ANNEX J

Guidance for Determination of Necessary Bandwidth

J.1 INTRODUCTION

This Annex contains guidance relating to the necessary bandwidth parameter. Necessary bandwidth forms part of the emission designator used for frequency management purposes and is used as a parameter in spectrum standards, frequency assignments, etc., throughout this Manual.

J.2 GENERAL

Except for radars, the necessary bandwidth may be determined by one of the following methods with the order of preference shown:

1. Use of the appropriate formula from Table A in this Annex.[1]
2. Computation in accordance with the Recommendations ITU-R SM.328-8 (1994) and SM.853 (1994).
3. Measurements of specialized modulations not covered by 1. or 2. above.
4. Use of the best available technical information from other sources.

The value so determined shall be used when the full designation of an emission is required for example, as indicated in Chapter 9.

See Section 5.1.5 for the desired relationship of occupied bandwidth to necessary bandwidth.

J.3 RADAR SYSTEMS

For radars the necessary bandwidth shall be determined at a point that is 20 dB below the peak envelope value of the spectrum by one of the following with the order of preference shown:

1. Computation in accordance with the following equations which assume trapezoidal pulse modulation, with equal rise and fall times.
2. Results of actual measurement.
3. Use of the best available technical information from other sources.

J.4 ANALOG FM

The basis of the formulas in Table A for the necessary bandwidth of analog FM and FDM/FM systems is Carson's Rule. This bandwidth is given by $B_1 = 2(D+M) = 2(a+1)M$, where D is the peak frequency deviation, "a" is the peak modulation index and M is the maximum modulating frequency. This rule represents an additive combination of the bandwidth expressions for extreme high $(B_1 \sim 2D = 2aM)$ and low $(B_1 \sim 2M)$ modulation index conditions. One of these two expressions prevails over the other for $\alpha >> 1$ or $\alpha << 1$, so that their linear superposition always yields the bandwidth measure for extreme index conditions.

An accepted relationship between analog FM bandwidth and a measure of performance such as allowable distortion as a function of the modulation index is not available. There is no distortion measure or criterion that is generally accepted for evaluation purposes, because of difficulties arising from the variety of modulating signal characteristics and models that occur in practice.

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[1] Individual formulas may be based on theoretical models for the modulation technique.

The normalized FM bandwidth (B1/M) for single tone sinusoidal modulation is shown in Figure 1 for various power percentages included. Each stepped line corresponds to a fixed power percentage (p). The solid stepped line represents p=99% power included. The normalized bandwidth based on Carson's Rule is given by (B1/M) =2(a+1), shown in Figure 1 by the solid straight line. Carson's Rule essentially follows the p=99% line for indices in the 0.9 < a < 4.3 range. It also includes more power at lower indices, but falls progressively below the 99% power curve at higher indices outside this range.

The case of a random modulating signal with a uniform baseband spectrum has also been analyzed using included power as the band-limiting distortion criterion. A peak to rms load ratio of 11 dB has been assumed to simulate representative conditions of FDM/FM telephony. The resultant normalized bandwidth can be estimated by (B1/M) = 2Z(a,q) where Z is a function of "a" and the fractional power rejected q=1-(p/100) as follows (Refs b and c):

$$Z(q,a) = a\left\lfloor\sqrt{1-\log_{(q^{5/7}\cdot 3^3)} - 0.05}\right\rfloor + 0.75$$

This expression is an effective approximation to a complicated integral formulation for moderate index values (1 < a < 5). The normalized bandwidth (B1/M) is shown in Figure 2 for various (q) values, along with the bandwidth formula corresponding to Carson's Rule. The latter can be noted to represent a power rejection in the $10^{-10} < q < 10^{-8}$ range, which is negligible.

The modulation cases shown in Figures 1 and 2 are extreme energy distribution conditions, in that one has all the baseband energy concentrated on a single frequency while the other has it spread uniformly over the baseband. The implication of Figures 1 and 2 is that Carson's Rule represents an effective bound to calculating analog FM bandwidth from a power included standpoint for modulation indices below five. The results also indicate that Carson's Rule includes considerably more power when the baseband modulation has a spread rather than concentrated spectral characteristic. Carson's Rule represents a q=0.01 power rejection for simple sinusoidal modulation, and $10^{-10} < q < 10^{-8}$ power rejection for a random modulation with a uniform baseband spectrum.

The necessary bandwidth of analog FM systems with modulation indices greater than 5.0 should be based on the methods of subparagraphs 2, 3 and 4 of the above GENERAL section.

