RECOMMENDATION ITU-R BS.1194-1

SYSTEM FOR MULTIPLEXING FREQUENCY MODULATION (FM) SOUND BROADCASTS WITH A SUB-CARRIER DATA CHANNEL HAVING A RELATIVELY LARGE TRANSMISSION CAPACITY FOR STATIONARY AND MOBILE RECEPTION

(Question ITU-R 71/10)

(1995-1998)

The ITU Radiocommunication Assembly,

considering

a) that many countries use the radio-data system (RDS) according to Recommendation ITU-R BS.643;

b) that although RDS is able to accommodate many of the data services required, the data capacity is nevertheless limited;

c) that it is a fundamental requirement that compatibility be achieved between FM stereophonic services including RDS and any new additional sub-carrier system;

d) that a much larger data capacity may be needed for some applications;

e) that sub-carrier data radio channel systems can provide a much larger capacity compared to RDS and are capable of meeting the requirement stated in § c) as regards protection ratios and interference levels;

f) that high-speed data systems have already been put into operation,

recommends

1 that one of the systems to be used for high capacity FM multiplex broadcasting for stationary and mobile reception is the Data Radio Channel (DARC) System, as specified in Annex 1 (see Notes 2 and 3).

NOTE 1 – Tests have indicated that at certain sub-carrier amplitudes, the ability of the receivers to reject interference from adjacent channels is affected by the presence of the DARC signal on the interfering source. For example, when an interfering signal on an adjacent channel was carrying a DARC signal which deviates the main FM carrier by ± 7.5 kHz, as well as an RDS signal which deviates the main FM carrier by ± 3 kHz, the required level of C/I for the range of receivers tested increased by up to 3 dB, but this was still below the criteria given in Recommendation ITU-R BS.412. In the case of high injection levels, attention will need to be paid to levels of deviation of sub-carriers to ensure conformance with protection ratios on which service planning is based.

Information regarding the operational characteristics of DARC is given in Annex 2.

NOTE 2 – Within the ITU-R extensive work is going on in the field of data services in FM broadcasting. Draft new Recommendation ITU-R BS.1350 specifying the system requirements will assist broadcasters in evaluating how to meet their service requirements with the available high-speed data systems.

NOTE 3 – Several additional high-speed data sub-carrier systems (such as HSDS and STIC systems) are already in use or under development in several countries, meeting different service requirements.

ANNEX 1

Specifications of the data radio channel (DARC)

1 Modulation characteristics (physical layer)

1.1 Sub-carrier frequency

The sub-carrier frequency is 76 kHz locked in phase to the fourth harmonic and, in the case of stereophonic services, is of pilot tone.

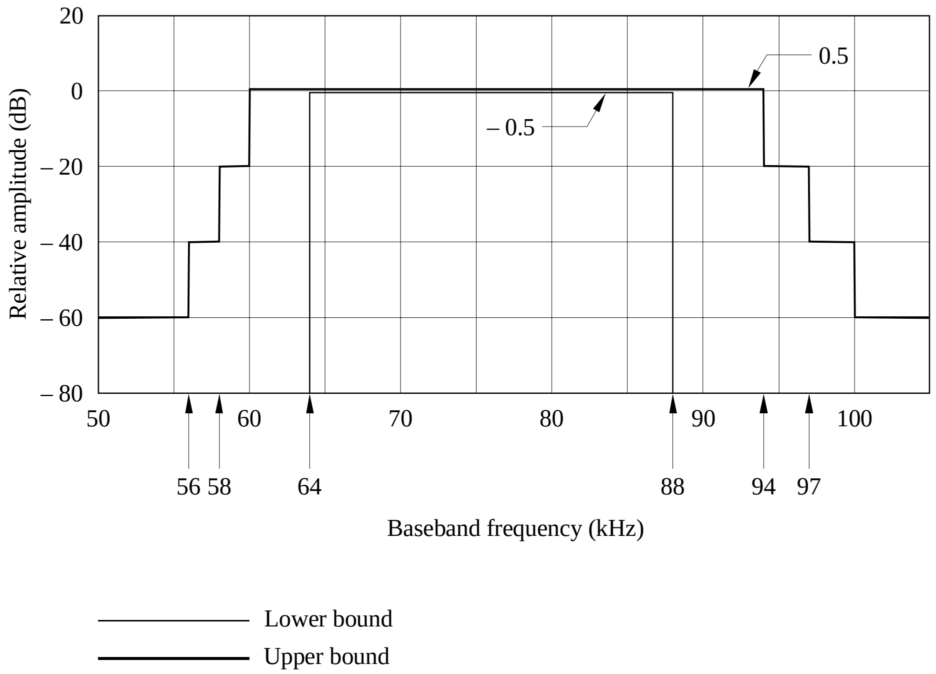
The frequency tolerance shall be within 76 kHz ± 7.6 Hz (0.01%) and the phase difference shall not exceed ± 5° for the phase of pilot tone.

1.2 Method of modulation

Level-controlled minimum shift keying (LMSK) modulation is used with a spectrum shaping according to Fig. 1. LMSK is a form of MSK in which the amplitude is controlled by stereo sound signals of left minus right. A frequency of 76 kHz + 4 kHz is used when the input data is 1 and 76 kHz - 4 kHz is used when the input data is 0.

FIGURE 1

Spectrum-shaping filter



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1.3 Bit rate

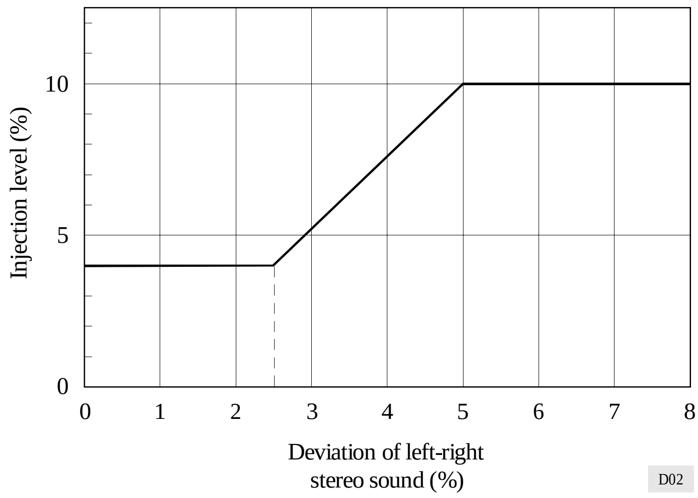
The bit rate is 16 kbit/s ± 1.6 bit/s.

1.4 Sub-carrier level

The sub-carrier level is varied depending on the level of the stereo L-R signals (see Fig. 2). If the deviation of the main FM carrier when modulated by the stereo L-R signals is less than 2.5%, the sub-carrier is deviated by 4% (± 3 kHz) of the main FM carrier. If the deviation of the main FM carrier when modulated by the stereo L-R signals is more than 5%, the sub-carrier is deviated by up to 10% (± 7.5 kHz) of the main carrier. Between these limits the deviation has a linear relation.

FIGURE 2

Sub-carrier deviation



2 Frame structure (data link)

2.1 General features

The largest element of the structure is called a "frame" and consists normally of 78 336 bits in total, organized as 190 information blocks of 288 bits each and 82 parity blocks of 288 bits each.

An information block comprises a block identification code (BIC) of 16 bits, information of 176 bits, a cyclic redundancy check (CRC) of 14 bits and parity of 82 bits.

A parity block comprises a BIC of 16 bits and parity of 272 bits.

There are four different types of BIC (see Table 1) to generate block synchronization and frame synchronization.

There are three methods to organize data, methods A and B, which both use product coding (272,190) × (272,190) and method C that uses only block code (272,190).

All three methods are identified and distinguished by the sequence of BICs.

TABLE 1

Block identification code (BIC)

BIC1	0001	0011	0101	1110
BIC2	0111	0100	1010	0110
BIC3	1010	0111	1001	0001
BIC4	1100	1000	0111	0101

2.2 Method A

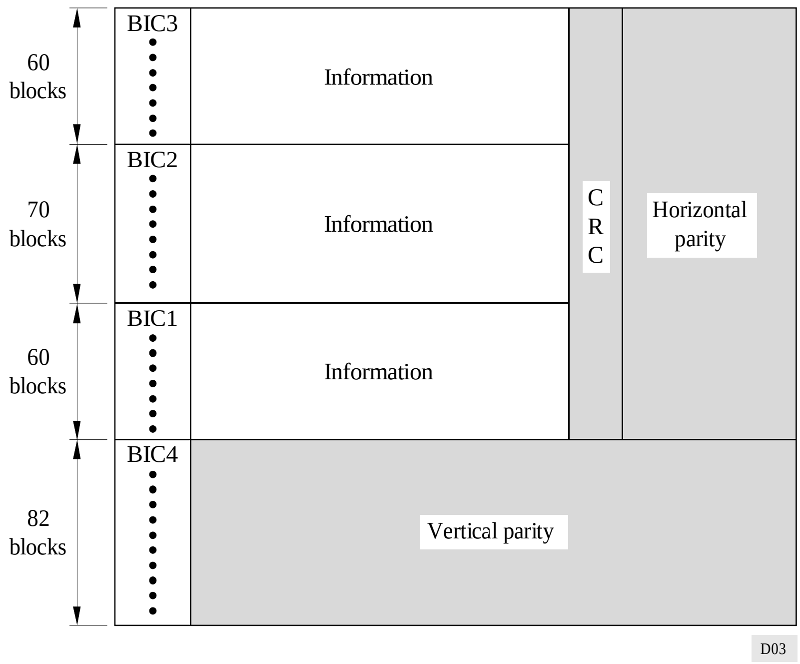
This method limits the transmission delay on the transmitter side. In method A the frame (called Frame A) consists normally of 190 information blocks followed by 82 parity blocks (see Fig. 3) but, for services with strong demand for real-time transmission it is possible to insert 12 additional information blocks (block coded only) among the parity blocks in the product coded frame.

The 12 inserted blocks are not a part of the product coded frame. They are placed at fixed positions, four blocks at a time at three positions (see Fig. 4). The first four blocks are placed after 20 parity blocks, the next four after another 21 parity blocks and the last four blocks after another 21 blocks.

The block identification code (BIC) for the inserted blocks is BIC2. The receiver extracts such blocks and decodes them immediately.

FIGURE 3

Frame according to method A, without insertion of real-time blocks



2.3 Method B

To allow an almost uniform transmission during the whole frame (called Frame B), the parity blocks are interleaved with the information blocks (see Fig. 5). This method causes a delay (about 5 s) on the transmitter side.

