2.1.8B MINIMUM EARTH STATION TRANSMITTER FREQUENCY RESOLUTION FOR SPACECRAFT RECEIVER ACQUISITION, CATEGORY B

The CCSDS,

considering

(a) that Category B spacecraft receivers typically have phase-locked loop bandwidths (2 B_{LO}) in the range of 10 to 100 Hz at their thresholds;

(b) that for spacecraft receivers having a second order phase-locked-loop with the threshold bandwidths shown in (a), the frequency lock-in range is typically 13 to 133 Hz;

(c) that steps in earth station's transmitter frequency which exceed the spacecraft receiver's lock-in range can result in long acquisition times or complete failure of the spacecraft to acquire the signal;

(d) that some margin should be included to ensure proper acquisition of the earth station's signal by the spacecraft receiver's phase-locked loop;

(e) that, with certain Category B missions, it is desirable to continuously tune the earth-to-space link's transmitter frequency to maintain its value, at the spacecraft, at a single, optimal frequency;

(f) that the spacecraft's receiver may fail to acquire or remain locked to the earth station's transmitted signal if abrupt phase discontinuities in that signal occur during the acquisition of that signal;

recommends

(1) that the earth station's transmitter frequency be variable over its specified operating range in increments (step size) of 5 Hz or less;

(2) that the earth station transmitter's RF phase continuity be maintained at all times during tuning operations, using frequency sweep rates that are in accordance with Recommendation 401 (2.1.4B) B-1, which will ensure that the spacecraft's receiver remains locked following acquisition.

2.2.6 SYMMETRY OF BASEBAND DATA MODULATING WAVEFORMS

The CCSDS,

considering

(a) that the earth station's transmitter power should be used as efficiently as possible;

(b) that undesired spectral components in the earth station's transmitted signal should be minimized;

(c) that time-asymmetry in the modulating waveform results in a DC-component;

(d) that such a DC-component in the modulating waveform results in a data power loss because of AC-coupling in the modulator;

(e) that, in addition to the power loss, time-asymmetry results in matched filter losses;

(f) that the above losses should not exceed 0.1 dB;

(g) that the out-of-band emissions resulting from the time-asymmetry in the modulating waveform can be reduced by additional filtering;

recommends

that, the symmetry of all baseband square wave modulating waveforms should be such that the symbol asymmetry[3,4] shall not exceed 1%.

NOTE:

1. This Recommendation is also filed as Rec. 401 (2.4.8) B-1 for the space-to-earth link.

2. Where Bi-Phase modulation is utilized, larger baseband signal losses, than are permitted by *considering (f)*, may result.

3. Definition of: $\textit{Symbol Asymmetry} = \frac{|\,\textit{long symbol} - \textit{short symbol}\,|}{\textit{long symbol} + \textit{short symbol}}$;

4. Symbol asymmetry shall be measured at 50% of the peak-to-peak amplitude point.

2.3.3A EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RANGE, CATEGORY A

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that for the coherent turnaround mode, the Doppler frequency shift induced on both the earth-to-space and the space-to-earth links is the major factor to be considered in selecting the frequency sweep range;

(c) that for the one-way mode, both the Doppler frequency shift induced on the space-to-earth link and the frequency stability of the spacecraft's oscillator are the major factors to be considered in selecting the frequency sweep range;

(d) that the maximum rate of change of distance between the earth station and Category A spacecraft can reach values of up to 10 km/s;

(e) that the minimum frequency stability found in Category A spacecraft reference frequency oscillators is about 2×10^{-5};

recommends

(1) that CCSDS agencies' earth station receivers be capable of frequency sweep ranges of at least:

± 150 kHz at 2 GHz
± 600 kHz at 8 GHz

(2) that CCSDS agencies provide a minimum sweep range that is consistent with their ability to predict the Doppler frequency shift.

2.4.6 TELEMETRY SUBCARRIER [1] FREQUENCY STABILITY IN RESIDUAL CARRIER TELEMETRY SYSTEMS

The CCSDS,

considering

(a) that the present use of subcarriers [1] for modulating the space-to-earth RF links as in CCSDS Recommendation 2.4.7 represents a mature technique for both Categories A and B missions and, therefore, is a well settled standard;

(b) that modifications of this standard imply costly changes to space agencies' networks;

(c) that the subcarrier[1] frequency-to-symbol rate ratio is an integer value as in CCSDS Recommendations 2.4.14A and 2.4.14B;

recommends

that spacecraft radio frequency subsystems generating telemetry subcarriers [1] be designed with characteristics equal to or better than:

Maximum Subcarrier [1] Frequency Offset	$\pm (1 \times 10^{-4}) f_{sc}$
Minimum Subcarrier [1] Frequency Stability (short term)	$\pm 1 \times 10^{-6}$
Minimum Subcarrier [1] Frequency Stability (long term)	$\pm 1 \times 10^{-5}$

NOTES:

1. For the purpose of this recommendation, subcarrier includes but is not limited to Bi-ϕ waveforms. In this case, the subcarrier-to-symbol rate ratio is one.
2. f_{sc} = frequency of telemetry subcarrier.
3. Short term time intervals are less than or equal, 100 times the subcarrier's waveform period.

2.4.9 MINIMUM MODULATED SYMBOL TRANSITION DENSITY ON THE SPACE-TO-EARTH LINK

The CCSDS,

considering

(a) that symbol clock recovery systems usually extract the clock's frequency from the received symbol transitions;

(b) that a large imbalance between ones and zeros in the data stream could result in a bit-error-rate degradation in the symbol detection process;

(c) that NRZ waveforms are widely used in standard modulation systems;

(d) that NRZ waveforms require sufficient symbol transitions for symbol clock recovery;

(e) that the tracking system loop bandwidth is usually less than, or equal to, one percent of the symbol rate;

(f) that, for Category A, the specified degradation in bit error rate, due to symbol sync error, is usually less than 0.3 dB;

(g) that, for Category B, the specified degradation in bit error rate, due to symbol sync error, is usually less than 0.1 dB;

(h) that symbol transitions are not a sufficient condition to ensure a stable lock condition;

(i) that the use of a pseudo-randomizer will improve the stability of lock conditions;

recommends

(1) that the maximum string of either ones or zeros be limited to 64 bits;

(2) that, for Category A, a minimum of 125 transitions occur in any sequence of 1000 consecutive symbols;

(3) that, for Category B, a minimum of 275 transitions occur in any sequence of 1000 consecutive symbols.

(4) that both Category A and B missions follow the guidance of CCSDS Recommendation *for Telemetry Synchronization and Channel Coding*, CCSDS 131-B-1, September 2003, or later issue with respect to the use of a pseudo-randomizer.

2.4.10 CHANNEL INPUT AND CODING CONVENTIONS FOR QPSK SYSTEMS

The CCSDS, considering

a) that a clear relation between digital information and the resulting RF carrier phase is necessary to reconstruct the digital data stream following reception and demodulation;

b) that the digital data format will conform to the CCSDS Recommendation for *Packet Telemetry*;

c) that some communications systems with high data rate transmission requirements use QPSK modulation;

d) that the phase states representing each of the possible dibit bit pairs values should be judiciously chosen so that a phase error of 90 degrees can cause an error in no more than one bit;

e) that it should be possible to have two logically independent channels;

f) that in the case of a single data stream the odd and even bits should be forwarded to two independent channels;

recommends

a) that the serial input digital data stream to QPSK systems be divided so that odd even bits (i.e. bits 2i where i=0,1,2,..(N/2)-1) are modulated on the I-channel and even odd bits (i.e. bits 2i+1) are modulated on the Q-channel (see also the bit numbering convention in figure 1).

b) that carrier phase states have the following meanings as given in figure 2:

   1) 0 45 degrees represents a "00" (IQ) bit pair;

   2) 90 135 degrees represents a "0110" (IQ) bit pair;

   3) 180 225 degrees represents a "11" (IQ) bit pair;

   4) 270 315 degrees represents a "1001" (IQ) bit pair.

The following convention is used to identify each bit in an *N*-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be ‘Bit 0’, the following bit is defined to be ‘Bit 1’, and so on up to ‘Bit *N*-1’. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., ‘Bit 0’ (see figure 1).

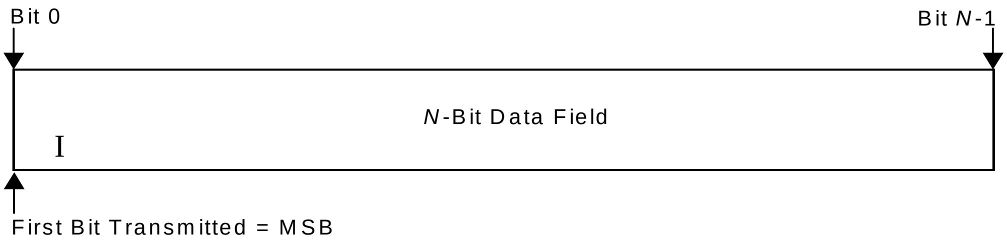


Figure 2-1: Bit Numbering Convention

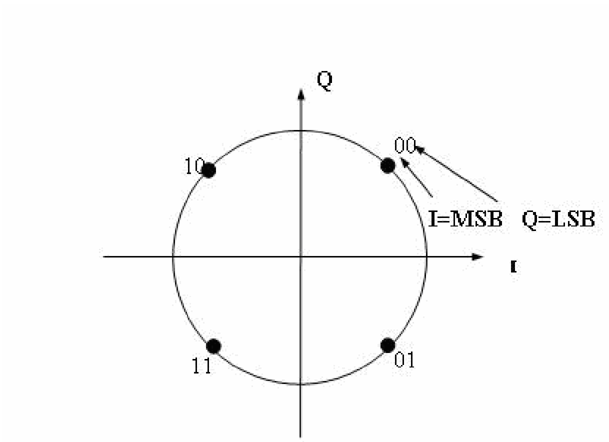


Figure 2-2: Constellation Mapping

2.4.14A ALLOWABLE VALUES FOR TELEMETRY SUBCARRIER FREQUENCY-TO-SYMBOL RATE RATIOS FOR PCM/PSK/PM MODULATION IN THE 2 AND 8 GHz BANDS, CATEGORY A

The CCSDS,

considering

(a) that, for Category A missions, a PCM/PSK/PM modulation scheme with a sinewave subcarrier is typically used for transmission of low data rates;

