RECOMMENDATION ITU-R F.240-7*, **

Signal-to-interference protection ratios for various classes of emission in the fixed service below about 30 MHz

(Question ITU-R 143/9)

(1953-1956-1959-1970-1974-1978-1986-1990-1992-2006)

Scope

This Recommendation describes minimum signal-to-interference protection ratios and frequency separations for various classes of emission in the fixed service below about 30 MHz.

The ITU Radiocommunication Assembly,

considering

a) that knowledge of the signal-to-interference protection ratios for various classes of emission is needed,

recommends

1 that the values of signal-to-interference protection ratios shown in Table 1 for stable conditions, below which harmful interference occurs, should be considered appropriate for the emissions indicated;

2 that studies should be continued to provide values of signal-to-interference protection ratios for stable conditions where they are not shown in Table 1 and also to review the values that are shown;

3 that the studies in connection with Recommendation ITU-R F.339 should be continued for the purpose of determining whether the provisional values given for the fading allowances may be accepted or should be modified;

4 that meanwhile, the values given may be regarded as provisional total fading allowances (combined fading safety factors intensity fluctuation factors) and may be used as a guide, in conjunction with the values for signal-to-interference protection ratios (for stable conditions), appropriate to the various classes of emission;

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* This Recommendation should be brought to the attention of the Radio Regulations Board and Radiocommunication Study Group 1.

** Radiocommunication Study Group 9 made editorial amendments to this Recommendation in 2000 in accordance with Resolution ITU-R 44.

TABLE 1

Minimum required protection ratios and frequency separations*

WANTED SIGNAL		CLASS OF EMISSION OF INTERFERING SIGNAL																											
Class of emission		Telegraphy												Telegraphy								Telegraphy							
		A1A Manual				A1B 50 Bd (1)				A1B 100 Bd				A2A Manual				A2B 24 Bd				F1B 50 Bd $2D$ = 200 Hz (1)				F1B 50 Bd $2D$ = 280 Hz (1)			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
		dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz		
A1A telegraphy aural reception		13				13				13												13				13			
A1B telegraphy 50 Bd printer B = 500 Hz		13				11	0.36	0.44	1.41	(2) 12	(2) 0.25	(2) 0.35										13				13	0.46	0.54	1.24
A1B telegraphy 100 and 120 Bd recorder B = 500 Hz		13				13				13												13				13			
A2A telegraphy aural reception																													
A2B telegraphy, 24 Bd																													
F1B telegraphy (3) 50 Bd, printer $2D$ = 280 Hz: B = 500 Hz						1.0	0.2	0.28	0.6	3												7				7.0	0.32	0.39	0.67
F1B telegraphy 50 Bd, printer $2D$ = 400 Hz: B = 500 Hz						1.0				(2) 3	(2) 0.35	(2) 0.50										7				7			
F7B telegraphy 200 Bd, printer ARQ $2D$ = 400 Hz B = 500 Hz		4				4				4																			
F7B telegraphy 200 Bd, printer ARQ $2D$ = 400 Hz: B = 500 Hz		4				4				(4) 4	(4) 0.40	(4) 0.55																	
F7B (2), 50 Bd printer	Channel 1																					8				8			
$2D$ = 1 200 Hz B = 1 200 Hz	Channel 2																					18				18			
R3C phototelegraphy		16				16				16												16				16			
F3C phototelegraphy 60 rpm, B = 1 000 Hz		15				15				15	1.00	1.20										15				15			
A3E telephony DSB	just usable	13				13				13				1				1				21				21			
	marginally commercial	29				29				29				17				17				33				33			
	good commercial	56				56				56				44				44				60				60			
H3E telephony SSB full carrier(5)	just usable	7				7				7				−5				−5				15				15			
	marginally commercial	23				23				23				11				11				27				27			
	good commercial	50				50				50				38				38				54				54			
R3E telephony SSB reduced carrier(5)	just usable	2				2				2				−10				−10				10				10			
	marginally commercial	18				18				18				6				6				22				22			
	good commercial	45				45				45				33				33				49				49			
J3E telephony SSB suppressed carrier(5)	just usable	1				1				1				−11				−11				9				9			
	marginally commercial	17				17				17				5				5				21				21			
	good commercial	44				44				44				32				32				48				48			
R8E telephony Two ISB reduced or suppressed carrier(5)	just usable	7				7				7				−5				−5				15				15			
	marginally commercial	23				23				23				11				11				27				27			
	good commercial	50				50				50				38				38				54				54			
J7B multichannel V.F. telegraphy 250-3 000 Hz		17.5				17.5				17.5												20.5				20.5			
J7B multichannel V.F. telegraphy 300-3 400 Hz (6)		17.5				17.5	1.7	1.7	8.0	17.5	1.7	1.8	9.1									20.5	1.9	1.9	2.0	20.5			
R7B multichannel V.F. telegraphy reduced carrier		18.5				18.5				18.5												21.5				21.5			
J2D data transmission SSB suppressed carrier PSK/QAM(13)		9				9				9				9				9				9				9			

TABLE 1 (*continued*)

WANTED SIGNAL	CLASS OF EMISSION OF INTERFERING SIGNAL																											
Class of emission	Telegraphy																Telegraphy											
	F1B 50 Bd $2D$ = 400 Hz (1)				F1B 100 Bd $2D$ = 400 Hz				F1B 100 Bd $2D$ = 500 Hz				F1B 200 Bd $2D$ = 500 Hz				F7B 100 Bd $2D$ = 400 Hz				F7B 100 Bd $2D$ = 1500 Hz				F7B 200 Bd $2D$ = 600 Hz			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz		
A1A telegraphy aural reception	13				13				13				13				3				3				3			
A1B telegraphy 50 Bd printer B = 500 Hz	13				13				13				13				(2) 3	(2) 0.40	(2) 0.55		3				3			
A1B telegraphy 100 and 120 Bd recorder B = 500 Hz	13				13				13				13				3				3				3			
A2A telegraphy aural reception																												
A2B telegraphy. 24 Bd																												
F1B telegraphy (3) 50 Bd, printer $2D$ = 280 Hz: B = 500 Hz	7				7				7				7				2				2				2			
F1B telegraphy 50 Bd, printer $2D$ = 400 Hz: B = 500 Hz	7				7				7				7				(2) 2	(2) 0.45	(2) 0.60		2				2			
F7B telegraphy 100 Bd, printer ARQ $2D$ = 400 Hz B = 500 Hz																	4				4				4			
F7B telegraphy 200 Bd, printer ARQ $2D$ = 400 Hz: B = 500 Hz																	(4) 4	(4) 0.50	(4) 0.70		4				4			
F7B (3), 50 Bd, printer – Channel 1	8	0.85	0.95	1.51	8				8				8				8				8				8			
$2D$ = 1 200 Hz B = 1 200 Hz – Channel 2	18	0.98	1.1	2.06	18				18				18				18				18				18			
R3C phototelegraphy	16				16				16				16				16				16				16			
F3C phototelegraphy 60 rpm, B = 1 000 Hz	15				15				15				15				15	1.10	1.20		15				15			
A3E telephony DSB – just usable	21				21				21				21				17				17				17			
A3E telephony DSB – marginally commercial	33				33				33				33				35				35				35			
A3E telephony DSB – good commercial	60				60				60				60				66				66				66			
H3E telephony SSB full carrier(5) – just usable	15				15				15				15				11				11				11			
H3E telephony SSB full carrier(5) – marginally commercial	27				27				27				27				29				29				29			
H3E telephony SSB full carrier(5) – good commercial	54				54				54				54				60				60				60			
R3E telephony SSB reduced carrier(5) – just usable	10				10				10				10				6				6				6			
R3E telephony SSB reduced carrier(5) – marginally commercial	22				22				22				22				24				24				24			
R3E telephony SSB reduced carrier(5) – good commercial	49				49				49				49				55				55				55			
J3E telephony SSB suppressed carrier(5) – just usable	9				9				9				9				5				5				5			
J3E telephony SSB suppressed carrier(5) – marginally commercial	21				21				21				21				23				23				23			
J3E telephony SSB suppressed carrier(5) – good commercial	48				48				48				48				54				54				54			
R8E telephony Two ISB reduced or suppressed carrier(5) – just usable	15				15				15				15				11				11				11			
R8E telephony Two ISB reduced or suppressed carrier(5) – marginally commercial	27				27				27				27				29				29				29			
R8E telephony Two ISB reduced or suppressed carrier(5) – good commercial	54				54				54				54				60				60				60			
J7B multichannel V.F. telegraphy 250-3 000 Hz	20.5				20.5				20.5				20.5				20.5				20.5				20.5			
J7B multichannel V.F. telegraphy 300-3 400 Hz (6)	20.5	1.9	1.9	2.1	20.5	1.9	1.9	2.8	20.5	2.0	2.0	2.9	20.5	1.9	2.0	3.1	20.5				20.5	2.4	2.5	3.5	20.5			
R7B multichannel V.F. telegraphy reduced carrier	21.5				21.5				21.5				21.5				21.5				21.5				21.5			
J2D data transmission SSB suppressed carrier PSK/QAM(13)	9				9				9				9				9				9				9			

