Ionospheric Performance of FSQ

Murray Greenman ZL1BPU
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The new FSQ mode was designed specifically for 80/40 metre NVIS conditions, and to this purpose uses a very low symbol rate and many tones. It also uses IFK+ and a 'sync-less' decoder, both of which assist in providing good reception under such conditions.

Good sensitivity was another goal, allowing the mode to operate well under fading conditions, particularly for short-hop communications on higher bands, even on VHF.

This report is the result of an evaluation of FSQ alongside a large number of other modes, which served to provide a reality check – did we get it right? Are there better modes out there?

Comparing Apples with Oranges

Of course FSQ and other modes were tested here solely on their ability to pass a certain amount of text in a given time, with an error rate to be determined; not on their level of encoding and error correction, bandwidth; nor are they tested on their 'slickness' (fast turn-around), a factor which is paramount in FSQ, but clearly of less concern to the designers of some of the other modes tested!

When testing and comparing simpler modes, alongside modes with Forward Error Correction, the characteristic differences show clearly. FEC modes tend to be slower starting to print, stop abruptly when the signal is very weak, but ride through fades very well. Modes without FEC have softer fade characteristics, and decode immediately.

Here follows a list of the modes tested for this report (in alphabetical order), along with their symbol rates, bandwidth, modulation, and FEC coding technique, where used.

Mode	Rate	BW	Mod	FEC Coding
AMTOR B	100	150	FSK	Sitor interleaved
BPSK31	31.25	50	BPSK	None
Contestia 4/125	125	150	4FSK	Walsh-Hadamard
DominoEX4	3.9	173	19FSK	None
DominoEX8	7.8	346	19FSK	None
DominoEX11	10.8	262	19FSK	None
FSQ3	2.93	300	33FSK	None
FSQ4	3.91	300	33FSK	None
FSQ6	5.86	300	33FSK	None
MFSK8	7.8	384	16FSK	Binary Convolution
MFSK16	15.6	384	32FSK	Binary Convolution
MT63-1k	10	1000	100PSK	Walsh Hadamard
Olivia 4-250	31.25	250	4FSK	Walsh Hadamard
PSK63RC4	62.5	330	4PSKR	Binary Convolution
PSK125RC4	125	650	4PSKR	Binary Convolution
PSK125R	125	250	PSKR	Binary Convolution
QPSK31	31.25	50	4PSK	Binary Convolution
RTTY45	45.5	270	2FSK	None
THOR4	3.9	173	19FSK	Binary Convolution
THOR8	7.8	346	19FSK	Binary Convolution
THOR11	10.8	262	19FSK	Binary Convolution
THOR16	15.6	379	19FSK	Binary Convolution

The modes shown were not tested for their other characteristics; for example their latency[1], or whether they offered only limited alphabets or used excessive bandwidth. Clearly these aspects are important when choosing a mode to use for a given occasion. FSQ was designed to provide a reasonably full (English language) alphabet, appropriate bandwidth for the required performance, and absolutely minimum latency.

Separating Wheat from Chaff

Many of the modes in the list above fell away during the testing. The requirements were strict – the mode must provide close to 80% Copy[2], under three different scenarios:

- Gaussian Noise at –12dB SNR
- CCIR 520-2 Good Conditions, at 0dB SNR
- CCIR Mid-Latitude Disturbed NVIS, at 0dB SNR

The only modes to pass this weeding out were Contestia 4/125, DominoEX8 and 11, FSQ3,4 and 6, MFSK8 and Olivia 4-250. Many modes completely failed one or more of the tests. The high-speed multi-carrier PSK modes, in particular, did not perform well. RTTY and PSK31, while still very popular, did not have the necessary sensitivity, nor would either of them meet the NVIS requirements, which was no surprise!

Gaussian Noise

This is a test of suitability for weak-signal operation, for example daytime on 80m, fades during single-hop HF QSOs, and VHF use. The graph below shows the results for all modes tested.