(b) that integer subcarrier frequency-to-symbol rate ratios (n) result in a data spectral density minimum around the carrier frequency;

(c) that the subcarrier frequency-to-symbol rate ratio (n) should be minimized to avoid unnecessary occupation of the frequency spectrum;

(d) that the lowest practicable value of n can be determined by the amount of acceptable interference from the data spectrum (I) into the carrier tracking loop bandwidth (B_L);

(e) that, for Category A missions, a 0.3 dB degradation in the symbol detection process shall not be exceeded, which requires a 15 dB Carrier-to-Noise ratio (C/N) in the carrier tracking loop, when using CCSDS concatenated coding schemes;

(f) that any additional degradation, due to data interference in the carrier tracking loop, shall be insignificant for which a C/I ratio greater than 20 dB is considered adequate;

(g) that, for small ratios of symbol rate-to-carrier tracking loop bandwidth, the modulation index has to be adjusted accordingly in order to achieve the required loop SNR resulting in a nearly constant C/I versus B_L/R_S;

(h) that, in the presence of only one telemetry signal, a small value of n (n = 4) is generally sufficient to obtain the required performance under typical operating conditions for subcarrier frequencies above 60 kHz;

(i) that for higher symbol rates, the presence of telecommand feed-through and/or ranging signals may require the selection of a slightly higher value of n;

(j) that CCSDS Recommendation 2.4.3 provides guidance regarding the use of subcarriers in low bit rate residual carrier telemetry systems;

recommends

(1) that the subcarrier frequency-to-symbol rate ratio, n, be an integer value;

(2) that a subcarrier frequency-to-symbol rate ratio of 4 be selected for subcarrier frequencies above 60 kHz unless *recommends (3)* applies;

(3) that, in the case of spectral overlaps with other signal components, the minimum integer value of n be selected to permit no more than a 0.3 dB degradation in the

symbol detection process.

2.4.14B ALLOWABLE VALUES FOR TELEMETRY SUBCARRIER FREQUENCY-TO-SYMBOL RATE RATIOS FOR PCM/PSK/PM MODULATION IN THE 2 AND 8 GHz BANDS, CATEGORY B

The CCSDS,

considering

(a) that, for Category B missions, a PCM/PSK/PM modulation scheme with a squarewave subcarrier is typically used for transmission of low data rates;

(b) that integer subcarrier frequency-to-symbol rate ratios (n) result in a data spectral density minimum around the carrier frequency;

(c) that the subcarrier frequency-to-symbol rate ratio (n) should be minimized to avoid unnecessary occupation of the frequency spectrum;

(d) that the lowest practicable value of n can be determined by the amount of acceptable interference from the data spectrum (I) into the carrier tracking loop bandwidth (B_L);

(e) that, for Category B missions, a 0.1 dB degradation in the symbol detection process shall not be exceeded, which requires an 18 dB Carrier-to-Noise ratio (C/N) in the carrier tracking loop, when using CCSDS concatenated coding schemes;

(f) that any additional degradation, due to data interference in the carrier tracking loop, shall be insignificant for which a C/I ratio greater than 25 dB is considered adequate;

(g) that, for small ratios of symbol rate-to-carrier tracking loop bandwidth, the modulation index has to be adjusted accordingly in order to achieve the required loop SNR resulting in a nearly constant C/I versus B_L/R_S;

(h) that, in the presence of only one telemetry signal, a small value of n (n = 5) is generally sufficient to obtain the required performance under typical operating conditions for subcarrier frequencies above 60 kHz;

(i) that for higher symbol rates, the presence of telecommand feed-through and/or ranging signals may require the selection of a slightly higher value of n;

(j) that CCSDS Recommendation 2.4.3 provides guidance regarding the use of subcarriers in low bit rate residual carrier telemetry systems;

recommends

(1) that the subcarrier frequency-to-symbol rate ratio, n, be an integer value;

(2) that a subcarrier frequency-to-symbol rate ratio of 5 be selected for subcarrier frequencies above 60 kHz unless *recommends (3)* applies;

(3) that, in the case of spectral overlaps with other signal components, the minimum integer value of n be selected to permit no more than a 0.1 dB degradation in the symbol detection process.

2.4.15A MINIMUM SYMBOL RATE FOR PCM/PM/Bi-ϕ MODULATION ON A RESIDUAL RF CARRIER, CATEGORY A

The CCSDS,

considering

(a) that data modulated on a residual carrier have spectral components which fall into the carrier tracking loop's bandwidth reducing the Carrier-to-Noise ratio (C/N);

(b) that the level of interference is a function of the carrier tracking loop's bandwidth (B_L), the symbol rate (R_S), and the modulation index (m);

(c) that a 0.3 dB degradation in the symbol detection process should not be exceeded requiring a Carrier-to-Noise (C/N) ratio in the carrier tracking loop of 10 dB (uncoded case) or 15 dB (CCSDS concatenated coded case);

(d) that any additional degradation resulting from data interference in the carrier tracking loop must be insignificant requiring a Carrier-to-Interference (C/I) ratio greater than 15 dB (uncoded case) and 20 dB (CCSDS concatenated coded case);

recommends

(1) that, when no coding is employed, Figure 2.4.15A-1 should be used for determining symbol rates (R_S), relative to loop bandwidth (B_L) where PCM/PM/Bi-ϕ modulation is not permitted;

(2) that, when CCSDS Concatenated coding is employed, Figure 2.4.15A-2 should be used for determining symbol rates (R_S), relative to loop bandwidth (B_L), where PCM/PM/Bi-ϕ modulation is not permitted.

2.4.15A MINIMUM SYMBOL RATE FOR PCM/PM/Bi-ϕ MODULATION ON A RESIDUAL RF CARRIER, CATEGORY A (Continued)

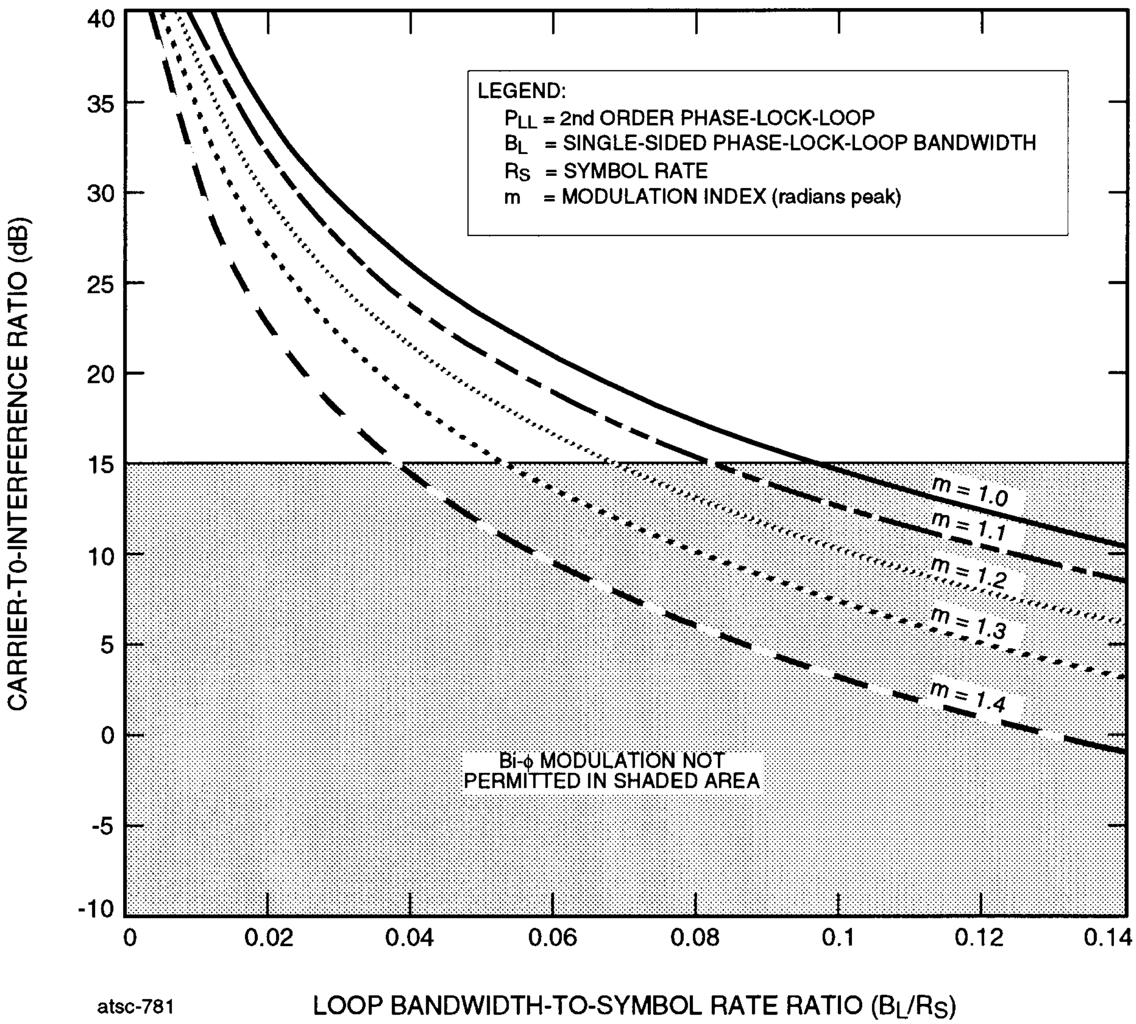


FIGURE 2.4.15A-1: OPERATING REGION FOR USE OF PCM/PM/Bi-ϕ MODULATION WHEN NO CODING IS EMPLOYED

2.4.15A MINIMUM SYMBOL RATE FOR PCM/PM/Bi-ϕ MODULATION ON A RESIDUAL RF CARRIER, CATEGORY A (Continued)