2.4 Method C

Method C comprises only information blocks of 288 bits. BIC3 is used within this method. This method is intended for services with a strong demand for real-time transmission, but at a lower level of error protection, e.g. for real-time services, stationary reception or repetitive information.

2.5 Error correction code

A product code (272,190) × (272,190) is used for the frame in methods A and B to enable the receiver/decoder to detect and correct errors which occur in reception. A block code (272,190) code is used for method C.

The (272,190) code is a shortened majority logic decodable difference set cyclic code. The generator polynomial for the (272,190) is given by:

$$g(x) = x^{82} + x^{77} + x^{76} + x^{71} + x^{67} + x^{66} + x^{56} + x^{52} + x^{48} + x^{40} + x^{36} + x^{34} + x^{24} + x^{22} + x^{18} + x^{10} + x^{4} + 1$$

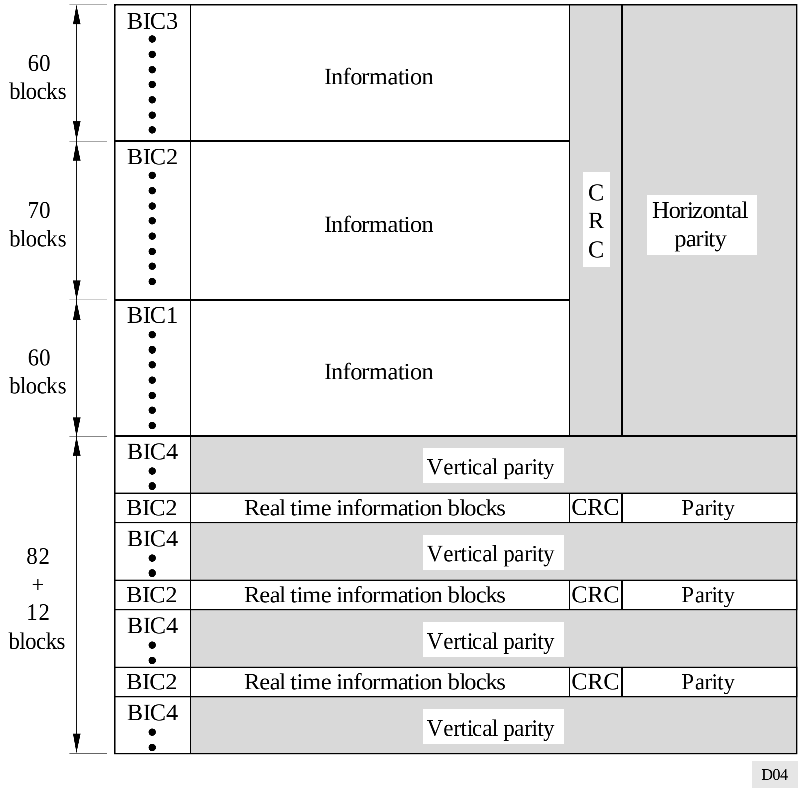
2.6 Error detection

14 bits of CRC are used to enable the receiver/decoder to detect errors. From the 176 information bits, a CRC is calculated using the generator polynomial:

$$g(x) = x^{14} + x^{11} + x^{2} + 1$$

FIGURE 4

Frame according to method A, with static insertion of real-time blocks



2.7 Scrambling

To avoid restrictions on the data input format and to spread the modulation spectrum, data should be scrambled by the pseudo-noise (PN) sequence specified by:

$$g(x) = x^9 + x^4 + 1$$

FIGURE 5

Frame according to method B, with block interleaving

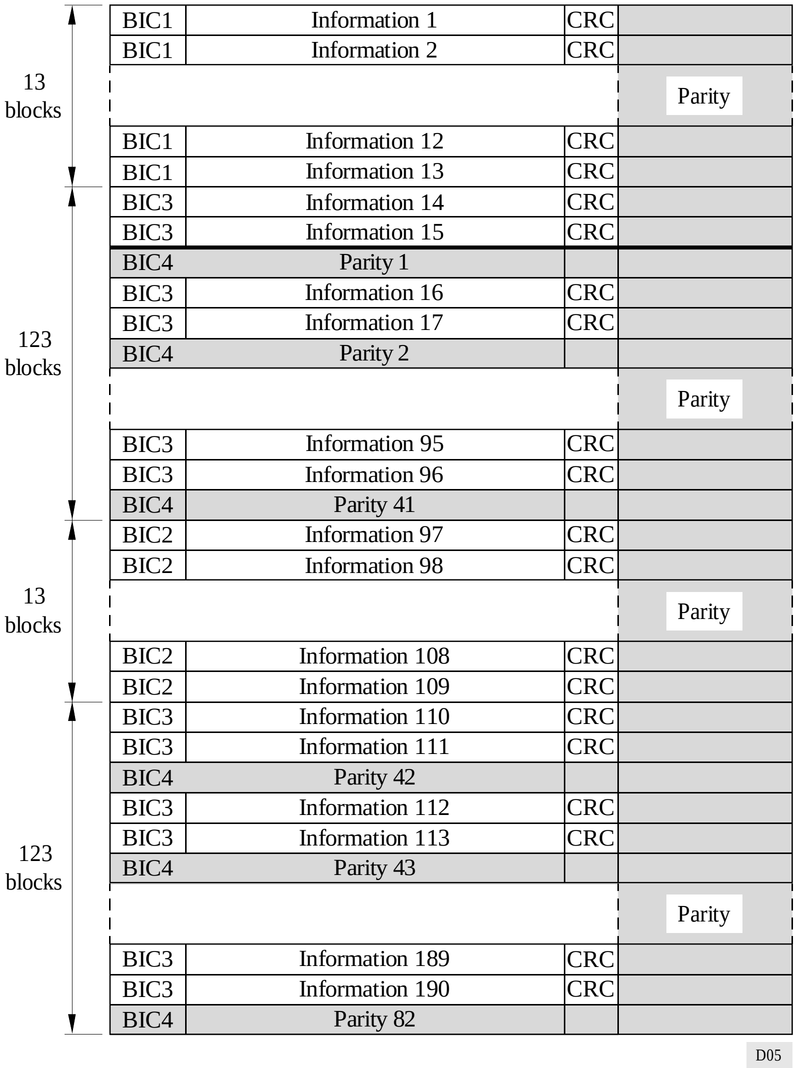
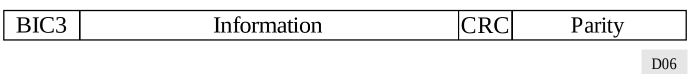


FIGURE 6

Frame according to method C, block code only



ANNEX 2

Operational characteristics of the data radio channel (DARC)

1 Transmission characteristics

1.1 Laboratory transmission tests

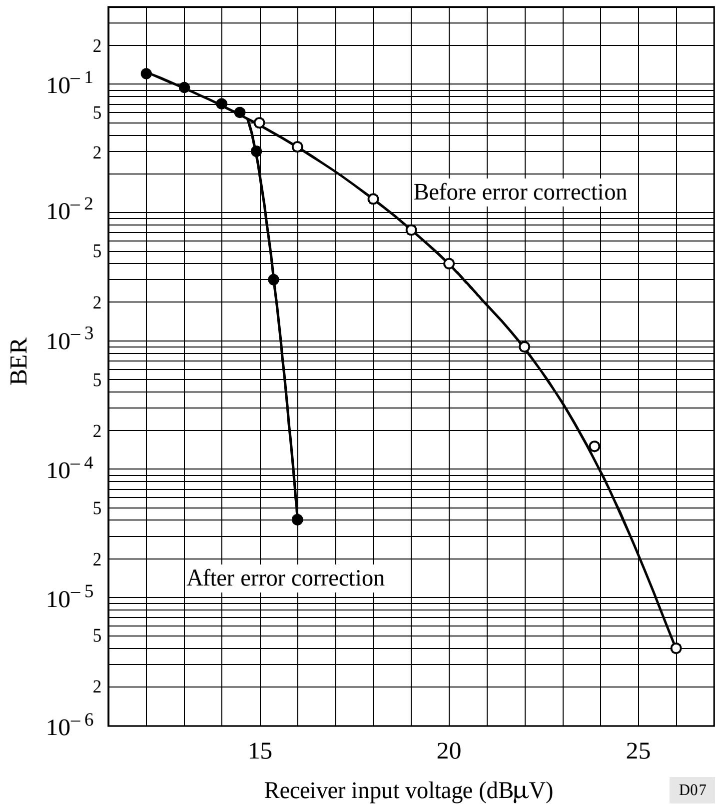
Laboratory transmission experiments of bit error rate (BER) characteristics against random noise and multipath fading were conducted.

Figure 7 shows BER characteristics in relation to receiver input voltage. It can be seen from the figure that error correction eliminates bit errors where the receiver input voltage is 16 dBμV orabove.

Figure 8 indicates BER characteristics under fading distortion. Without error correction, the error rate does not come below 1×10^{-3} even if the receiver input voltage is increased. The use of error correction will enable the BER to be kept to an adequately low level for input voltages above 27 dBμV.

FIGURE 7

Bit error characteristics for random noise

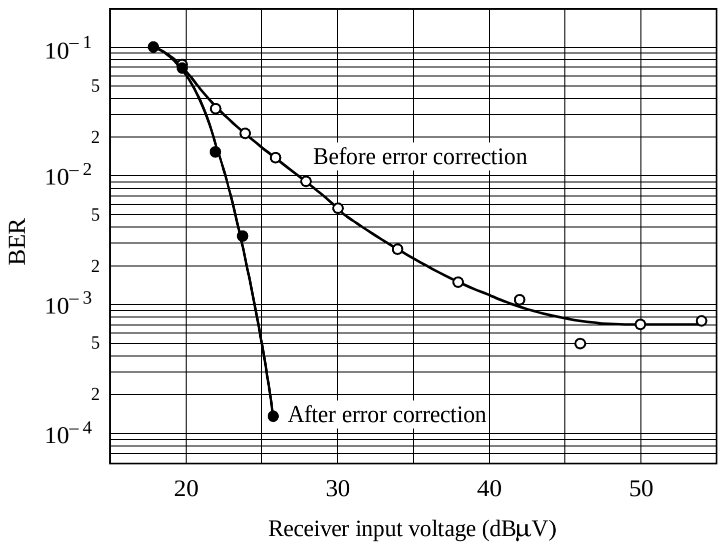


1.2 Field transmission tests

Figure 9 shows the correct reception time rates for mobile reception. When a page is made up of one packet, a time rate of 90% or over can be secured by using DARC Frame C shown in Fig. 6. When a page is formed with 250 packets (8 500 bytes), DARC Frames A and B would ensure a correct reception time rate of about 85%.

