# APPENDIX C

## PCM STANDARDS (ADDITIONAL INFORMATION AND RECOMMENDATIONS)


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# APPENDIX C

## 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 2-1. 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 C-1 for IF bandwidths equal to the bit rate and 1.5 times the bit rate. An approximate expression for the BEP is

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

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.

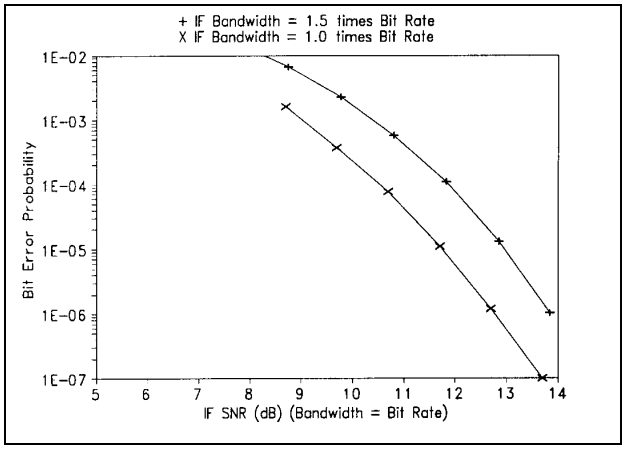


Figure C-1. BEP vs IF SNR in bandwidth = bit rate for NRZ-L PCM/FM.

1.3 It is recommended that the maximum period between bit transitions be 64-bit intervals to ensure adequate bit synchronization. Table C-1 contains recommended frame synchronization patterns for general use in PCM telemetry.

## 2.0 Recommended PCM Synchronization Patterns

Table C-1 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.[1] The patterns for lengths 31 through 33 were obtained from a second source.[2]

## 3.0 Spectral and BEP Comparisons for NRZ and Biϕ[3]

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

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

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

where $T$ is the bit period.

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[1] 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.

[2] 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.

[3] 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. OPTIMUM FRAME SYNCHRONIZATION PATTERNS FOR PCM TELEMETRY**

| Pattern Length | Patterns | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

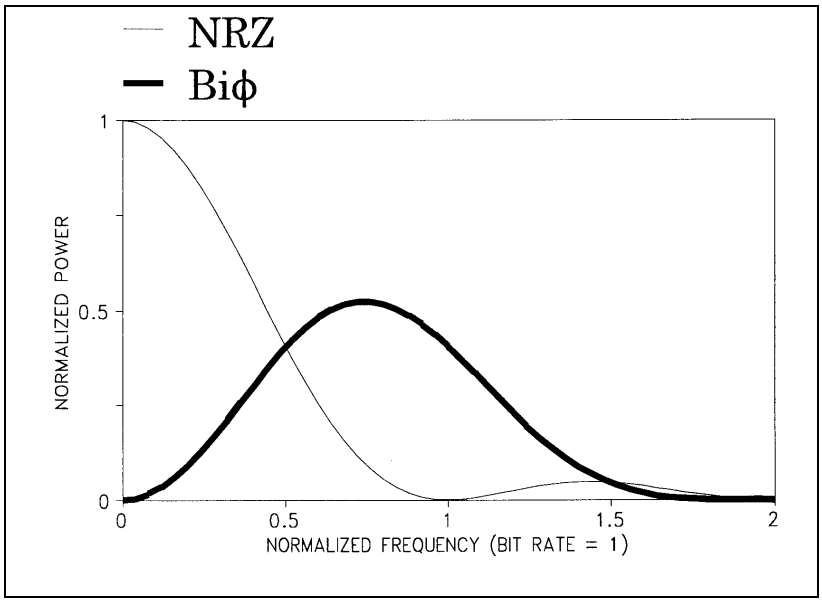



Figure C-2. Spectral densities of random NRZ and Biϕ codes.

