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AMATEUR USE OF NOVEL SIGNALLING METHODS AT LOW FREQUENCIES

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INTRODUCTION

In 1996 Radio Amateurs in the UK gained a new frequency band at 73kHz for experimentation and research into antennas and signalling methods at Low Frequencies. It soon became apparent that some novel techniques would have to be employed to make use of the 1 Watt Effective Radiated Power power limitation and the high losses associated with realistic ‘back garden’ antennas. Initial tests with aurally received Morse code indicated that distances of a few tens of kilometres were achievable with 100 watts of RF power when employing antennas of around 8m tall – typical of an amateur installation. With this set-up, ERPs in the range of 0.1 to 2mW were usually possible depending on antenna system efficiency. To achieve greater distance would need either a lot more RF power or a considerable reduction in bandwidth.

VERY NARROW BANDWIDTH SIGNALLING

The first tests using very narrow bandwidth signalling occurred in 1996 when Peter Martinez in Cumbria used a Motorola 56002EVM DSP evaluation module to downconvert, decimate and filter the output of an SSB receiver at 73kHz. A Fast Fourier Transform routine was applied to the resulting signal and the results displayed on a ‘waterfall’ plot. Here, the X co-ordinate of the plot represents frequency, the Y dimension is time (although these are often swapped) and signal strength is shown by the greyscale, or colour, of the plot. Received signals roll down (or across) the screen over time – hence the name waterfall. The plot of the decimated signal occupied a bandwidth of 6 Hz, and the FFT bin size, or resolution was 0.01Hz. Such narrow bandwidths naturally require very slow data signalling methods, so for the transmitting end software was written to encode Morse characters at a rate of many seconds per dot. Initial tests were conducted in the early morning when naturally occurring noise levels were at a minimum, starting the transmitter on a timer so a typical callsign exchange would be finished after several hours of transmitting at around 0800. The results were very successful, with signals being received over the 393km path with a Signal to Noise ratio typically in the region of 10 – 25dB, in bandwidths which were varied over the range 8 to 20mHz. A typical waterfall plot of the received signal over this path is shown in Figure 1.

The EVM module was rather complicated for many radio amateurs to set up and use, so this technique was adopted by only very few operators, but it had set the precedent among the radio amateur community. By this time, soundcards in PCs were becoming commonplace and it wasn’t long before software appeared that made narrowband reception available for anyone who could connect a receiver to a PC audio input. SlowCW, or ‘QRSS’ as the mode was called, became the most common communication mode on 73kHz for weak signal working, with dot lengths that ranged from the 100-200 seconds region used originally, down to 1 second for more local contacts over shorter timescales. The visual eye-brain interpretation needed to extract a signal from a noisy background meant that this technique still had an ‘amateur feel’ to it, and the fact that communications could now proceed at 73kHz over most UK paths with our limited power / antenna combinations kick-started interest in LF. Many more radio amateurs were now taking part, investigating propagation, antennas, receiver and transmitter design and related areas of DSP, but so far only limited to the UK.

