Digital Amateur Radio – Bridging the Gap

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HF Data Communications

In this month's article we take a look at data communications using HF. Perhaps our first question ought to be "Why would you want to use HF in the first place?" The answer is simple – HF can be used in situations where conventional VHF and UHF cannot provide the coverage over the area we wish to communicate. This might be due to the terrain, which blocks the line-of-sight path we require; or because a temporary repeater cannot be used due to access, time or frequency restrictions; or simply because the area we need to cover is simply too large.

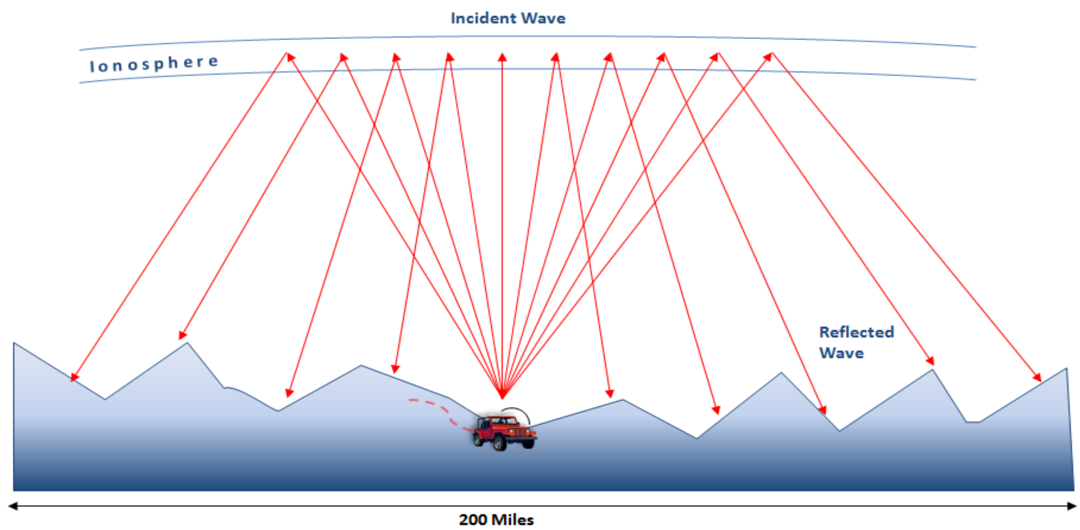
This article aims to provide some guidance, as operating data modes on HF is a complex subject, and is perhaps outside the scope of our collective experiences to date.

Antennas and Propagation

> *"The antenna is critical to success in emergency communications. A poor choice means you will not be able to communicate efficiently over the chosen distance, or worse still, not at all!" – Raynet HF Team.*

