ADDITION OF A 49TH BIT TO THE MITRE HF ALE WAVEFORM

ERIC E. JOHNSON

PRC-EEJ-88-002 -- MARCH 1988

DEPARTMENT OF

ELECTRICAL AND COMPUTER
ENGINEERING

TECHNICAL REPORT SERIES

NMSU
1888 Centennial Celebration 1988

ADDITION OF A 49TH BIT TO THE MITRE HF ALE WAVEFORM

ERIC E. JOHNSON

PRC-EEJ-88-002 -- MARCH 1988

ADDITION OF A 49TH BIT TO THE MITRE HF ALE WAVEFORM

by

ERIC E. JOHNSON

ABSTRACT

The addition of a 49th bit to the MITRE High Frequency (HF) radio Automatic Link Establishment (ALE) waveform has been proposed as a method to achieve better performance under a variety of conditions. In this report, we examine the rationale for such a modification, describe the requirements and opportunities for receive signal processing this offers, and present an example of the utility of the 49-bit waveform.

This work was supported in part by the U.S. Army Information Systems Command under contract DAEA-18-84-D-0058.

I. INTRODUCTION

The second working group draft of MIL-STD-188-141A (25 November 1987) includes a modification to the originally proposed Mitre waveform for HF automatic link establishment (ALE): in addition to the 48 data bits in the ALE word, a transmitted word also includes a 49th "stuff" bit which is always zero. The intended function of this added bit is to reduce the susceptibility of this waveform to certain types of noise and interference in the channel by providing some time and in-band frequency diversity.

This diversity results from a permutation of the symbols (tones) used to transmit each bit in the triply redundant format:

Tone	Bits			Tone	Bits			Tone	Bits		
1	1	2	3	17	1	2	3	33	1	2	3
2	4	5	6	18	4	5	6	34	4	5	6
3	7	8	9	19	7	8	9	35	7	8	9
4	10	11	12	20	10	11	12	36	10	11	12
5	13	14	15	21	13	14	15	37	13	14	15
6	16	17	18	22	16	17	18	38	16	17	18
7	19	20	21	23	19	20	21	39	19	20	21
	.				.				.		
	.				.				.		
	.				.				.		
16	46	47	48	32	46	47	48	48	46	47	48

Figure 1: Original 48-Bit Format

Tone	Bits			Tone	Bits			Tone	Bits		
1	1	2	3	17	49	1	2	33	48	49	1
2	4	5	6	18	3	4	5	34	2	3	4
3	7	8	9	19	6	7	8	35	5	6	7
4	10	11	12	20	9	10	11	36	8	9	10
5	13	14	15	21	12	13	14	37	11	12	13
6	16	17	18	22	15	16	17	38	14	15	16
7	19	20	21	23	18	19	20	39	17	18	19
	.				.				.		
	.				.				.		
	.				.				.		
16	46	47	48	32	45	46	47	48	44	45	46
								49	47	48	49

Figure 2: Proposed 49-Bit Format

As can be seen in Figure 1 on the previous page, in the 48-bit format the repeated bits in the triply redundant transmission result in repeated tones for the three redundant words; that is, tone 1 is the same as tone 17, which is the same as tone 33, because they are selected by the same bits from the ALE word to be transmitted; the same holds for tones 2, 28, and 34, and so on.

In the presence of in-band interference or a tone jammer, the signal processor in an advanced receiver could respond with one of several techniques; for example, it could excise the offending frequency, but this would probably result in the loss of one of the tones from the ALE tone suite, with the result that legitimate tones in the stop band would be lost, and the demodulator would output random bits for the corresponding symbols, resulting in a significant irreducible error rate.

If a 49th bit is added to each transmitted ALE word (Figure 2), the bits which select the tones in the triply redundant word are shifted from one repetition of the word to the next, as seen in the lower figure on the previous page. The result is that the repeated bits do not result in repeated tones, giving in-band frequency diversity. In the previous example of a notch filter employed for frequency excision, bits which produce a tone in the stop band during one repetition will probably get through in the other two repetitions; with 2-of-3 majority voting, this should greatly improve the irreducible error rate.

