9E4: HF radiotelegraphy

RECOMMENDATION ITU-R F.436-4

ARRANGEMENT OF VOICE-FREQUENCY, FREQUENCY-SHIFT TELEGRAPH CHANNELS OVER HF RADIO CIRCUITS

(Question ITU-R 145/9)

(1966-1970-1978-1994-1995)

The ITU Radiocommunication Assembly,

considering

a) that lack of standardization in the arrangement of channels for voice-frequency multi-channel telegraph systems working over HF radio circuits can give rise to difficulties when setting up such systems;

b) that it is necessary to use the radio-frequency spectrum to the best advantage in the interests of both spectrum economy and circuit efficiency;

c) that frequency shift systems are in use on many routes;

d) that the frequency exchange method of operation is in use on long routes suffering from severe multipath distortion,

recommends

1 that the channel arrangement shown in Table 1 be preferred for start-stop systems operating at a modulation rate of 50 Bd;

2 that the channel arrangement shown in Table 2 be preferred for synchronous systems operating at a modulation rate of approximately 100 Bd (96 Bd with automatic error correction);

3 that the channel arrangement shown in Table 3 be preferred for synchronous systems operating at a modulation rate of approximately 200 Bd (192 Bd with automatic error correction);

4 that for frequency-exchange systems, the central frequencies of Tables 1, 2 and 3 should be paired in the manner found to be best suited to the propagation considerations of the route. (A typical arrangement would take adjacent channels giving 240 Hz or 340 Hz or 480 Hz between tones);

5 that reference should be made to Annex 1 for additional information concerning diversity techniques.

NOTE 1 – Theoretical work in Japan indicates an optimum frequency-shift of 0.8 B (Hz), where B is the modulation rate (Bd). This would lead to a required minimum bandwidth (at the –3 dB points) of B (Hz). Laboratory experiments and measurements on the synchronous ARQ circuits Frankfurt-Osaka support these conclusions. For circuits which are not operating near MUF and for asynchronous circuits, some theoretical results indicate B to $2B$ as the best frequency-shift.

TABLE 1

Central frequencies of voice-frequency-shift telegraph channels with a channel separation of 120 Hz and a modulation index of about 1.4 (Frequency-shift: ± 35 Hz or ± 30 Hz)

Channel position	Central frequency (Hz)	Channel position	Central frequency (Hz)
1	420	11	1 620
2	540	12	1 740
3	660	13	1 860
4	780	14	1 980
5	900	15	2 100
6	1 020	16	2 220
7	1 140	17	2 340
8	1 260	18	2 460
9	1 380	19	2 580
10	1 500	20	2 700

NOTE 1 – See ITU-T Recommendation R.39.

TABLE 2

Central frequencies of voice-frequency-shift telegraph channels with a channel separation of 170 Hz and a modulation index of about 0.8 (Frequency-shift: ± 42.5 Hz or ± 40 Hz)

Channel position	Central frequency (Hz)	Channel position	Central frequency (Hz)
1	425	8	1 615
2	595	9	1 785
3	765	10	1 955
4	935	11	2 125
5	1 105	12	2 295
6	1 275	13	2 465
7	1 445	14	2 635
		15	2 805

NOTE 1 – See ITU-T Recommendation R.39.

NOTE 2 – Theoretical work in Japan indicates an optimum frequency-shift of 0.8 *B* (Hz), where *B* is the modulation rate (Bd). This would lead to a required minimum bandwidth (at the –3 dB points) of *B* (Hz). Laboratory experiments and measurements on the synchronous ARQ circuit Frankfurt-Osaka support these conclusions. For circuits which are not operating near MUF and for asynchronous circuits, some theoretical results indicate *B* to 2*B* as the best frequency-shift.

TABLE 3

Central frequencies of voice-frequency-shift telegraph channels with a channel separation of 480 Hz and a modulation index of about 0.8 (Frequency-shift: ±80 Hz)

Channel position	Central frequency (Hz)	Channel position	Central frequency (Hz)
1	600	4	2 040
2	1 080	5	2 520
3	1 560	6	3 000

NOTE 1 – See ITU-T Recommendation R.38A.