FIGURE 8

Bit error characteristics for fading distortion



Fading frequency: 3.3 Hz
Multipath *D*/*U*: 10 dB
Delay time: 5 μs

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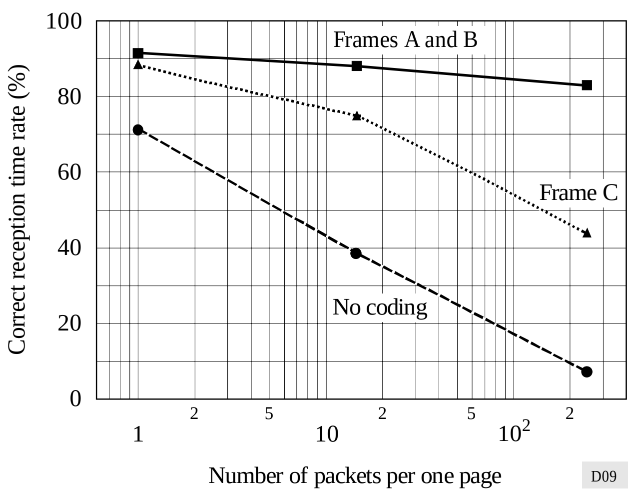
FIGURE 9

Effect of error correction code in the FM service area



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2 Compatibility with stereo sound broadcasting

2.1 Questionnaire survey

Compatibility with stereo sound broadcasting is important in deciding the multiplexing level of multiplex signals. A mail questionnaire survey of more than 2 000 persons was conducted by changing the multiplexing level of the LMSK signals which was experimentally multiplexed with the stereo sound signals. Speech and piano music were used as stereo sound signals.

Table 2 shows the results of the survey in terms of percentage of receivers out of the total number of answers, which showed a quality impairment of two grades as a function of six multiplexing levels.

TABLE 2

The number and percentage of impaired receivers as a function of the multiplexing level

LMSK minimum multiplexing level (%)	No. of receivers	Ratio (%)
2	7	0.31
3	7	0.31
4	10	0.44
5	14	0.61
6.5	18	0.78
10	27	1.18

The questionnaire survey has shown that the ratio of deteriorated receivers could be controlled at below 0.5% if the minimum multiplexing level of the LMSK was below 4%.

2.2 Subjective assessment of sound quality

The test procedure was based on Recommendation ITU-R BS.562. Three types of programme material were used, namely piano music, pop music and female speech.

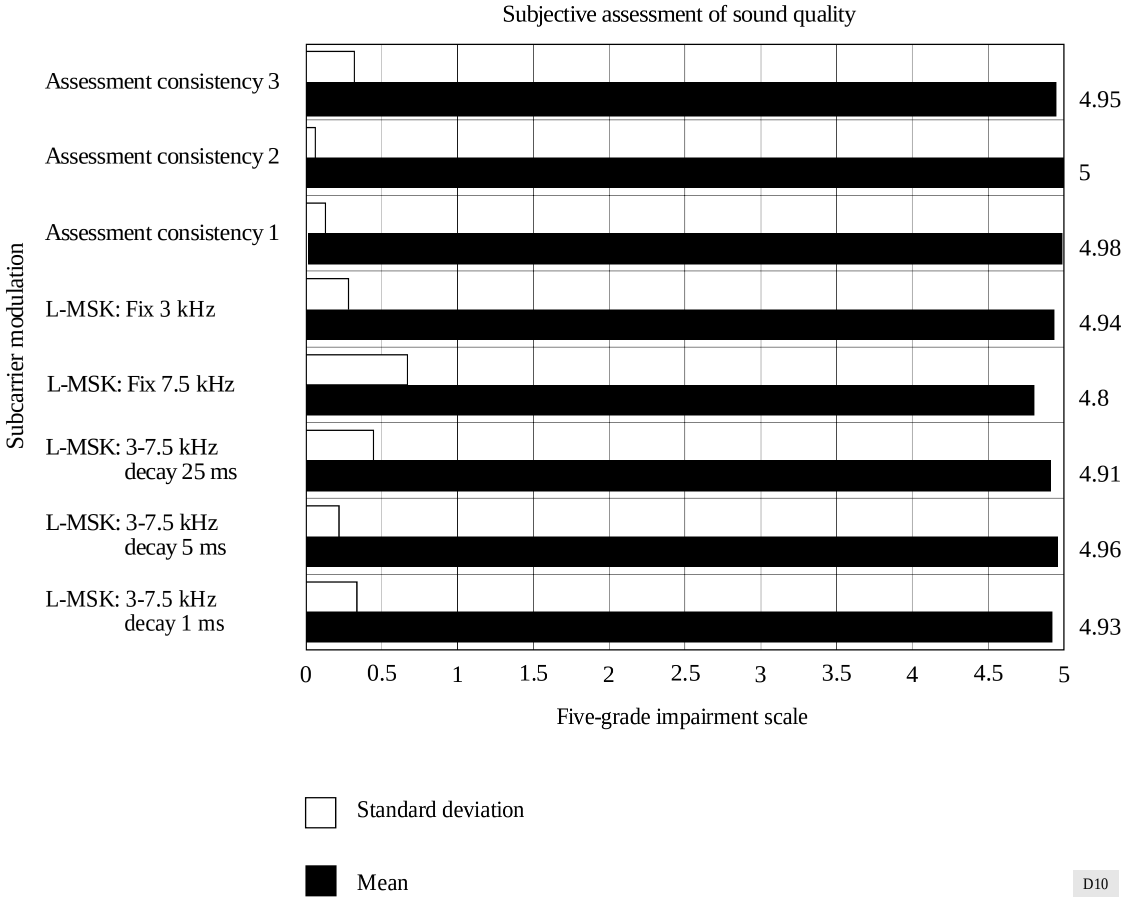
Slightly more than 100 persons more or less experts on sound quality responded by listening to the test transmission in their homes and reporting their assessment on a special form.

Figure 10 gives the main results. The assessment for eight different sub-carrier parameter combinations is shown for the three types of programme material together. Results for three decay values and with the sub-carrier level control characteristic finally chosen are shown. The outcome of the consistency test cases (without sub-carrier) is shown for comparison as well as the results for constant sub-carrier levels 3 and 7.5 kHz.

The test has shown that a sub-carrier frequency of 76 kHz and LMSK with the sub-carrier level controlled to give a main carrier deviation varying between 3-7.5 kHz and with a decay time of 5 ms gives the best result. The mean assessment grade is 4.96 on the five-grade impairment scale and the system is therefore considered to be compatible with the FM stereophonic sound-broadcasting system at VHF.

FIGURE 10

Test results from subjective assessment of sound quality



2.3 Multipath distortion

The above compatibility tests have not assessed the effects of multipath propagation. It is to be expected that such conditions may cause some interference to the main programme signal, as well as, perhaps, the RDS signal if this is transmitted simultaneously. In such circumstances, however, the received programme signal is also expected to be impaired by multipath distortion.

In this section, compatibility tests of the DARC signal with the main programme under condition of multipath propagation are described.

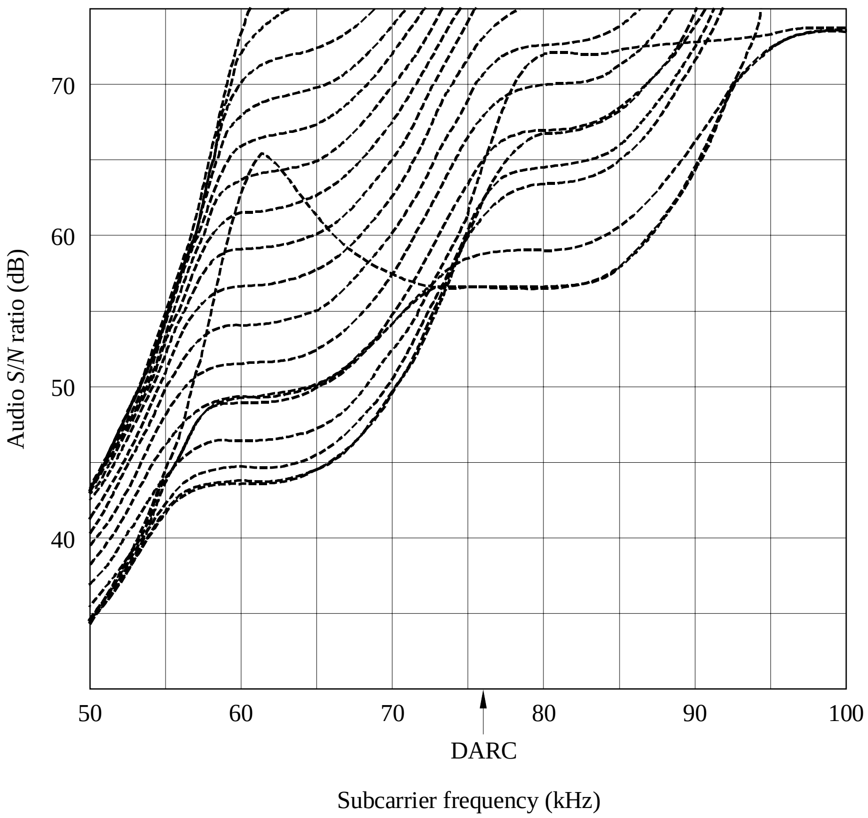
Inter-modulation between a DARC signal and the pilot tone of 19 kHz causes interference within the audio frequency band.

Figure 11 indicates the audio signal-to-noise ratio (S/N) ratio for various sub-carrier frequencies in which the bit rate of 16 kbit/s and LMSK modulation scheme are used under the multipath condition. This figure shows that a better S/N ratio can be obtained when the centre sub-carrier frequency is higher than 73 MHz. This result shows that the DARC has a good performance since its sub-carrier frequency is specified to 76 kHz.

Figure 12 shows the simulation results of the audio S/N ratio. These figures indicate that the worst S/N ratio occurs at a RF-phase shift of 180° and a multipath delay time of 9 μs.