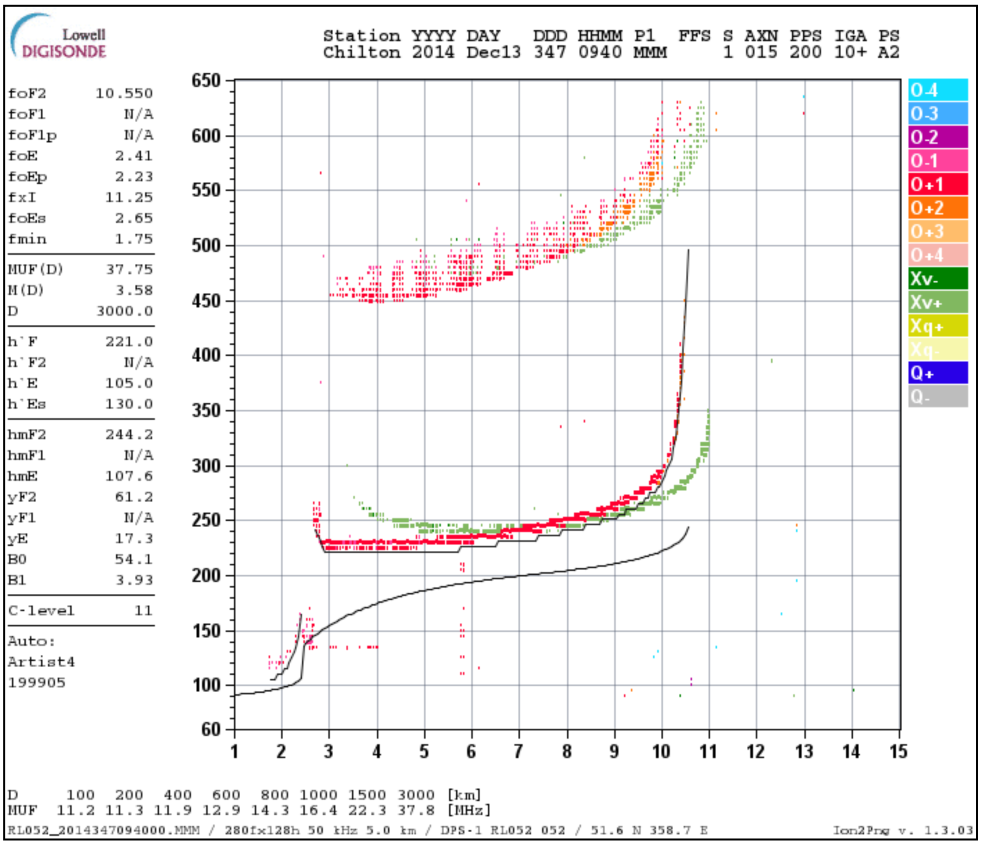
Let's start with the antenna, as this is obviously critical to our success in using HF. In our normal operation as radio amateurs, we aim to maximise our chances of working rare DX stations on other continents, and generally install our antennas as high as possible above the ground in order to achieve a low angle of radiation. Clearly, these antennas aren't going to work efficiently for the local communications we are after, and our input would only be a hindrance to the activities supporting an earthquake in Haiti!

In order to achieve the local coverage we are looking for, we are going to draw upon the expertise of the military in setting up our antennas for a mode of propagation known as Near Vertical Incidence Skywave, or NVIS for short. Signals are sent vertically upwards using low-slung wire antennas and are then hopefully reflected back to earth by the ionosphere. Operation is normally from fixed or temporary stations, and mobile operation presents a challenge as vertical antennas cannot be used as they radiate very little energy directly upwards. Most of you will have seen the typical configuration seen on military vehicles, where the antenna is mounted on the front wing and arched over the vehicle body and attached to the rear bumper? Now you know why!



Because NVIS relies upon the ionosphere to reflect signals back to earth, the frequencies that can be used vary on both a daily and a seasonal basis: if the operating frequency is too low, then the signals are absorbed by the D-Layer; and conversely if the operating frequency is too high, then signals will be lost into space and not reflected by the F-Layers. In practice, several frequency bands are required to give all-year-round coverage; the 5MHz band being particularly useful as it tends to sit in the middle and provides coverage for most of the time, which explains why it used by the military almost world-wide!

A useful resource for predicting the ionospheric conditions is the Chilton Ionosonde, which is located at the Rutherford Appleton Laboratory in Oxfordshire. The system is a type of radar that transmits a signal towards the ionosphere, and then times the return signal to determine the height of the various ionised layers. It performs an automated sweep of the entire HF spectrum every 10 minutes and automatically publishes its results on the web.[i]



Basic information can be obtained from these charts with a limited knowledge of the underlying theory – the horizontal axis on the graph represents the operating frequency (which is between 1 and 15 MHz), and the vertical axis represents the height at which the signal is reflected. In general, as the frequency increases it passes through the lower layers and reflected by the layers higher up.