THE 137kHz EXPERIMENT

In 1997, partly as a result of the success of the UK 73kHz experiment, a band at 137kHz was released internationally to the amateur community. On this band, antennas were typically 6 - 10dB more efficient, and it was felt propagation ‘ought’ to give longer distance communication. During this phase of the experiment, the earlier research that had been done in radio at the beginning of the century was being consulted, as most of this had been initially at low frequencies before it was discovered that shortwaves were the route to go for long distance communications. We soon realised that there was a lack of real information about long distance propagation at LF, i.e. in the 100kHz region. There was a lot of information on VLF where work had continued for submarine communications, and a lot of work at MF to HF for the broadcasting communities, so we were to some extent in the dark at LF. Over the next year most European paths were worked, with distances of 2000km plus being achieved usually by Slow CW and thoughts turned to trying to bridge the Atlantic. Some UK amateurs had by now managed to achieve the maximum permitted 1 Watt ERP by a combination of 1kW plus transmitters, coupled with huge antenna structures, making use, for example, of a block of derelict flats or a church tower to support an LF antenna. On 10th September 2000 a Slow CW signal transmitted from a station in west London was eventually received in Nova Scotia, at a distance of 4332km. A 3 second dot period was selected, received in a bandwidth of approximately 1 Hz which happened to coincide with a peak in propagation conditions. The transmitting system was huge by amateur standards, making use of a pair of wires 80m long supported from a block of flats, supplied with 1200 Watts from an old modified Decca Navigator transmitter. After the success of this attempt, more modest stations tried, using longer dot periods and narrower bandwidths. Tests typically lasted all night with the enthusiasm to try to 'make it across the Atlantic'. It now became apparent that the Transatlantic path at 137kHz would not support very low signalling rates. Attempts to use dot periods of several minutes, required for sub 10mHz bandwidth reception, showed that the signal strength varied over a period of a few tens of minutes, causing symbol periods to be broken up and making Slow CW of less value for this path. For example, a dash could be broken up by a signal fade to appear as two dots turning one letter into another. This was obviated to some extent by adopting FSK keying and making a few simple changes to the signalling alphabet such as reducing the dot/dash length ratio, but a complete exchange of information could still take all night running into the early morning where noise levels rise closing down the path completely. What was needed was a signalling mode that could keep the low noise bandwidth but speed up the signalling, or baud, rate in order to fit between the fades.

CUSTOMISED DATA MODES

Two routes were followed. One US operator adopted a scheme based on 10 Bit/s second Binary Phase Shift Keying. By using a 6:1 interleaved coding scheme convolved with a pseudo random sequence with optimised correlation properties, a message consisting of up to 16 ASCII characters could be coded into a waveform which was transmitted in a 96 second block, but organised such that for a good signal the message could be derived from just an 18 second portion of the data. Receiving software could coherently sum together successive blocks and gradually extract a repeated message with progressively fewer errors. This mode, called WOLF, was used successfully for a Transatlantic test on 19 March 2001 between a station north of London and Worcester, Massachusetts. A test message was received with perfect copy after integrating the 10 B/s signal for 25 minutes. Figure 2 shows how the signal builds up in 18 second intervals over the 96 second block.

WOLF was not liked by many due to the requirement for separate modulator / demodulator hardware and the non real-time nature of the mode. So another amateur in Italy developed a multi-level Frequency Shift Keying system making use of a PC sound card to demodulate the audio input from a receiver, and generate the signal for transmission. The normal approach used for multilevel FSK – such as the old 32 tone Piccolo system used on HF in the 1960s, - uses one tone per character and relies on very accurate tuning of the receiver; an accuracy at least equal to half the tone spacing being needed. To obviate the tuning accuracy requirement, differential FSK was employed. A sequential 17 tone system was adopted where characters are encoded four bits at a time based on the frequency shift, upwards, from one tone to the next. Where the positive shift would take the frequency outside the 17 tone bandwidth, it is wrapped around, modulo 17, to keep to the standard levels. At four bits per symbol, a subset of 64 characters of the standard ASCII set were coded at two symbols per character, with some overhead for symbol framing. The symbol rate and tone spacing are all synchronous and locked to the soundcard clock at 11025Hz. The entire signalling scheme is based around an FFT energy detection scheme, so accordingly tone spacing is set at three FFT bins, and symbol rate at the reciprocal of each bin. The speed adopted is based on a 2^{17} point FFT so tone spacing is a little over 0.25Hz, giving a total signal bandwidth of 4.3Hz, and 11.89 seconds per symbol, or 23.8 seconds per character. Noise bandwidth is defined by the FFT bin size of 0.084Hz. This mode was named JASON and at the time of writing has only been available for a few months. so no transatlantic tests have been tried with it over the noisy summer period. The winter period traditionally gives much lower noise levels on all lower frequency bands from LF to HF, so TA tests will resume later this year. However, Jason has been tested within Europe by stations running very low power – ERPs in the 100 microwatt to 1mW range. Results look encouraging when compared to Slow CW, and as the mode is a lot easier to set up and tune than WOLF was, the forthcoming winter Transatlantic tests should result in more people 'making the jump'.

