International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R SM.1138-3

(10/2019)

Determination of necessary bandwidths including examples for their calculation and associated examples for the designation of emissions

SM Series

Spectrum management

International Telecommunication Union

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2019

RECOMMENDATION ITU-R SM.1138-3

Determination of necessary bandwidths including examples for their calculation and associated examples forthe designation of emissions

(1995-2007-2008-2019)

Scope

This Recommendation serves as a basis for the determination of necessary bandwidths of emissions under amplitude, frequency and pulse modulation by various types of signals. Sample calculations and designation of emissions are also provided.

Keywords

Necessary bandwidth, automated spectrum management system, calculation

The ITU Radiocommunication Assembly,

considering

a) that the assignment of frequencies requires the determination of the necessary bandwidth of emissions;

b) that necessary bandwidth is a key data element of all automated spectrum-management systems,

recommends

that the formulae given in Annex 1 shall be used to calculate the necessary bandwidth when required by the Radio Regulations (RR).

Annex 1

Determination of necessary bandwidths, including examples for their calculation and associated examples for the designation of emissions

1 The necessary bandwidth is not the only characteristic of an emission to be considered in evaluating the interference that may be caused by that emission.

2 In the formulation of the table, the following terms have been employed:

B_n: necessary bandwidth (Hz)

B: modulation rate (Bd)

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

M: maximum modulation frequency (Hz)

C: sub-carrier frequency (Hz)

D: peak deviation, i.e. half the difference between the maximum and minimum values of the instantaneous frequency. The instantaneous frequency (Hz) is the time rate of change in phase (rad) divided by 2π

t: pulse duration (s) at half-amplitude

t_r: pulse rise time (s) between 10% and 90% amplitude

K: an overall numerical factor which varies according to the emission and which depends upon the allowable signal distortion. In the case of orthogonal frequency division multiplexed multi-carrier signal, K is the number of active sub-carriers as defined by equation (52) in Recommendation ITU-R SM.328

N_c: number of baseband channels in radio systems employing multichannel multiplexing

f_p: continuity pilot sub-carrier frequency (Hz) (continuous signal utilized to verify performance of frequency-division multiplex systems)

N_s: frequency separation between two sub-carriers (kHz).

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
I. NO MODULATING SIGNAL			
Continuous wave emission	–	–	NONE
II. AMPLITUDE MODULATION			
1. Signal with quantized or digital information			
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 Bandwidth: 100 Hz	100HA1AAN
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 = 1 000, K = 5 Bandwidth: 2 100 Hz = 2.1 kHz	2K10A2AAN
Selective calling signal using sequential single frequency code, single-sideband full carrier	$B_n = M$	Maximum code frequency is: 2 110 Hz M = 2 110 Bandwidth: 2 110 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 Bandwidth: 134 Hz	134HJ2BCN
Telegraphy, multichannel 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 frequency is: 2 805 Hz B = 100 D = 42.5 Hz (85 Hz shift) K = 0.7 Bandwidth: 2 885 Hz = 2.885 kHz	2K89R7BCW
2. Telephony (commercial quality)			
Telephony, double-sideband (single channel)	$B_n = 2M$	M = 3 000 Bandwidth: 6 000 Hz = 6 kHz	6K00A3EJN
Telephony, single-sideband, full carrier (single channel)	$B_n = M$	M = 3 000 Bandwidth: 3 000 Hz = 3 kHz	3K00H3EJN
Telephony, single-sideband, suppressed carrier (single channel)	$B_n = M$ – lowest modulation frequency	M = 3 000 lowest modulation frequency = 300 Hz Bandwidth: 2 700 Hz = 2.7 kHz	2K70J3EJN

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
2. Telephony (commercial quality) (*cont.*)			
Telephony with separate frequency modulated signal to control the level of demodulated speech signal, single-sideband, reduced carrier (Lincompex) (single channel)	$B_n = M$	Maximum control frequency = 2 990 Hz M = 2 990 Bandwidth: 2 990 Hz = 2.99 kHz	2K99R3ELN
Telephony with privacy, single-sideband, suppressed carrier (two or more channels)	$B_n = N_c M$ – lowest modulation frequency in the lowest channel	N_c = 2 M = 3 000 lowest modulation frequency = 250 Hz Bandwidth: 5 750 Hz = 5.75 kHz	5K75J8EKF
Telephony, independent sideband (two or more channels)	B_n = sum of M for each sideband	2 channels M = 3 000 Bandwidth: 6 000 Hz = 6 kHz	6K00B8EJN
3. Sound broadcasting			
Sound broadcasting, double-sideband	$B_n = 2M$ M may vary between 4 000 and 10 000 depending on the quality desired	Speech and music M = 4 000 Bandwidth: 8 000 Hz = 8 kHz	8K00A3EGN
Sound broadcasting, single-sideband, reduced carrier (single channel)	$B_n = M$ M may vary between 4 000 and 10 000 depending on the quality desired	Speech and music M = 4 000 Bandwidth: 4 000 Hz = 4 kHz	4K00R3EGN
Sound broadcasting, single-sideband, suppressed carrier	$B_n = M$ – lowest modulation frequency	Speech and music M = 4 500 lowest modulation frequency = 50 Hz Bandwidth: 4 450 Hz = 4.45 kHz	4K45J3EGN
4. Television			
Television, vision and sound	Refer to relevant ITU-R documents for the bandwidths of the commonly used television systems	Number of lines: 625 Nominal video bandwidth = 5 MHz Sound carrier relative to video carrier: 5.5 MHz Total vision Bandwidth: 6.25 MHz FM sound bandwidth including guardbands: 750 kHz RF channel Bandwidth: 7 MHz	6M25C3F -- 750KF3EGN
5. Facsimile			
Analogue 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 = 1 100 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 length. C = 1 900 D = 400 Hz Bandwidth: 2 890 Hz = 2.89 kHz	2K89R3CMN
Analogue 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 = 1 100 D = 400 Hz Bandwidth: 1 980 Hz = 1.98 kHz	1K98J3C --

