher and lower), then dissipates.

FFT
Fast Fourier Transform. A complicated mathematical process which, by sampling a complex signal and performing repeated discrete transforms, enables the signal to be analysed into its different frequency components. Nowadays this can be done in real time.

FSQCall
A digital transmission protocol which was devised to be highly robust in the presence of NVIS propagation. It was developed by the author and Con Wassilieff ZL2AFP.

KiwiSDR
A device which consists of a self-contained Software Defined Radio receiver (SDR) and a computer interface to the internet. KiwiSDRs are available around the world via an application which allows these receivers to operate in any mode on a wide range of frequencies. Most have the ability to serve multiple clients using different modes and frequencies.

MUF
Maximum Usable Frequency. The frequency above which radio signals on a given path are not returned to earth, but escape the ionosphere completely. The MUF depends on the distance between transmitter and receiver, but is typically quoted for vertically propagated signals.

NVIS
Near Vertical Incidence Signals. At lower HF, signals projected nearly vertically are returned strongly to stations within a radius of up to 500 km. Such signals are returned by the F Layer, the highest and most active area of the ionosphere. NVIS propagation has very strong returns, and is characterised by multiple paths with marked timing shifts (100s of milliseconds) and Doppler shift (up to $1e^{-6}$).