FIGURE 11

Audio S/N ratio for various sub-carrier frequencies



Injection level : 4%
Desired-to-undesired signal (D/U) :15 dB
Delay time : 8 µs
RF-phase shift : 0°, 10°, 20°, ..., 180°

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FIGURE 12

Audio *S*/*N* ratio versus multipath RF-phase shift and delay time

(D/U ratio: 15 dB)

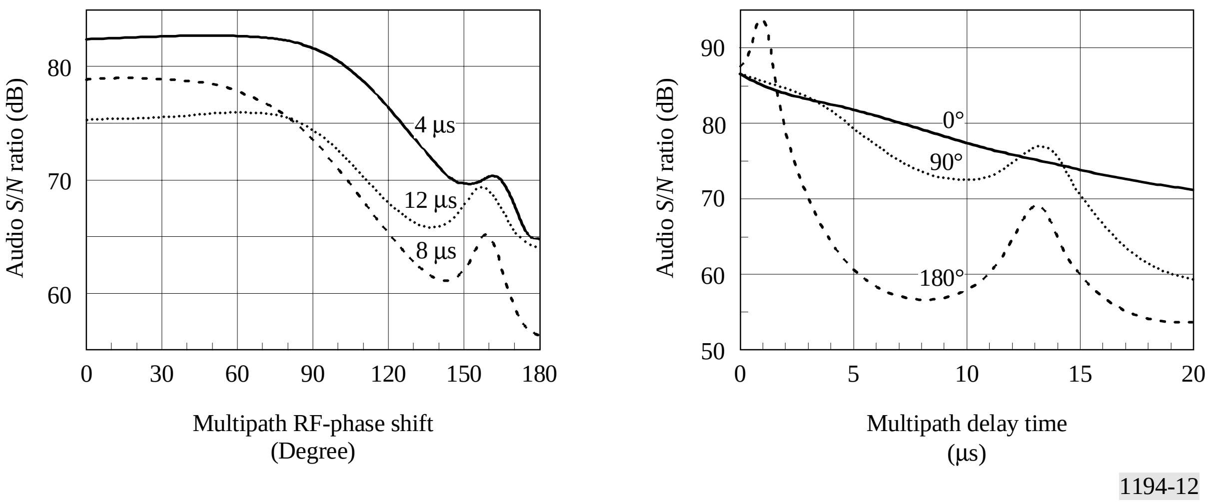

Figure 13 shows the diagram of the laboratory tests. The receiver input level was set to -60 dBmS and the noise level measured by a quasi-peak level meter with a weighting network in accordance with Recommendation ITU-R BS.468. Figure 14 shows the audio S/N ratio versus multipath delay time. Delay times of between 7 µs and 10 µs gives the worst S/N ratios. From the measurement of delay spread in the Tokyo area, it has been revealed that the D/U ratio of a 7 µs delay multipath signal is greater than 15 dB and the case 9 µs is greater than 19 dB for 99% area ratio. This indicates that the 99% worst multipath condition for audio S/N ratio is a D/U ratio of 15 dB, for a delay time of 7 µs and a RF-phase shift of 180°. Figure 15 shows the audio S/N ratio versus a lower injection level of LMSK under the worst multipath condition. DARC uses LMSK with the lower injection level of 4%. Figure 15 indicates that the degradation of audio S/N ratio due to multiplexing DARC is controlled to a level below 1.5 dB in the 9% worst multipath condition.

The compatibility tests of the DARC signal with the main programme under conditions of multipath propagation show that, under the 99% worst multipath condition of D/U ratio of 15 dB, delay time of 7 µs and a RF-phase difference of 180° in Tokyo area, less than 1.5 dB degradation of audio S/N ratio was observed when the DARC signal was multiplexed.

3 Compatibility with RDS

Tests have been carried out by measuring BER for RDS for five different combinations of multiplex signals, as a function of signal strength. They refer to stationary reception conditions. The different components of the multiplex signal are described in Table 3.

The RDS sub-carrier and the DARC sub-carrier were modulated with two uncorrelated PN sequences.

The results from the measurements with five combinations of multiplex components is shown in Fig. 16.

The bottom curve is a measure of the performance of the actual receiving equipment. When the pilot tone is added a slight degradation appears. This degradation is in the range of 0.5 to 1 dB. The further addition of a further DARC signal does not cause any increase of the bit error rate. A somewhat larger degradation in performance can be observed for the two upper curves. This degradation is however caused by the M- and S-signals and not by the DARC signal in itself.

FIGURE 13

Diagram of the laboratory tests

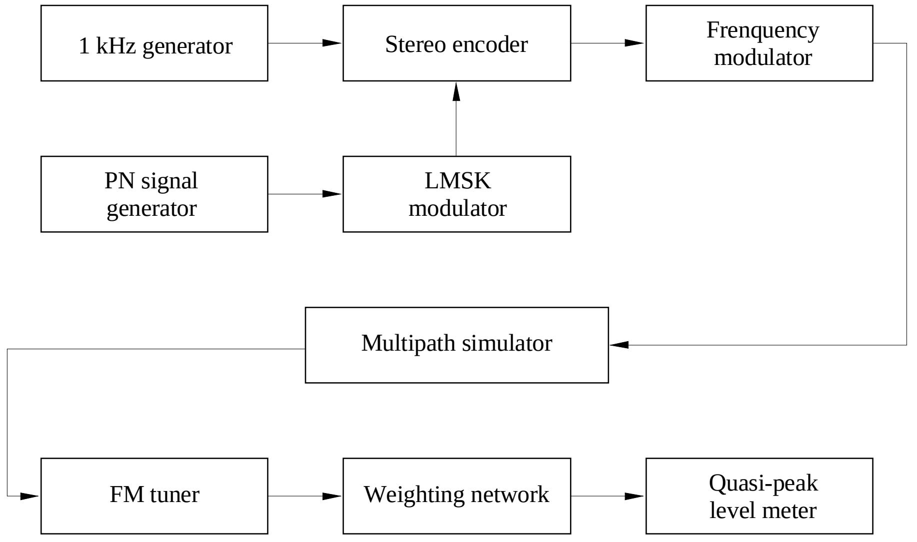

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FIGURE 14

Audio S/N ratio versus multipath delay time

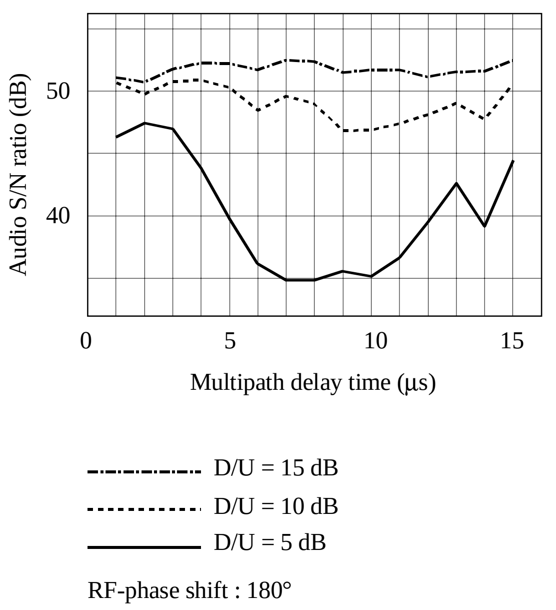

FIGURE 15

Audio S/N ratio versus lower injection level of LMSK

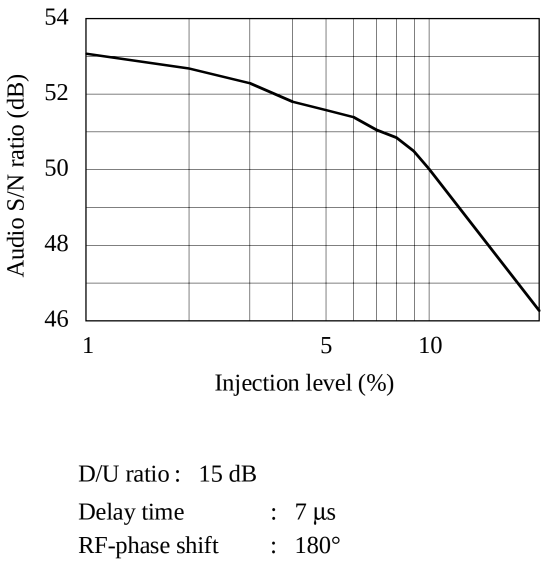

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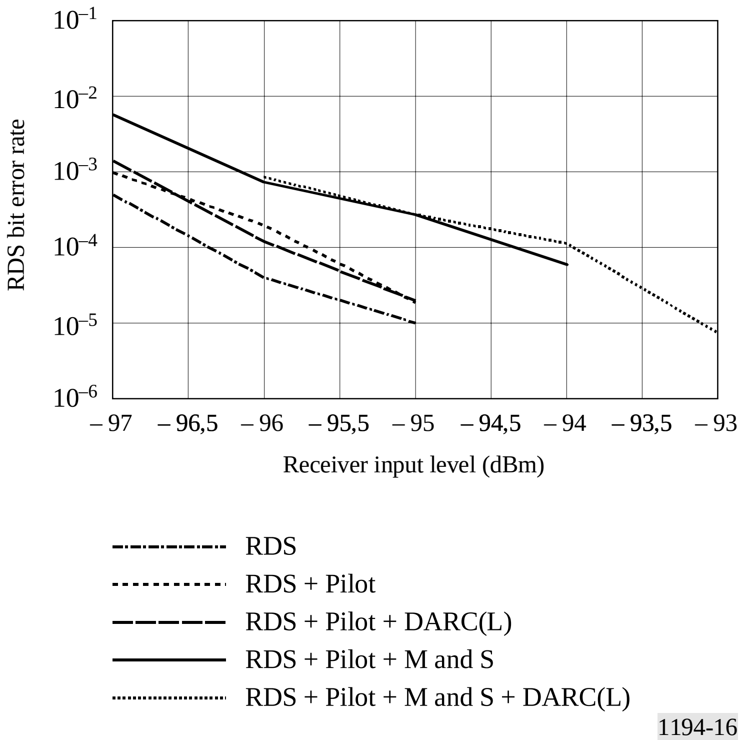
TABLE 3

MPX component	Description
RDS	RDS deviates the main carrier 3 kHz (4%)
Pilot tone	Pilot tone deviates the main carrier 6.75 kHz (9%)
Stereo signal (M&S)	“Normal” stereophonic M- and S-signal created by representative levels of noise weighted in accordance with Rec. ITU-R BS.559. The deviation thus corresponds to the present-day practice (see Rec. ITU-R BS.641)
DARC	The deviation of the main carrier caused by DARC varies between 3 kHz (4%) and 7.5 kHz (10%), controlled by the S-signal (a feature inherent in the DARC system)

