Digital Cave Communications - Smaller, Lighter, Cheaper!

***Ian Drummond**, VE6IXD, reports on the development and testing of a newly available low-cost digital transceiver, modified to operate on 137.5 kHz. Employing weak signal modes such as WSPR and FT8, ranges of up to 3 km have been achieved using small loop antennas.*

The amateur radio world has changed since 2001 when WSJT (Weak Signal Joe Taylor) was first released. The weak signal technology has enabled radio contacts around the world on a few (milli)-watts of power, and techniques such as meteor scatter and moonbounce have become accessible to quite modest amateur radio stations, when compared to last-century technology. See **wsjt.sourceforge.io/**.

Unfortunately, these techniques have proved less accessible for portable operations, in particular for cave communications. Part of the reason lies in the equipment commonly used for the digital modes when they are implemented in an amateur radio shack. A computer generates audio tones that pass through a wired interface into a single-sideband (SSB) radio. All this equipment is usually available in an amateur radio shack, and it remains the most common way to implement a digital radio station. Unfortunately, it is bulky, heavy, expensive and requires technical skill for proper operation, and that is why it has not been adopted widely for underground use.

Recent advances in microelectronics have created devices that can synthesize the radio frequencies needed for digital communications directly. It is no longer necessary to use an SSB radio. The synthesis of exactly the RF frequency needed, and only that frequency without the unwanted sideband or carrier, greatly reduces the technical demands on the filtering and amplifying circuits of the radio, making it smaller, lighter and cheaper.

These devices are now available commercially for the amateur radio world. I have chosen to use the radio kits designed and produced by Hans Summers, G0UPL. I have no commercial interest in QRP Labs, but I find their equipment to be very well-designed, and accurately and clearly described.

Figure 1 – Ken Smith successfully making contact
Note the 1m loop antenna in the foreground
(Photo: Gavin Elsley)

This report describes my efforts at adapting and using this equipment for cave communications.

The Parts of a Digital Cave Communication System

- The digital transceiver
- The user's interface or terminal device (hardware)
- The user's interface (software)
- The antenna
- The power supply

Each part of the system will now be discussed, describing how it was implemented by me.

The Digital Transceiver

Kits were purchased from QRP Labs for a QDX-M transceiver. **shop.qrp-labs.com/qdxm?search=qdx-m**

The kits were nominally for operation on the amateur 12 m band (24 MHz) as that was the only frequency option available in mid-2023. The description of the device included the expectation that other frequencies would become available, including 2200 m (136 kHz), which is a suitable frequency for cave communications. This frequency option was not available in September 2023, and it was necessary to modify the QDX-M devices for operation at 136 kHz. Fortunately, this was not difficult, as the frequency-sensitive components requiring change are all through-the-hole components, and none of the surface-mount circuitry needed changing. The firmware provided by QRP Labs for the QDX-M already had the ability to handle the 2200 m band (as well as all other amateur bands up to 10 m).

QRP Labs provides excellent quality documentation online, including circuit diagrams. I can therefore specify the changes I made for 137.5 kHz operation by providing a list of the parts that I needed to change the frequency of operation to the 2200 m band.

When building the QDX-M kit, it is necessary to choose between using a supply voltage of 9 V or 12 V, as the final output transformer requires different turns for the different voltages. I chose to make my units for 9 V, which requires use of a power supply regulator between the QDX-M and the usual battery options of 11.1 V LiPo, or 12 V lead-acid batteries. The reason that I did this was numerous reports of burnt RF finals in the QDX-M, sometimes caused by supply over-voltage (eg 13.8 V instead of the firm 12 V specified by QRP Labs). Building to 9 V requires the use of a voltage regulated supply and is intended to avoid the use of off-specification power supplies. The regulator I use is a small, switched supply with Anderson Powerpoles for connection to the battery (as is common usage for "12 Volt" batteries), and the barrel connector supplied by QRP Labs for the radio connection. I have observed no problems in operation of the radio, caused by the use of the switched supply.

