## **APPENDIX C**

# PCM STANDARDS (ADDITIONAL INFORMATION AND RECOMMENDATIONS)

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## PCM STANDARDS (ADDITIONAL INFORMATION AND RECOMMENDATIONS)

### 1.0 Bit Rate Versus Receiver Intermediate-Frequency Bandwidth

The following subparagraphs contain information about selection of receiver intermediate-frequency (IF) bandwidths. Additional information is contained in RCC document 119, *Telemetry Applications Handbook*.

1.1 The standard receiver IF bandwidth values are listed in Table <u>2-1</u>. Not all bandwidths are available on all receivers or at all test ranges. Additional bandwidths may be available at some test ranges. The IF bandwidth, for data receivers, should typically be selected so that 90 to 99 percent of the transmitted power spectrum is within the receiver 3-dB bandwidth.

1.2 For reference purposes, in a well-designed PCM/FM system (NRZ-L data code) with peak deviation equal to 0.35 times the bit rate and an IF bandwidth (3 dB) equal to the bit rate, a receiver IF signal-to-noise ratio (SNR) of approximately 13 dB will result in a bit error probability (BEP) of  $10^{-6}$ . A 1-dB change in this SNR will result in approximately an order of magnitude change in the BEP. The relationship between BEP and IF SNR in a bandwidth equal to the bit rate is illustrated in Figure <u>C-1</u> for IF bandwidths equal to the bit rate and 1.5 times the bit rate. An approximate expression for the BEP is

$$BEP = 0.5 e^{(k \cdot SNR)}$$
(C-1)

where:

 $k \approx -0.7$  for IF bandwidth equal to bit rate  $k \approx -0.65$  for IF bandwidth equal to 1.2 times bit rate  $k \approx -0.55$  for IF bandwidth equal to 1.5 times bit rate

SNR = IF SNR•IF bandwidth/bit rate.

Other data codes and modulation techniques have different BEP versus SNR performance characteristics.

1.3 It is recommended that the maximum period between bit transitions be 64-bit intervals to ensure adequate bit synchronization. Table <u>C-1</u> contains recommended frame synchronization pattern

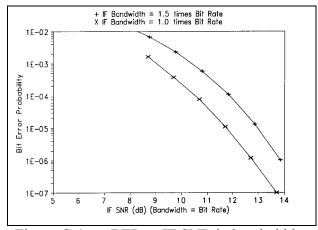


Figure C-1. BEP vs IF SNR in bandwidth = bit rate for NRZ-L PCM/FM.

recommended frame synchronization patterns for general use in PCM telemetry.

#### 2.0 Recommended PCM Synchronization Patterns

Table <u>C-1</u> contains recommended frame synchronization patterns for general use in PCM telemetry. Patterns are shown in the preferred order of transmission with "111" being the first bit sequence transmitted. This order is independent of data being LSB or MSB aligned. The technique used in the determination of the patterns for lengths 16 through 30 was essentially that of the patterns of  $2^n$  binary patterns off a given length, n, for that pattern with the smallest total probability of false synchronization over the entire pattern overlap portion of the ground station frame synchronization.<sup>1</sup> The patterns for lengths 31 through 33 were obtained from a second source.<sup>2</sup>

#### **3.0** Spectral and BEP Comparisons for NRZ and Bio<sup>3</sup>

Figure <u>C-2</u> shows the power spectral densities of baseband NRZ and Bi $\phi$  codes with random data. These curves were calculated using the equations presented below. Figure <u>C-3</u> presents the theoretical bit error probabilities versus signal-to-noise ratio for the level, mark, and space versions of baseband NRZ and Bi $\phi$  codes and also for RNRZ-L. The noise is assumed to be additive white gaussian noise.

NRZ SPECTRAL DENSITY 
$$\alpha \frac{\sin^2(\pi fT)}{(\pi fT)^2}$$
 (C-2)

Bi 
$$\phi$$
 SPECTRAL DENSITY  $\alpha = \frac{\sin^4(\pi fT/2)}{(\pi fT/2)^2}$  (C-3)

where *T* is the bit period.

<sup>&</sup>lt;sup>1</sup> A more detailed account of this investigation can be found in a paper by J. L. Maury, Jr. and J. Styles, "Development of Optimum Frame Synchronization Codes for Goddard Space Flight Center PCM Telemetry Standards," in *Proceedings of the National Telemetering Conference*, June 1964.

<sup>&</sup>lt;sup>2</sup> The recommended synchronization patterns for lengths 31 through 33 are discussed more fully in a paper by E. R. Hill, "Techniques for Synchronizing Pulse-Code Modulated Telemetry," in *Proceedings of the National Telemetering Conference*, May 1963.

<sup>&</sup>lt;sup>3</sup> Material presented in paragraph 3.0 is taken from a study by W. C. Lindsey (University of Southern California), *Bit Synchronization System Performance Characterization, Modeling and Tradeoff Study*, Naval Missile Center Technical Publication.