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
6. Composite emissions			
Double-sideband, television relay	$B_n = 2C + 2M + 2D$	Video limited to 5 MHz, audio on 6.5 MHz, frequency modulated sub-carrier, sub-carrier deviation = 50 kHz: $C = 6.5 \times 10^6$ $D = 50 \times 10^3$ Hz $M = 15\ 000$ Bandwidth: 13.13×10^6 Hz = 13.13 MHz	13M1A8W --
Double-sideband radio-relay system, frequency division multiplex	$B_n = 2M$	10 voice channels occupying baseband between 1 kHz and 164 kHz $M = 164\ 000$ Bandwidth: 328 000 Hz = 328 kHz	328KA8E --
Double-sideband emission of VOR with voice (VOR: VHF omnidirectional 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 9 960 Hz tone – a telephone channel – a 1 020 Hz keyed tone for continual Morse identification $C_{max} = 9\ 960$ $M = 30$ $D = 480$ Hz Bandwidth: 20 940 Hz = 20.94 kHz	20K9A9WWF
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. Rec. ITU-R F.348). 3 telephone channels and 15 telegraphy channels require the bandwidth: 12 000 Hz = 12 kHz	12K0B9WWF
7. Standard frequency and time signals 7.1 High frequency (voice)			
Voice announcements, double-sideband	$B_n = 2M$	Speech $M = 4\ 000$ Bandwidth: 8 000 Hz = 8 kHz	8K00A3XGN
7.2. High frequency (time code)			
Time code as telegraphy	$B_n = BK + 2M$	$B = 1$/s $M = 1$ $K = 5$ Bandwidth: 7 Hz	7H00A2XAN
7.3. Low frequency (time code)			
Time code as telegraphy	$B_n = BK + 2M$	$B = 1$/s $M = 1$ $K = 3$ Bandwidth: 5 Hz	5H00A2XAN

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
III-A. FREQUENCY MODULATION			
1. Signal with quantized or digital information			
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) Bandwidth: 304 Hz	304HF1BBN
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) Bandwidth: 304 Hz	304HF1BCN
Selective calling signal	$B_n = 2M + 2DK$ $M = \frac{B}{2}$ $K = 1.2$ (typically)	$B = 100$ $D = 85$ Hz (170 Hz shift) Bandwidth: 304 Hz	304HF1BCN
Four-frequency duplex telegraphy	$B_n = 2M + 2DK$ B: modulation rate (Bd) 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 Bandwidth: 1 420 Hz = 1.42 kHz	1K42F7BDX
2. Telephony (commercial quality)			
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, $D = 5\,000$ Hz $M = 3\,000$ Bandwidth: 16 000 Hz = 16 kHz	16K0F3EJN
3. Sound broadcasting			
Sound broadcasting	$B_n = 2M + 2DK$ $K = 1$ (typically)	Monaural $D = 75\,000$ Hz $M = 15\,000$ Bandwidth: 180 000 Hz = 180 kHz	180KF3EGN
4. Facsimile			
Facsimile by direct frequency modulation of the carrier; black and white	$B_n = 2M + 2DK$ $M = \frac{N}{2}$ $K = 1.1$ (typically)	$N = 1\,100$ elements/s $D = 400$ Hz Bandwidth: 1 980 Hz = 1.98 kHz	1K98F1C --
Analogue facsimile	$B_n = 2M + 2DK$ $M = \frac{N}{2}$ $K = 1.1$ (typically)	$N = 1\,100$ elements/s $D = 400$ Hz Bandwidth: 1 980 Hz = 1.98 kHz	1K98F3C --