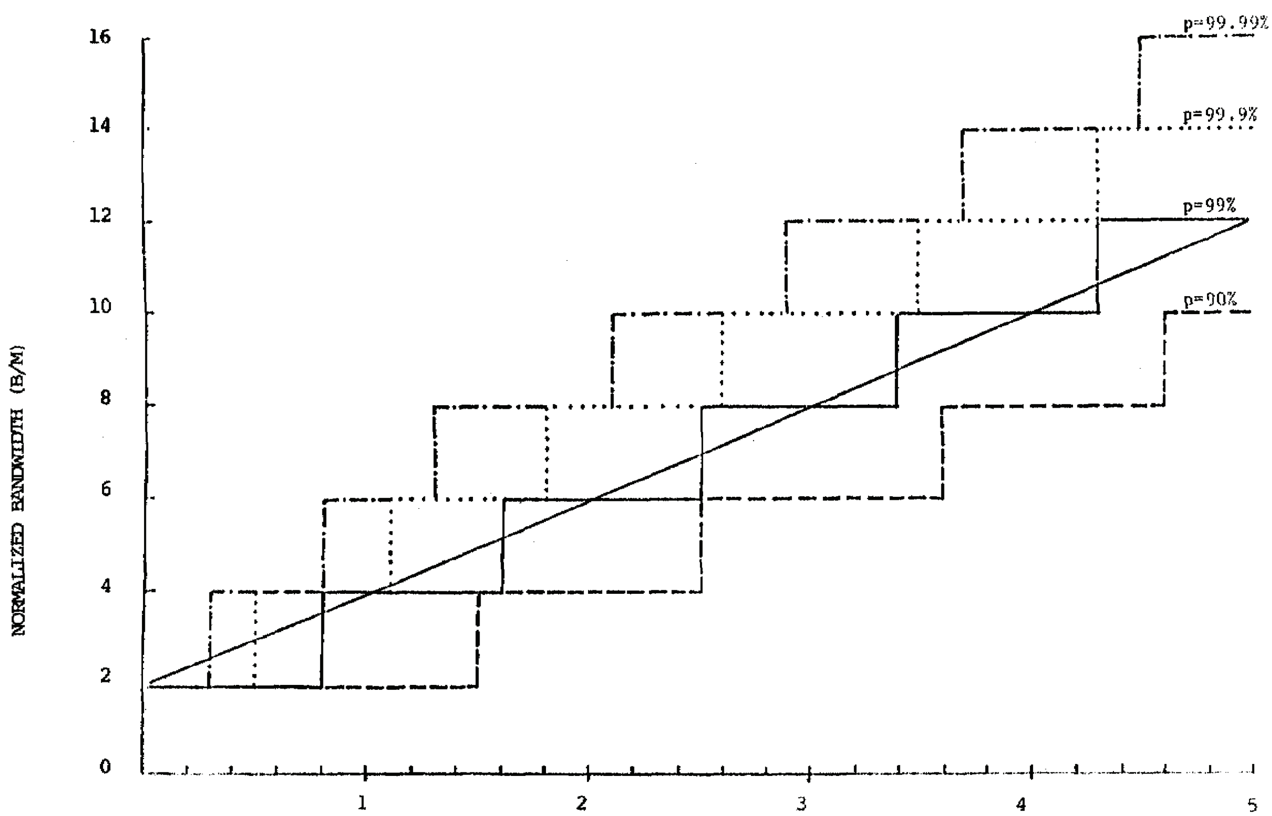
See References a, b, and c.

J.5 SYMBOLS

As appropriate, the following table shall be used for calculation of necessary bandwidth. The following symbols are used in this table:

- B = Digital symbol rate for telegraphy (i.e. baud)
- Bc = Bandwidth of the frequency deviation (the total frequency shift during the pulse duration) in MHz.
- Bd = Bandwidth of the frequency deviation (peak difference between instantaneous frequency of the modulated wave and the carrier frequency for FM/CW radar systems)
- Bn = Necessary bandwidth
- C = Sub-carrier frequency
- Cmax = Highest sub-carrier frequency used.
- CS = Separation in frequency between adjacent sub-carriers or carriers of a multi-carrier modulation.
- D = Peak deviation, i.e., half the difference between the maximum and minimum values of the instantaneous frequency.
- Fp = Continuity pilot sub-carrier frequency (continuous signal utilized to verify performance of frequency-division multiplex systems).