Operation on the 2200 m band requires the QDX-M to have firmware 1_10 or later, installed. The QDX-M requires configuration of the 2200 m band, which is done by connecting the device to a computer running a terminal program such as PuTTY. The full instructions to make the connection are given in the operating manual provided by QRP Labs. *Figure 3* shows the configuration screen of the QDX-M.

The QDX-M building instructions for the 12 m version detail placement of soldered jumper connections to specify the operating band. The jumpers for 2200 m operation are not specified, but it is OK to leave all jumpers out. Their function appears to be only to simplify the Band Configuration file and it is OK to just "Disable" the unused bands.

The Terminal function includes useful test programs built into the QDX-M, so that the correct operation of the RF generator, the low-pass filter, the audio filter, and other functions can be configured without any additional equipment being required, see *Figure 2*.

Finally, there is a very active QRPLabs support group, **groups.io/g/QRPLabs** where the solutions to many difficulties have been posted already!

The User Interface, Hardware Devices and Software Apps

The objective of my project was to develop a communications system for caving. I therefore wanted to use an interface that is small, tough and cheap, as well as familiar to most operators. In short, an obsolete smartphone would seem to fit the bill! There are two main issues with the smartphone approach; the phone may not have the computing ability to run some

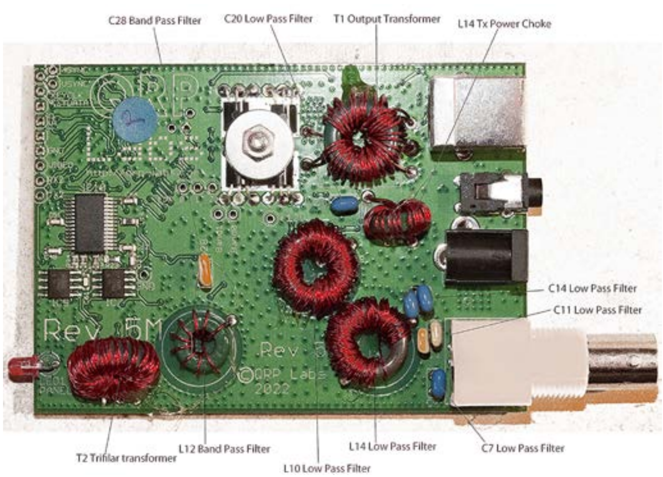

Figure 2 – The QDX-M Board

Showing modifications to enable operation on 137.5 kHz (2200m)

Part	Toroids	Wire	Turns	µH	Function
T1	FT50A-75	24 AWG	20: (10+10)	1200	9V output transformer
T2	FT50A-75	28 AWG	40:40:40	4800	Trifilar transformer
L4	T50-2	28 AWG	98	51.4	Low-pass filter
L10	T50-2	28 AWG	101	57.9	Low-pass filter
L12	FT37-75	24 AWG	9	180	Bandpass filter
L14	FT37-75	24 AWG	30	1680	TX power choke
	Capacitors			**nF**	
C7				22	Low-pass filter
C11	2.88nf (2.2nf + 680pf) is the correct value)			~~28.8~~	Low-pass filter (~~22+6.8~~)
C14				44	Low-pass filter (22+22)
C20				22	Low-pass filter
C28				6.8	Bandpass filter

Note: Two Zener diodes IN5261B (47 V) were added, one to each pair of BS170 MOSFETS, to limit the drain voltage below the maximum rating of 60 V

All capacitors are 100 V COG; ferrite toroid cores were purchased from **Digikey.ca**; and the iron toroid cores from **KitsandParts.com**.

Components listed refer to PCB Rev 5M, http://qrp-labs.com/images/qdxm/schem5m.png (document version 1.02 published 08-Feb-2023)
Low-pass filter design by Ross Ballantyne, VK1UN

QDX-M Modifications for 2200m Band

digital communication programs, in particular WSJT-X and JS8Call; and the small screen may make it difficult to manipulate large files or images. So at least initially, the project has used both smartphones and laptop computers as the hardware interface.