TABLE 1 (*continued*)

WANTED SIGNAL		CLASS OF EMISSION OF INTERFERING SIGNAL																											
Class of emission		Telegraphy								Telegraphy								Telephony											
		F7B 200 Bd 2*D* = 3 000 Hz				A1B 200 Bd 2*D* = 1 200 Hz				R3C				F3C				A3E DSB (7)				H3E full carrier				R3E reduced carrier			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
		dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz		
A1A telegraphy aural reception		3				3												5				5				10			
A1B telegraphy 50 Bd, printer *B* = 500 Hz		3				3												5				5				10			
A1B telegraphy 100 and 120 Bd recorder *B* = 500 Hz		3				3												5				5				10			
A2A telegraphy aural reception																		5				11				16			
A2B telegraphy, 24 Bd																		5				11				16			
F1B telegraphy (3) 50 Bd, printer 2*D* = 280 Hz: *B* = 500 Hz		2				2												–3				3				8			
F1B telegraphy 50 Bd, printer 2*D* = 400 Hz: *B* = 500 Hz		2				2												–3				3				8			
F7B telegraphy 100 Bd, printer ARQ 2*D* = 400 Hz *B* = 500 Hz		4				4																							
F7B telegraphy 200 Bd, printer ARQ 2*D* = 400 Hz: *B* = 500 Hz		4				4																							
F7B (3), 50 Bd, printer	Channel 1	8				8	1.24	1.33	2.32																				
2*D* = 1 200 Hz *B* = 1 200 Hz	Channel 2	18				18	1.33	1.51	3.08																				
R3C phototelegraphy		16				16																							
F3C phototelegraphy 60 rpm, *B* = 1 000 Hz		15				15																							
A3E telephony DSB	just usable	17				17				19				20				6				12				17			
	marginally commercial	35				35				34				35				18				24				29			
	good commercial	66				66				64				65				39				45				50			
H3E telephony SSB full carrier(5)	just usable	11				11				13				14				0				6				11			
	marginally commercial	29				29				28				29				12				18				23			
	good commercial	60				60				58				59				33				39				44			
R3E telephony SSB reduced carrier(5)	just usable	6				6				8				9				–5				1				6			
	marginally commercial	24				24				23				24				7				13				18			
	good commercial	55				55				53				54				28				34				39			
J3E telephony SSB suppressed carrier(5)	just usable	5				5				7				8				–6				0				5			
	marginally commercial	23				23				22				23				6				12				17			
	good commercial	54				54				52				53				27				33				38			
R8E telephony Two ISB reduced or suppressed carrier(5)	just usable	11				11				13				14				0				6				11			
	marginally commercial	29				29				28				29				12				18				23			
	good commercial	60				60				58				59				33				39				44			
J7B multichannel V.F. telegraphy 250-3 000 Hz		20.5				20.5																							
J7B multichannel V.F. telegraphy 300-3 400 Hz (6)		20.5	3.2	3.3	5.1	20.5																							
R7B multichannel V.F. telegraphy reduced carrier		21.5				21.5																							
J2D data transmission SSB suppressed carrier PSK/QAM(13)		9				9				9				9				9				9				9			

TABLE 1 (*continued*)

WANTED SIGNAL		CLASS OF EMISSION OF INTERFERING SIGNAL															
Class of emission		Telephony								Telegraphy							
		J3E suppressed carrier				B8E reduced or suppressed carrier				J2B				H2A/H2B			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
		dB	kHz			dB	kHz			dB	kHz			dB	kHz		
A1A telegraphy aural reception		11				5				13				7			
A1B telegraphy 50 Bd, printer B = 500 Hz		11				5				13				7			
A1B telegraphy 100 and 120 Bd recorder B = 500 Hz		11				5				13				7			
A2A telegraphy aural reception		17				11											
A2B telegraphy, 24 Bd		17				11											
F1B telegraphy (3) 50 Bd, printer $2D$ = 280 Hz: B = 500 Hz		9				3				3				–3			
F1B telegraphy 50 Bd, printer $2D$ = 400 Hz: B = 500 Hz		9				3				3				–3			
F7B telegraphy 100 Bd, printer ARQ $2D$ = 400 Hz B = 500 Hz										4				–2			
F7B telegraphy 200 Bd, printer ARQ $2D$ = 400 Hz: B = 500 Hz										4				–2			
F7B (3), 50 Bd, printer $2D$ = 1 200 Hz B = 1 200 Hz	Channel 1																
	Channel 2																
R3C phototelegraphy										16				10			
F3C phototelegraphy 60 rpm, B = 1 000 Hz										15				9			
A3E telephony DSB	just usable	18				12				13				7			
	marginally commercial	30				24				29				23			
	good commercial	51				45				56				50			
H3E telephony SSB full carrier(5)	just usable	12				6				7				1			
	marginally commercial	24				18				23				17			
	good commercial	45				39				50				44			
R3E telephony SSB reduced carrier(5)	just usable	7				1				2				–4			
	marginally commercial	19				13				18				12			
	good commercial	40				34				45				39			
J3E telephony SSB suppressed carrier(5)	just usable	6				0				1				–5			
	marginally commercial	18				12				7				11			
	good commercial	39				33				44				38			
R8E telephony Two ISB reduced or suppressed carrier(5)	just usable	12				6				7				1			
	marginally commercial	24				18				23				17			
	good commercial	45				39				50				44			
J7B multichannel V.F. telegraphy 250-3 000 Hz										17.5				11.5			
J7B multichannel V.F. telegraphy 300-3 400 Hz (6)										17.5				11.5			
R7B multichannel V.F. telegraphy reduced carrier										18.5				12.5			
J2D data transmission SSB suppressed carrier PSK/QAM(13)		9				9				9				9			

TABLE 1 (*end*)