K =	An overall numerical factor which varies according to the emission and which depends upon the allowable signal distortion.
M =	Maximum modulation frequency
Nc =	Number of baseband channels in radio systems employing multichannel multiplexing.
NS =	Number of Sub-carriers.
R =	Total bit rate, which includes data, encoding, and any other overhead bits.
S =	Number of equivalent non-redundant signaling states.
t =	Emitted pulse duration in µsec at 50% amplitude (voltage) points. The 100% amplitude is the nominal peak level of the pulse.
tf =	Emitted pulse fall time in µsec from the 90% to the 10% amplitude points on the trailing edge.
tr =	Emitted pulse rise time in µsec from the 10% to the 90% amplitude points on the leading edge.
X =	Average "talker power level" (in dBm0) used to determine the peak frequency deviation in FM/FDM systems. These values are normally specified by the equipment manufacturer (see Table B later in this annex for more information).



MODULATION INDEX (a)

FIGURE 1. FM Bandwidth Occupancy and Power Preservation with Sinusoidal Modulation

(Note: Carson's Rule is the Straight Line)

(Legend: p is the Power Percentage Preserved)

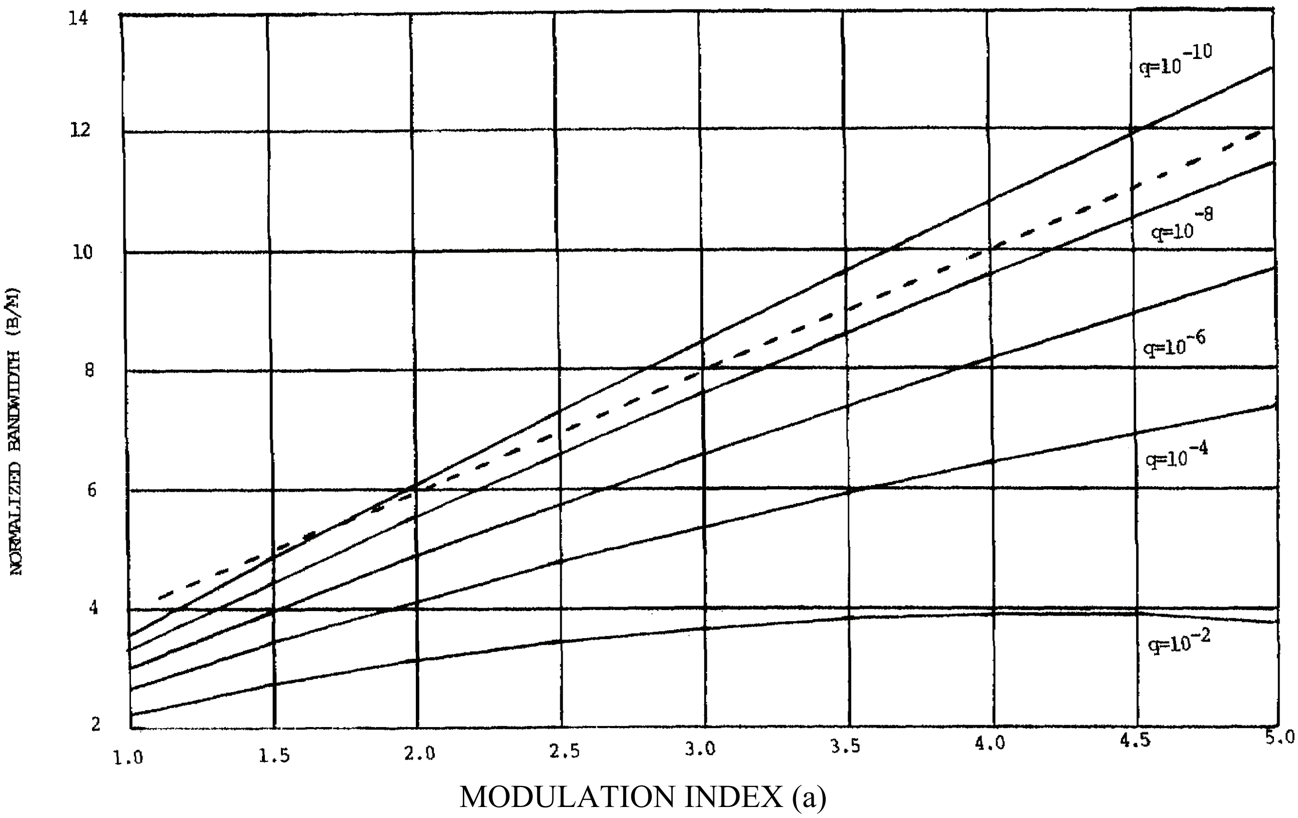


FIGURE 2. FM Bandwidth Occupancy and Power Preservation with Band-Limited White Modulation

(Note: Carson's Rule is the Dotted Line)

(Legend: q is the Power Fraction Rejected)

