FSQ — Fast Simple QSO

This new digital chat mode includes a rich set of features for public service communications.

Murray Greenman, ZL1BPU

FSQ (Fast Simple QSO) is a new type of digital mode that is keyboard "chat" oriented and supports a good typing speed. It has a low error rate, is highly versatile, and supports image transmission and selective calling with a wide range of commands. FSQ was designed for simple, enjoyable chat operation, but with public service and disaster communications operations in mind. Other than a transceiver, all you need is a sound device interface.

Introducing FSQ

Con Wassilieff, ZL2AFP, and Murray Greenman, ZL1BPU, designed and developed FSQ for short-distance, single-hop NVIS (near vertical incidence skywave) ionospheric propagation, which is typical of low bands, 1.8 – 10 MHz, but it is also useful on longer single-hop (grey-line) paths, and on VHF FM. The main challenge was to achieve world-class performance under conditions of fading, multi-path reception, Doppler shift, and significant impulse interference, without using error correction.

Long latencies and slow turnaround (principally caused by error correction coding) encourage bad operating habits such as long transmissions, one-sided QSOs, and QSO by macro. We decided that it was time for a new mode that would depart from the conventional digital mode model, and introduce hams to very simple "chat operation," not unlike cell phone texting or Internet chat. See the list of FSQ calling frequencies in Table 1.

Complex vs. Simple

In recent years, digital modes have become increasingly complex. Ham radio should be about friends chatting with easy-to-use equipment, not fighting with the technology, or struggling to understand it.

While some recent complex modes may be technically excellent, that excellence comes at the cost of complexity and operational pleasure — they are not conversational modes. They can be very sluggish (cause delay), and can require more bandwidth and higher symbol rates that further add to complexity and to problems on HF paths. For chatting, we need a very slick mode, with no error correction or other delays.

We deliberately exploited robustness through simplicity in FSQ. We elected to use an MFSK (Multi-Frequency Shift Keying) system of 33 tones, operating at a maximum of nearly 6 baud, that provides nearly 60 words per minute throughput. Overall signal bandwidth is 300 Hz, but the filter bandwidth per tone is only about 3 Hz, hence it has excellent sensitivity.

The new mode operates in a "chat" manner — you type a sentence, press ENTER, and off it goes. Users quickly get used to the idea, and it leads to more immediate and enjoyable QSOs. FSQ has very low latency — the first letter prints within 200 ms of the start of reception, as fast as RTTY.

Figure 1 shows the simple user interface with its large receive screen at the top, a smaller typing window below, and a waterfall tuning display. There is an SNR meter calibrated in dB, and a speed meter.

Directed Messaging

Because FSQ is simple, robust, and slick, we added a Directed Messaging option (like selective calling with extra features). You can operate on one of several published calling frequencies, and simply call a friend by call sign, check that your friend's equipment is operating, check your signal report, leave

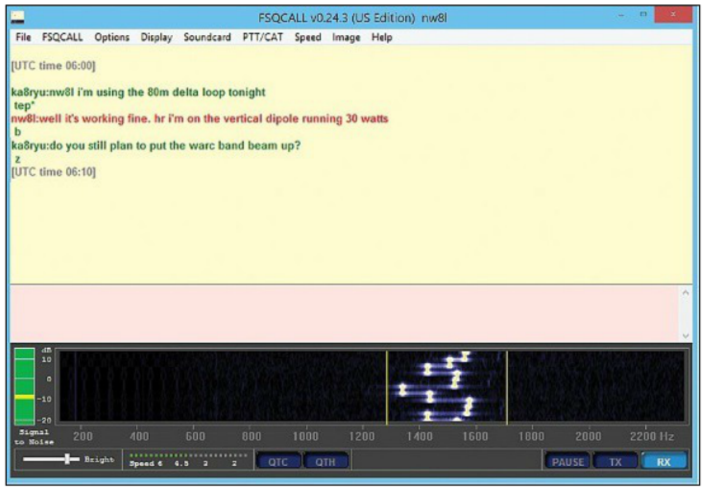


Figure 1 — The FSQ program screen. [Bob Cunnings, NW8L, image]

Table 1
FSQ Calling Frequencies

All frequencies are "dial frequencies" with the transceiver in the USB mode.