In addition to the in-band frequency diversity seen above, addition of a 49th bit also yields a measure of time diversity. Because the tones in the modified system carry different bits in each repetition of the ALE word, the error patterns produced by short noise bursts will change somewhat: errors are spread to adjacent bits, which gives the 2-of-3 majority decoder a slightly better chance of recovering the correct bits. The improved quality of the majority decoder output may, in turn, allow adjustment of the power of the Golay FEC algorithm so that it can correct more of the errors which do get through the decoder.

II. RECEIVE SIGNAL PROCESSING OF THE PROPOSED 49-BIT WAVEFORM

Figure 3 shows conceptual signal flow for processing an incoming MITRE HF ALE signal. The receiver consists of circuitry to extract amplitude modulation from a selected narrow band of the RF spectrum. If the receiver is tuned to receive a signal conforming to the MITRE waveform (draft MIL-STD-188-141A), the receiver output will consist of 8-ary FSK tones plus noise. This baseband analog signal is fed to the receive side of a modem, which attempts to synchronize itself with the timing of the FSK signal, and produces a digital output (bit stream) corresponding to its best guess of the tone transmitted during each signalling interval. This bit stream is the output of what may be considered the Physical layer in an OSI rendering of the MITRE architecture.

The mechanisms which implement the Data Link and higher protocol layers of the MITRE architecture are collectively called a controller. The bit stream output from the modem is fed to the receive side of the controller, where several operations are performed to attempt to recover the 24-bit ALE word sent by the transmitting station.

On arrival at the controller, each bit enters a 99-bit shift register; this bit is compared with two previously-received bits, one 49 bit times old, and another 98 bit times old. A 2-of-3 majority decoder is given these three bits and produces an output bit corresponding the the majority of its inputs. In each bit time, a new bit is clocked into the

