NORTH ATLANTIC TREATY ORGANIZATION

ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD

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MAS/111-EL/4197
2 April 1984

To : See distribution overleaf

Subject : STANAG 4197 EL(EDITION 1) - MODULATION AND CODING CHARACTERISTICS THAT MUST BE COMMON TO ASSURE INTEROPERABILITY OF 2400 BPS LINEAR PREDICTIVE ENCODED DIGITAL SPEECH TRANSMITTED OVER HF RADIO FACILITIES

Reference : AC/302-D/185 dated 20 January 1982

Enclosure : STANAG 4197(Edition 1)

1. The enclosed NATO Standardization Agreement which has been ratified by nations as reflected in page iii is promulgated herewith.

2. The reference listed above is to be destroyed in accordance with local document destruction procedures.

3. AAP-4 should be amended to reflect the latest status of the STANAG.

ACTION BY NATIONAL STAFFS

4. National staffs are requested to examine page iii of the STANAG and, if they have not already done so, to advise the Defence Support Division of the International Staff, through their national delegation as appropriate, of their intention regarding its ratification and implementation.

P.J. MITCHELL
Major-General, CAAR
Chairman, MAS

STANAG No. 4197
(Edition 1)

NORTH ATLANTIC TREATY ORGANIZATION

(NATO)

MILITARY AGENCY FOR STANDARDIZATION

(MAS)

STANDARDIZATION AGREEMENT

SUBJECT : MODULATION AND CODING CHARACTERISTICS THAT MUST BE COMMON TO ASSURE INTEROPERABILITY OF 2400 BPS LINEAR PREDICTIVE ENCODED DIGITAL SPEECH TRANSMITTED OVER HF RADIO FACILITIES

Promulgated on 2 April 1984

for P.J. MITCHELL
Major-General, CAAR
Chairman, MAS

RECORD OF AMENDMENTS

No.	Reference/date of amendment	Date entered	Signature
1-2		21.1.87	[signature]
3		August 1 2002.	[signature]

EXPLANATORY NOTES

AGREEMENT

1. This NATO Standardization Agreement (STANAG) is promulgated by the Chairman MAS under the authority vested in him by the NATO Military Committee.

2. No departure may be made from the agreement without consultation with the tasking authority. Nations may propose changes at any time to the tasking authority where they will be processed in the same manner as the original agreement.

3. Ratifying nations have agreed that national orders, manuals and instructions implementing this STANAG will include a reference to the STANAG number for purposes of identification.

DEFINITIONS

4. Ratification is "The declaration by which a nation formally accepts the content of this Standardization Agreement".

5. Implementation is "The fulfilment by a nation of its obligations under this Standardization Agreement".

6. Reservation is "The stated qualification by a nation which describes that part of this Standardization Agreement which it cannot implement or can implement only with limitations".

RATIFICATION, IMPLEMENTATION AND RESERVATIONS

7. Page iii gives the details of ratification and implementation of this agreement. If no details are shown it signifies that the nation has not yet notified the tasking authority of its intentions. Page iv (and subsequent) gives details of reservations and proprietary rights that have been stated.

STANAG 4197
(Edition 1)

NAVY/ARMY/AIR

NATO STANDARDIZATION AGREEMENT (STANAG)

MODULATION AND CODING CHARACTERISTICS THAT MUST BE COMMON TO ASSURE INTEROPERABILITY OF 2400 BPS LINEAR PREDICTIVE ENCODED DIGITAL SPEECH TRANSMITTED OVER HF RADIO FACILITIES

Annexes: A - Modulation Characteristics Required of the Narrow Band Digital Voice HF Modem

B - Coding Characteristics Required of the HF Modem

C - Typical Performance Data on the HF Modem for Narrow Band Digital Voice Transmission (for information only)

Related Documents:

(1) STANAG 4203: Technical Standards for Single Channel HF Radio Equipment

(2) STANAG 4198: Parameters and Coding Characteristics that must be Common to Assure Interoperability of 2400 bps Linear Predictive Encoded Digital Speech

AIM

1. The aim of this agreement is to define the coding and modulation characteristics to ensure the compatibility of the analogue signal of modems used over single channel high frequency radio facilities for sky-wave transmission of 2400 bps digital voice produced using Linear Predictive Encoding.

AGREEMENT

2. Participating nations agree to use the characteristics contained in this STANAG for their modems used to transmit 2400 bps linear predictive encoded digital speech transmitted over single channel HF facilities.

GENERAL

3. The modulation characteristics are detailed in Annex A. The coding characteristics are detailed in Annex B. A set of typical performance data is at Annex C for information purposes.

IMPLEMENTATION OF THE AGREEMENT

4. This STANAG is considered implemented by a nation when all such equipment used in its forces are manufactured in accordance with the specifications detailed in this agreement and are placed in service.

MODULATION CHARACTERISTICS REQUIRED OF THE NARROW BAND DIGITAL VOICE HF MODEM

MODULATION

1. The modulation technique shall be frequency division multiplexing of tones with four phase differentially coherent phase shift keying. The transmitted phase of each tone at the beginning of a given frame shall be defined as:

$$\theta_n = \theta_{n-1} + \theta_s$$

where:

θ_n = signal phase at beginning of present frame;

θ_{n-1} = signal phase at beginning of previous frame;

θ_s = phase shift due to data.

The phase shift due to the data shall be defined as specified in Figure 1. The left hand digit of the debit is the bit occurring first in the data stream as it enters the modulator.

TONE LIBRARY

2. The modulator shall generate two separate signal formats based on the characteristics specified in Table 1 and tone libraries specified in Table 2. The 16-tone library shall be used for the preamble and the 39-tone library for digital voice data.

PREAMBLE

3. The preamble shall be used in the receive modem for the detection of signal present, the correction of doppler, and the identification of the beginning of the system preamble. The preamble format is shown in Figure 2.

4. Part one of the preamble shall consist of four unmodulated tones with equal amplitudes and with initial phases selected to minimize the ratio of peak-to-rms amplitude of the composite signal. The length of part one shall be 24 frames at 0.0133 s/frame.

5. Part two shall consist of three tones simultaneously phase modulated 180 degrees at the frame rate. The initial phases shall be selected to minimize the peak-to-rms ratio. Part two shall be 8 frames long.

6. Part three shall be used to identify the beginning of the system preamble. It shall consist of the 16-tone library with biphase DPSK modulation. With biphase modulation, a zero and a one-bit shall be encoded as +90° and -90° phase changes, respectively. The information transmitted shall be a 15-bit PN sequence. The sequence shall be transmitted 16 times during a period 15 frames. It shall be preceded by a phase reference frame.

7. The frequency assignments, the initial phases, and the PN sequence are specified in Table 3. The polynomial for the PN sequence generator is $x^4 + x + 1$. The initial load for the generator is all ones.

SYSTEM PREAMBLE

8. The system preamble, which immediately follows the modem preamble, consists of a 4-bit unencrypted code word to indicate the mode of the transmitting terminal combined with a 108-bit COMSEC message indicator (MI), plus a 16-bit all-zero word. These 128 bits are encoded by a Bose-Chaudhuri-Hocquenghen (BCH) error correction code (252,128). This shall be a shortened (255,131) code with a generator polynomial as defined in Table 11.3 on page 370 of "Principles of Data Communications", by R.W. Lucky, J. Salz, and E.J. Weldon, Jr.

9. Figure 3 shows the format of the 252-bit BCH code word. The bit identified as bit one of the 108 bit MI is the first bit read into the modulator. The bit identified as bit one of the control word is the least significant bit of that 4-bit word. The encoding process starts with bit 16 of the all-zero word and proceeds sequentially to the left until the last bit encoded is bit one of the mode control word. The first parity bit generated is stored as the 252nd bit of the code word, and the last parity check bit is stored as bit number 129 in the code word.

10. The 252 bits are transmitted as 126 dibits on the 16-tone library in accordance with the plan specified in Table 4, with dibit number one composed of bits one and two of the code word. Each dibit shall be transmitted with eighth order diversity within a time span of 63 frames. Each such period of 63 frames shall be followed by the transmission of three dummy frames, also using the 16-tone library, to provide time for the BCH decoding function.

RECOMMENDED PERFORMANCE CHARACTERISTICS FOR RADIO FREQUENCY EQUIPMENT

11. To achieve optimum performance, it is recommended that the radio frequency equipments have a bandwidth of 575 Hz to 2910 Hz + 0.5 dB with a differential phase delay of less than 0.5 milliseconds (ms) over the same bandwidth. The recommended frequency stability is one part in 10^6 or better.