TABLE A. Necessary Bandwidth Calculations

Description of Emission	Formula	Sample Calculation	Sample Emission Designator
NO MODULATION			
Continuous wave emission	$B_n = 0$	Satellite downlink beacon	N0N
CW radars [2]	$B_n = 0$	Speed measuring CW radar $B_n = 0$ Hz	0H00N0N
ANALOG			
Amplitude Modulation			
Broadcasting			
Sound broadcasting, double-sideband	$B_n = 2M$ M may vary between 4000 and 10000 depending on the quality desired	Speech and music $M = 4000$ $B_n = 8000$ Hz = 8 kHz	8K00A3EGN

2 The emission bandwidth of a CW transmitter typically will not be zero due to noise and other considerations. However, designating zero as the necessary bandwidth is a valid method for identifying such equipment.

Description of Emission	Formula	Sample Calculation	Sample Emission Designator
Sound broadcasting, single-sideband, suppressed carrier	$B_n = M$ (lowest modulation frequency)	Speech and music $M = 4500$ lowest modulation frequency = 50 Hz $B_n = 4450$ Hz = 4.45 kHz	4K45J3EGN
Sound broadcasting, singlesideband, reduced carrier (single channel)	$B_n = M$ M may vary between 4000 and 10000 depending on the quality desired	Speech and music $M = 4000$ $B_n = 4000$ Hz = 4 kHz	4K00R3EGN
Radio Relay			
Double-sideband radiorelay system, frequency division multiplex	$B_n = 2M$	10 voice channels occupying base band between 1 kHz and 164 kHz $M = 164000$ $B_n = 328000$ Hz = 328 kHz	328K00A8E
Double-sideband, television relay	$B_n = 2C + 2M + 2D$	Video limited to 5 MHz, audio on 6.5 MHz frequency modulated subcarrier, subcarrier deviation = 50 kHz: $C = 6.5\ \ 10^6 \quad D = 50\ \ 10^3$ Hz $M = 15000$ $B_n = 13.13\ \ 10^6$ Hz = 13.13 MHz	13M13A8W
Telephony			
Telephony, doublesideband (single channel)	$B_n = 2M$	$M = 3000$ $B_n = 6000$ Hz = 6 kHz	6K00A3EJN
Telephony, independent sideband (two or more chan nels)	B_n = sum of M for each side band	2 channels $M = 3000 \quad B_n = 6000$ Hz = 6 kHz	6K00B8EJN
Telephony, single-sideband, full carrier (single channel)	$B_n = M$	$M = 3000$ $B_n = 3000$ Hz = 3 kHz	3K00H3EJN
Telephony, single-sideband, suppressed carrier (single channel)	$B_n = M$ (lowest modulation frequency)	$M = 3000$ lowest modulation frequency = 300 Hz $B_n = 2700$ Hz = 2.7 kHz	2K70J3EJN
Telephony with privacy, sin gle-sideband, suppressed carrier (two or more chan nels)	Bn = Nc M (lowest modulation frequency in the lowest channel)	$Nc = 2$ $M = 3000$ lowest modulation frequency = 250 Hz $B_n = 5750$ Hz = 5.75 kHz	5K75J8EKF
Telephony with separate fre quency modulated signal to control the level of demodu lated speech signal, single-sideband, reduced carrier (Lincompex) (single chan nel)	$B_n = M$	Maximum control frequency = 2990 Hz $M = 2990$ $B_n = 2990$ Hz = 2.99 kHz	2K99R3ELN
Television			
Television, vision and sound	Refer to Recommendations ITU-R BT.470 and BO.650 for the bandwidths of the com monly used television sys tems.[3]	Number of lines = 525 Number of lines per second = 15,750 Video bandwidth: 4.2 MHz Total visual bandwidth: 5.75 MHz FM aural bandwidth including guard bands: 250 kHz Total bandwidth: 6 MHz	5M75C3F 250K0F3EGN

3 ITU-R Recommendations and other publications are available on the internet at http://www.itu.int/ITU-R/pub lications/index.html.

