An MFSK Mode for HF DX

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Abstract

Development of a very robust and sensitive modem for Amateur DX use. A description of the main problems involved in receiving digital modes on HF, and ways to counter them; a brief history of MFSK, and a description of MFSK technology. A description of the design process of a new MFSK mode for amateurs, its performance, and the software used to demonstrate it.

Concept

Multi-tone FSK modes have never until now been used in Amateur radio circles, and it is hard to understand why. Examples of these modes do exist, for example some of the older robust radio-teletype modes used for fixed links in the diplomatic service.

The author was dissatisfied with the DX performance of existing HF rag-chew modes, such as RTTY, PSK3 1 and MT63, especially on long path, and decided to tackle the solution to reliable digital DX communications by fast considering the problems. An analysis of these prompted an investigation of slow baud rate multi-tone FSK to counter multi-path problems, while retaining immunity to Doppler flutter.

An appreciation of the performance of historical robust modes, especially Piccolo, led to the idea of replicating something similar in a modem environment, making the most of the DSP forces now available. The idea was of course to achieve and confirm the performance promised in theory, and claimed in the papers of the time. Using PC based DSP software allowed many different signaling parameters to be tested, and the best combinations chosen. The results of the tests led directly to the development of two new modes for Radio Amateurs, equal to others in sensitivity, and superior in handling poor propagation conditions. MFSK16 and MFSK8 have been designed as conversation modes, suitable also for nets and broadcasts.

The Problems

There are three main problems that make HF digital communications, and especially long path DX, a real challenge:

1. Multi-path propagation, which causes fading, selective fading, and timing changes.
2. Polar flutter, which modulates the signal, especially affecting the phase.
3. Noise, QRM, carrier interference, man-made crud and lightning noise.

1. Multi-path

Multi-path affects digital transmissions in several ways. Perhaps the most difficult to handle is the different *time-of-flight* of signals arriving at the receiver over different paths. As the signals change in strength, the timing can change slowly, or suddenly shift by 5 - 10 ms, and sometimes more. Often two rays of similar strength and different timing will exist. If the signal is arriving long-path, and short path is also viable, this difference can be as much as 50ms. Obviously data symbols as short as 32 ms (at 3 1.25 baud) are seriously affected - as successive symbols are differently timed or even run over the top of each other. These multi-path problems can be overcome to a large extent by using lower baud rates. At 8 baud for example, the symbols are 128ms long.

By “windowing” the data in the time domain before performing an FFT, the beginning and. end of each of the symbols are ignored. Of course it is at the transitions between symbols where the timing problem is most apparent, and thus multi-path affects can be further rejected.

Multi-path reception also causes fading of the signal, as the rays from different paths cancel. If this happens across the bandwidth of the signal, the best strategy is to use as much sensitivity as is possible. If however the cancellation is frequency selective, which will be the case with short differential delays, the transmission must be recovered with some of its components severely attenuated or missing. 160 meters is perhaps the most difficult band in this regard, with slow and very deep selective fades. The best strategy for this problem is frequency and time diversity, for example multiple tones, with an FEC technique and interleaver to fill in the missing data.

Multi-path can really only be conquered **using very** low baud rates.

2. Polar Flutter

Flutter or “Doppler” is a much misunderstood phenomenon, and has until recently been largely ignored in Amateur circles. The arrival of PSK3 1 on the scene brought this problem to prominence. When signals pass through the ionosphere, especially in the region of the poles, they are subjected to quite large variations in refractive index, and therefore velocity. These changes in the reflective and transmissive properties of the ionosphere vary all the time, and can vary very quickly in a random way, resulting in both frequency and phase shift of the signal. At the receiver, the signal appears to change in amplitude as well due to multiple ray cancellation and augmentation.

Very narrow-band signals are especially prone to flutter problems, as the carrier is essentially Doppler modulated by the ionosphere. With low baud rates the problem is exacerbated, as the carrier phase has more opportunity to change during each symbol than at higher speeds. It is for this reason that differential PSK is used. PSK3 1 operates right at the limit for differential PSK modes on HF, and as digi-DX operators have found, PSK3 1 is of limited use on polar paths, both short path and long path. Even worse, QPSK3 1, which offers promise due to added FEC, is in fact worse than PSK3 1 because the phase modulation per symbol is reduced from 180” to 90”, and the phase error margin is similarly reduced. From experience, QPSK3 1 is really only of use on VHF.