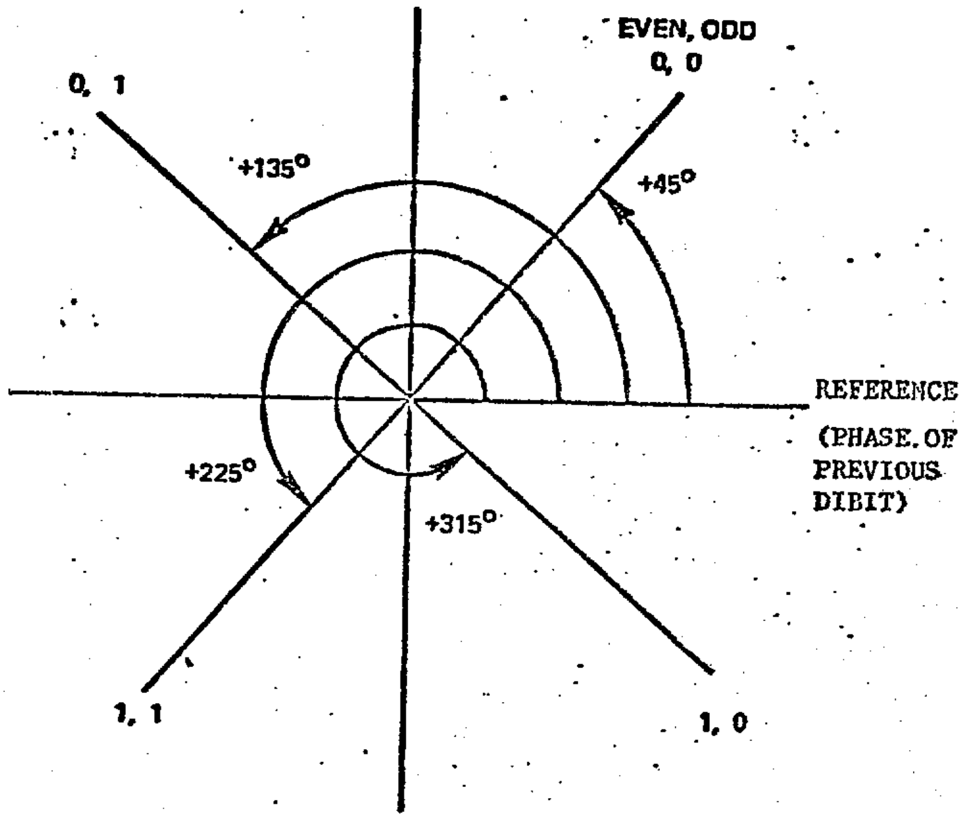

FIGURE 1 - GRAY CODING FOR FOUR-PHASE DIFFERENTIALLY COHERENT PHASE SHIFT KEYING

Part 1	Part 2		Part 3
Doppler Tones	Sync Tones	Ø Reference	Framing

FIGURE 2 - SEQUENCE OF TRANSMISSION, HF PREAMBLE

1 … 252

1 … 4	1 … 108	1 … 16	1 … 124
MODE	MI	ZEROS	PARITY

FIGURE 3 - BCH ENCODER OUTPUT FORMAT

Library	No. of Tones	Freq. Spacing (Hz)	Keying Period (s)	Samples Per Second	Samples Per Frame	Orthogonal Period (Samples)	Transmission Rate (b/s)
1	39	56.25	.0225	7200	162	128	3466.67
2	16	112.5	.0133	7200	96	64	2400.

TABLE 1 - TONE LIBRARY CHARACTERISTICS

Library Number One

Tone Number	Frequency (Hz)	Tone Number	Frequency (Hz)
1	675.0	21	1800.0
2	731.25	22	1856.25
3	787.5	23	1912.5
4	843.75	24	1968.75
5	900.0	25	2025.0
6	956.25	26	2081.25
7	1012.5	27	2137.5
8	1068.75	28	2193.75
9	1125.0	29	2250.0
10	1181.25	30	2306.25
11	1237.5	31	2362.5
12	1293.75	32	2418.75
13	1350.0	33	2475.0
14	1406.25	34	2531.25
15	1462.5	35	2587.5
16	1518.75	36	2643.75
17	1575.0	37	2700.0
18	1631.25	38	2756.25
19	1687.5	39	2812.5
20	1743.75		

Library Number Two

Tone Number	Frequency (Hz)
1	900.0
2	1012.5
3	1125.0
4	1237.5
5	1350.0
6	1462.5
7	1575.0
8	1687.5
9	1800.0
10	1912.5
11	2025.0
12	2137.5
13	2250.0
14	2362.5
15	2475.0
16	2587.5

TABLE 2 - TONE LIBRARIES FREQUENCY ASSIGNMENTS

Part I
Four Doppler Tones

Tone No.	Freq. (Hz)	Phase (Radians)
1	787.5	0.0
2	1462.5	1.81
3	2137.5	1.81
4	2812.5	0.0

Part II
Three Sync Tones

Tone No.	Freq. (Hz)	Phase (Radians)
1	1125	0.0
2	1800	1.57
3	2475	0.0

Part III
240 Bit Framing Sequence

Tone No.	Framing Sequence Transmitted in 15 Frames														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	0	0	0	1	0	0	1	1	0	1	0
2	1	1	1	0	0	0	1	0	0	1	1	0	1	0	1
3	1	1	0	0	0	1	0	0	1	1	0	1	0	1	1
4	1	0	0	0	1	0	0	1	1	0	1	0	1	1	1
5	0	0	0	1	0	0	1	1	0	1	0	1	1	1	1
6	0	0	1	0	0	1	1	0	1	0	1	1	1	1	0
7	0	1	0	0	1	1	0	1	0	1	1	1	1	0	0
8	1	0	0	1	1	0	1	0	1	1	1	1	0	0	0
9	0	0	1	1	0	1	0	1	1	1	1	0	0	0	1
10	0	1	1	0	1	0	1	1	1	1	0	0	0	1	0
11	1	1	0	1	0	1	1	1	1	0	0	0	1	0	0
12	1	0	1	0	1	1	1	1	0	0	0	1	0	0	1
13	0	1	0	1	1	1	1	0	0	0	1	0	0	1	1
14	1	0	1	1	1	1	0	0	0	1	0	0	1	1	0
15	0	1	1	1	1	0	0	0	1	0	0	1	1	0	1
16	1	1	1	1	0	0	0	1	0	0	1	1	0	1	0

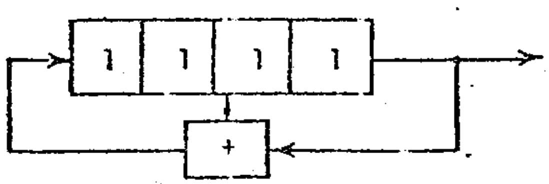

TABLE 3 - HF MODEM PREAMBLE FORMAT

TABLE 4 - DIBIT ASSIGNMENT OF BCH ENCODED DATA ON 16 TONES WITH EIGHTH ORDER DIVERSITY

Frame	Dibit Assignment for 16 Tones															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
3	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
4	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
5	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
6	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
7	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112
8	113	114	115	116	117	118	119	120	121	122	123	124	125	126	1	2
9	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
10	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
11	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
12	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
13	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
14	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
15	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114
16	115	116	117	118	119	120	121	122	123	124	125	126	1	2	3	4
17	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
18	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
19	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
20	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
21	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

(continued)

TABLE 4 - DIBIT ASSIGNMENT OF BCH ENCODED DATA ON 16 TONE WITH EIGHTH ORDER DIVERSITY (Continued)

Frame	Dibit Assignment for 16 Tones															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
22	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
23	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
24	117	118	119	120	121	122	123	124	125	126	1	2	3	4	5	6
25	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
26	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
27	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
28	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70
29	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
30	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102
31	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
32	119	120	121	122	123	124	125	126	1	2	3	4	5	6	7	8
33	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
34	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
35	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
36	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
37	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
38	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
39	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
40	121	122	123	124	125	126	1	2	3	4	5	6	7	8	9	10
41	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
42	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42

(Continued)

TABLE 4 - DIBIT ASSIGNMENT OF BCH ENCODED DATA ON 16 TONES WITH EIGHTH ORDER DIVERSITY (Continued)

Frame	Dibit Assignment for 16 Tones															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
43	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
44	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
45	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
46	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
47	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122
48	123	124	125	126	1	2	3	4	5	6	7	8	9	10	11	12
49	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
50	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
51	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
52	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
53	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
54	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108
55	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124
56	125	126	1	2	3	4	5	6	7	8	9	10	11	12	13	14
57	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
58	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
59	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
60	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
61	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
62	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110
63	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126

CODING CHARACTERISTICS REQUIRED OF THE HF MODEM

CODING OF DIGITAL VOICE

1. The Linear Predictive Code (LPC) provides 54 bits per frame at 44.44 frames per second. The format for the 54 bits is specified in Table 1. Twenty-four bits from each frame shall be encoded to protect them against transmission errors. The 24 bits shall be divided into two 12-bit words. Each word will be encoded using a (24,12) block code, which is the (23,12) Golay code with an overall parity bit. Even parity shall be used. The generator polynomial for this code is $x^{11} + x^9 + x^7 + x^6 + x^5 + x + 1$.