[1] Latency measures the time taken to turn around between overs. It is affected by the length of idling that needs to be used to train the receiver sync, and especially by the delay in FEC buffers and interleavers. The latency in FSQ3 is 300ms, in FSQ6, 150ms. In MFSK8 it is around 16 SECONDS, and even longer in Olivia.

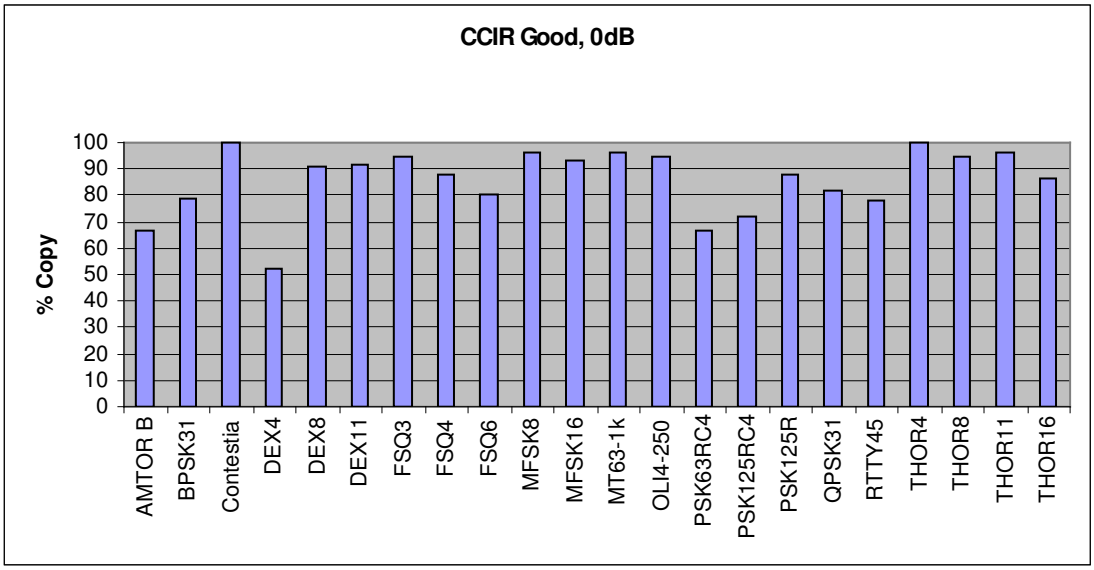
[2] '% Copy' is defined as 100 times the number of complete unblemished words received in one minute, divided by the number of words transmitted. Missing spaces are ignored: partial words don't count. Experience has shown that QSOs are possible at 80% Copy, and become comfortable above 90%. File transfer realistically requires better than 95%.

The test involves reception with a direct simulator path, but at –12dB S/N in 2.4 kHz bandwidth. Most PSK modes performed poorly, as expected. MFSK has sensitivity advantages that show clearly here. DominoEX4 and THOR4 do not perform as well as one should expect. This is believed to be due to their limited weak-signal sync-tracking ability at low symbol rates. Note that FSQ4 (with no sync as such) does not have this limitation.

It is important to acknowledge that of the dozen modes that do pass this test (i.e. provide greater than 80% copy), five of them use no error correction! These are the FSQ and DominoEX modes, and all of these use some form of IFK modulation. (And all come from the ZL2AFP/ZL1BPU stable, but we'll gloss over that).

CCIR Good 0dB SNR

This simulation tests the ability of the mode to handle fades, mild multi-path timing errors, and Doppler frequency/phase change issues typical of a single-hop mid-HF path. The fades are very deep under these circumstances, and the modes with FEC and long interleaf tend to do well. This is a rather severe test for modes without FEC.