	TABLE C-1.	OPTI	MUM FRA	ME SYN	CHRONIZ	ATION P	ATTERN	S FOR PC	CM TELE	METRY	
Pattern <u>Length</u>					<u>P</u>	atterns					
16	111	010	111	001	000	0					
17	111	100	110	101	000	00					
18	111	100	110	101	000	000					
19	111	110	011	001	010	000	0				
20	111	011	011	110	001	000	00				
21	111	011	101	001	011	000	000				
22	111	100	110	110	101	000	000	0			
23	111	101	011	100	110	100	000	00			
24	111	110	101	111	001	100	100	000			
25	111	110	010	110	111	000	100	000	0		
26	111	110	100	110	101	100	110	000	00		
27	111	110	101	101	001	100	110	000	000		
28	111	101	011	110	010	110	011	000	000	0	
29	111	101	011	110	011	001	101	000	000	00	
30	111	110	101	111	001	100	110	100	000	000	
31	111	111	100	110	111	110	101	000	010	000	0
32	111	111	100	110	101	100	101	000	010	000	00
33	111	110	111	010	011	101	001	010	010	011	000

F

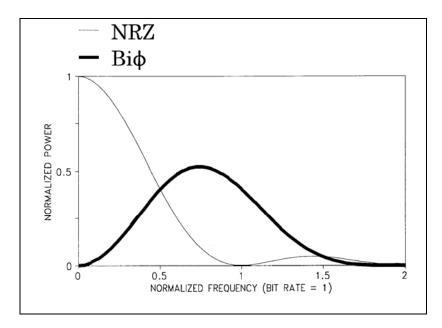


Figure C-2. Spectral densities of random NRZ and Bio codes.

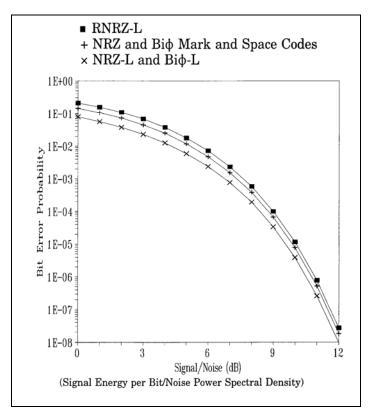


Figure C-3. Theoretical bit error probability performance for various baseband PCM signaling techniques (perfect bit synchronization assumed).

#### 4.0 PCM Frame Structure Examples

Figures C-4, C-5, and C-6 show examples of allowable PCM frame structures. In each example, the Minor Frame Sync Pattern is counted as one word in the minor frame. The first word after the Minor Frame Sync Pattern is word 1.

Figures C-5 and C-6 show the preferred method of placing the subframe ID counter in the minor frame. The counter is placed before the parameters that are referenced to it.

Major Frame Length is as follows:

Figure <u>C-4</u>: Major Frame Length = Minor Frame Maximum Length.
Figure <u>C-5</u>: Major Frame Length = Minor Frame Maximum Length multiplied by Z.
Figure <u>C-6</u>: Major Frame Length = Minor Frame Maximum Length multiplied by Z.

•					all not e	xceed 8	<b>ximum</b> 1 192 bits	0 /		<b>ls or B F</b> words	Bits			
	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Word 10			 Word N-2	Word N-1
Minor Frame Sync Pattern	Param A0	Param A1	Param A2	Param A3	Param A4	Param A2	Param A5	Param A6	Param A2	Param A7			 Param A2	Param A(X)
Pa	arameters arameter ne rate of	A2 is su	percomr	nutated of	on the M	linor Fra	ime.						· · · · ·	

Figure C-4. Major Frame Length = Minor Frame Maximum Length.

•			Minor Class I			<b>um Ler</b> d 8192 bi	<b>-</b>			ts –			
Class II: 16 384 bits													
	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Word 10	•••	Word N-2	Word N-1
											•••		
Minor Frame Sync Pattern	SFID =1	FFI	Param A2	Param B1	Param A4	Param A2	Param A5	Param A6	Param A2	Param C1	•••	Param A2	Param A(X)
5	SFID		1	Param		1	1	1		Param			
	=2			B2						C2			
	SFID			Param						Param			
	=3			B3						C3			
	SFID			Param						Param			
	=4			B4						C4			
	SFID			Param						Param			
	=5			B2						C5			
	SFID			Param						Param			
	=6			B5						C6			
	SFID			Param						Param			
	=7			B6						C7			
	:				•					•			
	•			Param B2	Ĺ					Param C(Z-1)			
Minor Frame	SFID	FFI	Param	Param	Param	Param	Param	Param	Param	Param		Param	Param
Sync Pattern	=Z		A2	BZ	A4	A2	A5	A6	A2	CZ	•••	A2	A(X)

The Frame Format Identifier (Word 2) is shown in the preferred position as the first word following the ID counter. Parameters B1, B3, B4, B5, ... BZ, and C1, C2, C3, ... CZ are sampled once each Subframe, at 1/Z multiplied by the Minor Frame rate. Parameter B2 is supercommutated on the Subframe and is sampled at less than the Minor Frame rate, but greater than the Subframe rate

Figure C-5. Major Frame Length = Minor Frame Maximum Length multiplied by Z.

Class II: 16 384 bits													
	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Word 10	•••	Word N-2	Word N-1
											•••		
Minor Frame Sync Pattern	SFID1 =1	FFI	Param A2	SFID2 =1	Param B1	Param A2	Param A5	Param E1	Param A2	Param C1	•••	Param A2	Param A(X)
	SFID1 =2			SFID2 =2	Param B2			Param E2		Param C2			
	SFID1 =3			SFID2 =3	Param B3			Param E3		Param C3			
	SFID1 =4			SFID2 =4	Param B4			Param E4		Param C4			
	SFID1 =5			SFID2 =5	Param B2			Param E5		Param C5			
	SFID1 =6			• • •	Param B5			•		Param C6			
	SFID1 =7			SFID2 =D	Param B6			Param ED		Param C7			
				•									
	• • •			•	Param B2					Param C(Z-1)			
Minor Frame Sync Pattern	SFID1 =Z	FFI	Param A2	SFID2 =N	Param BZ	Param A2	Param A5	Param EN	Param A2	Param CZ	•••	Param A2	Param A(X)

Figure C-6. Major Frame Length = Minor Frame Maximum Length multiplied by Z..

\*\*\*\* END OF APPENDIX C \*\*\*\*