

RECOMMENDATION ITU-R BS.1194-2

**SYSTEMS FOR MULTIPLEXING FREQUENCY MODULATION (FM) SOUND
BROADCASTING 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;
- g) that the diversity of applications as described in ITU-R BS.1350 precludes the suitability of a single system for all applications,

recommends

- 1** that one of the following 3 systems be used for multiplexing frequency modulation (FM) sound broadcasting with a sub-carrier data channel having a relatively large transmission capacity for stationary and mobile reception:
- the Data Radio Channel (DARC) System, as specified in Annex 1, which is best suited for its high level of compatibility with the main broadcast audio channel and for Intelligent Transportation Services; or
 - the High Speed Data System (HSDS) as specified in Annex 2, which is best suited for its minimum duty cycle for power savings and for paging services; or
 - the Sub-carrier Transmission Information Channel (STIC) system as specified in Annex 3, which is best suited for its long message reliability in multipath and for Intelligent Transportation Services particularly when a high level of audio processing is used on the main broadcast audio channel.

NOTE 1 – 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 2 – A comparison of systems is provided in Appendix 1. Appendix 2 provides test results for 3 systems, tested side-by-side by an independent body in the United States.

System description: System A, Data Radio Channel (DARC)

The DARC system provides a highly acceptable balance of throughput, robustness and occupied bandwidth to support multiple applications of a standardized data sub-carrier. The system is designed to minimize the effects of multipath and fading on the channel in both stationary and mobile environments. Three dimensional error correction/detection provides virtually error-free data reception on all types of receiver.

Some multiplexed applications that DARC supports are:

- receiver displayed information in the form of multiple page text and graphics including, but not limited to, audio program information, news, sport, weather, navigational data and travel information;
- computer database refreshing and file transfer;
- portable paging/messaging and conditional access (receiver addressability);
- DGPS correction data for portable and mobile receivers.

DARC's Level-controlled Minimum Shift Keying (LMSK) modulation method allows easy, inexpensive receiver implementation.

The DARC FM sub-carrier specifications are a matter of ETSI Standard ETS 300 751.

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 $76 \text{ kHz} \pm 7.6 \text{ Hz}$ (0.01%) and the phase difference shall not exceed $\pm 5^\circ$ for the phase of pilot tone.

1.2 Method of modulation

LMSK modulation is used with a spectrum shaping according to Figure 1. LMSK is a form of MSK in which the amplitude is controlled by stereo sound signals of left minus right. A frequency of $76 \text{ kHz} + 4 \text{ kHz}$ is used when the input data is 1 and $76 \text{ kHz} - 4 \text{ kHz}$ is used when the input data is 0.