2. The identity of the information bits for both code words is specified in Table 1. The encoding process starts with bit one of each code word, with the first parity bit stored as bit 14 in the code word, as shown in Figure 1. The overall parity bit is stored as bit 13 of the code word.

MODULATOR

3. The modulator shall accept 78 bits per frame from the encoder. These 78 bits shall consist of two (24,12) Golay code words plus 30 uncoded bits. The data shall be assigned to 39 dibits as specified in Table 2. The identity of the 30 uncoded bits are specified in Table 1.

DATA PERMUTATION

4. The 39 dibit/tone assignments shall be permuted to minimize the effect of frequency selective fading and narrow-band interference on both the coded and uncoded data. For the first frame, the tone number assigment shall agree with the dibit number with the lowest frequency tone containing dibit one. For each successive frame, the starting point for the tone assignment shall be shifted by 34 (modulo 39). Table 3 illustrates the dibit/tone assignments for the first three frames. The pattern shall repeat after 39 frame periods.

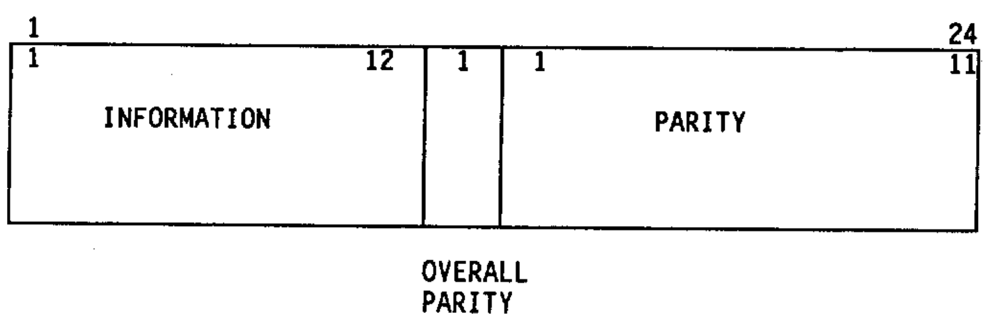

FIGURE 1 - GOLAY ENCODER OUTPUT FORMAT

TABLE 1 - BIT IDENTITY OF DIGITAL VOICE DATA

Bit No.	Function		Encoded Bits		Bit No.	Function		Encoded Bits	
	Voiced Frame	Unvoiced Frame	cw #1	cw #2		Voiced Frame	Unvoiced Frame	cw #1	cw #2
1	r(1) - 0	r(1) - 0			28	r(2) - 4	r(2) - 4	Bit 11	
2	r(2) - 0	r(2) - 0			29	r(7) - 0	r(3) - 5*		
3	r(3) - 0	r(3) - 0			30	r(8) - 0	A - 5*		
4	P - 0	P - 0			31	P - 4	P - 4		Bit 9
5	A - 0	A - 0			32	r(4) - 4	r(4) - 4		Bit 10
6	r(1) - 1	r(1) - 1	Bit 1		33	r(5) - 0	r(1) - 5*		
7	r(2) - 1	r(2) - 1	Bit 2		34	r(6) - 0	r(2) - 5*		
8	r(3) - 1	r(3) - 1			35	r(7) - 1	r(3) - 6*		
9	P - 1	P - 1		Bit 1	36	r(10) - 0	r(4) - 5*		
10	A - 1	A - 1		Bit 2	37	r(8) - 1	A - 5*		
11	r(1) - 2	r(1) - 2	Bit 3		38	r(5) - 1	r(1) - 6*		
12	r(4) - 0	r(4) - 0			39	r(6) - 1	r(2) - 6*		
13	r(3) - 2	r(3) - 2	Bit 4		40	r(7) - 2	r(3) - 7*		
14	A - 2	A - 2		Bit 3	41	r(9) - 0	r(4) - 6*		
15	P - 2	P - 2		Bit 4	42	P - 5	P - 5		Bit 11
16	r(4) - 1	r(4) - 1			43	r(5) - 2	r(1) - 7*		
17	r(1) - 3	r(1) - 3	Bit 5		44	r(6) - 2	r(2) - 7*		
18	r(2) - 2	r(2) - 2	Bit 6		45	r(10) - 1	D/C		
19	r(3) - 3	r(3) - 3	Bit 7		46	r(8) - 2	A - 7*		
20	r(4) - 2	r(4) - 2			47	P - 6	P - 6		Bit 12
21	A - 3	A - 3		Bit 5	48	r(9) - 1	r(4) - 7*		
22	r(1) - 4	r(1) - 4	Bit 8		49	r(5) - 3	r(1) - 8*		
23	r(2) - 3	r(2) - 3	Bit 9		50	r(6) - 3	r(2) - 8*		
24	r(3) - 4	r(3) - 4	Bit 10		51	r(7) - 3	r(3) - 8		
25	r(4) - 3	r(4) - 3		Bit 6	52	r(9) - 2	r(4) - 8		
26	A - 4	A - 4		Bit 7	53	r(8) - 3	A - 8		
27	P - 3	P - 3		Bit 8	54	SYNC	SYNC	Bit 12	

*LPC error control bits.

r(1)-0 = LSS of Reflection Coefficient r(1)
P-0 = LSB of Pitch
A-0 = LSB of Amplitude

TABLE 2 - DIBIT FORMAT FOR CIPHER TEXT IN DIGITAL VOICE MODE

Dibit	Bit Identity					
(odd, even)	Odd Bit			Even Bit		
1	CW1	Bit	1	CW2	Bit	1
2	CW1	Bit	2	CW2	Bit	2
3	UC	Bit	1	UC	Bit	37
4	CW1	Bit	3	CW2	Bit	3
5	CW1	Bit	4	CW2	Bit	4
6	UC	Bit	2	UC	Bit	38
7	CW1	Bit	5	CW2	Bit	5
8	CW1	Bit	6	CW2	Bit	6
9	UC	Bit	3	UC	Bit	39
10	CW1	Bit	7	CW2	Bit	7
11	CW1	Bit	8	CW2	Bit	8
12	UC	Bit	4	UC	Bit	40
13	CW1	Bit	9	CW2	Bit	9
14	CW1	Bit	10	CW2	Bit	10
15	UC	Bit	5	UC	Bit	41
16	CW1	Bit	11	CW2	Bit	11
17	CW1	Bit	12	CW2	Bit	12
18	UC	Bit	8	UC	Bit	43
19	CW1	Bit	13	CW2	Bit	13
20	CW1	Bit	14	CW2	Bit	14
21	UC	Bit	12	UC	Bit	44
22	CW1	Bit	15	CW2	Bit	15
23	CW1	Bit	16	CW2	Bit	16
24	UC	Bit	16	UC	Bit	45
25	CW1	Bit	17	CW2	Bit	17
26	CW1	Bit	18	CW2	Bit	18
27	UC	Bit	20	UC	Bit	46
28	CW1	Bit	19	CW2	Bit	19
29	CW1	Bit	20	CW2	Bit	20
30	UC	Bit	29	UC	Bit	48
31	CW1	Bit	21	CW2	Bit	21
32	CW1	Bit	22	CW2	Bit	22
33	UC	Bit	30	UC	Bit	49
34	CW1	Bit	23	CW2	Bit	23
35	CW1	Bit	24	CW2	Bit	24
36	UC	Bit	33	UC	Bit	50
37	UC	Bit	34	UC	Bit	51
38	UC	Bit	35	UC	Bit	52
39	UC	Bit	36	UC	Bit	53

UC = uncoded bit
CW1 = Golay Code word #1
CW2 = Golay Code word #2

TABLE 3 - PERMUTATION OF DIGITAL VOICE DATA

Dibit	Tone Assignments for First 3 Frames		
	1	2	3
1	1	35	30
2	2	36	31
3	3	37	32
4	4	38	33
5	5	39	34
6	6	1	35
7	7	2	36
8	8	3	37
9	9	4	38
10	10	5	39
11	11	6	1
12	12	7	2
13	13	8	3
14	14	9	4
15	15	10	5
16	16	11	6
17	17	12	7
18	18	13	8
19	19	14	9
20	20	15	10
21	21	16	11
22	22	17	12
23	23	18	13
24	24	19	14
25	25	20	15
26	26	21	16
27	27	22	17
28	28	23	18
29	29	24	19
30	30	25	20
31	31	26	21
32	32	27	22
33	33	28	23
34	34	29	24
35	35	30	25
36	36	31	26
37	37	32	27
38	38	33	28
39	39	34	29

TYPICAL PERFORMANCE DATA ON THE HF MODEM FOR NARROW BAND DIGITAL VOICE TRANSMISSION

(for information only)

CONTENTS

Synopsis of signal design

This modem is tailored to the application of transmitting 2400 bps LPC digital voice in half-duplex net operation over beyond-line-of-sight HF circuits. In that mode the signal design consists of three basic parts. They are, as shown in Figure 1, the modem preamble, the message indicator (MI), and the digital voice message.