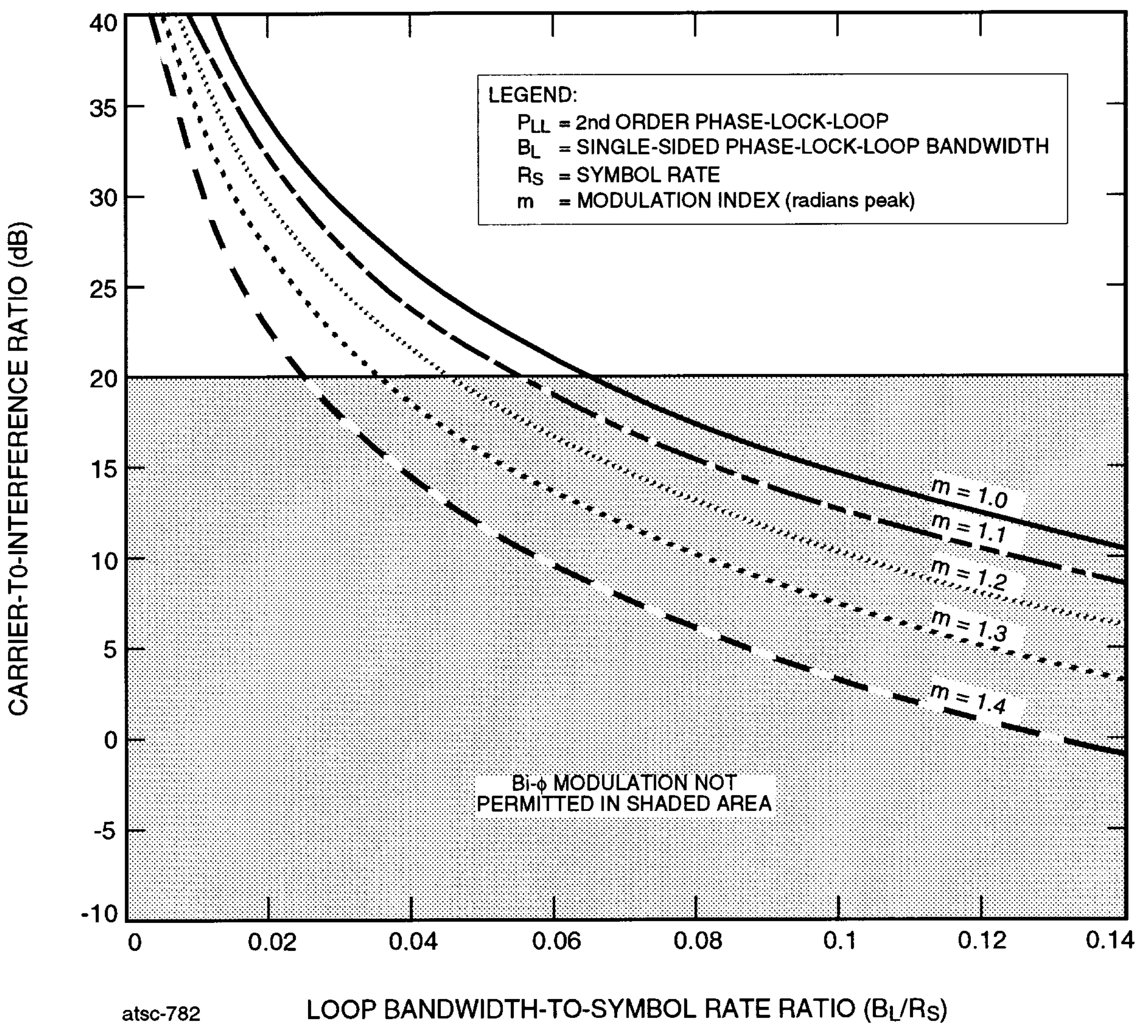


FIGURE 2.4.15A-2: OPERATING REGION FOR USE OF PCM/PM/Bi-ϕ MODULATION WHEN CCSDS CONCATENATED CODING IS EMPLOYED

2.4.15B MINIMUM SYMBOL RATE FOR PCM/PM/Bi-ϕ MODULATION ON A RESIDUAL RF CARRIER, CATEGORY B

The CCSDS,

considering

(a) that data modulated on a residual carrier have spectral components which fall into the carrier tracking loop's bandwidth reducing the Carrier-to-Noise ratio (C/N);

(b) that the level of interference is a function of the carrier tracking loop's bandwidth (B_L), the symbol rate (R_S), and the modulation index (m);

(c) that a 0.1 dB degradation in the symbol detection process should not be exceeded requiring a Carrier-to-Noise (C/N) ratio in the carrier tracking loop of 12 dB (uncoded case) or 18 dB (CCSDS concatenated coded case);

(d) that any additional degradation resulting from data interference in the carrier tracking loop must be insignificant requiring a Carrier-to-Interference (C/I) ratio greater than 17 dB (uncoded case) and 25 dB (CCSDS concatenated coded case);

recommends

(1) that, when no coding is employed, Figure 2.4.15B-1 should be used for determining symbol rates (R_S), relative to loop bandwidth (B_L) where PCM/PM/Bi-ϕ modulation is not permitted;

(2) that, when CCSDS Concatenated coding is employed, Figure 2.4.15B-2 should be used for determining symbol rates (R_S), relative to loop bandwidth (B_L), where PCM/PM/Bi-ϕ modulation is not permitted.

2.4.15B MINIMUM SYMBOL RATE FOR PCM/PM/Bi-ϕ MODULATION ON A RESIDUAL RF CARRIER, CATEGORY B (Continued)

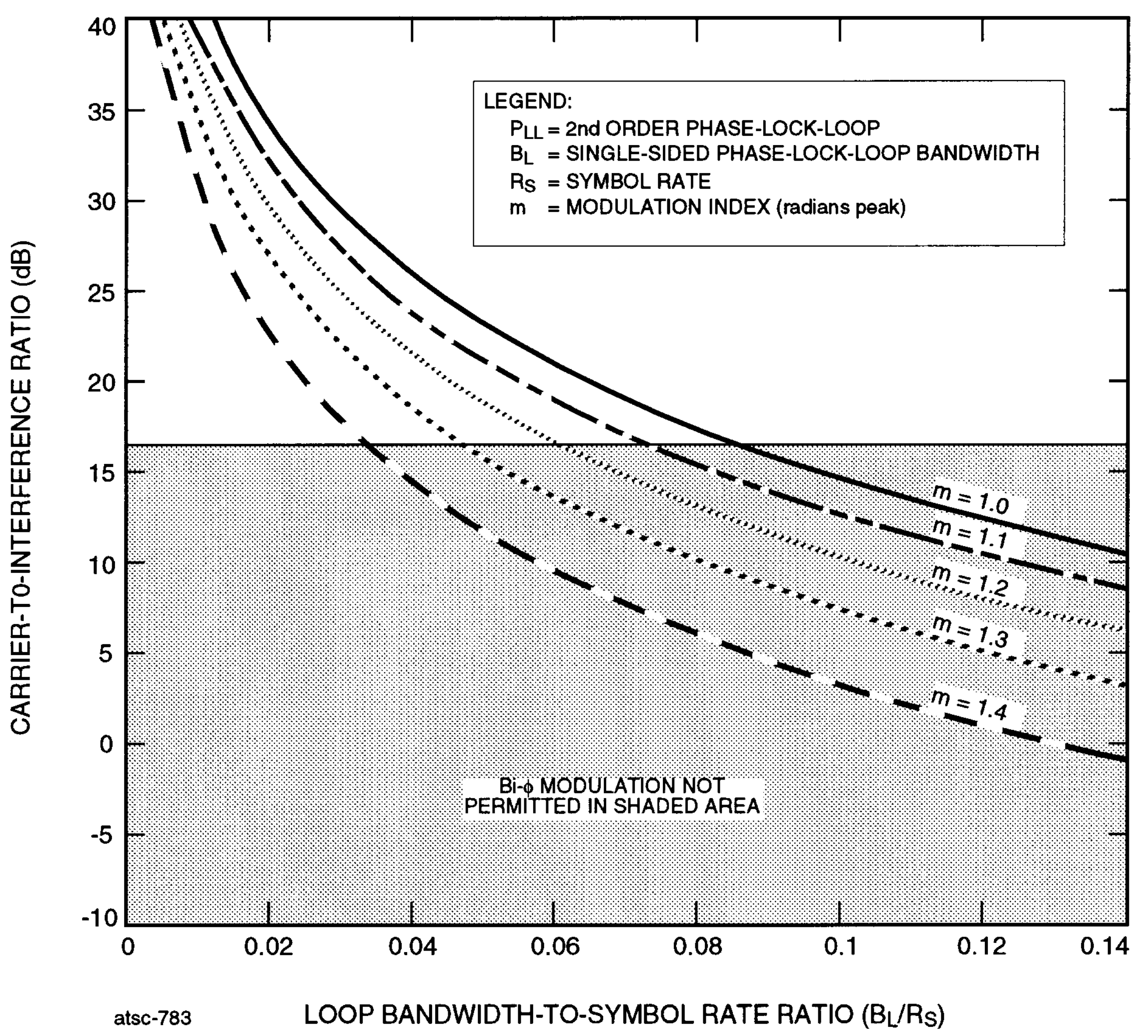


FIGURE 2.4.15B-1: OPERATING REGION FOR USE OF PCM/PM/Bi-ϕ MODULATION WHEN NO CODING IS EMPLOYED

2.4.15B MINIMUM SYMBOL RATE FOR PCM/PM/Bi-ϕ MODULATION ON A RESIDUAL RF CARRIER, CATEGORY B (Continued)