ITU Region 1 (Africa, Middle East, Europe, Russia)	ITU Region 2 (North and South America, including Hawaii)	ITU Region 3 (Asia, Australia, Oceania)
3588 kHz	3594 kHz	3580 kHz
7044 kHz	7104 kHz	7105 kHz
10144 kHz	10144 kHz	10149 kHz

a message, or send a file or picture — even when your friend is away from the shack.

We did this because we had disaster communications and public service operation in mind for FSQ. We wanted to make operation and keeping in touch with friends easy and a pleasure; thus we knew we could attract users who would be training as emergency operators.

FSQ Coding and Modulation

FSQ uses 33-FSK, with tones encoded with IFK+ (Incremental Frequency Keying — differential MFSK with an offset of +1). This signaling offers improved performance under NVIS propagation conditions because the tone rotation significantly reduces the risk of adjacent symbols causing ISI (inter-symbol interference). Data is differentially coded, so IFK+ has significantly improved tolerance of Doppler shift, frequency drift, and poor tuning.

Symbol Table

32 tone *differences* are available in FSQ. We allocated 29 tone differences directly to the most used characters (lower-case letters a – z, and the most common punctuations). The remaining three differences indicate three additional code tables. Characters from these tables are sent as sequential tone pairs where the initial tone difference defines the character, and the following tone difference defines the code page.

The 104-character alphabet (see the *QST* in Depth web page) includes lower and upper-case letters, and a wide range of symbols.[1] When the receiver sees a tone difference in the range 0 – 28, followed by another in the range 0 – 28, it recognizes the first as a single-tone character (lower case, etc), which it looks up in the primary table. If the second tone difference is in the range 29 – 31, it uses the second difference to choose the character from a different table.[2]

We designed the user interface to make keyboard chatting incredibly simple, efficient, and enjoyable.

FSQ operates a simple varicode, where one tone difference encodes the most used characters and two tone differences encode lesser-used characters. This markedly improves plain text sending efficiency. These most used characters (lower case) are sent in half the time of the rest. The average error rate of the received lower case letters is half that of the other characters, since only one tone difference is required.

IFK Coding

After the characters are encoded, IFK+ coding is applied to create the FSQ signal. Steve Olney, VK2XV, pioneered this technique, and the FSQ developers had also implemented it in DominoEX, EXChat, and WSQ. It is also used in THOR. IFK+ encodes the data from the character table as differences between two tones rather than as an absolute tone. IFK+ provides tolerance of tuning (±50 Hz), and of drift (±18 Hz/s at 6 baud), and has excellent ISI performance. ISI occurs when signal copies arrive at the receiver via different paths having different propagation delays and even different frequencies. Tone rotation introduced by IFK+ eliminates the possibility of sequential tones being close together in frequency. This also makes possible syncless detection in FSQ. The FSQ rotation is achieved by adding "1" to every difference that is coded to a tone.

When the tone number reaches 33, then 33 is subtracted to keep the transmitted tones in the range 0 – 32. The resulting tone number is then multiplied by three, and sent to the modulator, which is a numerical oscillator operating at 12,000 samples per second, and a frequency resolution of 12,000/4096, or 2.9296875 Hz. Multiplication by three results in a tone spacing of 2.9296875 × 3 = 8.7890625 Hz.

Baud rates are also integer fractions of 12,000 in order to maintain tone orthogonality at the receiver detector. For example, "6 baud" is actually 12,000/2048 = 5.859375 baud; where 2048 samples of the numerical oscillator are sent for each symbol. The differences are sent sequentially, so only one tone is transmitted at a time.