The modem preamble is further subdivided into three parts consisting of the doppler detection signal, the frame synchronization signal, and a framing epoch to denote the beginning of the MI. This is depicted in Figure 2. The doppler detection signal consists of four unmodulated tones. They are followed by a framing signal composed of three biphase modulated tones. The epoch is obtained from a 240-bit PN sequence transmitted at 1200 bps using biphase DPSK modulation on 16 parallel tones.

The MI signal is the output of a (252,128) BCH encoder, which is transmitted with eighth order diversity at 2400 bps using four-phase DPSK modulation on 16 parallel tones. The MI information contains an unencrypted four-bit mode control word.

The 2400 bps LPC data are transmitted at 3466.66 bps using four-phase DPSK modulation on 39 parallel tones. The increased transmission rate provides for the application of a one-half rate Golay error correction code (24,12) on the most sensitive data bits, as shown in Figures 3 and 4. Figure 5 is a tabulation of the principle characteristics of the modem in the digital data and preamble modes. Figure 6 lists the modem characteristics in the digital voice mode.

Preamble acquisition

DPSK demodulation is sensitive to frequency errors due to translation offsets and/or doppler shifts. To accommodate large errors, the doppler detection/correction is performed in two steps, corresponding to measuring the frequency error in two bandwidths. Examples of the performance obtained are shown in Figures 7, 8 and 9 where the values on the ordinate are the absolute value of the error in the estimate of the frequency offset. The abscissia is the signal-to-noise density ratio. For the conditions shown in Figure 7, the estimate was made in one narrowband step, because the initial frequency offset was zero. Figure 8 shows the results when both a wideband and a narrowband estimate are made. Figure 9 demonstrates a condition where the initial frequency offset was extreme. For that condition, two wideband estimates were made. There was insufficient time to follow these with a normal narrowband estimate. The results of these and similar tests indicate that the two-step doppler detection algorithm will estimate the frequency with an accuracy of one Hz or less for signal-to-noise density ratios greater than 38 dB for frequency offsets up to 112.5 Hz.

Synchronization is accomplished in two steps by first detecting frame transitions and then correlating on the 240-bit PN sequence. Figure 10 shows the correlation achieved as a function of the signal-to-noise density ratio. A PN detection threshold corresponding to a correlation of +96 represents approximately a 30% bit error rate condition. Correlation is defined as the number of agreements minus the number of disagreements.

Message indicator detection

Figure 11 shows the gain in signal plus noise to noise ratio obtained by diversity combining the received MI symbols. The maximum gain with eighth order diversity is 9.03 dB, which is reached at a P/N_T of approximately 42 dB. The gain is reduced to 5.5 dB at a P/N_T of 31 dB, which is the threshold of operation for the BCH decoder, as shown in Figure 12. N_T is the noise density of the total noise, which is the sum of the additive Gaussian noise and the interference created by peak clipping the modulator output. Figure 13 shows the relationship between signal-to-noise density ratios and energy-per-bit. The 16-tone DPSK signal used for transmitting the PN sequence and the MI are normally peak clipped by 8 dB in the modulator, in order to increase the power/tone and produce an output signal with a peak-to-rms ratio approximately equal to the 4-tone and 3-tone preambles. 9.5 dB of peak clipping was used on the 39 tone digital voice signal for the same purpose.

Figure 14 is a plot of the probability of detecting the epoch and MI as a function of the signal-to-noise ratio. Detection of the MI is conditioned on detecting the PN sequence. The epoch detection algorithm is the most robust portion of the modem signal design. There is a 99% probability of detecting a valid PN sequence for a P/N_0 of 33.1 dB. The message indicator requires a P/N_0 of approximately 34.4 dB for a 99% probability of correct detection.

Digital voice performance

In the ditigal voice mode, each frame of 39 tones contains 24 tones with sensitive information coded with the (24,12) error correction code and 15 tones containing less sensitive uncoded information. Each frame period the assignment of tones containing the coded information is permuted to lessen the effects of narrowband interference and poor frequency response of the transmission filters. Figure 15 shows the resulting bit error rate for both the coded and uncoded data as a function of P/N_T. The threshold of operation for digital voice in a Gaussian noise environment is at a P/N_T of approximately 38 to 39 dB.

MODEM PREAMBLE	MI + MODE	DIGITAL VOICE

Fig. 1 - Sequence of transmissions

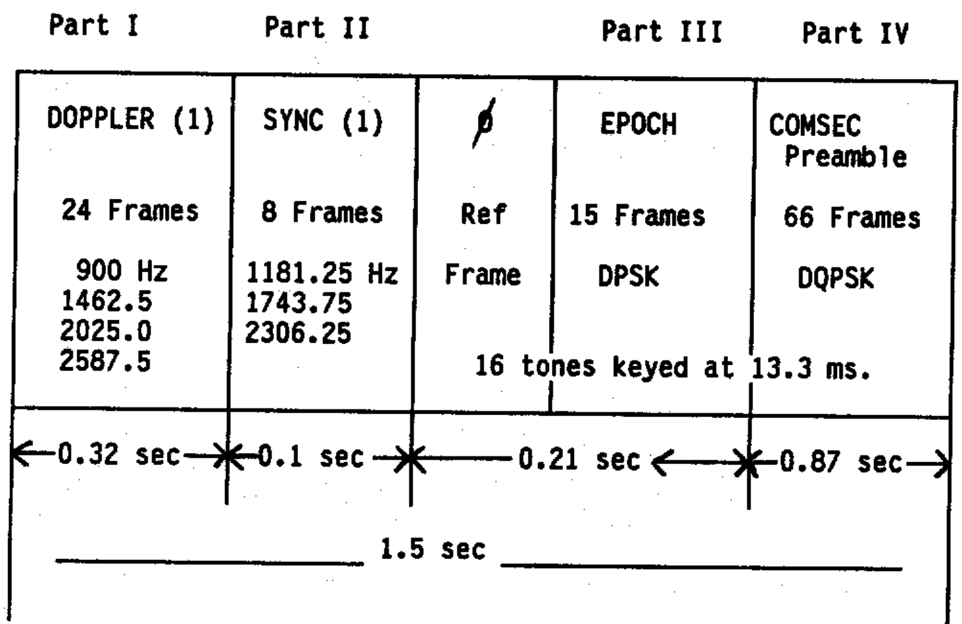

Fig. 2 - Preamble design

(1) The doppler and synch. tones shown here are not the correct tones and were picked to simplify the testing. Annex A Page A-6 shows the correct tones.