WANTED SIGNAL		CLASS OF EMISSION OF INTERFERING SIGNAL																Provisional total fading allowances(8) for the protection of a fading signal against an interfering signal subject to fading and day-to-day intensity fluctuations. (See (9)) (dB to be added to values in columns numbered 1)	
Class of emission		Multichannel V.F. telegraphy												Data transmission					
		J7B suppressed carrier 250-3 000 Hz				J7B suppressed carrier 300-3 400 Hz				R7B reduced carrier				J2D PSK/QAM					
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	Non-diversity	Diversity
A1A telegraphy aural reception														11					
A1B telegraphy 50 Bd, printer B = 500 Hz														11					27(10)
A1B telegraphy 100 and 120 Bd recorder B = 500 Hz														11					
A2A telegraphy aural reception														17					
A2B telegraphy, 24 Bd														17					
F1B telegraphy (3) 50 Bd, printer $2D$ = 280 Hz: B = 500 Hz														9					
F1B telegraphy 50 Bd, printer $2D$ = 400 Hz: B = 500 Hz														9					27(10)
F7B telegraphy 100 Bd, printer ARQ $2D$ = 400 Hz B = 500 Hz																			
F7B telegraphy 200 Bd, printer ARQ $2D$ = 400 Hz: B = 500 Hz																			12(11)
F7B (3), 50 Bd, printer $2D$ = 1 200 Hz B = 1 200 Hz	Channel 1																		
	Channel 2																		
R3C phototelegraphy																		20	
F3C phototelegraphy 60 rpm, B = 1 000 Hz																		20	
A3E telephony DSB	just usable	20				20				19				18					
	marginally commercial	34				34				33				30					
	good commercial	56				56				55				51				17(12)	
H3E telephony SSB full carrier (5)	just usable	14				14				13				12					
	marginally commercial	28				28				27				24					
	good commercial	50				50				49				45					
R3E telephony SSB reduced carrier(5)	just usable	9				9				8				7					
	marginally commercial	23				23				22				19					
	good commercial	45				45				44				40				17(12)	
J3E telephony SSB suppressed carrier(5)	just usable	8				8				7				6					
	marginally commercial	22				22				21				18					
	good commercial	44				44				43				39				17(12)	
R8E telephony Two ISB reduced or suppressed carrier(5)	just usable	14				14				13				12					
	marginally commercial	28				28				27				24					
	good commercial	50				50				49				45					
J7B multichannel V.F. telegraphy 250-3 000 Hz																			
J7B multichannel V.F. telegraphy 300-3 400 Hz (6)																			
R7B multichannel V.F. telegraphy reduced carrier																			
J2D data transmission single sideband suppressed carrier PSK/QAM(13)		9				9				9				9					

Notes to Table 1:

DSB: Double sideband

ISB: Independent sideband

SSB: Single sideband

* Under "class of emission", *B* represents the receiver bandwidth and 2*D* represents the total frequency shift.

([1]) Bandwidth of interfering signals limited to 500 Hz.

([2]) For a probability of character error $P_C = 0.0001$.

([3]) For a probability of character error $P_C = 0.001$.

([4]) For a traffic efficiency of 90%.

([5]) For telephony the values of protection ratios for stable conditions have been derived from information contained in Annexes 1 and 2. The figures for A3E telephony are valid only for reception with an SSB receiver.

([6]) Values derived from information contained in Annex 3.

([7]) Average degree of modulation 70%; sideband components extended to ± 3 kHz.

([8]) Combined allowances for fading safety factor and intensity fluctuation factor.

([9]) The probability distribution of the radio of two signals fading independently has been applied. The combined intensity fluctuation allowance for two signals has been taken as 7 dB, which represents a compromise between the 0 dB allowance, appropriate to perfectly correlated intensity fluctuations of the two signals, and the 14 dB allowance appropriate to uncorrelated intensity fluctuations of the two signals.

([10]) For protection 99.99% of the time.

([11]) Based on 90% traffic efficiency.

([12]) Based on 90% protection.

([13]) The protection ratio for the J2D wanted signal is the values for user data rate of 3.2 kbit/s in the wanted signal. For the other user data rate, add the correction factor (dB) shown below:

User data rate (kbit/s)	3.2 or less	4.8	6.4	8.0	9.6	12.8
Correction factor (dB)	0	4	7	10	12	18

5 that Annex 1 should be referred to for measurement of protection ratios for J3E emission;

6 that Annex 2 should be referred to for conversion factors for deriving the protection ratios;

7 that Annex 3 should be referred to for measurement of protection ratios and minimum necessary frequency separation for class of emission J7B.

8 that the Notes shown below should be considered as part of this Recommendation.

NOTE 1 – Use of the recommended values only permits an estimate to be obtained, which may have to be adjusted for radio circuits of different lengths, depending on the grade of service required and on the specific propagation conditions on these radio circuits. In calculating the fading safety factor for rapid or short-period fading, a log-normal amplitude distribution of the received fading signal has been used (using 7 dB for the ratio of median level to level exceeded for 10% or 90% of the time), except for high-speed automatic telegraphy services, where the protection has been calculated on the assumption of a Rayleigh distribution.

NOTE 2 – Table 1 provides, in column 1 for each interfering signal, the value of the protection ratio as the ratio of wanted-to-unwanted signals whose powers are expressed in terms of peak envelope power (*P*X) in general when the occupied band of the interfering emission either falls entirely within the passband of the receiver, or covers it completely.

When one of the signals is expressed in terms of mean power (*P*Y) or carrier power (*P*Z) the corresponding value of the protection ratio can be obtained by appropriately using the conversion factors given in Recommendation ITU-R SM.326.

For the wanted signal of the J2D emission, the value of the protection ratio is given as the power ratio of wanted-to-unwanted signals whose powers are expressed in terms of mean power.

NOTE 3 – Columns 2, 3 and 4 of Table 1 indicate the frequency separation necessary between the assigned frequency of a wanted signal and that of an interfering signal when the level of the latter is respectively 0, 6 and 30 dB higher than the wanted signal (as defined in No. 1.148 of the Radio Regulations, the assigned frequency is the centre of the assigned frequency band).

NOTE 4 – Signal processing techniques such as Lincompex, Syncompex, etc., and the use of noise reducers and notch filters may reduce the susceptibility of radiotelephone signals to interference.

Annex 1

Measurement of protection ratios for J3E emission

1 Introduction

Protection ratio is defined in No. 1.170 of the Radio Regulations as follows:

> "*Protection Ratio* (R.F.): The minimum value of the wanted-to-unwanted signal ratio, usually expressed in decibels, at the receiver input, determined under specified conditions such that a specified reception quality of the wanted signal is achieved at the receiver output."

In the study of protection ratios for speech communications, there are two basic difficulties. One is to determine what type of signal power ratio should be applied, and the other is to determine exactly what type of evaluation should be associated with the degradation of service due to interference.

The measurement programme described in this annex was based on Recommendation ITU-R F.339, in which audio signal-to-noise (*S*/*N*) ratios of 33 dB, 15 dB and 6 dB give the service grades of good commercial, marginally commercial and just usable respectively. The objective was to obtain audio signal-to-interference (*S*/*I*) ratios for various interfering signals that give the same opinion scores as those corresponding to the specified *S*/*N* ratios.

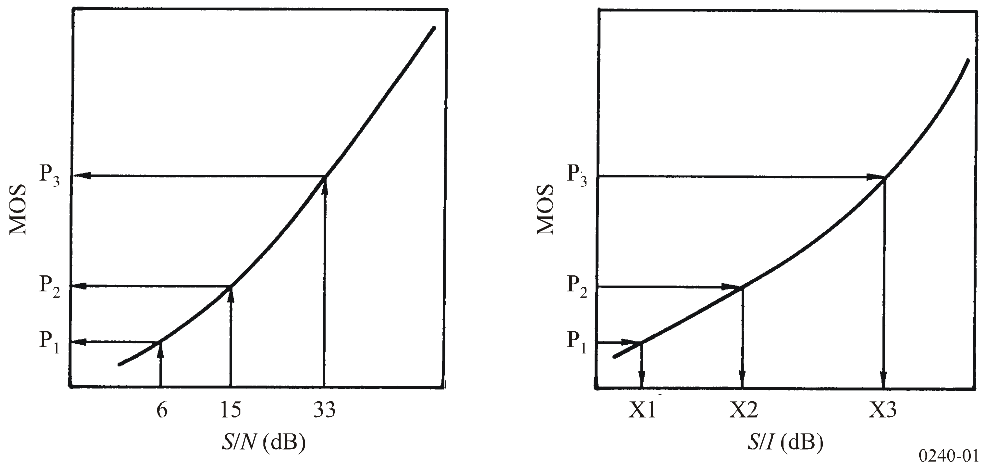
2 Measurement

2.1 Measurement principle

Mean opinion score (MOS) value versus *S*/*N* ratio curves and MOS value versus *S*/*I* ratio curves were obtained by opinion tests. From these curves, the *S*/*I* ratios (*X*1, *X*2, *X*3) corresponding to each of the above service grades were obtained for the same MOS values (P_1, P_2, P_3) as those which correspond to each *S*/*N* value of 33 dB, 15 dB and 6 dB (see Recommendation ITU-R F.339). The method is shown in Fig. 1.