Description of Emission	Formula	Sample Calculation	Sample Emission Designator
		Miscellaneous	
Double-sideband emission of VOR with voice (VOR: VHF omnidirec tional radio range)	$B_n = 2Cmax + 2M + 2DK$ $K = 1$ (typically)	The main carrier is modulated by: a 30 Hz sub-carrier a carrier resulting from a 9960 Hz tone frequency modulated by a 30 Hz tone a telephone channel a 1020 Hz keyed tone for con tinual Morse identification $Cmax = 9960$ $M = 30$ $D = 480$ Hz $B_n = 20940$ Hz = 20.94 kHz	20K9A9WWF
		Angle Modulation	
		Broadcasting	
Sound broadcasting	$B_n = 2M + 2DK$ $K = 1$ (typically)	Monaural $D = 75000$ Hz $M = 15000$ $B_n = 180000$ Hz = 180 kHz	180KF3EGN
Stereophonic sound broad casting with multiplexed subsidiary telephony sub-carrier	$B_n = 2M + 2DK$ $K = 1$ (typically)	Pilot tone system; $M = 75000$ $D = 75000$ Hz $B_n = 300000$ Hz = 300 kHz	300K0F8EHF
		Radar	
FM/CW radars	$B_n = 2Bd$	FM-CW Doppler radar sweeps ±100 MHz from center frequency over a sweep duration of 50 msec. $B_n = 200$ MHz	200MF3N
		Radio Relay	
Radio-relay system; frequency division multiplex	$B_n = 2M+2DK$ K = 1 (typically)	960 data channels that operate at a uniform power level of -15 dBm occupying baseband between 60 kHz and 4028 kHz; rms per channel deviation: 200 kHz; continuity pilot at 4715 kHz produces 140 kHz rms deviation of main carrier.[4] X = -15 D = (200 x 103) (3.76) (5.5) = 4.14 x 106 Hz; M = 4.028 x 106; f_p = 4.715 x 106, (2M+2DK) > $2f_p$ B_n = 16.34 x 106 Hz = 16.34 MHz	16M3F8DJF
Radio-relay system, fre quency division multiplex	$B_n = 2f_p$	600 telephone channels occupying baseband between 60 kHz and 2540 kHz; rms per-channel deviation: 200 kHz continuity pilot at 8500 kHz pro duces 1440 kHz rms deviation of main carrier. For X = -19.6: D = (200x103) (3.76) (2.56) = 1.93 x 106 Hz	17M0F8EJF

4 See the Table B instructions.

Description of Emission	Formula	Sample Calculation	Sample Emission Designator
		M = 2.54x106 K = 1 f_p = 8.5x106 Use 2f_p since it is > (2M+2DK). Bn = 17 x 106 Hz = 17 MHz	
Radio-relay systems, fre quency division multiplex	$B_n = 2 f_p$ +2DK K = 1 (typically)	60 all voice telephone channels occupying baseband between 60 kHz and 300 kHz; rms per-channel deviation: 200 kHz; continuity pilot at 331 kHz produces 100 kHz rms deviation of main carrier For X = -5.6: D = (200 x 103)(3.76)(1.19) = 8.95 x 105 Hz; M = 0.3 x 106 f_p = 0.331 x 106 Hz Use 2f_p + 2DK since f_p > M. B_n = 2.45 x 106 Hz=2.45 MHz	2M45F8EJF
Telephony			
Commercial telephony	$B_n = 2M + 2DK$ K = 1 (typically, but under certain conditions a higher value of K may be necessary)	For an average case of commercial telephony, D = 5000 Hz M = 3000 B_n = 16000 Hz = 16 kHz	16K0F3EJN
Digital			
Amplitude Modulation			
Telegraphy			
Continuous wave telegraphy, Morse code	B_n = BK K = 5 for fading circuits K = 3 for non-fading circuits	25 words per minute $B = 20$, $K = 5$ B_n = 100 Hz	100H0A1AAN
Telegraphy by on-off key ing of a tone modulated car rier, Morse code	$B_n = BK + 2M$ K = 5 *for* fading circuits K = 3 for non-fading circuits	25 words per minute $B = 20$, $M = 1000$, $K = 5$ B_n = 2100 Hz = 2.1 kHz	2K10A2AAN
Independent sidebands; sev eral telegraph channels with error-correction together with several telephone chan nels with privacy; frequency division multiplex	B_n = sum of M for each side band	Normally composite systems are operated in accordance with stan dardized channel arrangements (e.g. Rec. ITU-R F.348). 3 telephone channels and 15 teleg raphy channels require the bandwidth: 12000 Hz = 12 kHz	12K0B9WWF
Selective calling signal using sequential single frequency code, single-sideband full carrier	$B_n = M$	Maximum code frequency is: 2110 Hz M = 2110 B_n = 2110 Hz = 2.11 kHz	2K11H2BFN
Direct-printing telegraphy using a frequency shifted modulating sub-carrier, with error-correction, single-side band, suppressed carrier (single channel)	$B_n = 2M + 2DK$ $M = \frac{B}{2}$	$B = 50$ D = 35 Hz (70 Hz shift) $K = 1.2$ B_n = 134 Hz	134H0J2BCN
Telegraphy, multichannel with voice frequency, errorcorrection, some chan nels are time-division multi plexed, single-sideband, reduced carrier	B_n = (highest central frequency) + $M + DK$ $M = \frac{B}{2}$	15 channels; highest central frequency is: 2805 Hz $B = 100$ D = 42.5 Hz (85 Hz shift) $K = 0.7$ B_n = 2885 Hz = 2.885 kHz	2K89R7BCW