As mentioned in the introduction, WSJT-X is enormously popular for many different digital modes, in particular WSPR as a beacon mode for testing signal propagation, and FT8 for exchanging two-way, highly structured messages. Many amateur radio operators are familiar with the configuration of WSJT-X and the operation of the program. Moreover, there is a program, JS8Call, that allows free-text keyboard-to-keyboard communication (as needed for meaningful cave communications), that is derived from WSJT-X and uses almost identical config-uration and oper-ations. I therefore started operations with WSJT-X, and because WSJT-X has not yet been implemented for use on Android phones, I used a Windows computer as the interface.

The physical connection of the computer and QDX-M is a USB cable (type A to Type B). That's it, so the overall assembly is very clean and not cluttered. The QDX-M has the same command set as a Kenwood TS-480 so this is the preferred radio to select in the WSJT-X configuration file. And the audio device to select, at least on Windows, for both input and output devices, is the device labelled "QDX".

It is recommended, when assembling a portable station, that each device (mouse, GPS, as well as the QDX-M) is plugged into the same USB port each time. Then, Windows keeps the same COM port assignments, and WSJT-X will work without having to re-configure the app, a significant saving in the field, especially in bad weather.

As mentioned above, JS8Call is built upon the WSJT-X model, and the configuration and use of the program should give few problems to someone familiar with WSJT-X.

I have been working to use a smartphone as the hardware interface. The intention is to use a mode called Olivia that is available in *AndFLmsg*, a program available for Android phones. It provides keyboard-to-keyboard free-text messages, and the ability to transfer files and images. The combination of *AndFLmsg* and a VHF radio is commonly implemented by a wired connection, or an audio connection through the air. With the QDX-M, the audio information must be transferred via the USB port, so it is essential to have an Android phone that is OTG-compatible. My

Galaxy S5 phone is old, but is OTG-compatible, so I am able to use an OTG connector with a micro-USB to fit the phone, and a USB type A socket on the other to accept the type A to B cable needed to connect to the QDX-M.

The second requirement is a modification to the QDX-M operating mode. *AndFLmsg* is not able to issue CAT commands (PTT in particular) to the QDX-M, therefore the QDX-M must operate in VOX mode. This is done by using a terminal program to modify the Configuration file (*Figure 3*) changing VOX mode to Enable, and CAT time-out to disabled.

The third requirement is that the phone be able to recognize the presence of the QDX-M as a USB device. This usually happens automatically if the USB device is

Figure 3 – QDX-M Configuration screen

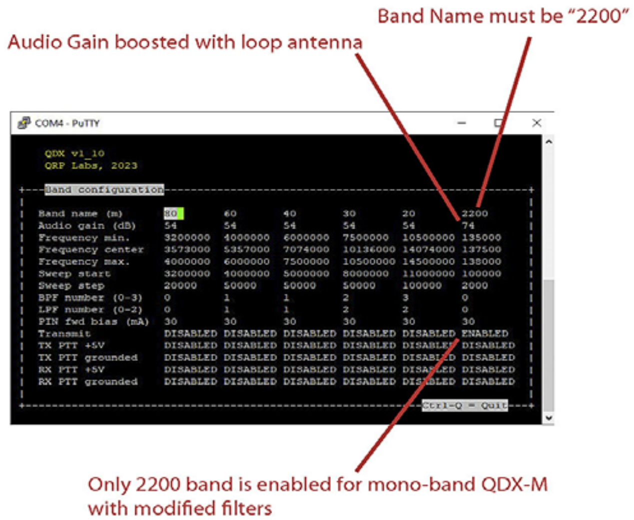

Figure 4 – QDX-M Band Configuration Screen

powered while unconnected; then plugged into the phone via an OTG connector; and finally, the controlling app is started. The order of these actions is important. In the case of *AndFLmsg* and the QDX-M, the app is able to send information to the QDX-M and so transmit text messages, but we are having difficulty getting the phone to recognize the audio feed from the QDX-M and so decode a reply. I am currently working (November 2023) with VK2ETA, the developer of *AndFLmsg,* to resolve this issue.