PCM	1 (MSB)	2	3	4	5	6	7
PITCH	G	G	G	G	G	G	
RMS	G	G	G	G			
R1	G	G	G	G			
R2	G	G	G	G			
R3	G	G	G				
R4	G	G					
R5							
R6							
R7							
R8							
R9							
R10							
SYNC	G						

G = PROTECTED WITH GOLAY CODE

Fig. 3 — Coding in modem on LPC-10 data (voiced frames)

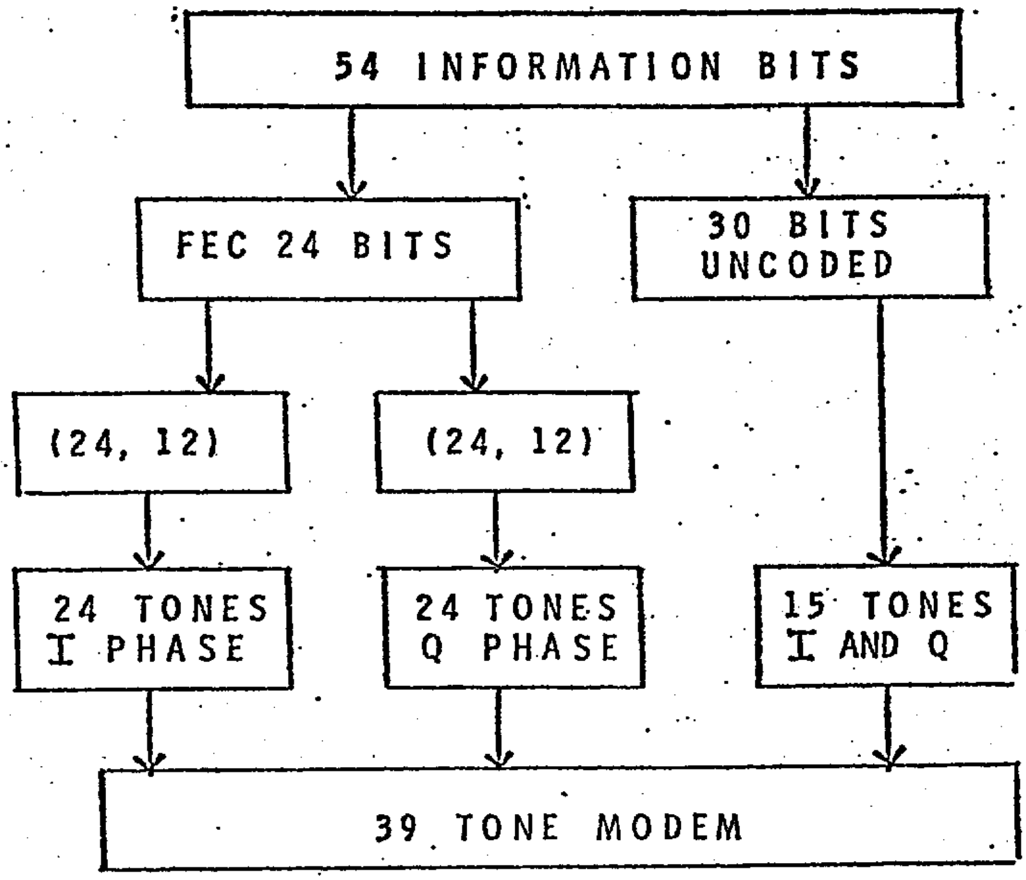

Fig. 4 — Modulation format for digital voice

- 16 TONES
- 4-PHASE DPSK
- 75 FRAMES/SEC (13.33 MSEC)
- INF. RATE - 300 TO 2400 BPS
- TX. RATE - 2400 BPS
- ΔF - 112.5 HZ
- BANDWIDTH - 1800 HZ
- DOPPLER TRACKING FROM DATA TONES
- SLOT SYNC TRACKING
- TIME GUARD - 4.4 MSEC
- SAMPLING RATE - 7200 HZ
- FFT - 64

Fig. 5 - HF modem characteristics, data and preamble modes

- 39 TONES
- 4-PHASE DPSK
- 44.44 FRAMES/SEC (22.5 MSEC)
- INF. RATE - 2400 bps
- TX. RATE - 3466.66 bps
- ΔF - 56.25 HZ
- BANDWIDTH - 2193.75 HZ
- DOPPLER TRACKING FROM DATA TONES
- SLOT SYNC TRACKING
- TIME GUARD - 4.7 MSEC
- SAMPLING RATE - 7200 HZ
- FFT SIZE - 128

