RECOMMENDATION ITU-R SM.1138*

## DETERMINATION OF NECESSARY BANDWIDTHS INCLUDING EXAMPLES FOR THEIR CALCULATION AND ASSOCIATED EXAMPLES FOR THE DESIGNATION OF EMISSIONS

(1995)

The ITU Radiocommunication Assembly,

*considering*

a)      the Final Report and recommendations of the Voluntary Group of Experts (VGE) to study allocation and improved use of the radio-frequency spectrum and simplification of the Radio Regulations (RR) was established in accordance with Resolution No. 8 of the Plenipotentiary Conference (Nice, 1989) and continued its work in accordance with Resolution No. 8 of the Additional Plenipotentiary Conference (Geneva, 1992);

b)      that the 1995 World Radiocommunication Conference (WRC-95) will consider and adopt, as appropriate, proposals for the Simplified RR,

*recommends*

**1**      that the formulae given in Annex 1 shall be used to calculate the necessary bandwidth when required by the 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 $2\pi$

$t$ :  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

$N_c$ :  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).

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\*      Reference has been made to this Recommendation in the Radio Regulations (RR) as revised by the World Radiocommunication Conference 1995 (WRC-95). This will come into force on 1 June 1998.

| 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 | $B_n = BK$<br>$K = 5$ for fading circuits<br>$K = 3$ for non-fading circuits | 25 words per minute<br>$B = 20$, $K = 5$<br>Bandwidth: 100 Hz | 100HA1AAN |
| Telegraphy by on-off keying of a tone modulated carrier, Morse code | $B_n = BK + 2M$<br>$K = 5$ for fading circuits<br>$K = 3$ for non-fading circuits | 25 words per minute<br>$B = 20$, $M = 1\,000$, $K = 5$<br>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<br>$M = 2\,110$<br>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) | $B_n = 2M + 2DK$<br>$M = \dfrac{B}{2}$ | $B = 50$<br>$D = 35$ Hz (70 Hz shift)<br>$K = 1.2$<br>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 $+ M + DK$<br>$M = \dfrac{B}{2}$ | 15 channels;<br>highest central frequency is: 2 805 Hz<br>$B = 100$<br>$D = 42.5$ Hz (85 Hz shift)<br>$K = 0.7$<br>Bandwidth: 2 885 Hz = 2.885 kHz | 2K89R7BCW |
| **2. Telephony (commercial quality)** | | | |
| Telephony, double-sideband (single channel) | $B_n = 2M$ | $M = 3\,000$<br>Bandwidth: 6 000 Hz = 6 kHz | 6K00A3EJN |
| Telephony, single-sideband, full carrier (single channel) | $B_n = M$ | $M = 3\,000$<br>Bandwidth: 3 000 Hz = 3 kHz | 3K00H3EJN |
| Telephony, single-sideband, suppressed carrier (single channel) | $B_n = M$ – lowest modulation frequency | $M = 3\,000$<br>lowest modulation frequency = 300 Hz<br>Bandwidth: 2 700 Hz = 2.7 kHz | 2K70J3EJN |
| 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<br>$M = 2\,990$<br>Bandwidth: 2 990 Hz = 2.99 kHz | 2K99R3ELN |