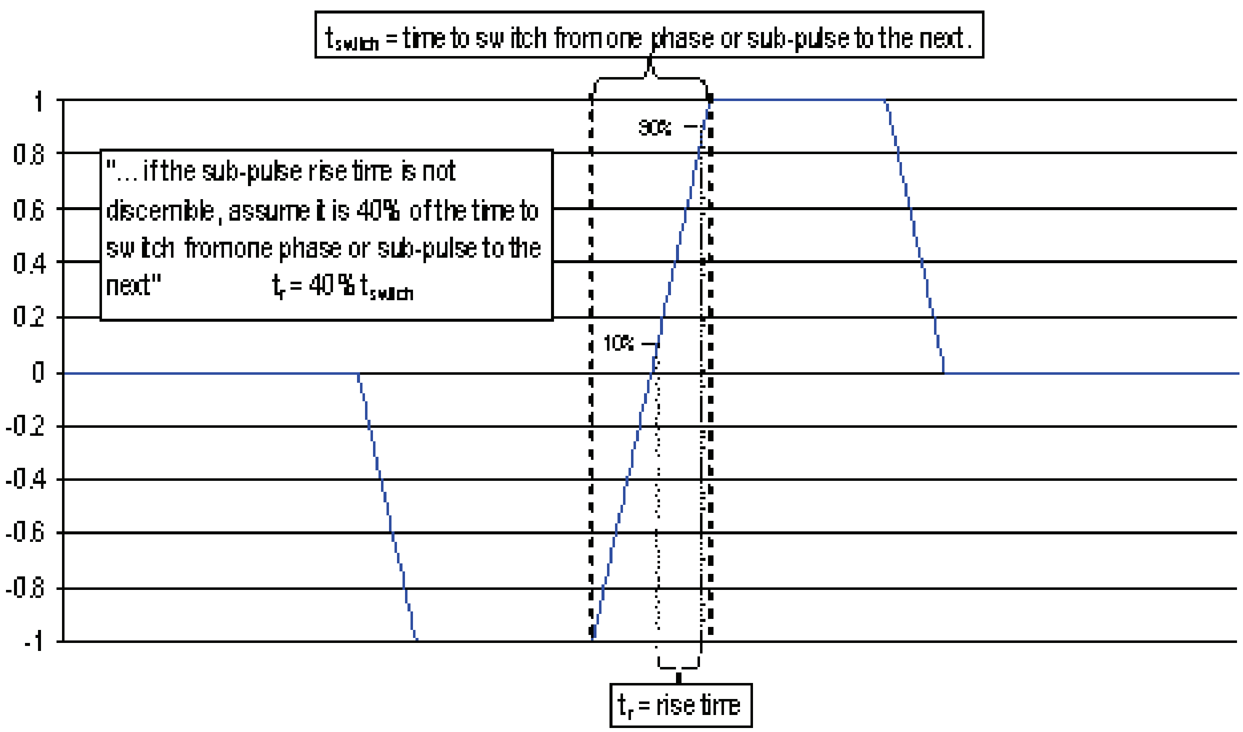
Description of Emission	Formula	Sample Calculation	Sample Emission Designator
Angle Modulation			
Telegraphy			
Telegraphy, narrow-band directprinting with errorcorrection (single channel) or Selective calling signal	$B_n = 2M + 2DK$ $M = \frac{B}{2}$ $K = 1.2$ (typically)	$B = 100$ $D = 85$ Hz (170 Hz shift) $B_n = 304$ Hz	304H0F1BCN
Telegraphy without error-correction (single channel)	$B_n = 2M + 2DK$ $M = \frac{B}{2}$ $K = 1.2$ (typically)	$B = 100$ $D = 85$ Hz (170 Hz shift) $B_n = 304$ Hz	304H0F1BBN
Four-frequency duplex teleg raphy	$B_n = 2M + 2DK$ B = modulation rate in bauds of the faster channel. If the channels are synchronized: $M = \frac{B}{2}$ (otherwise, $M = 2B$) $K = 1.1$ (typically)	Spacing between adjacent frequencies = 400 Hz Synchronized channels $B = 100$ $M = 50$ $D = 600$ Hz $B_n = 1420$ Hz = 1.42 kHz	1K42F7BDX
Miscellaneous			
Binary Frequency Shift Key ing [5]	If $\left(0.03 < \frac{2D}{R} < 1.0\right)$ Then $B_n = 3.86D + 0.27R$ If $\left(1.0 < \frac{2D}{R} < 20\right)$ Then $B_n = 2.4D + 1.0R$	Digital modulation used to send 1 megabit per second by frequency shift keying with 2 signaling states and 0.75 MHz peak deviation of the carrier. R = 1x106 bits per second; D = 0.75x106 Hz; B_n = 2.8 MHz	2M80F1DBC
Multilevel Frequency Shift Keying	$B_n = \frac{R}{\log_2 S} + 2DK$ $K \leq 0.89$ (99% bandwidth, Bn=R/$\log_2$S + 1.78D)	Digital modulation to send 10 Mbps by use of frequency shift keying with 4 signaling states and 2 MHz peak deviation of the main carrier. R = 107 bps; D = 2 MHz; K = 0.89; S = 4; B_n = 8.56 MHz	8M56F1DDT
Gaussian Minimum Shift Keying (GMSK)	$B_n = \frac{R}{\log_2 S} + 0.5RK$ $K \leq 0.28$ (99% bandwidth, B_n=(1/$\log_2$S 0.14)R)	Digital modulation used to send 10 megabits per second by use of GMSK (S=2) R=10x106 bits per second; B_n = 8.6 MHz	8M60G1DDN
Minimum Shift Keying	$B_n = \frac{R}{\log_2 + 0.5RK}$	Digital modulation used to send 2 megabits per second using 2-ary minimum shift keying:	2M36G1DBN

