ANNEX J

Guidance for Determination of Necessary Bandwidth

1.1 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.

2.1 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.

3.1 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.

a. for non-FM pulsed radars[2] (including spread spectrum or coded pulse radars):

$$B(-20\text{dB}) = \frac{1.79}{\sqrt{t_r t}} \quad \text{or} \quad \frac{6.36}{t} \quad \text{whichever is less}$$

b. for FM-pulse radars (intentional FM)[2]

$$B(-20\text{dB}) = \frac{1.79}{\sqrt{t_r t}} + 2B_c$$

c. for CW radars[3] ***B(necessary) = 0***

---

1. Individual formulas may be based on theoretical models for the modulation technique.
2. If t_f is less than t_r, then t_f is to be used in place of t_r when performing the necessary bandwidth calculations.
3. The emission bandwidth of a CW transmitter typically will not be zero due to noise and frequency tolerance considerations. However, designating zero as the necessary bandwidth is a valid method for identifying such equipment.

d. for FM/CW radars ***B(necessary) = 2B_d***

Where:

B=necessary bandwidth in MHz.
B_c=bandwidth of the frequency deviation (the total frequency shift during the pulse duration) in MHz.
B_d=bandwidth of the frequency deviation (peak difference between instantaneous frequency of the modulated wave and the carrier frequency for FM/CW radar systems) in MHz.
B_s=maximum range in MHz over which the carrier frequency will be shifted for a frequency hopping radar.
t=emitted pulse duration in : sec at 50% amplitude (voltage) points. For coded pulses, the pulse duration is the interval between 50% amplitude points of one chip (sub-pulse). The 100% amplitude is the nominal flat top level of the pulse.
t_r=emitted pulse rise time in : sec from the 10% to the 90% amplitude points on the leading edge. For coded pulse, it is the rise time of a sub-pulse; if the sub-pulse rise time is not discernible, assume it is 40% of the time to switch from one phase or sub-pulse to the next.
t_f=emitted pulse fall time in μ sec from the 90% to the 10% amplitude points on the trailing edge.

2. Computation in accordance with ITU-R Appendix 1 and ITU-R M1138. If ITU Regulations are used, the value of K should be 4.5, for the formula B_n=2K/t.
3. Results of actual measurement.
4. Use of the best available technical information from other sources.

4.1 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 ~ 2D=2aM) and low (B_1 ~ 2M) modulation index conditions. One of these two expressions prevails over the other for $a \gg 1$ or $a \ll 1$, 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.

The normalized FM bandwidth (B_1/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 (B_1/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 $(B_1/M)=2Z(a,q)$ where Z is a function of "a" and the fractional power rejected q=1-(p/100) as follows (Refs b and c):

$$Z(q,a) = a[\sqrt{1-\log_{(q^{5/7}.3^3)}}-0.05] + 0.75$$

This expression is an effective approximation to a complicated integral formulation for moderate index values ($1 < a < 5$). The normalized bandwidth (B_1/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.

5.1 SYMBOLS

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

B_n=Necessary bandwidth

B =Digital symbol rate for telegraphy (i.e. baud)

N =Maximum possible number of black plus white elements to be transmitted per second, in facsimile

M= Maximum modulation frequency

C = Sub-carrier frequency

D = Peak deviation, i.e., half the difference between the maximum and minimum values of the instantaneous frequency.

t = Pulse duration in seconds at half-amplitude

K = An overall numerical factor which varies according to the emission and which depends upon the allowable signal distortion

N_c= Number of baseband channels in radio systems employing multichannel multiplexing