A dummy tone is transmitted first, so that a difference can be measured for the next symbol. After the dummy tone, the first actual character transmitted is CR/LF, so at "6 baud," the first character arrives at the receiver just 171 ms (plus the propagation path delay) after transmission.

Transmit Functions

Type into a keyboard buffer displayed by the FSQcall program transmit pane. You can edit the buffer if necessary before transmission. Press ENTER to start transmission. You can send one or more sentences, but the shorter the transmission, the better.

Conventional COM-port PTT or VOX operation can be used, as can CAT control. Transmissions can also be started by several automatic processes (described later). At the end of the transmission, the transmitter turns off after sending CR/LF. In DIRECTED MODE, a special end of transmission sequence is sent. This has the effect of controlling the squelch function, which has different characteristics in DIRECTED MODE.

Symbol Rate

The transmitted tone timing is defined by the number of samples sent to the sound card for each tone. Tone spacing is fixed at ~9 Hz, but the spacing of the receiver detector filters also defines the maximum symbol rate. The *FSQcall* software offers speeds of about 2, 3, 4.5, and 6 baud. An exact number of samples (for example, 2048 samples at 6 baud) are sent for each tone. The tones change in a phase and amplitude continuous manner that minimizes keying sidebands.

Transmission Bandwidth

The 33 transmission tones result in a tone spread of 290.0390625 Hz. Using the ITU-R SM.1138 assessment method, the emissions easily meet 300 Hz bandwidth at all signaling speeds, so the ITU emission designator is 300HF1B. The center of the tone transmissions is 1500 Hz above the radio dial frequency, and tones range from 1350 to 1650 Hz.

Channel Access

FSQ is intended for fixed-channel operation. Stations can send sentences at any time, especially in DIRECTED MODE where responses can be automatic. An effective channel access protocol is important. FSQ operates a CSMA (Carrier Sense Multiple Access) that uses the receiver squelch function to lock out transmission if the channel is busy.

DIRECTED MODE operates with three levels of priority. The highest priority is manually sent transmissions (where the operator listens to the channel), the second level is automated responses, while the lowest level is assigned to sounding (automatic ID). The levels of priority are defined by a fixed delay plus an additional random delay for the lowest two levels, with the longest delay on the lowest priority messages.

Sounding

FSQ provides a very simple method of

station identification. The user never needs to type his own call sign, as every transmission has a call sign preamble. Thus the shortest transmission (just press ENTER) is this preamble. In the Directed Messaging mode, the preamble is used as a sounding message, allowing other stations on the channel to record not only the active stations but time and signal quality. From this recorded log you can determine the best time of day to call a specific station. The optional sounding transmissions are very short (about 10 seconds) and typically sent every 30 minutes in DIRECTED MODE.

Receiving

Receiving is simple and foolproof. Tune to the chosen calling or net frequency (always USB, always quoted as the radio dial frequency). Check that the squelch setting is appropriate (set just above the noise level), and if appropriate, set the Directed Message mode FSQCALL to ON. That's it!

Fast Fourier Transform

The receiver software operates an overlapping Fast Fourier Transform (FFT) at a 12,000 Hz sample rate, determined by the sound card. The FFT is 4096 samples long, resulting in a bin spacing of 2.9296875 Hz. Calculations are made every 256 samples, when $\frac{1}{16}$-th of the samples are replaced by new ones. The 4096 sample buffer is windowed, and the FFT recalculated. The FFT also provides the waterfall display.

The FFT bin spacing is one third of the tone spacing, so the difference between the current biggest bin index and the previous biggest bin index provides the received data number, and the value must be divided by three. The rounding that occurs during this division removes Doppler shifts as well as small incremental errors due to drift and tuning.

The detector inspects only the bins within the expected range of tones (slightly more than 300 Hz), so signals outside this range are ignored. You can operate with a wide SSB filter with no performance disadvantage.