FIGURE 1

Conversion from *S*/*N* to *S*/*I* through MOS



2.2 Interfering signals

The A1B, F1B, F3C, F7B, J7B and J3E emissions shown in Table 2 were added to the wanted J3E emissions (male and female Japanese speech signals) as interfering signals. The centre frequency of the interfering signal was set at 1 400 Hz except for the J7B emission which occupied the band between 0.3 to 3.0 kHz.

TABLE 2

Type of interfering signal

Class of emission	Frequency shift (Hz)	Modulation rate (Bd)
A1B	–	100
F1B	400	200
F3C	800	(60 rpm)
F7B	600	100
J7B	85 per channel	100 per channel
J3E	–	–

2.3 Measurement method

2.3.1 Test speech samples and sending order

As shown in Table 3, 29 test speech samples containing 14 different *S*/*N* ratios and 15 different *S*/*I* ratios, were presented randomly to the listeners for their evaluation. The time duration for one test speech sample was 5 s and a period of 10 s silence was provided between successive 5 s samples. This silent period was used by the listeners to log the speech quality on a questionnaire.

TABLE 3

An example of the random sending order of the test speech samples

Sample No.	Power ratio (dB)		Sending order
1	*S*/*N*	0 ([1])	14
2		4	4
3		6	25
4		8	27
5		12	23
6		15 ([1])	9
7		20	29
8		24	22
9		28 ([1])	13
10		33	24
11		36	16
12		40 ([1])	1
13		44	8
14		48 ([1])	11
15	*S*/*I*	−8	19
16		−4 ([1])	10
17		0	26
18		4 ([1])	5
19		8 ([1])	17
20		12 ([1])	7
21		16	12
22		20	15
23		24	20
24		28	3
25		32	21
26		36 ([1])	28
27		40	18
28		44 ([1])	6
29		48	2

Note 1 – The samples and sending order indicated above were used for the preliminary test in the case of F1B interfering signal.

([1]) These power ratios were selected for detailed tests.

2.3.2 Mean opinion score (MOS)

Speech quality was evaluated by a five-point listening effort scale (see Supplement No. 2, § 3, ITU-T Yellow Book, Volume V) as follows:

4 complete relaxation possible (no effort required)

3 attention necessary (no appreciable effort required)

2 moderate effort required

1 considerable effort required

0 no meaning understood, with any feasible effort.

MOS was calculated as the mean value of the scores of 12 Japanese (5 male and 7 female) listeners.

2.3.3 Listening conditions

Standard conditions as indicated in ITU-T Recommendation P.74 and in Supplement No. 2 and set out below, were used for the listening tests:

– telephone set: No. 601 (side tone added)

– room noise: +36 dB (A)

– sound pressure level: 75-80 dB.

2.3.4 Setting of *S*/*N* ratio and *S*/*I* ratio

A schematic diagram of the configuration used for the tests is shown in Fig. 2. The magnetic tapes used for the measurements were prepared as follows:

– speech signals and interfering signals were separately recorded in advance on analogue magnetic recording tapes. These signals were played back, digitized by A/D converter (12 bits) and recorded on magnetic tape (MT-A) in the form of digital data. The sampling frequency of the A/D conversion was 8 kHz;

– in the computer (CPU), the mean power of the wanted speech signal, interfering signal and noise, as well as the coefficient α, which gives the required S/I or S/N ratio, were calculated from the following equation:

$$S/I\,(\text{or } S/N) = 10 \log \frac{\frac{1}{n}\sum_{i=1}^{n}(d_i)^2}{\frac{1}{m}\sum_{k=1}^{m}(\alpha d_k)^2}$$

where:

d_i : sampled data of amplitude of wanted signal

d_k : sampled data of amplitude of interfering signal

α : coefficient for setting S/N or S/I ratio;

– the predetermined S/I or S/N ratio of test speech sample (S_i) was obtained by multiplying each sample of the amplitude of the interfering signal (d_k) by α and adding the result to the value of the sample of the amplitude of the wanted signal (d_i). This sum (S_i) was then converted to the analogue signal by the D/A converter ($S_i = \alpha d_k + d_i$).

The measured mean power to peak envelope power ratios of the signals are shown in Table 4.

2.3.5 Determination of sending order of speech samples

As an example, the random sending order of 29 test speech samples is shown in Table 3. The digital signals in each sample were converted to analogue signals by the D/A converter, and recorded on magnetic tape B (MT-B) through a 3 kHz band pass filter.

The processes described above were carried out automatically by the computer.

FIGURE 2

Configuration of the test

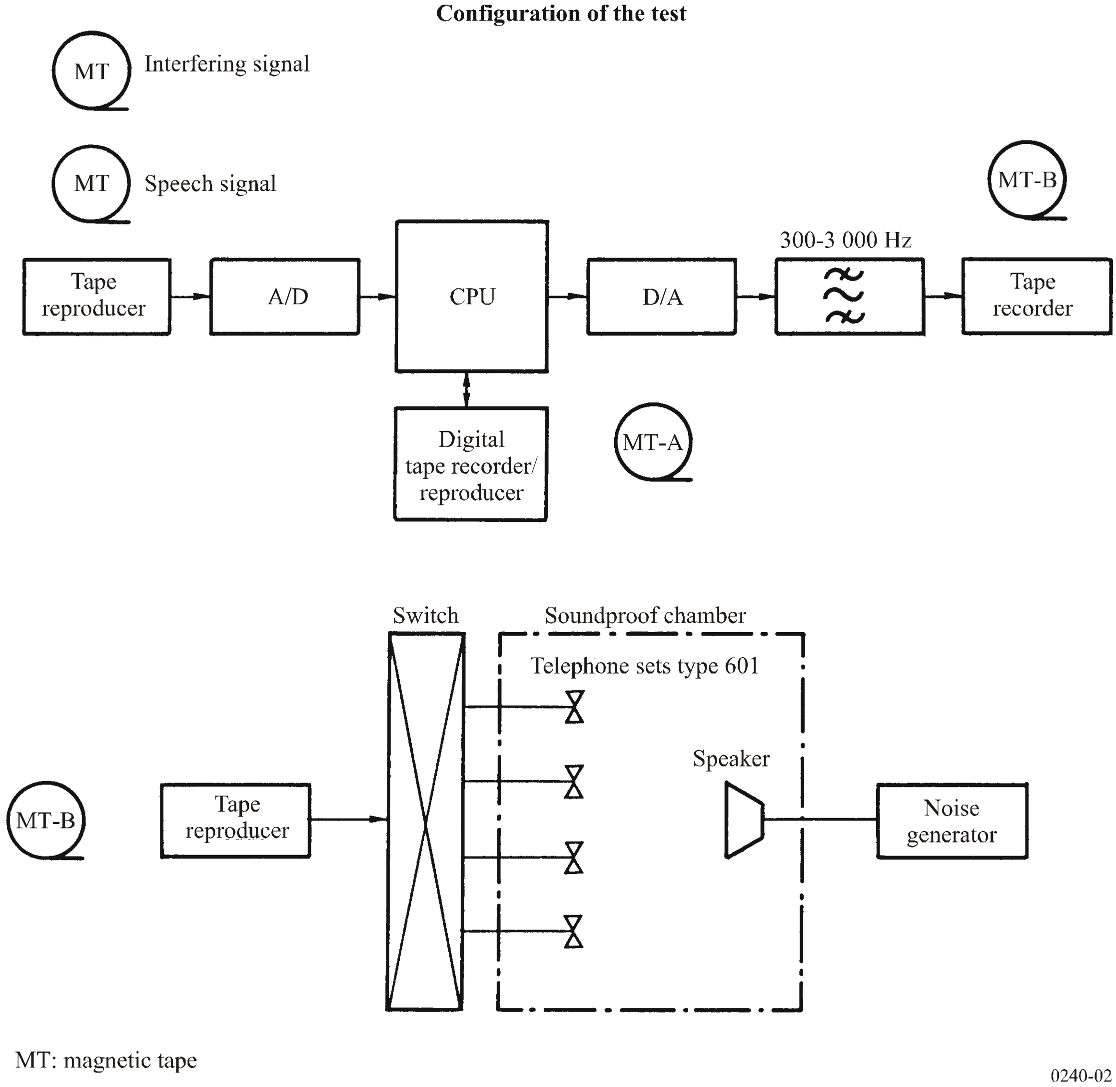


TABLE 4

Measured mean power to peak envelope power ratios

Class of emission	Mean power (1) to peak envelope power (dB)	Mean power (2) to peak envelope power (dB)
J3E	–15	–17.5
A1B	0	–3.2
F1B	0	0
J7B	–11	–

(1) This mean power was averaged during the time when the signal level was above a threshold which was negligibly small.