So in this example, there is the minor reflection from the E-layer which occurs at around 2.5 MHz, and then there is the main reflection from the F-layer which occurs between 3 to 10.5 MHz, and above 10.5 MHz nothing reflected at all – this is known as the Maximum Usable Frequency (MUF). The line above represents multiple hops between the earth and the ionosphere.[ii]

An alternative approach to these charts, whilst in the field, is the automated propagation beacons that operate on 5.290MHz. They transmit in a sequence every 15 minutes from the Rutherford Appleton Laboratory (GB3RAL), Cumbria (GB3WES) and the Orkneys (GB3ORK), and give a good indication of UK propagation.[iii]

Data Modes

Data communications on HF invariably takes place using single sideband (SSB) which requires a lot more skill than FM, as all the stations must to be netted together on the *exact frequency* used. Perhaps a gentle reminder is required to explain that a single audio tone will result in a single frequency on SSB, which is offset from the carrier by the frequency of the tone. This is either plus or minus depending upon the sideband selected – this should always be USB for data, and hence the offset is always positive. Operators must be familiar with the relationship between the displayed frequency (which is usually that of the suppressed carrier) plus or minus any errors, the frequency of the modulating audio signal, and hence the resulting transmit frequency on their particular radio. A frequency calibration from an on air standard such as WWV is highly recommended.[iv]

Although there are several high-end HF transceivers that can operate data modes without requiring a host computer, it is the widespread availability of laptops and mobile transceivers that has made HF data communications in the field a viable option. When the modulating signals are computer generated, it is just a matter of connecting an appropriate interface between the transceiver's data socket and the laptop's headphone and microphone sockets, the possibilities are endless!

Radio Teletype

Amateur radio data communications started over 50 years ago, when radio amateurs started adapting surplus mechanical teleprinters to operate over the radio, adopting the term 'RTTY'. The machines were connected to an interface, which was often home-made, that converted the stream of "0's and 1's" of the 5-bit Baudot code into a pair of audio tones that could be transmitted using an SSB radio. This process is reversed in the receiver, where analogue filters turn the pair of tones back into the "0's and 1's" again. Radio teletype operates without any form of error detection or detection, relies upon the operators to manually request the retransmission of any missing portions that might occur. However, despite its simplicity, it was ideally suited to passing formal telex messages originating from the User Services, as the machines usually had a punched paper tape reader that could record and replay messages.

Amateur Teletype over Radio (AMTOR) is an improved version of RTTY that is able to detect when errors in transmission occur. This is achieved by adding two additional bits to each of the 5-bit Baudot codes; these are arranged in such a way that each code word **always** contains four "0"s and three "1"s, and hence when an error occurs, that changes one of these bits, it can be detected. Furthermore, each code word is also arranged so that a change in two bits is required before the code word is incorrectly interpreted as a different character – this is known in information theory as a *Hamming Distance* of two.

AMTOR operates in two distinct modes: AMTOR-A (or ARQ) is intended for point-to-point links between two stations, and is particularly effective against the type of errors caused by static crashes. It operates in a ***connected*** mode: where messages are broken down into three-letter groups, which are acknowledged by the receiving station; otherwise an ***automatic repeat request*** (ARQ) is sent and the group is repeated. This requires both precise timing and a rapid turn-around between transmit and receive, and hence a dedicated controller is required. AMTOR-B (or FEC) is an ***unconnected*** mode which is used to send broadcast messages between groups of operators. It operates using a primitive ***forward error correction*** (FEC) by introducing ***redundancy*** and sending each character twice in succession; if the first character is corrupted then the duplicate copy is used in its place, otherwise the missing character is discarded. As this is transmitted as a continuous stream of data, it can be sent and received using a basic soundcard interface.

PSK-31

Perhaps the most obvious candidate for data communications on HF is probably PSK-31 due to its widespread use, thanks to its ease of use and ability to work stations from around the world on low power – often under conditions where the signal is barely audible in the receiver's speaker.