Fig. 6 — HF modem characteristics, voice mode

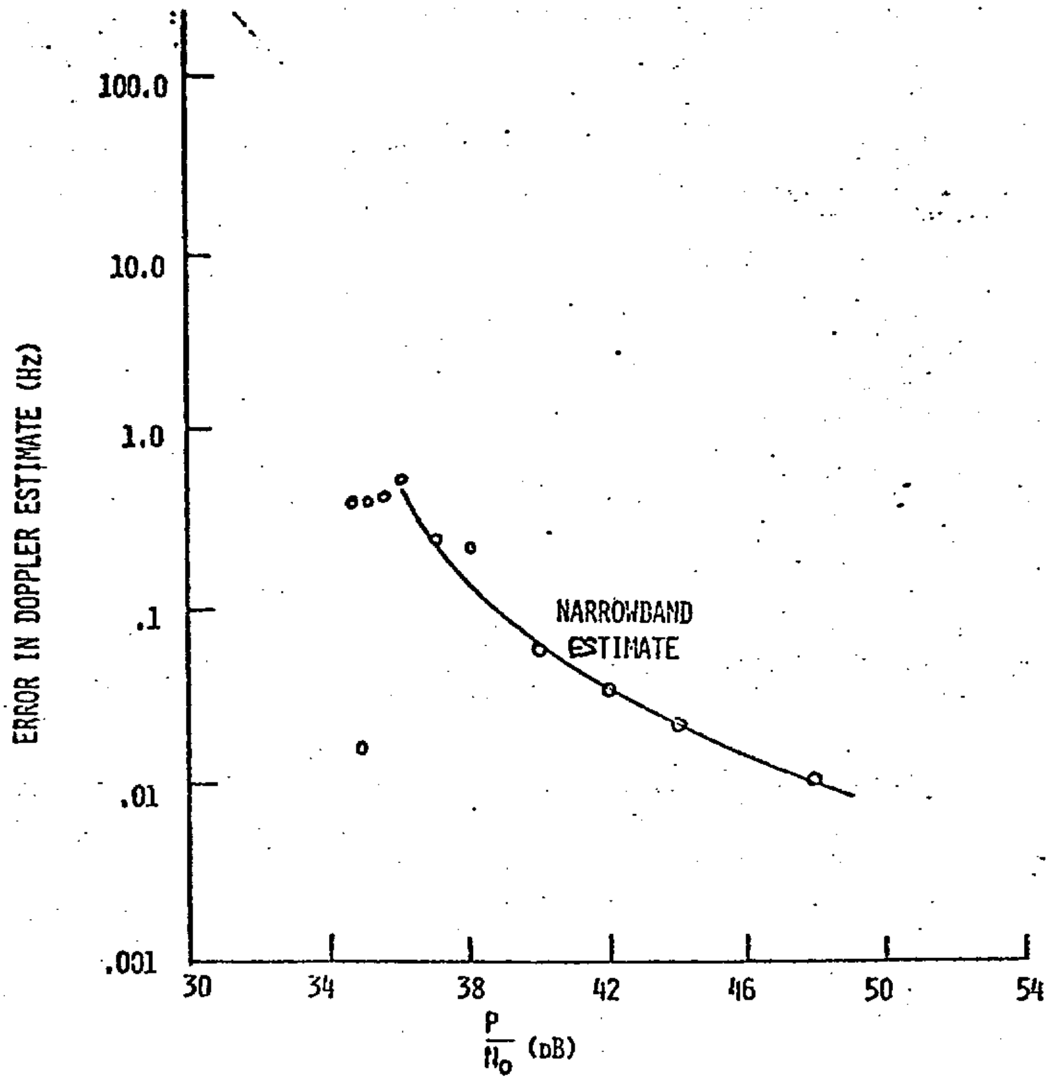

Fig. 7 — Doppler performance for frequency error of 0 Hz

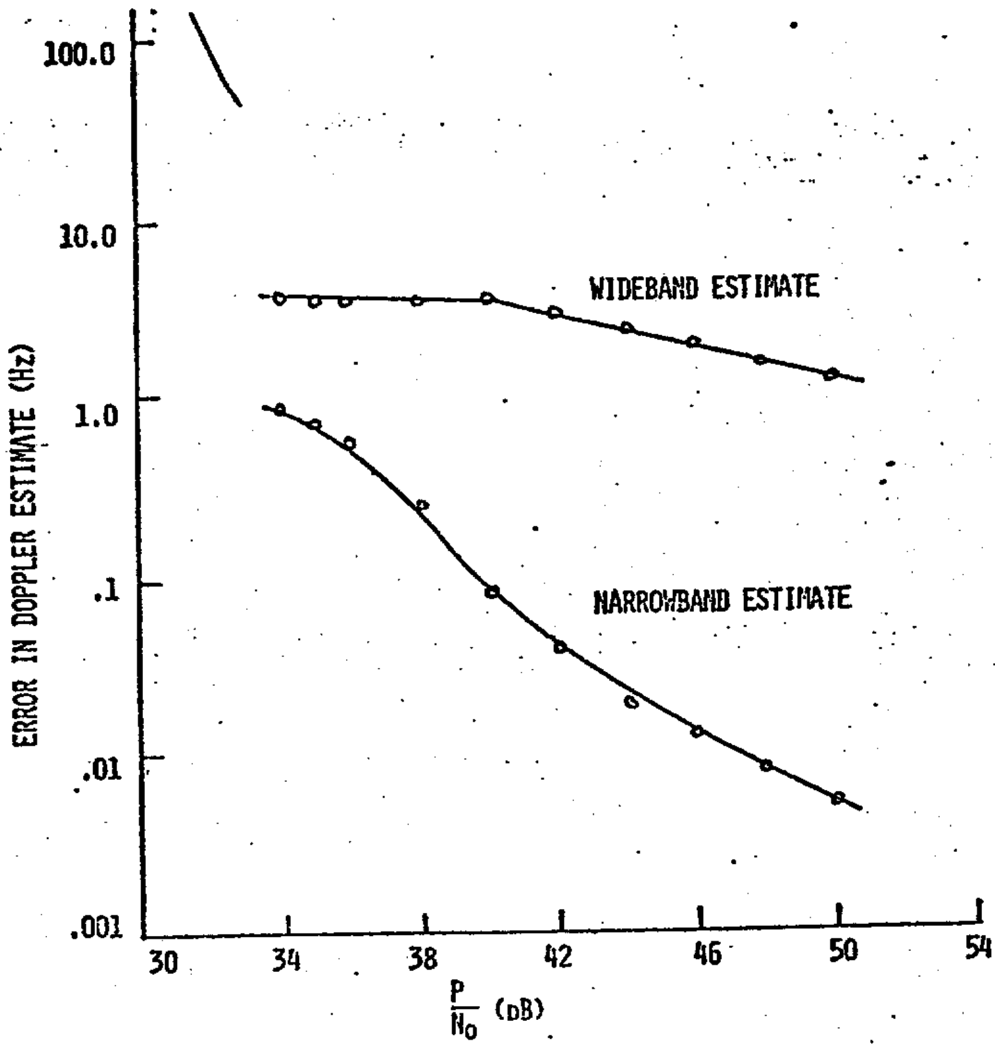

Fig. 8 — Doppler performance for frequency error of 62.5 Hz

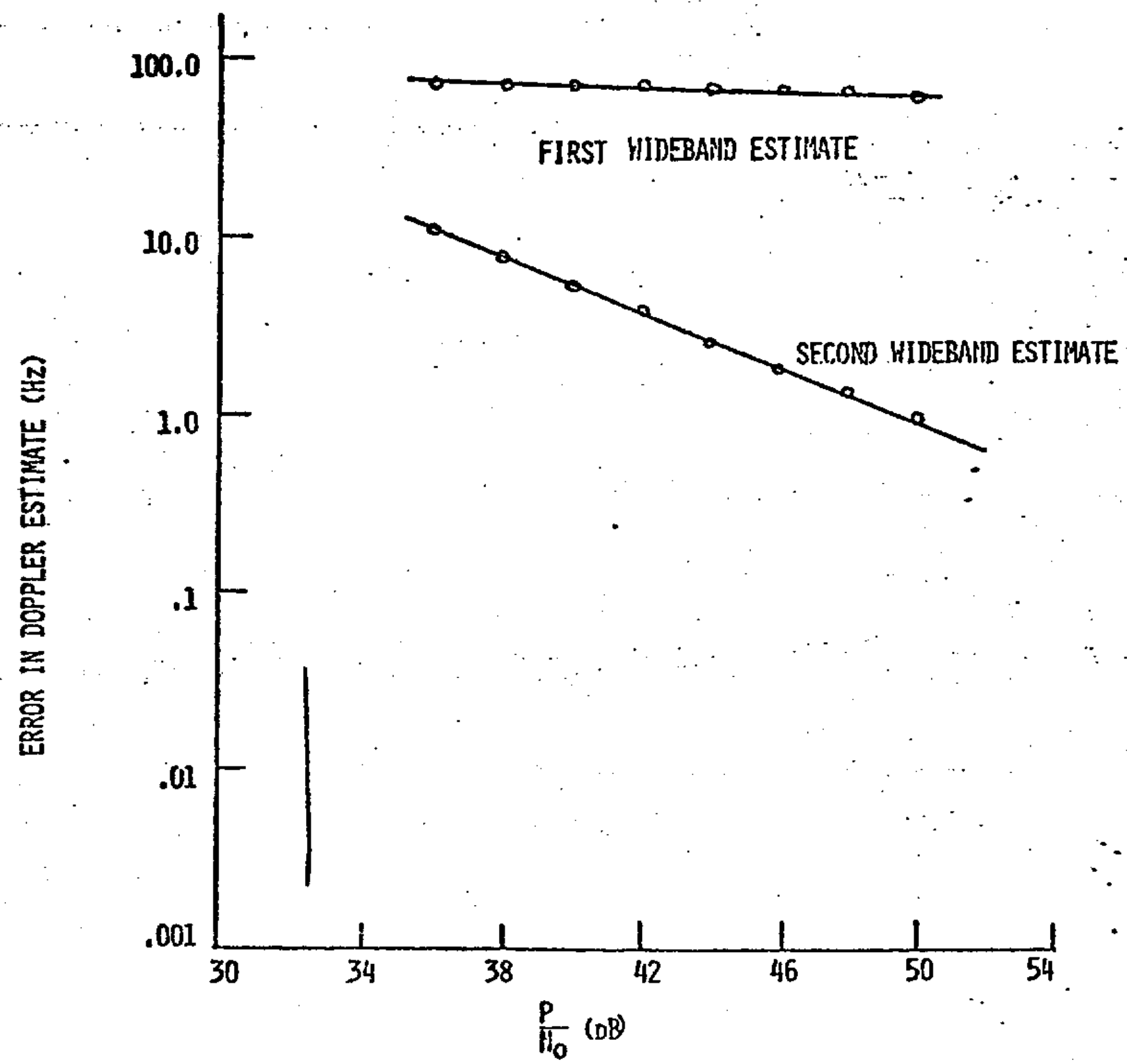

Fig. 9. — Doppler performance for frequency error of 150 Hz

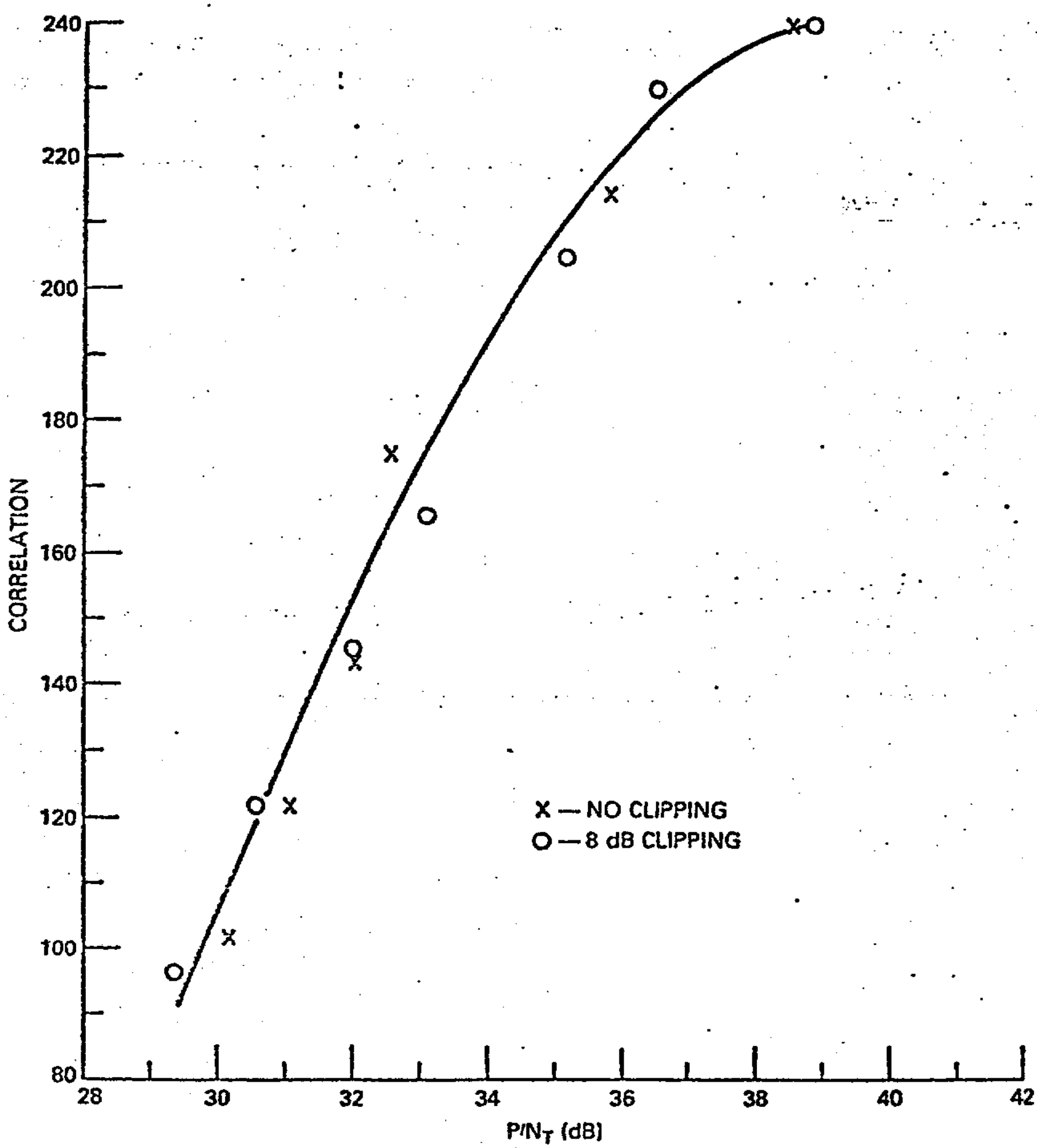

Fig.10— Correlation on PN sequence versus P/N_T

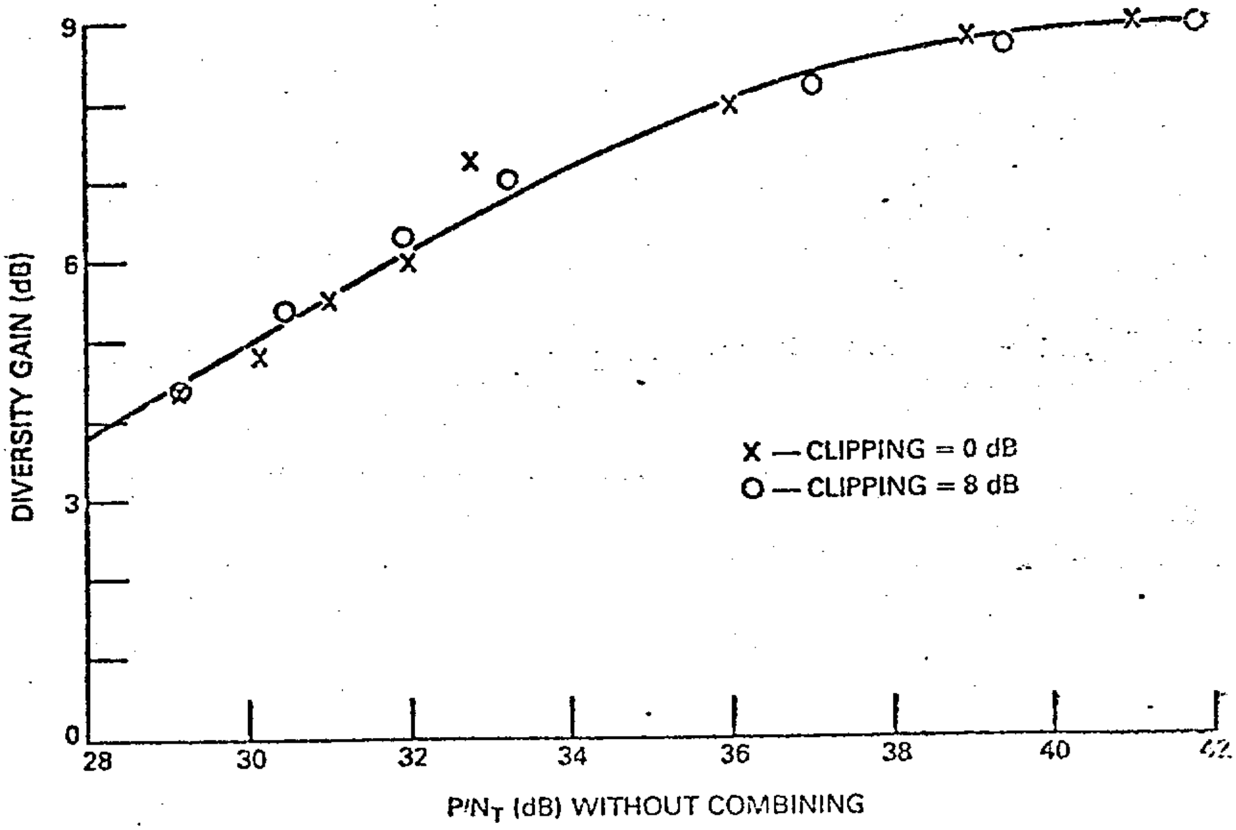

Fig. 11 — Diversity gain on message indicator versus P/N_T without combining, for constant clipping level

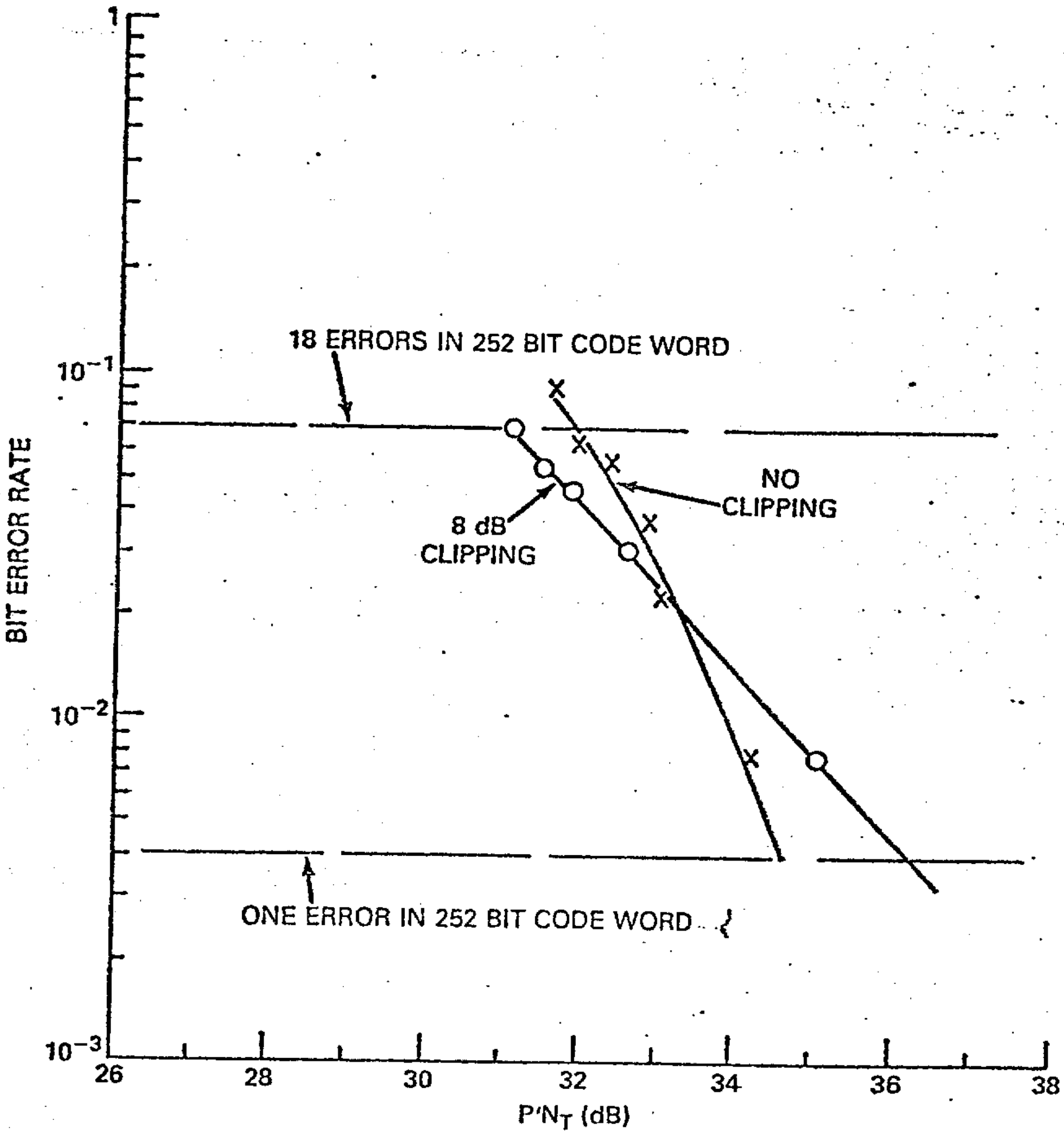

Fig. 12 — Bit error rate on message indicator before decoding versus P/N_T, for constant clipping level

uncoded data, voice mode

$$\frac{P}{N_o} = \frac{E_b}{N_o} + 10 \log (\text{inf. rate}) + 10 \log\left(\frac{\text{tone spacing}}{\text{frame rate}}\right) + 10 \log\left(\frac{\text{total no. of tones transmitted}}{\text{no. of uncoded tones}}\right)$$

$$= \frac{E_b}{N_o} + 10 \log (1333.33) + 10 \log \left(\frac{56.25}{44.44}\right) + 10 \log \left(\frac{39}{15}\right)$$

$$= \frac{E_b}{N_o} + 31.25 + 1.023 + 4.15$$

$$= \frac{E_b}{N_o} + 36.423 \text{ dB}$$

coded data, voice mode

$$\frac{P}{N_o} = \frac{E_b}{N_o} + 10 \log (1066.66) + 10 \log\left(\frac{56.25}{44.44}\right) + 10 \log\left(\frac{39}{24}\right)$$

$$= \frac{E_b}{N_o} + 30.28 + 1.023 + 2.11$$

$$= \frac{E_b}{N_o} + 33.413 \text{ dB}$$

Figure 13 - Relationship between signal-to-noise density ratio (P/N_o) and energy-per-bit (E_b/N_o)