Polar frequency flutter also occurs. However, provided a non-coherent detection system is used (not phase sensitive), polar flutter has little effect on FSK modes with reasonable shifts. Flutter effects of the order of about 5 Hz peak-peak are typical. Doppler frequency modulation broadens the received signal, so the receive detector must cope with this effect. MFSK uses an orthogonal detector capable of rejecting this spillover energy. Traditional RTI’Y achieved this rejection using wide spaced tones.

3. Noise and QIXM

Coping with noise (white noise) is a matter of sensitivity. PSK modes have been demonstrated to achieve very high sensitivity, but then so can MFSK modes, as has been shown with MFSK16 and MFSKS.

QRM, such as SSB splatter, Pactor interference and so on, requires an error reduction system to control and limit the damage. Much the same applies to lightning noise, although this tends to have very high energy and lower occurrence rate. Burst noise such as this is best countered by a strong FEC system with a good Interleaver.

Rejecting crud such as power noise is to some extent a sensitivity issue, and partly a bandwidth issue. The advantage of MFSK in this regard is that the bandwidth of each individual receiver is very narrow and the diversity is good. Good detector decision strategies recover the most likely data despite high levels of noise.

Carrier interference (TV birdies, Morse, AM broadcast stations, PSK3 1) is a problem with most modes. Narrow modes avoid this better by taking up less bandwidth, so reducing the risk. Very wide modes such as MT63 achieve resistance to carrier interference through redundancy and diversity. MFSK resists carrier interference well, unless the carrier is strong. If this is the case, the carrier captures the detector decision system and reception stops. Intelligent decision systems can effectively notch out a constant carrier, and through the use of FEC good copy returns.

The History

Having reviewed the problems to be solved, it became obvious that what was required was a low baud rate, fast, time and frequency diverse, phase-insensitive system with narrow bandwidth! These may sound like ambitious and contradictory requirements, but one class of transmission does have these properties - MFSK, Multiple Frequency Shift Keying. Very little information is readily available about MFSK, and virtually none in Amateur literature, since it has never before been used in Amateur service.

There have been a number of commercial and military applications of MFSK, the most notable and groundbreaking example being Piccolo, developed in the 1960's by the Diplomatic Wireless Service for British Foreign Office diplomatic fixed link service. Most MFSK systems have now fallen into disuse, to be replaced by faster satellite links and ALE systems.

Perhaps the earliest MFSK system for HF was the LMT "Seven Tone Radio Printer", developed in France in 1935. ' This non-synchronous system used seven wide spaced concurrent tones, and a direct printing system not dissimilar to Hellschreiber.' Such a system would today be called Multi-Tone Hellschreiber. Another system, rarely used on HF, is the familiar DTMF telephone tone system, which has a two-of-eight tone set.

Coquelet was developed by ACEC in Belgium for police and military use during the early 1960s. This equipment was relatively portable, largely electro-mechanical but not very sophisticated, using reeds for the tone generators and filters. An important paper published by ACEC demonstrates that the error rate on a digital radio channel is lowest when the number of symbols per character is the least possible.' Coquelet operated asynchronously used high and low tone groups, 12 tones, and two symbols per character.

Piccolo was developed to provide a secure and reliable link between diplomatic posts. The fllrst permanent link was established between England and Delhi in 1965, and later with Singapore, using a 32-tone system. Later systems used 6 or 12 tones. Piccolo was significantly more sophisticated than other systems of the time, and used a synchronous technique, two symbols per tone, and amplitude modulation to provide symbol framing.