(2) This mean power was averaged during the whole time, including the time when no signal was present.

3 Measurement results

3.1 MOS versus *S*/*N* ratio

As shown in Table 3, for every group of 29 speech samples, the MOS was measured for both *S*/*I* and *S*/*N* ratios. The MOS versus *S*/*N* data were then used to derive the *S*/*I* ratios corresponding to the service grades of just usable, marginally commercial and good commercial quality.

By averaging all of the 480 MOS values for each of the 14 *S*/*N* ratios tested, a mean value, having a small error, was obtained. The 95% confidence interval calculated for each of the mean *S*/*N* values varied between 0.072 and 0.039.

The mean values thus obtained for 14 cases of *S*/*N* are plotted in Figs. 3 to 8 with black circles.

3.2 MOS versus *S*/*I* ratio

Similarly, for the MOS versus *S*/*I* data, the MOS levels corresponding to the values of the *S*/*I* ratio for each of the three grades of service quality, are obtained by interpolating or extrapolating between the two mean *S*/*I* values as shown in Figs. 3 to 8.

In Figs. 3 to 8, each value represents the mean of 240 MOS tests at each *S*/*I* ratio, and the values P_1, P_2 and P_3 represent just usable, marginally commercial and good commercial grades of service respectively.

For the *S*/*I* measurement, detailed tests were conducted only for a limited number of values of *S*/*I* (the six points plotted in Figs. 3 to 8 as black squares), which were expected to give MOS values very close to the *S*/*N* ratios corresponding to the three grades of service, in order to increase the test reliability and to save time.

The confidence interval calculated for all measured MOS versus *S*/*I* ratio values ranged from 0.06 to 0.117 for the J7B tests.

4 Considerations

4.1 MOS

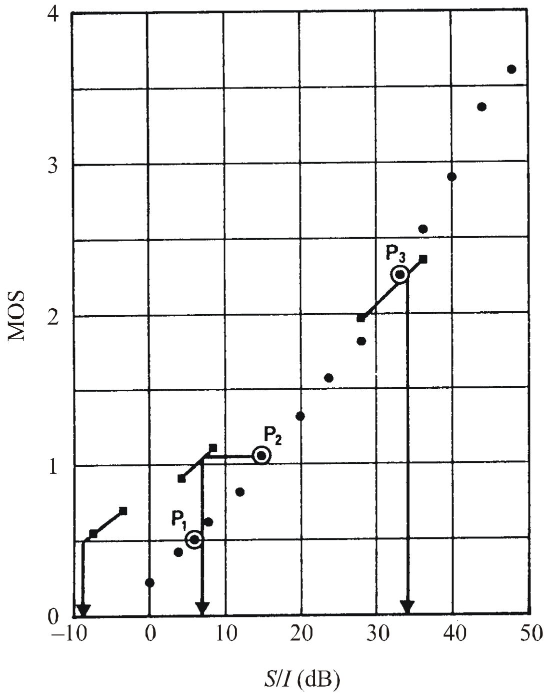
It is interesting to note that the MOS versus *S*/*I* ratio curves and MOS versus *S*/*N* ratio curves cross at certain *S*/*I* and *S*/*N* ratios as shown in Figs. 3 to 8. This was not anticipated before the measurements were made. For example, in cases when an F1B or an A1B emission was the interfering signal, noise was more unpleasant than the interfering signal when the *S*/*I* ratio was small. On the other hand, the interfering signal was more annoying than white Gaussian noise when the *S*/*I* ratio was large, because the interfering signal was easily recognizable.

4.2 Protection ratios

Based upon the measurements above, required *S*/*I* ratios for J3E emissions against various interfering signals were obtained as shown in Table 5. For obtaining the RF protection ratios for J3E emissions, it is necessary to convert the values of Table 5 by using the relationships between the power ratios of the various kinds of interfering emissions. The conversion factors for obtaining protection ratios of various types of emissions against various interfering signals are discussed in Annex 2.

FIGURE 3

MOS for speech signal with A1B interference

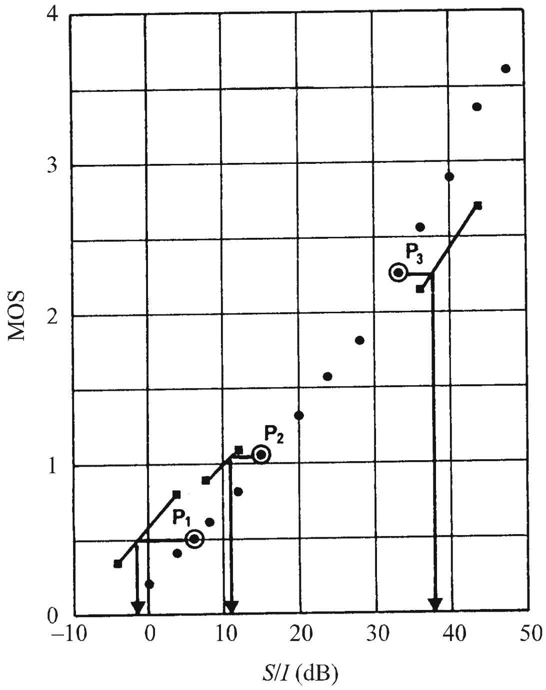


Note 1 – The • in Figs. 3 to 8 indicates MOS value to *S/N* ratios (dB).

Note 2 – P_1, P_2 and P_3 represent just usable, marginally commercial and good commercial grades of service respectively.