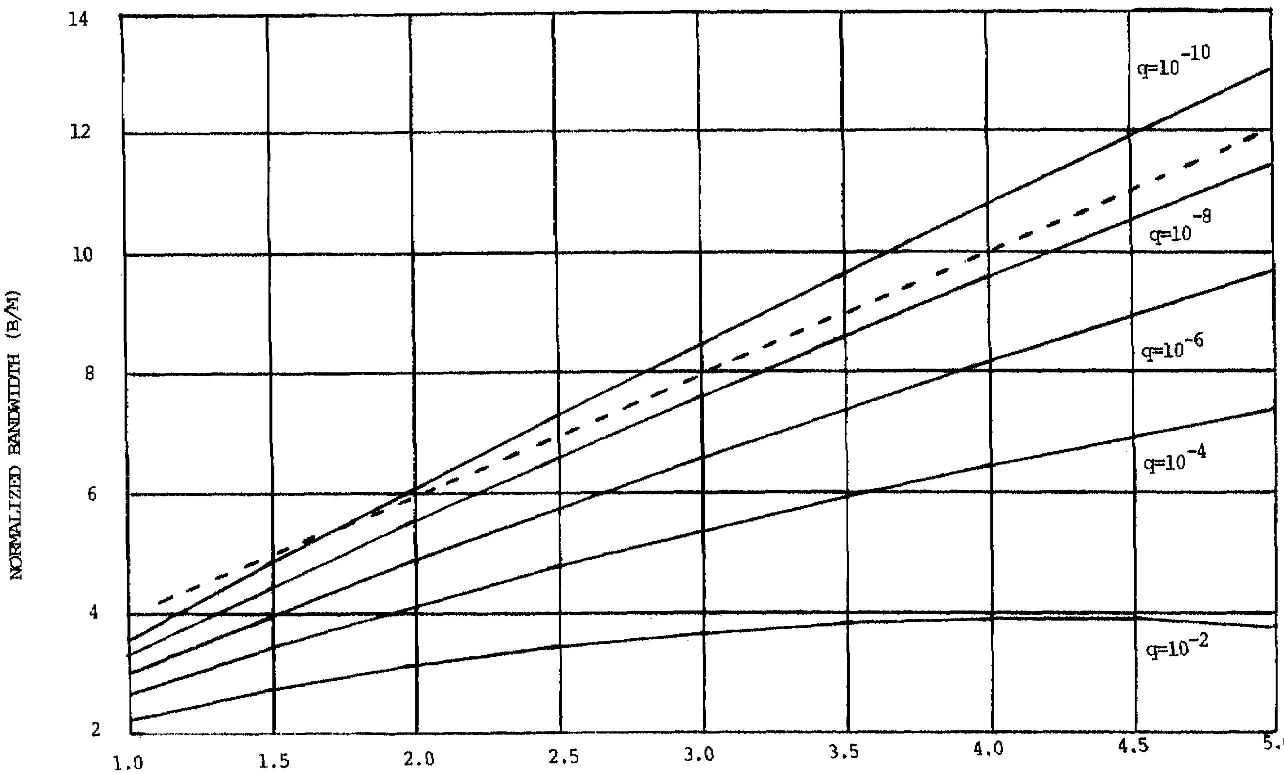
f_p = Continuity pilot sub-carrier frequency (continuous signal utilized to verify performance of frequency-division multiplex systems).

P = Continuity pilot sub-carrier frequency in hertz[4]

R = Digital information rate

S = Number of equivalent non-redundant signaling states.