FIGURE 16

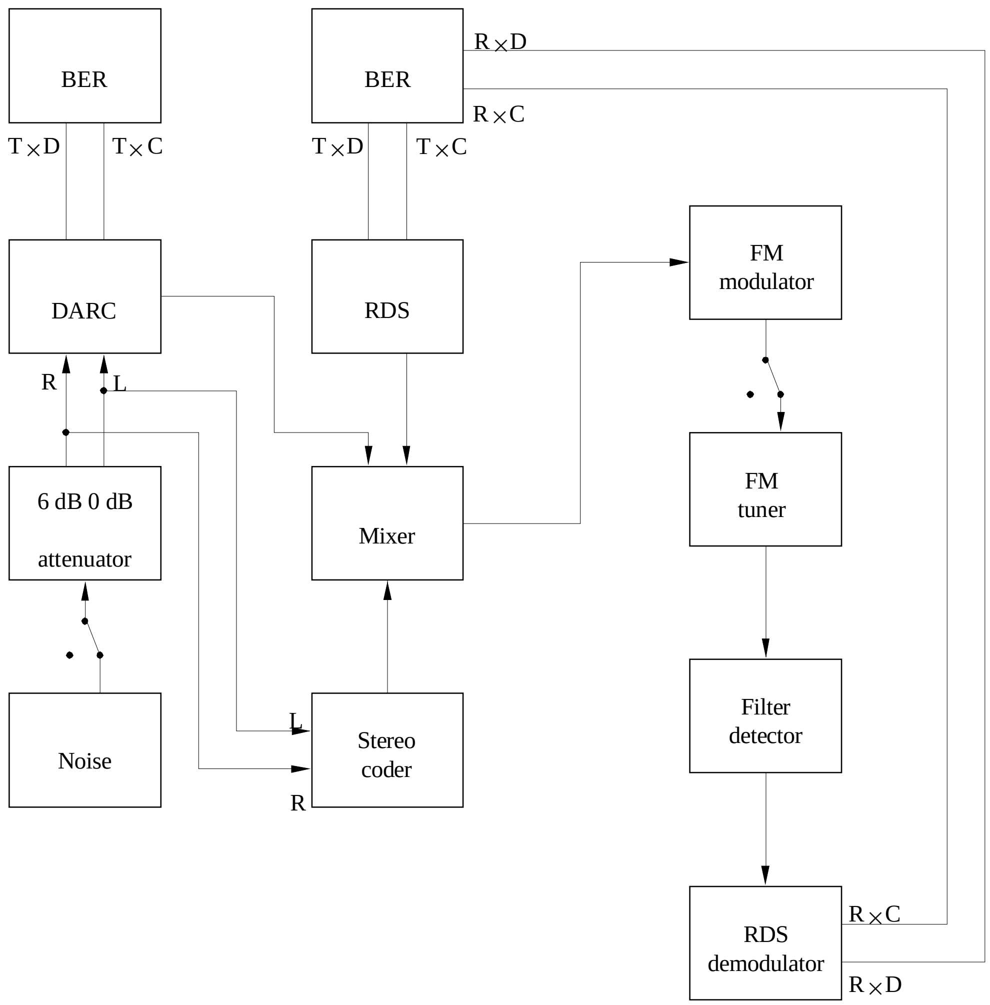
RDS bit-error rate as a function of receiver input level for different multiplex content



The measuring arrangement is shown in Fig. 17. The DARC modulator used is made by EIDEN. The receiver used was a STUDER A764 with an external filter and a special product demodulator. For recovery of RDS data (clock and data) a special bi-phase demodulator has been used.

FIGURE 17

Measuring arrangement for compatibility with RDS



The measurements presented in this Recommendation show that the RDS performance is not affected by the introduction of another sub-carrier system in accordance with the DARC specification.

4 Protection ratios

4.1 Protection ratio for FM sound signals

The measurements were made in accordance with Recommendation ITU-R BS.641. Figure 18 shows the diagram of the measuring system. The unwanted signals comprised monaural coloured noise and the DARC signal.

Figure 19 shows the result of measurement for monaural sound signals. Figure 20 shows the result of measurement for stereo sound signals. The measurement results show that the interference from the DARC signal can be controlled to a level below the standard specified in Recommendation ITU-R BS.412 for various tuners.

Figure 21 shows the results of measurements for stereo sound signals interfered with by either the DARC signal or the RDS signal. Frequency components deteriorated by interference from the DARC signal are higher than those for the RDS signal.