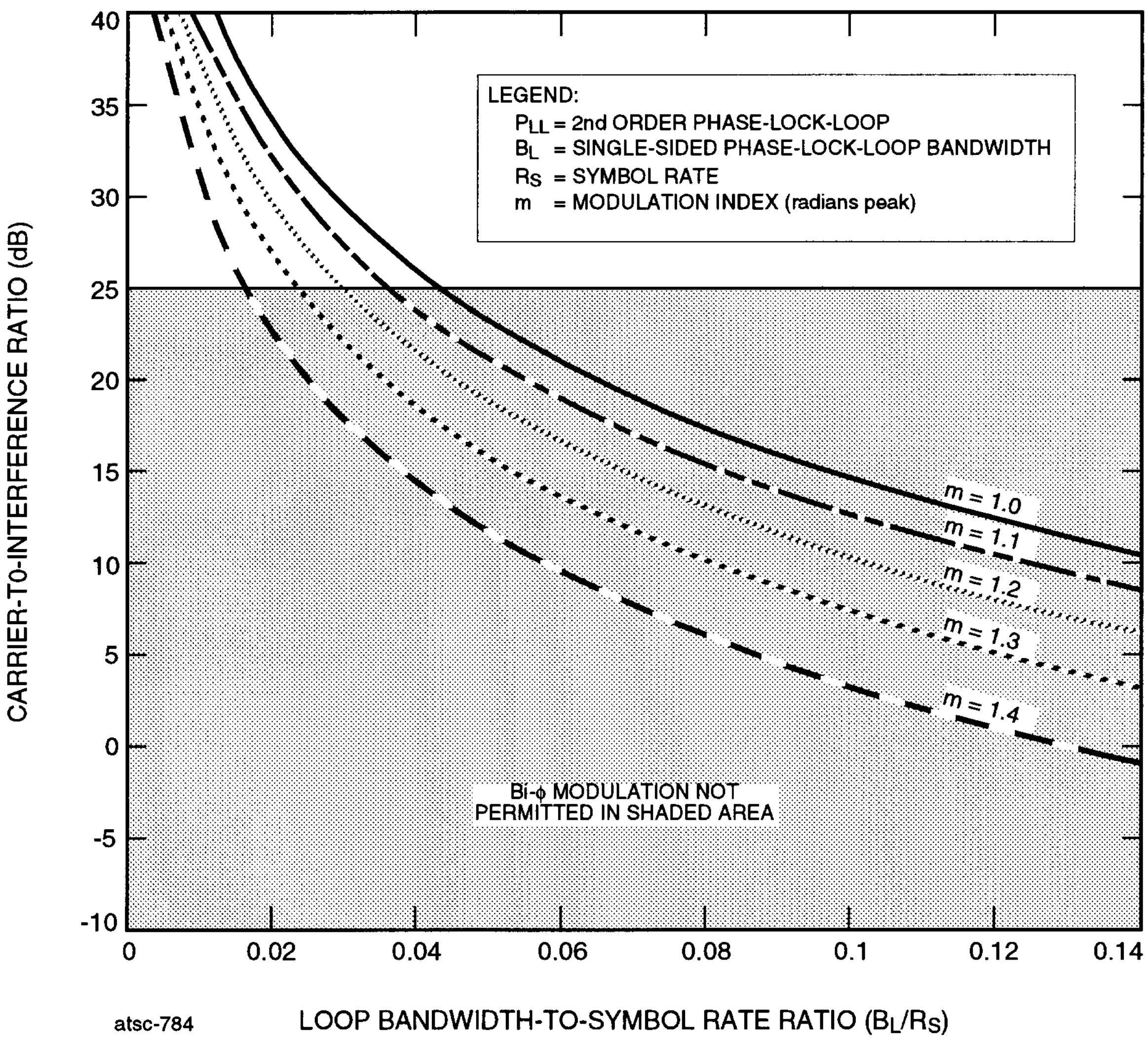


FIGURE 2.4.15B-2: OPERATING REGION FOR USE OF PCM/PM/Bi-ϕ MODULATION WHEN CCSDS CONCATENATED CODING IS EMPLOYED

2.4.16 MAXIMUM PERMISSIBLE SPURIOUS EMISSIONS

The CCSDS,

considering

(a) that spurious emissions (ITU-RR-1.145) in the form of spectral lines can cause harmful interference to receiving stations operating in the allocated or adjacent frequency bands;

(b) that such spurious emissions are caused by technological imperfections in the transmitting station, such as asymmetry of the baseband modulating waveform and crosstalk of the operating frequencies on the electronic power conditioners;

(c) that current technology permits reduction of these spectral components to -60 dBc or lower;

(d) that protection criteria specified for neighboring *radiocommunication services* may require additional reduction of spectral components;

(e) that filtering can be applied if further reduction in the level of spectral components is required;

recommends

that the total power contained in any single spurious emission shall not exceed -60 dBc [1].

NOTE:

1. dBc is measured with respect to the unmodulated carrier level's total power.

2.5.6B DIFFERENTIAL ONE-WAY RANGING FOR SPACE-TO-EARTH LINKS IN ANGULAR SPACECRAFT POSITION DETERMINATION, CATEGORY B

The CCSDS,

considering

(a) that Very Long Baseline Interferometry (VLBI) measurement allow determination of geometric delay for space radio sources by the simultaneous reception and processing of radio signals at two stations;

(b) that using the VLBI geometric delay measurements from two stations, the angular position of a spacecraft can be accurately determined for navigational purposes;

(c) that the VLBI technique requires differencing phase measurements of sinusoidal tones or harmonics (known as Differential One-way Ranging [DOR] tones), modulated on the spacecraft's downlink RF carrier, which have been acquired at two (or more) stations;

(d) that VLBI accuracy depends upon a priori knowledge of both the length and orientation of the baseline vector between the stations, the station clock drift, and the media delays;

(e) that measurement errors can be greatly reduced by observing a quasar or Extra-Galactic Radio source (EGRS), that is angularly near the spacecraft, and then differencing the delay measured from the ERGS observation with the delay measured from observing the spacecraft (ΔDOR);

(f) that the spacecraft delay measurement's precision depends upon the received power (P_{DOR}) in the two most widely spaced DOR tones, f_{BW} Hz apart, as shown in the error relationship:

$$\varepsilon_\tau = \left[f_{BW} \sqrt{4\,\pi\,\frac{P_{DOR}}{N_0}\,T_{obs}} \right]^{-1} \text{ seconds, where:}$$

f_{BW} = DOR tone spanned bandwidth[1] (Hz)
T_{obs} = observation time (seconds);

(g) that a narrow spanned bandwidth is needed for integer cycle ambiguity resolution because the ΔDOR time delay ambiguity equals the reciprocal of the minimum spanned bandwidth;

[1] NOTE: The spanned bandwidth is the widest separation between detectable tones in the downlink spectrum. This is usually given as twice the frequency of a sinusoidal "DOR Tone" modulated onto the carrier.

(h) that, contrary to *considering (g)*, a wide spanned bandwidth is needed for high measurement accuracy;

(i) that doubling the spanned bandwidth of spacecraft DOR tones, while holding the other parameters fixed, will reduce errors resulting from low spacecraft SNR, low quasar SNR, and instrument phase ripple by half;

(j) that delay ambiguities in observables generated from wider bandwidths are resolved successively by using delay estimates from the narrower spanned bandwidths;

(k) that a typical ΔDOR error budget is dominated by errors due to low quasar SNR, quasar position uncertainty, instrument phase ripple, and the troposphere;

(l) that EGRS delay measurement precision and instrument errors vary as $1/f_{BW}$;

(m) that direct phase modulation of a sinewave tone on the downlink RF carrier is more spectrum efficient than squarewave modulation and allows appropriate choices of spanned bandwidth and tone power;

(n) that the received spacecraft DOR tone power must be adequate for tone detection, with the threshold approximately determined by:

$$Threshold = \left[\frac{P_{DOR}}{N_0}\right] = 13 \text{ dB} \bullet \text{Hz}$$ if no carrier aiding is used;

(o) that the DOR tone threshold reduces to:

$$Threshold = \left[\frac{P_{DOR}}{N_0}\right] = 1 \text{ dB} \bullet \text{Hz}$$ provided that the spacecraft RF carrier's SNR is greater than 13 dB and that the extracted carrier phase is used to aid in tracking the DOR tone whose frequency is a coherent submultiple of the spacecraft's RF carrier frequency;

(p) that the stability of the spacecraft's RF carrier stability, over a 1-second averaging time, must be adequate for signal detection;

(q) that the *Space Research service* frequency allocation for Category B missions is 10 MHz in the 2 GHz band, 50 MHz in the 8 GHz band, 400 MHz in the 32 GHz band, and 1 GHz in the 37 GHz band;

(r) that quasar flux is reduced and system noise temperature is higher at 32 and 37 GHz as compared to 8 GHz;

recommends

(1) that DOR tone be sinewaves;

(2) that either direct tone detection or carrier-aided tone detection be used;

(3) that DOR tones be coherent with the downlink RF carrier frequency if carrier-aided detection is used;

(4) that one DOR tone pair be used in the 2 GHz band, two DOR tone pairs be used in the 8 GHz band, and three DOR tone pairs be used in the 32 and 37 GHz band

(5) that the approximate DOR tone frequencies used in each band be those in Table 2.5.6-1;

TABLE 2.5.6-1: RECOMMENDED DOR TONES

Space-to-Earth Frequency Band	Number of DOR Tones	Approximate DOR Tone Frequencies (± 10%)
2 GHz	1	4 MHz
8 GHz	2	4 MHz and 20 MHz
32 & 37 GHz	3	4 MHz, 20 MHz, and 76 MHz

Note: Depending on mission requirement (accuracy versus integration time), lower tone frequencies (< 4 MHz) may be used. In this case, if the down-link modulator is to be implemented digitally, square-wave DOR modulation may be applied in order to reduce transponder complexity.

(6) that, if spacecraft DOR data are to be acquired in the one-way mode, the spacecraft's oscillator stability over a 1-second averaging time shall be:

$\Delta f/f \leq 4.0 \times 10^{-10}$ at 2 GHz,
$\Delta f/f \leq 1.0 \times 10^{-10}$ at 8 GHz,
$\Delta f/f \leq 0.3 \times 10^{-10}$ at 32 and 37 GHz

where: $\Delta f/f$ denotes the spacecraft oscillator's frequency variations (square root of Allan's variance);

3.1.1 EFFICIENT UTILIZATION OF THE 2 GHz BANDS FOR SPACE OPERATION

The CCSDS,

considering

(a) that the frequency bands 2025–2110 and 2200–2290 MHz are shared co-equally by the Space Research, Space Operation, and Earth Exploration Satellite services;

(b) that bands allocated to the Space Operation service may be used for space tracking, space telemetry, and space telecommand (TTC) by other space services;

(c) that the definition of the Space Operation service (ITU-RR-1.23) postulates that these TTC activities by other space services normally be carried out in their service bands;

(d) that the bands 2025–2110 and 2200–2290 MHz, which are already now densely occupied, are of prime importance for space science missions of CCSDS agencies and will remain so for many years to come as no comparable alternative frequency allocations are available;

recommends

that, in order to make maximum use of these bands for satellite missions of all kinds, appropriate technical and operational constraints be observed, particularly:

i Geostationary space systems of space services other than the space science services[2] which are designed to operate in mission bands other than 2025–2110 and 2200–2290 MHz, but which utilize TTC systems within these bands, shall limit the use of such TTC systems to a single frequency pair per satellite and to launch, orbit insertion, and emergency operations.

ii TTC systems for geostationary satellites of space services other than the space science services should be designed in accordance with the general characteristics as contained in Table 3.1.1-1.

iii Non-geostationary satellites of services other than the space science services avoid using these bands for TTC.