The most important invention used in Piccolo was the integrate-and-dump detector, with loss-less filters quenched at the start of each symbol period. In one stroke this device provided very high sensitivity, a robust receiver, and most important of all, very good rejection of adjacent channel energy. This detector provided orthogonal detection with spacing equal to

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' "Seven Tone Radio Printer", Electrical Communicafion. 1937 by L. Devaux and F. Smets.
* See http://www.@.net/zl1 bpu for the history and modern use of Hellschreiber systems.
[3] "Les TMimprimeurs, TMchiffreurs et Transcodeurs ACEC - Systeme Coquelet", ACEC-Revue, No 3-4, 1970.

the baud rate - 20 Hz spacing at 20 baud. An excellent analysis of the detector[4] in the time domain shows how the energy from one tone cancels in the detector for the adjacent tones if the signal is sampled at a baud rate equal to the channel spacing. A modem analysis in the frequency domain[5] comes to the same conclusions.

What is MFSK?

MFSK, Multi-Frequency Shift Keying or M-ary FSK, is a technique where one or more tones bursts from a set of many tones are transmitted at one time. These events are the smallest entity of the transmission, the “symbol”. Unlike RTTY (which is 2-ary FSK), each MFSK symbol can carry more than one data bit. In fact, the nu:mber of bits depends on the number of tones used. Most MFSK systems transmit just one tone at a time,[6] and so:

$$N = log,m$$

(where N = number of bits/symbol and m = number of tones in sy.mbol set)

It can be very confusing to realize that the transmission data rate exceeds the baud rate, but that is most certainly the case. Not only does this give MFSK a needed advantage, since the baud rates need to be low to counter multi-path effects. but by using error reduction with care, the frequency diversity provided by an MFSK system adds worthwhile robustness.

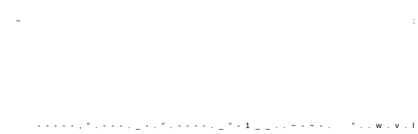

Fig. 1 A single MFSK tone burst

MFSK symbols are traditionally hard-keyed, in other words, the symbols are sharp edged carrier tone bursts as in Fig. 1, giving the signal a certain harshness and perhaps unnecessary bandwidth. Of course these tones are not transmitted in an isolated manner as shown above, but are a continuous train of slightly differing frequencies. The signal quality and bandwidth can be improved considerably through the use of phase continuous tone generation (as has been done for years in RTTY). With a good sine wave phase continuous modulator the bandwidth of the transmission will be very little more than

$$Bandwidth = 2.m + 2.b$$

(where m = number of tones in symbol set, b = baud rate:)

The following diagram shows the characteristic sin(x)/x shape of a hard keyed tone burst. ‘The first nulls are either side of center by the baud rate, and each successive null is spaced by the baud rate multiplied by an integer.

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[4] “Multi-tone signalling system employing quenched resonators for use on noisy radio- teleprinter circuits”, Proc. IEE Vol 110 No. 9, September 1963, H.K. Robin OBE et al.

[5] “Wireless Digital Communications: Design and Theory”, Chapter 4, Tom McDermott NSEG

[6] 2-of m systems do exist. DTMF of course is one example - G3PPT’s Throb is another.

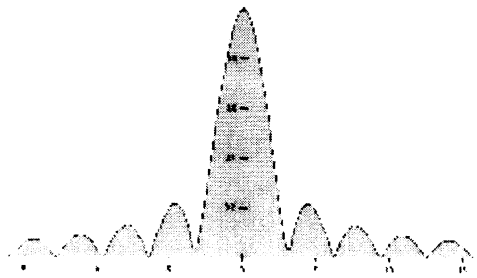

Fig. 2 Frequency domain response of a single tone burst

The big advantage of a hard keyed system is that the transmitter need not be linear. There is no amplitude modulation and no raised cosine envelope to control the switching noise or transfer symbol clock information, so no inter-modulation can occur. The Piccolo system did transmit a symbol pair clock, by keying the screen grid of the class C transmitter to change the power level by 10%. Coquelet achieved symbol sync by using unique symbol sets for the first and second tone of each pair. Our new system is single-symbol oriented and uses only the symbol transition properties to provide clock recovery. There is no amplitude modulation.

Theory (both earlier time domain analysis and recent frequency domain analysis) tells us that orthogonal reception of close spaced tones with an asynchronous detection system can only be achieved when the tone spacing equals the symbol rate (baud rate) or multiples thereof:

Tone spacing for orthogonal reception = 6.i (where i is an integer)

Piccolo was probably the first mode to achieve a spacing of i = 1; Coquelet used mechanical reeds as filters and used i = 3. 'Nith FFT techniques i = 1 is easily achieved.