FIGURE 4

MOS for speech signal with F1B interference



0240-03

FIGURE 5

MOS for speech signal with F3C interference

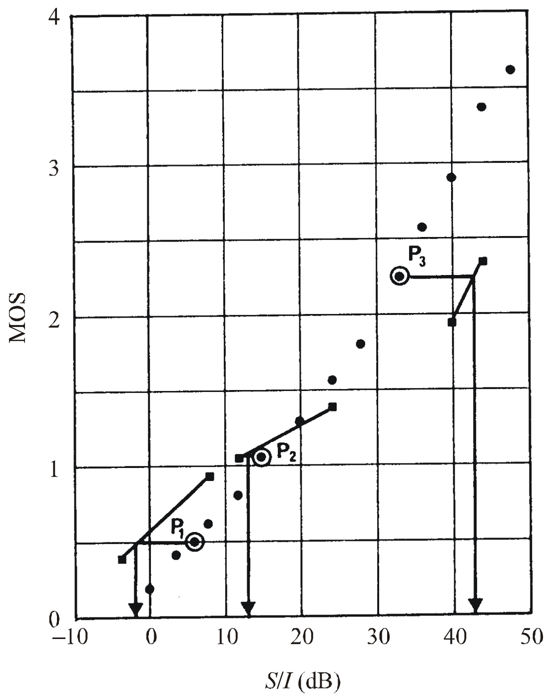


FIGURE 6

MOS for speech signal with F7B interference

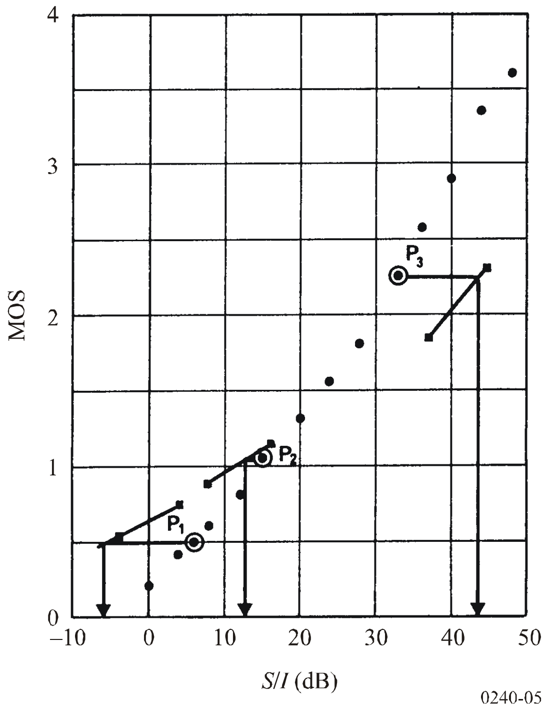


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FIGURE 7

MOS for speech signal with J7B interference

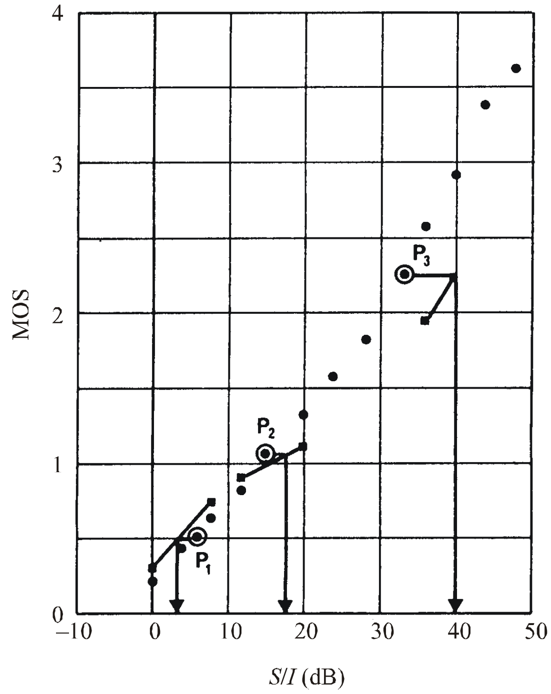


FIGURE 8

MOS for speech signal with J3E interference

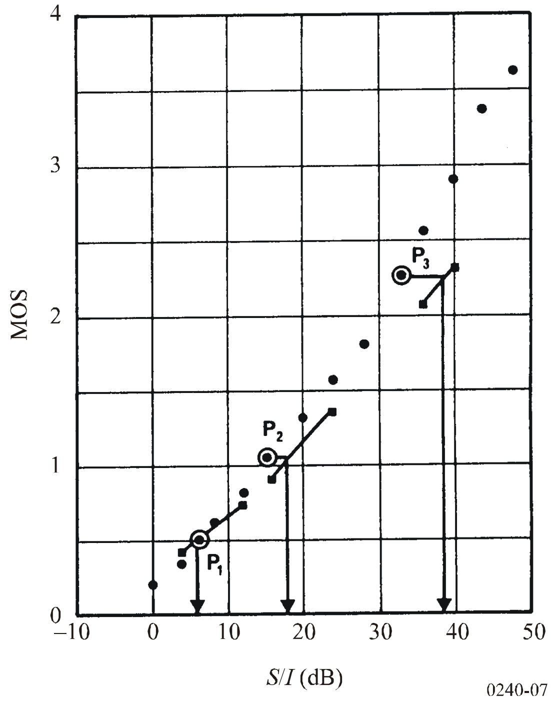


TABLE 5

Required *S*/*I* ratios for J3E emissions against various interfering signals

Type of interfering signal	Required *S*/*I* ratios (dB)		
Class of emission	Just usable	Marginally commercial	Good commercial
A1B	–9 (–17)	7 (–8)	34 (10)
F1B	–1 (–6)	11 (3)	38 (21)
F3C	–2 –	13 –	43 –
F7B	–5 –	13 –	44 –
J7B	4 –	18 –	40 –
J3E	6 –	18 –	39 –
White Gaussian noise	6 (5)	15 (14)	33 (32)

Note 1 – The values in parentheses in each column are the protection ratios shown in Report 525 (Düsseldorf, 1990) of Study Group 1.

Note 2 – The audio signal powers for the A1B and J3E cases were measured during the time when the signal was above a specified threshold level.

Annex 2

Conversion factors for deriving the protection ratios

1 Introduction

The protection ratios for J3E, R3E, H3E, A3E and B8E emissions (radiotelephony) are shown in Table 1. These values are derived from the results of the measurements of J3E protection ratios given in Annex 1.

This Annex describes the conversion between the mean power measured data of Annex 1 and the protection ratios given in this Recommendation. These protection ratios are expressed in terms of peak envelope power (*P*X).

Protection ratio values for non-telephony emissions such as A1A, A1B, A2A, A2B, F1B, F7B, R3C, F3C, J7B and R7B emissions can also be obtained by applying the concept of the conversion factors.

2 Calculation of protection ratios

2.1 Calculation method

Protection ratios for various radiotelephony signals can be obtained by using the required *S*/*I* ratios for J3E emission against various interfering signals appearing in Table 5, of Annex 1 and the conversion factors appearing in Table 6 for the case where interfering signals are radiotelephony. For the case where interfering signals are radiotelephony, the following conversion factors should be applied:

– in the case of F1B, F7B and F3C emissions, *P*X is equal to the mean power (*P*Y):
  - *P*X of a J7B emission is 6 dB higher than *P*Y;
  - *P*X of an R7B emission is 7 dB higher than *P*Y;
  - *P*X of A1B and J2B (negligible carrier) emissions is 3 dB higher than *P*Y;
  - *P*X of an H2A/H2B emission is 6 dB higher than *P*Y and is identical to *P*X of a J2B emission;
  - *P*X of an R3C emission is 1 dB higher than *P*Y;
  - *P*X of A1A and A1B (50 Bd) emissions is the same as that of an A1B (100 Bd) emission;
  - *P*X of an A2A emission is the same as that of an A2B emission;
  - the interference from an F1B or an F7B emission is the same, regardless of its channel rate and frequency shift.

2.2 J3E emission

The values given in Table 5 are –1, 11 and 38 dB for just usable, marginally commercial and good commercial quality respectively, where the interfering signal is a 200 Bd F1B emission with 400 Hz shift.

Since the transmitting power is usually defined as peak envelope power (*P*X), for practical use the protection ratio should be expressed by the ratio of the peak envelope powers (*P*X). Then the J3E protection ratios expressed as the ratios of *P*X in stable conditions are given as 9, 21 and 48 dB since the power ratios between *P*X and *P*Y are 10 and 0 dB for J3E and F1B emissions respectively.

TABLE 6

Conversion factors

Class of emission	*P*X-*PZ* (dB)	*P*X-*P*ys (dB)	*P*xs-*P*ys (dB)	*P*X-*P*xs (dB)
J3E	> 40	10	10	0
R3E	20	11	10	1
H3E	6	16	10	6
A3E	6	22	10	12
B8E	> 40 or 20	16	10	6

*P*X : peak envelope power
PZ : carrier power
*P*xs : peak envelope power of one speech channel i.e. the power of a reference sinusoidal signal
*P*ys : mean power of one speech channel

2.3 R3E, H3E and A3E emissions

The peak envelope power (*P*X) for R3E, H3E and A3E is 1, 6 and 12 dB respectively higher than the *P*X of a J3E emission when the *P*X of one sideband is equal to the reference power. Therefore, the protection ratios for R3E, H3E and A3E emissions should be 1, 6 and 12 dB higher than the protection ratios for a J3E emission.

The protection ratio for the A3E emission using the above conversion factors is only applicable to reception using an SSB receiver, since the centre frequency of the interfering signal is assumed to be 1.4 kHz higher than the carrier frequency of the A3E emission.

2.4 B8E emission

For a multi-channel B8E emission, it is assumed that the protection ratio is derived when one of the channels of the wanted emission is degraded by an interfering emission. In this case, the occupied band of the interfering emission either falls entirely within a band, approximately 3 kHz for one speech channel, or covers it completely. The protection ratios for multi-channel B8E emissions can be obtained by using the conversion factors given in Table 6.