The detector determines which bin has the biggest signal at each sample point. Power in the bin receiving a tone builds up linearly over a number of samples, stays there until the tone stops, and then decays again, as power builds in another bin.

Sync-less Symbol Recovery

No sync-recovery process is used to decide where the symbols are located. As time passes (about 50 times per second) the FFT result is inspected, and when the bin containing the biggest value changes (as one tone decays and another builds up), FSQ decides that this symbol has finished, and a new one has started. In other words, symbol detection is asynchronous.

Alberto DiBene, I2PHD, first used this technique in a very slow 17-FSK mode for LF (JASON), and we recently discovered that it also works well at HF. Once three consecutive samples have had the same maximum bin, a valid symbol is determined. The process then waits for another three samples in a different bin to be the same to determine the next symbol.

This approach has several important advantages: (1) no phase-locked loop is required, (2) problems with sync stability at low baud rates are eliminated, and (3) the effects of multi-path arrival time errors are completely eliminated.

A unique benefit of asynchronous detection is that the receiver is very tolerant of signaling speed. You can send at 2 baud, or 6 baud, or anywhere in between. This is good news for unattended operation, as the sender can decide the best rate to use for the conditions. There has never been a mode like this before.

Squelch

The software measures the SNR of the signal (compares the strongest bin with the others), and if the SNR is above a user-set limit, allows the signal to print. This limits the appearance on the receiving screen of random noise generated characters. Squelch has a second purpose. An open squelch prevents the transmitter from operating, thus reducing the risk of two stations transmitting at the same time.

Directed Messaging

FSQ was designed as a "chat" mode, not intended for "long overs." Conversation flows best when sending just one or two sentences at a time, similar to a face-to-face conversation. In FSQ, we call each of these "short overs" a sentence, whether it's a short phrase or multiple phrases. The FSQ sentence always starts with an automatic preamble, and ends with ENTER.

In the non-directed FSQ chat mode, the preamble is "call sign:" in lower case by convention. This means that every transmission you make is automatically identified in-mode. There is, however, nothing to say for whom the message is intended.

Directed Protocol

In DIRECTED MODE (optional), the program adds an extra "Monitor" pane along with some extra tabs and buttons (Figure 2). Also the behavior of some functions, such as squelch, change slightly. In addition, a command processor and call sign validator become active in the receiver. These changes allow the system to direct a message to a specific call sign, or to several call signs, or to everyone on the channel. Most messages will be simple sentences, but some will be commands that initiate automated functions at the receiving station. Some even initiate automated replies.

Those interested in public service activities

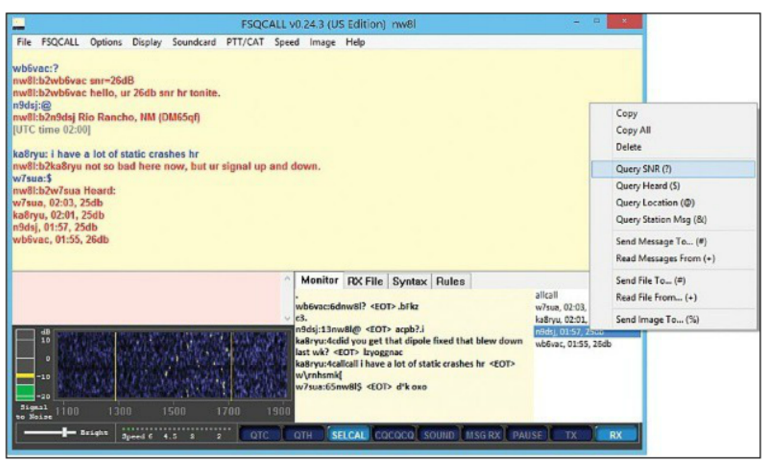


Figure 2 — The FSQ screen for DIRECTED MODE includes a MONITOR pane and extra tabs and buttons. [Bob Cunnings, NW8L, image]

such as ARES, American Red Cross welfare messages, public parades, and message relaying, will immediately see the importance of these functions (see the sidebar, “Public Service with FSQCall”).