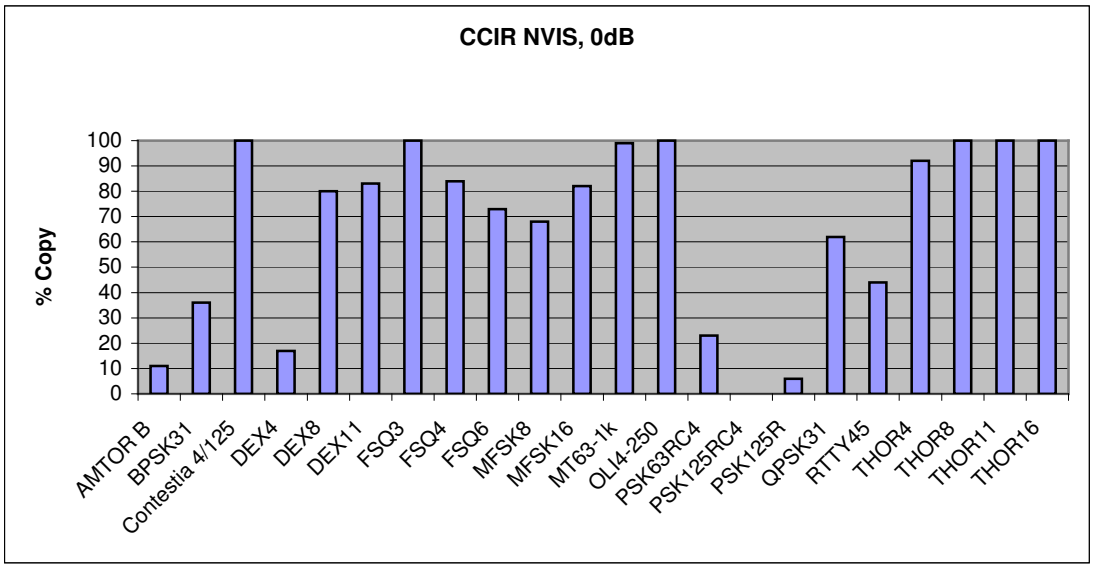


It was pleasing to see that the FSQ modes performed adequately, and although not perfect, they hold up well. They have (at 0dB SNR) a good sensitivity margin, but not enough to survive the deepest fades. The multi-path and Doppler are relatively benign in this test.

The two modes with 100% results both have very strong error correction, but also suffer from poor latency and very slow typing speed.

CCIR Mid-Latitude Disturbed NVIS

This test is the one that sorts out the candidates for nighttime short-distance 80m operation. This band is characterized by fierce multi-path reception with significant timing issues. It can be a really trying situation for low power mobile operation.



Here again some FEC modes do well, especially the wide bandwidth ones, and those with good Doppler capabilities. As we have also discovered in practice, FSQ3 is excellent, and FSQ4 quite adequate for QSOs. The performance of FSQ6 at 73% was a bit disappointing.

Summary of Results

The modes that passed, or nearly passed, the 80% Copy barrier ***in all three tests*** are listed in the table below, along with their speed, and the scores (% Copy) for the three tests.

	Mode	WPM	AWGN	CCIR Good	CCIR NVIS
	Contestia 4/125	20	100%	100%	100%
*	DominoEX8	44	100	91	80
*	DominoEX11	66	100	92	83
*	FSQ3	20	100	95	100
*	FSQ4	25	100	88	84
*	FSQ6	40	90	80	73
	MFSK8	25	100	96	68
	Olivia 4-250	19	100	95	100

* Indicates a mode with no Forward Error Correction

The WPM figures are those from the test, and may be less than quoted elsewhere. The test message (see Appendix) contained a high proportion of upper case text, which results in the Varicoded modes giving lower than expected throughput. On plain lower case text, FSQ6, for example, gets very close to 60 WPM.

The test does not discriminate against long latency modes, as the message counted included everything that came in after the one-minute 'transmission' had stopped.

Useful Throughput

Another interesting analysis, which can be performed on the data collected during this study, is to assess how much good data a given mode can actually send during a certain amount of time. This is achieved by multiplying the WPM figure by the % Copy score, and dividing by 100.

We can call this the ***useful throughput***. Whether it is a useful metric depends very much on the circumstances. Clearly a very fast mode with a poor copy rate will result in lots of disconnected useful text, plus a large amount of garbage!