[2] Space Science Services include the Space Research, Space Operation, Earth Exploration Satellite and Meteorological Satellite Services

3.1.1 EFFICIENT UTILIZATION OF THE 2 GHz BANDS FOR SPACE OPERATION (Continued)

TABLE 3.1.1-1

TYPICAL SYSTEM PARAMETERS FOR SPACE OPERATION OF GEOSTATIONARY SATELLITES AT 2 GHz

MODE	SYSTEM PARAMETERS	
Reception at Earth station	Telemetry bandwidth Tracking bandwidth G/T, Earth stations	100 kHz 400 kHz 20 dB/K
Transmission from Earth stations	Telecommand bandwidth Tracking bandwidth EIRP, Earth station	100 kHz 400 kHz 65 dBW

3.1.6B CHANNEL FREQUENCY PLAN FOR 2, 7, 8, 32, AND 34 GHZ, CATEGORY B

The CCSDS,

considering

(a) that channel frequency plans for Category B missions exist for the 2, 7, 8, 32, and 34 GHz bands;

(b) that the sets of channel frequency pairs in these existing plans are based upon the recommended turnaround ratios;

(c) that members of the Space Frequency Coordination Group (SFCG) have resolved to select frequencies for their Category B missions from the existing channel frequency plans;

(d) that most past, existing, and planned Category B missions have assigned frequencies that were selected on the basis of these existing channel frequency plans;

(e) that CCSDS agencies conducting Category B missions have coordinated the selection of frequencies from those embodied in the existing channel frequency plans in order to avoid interference between missions;

recommends

(1) that CCSDS agencies select frequencies for their Category B missions operating in the 2, 7, 8, 32, and 34 GHz bands from the channel frequency plan contained in Table 3.1.6B-1;

(2) that frequency selection be coordinated with an appropriate organization, such as the SFCG, to ensure the orderly use of the channel frequency plan.

TABLE 3.1.6B-1 - Channel Frequencies for Category B (Deep-Space) Missions

BAND (GHz):	**2 E-S**	**2 S-E**	**7 E-S**	**8 S-E**	**32 S-E**	**32 S-E**	**32 S-E**	**34 E-S**
FACTOR:	**221**	**240**	**749**	**880**	**3328**	**3344**	**3360**	**3599**
CHANNEL	**F2DN**							
1	* 2108.878858	2290.185185	7147.286265	* 8397.345679	#31757.234568	# 31909.913580	#32062.592592	# 34343.235339
2	* 2109.219908	2290.555556	7148.442132	* 8398.703706	#31762.370379	# 31915.074083	#32067.777787	# 34348.789361
3	* 2109.560957	2290.925926	7149.597994	8400.061729	#31767.506176	# 31920.234571	#32072.962966	# 34354.343368
4	* 2109.902006	2291.296296	7150.753857	8401.419752	#31772.641973	# 31925.395059	#32078.148146	# 34359.897374
5	2110.243056	2291.666667	7151.909724	8402.777780	31777.777784	31930.555562	32083.333340	34365.451396
6	2110.584105	2292.037037	7153.065587	8404.135803	31782.913581	31935.716050	32088.518519	34371.005402
7	2110.925154	2292.407407	7154.221450	8405.493826	31788.049378	31940.876538	32093.703699	34376.559408
8	2111.266204	2292.777778	7155.377316	8406.851853	31793.185190	31946.037042	32098.888893	34382.113431
9	2111.607253	2293.148148	7156.533179	8408.209876	31798.320986	31951.197530	32104.074073	34387.667437
10	2111.948303	2293.518519	7157.689045	8409.567903	31803.456798	31956.358033	32109.259267	34393.221460
11	2112.289352	2293.888889	7158.844908	8410.925927	31808.592595	31961.518521	32114.444447	34398.775466
12	2112.630401	2294.259259	7160.000771	8412.283950	31813.728392	31966.679009	32119.629626	34404.329472
13	2112.971451	2294.629630	7161.156637	8413.641977	31818.864203	31971.839512	32124.814821	34409.883494
14	2113.312500	2295.000000	7162.312500	8415.000000	31824.000000	31977.000000	32130.000000	34415.437500
15	2113.653549	2295.370370	7163.468363	8416.358023	31829.135797	31982.160488	32135.185179	34420.991506
16	2113.994599	2295.740741	7164.624229	8417.716050	31834.271608	31987.320991	32140.370374	34426.545528
17	2114.335648	2296.111111	7165.780092	8419.074073	31839.407405	31992.481479	32145.555553	34432.099534
18	2114.676697	2296.481481	7166.935955	8420.432097	31844.543202	31997.641967	32150.740733	34437.653540
19	2115.017747	2296.851852	7168.091821	8421.790124	31849.679014	32002.802470	32155.925927	34443.207563
20	2115.358796	2297.222222	7169.247684	8423.148147	31854.814810	32007.962958	32161.111107	34448.761569
21	2115.699846	2297.592593	7170.403550	8424.506174	31859.950622	32013.123462	32166.296301	34454.315592

Note: Channel frequencies marked " * " are not within the Category B band allocation.

Channel frequencies marked " # " may be used in conjunction with the corresponding channel in a lower frequency band if that channel is not marked by " * ".

F2DN = N(10/27) + 2295 MHz, where N is in the range -13 to +28 for this Table. The value of F2DN is rounded to the nearest Hz. Frequencies in the 2 GHz E-S band are then computed and rounded to the nearest Hz. Channel numbers are equal to N + 14. Frequencies in other bands are derived from the 2 GHz E-S frequencies by using the corresponding ratio of frequency factors, and then rounding to the nearest Hz.

TABLE 3.1.6B-1 (continued): Channel Frequencies for Category B (Deep-Space) Missions

BAND (GHZ):	2 E-S	2 S-E	7 E-S	8 S-E	32 S-E	32 S-E	32 S-E	34 E-S
FACTOR:	221	240	749	880	3328	3344	3360	3599
CHANNEL	F2DN							
22	2116.040895	2297.962963	7171.559413	8425.864197	31865.086419	32018.283950	32171.481481	34459.869598
23	2116.381944	2298.333333	7172.715276	8427.222220	31870.222216	32023.444438	32176.666660	34465.423604
24	2116.722994	2298.703704	7173.871143	8428.580248	31875.358027	32028.604941	32181.851854	34470.977626
25	2117.064043	2299.074074	7175.027006	8429.938271	31880.493824	32033.765429	32187.037034	34476.531632
26	2117.405092	2299.444444	7176.182868	8431.296294	31885.629621	32038.925917	32192.222213	34482.085639
27	2117.746142	2299.814815	7177.338735	8432.654321	31890.765432	32044.086420	32197.407408	34487.639661
28	2118.087191	* 2300.185185	7178.494597	8434.012344	#31895.901229	# 32049.246908	#32202.592587	# 34493.193667
29	2118.428241	* 2300.555556	7179.650463	8435.370371	#31901.037041	# 32054.407411	#32207.777782	# 34498.747689
30	2118.769290	* 2300.925926	7180.806327	8436.728395	#31906.172838	# 32059.567899	#32212.962961	# 34504.301695
31	2119.110339	* 2301.296296	7181.962190	8438.086418	#31911.308634	# 32064.728387	#32218.148140	# 34509.855701
32	2119.451389	* 2301.666667	7183.118056	8439.444445	#31916.444446	# 32069.888891	#32223.333335	# 34515.409724
33	2119.792438	* 2302.037037	7184.273919	8440.802468	#31921.580243	# 32075.049379	#32228.518514	# 34520.963731
34	* 2120.133487	* 2302.407407	7185.429782	8442.160491	#31926.716040	# 32080.209867	#32233.703694	# 34526.517737
35	* 2120.474537	* 2302.777778	7186.585648	8443.518518	#31931.851851	# 32085.370370	#32238.888888	# 34532.071759
36	* 2120.815586	* 2303.148148	7187.741511	8444.876542	#31936.987648	# 32090.530858	#32244.074068	# 34537.625765
37	* 2121.156636	* 2303.518519	7188.897377	8446.234569	#31942.123460	# 32095.691361	#32249.259262	# 34543.179787
38	* 2121.497685	* 2303.888889	* 7190.053240	8447.592592	#31947.259256	# 32100.851849	#32254.444442	# 34548.733793
39	* 2121.838734	* 2304.259259	* 7191.209103	8448.950615	#31952.395053	# 32106.012337	#32259.629621	# 34554.287799
40	* 2122.179784	* 2304.629630	* 7192.364969	* 8450.308642	#31957.530865	# 32111.172840	#32264.814816	# 34559.841822
41	* 2122.520833	* 2305.000000	* 7193.520832	* 8451.666665	#31962.666662	# 32116.333328	#32269.999995	# 34565.395828
42	* 2122.861882	* 2305.370370	* 7194.676696	* 8453.024689	#31967.802458	# 32121.493816	#32275.185174	# 34570.949834

Note: Channel frequencies marked " * " are not within the Category B band allocation.

Channel frequencies marked " # " may be used in conjunction with the corresponding channel in a lower frequency band if that channel is not marked by " * ".

F2DN = N(10/27) + 2295 MHz, where N is in the range -13 to +28 for this Table. The value of F2DN is rounded to the nearest Hz. Frequencies in the 2 GHz E-S band are then computed and rounded to the nearest Hz. Channel numbers are equal to N + 14. Frequencies in other bands are derived from the 2 GHz E-S frequencies by using the corresponding ratio of frequency factors, and then rounding to the nearest Hz.