Antennas

The output of the QDX-M described here is 50 Ω, and so any antenna system that presents a 50 Ω non-reactive load to the device can be used. The options for cave communications could include a tuned-loop antenna, or an accurately matched earth electrode injection system. I have chosen to use tuned-loop antennas because in Alberta, the ground conductivity can be very low due to rocky ground or deep snow cover, making it difficult to establish good ground connections.

The antenna must provide a stable, accurate impedance to the radio. There are reports about the QDX, when used on HF frequencies, of the final amplifier being burnt out when presented with a mis-matched load, for example when an auto-tuner switches through a series of test settings.

The loop antenna I use has a rigid, collapsible frame that is 1 m square, as seen in *Figure 1*).

The wire harness is 2 turns of electrical extension cable, each turn of cable containing 3 turns of 16 AWG stranded wire. The wire is connected as 6 turns, tapped at one turn. The inductance of the coil is about 150 µH, requiring about 9.1 nF for resonance at 137.5 kHz,

I selected the values of the capacitors to be within 100 Hz of the operating frequency. The capacitors must be high voltage, high current and temperature stable. I used polystyrene caps rated at 630 V that I obtained from Digikey. I matched the tuned loop for an input impedance of 50 Ω by using an Amidon 1811-77 pot-core with 10 turns of 24 AWG primary and 35 turns of 26 AWG secondary, feeding the loop through the 1 turn tap. The Q of the antenna was about 100, so the resonant frequency needed to be 137.5 kHz ± 100 Hz for accurate impedance matching.

The bandwidth for the digital modes discussed here is adequate.

Operational Testing

The first test that I ran was to use WSPR. A loop antenna was placed, plane vertical and pointing in the direction I was going to travel, in my suburban garden and the QDX-M was operated as a WSPR beacon. I then moved away from the beacon, stopping to record the beacon message with associated S/N information. I was able to decode the beacon at a distance of 1.4 km when the S/N was -27 dB.

The WSPR test was repeated in a rural setting, where the background noise level was about 40 dB lower than the suburban setting! Extrapolating to a S/N ratio of -24 dB suggests the range of the beacon is about 4 km. We also tested FT8 communication and exchanged JS8Call messages at a distance of 2 km, a very satisfactory set of tests!

Encouraged by these results, we hiked to the top of two summits in the foothills of the Canadian Rockies that are only 1.4 km apart, and successfully exchanged FT8 messages, to make what is probably the first summit-to-summit (S2S) contact on the 2200 m band as part of the SOTA (Summits on the air) program. People are amused when they realize the two summits are less than one wavelength apart!

Testing continues. The devices were taken underground at Canmore Caverns in October 2023 using *JS8Call* as the communications app. Text messages were exchanged from 100 m depth and 200 m offset with a S/N value of +9 dB, indicating much deeper depths will be reached.

Experiments to use *AndFLmsg* as the app continue. The attraction of this app is that it has been used successfully in Cheve in Mexico to transfer survey data and images over a single-wire telephone line. The data method used was Olivia, one of the many modes available through *AndFLmsg*.

Conclusion

The availability of the QDX-M kit radio opens the way to utilize efficient and effective modes of communication for the cave environment. The range of the QDX-M operating at 5 W into a portable loop antenna is already as much as 3 km under quiet rural conditions, and exceeds 1 km in noisy suburban conditions. The apps are already available for message delivery and storage, to relay messages and to transfer files and images. Best of all, the radio transceivers are commercially available (as kits) and are very reasonable in price.

I look forward to hearing about the many ways the technology can be developed.