| Description of emission | Necessary bandwidth | | Designation of emission |
|---|---|---|---|
| | Formula | Sample calculation | |
| 2. Telephony (commercial quality) *(cont.)* | | | |
| Telephony with privacy, single-sideband, suppressed carrier (two or more channels) | $B_n = N_c M$ – lowest modulation frequency in the lowest channel | $N_c = 2$<br>$M = 3\,000$<br>lowest modulation frequency = 250 Hz<br>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<br>$M = 3\,000$<br>Bandwidth: 6 000 Hz = 6 kHz | 6K00B8EJN |
| 3. Sound broadcasting | | | |
| Sound broadcasting, double-sideband | $B_n = 2M$<br>$M$ may vary between 4 000 and 10 000 depending on the quality desired | Speech and music<br>$M = 4\,000$<br>Bandwidth: 8 000 Hz = 8 kHz | 8K00A3EGN |
| Sound broadcasting, single-sideband, reduced carrier (single channel) | $B_n = M$<br>$M$ may vary between 4 000 and 10 000 depending on the quality desired | Speech and music<br>$M = 4\,000$<br>Bandwidth: 4 000 Hz = 4 kHz | 4K00R3EGN |
| Sound broadcasting, single-sideband, suppressed carrier | $B_n = M$ – lowest modulation frequency | Speech and music<br>$M = 4\,500$<br>lowest modulation frequency = 50 Hz<br>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<br>Nominal video bandwidth = 5 MHz<br>Sound carrier relative to video carrier: 5.5 MHz<br>Total vision Bandwidth: 6.25 MHz<br>FM sound bandwidth including guardbands: 750 kHz<br>RF channel Bandwidth: 7 MHz | 6M25C3F --<br><br>750KF3EGN |
| 5. Facsimile | | | |
| Analogue facsimile by sub-carrier frequency modulation of a single-sideband emission with reduced carrier, monochrome | $B_n = C + \dfrac{N}{2} + DK$<br>$K = 1.1$<br>(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.<br>$C = 1\,900$<br>$D = 400$ Hz<br>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 | $B_n = 2M + 2DK$<br>$M = \dfrac{N}{2}$<br>$K = 1.1$<br>(typically) | $N = 1\,100$<br>$D = 400$ Hz<br>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: <br> $C = 6.5 \times 10^6$ <br> $D = 50 \times 10^3$ Hz <br> $M = 15\,000$ <br> Bandwidth: $13.13 \times 10^6$ Hz <br> = 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 <br> $M = 164\,000$ <br> Bandwidth: 328 000 Hz = 328 kHz | 328KA8E -- |
| Double-sideband emission of VOR with voice (VOR: VHF omnidirectional radio range) | $B_n = 2C_{max} + 2M + 2DK$ <br> $K = 1$ <br> (typically) | The main carrier is modulated by: <br> – a 30 Hz sub-carrier <br> – a carrier resulting from a 9 960 Hz tone frequency modulated by a 30 Hz tone <br> – a telephone channel <br> – a 1 020 Hz keyed tone for continual Morse identification <br> $C_{max} = 9\,960$ <br> $M = 30$ <br> $D = 480$ Hz <br> 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 <br> (e.g. Rec. ITU-R F.348). <br> 3 telephone channels and 15 telegraphy channels require the bandwidth: <br> 12 000 Hz = 12 kHz | 12K0B9WWF |
| III-A.  FREQUENCY MODULATION | | | |
| 1. Signal with quantized or digital information | | | |
| Telegraphy without error-correction (single channel) | $B_n = 2M + 2DK$ <br> $M = \dfrac{B}{2}$ <br> $K = 1.2$ <br> (typically) | $B = 100$ <br> $D = 85$ Hz (170 Hz shift) <br> Bandwidth: 304 Hz | 304HF1BBN |
| Telegraphy, narrow-band direct-printing with error-correction (single channel) | $B_n = 2M + 2DK$ <br> $M = \dfrac{B}{2}$ <br> $K = 1.2$ <br> (typically) | $B = 100$ <br> $D = 85$ Hz (170 Hz shift) <br> Bandwidth: 304 Hz | 304HF1BCN |
| Selective calling signal | $B_n = 2M + 2DK$ <br> $M = \dfrac{B}{2}$ <br> $K = 1.2$ <br> (typically) | $B = 100$ <br> $D = 85$ Hz (170 Hz shift) <br> Bandwidth: 304 Hz | 304HF1BCN |

| Description of emission | Necessary bandwidth | | Designation of emission |
|---|---|---|---|
| | Formula | Sample calculation | |
| **1. Signal with quantized or digital information** *(cont.)* | | | |
| Four-frequency duplex telegraphy | $B_n = 2M + 2DK$<br>$B$: modulation rate (Bd) of the faster channel.<br>If the channels are synchronized:<br>$M = \dfrac{B}{2}$ (otherwise, $M = 2B$)<br>$K = 1.1$<br>(typically) | Spacing between adjacent frequencies = 400 Hz<br>Synchronized channels<br>$B = 100$<br>$M = 50$<br>$D = 600$ Hz<br>Bandwidth: 1 420 Hz = 1.42 kHz | 1K42F7BDX |
| **2. Telephony (commercial quality)** | | | |
| Commercial telephony | $B_n = 2M + 2DK$<br>$K = 1$<br>(typically, but under certain conditions a higher value of $K$ may be necessary) | For an average case of commercial telephony,<br>$D = 5\,000$ Hz<br>$M = 3\,000$<br>Bandwidth: 16 000 Hz = 16 kHz | 16K0F3EJN |
| **3. Sound broadcasting** | | | |
| Sound broadcasting | $B_n = 2M + 2DK$<br>$K = 1$<br>(typically) | Monaural<br>$D = 75\,000$ Hz<br>$M = 15\,000$<br>Bandwidth: 180 000 Hz = 180 kHz | 180KF3EGN |
| **4. Facsimile** | | | |
| Facsimile by direct frequency modulation of the carrier; black and white | $B_n = 2M + 2DK$<br>$M = \dfrac{N}{2}$<br>$K = 1.1$<br>(typically) | $N = 1\,100$ elements/s<br>$D = 400$ Hz<br>Bandwidth: 1 980 Hz = 1.98 kHz | 1K98F1C -- |
| Analogue facsimile | $B_n = 2M + 2DK$<br>$M = \dfrac{N}{2}$<br>$K = 1.1$<br>(typically) | $N = 1\,100$ elements/s<br>$D = 400$ Hz<br>Bandwidth: 1 980 Hz = 1.98 kHz | 1K98F3C -- |
| **5. Composite emissions (see Table III-B)** | | | |
| Radio-relay system, frequency division multiplex | $B_n = 2f_p + 2DK$<br>$K = 1$<br>(typically) | 60 telephone channels occupying baseband between 60 kHz and 300 kHz;<br>rms per-channel deviation: 200 kHz;<br>continuity pilot at 331 kHz produces 100 kHz rms deviation of main carrier.<br>$D = 200 \times 10^3 \times 3.76 \times 2.02$<br>$\quad = 1.52 \times 10^6$ Hz<br>$f_p = 0.331 \times 10^6$ Hz<br>Bandwidth: $3.702 \times 10^6$ Hz<br>$= 3.702$ MHz | 3M70F8EJF |