4. The frequency (P) of a continuity pilot sub-carrier in frequency modulated radio relay systems may exceed M.

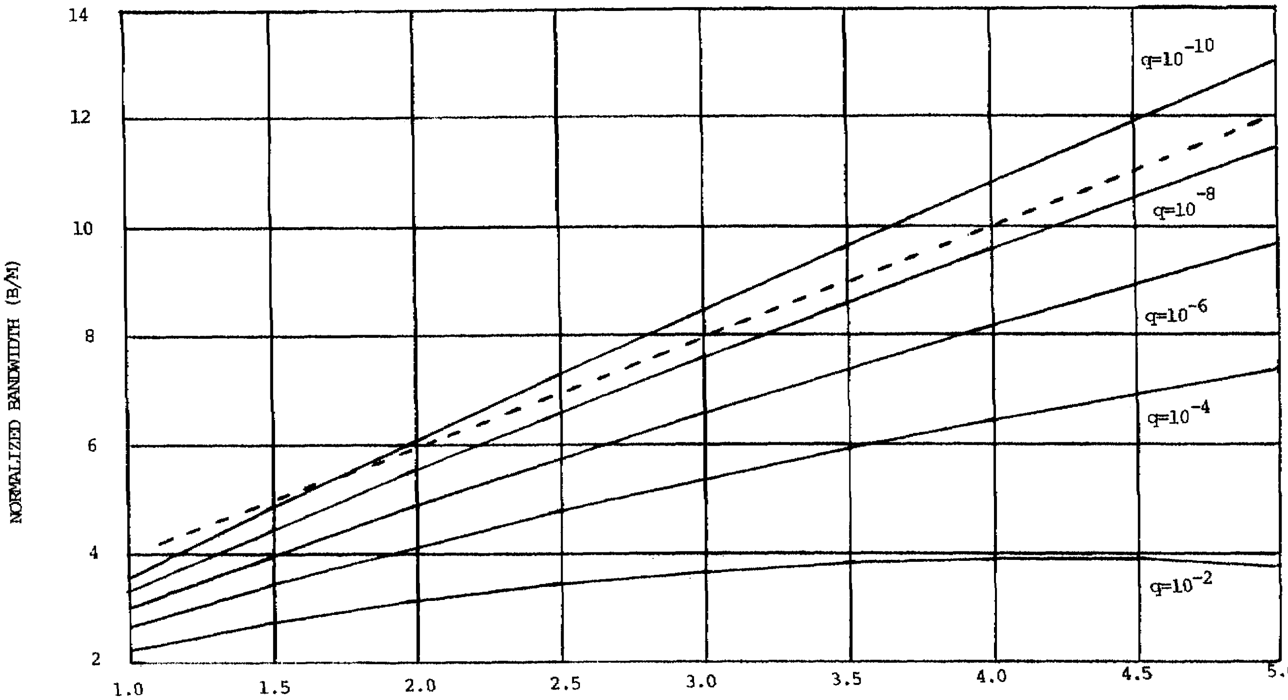


MODULATION INDEX (a)

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)



MODULATION INDEX (a)

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

I. UNMODULATED SIGNAL

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Continuous wave emission	--	--	N0N

II. AMPLITUDE MODULATION

1. Signal with Quantized or Digital Information

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
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	100H00A1AAN
Telegraphy by on-off keying of a tone modulated carrier, 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
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-sideband, 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	134H00J2BCN
Telegraphy, multi-channel with voice frequency, error correction, some channels are time-division multiplexed, single-sideband, reduced carrier	B_n=(highest central frequency) + M + DK; $M = \frac{B}{2}$	15 channels; highest central is: 2805 Hz, B=100, D=42.5 Hz (85 Hz shift), K=0.7; B_n=2885 Hz=2.885 kHz	2K89R7BCW

2. Telephony (Commercial Quality)

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Telephony, double-sideband (single channel)	B_n=2M	M=3000 B_n=6000 Hz=6 kHz	6K00A3EJN
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 is 300 Hz; B_n=2700 Hz=2.7 kHz	2K70J3EJN
Telephony with separate frequency modulated signal to control the level of de-modulated speech signal, single-sideband, reduced carrier (Limcompex) (single channel)	B_n=M	Maximum control frequency is 2990 Hz, M=2990; B_n =2990 Hz=2.99 kHz	2K99R3ELN

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Telephony with privacy, single-sideband, suppressed carrier (two or more channels)	$B_n = N_c M$ lowest modulation frequency in the lowest channels	$N_c = 2$, $M = 3000$, lowest modulation frequency is 250 Hz; $B_n = 5750 = 5.75$ kHz	5K75J8EKF
Telephony independent sideband (two or more channels)	B_n = sum of M for each side-band	Two channels, $M = 3000$; $B_n = 6000$ Hz = 6 kHz	6K00B8EJN

3. Sound Broadcasting

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Sound broadcasting double-side-band	$B_n = 2M$, M may vary between 4000 and 10000 depending on the quality desired	Speech and music, $M = 4000$; $B_n = 8000$ Hz = 8 kHz	8K00A3EGN
Sound broadcasting, single-side-band 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
Sound broadcasting, single-side-band, 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