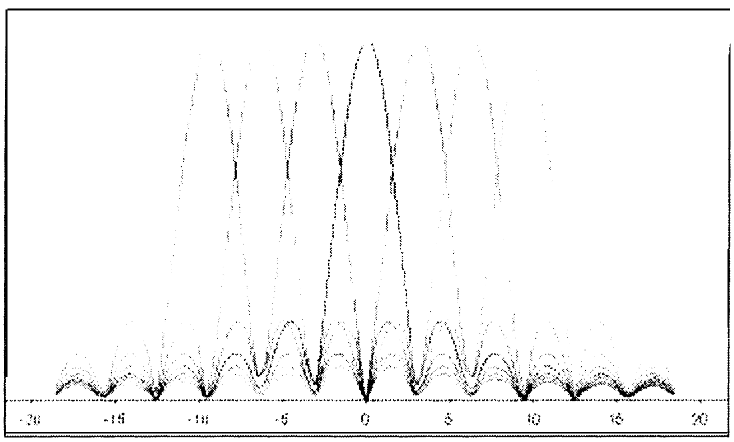

Fig. 3 Seven MFSK tones spaced at i = 1

In Fig. 3 it is easy to see how the frequency domain null of one tone fits exactly under the peak of the next, when the correct spacing is chosen. The diagram also gives some idea of the overall spectrum of an MFSK transmission.

In the receiver, a separate detector follows each tone filter, and the weight of each filter is compared to find the one with the most energy at the end of the symbol period. The integrate-and-dump filters do not respond to random noise, due to the integrative nature of the technique, and thus the system is very sensitive. Further, since the system is orthogonal, each filter responds only to the matched tone, and not its neighbors. In fact a null occurs at the end of the symbol period when the neighbor tone is received (which is why the integer spacing is used).

All these techniques (except phase synchronous tones) were used in Piccolo. There are however a number of modem digital techniques which can be added to an MFSK system to further enhance the performance. Here are just a few:

- Modulator weighting using Gray code for minimum Hamming distance and therefore minimum bit error.
- Multiple baud rate options using tone spacing = baud rate.
- FEC with auto-synchronising Interleaver to gain error reduction and rejection of systematic interference such as carriers. The Interleaver adds time diversity as well as easing the load on the FEC decoder. Unpredictable order of coded dibits recovered by using trial decoders.
- Symbol shape correlation or carrier phase related symbol phase recovery.
- Synchronous FFT filter and demodulation, with a soft decision decoder. Decoder phase and amplitude metrics used for AFC, tuning display and signal / noise meter. Soft decisions fed to FEC decoder.
- Windowed FFT for excellent rejection of multi-path delays of 1Oms or more.
- Highly efficient varicode alphabet, with extended ASCII character set, and super-ASCII control codes.
- The MFSK modem can be completely realized in DSP, using a modest Pentium class PC with a 16 bit sound card

Almost all of these techniques are now in use in the MFSK16 software already released. The addition of FEC and the Interleaver means that the signal can be decoded with little more than 50% of the available data clearly received. The use of soft decisions could add several dB in sensitivity (yet to be realized). The Varicode improves the text throughput by in excess of 25% compared with ASCII. The robustness is appreciable. The modem is inexpensive and simple to install and operate since only a PC with sound card is required.

Designing a New Mode

It was obvious from the research that the time had arrived to make a serious attempt at designing a new MFSK mode. While one of the Piccolo versions could have been replicated, it was thought best to start afresh, with no preconceived ideas. It might seem a tall order, but this was the design brief:

- A mode insensitive to multi-path, with a baud rate of 16 baud or less
- A mode insensitive to polar flutter, and robust in noise and QRM
- A typing speed in excess of 35 words per minute
- A constant amplitude transmission, with minimum bandwidth and constant phase
- Tone spacing equal to baud rate - transmission to fit within a standard CW filter
- Transmission to be bit-stream based, with single symbol per data block
- Varicode alphabet allowing extended ASCII character set and control codes
- Full-time strong convolutional code FEC with Interleaver.
- Orthogonal decoder using integrate-and-dump techniques
- The complete modem to be DSP, operating with a PC sound card

Plenty of useful feedback and good advice was received when the MFSK16 Specification was first issued, via the TAPR HFSIG and a number of other email groups frequented by DSP and coding experts. In addition, Nino Porcine IZ8BLY offered to graft the system into his “Stream” development software, designed for easy experimentation with different digital modes. This provided a very quick way to try out the various options. Nino is a DSP coding expert of no mean ability.