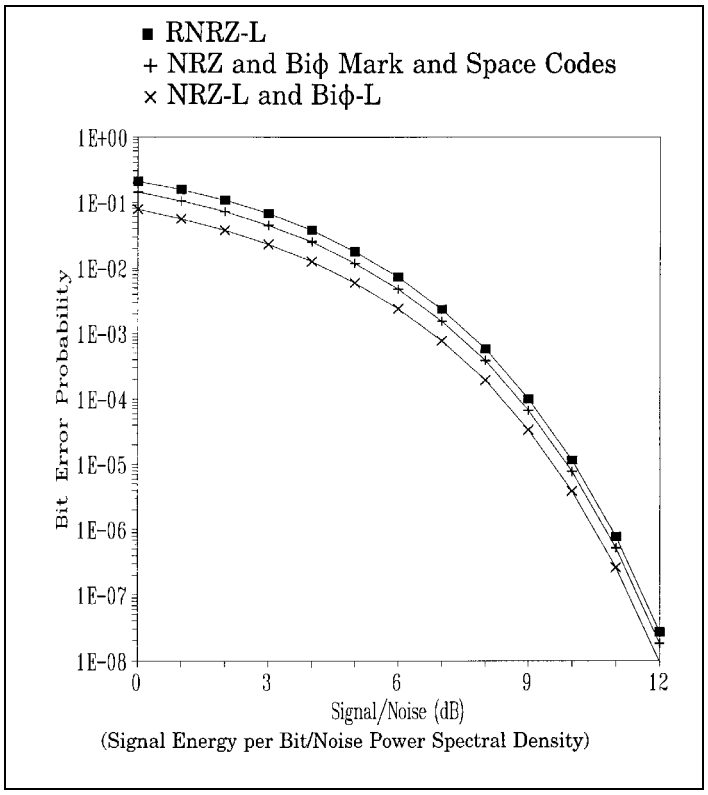



Figure C-3. Theoretical bit error probability performance for various baseband PCM signaling techniques (perfect bit synchronization assumed).

## 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 C-4: Major Frame Length = Minor Frame Maximum Length.
Figure C-5: Major Frame Length = Minor Frame Maximum Length multiplied by Z.
Figure C-6: Major Frame Length = Minor Frame Maximum Length multiplied by Z.