4. Television

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Television, vision and sound	Refer to Recommendations ITU-R BT.470-3 (1994) and BO. 650 (1994) for the bandwidths of the commonly used television systems	Number of lines = 525; Number of lines per second = 15,750; Video bandwidth: 4.2 MHz; Total visual band-width: 5.75 MHz; FM aural bandwidth including guardbands: 250 kHz Total bandwidth: 6 MHz	5M75C3F; 250K00F3EGN; 6M25C3F

5. Facsimile

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Analog facsimile by sub-carrier frequency modulation of a single-sideband emission with reduced carrier, monochrome	$B_n = C + \frac{N}{2} + DK$ K=1.1 (typically)	N=1100, corresponding to an index of cooperation of 352 and a cycler rotation speed of 60 rpm. Index of cooperation is the product of the drum diameter and number of lines per unit of length; C=1900, D=400 Hz; B_n=2890 Hz=2.89 kHz	2K89R3CMN
Analog facsimile; frequency modulation of an audio frequency sub-carrier which modulates the main carrier, single-sideband suppressed carrier	B_n=2M+2DK; $M = \frac{N}{2}$ K=1.1 (typically)	N=1100, D=400 Hz; B_n=1980 Hz=1.98 kHz	1K98J3C

6. Composite Emissions

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Double-sideband television relay	$B_n=2C+2M+2D$	Video limited to 5 MHz, audio on 6.5 MHz frequency modulation sub-carrier, sub-carrier deviation=50 kHz $C=6.5X10^6$ $D=5X10^3$ Hz $M=15000$ $B_n=13.13X10^6$ Hz=13.13 MHz	13M10A8W
Double-sideband radio-relay system, frequency division multiplex	$B_n=2M$	10 voice channels occupying baseband between 1 kHz and 164 kHz; $M=164000$ $B_n=328000$ Hz=328 kHz	328K00A8E
Double-sideband emission of VOR with voice (VOR=VHF omni-directional radio range)	$B_n=2C_{max}+2M+2DK$; 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 continual Morse identification $C_{max}=9960$, $M=30$, D=480 Hz $B_n=20940$ Hz=20.94 kHz	20K90A9WWF
Independent sidebands; several telegraph channels with error-correction together with several telephone channels with privacy; frequency division multiplex	B_n=sum of M for each sideband	Normally composite systems are operated in accordance with standardized channel arrangements (e.g. ITU-R Rec. 348-4 (1994)). 3 telephone channels and 15 telegraphy channels require the bandwidth 12000 Hz=12 kHz	12K00B9WWF

III. ANGLE MODULATION

1. Signal with Quantized or Digital Information

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
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	304H00F1BBN
Telegraphy, narrow-band direct-printing with 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	304H00F1BCN
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	304H00F1BCN
Four-frequency duplex telegraphy	$B_n=2M+2DK$, 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

2. Telephony (Commercial Quality)

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Commercial telephony	$B_n=2M+2DK$, K=1 (typically, but under certain conditions a higher value may be necessary)	For an average case of commercial telephony: D=5000 Hz, M=3000 $B_n=16000$ Hz=16 kHz	16K00F3EJN

3. Sound Broadcasting

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Sound Broadcasting	$B_n=2M+2DK$, $K=1$ (typically)	Monaural $D=75000$ Hz, $M=15000$ $B_n=180000$ Hz$=180$ kHz	180K00F3EGN

4. Facsimile

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Facsimile by direct frequency modulation of the carrier; black and white	$B_n=2M+2DK$; $M = \frac{B}{2}$ $K=1.1$ (typically)	$N=1100$ elements/ sec, $D=400$ Hz; $B_n=1980$; Hz$=1.98$ kHz	1K98F1C
Analogue facsimile	$B_n=2M+2DK$; $M=N$ OVER 2 $K=1.1$ (typically)	$N=1100$ elements/ sec, $D=400$ Hz; $B_n=1980$; Hz$=1.98$ kHz	1K98F3C