FIGURE 18

Diagram of the measuring system

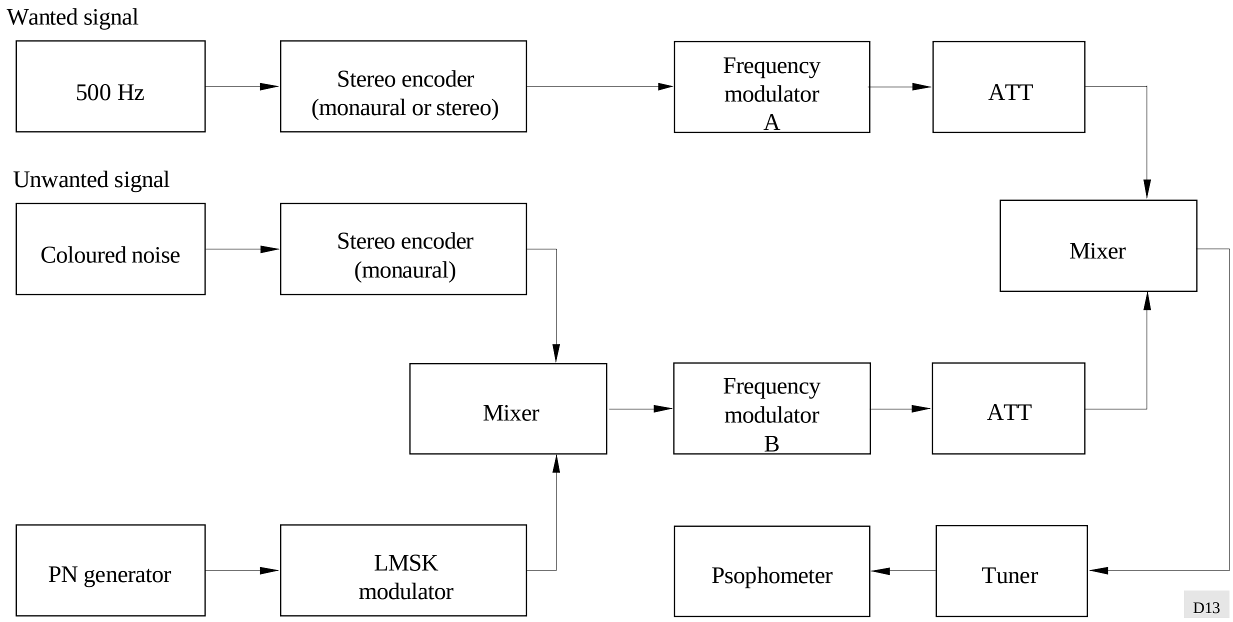


FIGURE 19

Protection ratios of monaural sound signals interfered from DARC signals

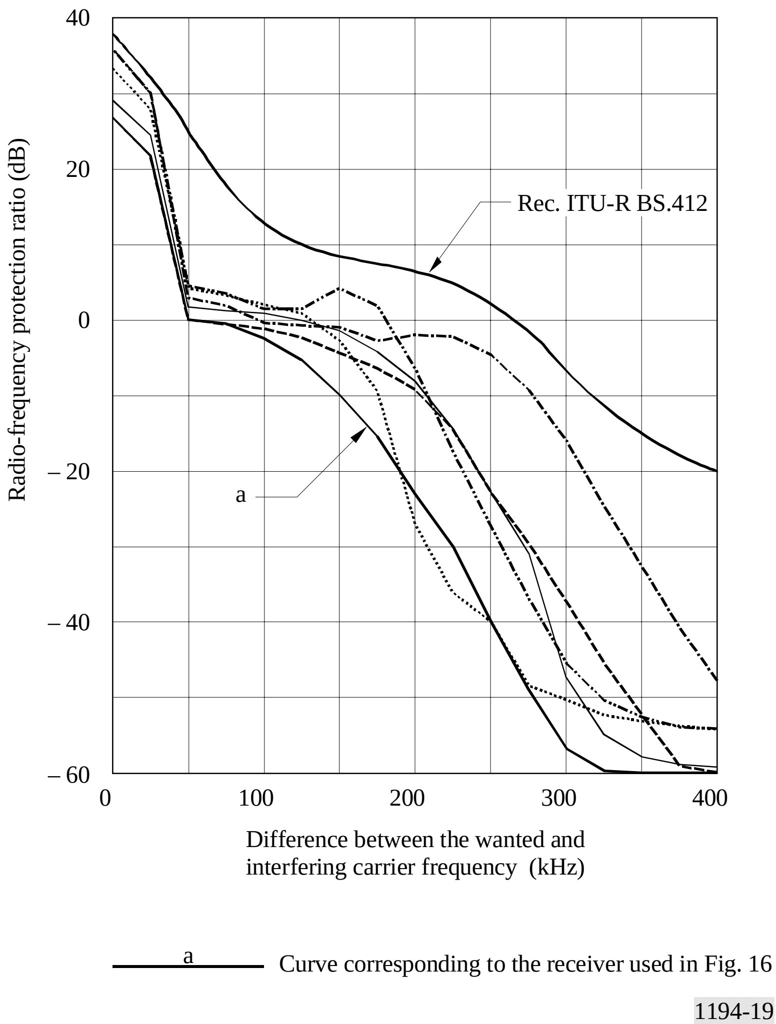


FIGURE 20

Protection ratios of stereo sound signals interfered from with by DARC signals

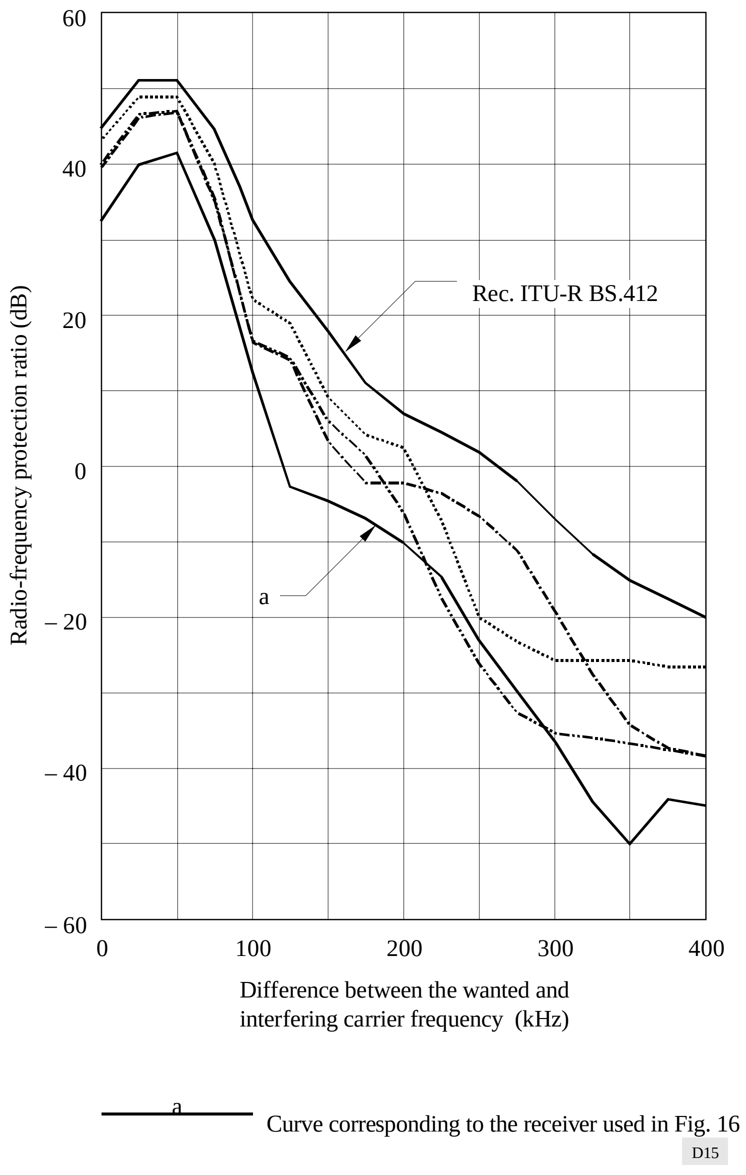
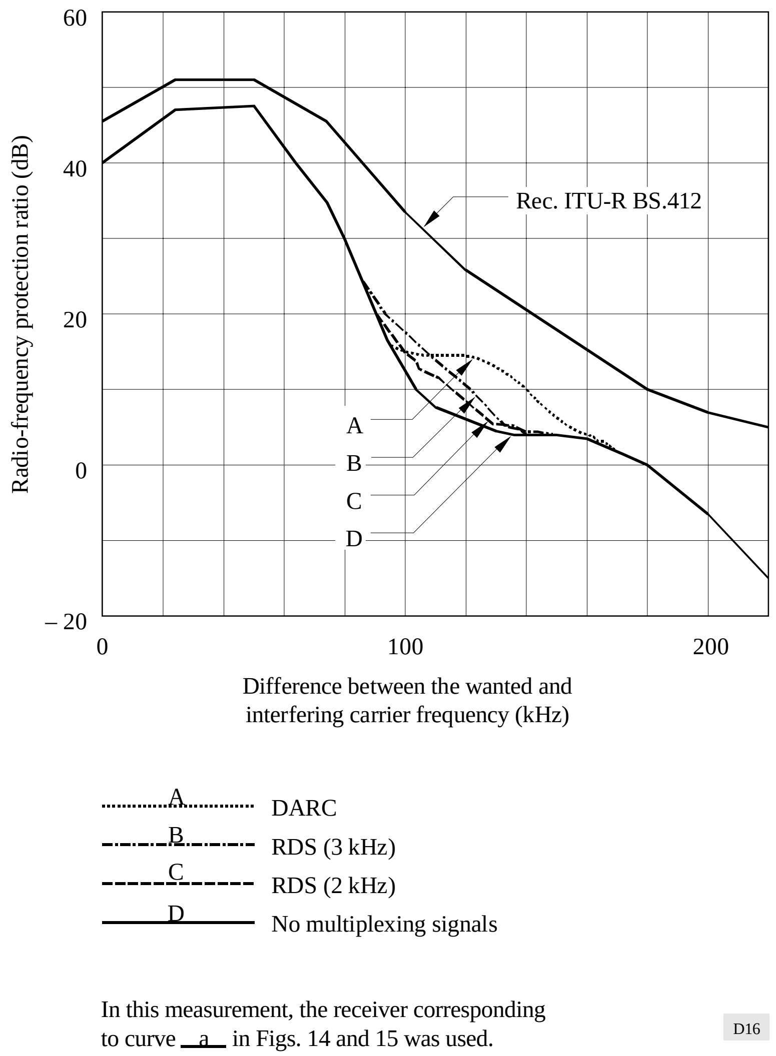


FIGURE 21

Protection ratios of stereo sound signals interfered with by multiplexed signals



The wanted transmitter was operated in monophonic mode with no sound modulation. The unwanted transmitter was modulated in monophonic mode with coloured noise, an RDS sub-carrier and a DARC sub-carrier. The deviation caused by the RDS signal was 3 kHz. The corresponding figure for the DARC signal was 7.5 kHz. The result of the measurement is plotted in Fig. 22. The corresponding curve without the two sub-carriers is plotted for comparison. For all the measurements a STUDER A764 receiver was used.

The unwanted transmitter was modulated in monophonic mode with coloured noise, an RDS sub-carrier and a DARC sub-carrier. The deviation caused by the RDS signal was 3 kHz. The corresponding figure for the DARC signal was 7.5 kHz. The result of the measurement is plotted in Fig. 23. The corresponding curve without the two sub-carriers is plotted for comparison. For all the measurements a STUDER A764 receiver was used. The wanted transmitter was operated in stereophonic mode with no modulating sound signal except the pilot tone.

4.2 Protection ratio for DARC signal

Figure 24 shows the diagram of the measuring system. Wanted signals were modulated with coloured noise and the DARC signal. The unwanted signal was monaural coloured noise. The DU ratio was measured at which the bit-error rate of the DARC signal was 1×10^{-2}.

FIGURE 22

Protection ratios for monophonic sound interfered with by a monophonic broadcast

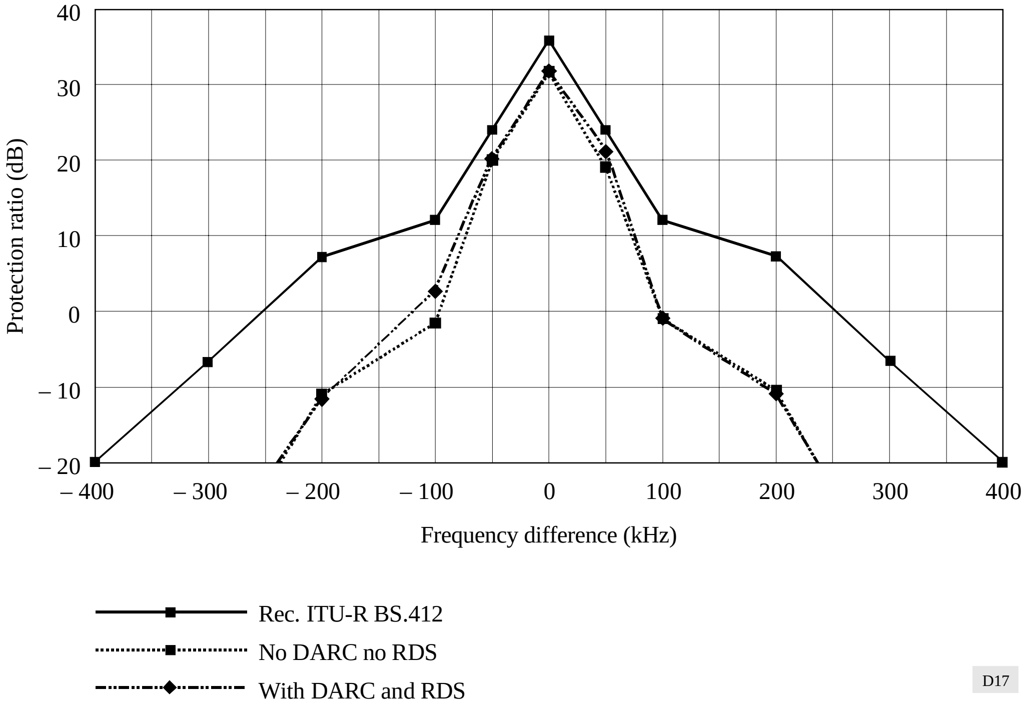


FIGURE 23

Protection ratio for stereophonic sound interfered with by a monophonic broadcast