Baud Rate

The baud rates chosen, 15.625 and 7.8125 baud, are precise binary divisions of 8000 Hz, making sampling simple. It was decided to keep the baud rate and tone spacing fixed at the same numeric values, so at 15.625 baud the tone spacing is 15.625 Hz. With 16 tones, this gives a signal 3 16 Hz wide. With 7.8 125 baud and 32 tones, the bandwidth is about the same.

At these baud rates, the channel data rate is the baud rate multiplied by the number of bits per symbol - four for 16 tones, and 5 for 32 tones. So, the channel data rate is 62.5 bps or 39.1 bps respectively, leaving room for an FEC system and still plenty of typing speed!

Transmitter Keying

In the interests of minimum bandwidth and maximum simplicity, a fixed amplitude transmitter modulation scheme was chosen, using a numerically controlled constant phase frequency shift keyed (CPFSK) sine wave generator to create the tones. In effect each symbol is a hard-keyed tone burst, but the transmission bandwidth is kept to a minimum by constant phase slewing from one tone to the next, with no bursts transmitted in isolation. Each symbol is of the same duration, and by virtue of the numerical relationship between baud rate and tone spacing, each symbol also starts and finishes at the same phase, although the complete number of cycles per symbol increases from one tone to the next. This can be important as an aid to recovering the symbol clock.

The major advantage of such a system is that transmitter non-linearity cannot cause the signal to become any broader. Of course the audio stages must remain linear to prevent audio second harmonic effects spaced up or down the band.’

Modulation Scheme

It was decided to weight the tones according to a gray-code, to minimize the bit errors when the signal is mistuned. The lowest frequency tone was chosen to represent binary “0000” or “00000” for 16 or 32 tones respectively.

The chosen modulation scheme was a synchronous, single symbol system. Therefore no symbol pair framing was necessary. Unlike Piccolo and other such modes, there was therefore no need to indicate the start of a symbol pair, and it was decided to attempt to recover symbol phase with no extra symbol synchronizing signal. (Remember, for example, that PSK3 1, also a symbol synchronous system, amplitude modulates the signal at the symbol rate to provide clock recovery). Several suitable methods of symbol clock recovery are known. The symbol clock can only be recovered if the data is varying - synchronism is lost if an idle carrier occurs.

The transmission consists of an apparently random bitstream, largely due to the effects of the Coder and Interleaver. When the transmitter falls idle (the buffer is empty), streams of zero bits are flushed through the Coder and Interleaver, resulting in an idle carrier at the lowest frequency (used for signal tuning). A null character is inserted occasionally during idle to keep the receiver symbol clock in alignment.

Receiver Demodulator

At the time the specification was issued in June 2000, several developers were experimenting with FFT detectors for digital mode demodulation, and it had been demonstrated by Lionel Sear G3PPT,[8] Pawel Jalocha SP9VRC[9] and others, that the FFT could be operated synchronously with the received symbols. For MFSK the FFT samples were windowed using a raised cosine envelope to exclude the first and last few milliseconds of the sample period, effectively providing a “guard band” to eliminate much of the multi-path problem.

The synchronous FFT accurately models the integrate-and-dump detector. It not only integrates the symbol throughout the whole symbol period, but it exhibits the same rejection in adjacent channels for orthogonal detection, and also matches the square transmitted pulse well.

