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:

*Bn*: 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 2

*t*: pulse duration (s) at half-amplitude

*tr*: 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

*Nc*: number of baseband channels in radio systems employing multichannel multiplexing

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

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

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| 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 | *Bn* = *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 | *Bn* = *BK* + 2*M* *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 | *Bn* = *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) | *Bn* = 2*M* + 2*DK* | *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 | *Bn* = highest central frequency + *M* + *DK* | 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) | *Bn* = 2*M* | *M* = 3 000 Bandwidth: 6 000 Hz = 6 kHz | 6K00A3EJN |
| Telephony, single-sideband,  full carrier (single channel) | *Bn* = *M* | *M* = 3 000 Bandwidth: 3 000 Hz = 3 kHz | 3K00H3EJN |
| Telephony, single-sideband, suppressed carrier (single channel) | *Bn* = *M* – lowest modulation frequency | *M* = 3 000 lowest modulation frequency = 300 Hz Bandwidth: 2 700 Hz = 2.7 kHz | 2K70J3EJN |

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| 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) | *Bn* = *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) | *Bn* = *Nc M* – lowest modulation frequency in the lowest channel | *Nc* = 2 *M* = 3 000 lowest modulation frequency = 250 Hz Bandwidth: 5 750 Hz = 5.75 kHz | 5K75J8EKF |
| Telephony, independent sideband (two or more channels) | *Bn* = 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 | *Bn* = 2*M* *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) | *Bn* = *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 | *Bn* = *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 | *Bn* = *C* +  + *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 | *Bn* = 2*M* + 2*DK* *M* =   *K* = 1.1 (typically) | *N* = 1 100 *D* = 400 Hz Bandwidth: 1 980 Hz = 1.98 kHz | 1K98J3C -- |

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| Description of emission | Necessary bandwidth | | Designation of emission |
| Formula | Sample calculation |
| 6. Composite emissions | | | |
| Double-sideband, television relay | *Bn*  2*C*  2*M*  2*D* | Video limited to 5 MHz, audio on 6.5 MHz, frequency modulated sub‑carrier, sub‑carrier deviation  50 kHz: *C*  6.5  106 *D*  50  103 Hz *M*  15 000 Bandwidth: 13.13  106 Hz  13.13 MHz | 13M1A8W -- |
| Double-sideband radio‑relay system, frequency division multiplex | *Bn*  2*M* | 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) | *Bn*  2*Cmax*  2*M*  2*DK K*  1 (typically) | The main carrier is modulated by: – a 30 Hz sub-carrier – a carrier resulting from a 9 960 Hz tone frequency modulated by a 30 Hz tone – a telephone channel – a 1 020 Hz keyed tone for continual Morse identification *Cmax*  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 | *Bn*  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 | *Bn*  2*M* | Speech *M* = 4 000 Bandwidth: 8 000 Hz = 8 kHz | 8K00A3XGN |
| 7.2. High frequency (time code) | | | |
| Time code as telegraphy | *Bn*  *BK*  2*M* | *B* = 1/s *M* = 1 *K* = 5 Bandwidth: 7 Hz | 7H00A2XAN |
| 7.3. Low frequency (time code) | | | |
| Time code as telegraphy | *Bn*  *BK*  2*M* | *B* = 1/s *M* = 1 *K* = 3 Bandwidth: 5 Hz | 5H00A2XAN |

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| 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) | *Bn* = 2*M* + 2*DK*  *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) | *Bn* = 2*M* + 2*DK*  *K*  1.2 (typically) | *B*  100 *D*  85 Hz (170 Hz shift) Bandwidth: 304 Hz | 304HF1BCN |
| Selective calling signal | *Bn* = 2*M* + 2*DK*  *K*  1.2 (typically) | *B*  100 *D*  85 Hz (170 Hz shift) Bandwidth: 304 Hz | 304HF1BCN |
| Four-frequency duplex telegraphy | *Bn* = 2*M* + 2*DK* *B*: modulation rate (Bd) of the faster channel.  If the channels are synchronized:  (otherwise, *M*  2*B*) *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 | *Bn* = 2*M* + 2*DK* *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 | *Bn* = 2*M* + 2*DK* *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 | *Bn* = 2*M* + 2*DK*  *K*  1.1 (typically) | *N*  1 100 elements/s *D*  400 Hz Bandwidth: 1 980 Hz  1.98 kHz | 1K98F1C -- |
| Analogue facsimile | *Bn* = 2*M* + 2*DK*  *K*  1.1 (typically) | *N*  1 100 elements/s *D*  400 Hz Bandwidth: 1 980 Hz  1.98 kHz | 1K98F3C -- |