Other modes used on LF have continued to be based around the use of a waterfall display – so called fuzzy modes where the eye-brain combination forms a major part of the decoding process. A reasonably successful mode has been a variant of the Hellschreiber system, first invented in 1929, where a raster representation of visual text was transmitted as a series of dots, the received signal being directly printed out on a paper tape. The variant adopted by amateurs is to let one direction of the raster, usually the vertical part, be represented by frequency. The horizontal part continues to be represented by time so the text can gradually build up. This speeds up transmission considerably and suitable tone spacing and duration can be chosen to match signalling time and bandwidth requirements. The name adopted for this is Sequential Multi Tone, or SMT, Hell. On 137kHz tests were made within Europe using very low powers, transmitting in various bandwidths of 2 – 20Hz total, with characters taking several seconds to minutes to build up. Results appeared to show that readability was generally similar to that of SlowCW, but testing of SMT Hell on LF has not yet been completed to an extent sufficient to characterise its effectiveness fully. More development and testing of the use of fuzzy modes is still needed. Figure 3 shows a typical SMT Hell signal received on a waterfall display.

PROPAGATION AND ANTENNA RESEARCH

In parallel with all these tests of new modes and hardware, others were continuously recording and monitoring signal strengths from various strong commercial transmitters around the world, as well as the amateur 137 kHz transmissions, in an attempt to measure and understand LF propagation and fill in some of the gaps in knowledge left when commercial users deserted these bands. To date, during the short time the experiments have been going on, a few facts do seem to have appeared. One is the lack of significant phase/frequency shifts on skywave signals compared with the considerable ionospheric influence experienced at MF/HF. A noticeable correlation between enhanced daytime strengths of received skywave signals and solar X-ray flares has been found. Good long distance openings are generally of 20 – 90 minutes duration and are probably due to multipath on the very tail of the after-effects of a geomagnetic storm. When solar conditions are quiet some long distance paths can be very stable for long periods and it is believed that the shorter links (2000kms) will support multiple paths with maybe up to 4 hops. Some tenuous evidence suggests that Proton events may also give a boost to propagation at 137kHz. More investigation is needed here, making use of phase information from some of the stable transmissions available from commercial stations and the amateurs using very high stability signal sources based on GPS locked, or similar, frequency standards

Amateur research into antennas has also revealed some new facts about making very small antennas more efficient. We have shown how very critical both the earth system and the local environment is, when trying to realise maximum gain. What has become very evident is that much of the current antenna modelling software, such as NEC, is quite incapable of predicting many of the effects noticed, which can only be found from experimentation and actual measurement.

CONCLUSIONS

In the relatively short time that radio amateurs have had access to an LF frequency allocation, some innovative and ingenious schemes have appeared to overcome the limitations, both imposed and natural, on use of these frequencies. Amateurs have shown how, by applying new technology to old communications techniques, as well as by using more standard waveforms side by side with experimental technique, very long distance communications can be achieved, making use of this otherwise neglected part of the spectrum. Such exploitation of the LF part of the spectrum may help to characterise these bands and possibly expand their potential use.