5 See References g, h, and i for further details.

Description of Emission	Formula	Sample Calculation	Sample Emission Designator
	$K \leq 0.36$ (99% bandwidth, $B_n = (1/\log_2 S + 0.18)R$)	R = 2Mbps S = 2 B_n = 2.36x106 Hz = 2.36 MHz	
Feher-patented Quadrature Phase Shift Key ing (FQPSK-B)	$B_n = 0.78R$	Digital modulation to send 10 megabits per second by use of FQPSK-B R = 10x106 bits per second; B_n = 7.8 MHz	7M80G1DDN
Phase Shift Keying	$B_n = 2RK / \log_2 S$ $0.5 \leq K \leq 1$ K = 0.7 to 0.8 (typically) [6]	Digital modulation used to send 10 megabits per second by use of phase shift keying with 4 signaling states R = 10x106 bits per second; K = 1; S = 4; B_n = 10 MHz	10M00G1DDT
Quadrature Amplitude Modulation (QAM)	$B_n = \frac{2RK}{Log_2 S}$ $K \leq 0.81$ (99% bandwidth, $B_n = 1.62R / \log_2 S$)	64 QAM is used to send 135 Mbps; R = 135x106 bps; S = 64; Roll-off = 1; K = 0.81 B_n = 36.45 MHz	36M45D1D
Orthogonal Frequency Divi sion Multiplexing (OFDM)	$B_n = (NS + 16.25)CS$ $NS > 16$	OFDM is used to send 20 Mbps. Guard time is 0.8 ìs. 48 sub-carri ers are used, each spaced 250 kHz apart. 16-QAM is used with rate ½ coding. B_n = (48 +16.25)0.25 = 16.1 MHz	16M1D1DEF
PULSED			
Radar			
Non-FM pulsed radars (including spread spectrum or coded pulse radars):[7]	*If* $\frac{t}{t_r} \langle 12.6$,then: $B_n = B(20dB) = \frac{1.79}{\sqrt{t_r t}}$ [8] *Otherwise:* $B_n = B(20dB) = \frac{6.36}{t}$	A radar transmits unmodulated pulses at 1172 pulses per sec. The pulse width is 1.03 *u*sec. Rise and fall times are 0.2 usec and 0.15 usec, respectively. Use tf since it is smaller than tr Since t is obviously less than 12.6 tf, use the first equation B_n = 4.55 MHz	4M55P0N
Phase coded pulse radars (including spread spec trum):10	If $\frac{t}{t_r} \langle 12.6$ then: $B_n = B(20dB) = \frac{1.79}{\sqrt{t_r t}}$, Otherwise: $B_n = B(20dB) = \frac{6.36}{\sqrt{t}}$	A Doppler pulse radar transmits 3000 pulses per second. The pulse width including a 13 bit Barker code is 6.6 µsec. Each chip has a 50% amplitude width of 0.5 µsec. Chip rise time is 0.02 µsec. Since t/t_r = 0.5/0.02 is obviously larger than 12.6, use the second equation:	12M7Q1N

6 The value for K here can theoretically vary from 0.5 to 1. For fixed microwave systems use of a value of K larger than 0.7 should be further justified.
7 For frequency hopping systems the necessary bandwidth is the instantaneous one of an individual channel.
8 If t_f is less than t_r, then t_f is to be used in place of tr when performing the necessary bandwidth calculations.