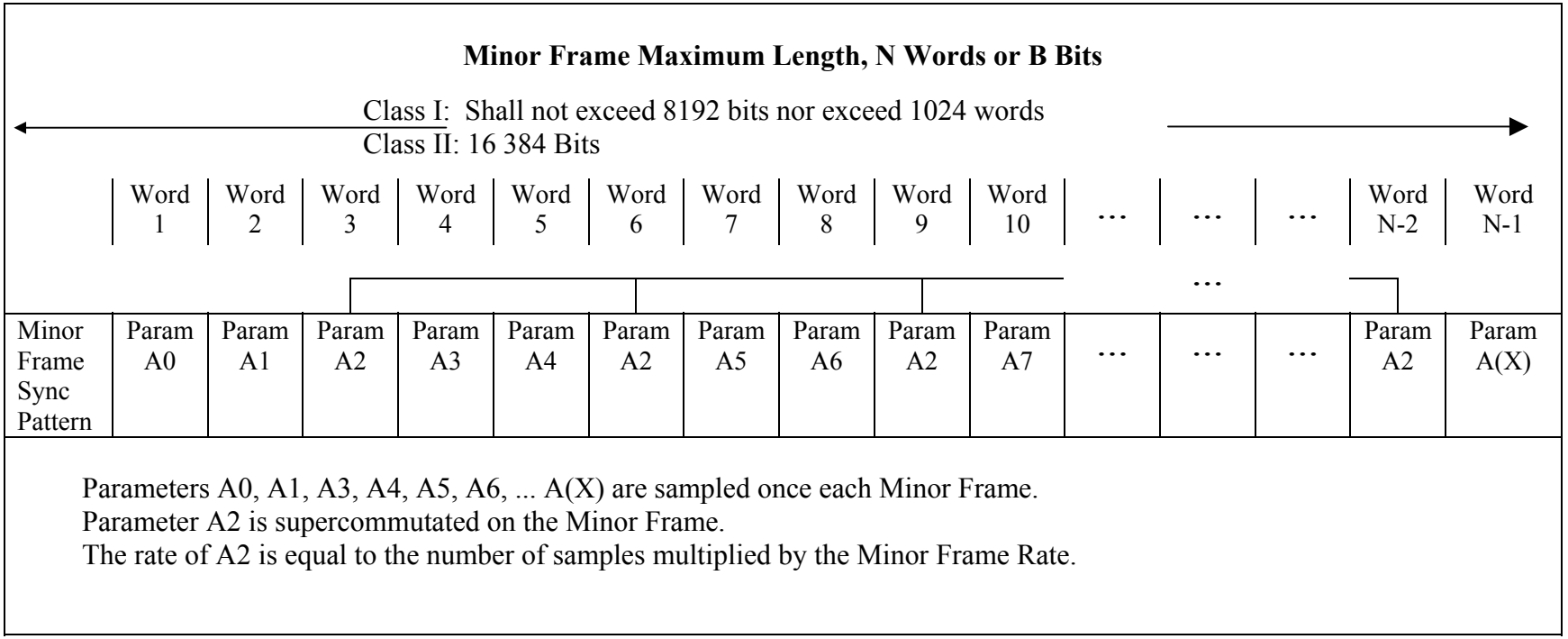
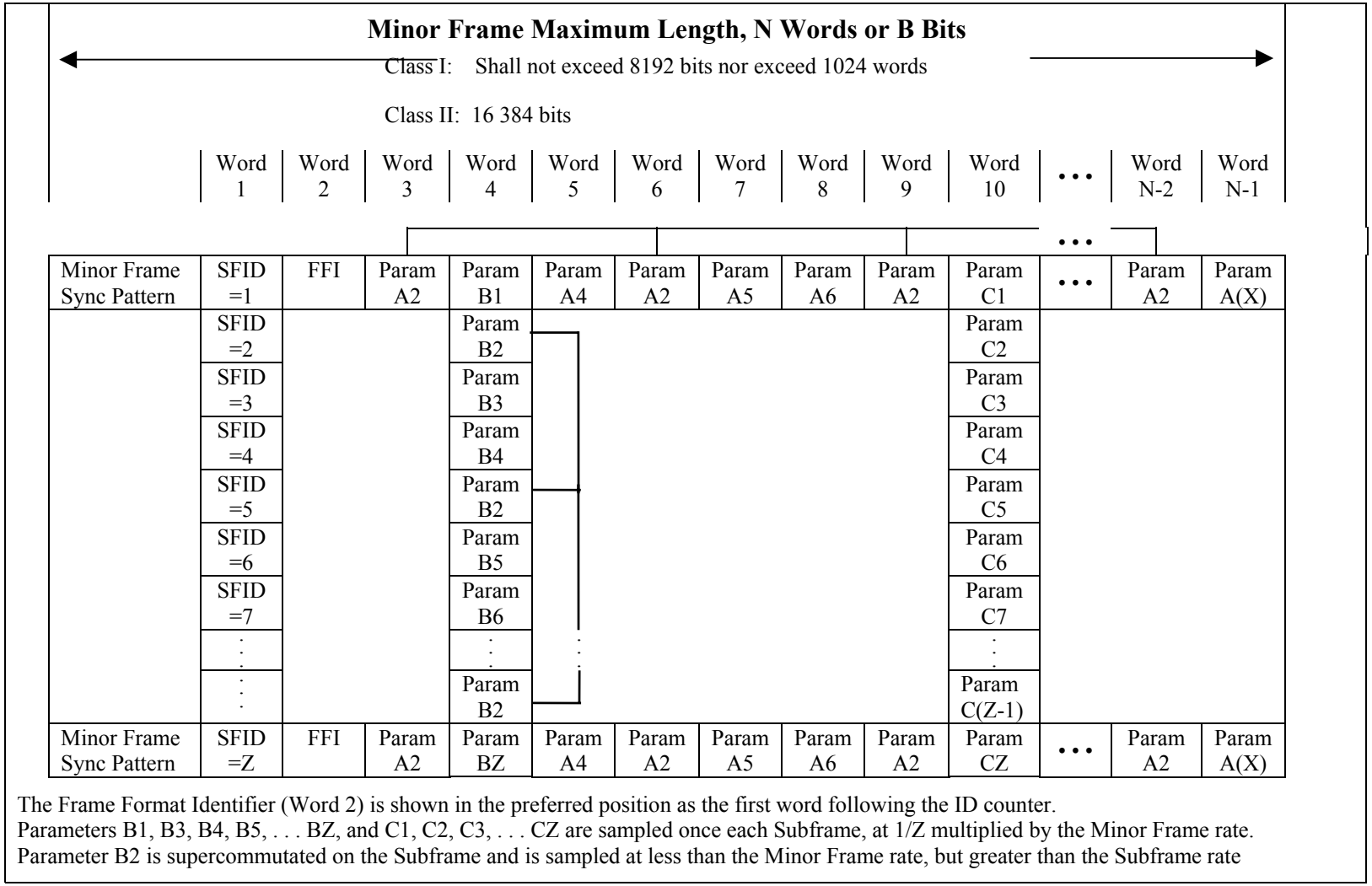
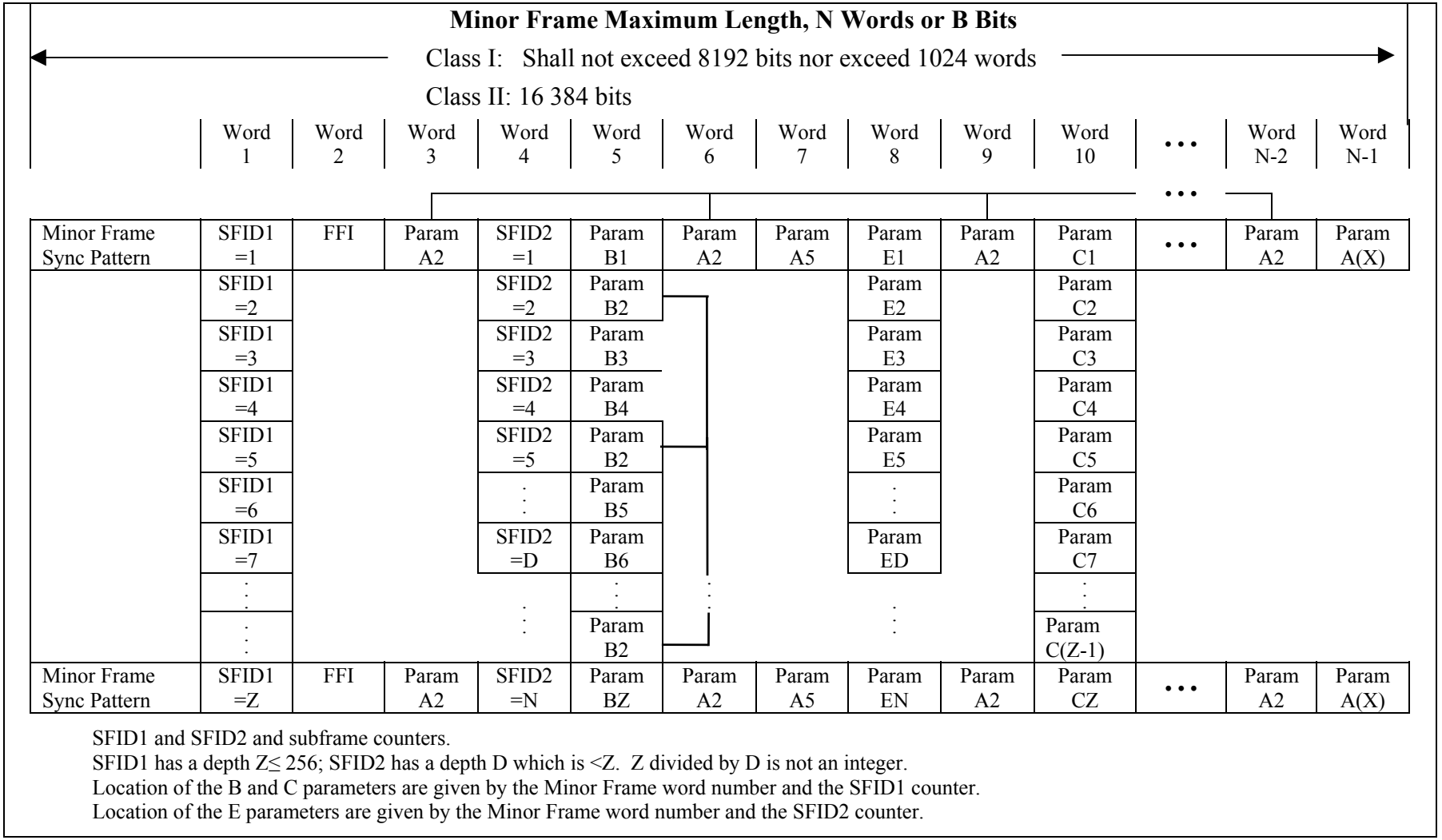



Figure C-4. Major Frame Length = Minor Frame Maximum Length.




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.




SFID1 and SFID2 and subframe counters.
SFID1 has a depth Z≤ 256; SFID2 has a depth D which is <Z. Z divided by D is not an integer.
Location of the B and C parameters are given by the Minor Frame word number and the SFID1 counter.
Location of the E parameters are given by the Minor Frame word number and the SFID2 counter.

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

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