The immunity to noise is mainly due to the low symbol rate of 31.5 bits per second, which occupies a very narrow transmitted bandwidth, and also the use of phase-shift keying which allows the receiver to resynchronise each time a phase change occurs. Its throughput is somewhat faster than we would expect from the raw symbol rate due as its encoding means the commonly occurring lower case letters are encoded with fewer bits and therefore take less time to transmit than the UPPER CASE letters and infrequently used ASCII symbols such as £&$%#!.

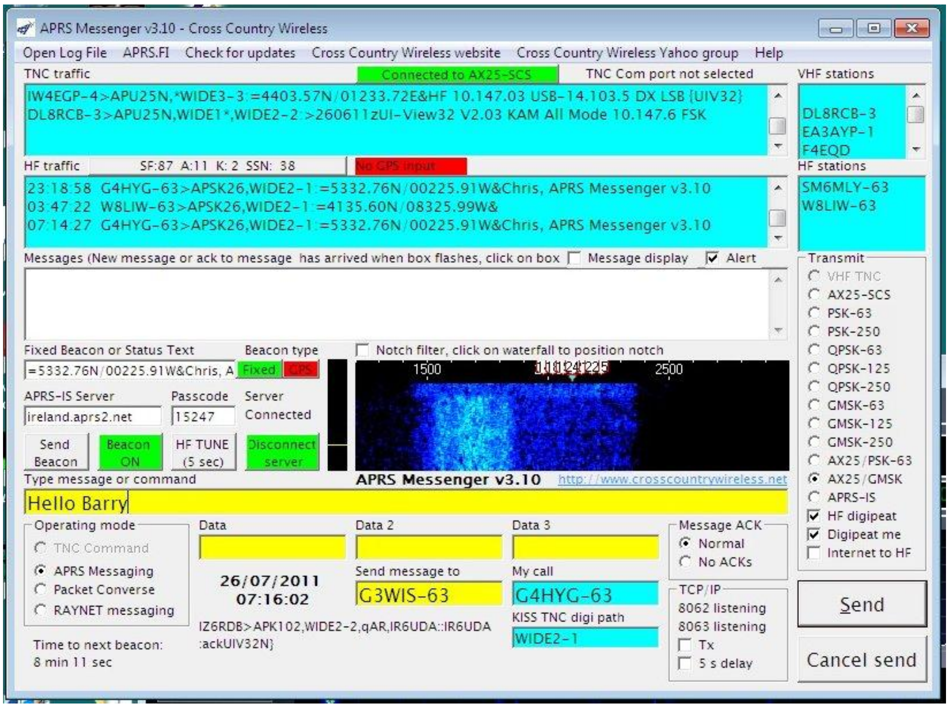
Operating PSK-31 is straightforward. Simply click on the incoming waterfall display to select the transmission you want to decode and then type in your reply, the transmitted tone is automatically changed to match. Whilst most programs support some degree of automation and can transmit text files; however very few provide support for formal messages or offer any form of error detection.

APRS Messenger

The APRS Messenger and Raynet Messenger software developed by Chris Moulding G4HYG are two programs that are capable of sending and receiving APRS position reports and formal RAYNET messages on HF using PSK-63 (a faster variant of PSK-31). The software supports a variety of modulation methods which can operate at speeds of up to 250 bits per second, with the inevitable trade off with an increased bandwidth and a corresponding reduction in noise immunity.

Unlike other soundcard programs, the frequency of the modulating audio signal is chosen during the initial start-up and cannot be subsequently changed by clicking on the waterfall display – this is to prevent accidental frequency changes being made by unintended mouse clicks that could potentially result in messages being lost.

APRS Messenger can operate simultaneously on HF, using its built-in soundcard modem, and on VHF using a conventional packet TNC, and via connect to an APRS server via a TCP/IP network socket. It can be setup as a "receive only" gateway that passes information it receives on HF onto VHF, or to the APRS Internet Service. The latter is useful as it can use other software, such as UI-View and APRSISCE, to provide mapping.