When the *P*X of one speech channel of the B8E emission is equal to that of the J3E emission, the *P*X of the B8E emission becomes 6 dB higher than the *P*X of the J3E emission. This means that the protection ratio for 2- or 4-channel B8E emissions shall be 6 dB higher than that of the J3E emission.

When an R3E, B8E or J3E emission is an interfering emission, the protection ratio for multi-channel B8E emissions can be obtained by using the conversion factors in Table 6, assuming that the carrier frequencies of the wanted and unwanted emissions are equal, and the effects of the carriers of wanted and unwanted emissions can be neglected.

3 Assumptions for conversion factors

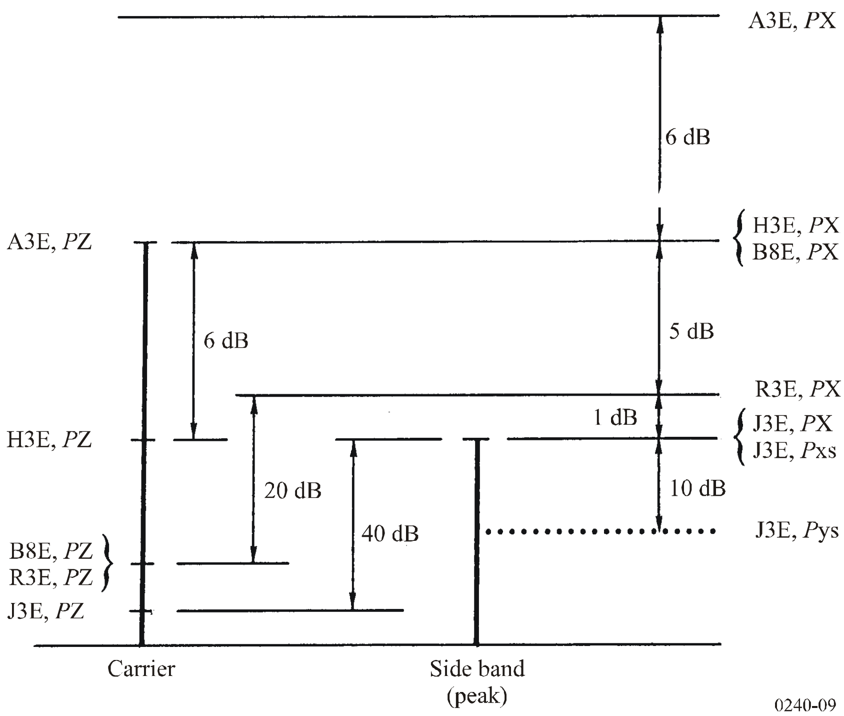
The following assumptions were made in preparing Table 6 and Fig. 9.

3.1 J3E emission

For J3E emission, the power of the sideband signal corresponding to 100% modulation is the same as its peak envelope power.

FIGURE 9

Relationship between *P*X, *P*Y, *P*Z, *P*xs and *P*ys of J3E, R3E, H3E, A3E and B8E emissions



3.2 R3E emission

For R3E emission, a pilot-carrier of –20 dB relative to peak envelope power is applied and the power of the sideband signal corresponding to 100% modulation is 1 dB lower than the peak envelope power (see Recommendation ITU-R F.339, Note 24 to Table 1).

3.3 H3E emission

For H3E emission, the powers of sideband signals and pilot-carrier corresponding to 100% modulation are each –6 dB relative to peak envelope power. An SSB receiver is used for reception (see Recommendation ITU-R F.339, Note 23 to Table 1).

3.4 A3E emission

For A3E emission, a carrier –6 dB relative to peak envelope power is applied and the power of a sideband signal corresponding to 100% modulation is 6 dB lower than the carrier power. An SSB receiver is used for reception.

3.5 B8E emission

For multi-channel B8E emission, the reference is the power of a sinusoidal oscillation which would modulate the transmitter to one quarter (–6 dB) of its peak envelope power.

For 3- or 4-channel B8E emissions, it is assumed that independent modulating signals are applied to each channel (see Recommendation ITU-R SM.326, Notes 2 and 3 to Table 1).

3.6 Mean power of speech signal

For smoothly read text, the mean power of the speech signal is 10 dB lower than the power of a reference sinusoidal signal (see Recommendation ITU-R SM.326, Note 2 to Table 1).

Annex 3

Measurement of protection ratios and minimum necessary frequency separation for class of emission J7B

1 Introduction

Recommendation 240 (Geneva, 1982) defines the *necessary frequency separation* as that between "the assigned frequency of a wanted signal and that of an interfering signal when the level of the latter is respectively 0, 6 and 30 dB higher than the wanted signal" (in No. 142 of the Radio Regulations, the assigned frequency is defined as "the centre of the frequency band assigned to a *station*").

One of the most promising methods of digital communication in the HF bands consists of the transmission of individual bit streams by frequency modulation (FM) of sub-carriers in the voice frequency band on a single multiplex radio channel. In the Radio Regulations, the operating modes can correspond to classes of emission J7B and R7B. All possible types of operation using frequencies in the voice band, should be considered as the interfering signal for the purpose of calculating protection ratios.

The theoretical estimation of the effect of interfering signals on multi-channel telegraphy signals generally constitutes a complex non-linear problem of analysis in non-steady state channel conditions, which can only be solved by making considerable simplifications.

This annex provides experimental data, obtained in stable conditions, on the effect of interfering signals of classes of emission A1B, F1B and F7B, which are currently widely used to transmit digital information in the HF range, on the wanted signal of class J7B.

2 Experiment

2.1 Measurement of protection ratios

In practice, protection ratios can be obtained by means of the circuit of Fig. 10.

A class J7B emission was used as the wanted signal. The baseband signal in the frequency range 300-3 400 Hz was made up of six independent sub-channels on frequencies given by the equation:

$$f_n = 600 + (n - 1)\,480 \text{ (Hz)}$$

where n is the number of sub-channels, e.g. 600 Hz, 1 080 Hz, 1 560 Hz, 2 040 Hz, 2 520 Hz and 3 000 Hz. The frequencies are in accordance with ITU-T Recommendation R.38A. The passband of the channel filters was 270 Hz.

The digital information was transmitted in each sub-channel at a rate of 200 bit/s by narrowband frequency modulation of the sub-carrier f_n with a modulation index of 0.6. In the experiment, six independent pseudo-random sequence generators producing recurrent pulse sequences of 511 bits were used as digital information sources.

Thus, at the modem transmitter output, the wanted signal had an effective bandwidth of 300-3 400 Hz (in accordance with ITU-T Recommendation R.38A) and a constant mean power. This signal was used to modulate the radio transmitter in a single-sideband suppressed carrier mode.

The main interfering signal characteristics are given in Table 7.

The interfering signals were obtained directly from the drive of a radio transmitter designed to operate in the classes of emission studied (Table 7).

Digital signals from pseudo-random sequence generators (similar to those used for the wanted signal modem) were sent to the drive inputs at rates of 50, 100 and 200 bit/s. The effect of the interference on the wanted signal was separately calculated in turn for each class of emission of the interfering signal by changing the operating mode of the drive.

Since the purpose of the study was to determine the protection ratio for stable conditions, the radio transmitters could be directly connected to the receiver input.