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| Description of emission | Necessary bandwidth | | Designation of emission |
| Formula | Sample calculation |
| 5. Composite emissions (see Table III-B) | | | |
| Radio-relay system, frequency division multiplex | *Bn*  2*fp*  2*DK* *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  103  3.76  2.02   1.52  106 Hz *fp*  0.331  106 Hz Bandwidth: 3.702  106 Hz  3.702 MHz | 3M70F8EJF |
| Radio-relay system, frequency division multiplex | *Bn*  2*M*  2*DK* *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  103  3.76  5.5  4.13  106 Hz *M*  4.028  106 *fp*  4.715  106 (2*M*  2*DK*)  2 *fp* Bandwidth: 16.32  106 Hz  16.32 MHz | 16M3F8EJF |
| Radio-relay system, frequency division multiplex | *Bn*  2*fp* | 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  103  3.76  4.36  3.28  106 Hz *M*  2.54  106 *K*  1 *fp*  8.5  106 (2*M*  2*DK*)  2 *fp* Bandwidth: 17  106 Hz  17 MHz | 17M0F8EJF |
| Stereophonic sound broadcasting with multiplexed subsidiary telephony sub-carrier | *Bn*  2*M*  2*DK* *K*  1 (typically) | Pilot tone system; *M*  75 000 *D*  75 000 Hz Bandwidth: 300 000 Hz  300 kHz | 300KF8EHF |

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| 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:  *Bn*  2*M*  2*DK*  The value of *D*, or peak frequency deviation, in these formulae for *Bn* iscalculated 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 *fp* exists above the maximum modulation frequency *M*, the general formula becomes:  *Bn*  2*fp*  2*DK*  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:  *Bn* = 2*fp* or *Bn* = 2*M*  2*DK*  whichever if greater. | |
|  | Multiplying factor(1) |
| Number of  telephone channels *Nc* |  |
| 3  *Nc*  12 |  |
| 12  *Nc*  60 |  |
|  | Multiplying factor(2) |
| Number of telephone channels *Nc* |  |
| 60  *Nc*  240 |  |
| *Nc*  240 |  |
| (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. | |

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| Description of emission | | Necessary bandwidth | | | | Designation of emission |
| Formula | | Sample calculation | |
| IV. PULSE MODULATION | | | | | | |
| 1. Radar | | | | | | |
| Unmodulated pulse emission | *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* ~ *tr*, only components down to 27 dB from the strongest are considered)  Then:       1  10–6 s  Bandwidth: 3  106 Hz  3 MHz | | 3M00P0NAN | |
| 2. Composite emissions | | | | | | |
| Radio-relay system | *K*  1.6 | | Pulse position modulated by 36 voice channel baseband; pulse width at half amplitude  0.4 s Bandwidth: 8  106 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 | *Bn* = 2*/tr* | | *tr* = 1 ms  Bandwidth: 2 000 Hz = 2 kHz | | 2K00K2XAN | |
| 3.2 Low frequency (time code) | | | | | | |
| Time code leading edge used for epoch measurement | *Bn* = 2*/tr* | | *tr* = 1 ms  Bandwidth = 2 000 Hz = 2 kHz | | 2K00K2XAN | |
| V. MISCELLANEOUS | | | | | | |
| Orthogonal frequency division multiplexing (OFDM) or coded OFDM (COFDM) | *Bn* = *Ns*∙*K* | | 53 active sub-carriers are used, each spaced 312.5 kHz apart (*K* = 53 and *Ns* = 312.5 kHz). Data sub-carriers can be BPSK, QPSK, QAM modulated  *Bn* = 312.5 kHz × 53 = 16.6 MHz | | 16M6W7D | |