The preamble in DIRECTED MODE also changes. In addition to the call sign and colon, it now sports a two-character cyclic redundancy checksum (CRC) used to verify the call sign. For example, my preamble now becomes “zl1bpu:b6.” This ensures that the call sign is received and logged correctly, and that a message source is recognized correctly, and of course that automated replies are sent to the correct call sign. Messages that do not have a valid call sign and CRC are always ignored. A slight change is made at the end of the “sentence” as well. A special end-of-transmission sequence is sent that closes the squelch quickly.

Direction and Trigger

In DIRECTED MODE, the main receive screen does not print all text as soon as the squelch opens. It requires a verified sender’s call sign, the correctly addressed receiver’s call sign (the station’s own call sign), as well as the squelch to be open. Text then prints, and other actions take place when the transmission ceases and the squelch closes.

Squelch action changes to fast attack and very slow decay in DIRECTED MODE. This allows printing to continue through fades. The special end-of-transmission sequence transmitted at the end of the DIRECTED MODE sentences quickly closes the squelch, to prevent printing junk.

To facilitate these actions, in DIRECTED MODE a *direction* and a *trigger* always follow the sentence preamble described above. The *direction* is the station call sign (or several call signs, or the special “everyone on channel” call sign, “allcall”) to which you wish to direct the message.

The *direction* is followed by a one-character *trigger* command, which defines what the receiving station should do with the message. This might sound very complicated, especially since these *directions* and *triggers* must be typed by hand, but in fact it quickly becomes second nature. These *triggers* are few, easy to learn, and often obvious.

The most common *trigger* is the “space” character. If you send “zl1bpu Hello Murray,” your message will print only on the

Table 2
List of Currently Available Commands

Symbol	Command
(sp)	Print sentence
?	What is my SNR (like HW? in CW)
*	Make station Active
!	Repeat my message
#	Save this message
@	Request station position or location
&	Request station message
< >	Slow down or speed up transmission
^	Which software used?
|	Show an Alert message & sound alarm
$	What stations heard?
;	Relay this message
%	Receive (or send) this image
~	Delayed repeat of message

Public Service with FSQCall

FSQ DIRECTED MODE was designed specifically for public service events (sports, parades), and for emergency service training exercises and operation with any HF SSB or VHF FM radio. DIRECTED MODE provides text messaging to a specific station, a specific list of stations, or to all stations. It can be used for orders, messages, alerts, schedule arrangements, sending pictures and small files, and so on.

FSQ DIRECTED MODE provides an *ad hoc* mesh network with forwarding, relaying, and message handling capability. Participants do not need pre-registration with a central organization, or any special pre-programmed equipment (a common problem with Selcall and ALE systems), since the Directed Messaging works on call sign alone. While in operation, the software builds a list of active stations, and logs their every transmission. Unseen “sounding” transmissions can be made automatically to ensure that a station is registered in all active station lists.

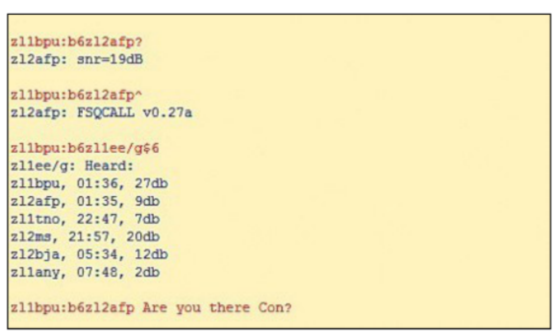
The call sign facility is completely free form — so for special events or emergencies, tactical call signs can be allocated — for example PARADE2, Newhaven, or HQ. Formal station identification requirements can be met by sending the “de call sign” sentence at appropriate intervals.

DIRECTED MODE reception is almost totally automatic. There are simple commands for just about every need. Manual responses are required only to conversations — any two stations can direct sentences to each other (which usually nobody else sees).