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[7] If the audio tones used are much below about 1.4 kHz, the second harmonic (created by audio clipping) will still be within the transmitter crystal filter passband.
[8] “Throb”, a simple concurrent tone pair MFSK system working at one or two baud
[9] “MT63”, a 64 tone PSK parallel carrier system with FFT phase demodulator

There are a number of areas in the receiver that could be improved. The decision decoder that takes the amplitude values from the FFT bins needs to have a better strategy than simply picking the strongest value. A strategy also needs to be developed to cope with carrier interference, which, if strong enough, can cripple an MFSK system. The decisions from the decoder should be soft, and the soft values applied to a soft decision FEC decoder.

The receiver has AFC, but currently the range is limited and it only operates on an idle carrier. There is room for development of a wide till-time AFC and also a strategy for receiving when mistuned by exactly one tone.

Alphabet

We chose a varicode alphabet similar to that developed for PSK3 1 .I[0] In fact the PSK31 alphabet was used at first, until it was realized that the idle synchronizing requirements were quite different to PSK3 1, and it was possible to assign many more short length codes than is possible with PSK3 1. This was achieved by defining the inter-character framing sequence as "00 1" rather than "OO", where the "1" is the first bit of the following character. This allowed "000" and "0000" and so on to be valid sub-sequences within characters. With other minor changes, such as giving higher priority to numbers and backspace, the throughput on plain text (average 7.4 bits/character) is some 15 - 20% better than PSK3 1 at the same bit rate.

Forward Error Correction

Several FEC schemes were experimented with, but for the sake of simplicity and universal understanding we went with the NASA standard R = 1/2, K = 7 coding" and the excellent Viterbi decoder developed by Phil Kam KA9Q.l'

For every input data bit there are two output data "dibits", generated by two polynomials from the taps of an 8 stage shift register. Call the outputs of these registers 0, to 0,. The polynomials are each the modulo .2 sum (XOR) of five of these register outputs. The polynomials are:

Dibit, = 0 , + 0 , + 0 , + 0 , + 0 ,
Dibit, = 0 , + 0 , + 0 , + 0 , + 0 ,

The dibits defined above are multiplexed into a single data stream, in order Dibit, then Dibit,.
Perhaps the most unusual aspect of FEC coding in the MFSK scenario is that the dibits are multiplexed into a single data stream, and no fixed relationship need exist between the coded dibits and the symbol weighting. The receiver therefore needs to work out for itself which order the dibits are in. This can be done with two Viterbi decoders, choosing the output with the best metrics. We elected to use a main decoder and a trial decoder sampling one bit apart, switching them around if the trial decoder gave better results. In MFSK16 the order of dibits is in fact constant and known (always the same weight in the symbol), so for lower performance computers a single decoder solution would be practical. This is not however true for MFSK8, since there are five bits per symbol. (Maybe an R = l/5 code is called for!)

Interleaver

The all-important Interleaver proved at first to be a problem. It is very important with an MFSK system to provide a good interleaf, since each symbol carries four or five bits. Loss of one or two adjacent symbols can cause serious problems in a Viterbi decoder. Most Interleavers require a framing system such as a Costas Signal for synchronism, and it was felt that since simplicity was important, we should attempt to find a way to use bit position in the symbol to provide automatic

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l[0] "PSK31 Fundamentals" by Peter Martinez G3PLX, http://aintel.bi.ehu.es/psk31 theoryhtml
l[1] "The MFSK FEC Coder", Nino Porcine and Murray Greenman, http://www.qsl.net/zIl bpu/MFSK
l[2] "Convolutional Decoders for Amateur Packet Radio", Phil Karn KASQ,
http://people.qualcomm.com/karn/papers/cnc~coding.html

synchronism. It actually turned out to be very easy - by using an interleaf table the same width as the number of bits per symbol, and reading the bits out diagonally, a modest but fully automatic Interleaver resulted. ”

Imagine the data bits to be transmitted can be represented by

"ABCDEFGHIJKLMOPQRSTUVWXYZO123456789....."

and so on. Then the bit stream about to be sent is arranged by the Interleaver into a table as deep as the number of bits per symbol, like this:

8 Tones:	16 Tones:	32 Tones:
ADGJMPSVY2...	AEIMQUY...	AFKPUZ...
BEHKNQTWZ3...	BFJNRVZ...	BGLQVl...
CFILORUX14...	CGKOSWO...	cHMRw2...
	DHLPTXl...	DINSX3...
		EJOTY4.m