3.2.1A LIMITATIONS ON EARTH-TO-SPACE LINK POWER LEVELS, CATEGORY A

The CCSDS,

considering

(a) that spectral occupation of frequency bands used by space agencies is increasing rapidly;

(b) that in many cases the same frequencies will be shared by several spacecraft;

(c) that the 2025–2110 MHz band is also shared with space-to-space links from data relay satellites to user satellites, which are limited to relatively small power levels by the provisions of ITU-RR-21.16and are consequently particularly susceptible to interference;

(d) that excessive EIRP from Earth stations will make intra-service frequency sharing increasingly difficult and result in inefficient use of the radio frequency spectrum;

(e) that excessive EIRP from Earth stations likewise unnecessarily complicates the coordination with terrestrial services and may in some cases increase the coordination area;

(f) that the required EIRP from an Earth station is determined by P_c/N_o, E_b/N_o, and the minimum signal level required by the spacecraft receiver;

recommends

(1) that CCSDS agencies limit the EIRP on the Earth-to-space links to that required for safe spacecraft operation by means of one or several of the following:

- CCSDS agencies avoid, whenever practicable, using high power transmitters having a fixed output but instead adjust their transmitted power level to the minimum needed to meet project requirements;

- CCSDS agencies obtain the required EIRP by using reasonable antenna diameters in order to reduce both sidelobe radiation and transmitter power (Guideline: antenna diameter/RF wavelength equal to or greater than 70);

- CCSDS agencies make Recommendation ITU-R SA.509 a requirement in antenna specifications;

(2) that spacecraft equipment designers endeavor to provide similar margins with regard to minimum P_c/N_o, minimum E_b/N_o and the minimum signal required by the spacecraft receiver.

3.3.1 OPTIMAL RANGING MODULATION WAVEFORMS FOR SIMULTANEOUS RANGING, TELECOMMANDING, AND TELEMETRY OPERATIONS

The CCSDS,

considering

(a) that two-way transmissions are employed for making range measurements to a distant spacecraft;

(b) that telecommand and telemetry signals are phase shift-keyed onto the subcarriers and then phase-modulated onto a sinusoidal residual RF carrier [see Recommendations 401 (2.1.1) B-1, 401 (2.4.3) B-1];

(c) that telemetry signals may also be directly modulated on the RF carrier in conformance with Recommendation 401 (2.4.7) B-1;

(d) that sine-wave subcarriers are recommended for the telecommand channel [see Recommendation 401 (2.2.2) B-1];

(e) that sine-wave subcarriers are recommended for Category A mission's telemetry channels, and square-wave subcarriers are recommended for Category B mission's telemetry channels [see Recommendation 401 (2.4.3) B-1];

(f) that, for simultaneous telecommand and ranging on the earth-to-space link, the telecommand performance suffers some degradation due to command-ranging cross-modulation components;

(g) that, for simultaneous telemetry and ranging on the space-to-earth link, the telemetry performance may be degraded due to interference from the filtered versions of the uplink ranging, feed-through telecommand, cross-modulation components and noise;

(h) that the timing offset due to different clocks between the telecommand and telemetry may cause serious telemetry bit error rate (BER) degradation;

(i) that the telecommand BER performance is virtually identical for either sine wave or square wave ranging modulation;

(j) that, for Category B missions, the telemetry BER performance is insensitive to the type of ranging waveforms used when operated simultaneously with the ranging on the space-to-earth link;

(k) that the use of a square-wave ranging signal makes the telemetry BER performance more susceptible to data-to-data interference (resulting from the timing offset due to different clocks between the telecommand and telemetry) than the sine-wave ranging;

(l) that, for Category A missions, the telemetry BER performance is sensitive to the timing offset when operated simultaneously with either a square-wave or sine-wave ranging signal;

(m) that for Category B missions, it is important to minimize the required transmitted power level on the space-to-earth link;

3.3.1 OPTIMAL RANGING MODULATION WAVEFORMS FOR SIMULTANEOUS RANGING, COMMANDING, AND TELEMETRY OPERATIONS (Continued)

(n) that for Category A missions, it is necessary to minimize the adjacent channels interference;

(o) that the use of a sine-wave ranging signal will minimize the occupied bandwidth;

recommends

(1) that, for Category B mission's earth-to-space links, either a sine wave or a square wave ranging signal may be used when operated simultaneously with the telecommand;

(2) that, for Category A mission's earth-to-space links, sine wave ranging shall be used when operated simultaneously with the telecommand;

(3) that, for Categories A and B mission's space-to-earth links, sine wave ranging should be used when operated simultaneously with the telemetry.

3.3.2A CRITERIA FOR USE OF DIRECT SEQUENCE SPREAD SPECTRUM MODULATION, CATEGORY A

The CCSDS,

considering

(a) that frequency bands must often be shared between several users which can result in mutual interference;

(b) that such mutual interference can result in significant link degradation or even unusable links for certain periods of time;

(c) that spread spectrum systems can be designed to tolerate a high level of interference from other communications systems;

(d) that, in some cases, spread spectrum modulation can assist in meeting the PFD limits set forth in the International Telecommunication Union's *(ITU) Radio Regulations*;

(e) that direct sequence spread spectrum systems can be designed to provide ranging measurements by using the spreading code which eliminates the need for a separate ranging signal;

recommends

(1) that direct sequence spread spectrum modulation be used in any of the following cases:

- where the intra-service sharing conditions are such that other modulation methods will not provide the required performance or mutual compatibility with other transmissions assigned to the same frequency band;

- where the inter-service sharing conditions are such that the susceptibility to actual or potential interference from transmissions in other services assigned to the same frequency band cannot be kept within acceptable limits by other modulation methods;

- where the power flux density limits, as set forth in the *ITU Radio Regulations, Article 21*, cannot be met using other methods;

(2) that spread spectrum systems shall be designed to minimize unwanted emissions in the same allocated frequency band;

(3) that unwanted emissions generated by spread spectrum systems shall conform with applicable protection criteria of radio communications services in other frequency bands.

3.6.2A INTERFERENCE FROM SPACE-TO-SPACE LINKS BETWEEN NON-GEOSTATIONARY SATELLITES TO OTHER SPACE SYSTEMS IN THE 2025 - 2110 AND 2200 - 2290 MHz BANDS, CATEGORY A

The CCSDS,

considering

(a) that space-to-space transmissions between two or more non-geostationary satellites shall not impose any constraints on other space transmissions (ITU-RR-5.392);

(b) that the planned increase in the number of space-to-space links between non-geostationary satellites will raise the likelihood of harmful interference;

recommends

that the power spectral density of space-to-space links between any two non-geostationary satellites be reduced by using appropriate modulation techniques and channel coding in accordance with CCSDS Recommendations, in order to reduce the potential for harmful interference to space-to-Earth, Earth-to-space, and space-to-space transmissions involving at least one geostationary satellite.

4.1.5 COMPUTATIONAL TECHNIQUE FOR THE MEAN AND VARIANCE OF THE MODULATION LOSSES FOUND IN THE CCSDS TELECOMMUNICATION LINK DESIGN CONTROL TABLE

The CCSDS,

considering

(a) that the term "modulation loss" as used in the CCSDS Link Design Control Table (DCT) [CCSDS Recommendation 401 (4.1.2) B-1] means "that fraction of the total transmitted power allotted to a designated channel";

(b) that the computation of the carrier, telecommand, telemetry and ranging link margins found in the CCSDS DCT requires an evaluation of the modulation losses;

(c) that the CCSDS DCT employs a statistical technique for computing the mean and variance of modulation losses for which most input parameters in the DCT require the specification of a design value together with its favorable and adverse tolerances;

(d) that computation of the modulation loss tolerances are based upon variations at the peak phase deviations (peak modulation indices);

(e) that the calculation of the variance on link performance can be tedious because it requires the designer to evaluate the several modulation losses for all possible combinations of favorable and adverse tolerances;

(f) that, for systems employing a coherent-turnaround ranging channel with a constant-power AGC simultaneously with telecommand and telemetry (Figure 4.1.5-1), there are 128 possible combinations of favorable and adverse tolerances affecting the several modulation losses which must be evaluated to compute the telemetry channel's performance;

(g) that computing a telecommunication system's performance by evaluating all possible combinations of favorable and adverse tolerances on the several modulation loss input parameters results in an unnecessary increase in computational complexity since the combinations producing the extreme performance variations are deterministic;

(h) that based on the mathematical expressions for the modulation losses, simple algorithms can be developed to avoid this unnecessary increase in computational complexity;

(i) that, due to the modulation schemes recommended by the CCSDS, [CCSDS Recommendations 401 (2.2.2) B-1, 401 (2.2.3) B-1, 401 (2.3.1) B-1, 401 (2.4.2) B-1 and 401 (2.4.3) B-1], computation of tolerances on the several modulation losses requires the use of Bessel, trigonometric and exponential functions;

(j) that, when the maximum modulation indices are less than 1.4 radians [see CCSDS Recommendations 401 (2.1.6) B-1 and 401 (2.3.8) B-2], the maximum and minimum values of some modulation losses do not occur when all modulation indices are simultaneously at their upper or lower bounds, respectively (see Figure 4.1.5-2);

4.1.5 COMPUTATIONAL TECHNIQUE FOR THE MEAN AND VARIANCE OF THE MODULATION LOSSES FOUND IN THE CCSDS TELECOMMUNICATION LINK DESIGN CONTROL TABLE (Continued)

(k) that a common set of computation algorithms will ease the information exchange between space agencies;

recommends

(1) that parameters defined in Tables 4.1.5-1a and 4.1.5-1b be used in the formulas for the computation of the maxima and minima of the modulation losses;

(2) that Algorithm 1 be used to compute the mean and variance of the earth-to-space modulation losses for simultaneous range and telecommand operations using sinewave subcarriers;

(3) that Algorithm 2 be used to compute the mean and variance of the space-to-earth modulation losses when a power-controlled AGC is employed on the turnaround ranging channel.

Note to the editor: the Annexes to 4.1.5 remain unchanged and have not been reproduced here.