At the receiver, FSQ DIRECTED MODE selectively prints only text directed to your call sign, or to allcall (everyone). The same applies to files, images, and messages. If the originator’s call sign is not received correctly and verified, the message is ignored.

Automatic responses are based on a combination of verified *directions* (station call signs) and *triggers* (specialized one-letter commands), and allow the station to automatically report the station position, send a preset station message, store and acknowledge a message or text file, or relay a message to another station. If the incoming call sign is incorrect or the trigger is unrecognized, the message is ignored.

You can query your signal quality at a remote station, even change the sending speed of the other station, send an alert message, determine the station status, or wake the software up if FSQCall is asleep. You can also send images — color photos and high resolution FAXes — to specific or to all stations. Reception is automatic in DIRECTED MODE.


```
zl1bpu:b6zl2afp?
zl2afp: snr=19dB

zl1bpu:b6zl2afp^
zl2afp: FSQCALL v0.27a

zl1bpu:b6zl1ee/g$6
zl1ee/g: Heard:
zl1bpu, 01:36, 27db
zl2afp, 01:35, 9db
zl1tno, 22:47, 7db
zl2ms, 21:57, 20db
zl2bja, 05:34, 12db
zl1any, 07:48, 2db

zl1bpu:b6zl2afp Are you there Con?
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Figure 3 — Another station can query your list of heard stations. [Murray Greenman, ZL1BPU, image]

screen of station ZL1BPU, assuming Murray is on channel and within range. Here the *direction* is "zl1bpu" and the *trigger* is "space," which means "print this sentence to screen." Table 2 lists the currently available commands.

Logging

An important task of the DIRECTED MODE receiver is tracking other stations. A list is displayed in the Monitor (Figure 2), which shows the most recent stations heard, the time, and the signal quality as last received. With the mouse you can select one of these stations to become the *direction* for a message. Another station can also query your list of heard stations (Figure 3). A complete log is kept of all transmissions heard. The log is a comma separated text file that can be read and analyzed in a spreadsheet. The log lists every transmission, sounding and message, in chronological order, complete with station call sign, date, time and SNR. Using this log, you can analyze signal quality to a specific station over the course of the day. You can select stations that would make useful relay stations, and you can also discover when a station is active, or not, or is out of range. Only verified call signs matching the CRC are logged. Stations in FSQ chat mode, and stations that have corrupted preambles, are not logged.

Use of Lower Case

Lower-case characters are quicker to type, faster to send, and error rate is half that of upper-case characters. Because FSQ is case sensitive, a message sent to "ZL1BPU" won't print at station "zl1bpu." You can refer to a station call sign as upper case in a message to a third station without the referred station printing the message.

Acknowledgement of Commands

Some commands have a reply message, or send a message acknowledgement when the action is completed. However, there is never a "negative acknowledgement" type of message. If you expect a reply, and don't get one, you can assume the message wasn't received, so you should try again. You can also send a print message to several stations selectively. For example "w1aw zl1ee w1hq Hello guys" will print at all three stations, but nowhere else.

Image Transmissions