FIGURE 10

Circuit used for measurement of protection ratios

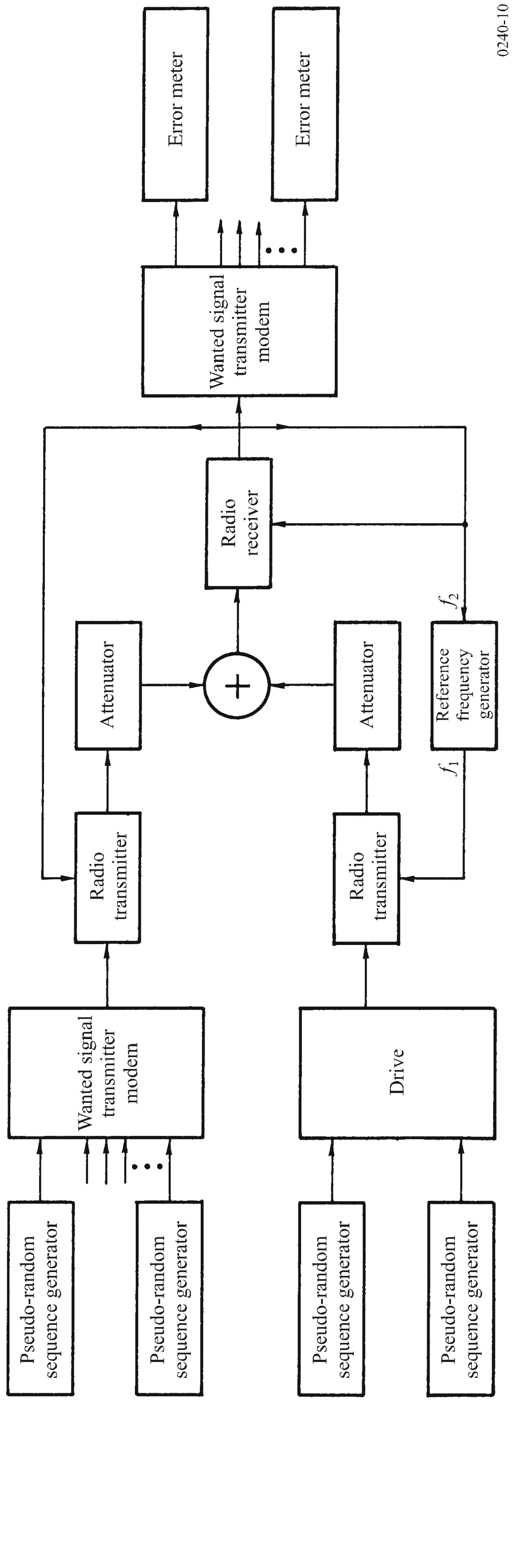


TABLE 7

Main interfering signal characteristics

Interfering signal	Total frequency shift, 2*D* (Hz)	Modulation rate (bit/s)
A1B, telegraphy		50
		100
F1B, telegraphy (one channel)	200	50
	400	
	400	100
	500	100
		200
F7B, telegraphy (two sub-channels in the band 300-3 400 Hz)	1 500	2 × 100
	3 000	2 × 200

Since the determination of protection ratios involves obtaining the minimum signal-to-interference ratio at which a given link quality is maintained for each sub-channel, and as the interference spectrum is narrower than the multi-channel signal spectrum, the experimental circuit provided for the possibility of changing the working frequency f_1 of the radio transmitter of the interfering signal in relation to frequency f_2 of the single-sideband receiver by means of a reference frequency generator with 100 Hz steps. Thus, with a step of 100 Hz and centre sub-channel frequencies of 600, 1 080, 1 560, 2 040, 2 520 and 3 000 Hz, the centre interference frequency was shifted relative to the centre sub-channel frequencies by 20, 40, 60, 80 and 100 Hz respectively.

This made it possible to fix the point of the greatest interference effect on a sub-channel with a frequency accuracy of 20 Hz.

The effect of interference on the wanted signal was estimated by the maximum error probability in any of the sub-channels of the wanted signal in the receiver modem.

Under the experimental conditions, the maximum bit error ratio in any of the sub-channels should not exceed 10^{-4}, which corresponds to the normally accepted value of HF digital information transmission quality. Hence, when the interference spectrum was shifted relative to the SSB receiver working band, the point at which the highest error rate was observed at any of the sub-channels of the wanted signal modem receiver was selected. An attenuator was used to establish a minimum interference level at which, in the sub-channel most affected by interference, the binary symbol error probability did not exceed 10^{-4}. This point characterizes the permissible interference level and hence, also the protection ratio for a multi-channel signal.

The interference and wanted signal levels were measured at the receiver input by means of an r.m.s. voltmeter.

The measurement results for different classes of interfering signals are given in column 1 of Table 8.

2.2 Determination of minimum frequency separation

For the effective use of the radio-frequency spectrum (apart from the maximum signal-to-interference protection ratio values which occur when the wanted and interfering signal spectra overlap), it is important to know the minimum values of the separation in assigned frequencies of the wanted and interfering signals for cases in which the interfering signal power is equal to the wanted signal power, 0 dB, or exceeds it by 6 and 30 dB.

TABLE 8

Results of the measurement of protection ratio and frequency separation

Wanted signal		Interfering signal: Class of emission F1B																			
		50 Bd 2D = 200 Hz				50 Bd 2D = 400 Hz				100 Bd 2D = 400 Hz				100 Bd 2D = 500 Hz				200 Bd 2D = 500 Hz			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
		dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz		
Multichannel telegraphy of emission J7B B = 3 100 Hz	FT([1]) 2D = 120 Hz	14.5	1.9	1.9	2.0	14.5	1.9	1.9	2.1	14.5	1.9	1.9	2.8	14.5	2.0	2.0	2.9	14.5	1.9	2.0	3.1
	2AT([2]) 2D = 1 440 Hz	9.5	1.7	1.8	2.5	9.5	1.8	1.9	2.6	9.5	1.6	1.9	2.7	9.5	1.9	2.0	2.8	9.5	1.9	2.0	2.8

(*continued*)

Wanted signal		Interfering signal: Class of emission A1B								Interfering signal: Class of emission F7B							
		50 Bd				100 Bd				100 Bd 2D = 1 500 Hz				200 Bd 2D = 3 000 Hz			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
		dB	kHz			dB	kHz			dB	kHz			dB	kHz		
Multichannel telegraphy of emission J7B B = 3 100 Hz	FT([1]) 2D = 120 Hz	14.5	1.7	1.7	8.0	14.5	1.7	1.8	9.1	14.5	2.4	2.5	3.5	14.5	3.2	3.3	5.1
	2AT([2]) 2D = 1 440 Hz	10.5	1.7	1.7	8.0	10.5	1.7	1.7	8.1	10.5	2.4	2.5	3.5	10.5	2.8	2.9	4.7

([1]) 6 × 200 Bd channels.

([2]) 3 × 200 Bd channels.

Numbers 1.148 and 1.149 of the Radio Regulations define the assigned frequencies of the classes of emission concerned as the centre of the necessary frequency bands of these emissions. Thus, for a wanted J7B signal, the assigned frequency corresponds to the centre frequency of the band 300-3 400 Hz, occupied by the baseband signal spectrum with the sub-carrier spacings given in ITU-T Recommendation R.38A.

The circuit shown in Fig. 10 was used to measure the minimum frequency separation.

In the experiment, the value of the difference frequency ($f_2 - f_1$) was measured to an accuracy of 100 Hz, and the error probability did not exceed 10^{-4} in all sub-channels of the wanted signal modem receiver.

The measurement results are given in Table 8, for signal-to-interference ratios of 0 dB, –6 dB and –30 dB, in columns 2, 3 and 4 respectively.

2.3 Measurements of multiplex mode 2AT

The measurements described in § 2.1 and 2.2 were also carried out for multiplex mode 2AT.

For measurements in 2AT mode, the wanted multiplex signal, selected in the range 300-3 400 Hz, is formed by three independent partial channels, the information being transmitted on each of them by two-tone keying with a frequency change of 1 440 Hz.

Table 9 indicates the mark and space frequencies of each of the three channels in the range 300-3 400 Hz.

TABLE 9

No. of 2AT channel	Mark (Hz)	Space (Hz)
1	600	2 040
2	1 080	2 520
3	1 560	3 000

The measurement results are also shown in the appropriate columns of Table 8.

3 Conclusions

For the transmission of digital information on HF radio channels using frequency modulation of sub-carriers in the voice frequency band with a bit error ratio not greater than 10^{-4} in stable conditions, the minimum protection ratio for the types of interfering signal considered must not be less than 14.5 dB.

The values of the minimum required frequency separation were also determined experimentally.

These measurements have been used to revise Table 1 for class of emission J7B wanted signal and nine types of interfering signals.