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
5. Composite emissions (see Table III-B)			
Radio-relay system, frequency division multiplex	$B_n = 2f_p + 2DK$ $K = 1$ (typically)	60 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. $D = 200 \times 10^3 \times 3.76 \times 2.02$ $= 1.52 \times 10^6$ Hz $f_p = 0.331 \times 10^6$ Hz Bandwidth: 3.702×10^6 Hz = 3.702 MHz	3M70F8EJF
Radio-relay system, frequency division multiplex	$B_n = 2M + 2DK$ $K = 1$ (typically)	960 telephone channels occupying baseband between 60 kHz and 4 028 kHz; rms per-channel deviation: 200 kHz; continuity pilot at 4 715 kHz produces 140 kHz rms deviation of main carrier. $D = 200 \times 10^3 \times 3.76 \times 5.5$ $= 4.13 \times 10^6$ Hz $M = 4.028 \times 10^6$ $f_p = 4.715 \times 10^6$ $(2M + 2DK) > 2\ f_p$ Bandwidth: 16.32×10^6 Hz = 16.32 MHz	16M3F8EJF
Radio-relay system, frequency division multiplex	$B_n = 2f_p$	600 telephone channels occupying baseband between 60 kHz and 2 540 kHz; rms per-channel deviation: 200 kHz; continuity pilot at 8 500 kHz produces 140 kHz rms deviation of main carrier. $D = 200 \times 10^3 \times 3.76 \times 4.36$ $= 3.28 \times 10^6$ Hz $M = 2.54 \times 10^6$ $K = 1$ $f_p = 8.5 \times 10^6$ $(2M + 2DK) < 2\ f_p$ Bandwidth: 17×10^6 Hz = 17 MHz	17M0F8EJF
Stereophonic sound broadcasting with multiplexed subsidiary telephony sub-carrier	$B_n = 2M + 2DK$ $K = 1$ (typically)	Pilot tone system; $M = 75\ 000$ $D = 75\ 000$ Hz Bandwidth: 300 000 Hz = 300 kHz	300KF8EHF

III-B. MULTIPLYING FACTORS FOR USE IN COMPUTING *D*,
PEAK FREQUENCY DEVIATION, IN FM FREQUENCY DIVISION
MULTIPLEX (FM-FDM) MULTI-CHANNEL EMISSSIONS

For FM-FDM systems the necessary bandwidth is:

$$B_n = 2M + 2DK$$

The value of D, or peak frequency deviation, in these formulae 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% of the rms value of per-channel deviation, the general formula becomes either:

$$B_n = 2f_p \quad \text{or} \quad B_n = 2M + 2DK$$

whichever if greater.

Number of telephone channels N_c	Multiplying factor[1]
	$(\text{Peak factor}) \times \text{antilog}\left[\dfrac{\text{value in dB above modulation reference level}}{20}\right]$
$3 < N_c < 12$	$4.47 \times \text{antilog}\left[\dfrac{\text{a value in dB specified by the equipment manufacturer or station licensee, subject to administration approval}}{20}\right]$
$12 \leq N_c < 60$	$3.76 \times \text{antilog}\left[\dfrac{2.6 + 2\log N_c}{20}\right]$
	Multiplying factor[2]
Number of telephone channels N_c	$(\text{Peak factor}) \times \text{antilog}\left[\dfrac{\text{value in dB above modulation reference level}}{20}\right]$
$60 \leq N_c < 240$	$3.76 \times \text{antilog}\left[\dfrac{-1 + 4\log N_c}{20}\right]$
$N_c \geq 240$	$3.76 \times \text{antilog}\left[\dfrac{-15 + 10\log N_c}{20}\right]$

(1) In the above chart, the multipliers 3.76 and 4.47 correspond to peak factors of 11.5 and 13.0 dB, respectively.

(2) In the above chart, the multipliers 3.76 correspond to peak factors of 11.5 dB.

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
IV. PULSE MODULATION			
1. Radar			
Unmodulated pulse emission	$B_n = \frac{2K}{t}$ K depends upon the ratio of pulse duration to pulse rise time. Its value usually falls between 1 and 10 and in many cases it does not need to exceed 6	Primary radar range resolution = 150 m K = 1.5 (triangular pulse where $t \simeq t_r$, only components down to 27 dB from the strongest are considered) Then: $t = \left[\frac{2 \times (\text{range resolution})}{\text{velocity of light}}\right]$ $= \frac{2 \times 150}{3 \times 10^8}$ $= 1 \times 10^{-6}$ s Bandwidth: 3×10^6 Hz = 3 MHz	3M00P0NAN
2. Composite emissions			
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 Bandwidth: 8×10^6 Hz = 8 MHz (Bandwidth independent of the number of voice channels)	8M00M7EJT
3. Standard frequency and time signals 3.1 High frequency (tone bursts)			
Ticks used for epoch measurement	$B_n = 2/t_r$	t_r = 1 ms Bandwidth: 2 000 Hz = 2 kHz	2K00K2XAN
3.2 Low frequency (time code)			
Time code leading edge used for epoch measurement	$B_n = 2/t_r$	t_r = 1 ms Bandwidth = 2 000 Hz = 2 kHz	2K00K2XAN
V. MISCELLANEOUS			
Orthogonal frequency division multiplexing (OFDM) or coded OFDM (COFDM)	$B_n = N_s \cdot K$	53 active sub-carriers are used, each spaced 312.5 kHz apart (K = 53 and N_s = 312.5 kHz). Data sub-carriers can be BPSK, QPSK, QAM modulated B_n = 312.5 kHz × 53 = 16.6 MHz	16M6W7D