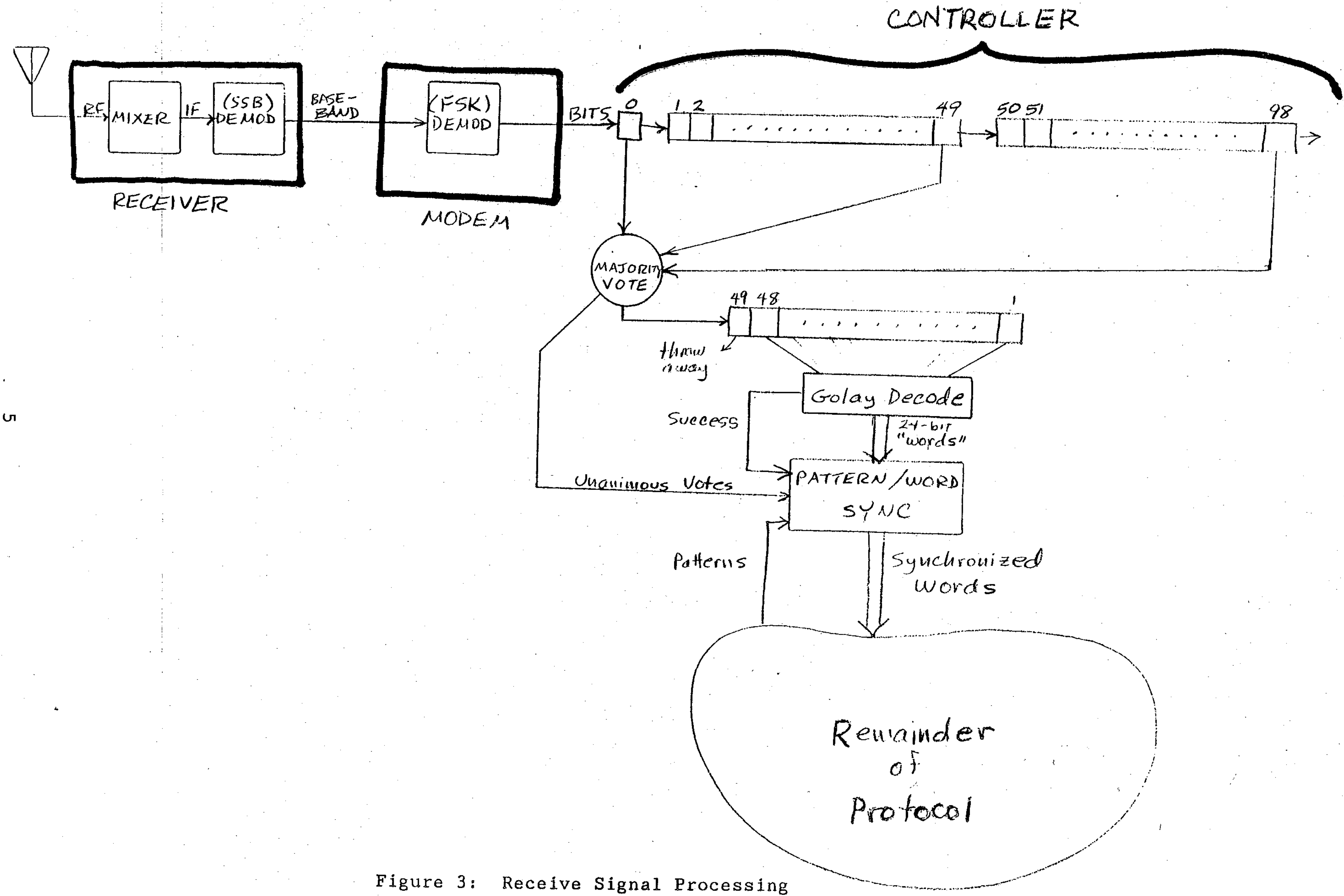

Figure 3: Receive Signal Processing

shift register, an old bit is lost "off the other end," and a Majority Bit is output from the decoder. The Unanimous Vote output from the majority decoder is asserted when all three of its inputs agree.

The majority bits are shifted into a 49-bit shift register, one per bit time; the contents of this shift register at any time constitute a 49-bit Majority Word. This majority word is deinterleaved and fed to an FEC decoder; the deinterleaving ignores the 49th bit of the majority word and splits the remaining 48 bits into two 24-bit words by assigning alternate bits to alternate words. The FEC decoder attempts to decode these two words using a (24,12) Golay code. If both 24-bit words are successfully decoded, the SUCCESS flag is set, and the two 12-bit Golay decoder outputs are concatenated to form a 24-bit word. Whenever the Golay decoder successfully produces a 24-bit word, this word is checked for correct word frame (synchronization). If a series of tests are passed, the receiving controller is deemed to be synchronized with the transmitting controller, and 24-bit ALE words are passed from the word sync process to the ALE protocol process.

Several things should be noted in the above discussion: first the isolation among the receiver, the modem, and the controller; each performs its particular sort of demodulation without significant interaction with the internal operation of its cohorts. Second, neither the receiver nor the modem stores or attempts to understand the signalling tones. Third, the controller, where such interpretation does take place, operates on bits, not tribits or tones; the storage within the receive side of the controller consists of a 99-bit shift register, a 49-bit shift register (majority word), and a 24-bit register to hold Golay decoder outputs.

The differences in the attached figure from the 48-bit case are as follows:

1) The first shift register is 99 bits long rather than 97 bits.

2) The second shift register is 49 bits long rather than 48 bits.

No changes are necessary in the receiver, the modem, the majority decoder, the deinterleaving circuitry (the 49th bit is ignored), the pattern/word sync module, or anywhere else in the receive side of the controller. Modifications to controller software consist of changing a few constants from 48 to 49. Apart from a throw-away output from the majority decoder, the 49th bit is not processed in the controller. Its only effect is to introduce a permutation of tones in the redundant word. Loss of the 49th bit due to any interference is of no consequence; it is always thrown away on receipt, anyway.