4.2.1 COMPUTATIONAL METHOD FOR DETERMINING THE OCCUPIED BANDWIDTH OF UNFILTERED PCM/PM SIGNALS

The CCSDS,

considering

(a) that the occupied bandwidth is defined as that band of frequencies which contain 99% of the total radiated power (ITU-RR-1.153);

(b) that the occupied bandwidth of unfiltered modulated signals provides a useful indication as to whether filtering may be necessary to optimally use the allocated frequency band;

(c) that a simple, closed-form expression for calculating the occupied bandwidth of PCM/PM signals, using either NRZ or Bi-Phase formats, is not available;

(d) that approximations for computing occupied bandwidth of PCM/PM signals, having an accuracy of better than 90% over the specified ranges of modulation indices, have been developed and are compared with theoretical values in Figure 4.2.1-1;

recommends

that the occupied bandwidth of PCM/PM signals containing 99% of the total radiated power can be calculated, with an accuracy of better than 90%, using the following approximations:

$BW = 2 \times (26.2m - 5.16)R_S$ for Bi-Phase format: (0.4 rads. $\leq m \leq$ 1.4 rads.);

$BW = 2 \times (8.93m - 1.75)R_S$ for NRZ format: (0.4 rads. $\leq m \leq$ 1.4 rads.);

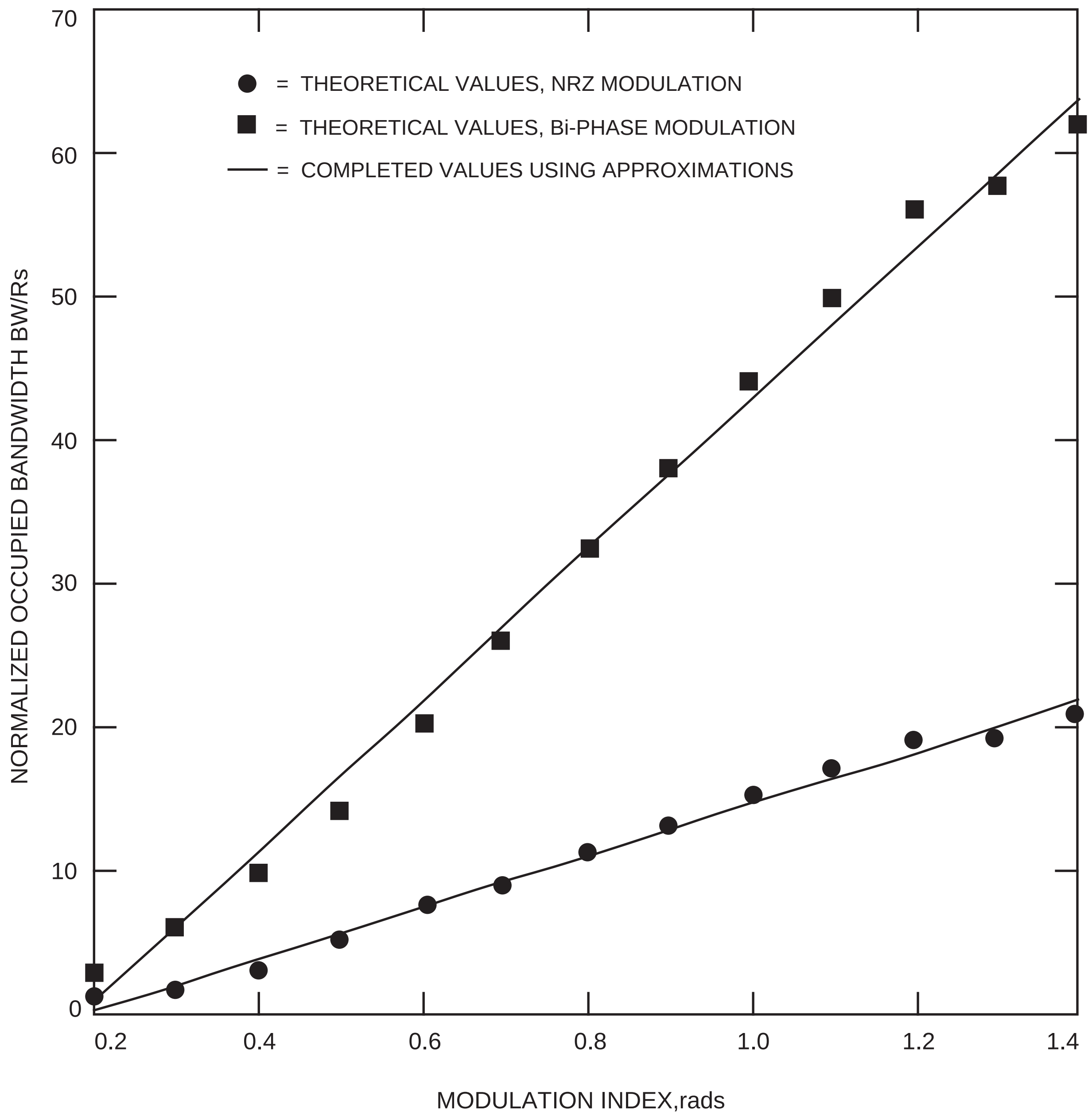
NOTES:

BW = Occupied Bandwidth is the band of frequencies containing 99% of the total radiated power,

R_S = Modulated Symbol Rate,

m = Modulation Index (in radians).

4.2.1 COMPUTATIONAL METHOD FOR DETERMINING THE OCCUPIED BANDWIDTH OF UNFILTERED PCM/PM SIGNALS (Continued)



6445-444ab

FIGURE 4.2.1-1: COMPARISON OF THEORETICAL AND COMPUTED APPROXIMATE VALUES FOR OCCUPIED BANDWIDTH

4.2.2 COMPUTATIONAL METHOD FOR DETERMINING THE OCCUPIED BANDWIDTH OF UNFILTERED PCM/PSK/PM MODULATION WITH A SINEWAVE SUBCARRIER

The CCSDS,

considering

(a) that prior to the design of spacecraft and the assignment of frequencies, the *Occupied Bandwidth* must be known;

(b) that the *Occupied Bandwidth* is defined as the frequency band containing 99% of the emitted power (ITU-RR-1.153);

(c) that for PCM/PSK/PM modulation with an NRZ data format, a simple, exact closed form expression to calculate the *Occupied Bandwidth* is not available over the full range of applicable modulation indices;

(d) that an approximation having better than 10% accuracy has been developed for a representative range of modulation indices;

(e) that the *Occupied Bandwidth* can be computed with high precision using numerical integration techniques and can be plotted for easy use;

recommends

(1) that the *Occupied Bandwidth*, B, for PCM/PSK/PM with a sinewave subcarrier be estimated by:

$$B = 4n \bullet R_S \text{ for } 0.8 < m < 1.35 \text{ and } n > 7 \text{ (in Hz)}$$

where: n = subcarrier frequency-to-symbol rate ratio
R_S = symbol rate (s/s)
m = modulation index (radians peak)

(2) that B for any other combination of m and n be determined by using Figure 4.2.2-1.

4.2.2 COMPUTATIONAL METHOD FOR DETERMINING THE OCCUPIED BANDWIDTH OF UNFILTERED PCM/PSK/PM MODULATION WITH A SINEWAVE SUBCARRIER (Continued)

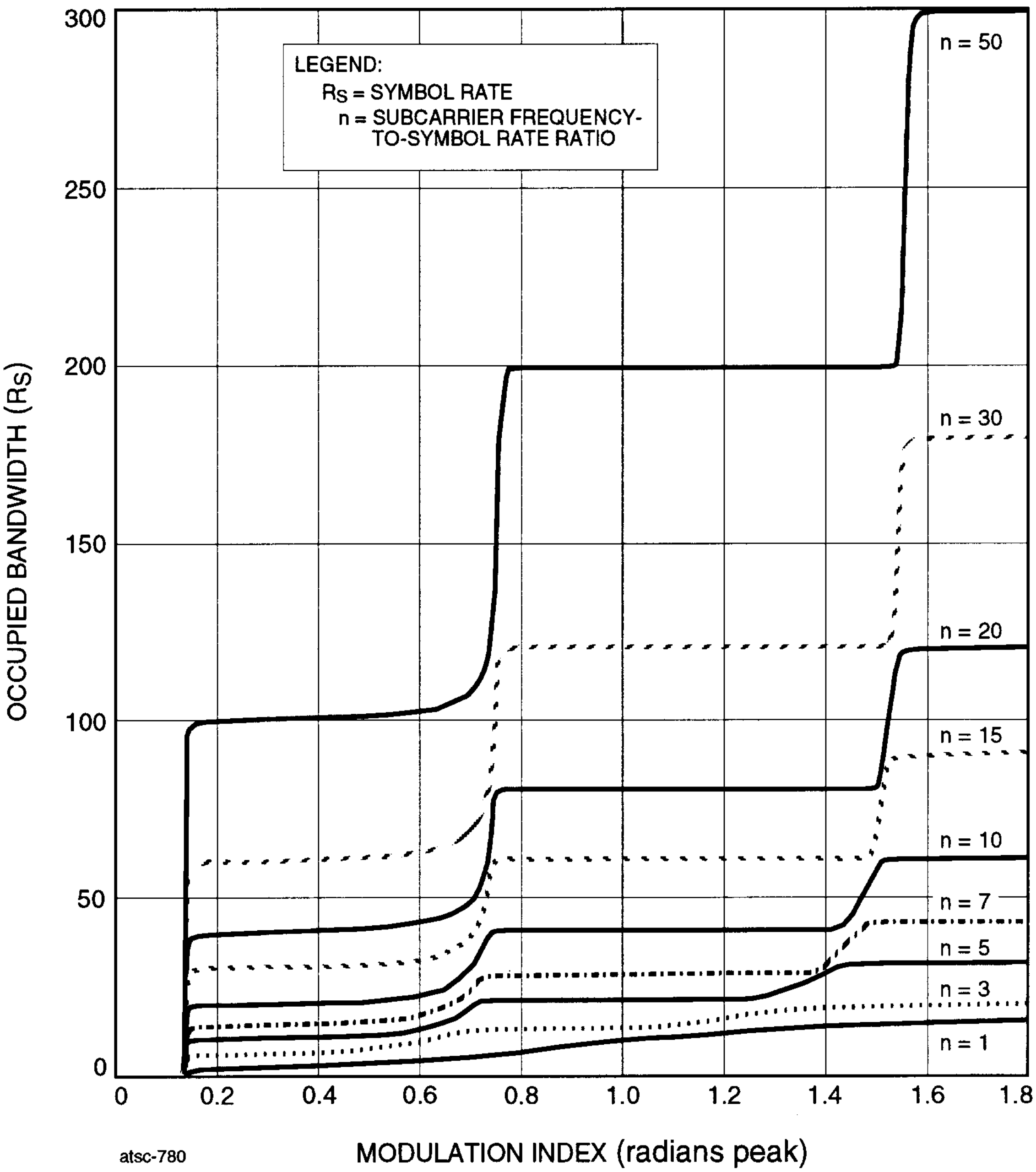


FIGURE 4.2.2-1: OCCUPIED BANDWIDTH OF UNFILTERED PCM/PSK/PM SIGNAL WITH A SINEWAVE SUBCARRIER

4.2.3 COMPUTATIONAL METHOD FOR DETERMINING THE OCCUPIED BANDWIDTH OF UNFILTERED PCM/PSK/PM MODULATION WITH A SQUAREWAVE SUBCARRIER

The CCSDS,

considering

(a) that prior to the design of spacecraft and the assignment of frequencies, the *Occupied Bandwidth* must be known;

(b) that the *Occupied Bandwidth* is defined as the frequency band containing 99% of the emitted power (ITU-RR-1.153);

(c) that for PCM/PSK/PM modulation with an NRZ data format, a simple, exact closed form expression to calculate the *Occupied Bandwidth* is not available over the full range of applicable modulation indices;

(d) that an approximation having better than 10% accuracy has been developed for a representative range of modulation indices;

(e) that the *Occupied Bandwidth* can be computed with high precision using numerical integration techniques and can be plotted for easy use;

recommends

(1) that the *Occupied Bandwidth*, B, for PCM/PSK/PM with a squarewave subcarrier be estimated by:

$$B = [(-43.2\,m^3 + 103\,m^2 - 2\,m - 1)\,n + 11] \bullet R_S \qquad \text{for } m > 0.5 \text{ radians}$$

(in Hz)

where:

where:	n	=	subcarrier frequency-to-symbol rate ratio
	R_S	=	symbol rate (s/s)
	m	=	modulation index (radians peak)

(2) that B for any other combination of m and n be determined by using Figure 4.2.3-1.