5. Composite Emissions

Necessary Bandwidth[a]			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Radio-relay systems, frequency division multiplex	$B_n=2f_p+2DK$ $K=1$ (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 $X=-5.6$: $D=(200X10^3)(3.76)(1.19)=8.95X10^5$ Hz; $f_p=0.331X10^6$ Hz; $B_n=2.45X10^6$ Hz$=2.45$ MHz	2M45F8EJF

Necessary Bandwidth[a]			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Radio-relay system; frequency division multiplex	$B_n=2M+2DK$ $K=1$ (typically)	960 all voice telephone channels 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 For $X=-19.6$: $D=(200X10^3)$ (3.76) $(3.24)=2.43X10^6$ Hz; $M=4.028X10^6$; $f_p=4.715X10^6$; $(2M+2DK)>2f_p$; $B_n=12.9X10^6$ Hz$=12.9$ MHz	12M9F8EJF
Radio-relay system, frequency division multiplex	$B_n=2f_p$	600 all voice telephone channels occupying baseband between 60 kHz and 2540 kHz; rms per channel deviations: 200 kHz; continuity pilot at 8500 kHz produces 1440 kHz rms deviation of main carrier For $X=-19.6$: $D=(200X10^3)$ (3.76) $(2.56)=1.92X10^6$ Hz; $M=2.54X10^6$, $K=1$; $f_p=8.5X10^6$; $(2M+2DK)<2f_p$; $B_n=17X10^6$; Hz$=17$ MHz	17M00F8EJF
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 $D=200X10^3$ (3.76) $(5.5)=$ $4.13X10^6$ Hz; $M=4.028X10^6$; $f_p=4.715X10^6$, $(2M+2DK)>2f_p$; $B_n=16.32X10^6$ Hz$=16.32$ MHz	16M32F8DJF

Necessary Bandwidth[a]			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Stereophonic sound broadcasting with multiplexed subsidiary telephone sub-carrier	$B_n=2M+2DK$ $K=1$ (typically)	Pilot tone system; $M=75000$, $D=75000$ Hz $B_n=300000$ Hz$=300$ kHz	300K00F8EHF
TV microwave relay system	$B_n=2M+2DK$ $K=1$ (typically)	Aural program on 7.5 MHz, aural sub-carrier deviation “150 kHz; continuity pilot at 8.5 MHz produces 140 kHz rms deviation of main carrier; $D=3.7X10^6$ Hz (visual) plus $0.3X10^6$ Hz (aural) Computation of B_n: $M=(2.0+0.2)X10^6$; $P=8.5X10^6$ Hz; $D=(3.7+0.3)X10^6$ Hz; $(2M+2DK)>2P$ $B_n=23.3X10^6$ Hz$=23.3$ MHz	23M3F3WJF
TV microwave relay system	$B_n=2P$	Aural program on 6.9 MHz sub-carrier; aural sub-carrier deviation “150 kHz; continuity pilot at 8.5 MHz produces 50 kHz rms deviation of main carrier $D=2X10^6$ (visual) plus $0.2X10^6$ (aural); Computation of B_n: $M=(2.0+0.2)X10^6$ Hz; $D=6.16X10^6$ Hz; $K=1$; $P=8.5X10^6$; $(2M+2DK)<2P$ $B_n=17X10^6$ Hz$=17$ MHz	17M00F3WJF
Binary Frequency Shift Keying[b]	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 sates and 0.75 MHz peak deviation of the carrier. $R=1X10^6$ bits per second; $D=0.75X10^6$ Hz; $B_n=2.8$ MHz	2M80F1DBC