We have already rolled out the ability to send images and we are planning for a variety of other facilities. The image transmission format is analog FM. There is no sync, and reception is started by an FSQ Directed command. The nearest similar mode is the digitally managed image facility in MFSK16. Image reception is entirely automatic if sender and recipient are in DIRECTED MODE. A special window pops up to display the incoming image as it is received. You can also send and receive images in chat mode, and also receive images not directed to you in DIRECTED MODE, but reception needs to be started manually.

Picture Formats

We defined three image formats, all in 4:3 aspect ratio: 160 × 120 color, 320 ×240 color, and 640 × 480 black and white (FSQ-FAX mode). The receiver recovers width × length pixels, then stops receiving. Figure 4 shows a low-resolution web camera image. A high-resolution color image is seen in Figure 5, and a black and white FSQ-FAX example is shown in Figure 6. All of these images were transmitted over a 300 km path at about 20 W power on 40 meters during the day, and are not in any way retouched.

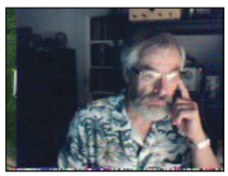


Figure 4 — A received low-resolution web camera image of Con, ZL2AFP. [Con Wassilieff, ZL2AFP, image]

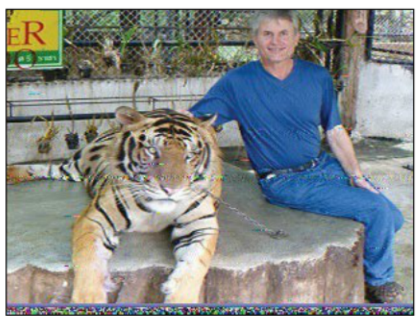


Figure 5 — A received high-resolution color image of Nigel, ZL2SEA. [Nigel Goldstone, ZL2SEA, image]

Narrow Band

Image transmissions are sampled at a 12 kHz rate, the same as FSQ text mode. Each pixel consists of 10 samples. It takes 48 seconds to send a low-resolution color picture, 192 seconds for high-resolution color, and 256 seconds for grey-scale FSQ-FAX. Image modulation is analog, –200 Hz for black, +200 Hz for white, relative to a center frequency of 1500 Hz. The ITU emission designator for all image modes is 400HF1B.

FSQ image transmissions were also designed to match NVIS propagation conditions, so they are sent slower than SSTV, and in less bandwidth. The resulting image quality is better than SSTV, because of improved SNR and reduced multi-path interference performance. Furthermore, because there is no sync, the receiver timing cannot be upset by interference and fades, conditions under which SSTV images tend to tear or slide sideways. There is also significantly less ghosting than with SSTV under NVIS conditions.

Reception is synchronized to the starting time when the command is received, so it is possible for the received image to be moved sideways due to differences in computer processor speeds. This can affect the alignment and color of the picture, but is easily

Figure 6 — A received black and white FSQ-FAX image. [Murray Greenman, ZL1BPU, image]

fixed after reception using a Phase control. Differences in sound card clock rates can also cause timing errors, which result in slanted images. A slider control fixes that as well.

Picture Sources

Images can be sourced from digital photo files, from a scanner, or by copying and pasting into the "Image Send" window. You can also send images of documents such as drawings, PDF, or word processor documents. Using FSQ-FAX mode you can send images of radiogram message forms, provided the text is large and clear.

Some FSQ software versions support transmission of images from laptop cameras, or USB web cameras, so you can send "selfies," or show the view out the window. Some versions also support remote picture transmission commands, so you can request a picture to be sent to you. This is a useful feature for checking images from a distant site.

Performance

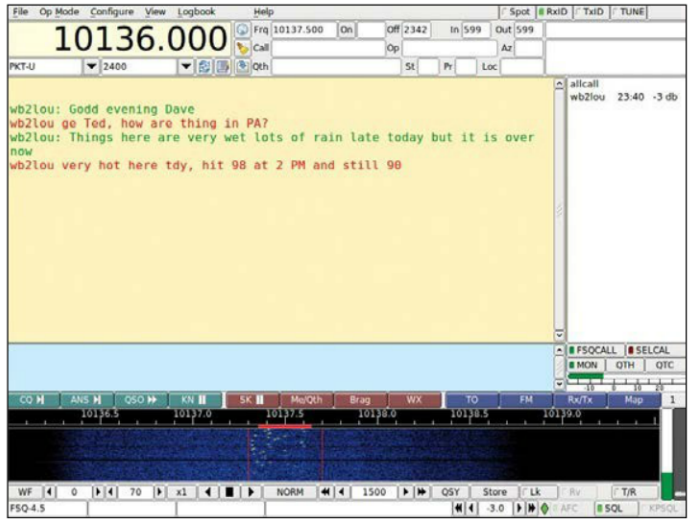
We carried out ionospheric simulations on a wide range of modes as part of the design verification for FSQ.[3] These were used to determine the comparative performance in conditions expected by FSQ applications. The sensitivity in Gaussian noise is about –12 dB SNR in 2.4 kHz bandwidth at 6 baud, and –15 dB at 3 baud. Tests on 40 meters during the day over a 300 km path using 5 W show that you can expect virtually 100% copy for hours on end. US stations have been relaying coast to coast on 30 meters. The error rate is much lower than the typo rate!