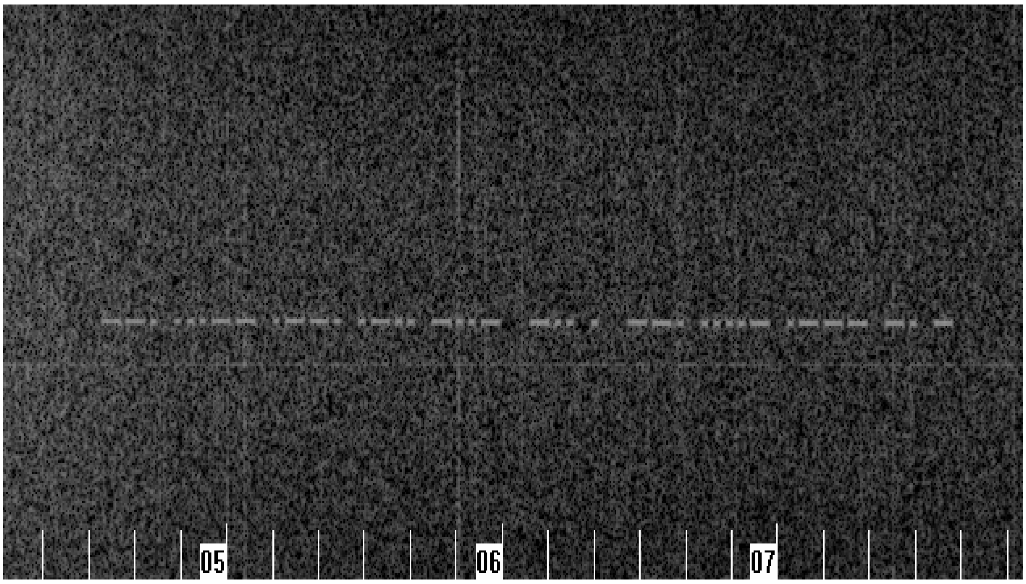

Figure 1 One of the first Slow CW signals to be transmitted on 73kHz. Plot bandwidth is 6Hz top to bottom, and numbers along the bottom are UTC hours. FFT Bin size is 15mHz. The CW text reads “G3PLX DE G4JNT” and took 3.2 Hours to send over the 393km path from Southampton to Keswick, Cumbria.

Signal received by John Andrews, W1TAG, on 19th March 2001 at Worcester, Massachusetts:

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C:\wolf>wolf -f 799.892 -r 8001.95 -t 0.02 -q bmu2.wav -s 1200
WOLF version 0.51
t:  24 f:-0.020 a: 1.0 dp: 99.4 ci:11 cj:391 94R.7A8A4???UWC ?
t:  48 f:-0.029 a:-1.5 dp:103.7 ci: 5 cj: 12 6A.S69BGZ//LK8B ?
t:  96 f: 0.019 a:-1.4 dp: 98.7 ci: 4 cj:207 JFWWUL???N*E .Y ?
t: 192 f: 0.029 pm: 118 jm:119               LQ5HQ*2G569R2MW ?
t: 288 f:-0.029 pm: 150 jm: 52               /S SYS7FZSV XXZ -
t: 384 f:-0.029 pm: 175 jm: 52               ??????AWI2N 20Y ?
t: 480 f:-0.029 pm: 195 jm: 52               /KR/F 2U4X8ZSMT -
t: 576 f:-0.029 pm: 198 jm: 52               VMEVXXDPY2J4RTJ ?
t: 672 f:-0.029 pm: 205 jm: 52               .L5DKCA9GEDS.AX -
t: 768 f:-0.029 pm: 226 jm: 52               3J0FRV/XG6S7D7X ?
t: 864 f:-0.029 pm: 238 jm: 52               RJSWH TQU4IJ6NS ?
t: 960 f:-0.029 pm: 256 jm: 52               PE41I9K3DDS9ZHM -
t:1056 f:-0.010 pm: 321 jm:211               H96XY075JF4B YU ?
t:1152 f:-0.010 pm: 357 jm:211               Q*CW RQAU447BNT ?
t:1248 f:-0.010 pm: 447 jm:211               6D 6FLYJTCVY0.N ?
t:1344 f:-0.010 pm: 472 jm:211               Q*C*GBR88N0/5*T ?
t:1440 f:-0.010 pm: 482 jm:211               CQ M0BMU M0BMU  -
t:1536 f:-0.010 pm: 499 jm:211               CQ M0BMU M0BMU  -
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Figure 2. Decoded text from the first WOLF transatlantic transmission, showing how the text is extracted by coherently integrating 18 seconds blocks of received data.