4.2.3 COMPUTATIONAL METHOD FOR DETERMINING THE OCCUPIED BANDWIDTH OF UNFILTERED PCM/PSK/PM MODULATION WITH A SQUAREWAVE SUBCARRIER (Continued)

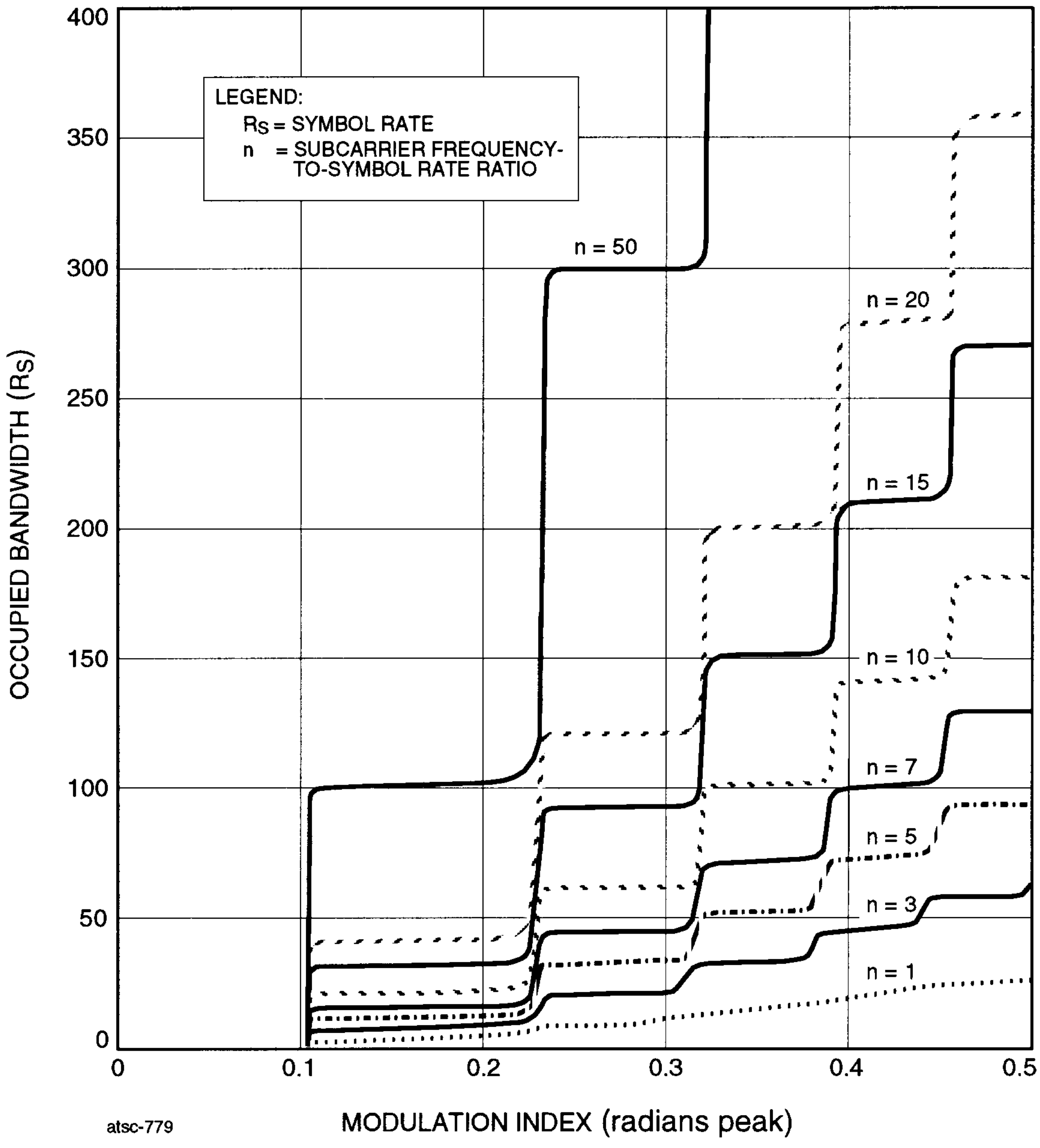


FIGURE 4.2.3-1: OCCUPIED BANDWIDTH OF UNFILTERED PCM/PSK/PM SIGNAL WITH A SQUAREWAVE SUBCARRIER

5.1 TERMINOLOGY

Autotrack	A system which causes earth station's antenna to automatically follow [track] a moving spacecraft.
Bit Rate	The baseband data rate exclusive of coding for either error correction or spectrum shaping purposes.
Category A Missions	Those missions whose altitude above the earth is less than 2×10^6 km.
Category B Missions	Those missions whose altitude above the earth is greater than, or equal to, 2×10^6 km.
Dibit	A group of two bits in 4-phase modulation, each possible *dibit* is encoded in the form of one of four unique phase shifts of the RF carrier.
Loop Bandwidth	The resultant phase locked bandwidth when the signal-to-noise ratio in the phase locked loop is 10 dB.
Loop Threshold	That signal level producing a signal-to-noise ratio of 10 dB in the phase locked loop's bandwidth.
Libration Point	A point of equal potential gravitational fields between two or more large bodies such as the Sun and the Earth.
Link Design Control Table	A set of tables used to display the operating parameters of a telecommunications link and to calculate the expected performance of that link.
Link and Weather Not Combined	With a Link Design Control Table, calculations are made assuming clear and dry weather conditions. Thereafter, the values obtained under such ideal conditions are adjusted using a correction factor representing the loss due to weather effects.
Modulo-2 Addition	Also called an *"exclusive or"*, this term refers to the manner in which a pair of bits are added such that like bits result in a 0 and unlike bits produce a 1.
Occupied Bandwidth	(ITU-RR-1.153): "The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage ß/2 of the total mean power of a given emission." [Unless otherwise specified by the CCIR for the appropriate class of emission, the value of ß/2 should be taken as 0.5%."]

5.1 TERMINOLOGY (Continued)

Radiocommunication Service	(ITU-RR-1.19) "A Service . . . involving the transmission, emission and/or reception of radio waves for specific telecommunication purposes."
Ranging Measurement	*A process for establishing, usually by a time delay measurement, the one-way distance between an earth station and a spacecraft.*
Symbol Rate	The baseband bit rate following error correction coding but excluding any spectrum modification encoding.

2.2.4 LOW-RATETELECOMMAND SYSTEMS

The CCSDS,

considering

(a) that many space agencies utilize PCM-PSK modulation for the telecommand links;

(b) that phase coherency between the PCM signal and the subcarrier facilitates system implementation;

(c) that subcarrier frequencies of either 8 kHz or 16 kHz are commonly used;

(d) that many space agencies have developed, or will develop, equipment using telecommand data rates in the range 8-4000 b/s;

recommends

(1) that CCSDS agencies provide telecommand bit rates in the range $4000/2^n$ b/s, where n = 0, 1, 2, ..., 9;

(2) that data bit and subcarrier transitions should coincide.

NOTE:

1. A 4000 b/s rate should only be used with a 16 kHz subcarrier and care should be taken to ensure that harmful interactions with other signals do not occur.

2.4.7 CHOICE OF PCM WAVEFORMS IN RESIDUAL CARRIER TELEMETRY SYSTEMS

The CCSDS,

considering

(a) that NRZ waveforms rely entirely on data transitions for symbol clock recovery, and this recovery becomes problematical unless an adequate transition density can be guaranteed;

(b) that due to the presence of the mid-bit transitions, Bi-ϕ waveforms provide better properties for bridging extended periods of identical symbols after initial acquisition;

(c) that convolutionally encoded data have sufficient data transitions to ensure symbol clock recovery in accordance with the CCSDS recommended standards;

(d) that with coherent PSK subcarrier modulation, it is possible by adequate hardware implementation to bridge extended periods of identical symbols even when NRZ waveforms are used;

(e) that NRZ waveforms without a subcarrier have a non-zero spectral density at the RF carrier;

(f) that coherent PSK subcarrier modulated by NRZ data and using an integer subcarrier frequency to symbol rate ratio, as well as Bi-ϕ waveforms, have zero spectral density at the RF carrier;

(g) that the ambiguity which is peculiar to NRZ-L and Bi-ϕ waveforms can be removed by adequate steps;

(h) that use of NRZ-M and NRZ-S waveforms results in errors occurring in pairs;

(i) that it is desirable to prevent unnecessary decoder node switching by frame synchronization prior to convolutional decoding (particularly true for concatenated convolutional Reed-Solomon coding);

(j) that to promote standardization, it is undesirable to increase the number of options unnecessarily, and that for any proposed scheme, those already implemented by space agencies should be considered first;

recommends

(1) that for modulation schemes which use a subcarrier, the subcarrier to bit rate ratio should be an integer;

(2) that in cases where a subcarrier is employed, NRZ-L should be used;

(3) that for direct modulation schemes having a residual carrier, only Bi-ϕ waveforms should be used;

(4) that ambiguity resolution should be provided.