The "good conditions" simulations included 0 dB SNR, mild multi-path timing errors, and Doppler frequency and phase changes, typical of single-hop mid-HF paths. The fades can be very deep under these circumstances, so this is a very severe test for a mode with no FEC. All the FSQ modes performed well.

The "disturbed conditions" test simulates 80 meters at night, and has fierce multi-path reception with significant timing issues, at 0 dB SNR. This is a really trying situation for portable night-time operation. The slower FSQ modes performed well. This mode was designed for this condition.

Software

There are two dedicated FSQ programs for *Windows*, the original one by Con, ZL2AFP, and the US Edition by Bob Cunnings, NW8L, and Mike Dannhardt, KA4CDN. The programs have small differences, but are generally interoperable. The US version is currently the preferred version. These programs can be downloaded from the ZL1BPU web page.[4] Software released in the future that includes FSQ support will also be linked here. The programs include a comprehensive help system, and features that explain the syntax, suggest calling frequencies, and operating procedures.



The FSQ mode is now available in *Fldigi*, thanks to Dave Freese, W1HKJ. You'll find *Fldigi* at **www.w1hkj.com**.

The design of FSQ is fully disclosed, with ANSI C source code available for both versions on the web page. A more detailed document on how FSQ works is available from the author. Both program versions also work under *Linux* using Wine. Both support COM port and CAT TX/RX functions for most popular transceivers, as well as VOX control.

Notes

[1]**www.arrl.org/qst-in-depth**

[2]You can also see the full character alphabet at **www.qsl.net/zl1bpu/MFSK/WSQ%20Varicode%20V3.png**.

[3]**www.qsl.net/zl1bpu/DOCS/Ionospheric%20Performance%20of%20FSQ.pdf**

[4]**www.qsl.net/zl1bpu/MFSK/FSQweb.htm**

Murray Greenman, ZL1BPU, has been a licensed amateur since 1966, and has held the equivalent of the US Amateur Extra class license since 1983. He is a retired electronics engineer. During his career he specialized in embedded, automotive, and RFID applications. He has worked in New Zealand, the UK, and Detroit, Michigan.

Murray has operated digital modes since the early 1970s, and was the first southern hemisphere operator on PSK31, MFSK16, and MT63, and has been world-first in QSOs with many new modes. He pioneered sequential multi-tone Hellschreiber (1988), and specified the first amateur MFSK mode, MFSK16 (1999). He has specified or had an influence on the design of numerous other modes, including PSKSounder, MSK-Hell, CMSK, DominoEX, THOR, and EXChat.

His designs are based on a thorough knowledge of ionospheric propagation, and are carefully tested, using ionospheric simulation as well as extensive on-air testing. He has worked with software designer Con Wassilieff, ZL2AFP, for about 15 years. Their pioneering design work and software has always been placed in the public domain.

Murray has three adult daughters, and is involved in choral music, brass playing, kite flying, and the local church. He operates mostly 80/40 meter SSB and digital modes, plus QRSS on 630 meters and HF, and maintains a remote-controlled all-band MEPT station as well as a remote FSQ station. You can reach Murray at 13 Totara Street, Waiuku, Auckland 2123, New Zealand or **denwood@orcon.net.nz**.

For updates to this article, see the *QST* Feedback page at www.arrl.org/feedback.