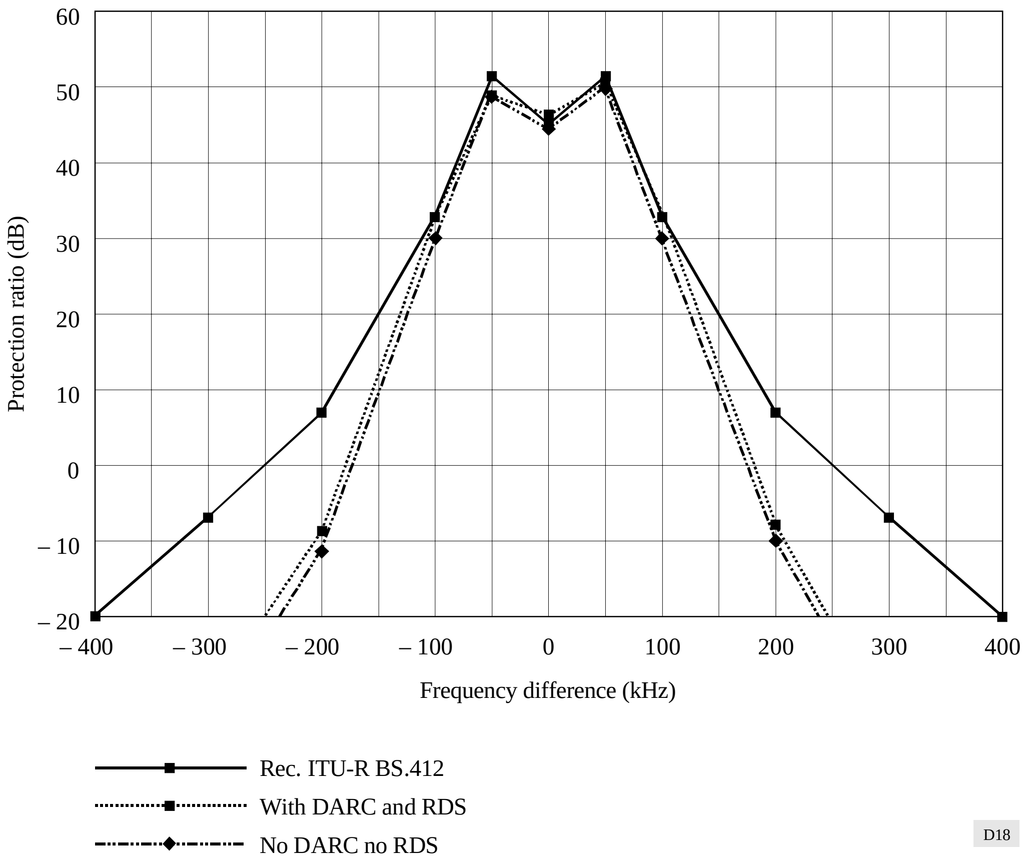


FIGURE 24

Diagram of the measuring system

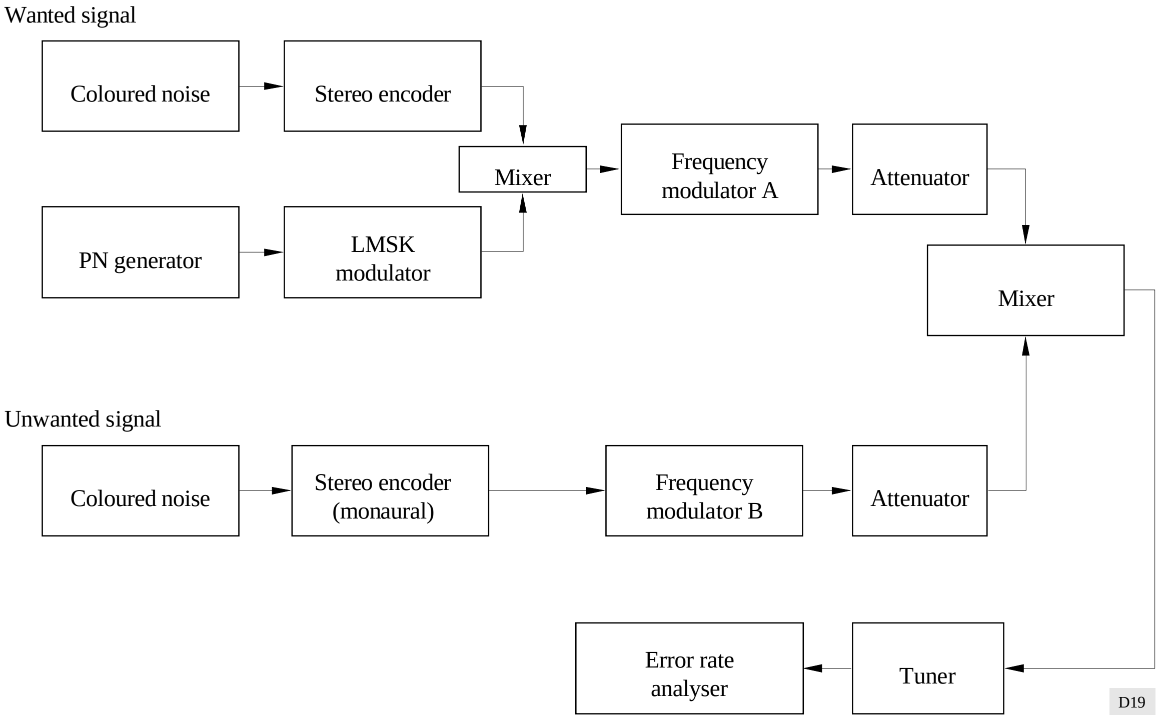


Figure 25 shows the result of measurements taken. The deterioration could also be controlled to a level below the criteria.

The stereophonic sound and RDS parameters of the wanted VHF/FM channel, which also was carrying the wanted DARC signal, were in accordance with Recommendations ITU-R BS.450 and ITU-R BS.643 using 2 kHz deviation for the RDS signal. The unwanted signal was a monophonic signal without RDS or DARC. Figure 26 shows the results for DARC deviations of 3 kHz and 7.5 kHz. In both cases the protection ratio is less than that required in Recommendation ITU-R BS.412 for stereophonic broadcast.

FIGURE 25

Protection ratios of DARC signals interfered with by FM sound signals

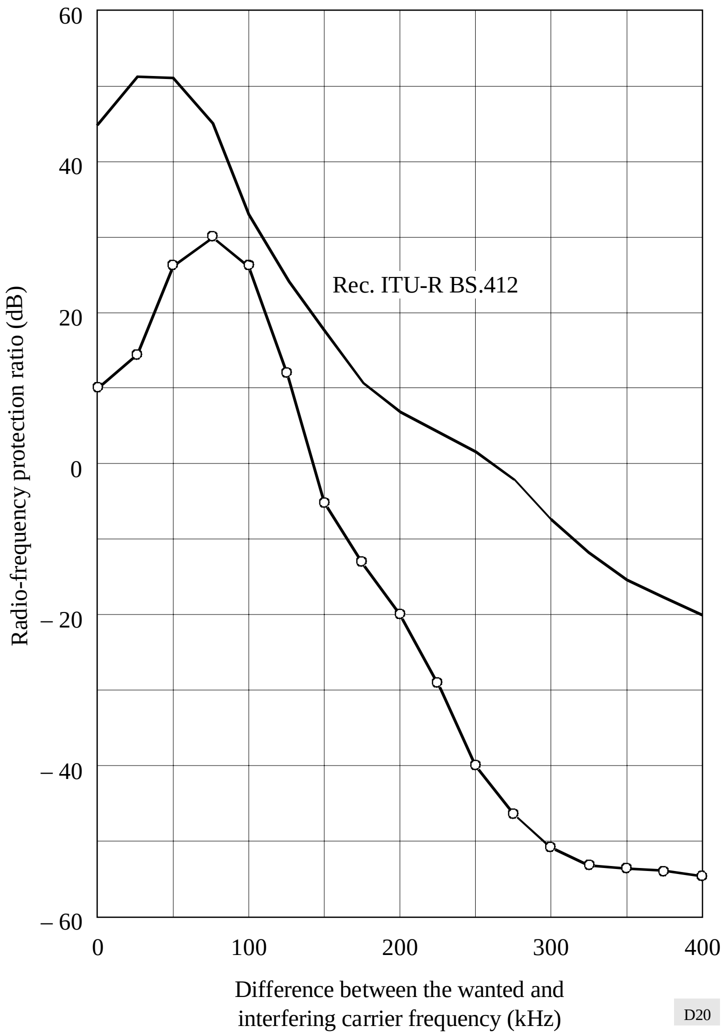
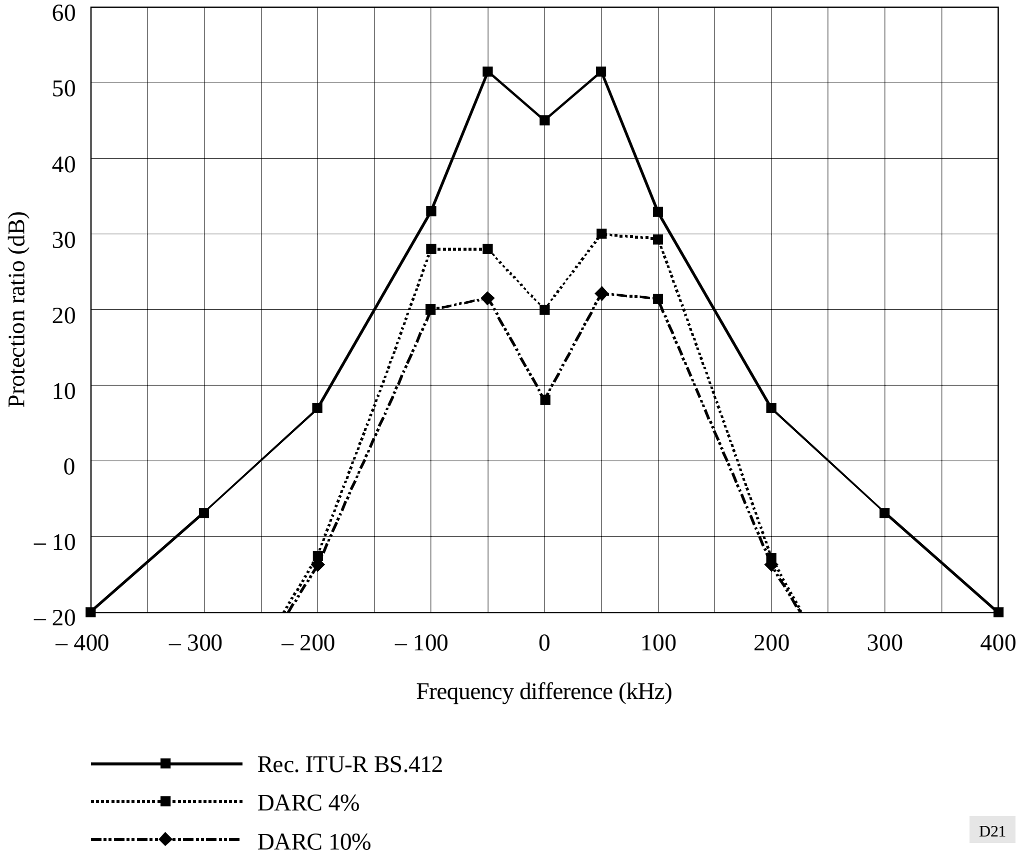


FIGURE 26

Protection ratios for DARC signals interfered with by a monophonic broadcast



4.3 Protection ratios for a signal interfered with by an RDS or DARC signal

The measurements were undertaken in France in accordance with Recommendation ITU-R BS.641.

RDS and DARC deviations were set to 4 kHz for both the wanted and interfering signals. The protection ratios were derived for a bit error rate of 10^{-2}.

The measurements show that the protection ratios are less than those required by Recommendation ITU-R BS.412 for stereophonic broadcasts but not for monophonic broadcasts.