Description of Emission	Formula	Sample Calculation	Sample Emission Designator
		$B_n = 6.36 / 0.5 = 12.7 MHz$	
FM-pulse radars (intentional FM)10	$B_n = B(20dB) = \frac{1.79}{\sqrt{t_r t}} + 2B_c$	FM pulsed radar chirping over 2.89 MHz with a 25.6 usec pulse width and 150 nsec rise time B_n = 6.69 MHz	6M69Q3N
Composite Emissions			
Radio-relay system	$B_n = \frac{2K}{t}$ $K \leq 1.6$ [9]	Pulse position modulated by 36 voice channel baseband; pulse width at half amplitude = 0.4 ìsec B_n = 8 106 Hz = 8 MHz Bandwidth independent of the number of voice channels)	8M00M7EJT
Composite transmission digi tal modulation using DSB-AM (Microwave radio relay system)	$B_n = 2RK / \log_2 S$	Digital modulation used to send 5 megabits per second by use of amplitude modulation of the main carrier with 4 signaling states R=5 x 106 bits per second; K = 1; S = 4 B_n = 5 MHz	5M00K7DD



9 In this case *K* depends upon the ratio of pulse width to pulse rise time. Its value usually falls between 1 and 10 and in many cases does not need to exceed 6. K = 1.6 roughly corresponds to rise time equal to pulse width, which is typical for these systems.

FIGURE 3. Estimation of chip rise time for phase coded pulse signals

TABLE B. MULTIPLYING FACTORS FOR USE IN COMPUTING D, PEAK FREQUENCY DEVIATION, IN FM FREQUENCY DIVISION MULTIPLEX (FM/FDM) MULTI-CHANNEL EMISSIONS

For FM/FDM systems the necessary bandwidth is (for systems having no continuity pilot sub-carrier or having a continuity pilot sub-carrier whose frequency is not the highest modulating the main carrier):

$$B_n = 2M + 2DK$$

The value of *D*, or peak frequency deviation, in these formulas for B_n is calculated by multiplying the rms value of per-channel deviation by the appropriate "multiplying factor" shown below.

In the case where a continuity pilot of frequency f_p exists above the maximum modulation frequency, *M*, the general formula becomes:

$$B_n = 2f_p + 2DK$$

In the case where the modulation index of the main carrier produced by the pilot is less than 0.25, and the rms frequency deviation of the main carrier produced by the pilot is less than or equal to 70 percent of the rms value of per-channel deviation, or in a radio system for television, the rms deviation of the main carrier due to the pilot does not exceed 3.55 percent of the peak deviation of the main carrier, the general formula becomes either: $B_n = 2f_p$ or $B_n = 2M + 2DK$ whichever is greater.

The selection of the values used to determine the multiplying factor are highly dependent upon the information transfer requirements placed upon the FM/FDM systems. Available technical information indicates that (depending on the number of channels) a value of "X" of -2, - 5.6 or -19.6 should be appropriate for modern commercial telephone circuits where most of the channels are actual speech. In smaller or older FM/FDM systems and those where most of the circuits are used for data transmission, "X" values of +2.6, -1.0 or -15 should be appropriate since typical commercial multichannel data circuits operate at power levels from -13 to -15 dBm0.

Number telephone channels N_c	Multiplying factors	Limits of $X(P_{avg}(dBm0)$
$3 < N_c < 12$	4.47 x antilog x $\frac{x}{20}$ X= a value in dB specified by the equipment manufacturer or station licensee, subject to NTIA approval	Not applicable
$12 < N_c < 60$	3.76 antilog $\frac{(X+2 \log_{10} N_c)}{20}$	X: -2 to +2.6
$60 < N_c < 240$	3.76 antilog $\frac{(X+4 \log_{10} N_c)}{20}$	X: -5.6 to -1.0
$N_c > 240$	3.76 antilog $\frac{(X+10 \log_{10} N_c)}{20}$	X: -19.6 to -15.0

Where Nc is the number of circuits in the multiplexed message load; 4.47 corresponds to a peak load factor of 13.0 dB, and 3.76 corresponds to a peak load factor of 11.5 dB.

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