The bits are arranged vertically as they arrive from the Coder, in a four bit wide FIFO shift register, but are sent on to the modulator ***diqpuzlly.*** After each diagonal is sent, the FIFO shifts left and the first column is discarded. The first group of bits sent has been highlighted in each case in the above table. So the bits sent are:

8 Tones: **AEI DHL GKO JNR MQU PTX SW1 UZ4 . . .**
16Tones: **AFKP EJOT INSX MRWl . . .**
32Tones: **AGMSY FLRX4 KQW39 . . .**

Once again the first group of bits sent on in each case is highlighted. The spreading of the bits is quite modest since the table is not very deep, but since the order of the bits is always known at the receiver (from the bit order in the received symbol), synchronization of the Interleaver is automatic. The receiver employs a similar FIFO register, writes received bits in vertically, and reads out the result on the opposite diagonal to the way they were sent.

To improve the bit spreading, ten of these simple interleavers are simply stacked one after another. The result is a spread of some 94 bits, with a 7 1 bit delay. The MFSK16 receiver will copy with up to four consecutive symbols knocked out.

Performance

The new modes were first of all tested on air under the conditions for which they were conceived - long path DX. 128BLY and ZL 1BPU had been in at least weekly communication for some time, and during this phase contacts were stepped up to almost daily, using gray-line long path. Before this software came along, the most reliable communications were on 20m using, PSK-Hell (also invented by ZLlBPU and coded by IZ8BLY), largely because it is very sensitive and not as badly affected by polar flutter as PSK3 1. Once the new MFSK modes came along, it was immediately obvious that the performance exceeded every other mode previously tried! To make conditions more difficult, and at the same time buying some slight privacy, tests were moved to 18 MHz, where signals were generally much weaker, while still suffering polar flutter and multi-path. Once again, copy was excellent, coping with fades into the noise without loss of copy. Receiver tuning took a little skill, but with reasonably stable transceivers and AFC, comfortable rag-chews for well over an hour became the norm, most of the time using as little as 5W. This is an 18,000 km polar path (22,000 km long path).

Tests on other bands soon followed, and it was quickly apparent that the new modes were also as good as any other on most HF paths, if a little more fussy in tuning than most. Users have been most impressed with the way that QSOs are viable under conditions that would not have been considered possible. On the lower bands, 160m to 4Om, no other modes coped as well with the combination of lightning and multi-path reception. The legendary robustness of MFSK has been fully

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l[3] The IZ8BLY Diagonal Interleaver, Nino Porcine IZ8BLY, http://www.qsl.net/zll bpu/MFSK/lNTERLEAVER.doc realized. 3,500 km night-time QSOs between ZL-VK and across Europe were relatively easily achieved with just a few watts. At no time is more power than 25W necessary. An additional bonus has been the reports of excellent VHF performance. European VHFers report that knife-edge diffraction and inversion fades are less of a problem than with PSK3 1, and the MFSK 16 is not affected by aircraft doppler problems.

Transmitter adjustment is easy, and the signal is invariably clean and sharp to tune across. The musical not is not unpleasant on the ear, and users quickly recognise and learn to tune the different modes, although a transmission on the wrong sideband is hard to identify until the transmission is briefly idle.

Johan Forrer KC7WW has tested MFSK16 and many other modes using an ionospheric simulator. Subjectively, MFSK 16 provides better copy under CCIR POOR conditions than any other rag-chew mode tested so far.1[4] In AWGN tests by Moe Wheatley AE4JY, the sensitivity was equal to that of Digipan (PSK3 1). These results are achieved at very respectable typing speeds.