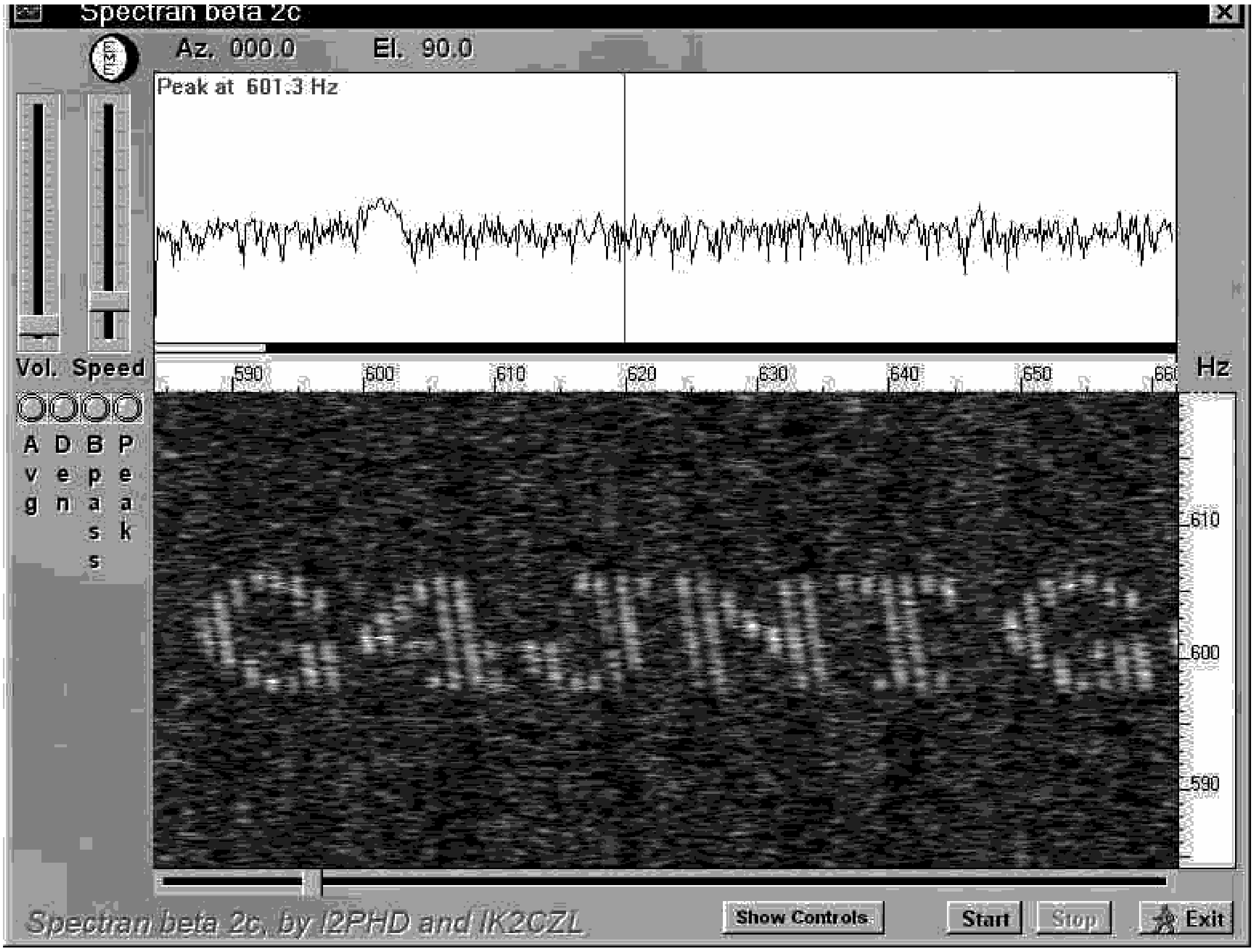

Figure 3. Typical Sequential Multitone Hellschreiber transmission received in a bandwidth of 10 Hz.