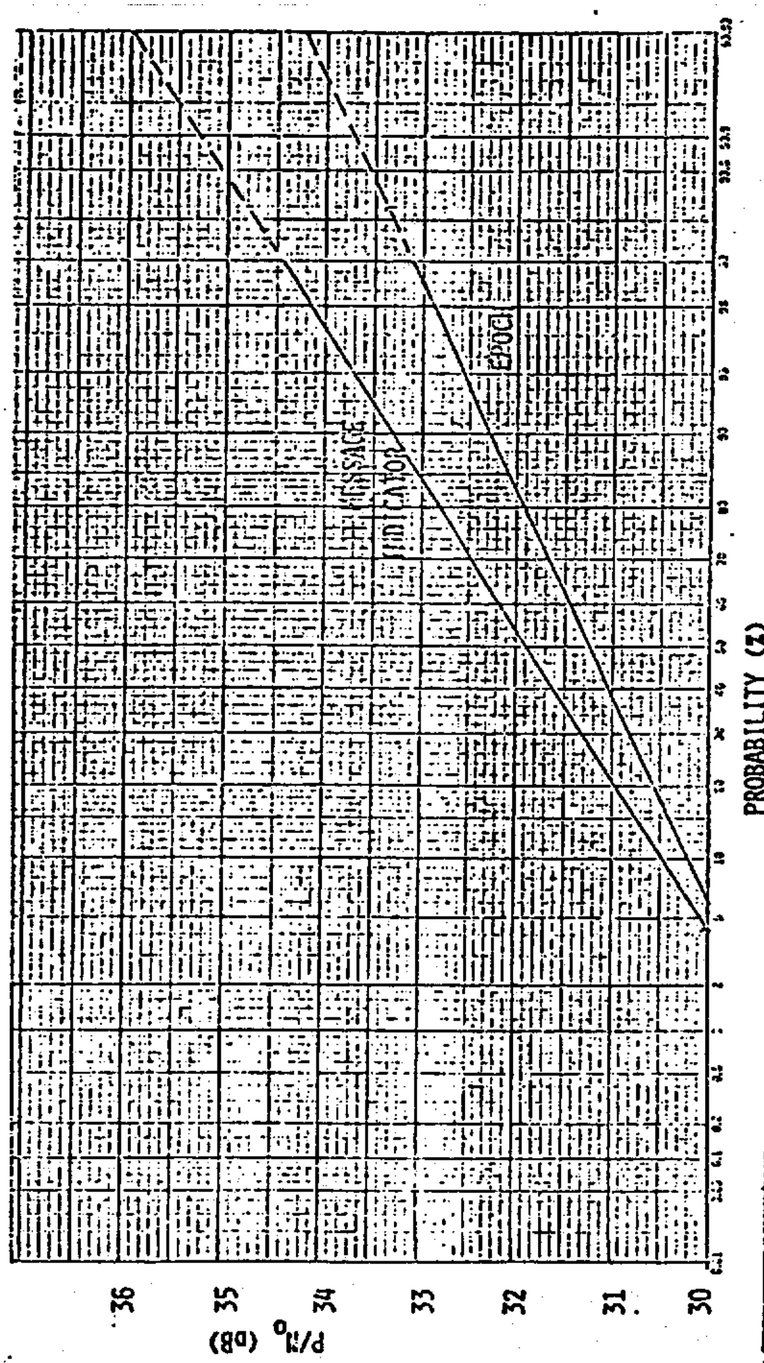

Fig.14 — Probability of detecting a valid preamble

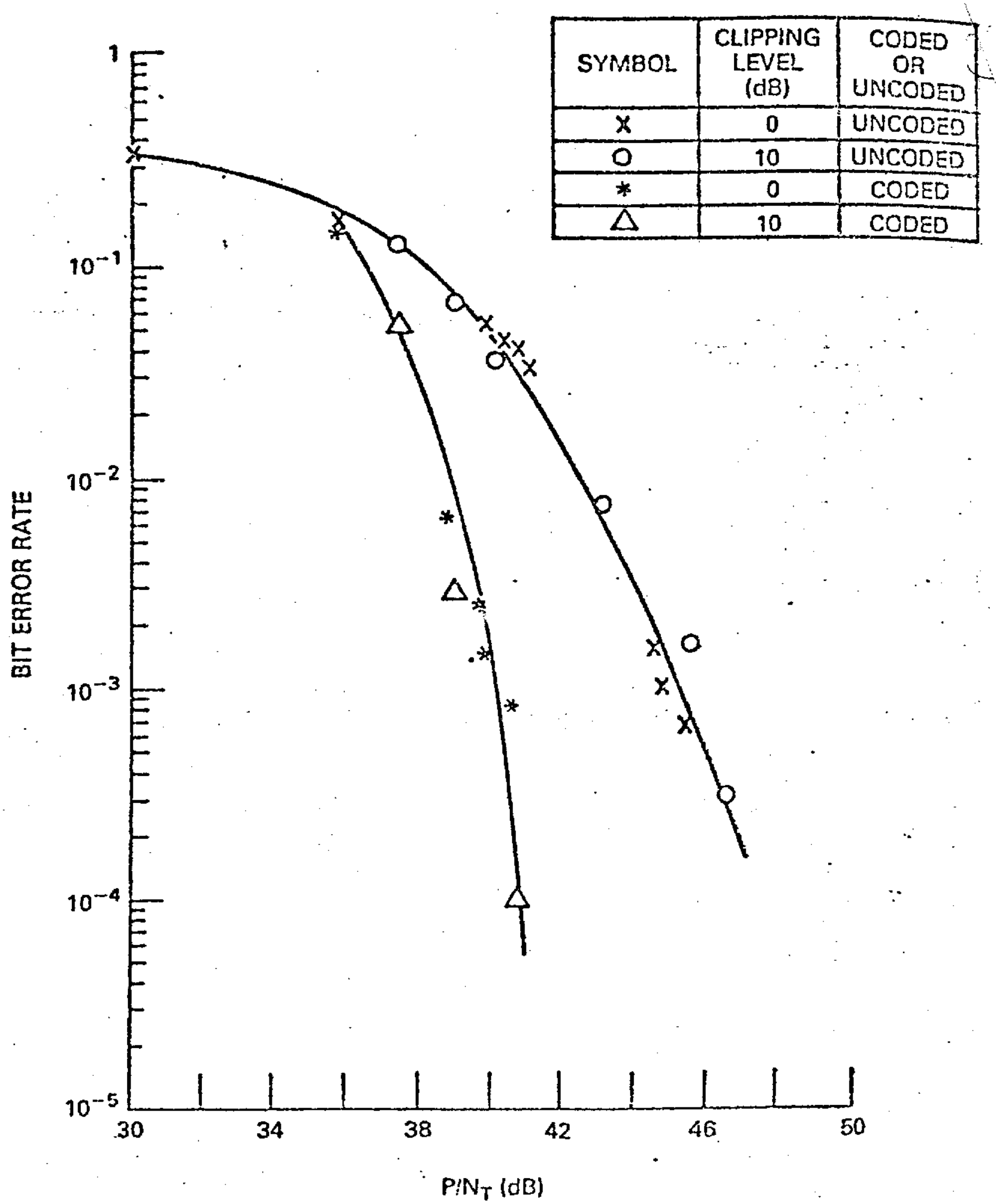

Fig. 15— Bit error rate on coded and uncoded voice versus P/N_T