The two MFSK modes chosen for release are:

Mode	Modulation	Baud Rate	Channel bps	Bandwidth	Typing Speed
MFSK8	320FSK	7.8125	39.0625	316 Hz	26 WPM
MFSK16	16-FSK	15.625	62.5	316 Hz	42 VVPM

The modes were named for their approximate baud rate, rather than the number of tones. A.s can be seen from the above table, the bandwidth of the two modes is the same, and comfortably fit through a CW filter. The two can be easily differentiated by ear, as MFSK8 at 7.8 baud is clearly audible as a sequential and musical progression of tones, while MFSK16 sounds more like a jumble of sound. The typing speed is all that is necessary for a rag-chew mode. The tum-around time between overs is about two seconds. Included in this time is an idle period at the start of transmission, which allows the receiver AFC to reacquire the signal. At the end of the transmission the buffer is again flushed until the idle carrier is heard.

MFSK8 is a little more sensitive, and a little more robust than MFSK16, while the typing speed is still reasonable. The tuning accuracy required is rather tight, and the turn-around time doubled. It has been found from experience that these disadvantages are a small price to pay for the opportunity to complete a QSO as the band fades out, or to make a QSO on LF or MF where one would not otherwise have been possible! The turn-around time is still rather less than for MT63.

MFSK16 and MFSKS seem to have very good immunity to most forms of noise and interference. Testers have deliberately tried transmitting MT63 and other modes on top of MFSK16, and found to their amazement that neither mode was disrupted by the other! The sole remaining challenge is carrier interference, if the interfering signal is stronger than the MFSK signal. In effect, the carrier “captures” the symbol decoder on every successive symbol, depriving the FEC decoder of useful data. The planned strategy to combat this is the development of an automatic notch filter to follow the FFT, since the FEC decoder provides copy with missing bits.

Narrow filters are not required for MFSK, any more than for PSK3 1, since the dynamic range of the detector is high and the detector is not sensitive to out-of-band signals. A narrow filter is however useful to reduce desensitization and AGC pumping in the receiver.

The User Software

The IZ8BLY development software used to prove the specification will run some 80 different combinations of modulation (8 to 64 tones), baud rate (4 to 32 baud) and different FEC regimes from none to R=l/6 and K=9! From this has evolved a relatively simple Windows 95™ user program, offering the two MFSK modes, MFSK16 and MFSKS. The software also includes PSK3 1 and PSK63F, Nino’s 62.5 baud full-time FEC PSK mode. Like the MFSK modes, the FEC in PSK63F is

l[4] See http://www.qsl.net/zll bpu/MFSKkimul.htmI for a comparison of several popular modes.

transmitted on a single data stream, so avoids the need for QPSK. PSK63F is relatively immune to polar flutter and is a great mode for short haul DX, local QSOs and for beginners, since it is simple to tune.

The modes are chosen from a simple menu. The software includes many useful pre-programmed "metacommands" that can be typed in or used in conjunction with user-defined buttons. Some of these metacommands are associated with the built-in log book, so it is possible to fill in the log data while receiving, and at the touch of a button reply with the signal report and relevant station information.

As well as the usual split window setup, the software has an excellent FFT-based waterfall tuning display, with point and click tuning. The tuning resolution is 1 Hz. There are a number of other excellent "meters", including a PSK3 1 style "Phase scope" which also indicates MFSK frequency error, a small "Bit shape" oscilloscope display, and perhaps the most interesting of all, a "Clock Alignment" display. This display is a small waterfall, with time in both directions - five sequential symbols are displayed horizontally (brightness indicates symbol amplitude), while vertically about ten seconds worth of these events are shown. When conditions are stable, five black and white bars appear. If the receiver and transmitter clocks are different, the bars tend to slope. As the ionosphere alters the timing, the bars slide left and right, or even jump if the path changes suddenly. When the path is very unstable, or the signal is very weak, the bands become very jagged. The display clearly shows what the ionosphere is up to.

This user program, called "Stream" is now available in beta-release form? The latest versions are fully functional and well documented. The software will operate on a Pentium 75 or faster, and requires a Windows™ compatible sound card. The algorithms, codes and alphabet are public domain/ making the mode legal to use in most countries of the world. It is intended to release source code, in order to promote development of improved software from other programmers, and for other platforms such as LINUX. There is also an email reflector'[7] for users to swap notes, report performance and problems, and to set skeds.

At the time of writing, there are some 200 MFSK16 users world-wide, from countries as diverse as Finland and Fiji. Most DX activity is on 20m and 17m, with local activity on 8Om and 40m.

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