Raynet Messenger offers similar functionality to APRS messenger for sending multi-part messages over the air. Neither APRS Messenger nor Raynet Messenger can interoperate with other programs as the checksum used to provide error detection is not recognised by other PSK programs.

FLDigi

The Raynet HF Team have recommended the FLDIGI software for emergency communications and have produced a very informative video that talks you through the process of downloading and configuring the software. It describes the process of using the software to send formal messages and forms using the FLMSG – an add-on which encapsulates messages in a wrapper that allows the recipient to verify that the message has arrived intact.[v]

As FLDIGI supports a large number of transmission modes that are indistinguishable to the human operator, it is able to transmit a header (known as the Reed-Solomon ID after its coding) that allows the receiving station to determine the correct mode being transmitted and adjust the audio passband of the software decoder automatically. The video shows MT63 – a mode which spreads the information to be transmitted over 63 individual carriers and sends this data repeatedly over an extended time period, effectively trading reliability and immunity from interference for transmission time and bandwidth.[vi]

Digital Radio Mondiale

There is one requirement that we have failed to address so far – this is the ability to send and receive photographic images or computer files over the air.

It should come as no surprise that radio amateurs have been routinely doing this for several years! Most people have standardised upon a program called EasyPAL that was written to replace the line-sequential slow-scan television. It is based on the Digital Radio Mondiale (DRM), a technology that was developed for digital broadcasts on HF, and has been adapted to use a standard 2.5 kHz SSB channel instead of the full 15 kHz used for broadcast, and consequently operates at proportionally slower bit-rate. It works in the same way as MT63, in that information is spread out over multiple carriers and offers a similar resistance to both frequency selective fading (QSB) and interference (QRM) due to its interleaving and forward error correction. However, unlike the broadcast medium, it has a mechanism for requesting missing information, which can be used by all other stations on the channel.

HF Digital Voice

The mainstream use of Digital Voice is a fairly recent development which has come about as a result of people using the new generation of multimode transceivers, such as the Icom IC-7100 (shown below) and Icom IC-9100, which include D-Star Digital Voice modes on HF.

Photo courtesy of Icom (UK)

The problem with this mode is that although these transmissions are considered to be narrow when compared with conventional FM voice, they still occupy a bandwidth of over 6 kHz, which is significantly more than the standard 2.7 kHz bandwidth occupied by a clean SSB transmission. Whilst communications are crystal clear, this is perhaps something to bear in mind when clear HF frequencies become scarce in an emergency situation – the saving grace of this radio is that the audio can be interfaced using a USB socket!

As D-Star, and probably most other digital voice systems, are based around proprietary CODECs that perform the task of analysing, encoding and decoding digital speech; there have been significant efforts to develop an open-source CODEC that better suits the experimental nature of amateur radio; and over the past year there has been a significant development with the release of FreeDV.

The application provides communications quality speech at a very low bit rate, and offers the potential for reliable communications at relatively low signal levels. Speech is encoded at 1375 bits per second using the open-source "CODEC 2"; the data is then modulated onto 15 quadrature phase shift keyed carriers that fit into a bandwidth of 1.125 kHz – less than half a standard SSB channel!

On receive it can be demodulated and decoded at low signal levels, with long distance contacts being reported using 1-2 watts of power. As both the encoding and modulation method used are completely open source, this frees amateurs from the patent restrictions and encourages experimentation – this system could grow into the ideal platform for emergency communications.

Conclusions

Currently most of these applications, particularly digital voice, require a computer or laptop to run as most microcontrollers are not powerful enough to handle to real-time signal processing. However with devices such the Raspberry Pi, which contains a full 32-bit ARM processor, a user-upgradable open-source software defined radio with these features built in must just be around the corner – especially when one includes chips such as the Xilinx Zync that include a Field Programmable Gate Array (FPGA) that is capable of doing most of this stuff in hardware.

Watch this space!

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