| Description of emission | Necessary bandwidth | | Designation of emission |
|---|---|---|---|
| | Formula | Sample calculation | |
| 5. Composite emissions *(cont.)* | | | |
| Radio-relay system, frequency division multiplex | $B_n = 2M + 2DK$ <br> $K = 1$ <br> (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. <br> $D = 200 \times 10^3 \times 3.76 \times 5.5$ <br> $= 4.13 \times 10^6$ Hz <br> $M = 4.028 \times 10^6$ <br> $f_p = 4.715 \times 10^6$ <br> $(2M + 2DK) > 2f_p$ <br> Bandwidth: $16.32 \times 10^6$ Hz <br> $= 16.32$ 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. <br> $D = 200 \times 10^3 \times 3.76 \times 4.36$ <br> $= 3.28 \times 10^6$ Hz <br> $M = 2.54 \times 10^6$ <br> $K = 1$ <br> $f_p = 8.5 \times 10^6$ <br> $(2M + 2DK) < 2f_p$ <br> Bandwidth: $17 \times 10^6$ Hz $= 17$ MHz | 17M0F8EJF |
| Stereophonic sound broadcasting with multiplexed subsidiary telephony sub-carrier | $B_n = 2M + 2DK$ <br> $K = 1$ <br> (typically) | Pilot tone system; <br> $M = 75\,000$ <br> $D = 75\,000$ Hz <br> 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:

$$B_n = 2M + 2DK$$

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:

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

whichever if greater.

| Number of telephone channels $N_c$ | Multiplying factor [1] |
|---|---|
| | (Peak factor) $\times$ antilog $\left[\dfrac{\text{value in dB above modulation reference level}}{20}\right]$ |
| $3 < N_c < 12$ | $4.47 \times$ antilog $\left[\dfrac{\text{a value in dB specified by the equipment manufacturer or station licensee, subject to administration approval}}{20}\right]$ |
| $12 \le N_c < 60$ | $3.76 \times$ antilog $\left[\dfrac{2.6 + 2 \log N_c}{20}\right]$ |
| Number of telephone channels $N_c$ | Multiplying factor [2] |
| | (Peak factor) $\times$ antilog $\left[\dfrac{\text{value in dB above modulation reference level}}{20}\right]$ |
| $60 \le N_c < 240$ | $3.76 \times$ antilog $\left[\dfrac{-1 + 4 \log N_c}{20}\right]$ |
| $N_c \ge 240$ | $3.76 \times$ 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 | $B_n = \dfrac{2K}{t}$<br><br>$K$ 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<br>range resolution = 150 m<br>$K = 1.5$ (triangular pulse where $t \simeq t_r$, only components down to 27 dB from the strongest are considered)<br>Then:<br><br>$t = \dfrac{2 \times (\text{range resolution})}{\text{velocity of light}}$<br><br>$= \dfrac{2 \times 150}{3 \times 10^8}$<br><br>$= 1 \times 10^{-6}$ s<br><br>Bandwidth: $3 \times 10^6$ Hz = 3 MHz | 3M00P0NAN |
| 2. Composite emissions | | | |
| Radio-relay system | $B_n = \dfrac{2K}{t}$<br>$K = 1.6$ | Pulse position modulated by 36 voice channel baseband; pulse width at half amplitude = 0.4 μs<br>Bandwidth: $8 \times 10^6$ Hz = 8 MHz<br>(Bandwidth independent of the number of voice channels) | 8M00M7EJT |

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