The technical challenge in implementing this 49th "stuff" bit is negligible. This bit is always added to every word in exactly the same place, which is much simpler than the bit stuffing used in bit-oriented protocols such as HDLC and SDLC, which have been successfully implemented since the 70's.

III. AN EXAMPLE

This example follows one suggested by Mr. Lloyd Stanley of USAISEC. We follow the ALE word "TO JIM" through the MITRE transmit and receive processing.

```
INPUT TO ALE PROTOCOL MODULE:       <to>   J       I       M

ALE WORD OUTPUT:                    010 1001010 1001001 1001101

INPUT WORDS TO GOLAY ENCODER:       010100101010   010011001101

GOLAY ENCODER OUTPUT:   010100101010111011100010
010011001101011110000011

INTERLEAVED 49-BIT WORD:
0011001001011000110110011011110111101000000001101o
 (o IS ZERO STUFF BIT)

TRANSMITTED TRI-BITS:  (TRIPLY REDUNDANT TRANSMISSION -- 49 TONES)

     001 100 100 101 100 011 011 001 101 111 011 110 100 000 001 101
     o00 110 010 010 110 001 101 100 110 111 101 111 010 000 000 110
     1o0 011 001 001 011 000 110 110 011 011 110 111 101 000 000 011 01o

RECEIVED TRI-BITS ASSUMING TONE 000 JAMMED:  (x is a random bit)

     001 100 100 101 100 011 011 001 101 111 011 110 100 xxx 001 101
     xxx 110 010 010 110 001 101 100 110 111 101 111 010 xxx xxx 110
     1o0 011 001 001 011 xxx 110 110 011 011 110 111 101 xxx xxx 011 01o

TIME SEQUENCE OF INPUTS TO MAJORITY DECODER:  (shown aligned for
clarity)

          . . . 00110010010110001101100110111101111010 0xxx001101x
                xx11001001011000110110011011110111101 0xxxxxx1101o
                001100100101 1xxx1101100110111101111 01xxxxxx01101o . . .

MAJORITY WORD:  00110010010110001101100110111101111010xxxxx01101o
Unanimous votes   ***********   *********************       ****

DEINTERLEAVED:  010100101010111011 1xxx10   010011001101011110 0xx011
(49th bit discarded)

GOLAY DECODER OUTPUT:       010100101010   010011001101    <SUCCESS>

SYNCHRONIZED ALE WORD:      010 1001010 1001001 1001101  (same as input)
```

This example shows the effectiveness of the 49th bit in allowing the MITRE waveform to communicate through tone jamming. The tone chosen (000) occurred slightly more often than average (7/49 vs. 1/8), and represents a fair test of the error correction capability. In particular, the adjacent occurrence of six zeroes in the data stream results in a burst of errors which probably (P = 0.75) gets through the majority decoder.

The error burst was corrected by the Golay decoder, because the code chosen is capable of triple error correction, and deinterleaving split the five-bit error burst into a 3-bit and a 2-bit burst.

Note that the "x" entries in the received bits is not necessarily an error: though the exact probabilities depend on the receive modem signal processing algorithm, it is about equally likely that each "x" is a 0 or a 1, so the probability of an "x" being an erroneous bit is about 0.5.

Note also that one of the seven tones lost contained a stuff bit, and that this loss in no way affected the integrity of the system. This bit is <u>not</u> used for synchronization, and is thrown away before Golay error detection and correction, so it does not contribute to the error count in either Golay word. The error statistics of this bit are identical to those of the information bits, so noting unanimous votes in the majority decoder for this bit does not reduce the value of this statistic for measuring channel quality.

IV. CONCLUSION

In summary, the addition of the 49th bit should provide some improvement in error performance under normal conditions, and a significant improvement under some rather difficult conditions. It adds no new capability, although it does enhance the value of a sophisticated signal processor in the receiver, and thereby enhances competition. The cost of implementating the 49th bit is expected to be quite small, and the bit rate reduction resulting from its use is just over 2 per cent. All in all, it appears to be a bargain, especially for military users, and for others who must operate in crowded bands.