ANNEX 1

Use of coding diversity

1 Introduction

There is a need for HF data transmission systems to provide reliable service in an efficient manner with multi-tone FSK modems, as described in this Recommendation, or multi-tone PSK modems, as described in Recommendation ITU-R F.763. To compensate for the unfavourable nature of the selective fading phenomenon of the transmission medium, in-band or other frequency diversity techniques are widely utilized.

This Annex describes a coding technique that improves the in-band frequency diversity system.

2 System description

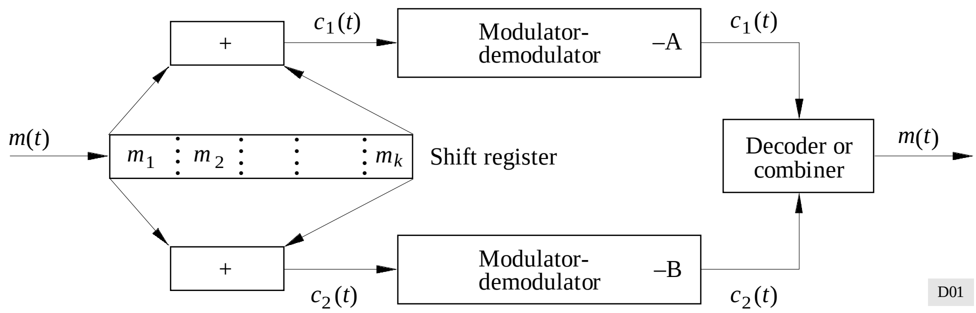
The transmission scheme is shown in Fig. 1. The output $m(t)$ from a binary information source is fed into an encoder shift register of length K. After each shift of the register at the source data rate, the encoder generates two code bits, $c_1(t)$ and $c_2(t)$, which in turn drive corresponding data modulators. In practice, the centre frequency separation of these data modulators is usually about 1 kHz. The combined output of the modulators is then fed into an HF SSB transmission system.

In frequency diversity operation, the system of Fig. 1 assumes its simplest form. The code bits are simply replicas of the information bit, i.e. $c_1(t) = c_2(t) = m(t)$. The decision on the value of a given information bit is based on the combined value of the outputs of the two demodulators. From an information theory context, frequency diversity can be described as a rate-half repetition coding technique that uses soft decisions.

In frequency diversity transmission, only two code bits contain information about any given information bit. With non-zero probability, both of these bits can be corrupted simultaneously by fading, interference or noise so that an incorrect decision is made on the information bit. When this occurs, there is no possibility of correcting the error by using the values of the other code bits. It therefore appears desirable to encode the information sequence such that more than a single pair of code bits is related to any given information bit. The system of Fig. 1 does this by mapping the information sequence prior to transmission.

FIGURE 1

General diversity structure



Any type of rate-half error correcting code could be used in coded frequency diversity transmission, but convolutional codes are particularly suitable because their encoder structure fits the structure of frequency diversity transmission systems, and the Viterbi algorithm can be used efficiently to carry out soft-decision decoding. The outputs of the demodulators are fed to *A*/*D* converters in a Viterbi decoder which replaces the combining operation of the frequency diversity system.

3 Experimental results

An on-air performance comparison of frequency diversity and coding diversity has been made. Convolutional codes of constraint length $K = 5$ and 7 were chosen, and the output of the encoder was fed into a multi-tone FSK modulator using centre frequencies 1 105 and 2 125 Hz with ± 42.5 Hz shift. The data rate of each synchronous channel was 75 bit/s. The eye signal from each demodulator was digitized by a sample taken from the centre of the eye period. The HF radio equipment used included a 100 W transmitter, broadband antennas, and a synthesized communications receiver. Maximal ratio combining was used for the diversity reception experiments. A real-time Viterbi decoder, implemented in software with an 8 bit general purpose microprocessor, was used for the coding experiments.