Abbreviations

W wanted signal

U interferer

M monophonic

S stereophonic

1 audio only

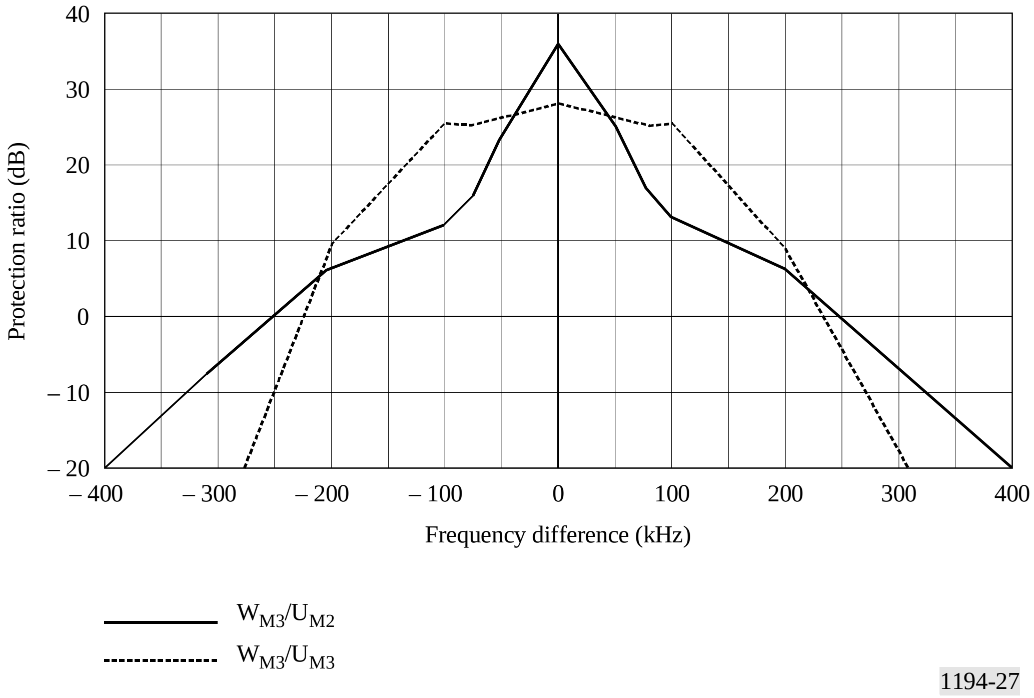
2 audio + RDS

3 audio + RDS + DARC.

4.3.1 Monophonic wanted signal and monophonic interferer

FIGURE 27

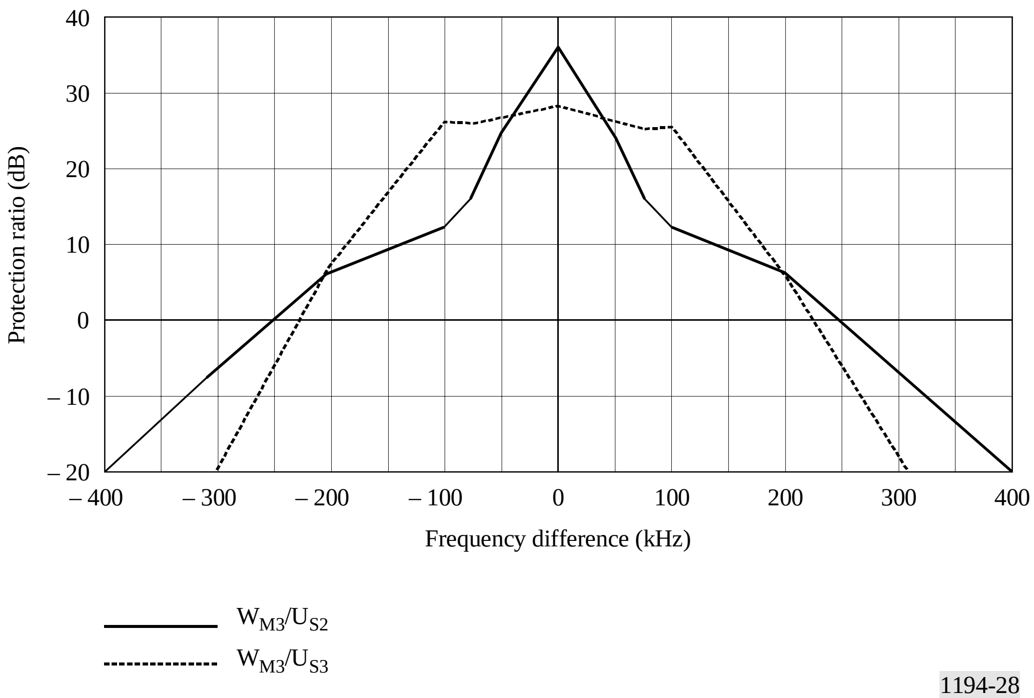
Protection ratios for monophonic wanted signal and monophonic interferer



4.3.2 Monophonic wanted signal and stereophonic interferer

FIGURE 28

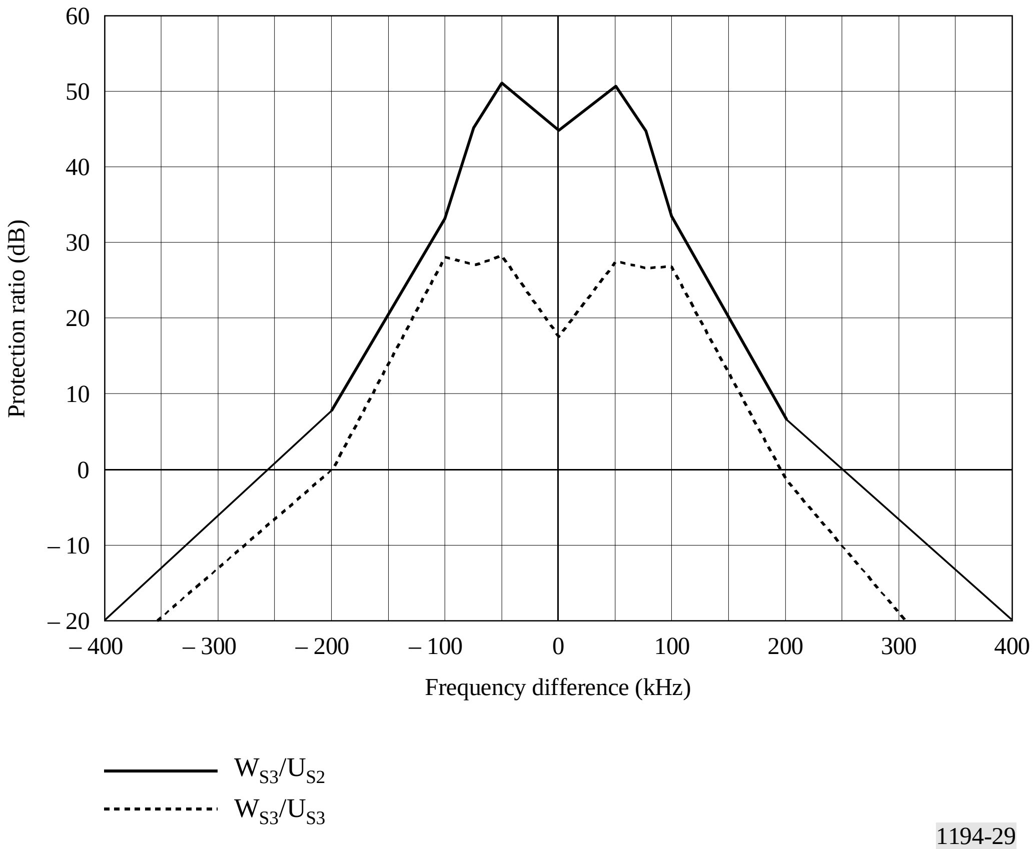
Protection ratios for monophonic wanted signal and stereophonic interferer



4.3.3 Stereophonic wanted signal and stereophonic interferer

FIGURE 29

Protection ratios for strereophonic wanted signal and strereophonic interferer

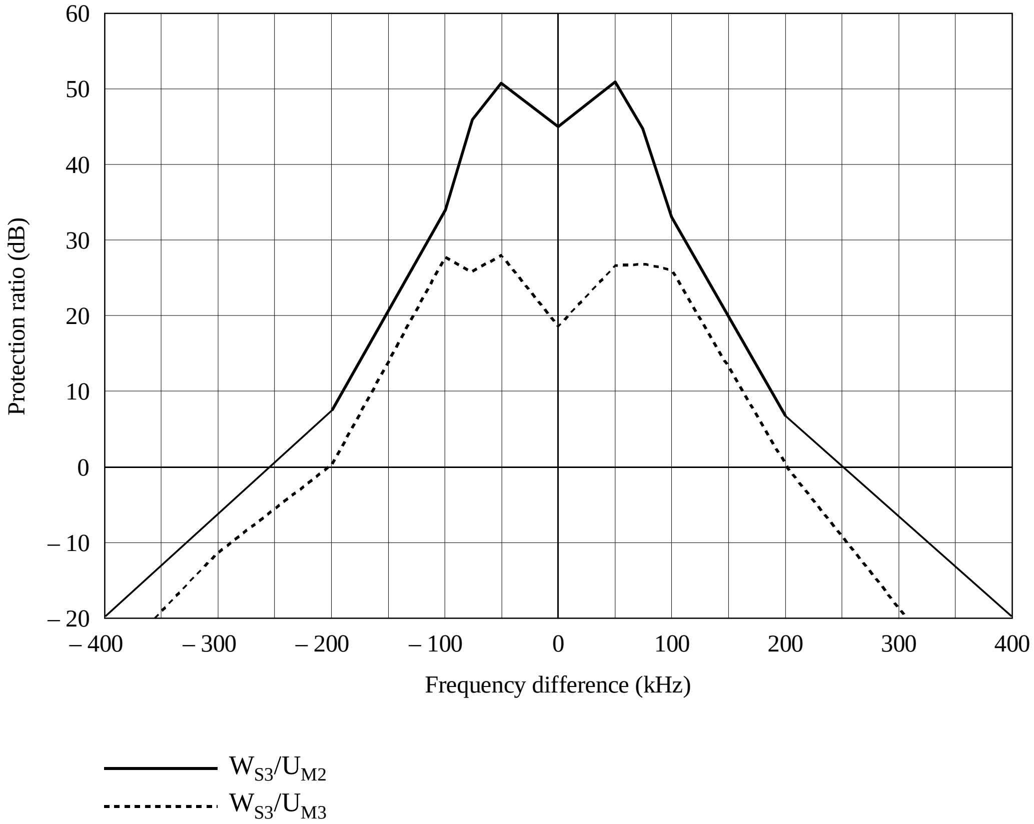


1194-29

4.3.4 Stereophonic wanted signal and monophonic interferer

FIGURE 30

Protection ratios for stereophonic wanted signal and monophonic interferer



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