Here are the best performers from this analysis. The figures are all WPM:

	Mode	WPM	AWGN	CCIR Good	NVIS
	Contestia 4/125	20	19	19	19
*	DominoEX8	44	44	40	35
*	DominoEX11	66	64	59	53
*	FSQ3	20	20	19	20
*	FSQ4	25	25	22	21
*	FSQ6	40	36	32	29
	MFSK8	25	25	24	17
	Olivia 4-250	19	19	18	19

So it looks as though, if you want to send a lot of data reliably under a wide range of conditions, DominoEX11 is still your best bet. If you are able to choose your conditions, choose the mode you use wisely, and you may achieve even better results.

FSQ may be slower than other modes, but has excellent all-round performance and impressive adaptability. It is also significantly ‘slicker’ than all the others.

Bandwidth Issues

It has long been a contention that many digital modes, especially MFSK modes, are unnecessarily wide. A simple analysis of bandwidth versus typing speed will clearly illustrate how effectively the bandwidth is used.

	Mode	WPM	BW, Hz	Hz/WPM
	Contestia 4/125	20	150	7.5
*	DominoEX8	44	346	7.8
*	DominoEX11	66	262	4.0
*	FSQ3	20	300	15
*	FSQ4	25	300	12
*	FSQ6	40	300	7.5
	MFSK8	25	316	12.6
	Olivia 4-250	19	19	13.2

Of course this table lists only the successful candidates in the three tests. There are many narrower modes (but in these tests unsuccessful), such as PSK31 (0.62 Hz/WPM) and 10 WPM Morse (5 Hz/WPM). There are many other modes that most assuredly are uncomfortably wide – candidates such as Olivia 32/1000 (41.6 Hz/WPM).

While keeping the bandwidth narrow is a desirable trait, it also limits signalling speed and has a marked effect on the multi-path, Doppler and drift performance of digital modes. Hence there must always be a compromise. With FSQ we were looking for good Doppler performance, so needed the bandwidth. But let's be realistic - with all the modes in the list above, you could fit at least seven such signals within the bandwidth of just one SSB signal.

Conclusions

Has the main target for FSQ design (good copy under NVIS conditions) been met? Most assuredly it has. FSQ3 gives 100% copy under such conditions, and you can go at double the speed (without changing anything at the receiver) if conditions allow.

Has weak signal performance also been met? Yes, fairly well. Not many modes will achieve 100% copy at –15dB, which FSQ does at 3 and 4 baud. The only competitors are DominoEX and a range of modes with strong error correction.

How does FSQ compare with other modes? It compares well, given the intention of the design – very low latency, no error correction, and good typing speed at low symbol rate in order to be appropriate for the 'Chat Mode' design. Yes, there are better, faster modes under some conditions, but few (Contestia 4/125 being the exception) with relatively low latency that perform well under all the listed conditions.

Appendix – Simulator

The simulator used for these tests was PathSim V1.0 by Moe Wheatley AE4JY. The test method involved recording one minute samples of standard text as .WAV files (achieved using the simulator to record files, with a direct path and no added noise), and playing them back through standard simulations provided by the program, plus added calibrated noise.

All operation took place within the same computer, using the Stereo Mix facility to route the audio from the playback to the digital mode software. The computer was a Lenovo Core Duo running Win 7 Pro 64-bit.

Reception was achieved using FLDIGI 3.22.05 for most modes, and FSQCall V0.24 US Edition for the FSQ modes.

Text was copied from the receiving software and pasted into a text document for analysis, manual counting of WPM and actual words received, then calculation of % Copy. These figures were appended to the analysis file (which is available on request).

The standard message contains 20 words in two lines, and is repeated as often as necessary to complete a one-minute recording:

```
Test de ZL1BPU ZL1BPU ZL1BPU ZL1BPU ZL1BPU ZL1BPU RF72is
The Quick brown Fox jumps over the lazy dog 12345 67890.
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In FSQ modes it necessarily has a '`zl1bpu:`' ahead of this, which also counts as one word.

The same recording was used for each test of each mode, with just the simulator settings changed. Anyone can repeat these tests. The author is confident that the same results will be forthcoming.