Three series of on-air tests were conducted from Ottawa: a short-range test over a distance of 60 km, which had a weak groundwave component, a medium-range distance of 400 km to Toronto, and a third test from a ship operating off the east coast of Canada. The ship travelled from Quebec City to the High Arctic, allowing tests to be carried out over distances ranging from about 400 to 2 500 km. During the latter part of this test period, the HF link traversed the auroral belt and rapid fading was often present. The short and medium distance experiments were conducted using various frequencies in the 3-9 MHz range and the ship experiments were conducted in the 5-15 MHz frequency bands.

The error patterns with frequency diversity and coding diversity were analysed. It was observed that both sets of data exhibited the burstiness characteristic of the HF channel, however in the case of diversity, transition between bursts and periods of lower error ratios were gradual. The errors were random much of the time, with frequent isolated single errors. The data from the coding diversity system had dense bursts with relatively abrupt beginning and end, longer error-free gaps, and an absence of single and double errors. The bursts tended to be longer than those in the diversity system. After a long burst the decoder requires some time to recover, thus the bit error ratio in the decoded sequence actually may be higher than that in the in-band frequency diversity system. This is not the case for the block error ratio performance.

This system is intended to be used in an ARQ protocol environment which precludes the use of interleaving or time diversity. These schemes have been shown to result in improvements in the bit error ratio, but they require delays corresponding to the transmission of the order of several hundred bits. In block transmissions, blocks are rejected due to single or multiple errors which is the case for frequency diversity combining, but in coding diversity the block rejection is reduced by the reduction of isolated errors. The tests were done for block sizes of 128 and 512 bits, which are typical for a system that is going to utilize coding diversity.

The block error ratios of the two techniques were compared and are shown in Table 4. The table includes the percentage increase in probability of receiving an error-free block for the coding technique versus frequency diversity. The improvement obtained varied from good to insignificant, and a larger improvement for the 512 bit block size is observed. In some instances the in-band frequency diversity transmission was virtually error-free itself, and thus there was little room for improvement; in other cases, the channel was so poor that neither system provided a usable error ratio. It was observed that in no instance was the performance of the convolutional coding significantly worse than that of the in-band frequency diversity system.

TABLE 4

Experimental block error ratio (BLER) results

a) Block size = 128 (bits)

Test number	Constraint length	Diversity BLER	Coding BLER	Total bits	Throughput improvement (%)
1	$K = 7$	0.293	0.201	1 430 000	13.0
2	$K = 7$	0.217	0.127	506 000	11.5
3	$K = 5$	0.321	0.227	352 000	13.8
4	$K = 7$	0.084	0.015	217 000	7.5
5	$K = 7$	0.083	0.019	217 000	6.5

b) Block size = 512 (bits)

Test number	Constraint length	Diversity BLER	Coding BLER	Total bits	Throughput improvement (%)
6	$K = 7$	0.548	0.406	1 430 000	31.4
7	$K = 7$	0.378	0.223	506 000	24.9
8	$K = 5$	0.570	0.420	352 000	34.9

4 Implementation considerations

The coding technique described in this Annex has a number of practical limitations and it will not replace a general purpose frequency diversity combiner in all applications. For example, it is incompatible with asynchronous data transmissions systems.

However, it is potentially useful with ARQ systems using synchronous transmissions provided that the transmissions are not so short that the improvement in throughput is nullified by the increase in overhead bits required for proper operation of the Viterbi decoder. The overhead is four times K bits (where K is the constraint length) needed at the beginning of the transmission, plus there is a postamble of $K – 1$ bits at the end of the transmission.

5 Conclusions

An error control scheme based on convolutionally coded frequency diversity has been tested and compared to in-band frequency diversity data transmission. Experimental results show that this system has better block error ratio performance than in-band frequency diversity systems. The coding technique is suitable for systems that presently use frequency diversity in combination with a synchronous ARQ protocol.