Necessary Bandwidth[a]			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Multilevel Frequency Shift Keying	$B_n=(R/\log_2 S) + 2DK$ $K \leq 0.89$ (99% bandwidth, $B_n=R/\log_2 S + 1.78D$)	Digital modulation to send 10 megabits per second by use of frequency shift keying with four signaling states and 2 MHz peak deviation of the main carrier $R=10X10^6$ bits per second; D=2 MHz; K=0.89; S=4; B_n=8.56 MHz	8.56MF1DDT
Phase Shift Keying	$B_n=2RK/\log_2 S$ $0.5 \leq K^1 \leq 1$ K=0.7 to 0.8 (typically[c])	Digital modulation used to send 10 megabits per second by use of phase shift keying with 4 signaling states $R=10X10^6$ bits per second; K=1; S=4; $B_n=10$ MHz[6]	10M00G1DDT
Minimum Shift Keying	$B_n=R/\log_2 S + 0.5RK$ $K \leq 0.36$ (99 % bandwidth, $B_n=(1/\log_2 S + 0.18)R$)	Digital modulation used to send 2 megabits per second using 2-ary minimum shift keying: R=2Mbps S=2 $B_n=2.36X10^6$ Hz=2.36 MHz	2M36G1DBN

a. See Table B for FM/FDM multiplying factors when "D" is not known.
b. See References g, h, and i for further details.
c. The value of K here can theoretically vary from .5 to 1. For fixed microwave systems use of a value of K larger that 0.7 should be further justified.

IV. AMPLITUDE-MODULATED AND ANGLE-MODULATED

1. Quadrature Amplitude Modulation

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Quadrature Amplitude Modulation (QAM)	$B_n=2RK/\log_2 S$ $K \leq 0.81$ (99% bandwidth, $B_n = 1.62\ R/\log_2 S$)	64 QAM is used to send 135 Mbps; $R=135X10^6$ bps; S=64; Roll off=1 K=0.81 B_n=36.45 MHz	36M45D1D

V. PULSE MODULATION

1. Radar

See paragraph 3.1 of this Annex for specific instruction on calculating necessary bandwidth for RADARS.

2. Composite Emissions

Necessary Bandwidth			
Description of Emission	Formula	Sample Calculation	Designation of Emission
Radio-relay system	$B_n = \frac{2K}{t}$ K=1.6	Pulse position modulated by 36 voice channel baseband: pulse width at half amplitude=0.4 μs; $B_n = 8X10^6$ Hz=8 MHz (Bandwidth independent of the number of voice channels)	8M00M7EJT
Composite transmission digital 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 $R = 5X10^6$ bits per second; K=1; S=4 $B_n = 5$ MHz	5M00K7DD

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

Where N_c 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.

REFERENCES

a. Taub and Schilling (1971), “Principles of Communication Systems”, McGraw-Hill Book Company, Chapter 4.

b. Filippi, C. (1983), “FM Spectral Modeling and FDM/FM Simulation Programs”, NTIA Report 83-134, available from National Technical Information Service, Springfield, VA 22161.

c. Medhurst, R. G. and Plotkin, S. C. (1968), “Comments on FM Bandwidth as a Function of Distortion and Modulation Index”, IEEE transaction on Communication Technology, p. 500 (June).

d. Bellamy, J. (1982), “Digital Telephony, John Wiley & Sons, Chapter 6.

e. Cohen, D. (1983), “Necessary Bandwidth and Spectral Properties of Digital Modulation”, NTIA-TR 84-168, available from National Technical Information Service, Springfield, VA 22161.

f. Prabhu, V. K. (1981), “MSK and Offset QPSK Modulation with Bandlimiting Filters”, IEEE Transactions on Aerospace and Electronic Systems, Volume AES-17, No. 1 (January).

g. K. L. McAdoo, “Speech Volumes on Bell System Message Circuits-1960 Survey”, Bell System Technical Journal, Vol. 42, No. 5, September 1963.

h. W. C. Ahern, F. P. Duffy, J. A. Maher, “Speech Signal Power in the Switched Message Network”, Bell System Technical Journal, Vol. 57, No. 7, Part 2, September 1978, pp 2695-2726.

i. Federal Communications Commission (FCC), Report and Order, “In the Matter of Amendment of Parts 2 and 21, of the Commissions' Rules Concerning Calculations of Necessary Bandwidth for Frequency Modulation Microwave Radio Relay Systems”, General Docket No. 81-743, Rule Making 3625, adopted March 3, 1983.