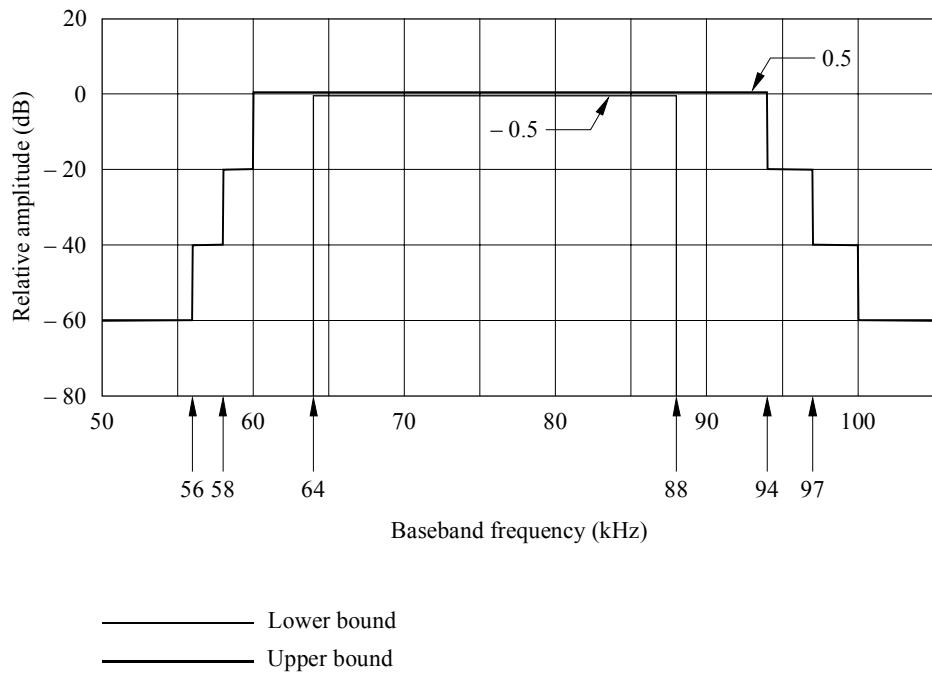
1.3 Bit rate

The bit rate is $16 \text{ kbit/s} \pm 1.6 \text{ bit/s}$.

1.4 Sub-carrier level

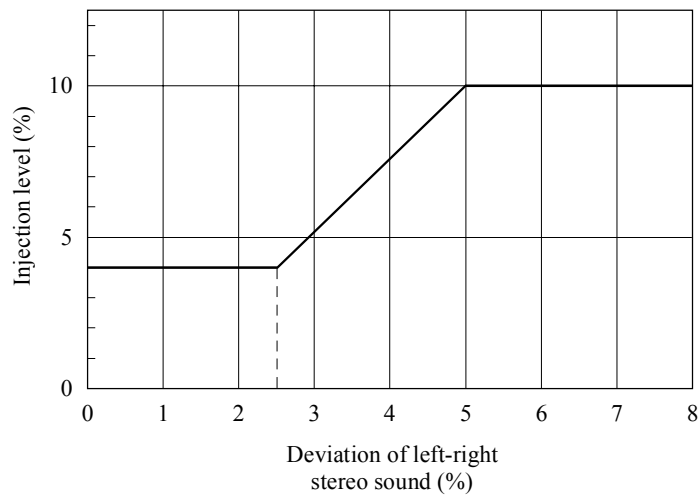
The sub-carrier level is varied depending on the level of the stereo L-R signals (see Figure 2). If the deviation of the main FM carrier when modulated by the stereo L-R signals is less than 2.5%, the sub-carrier is deviated by 4% ($\pm 3 \text{ kHz}$) of the main FM carrier. If the deviation of the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

FIGURE 1
Spectrum-shaping filter



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FIGURE 2
Sub-carrier deviation



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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 $(272,190) \times (272,190)$ and method C that uses only block code $(272,190)$.

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

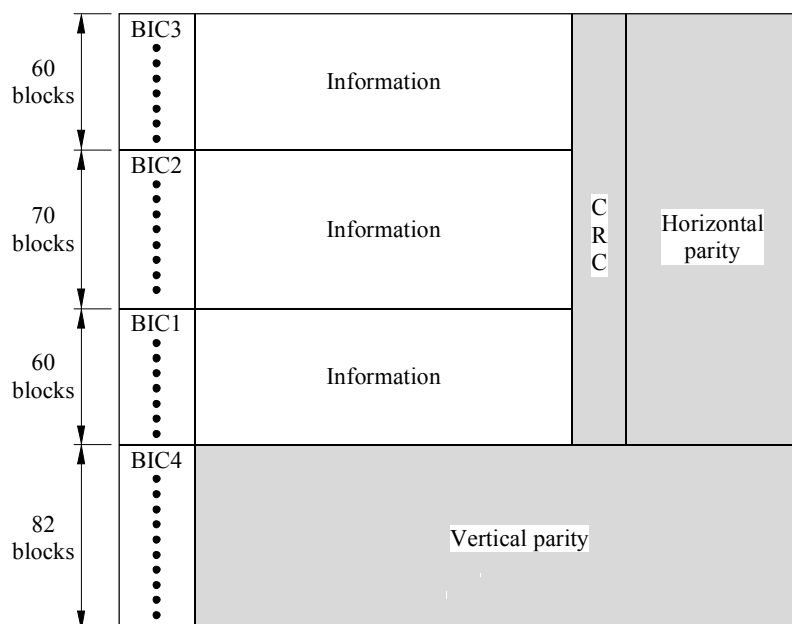
TABLE 1
Block Identification Code (BIC)

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 Figure 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.

FIGURE 3
Frame according to method A, without insertion of real-time blocks



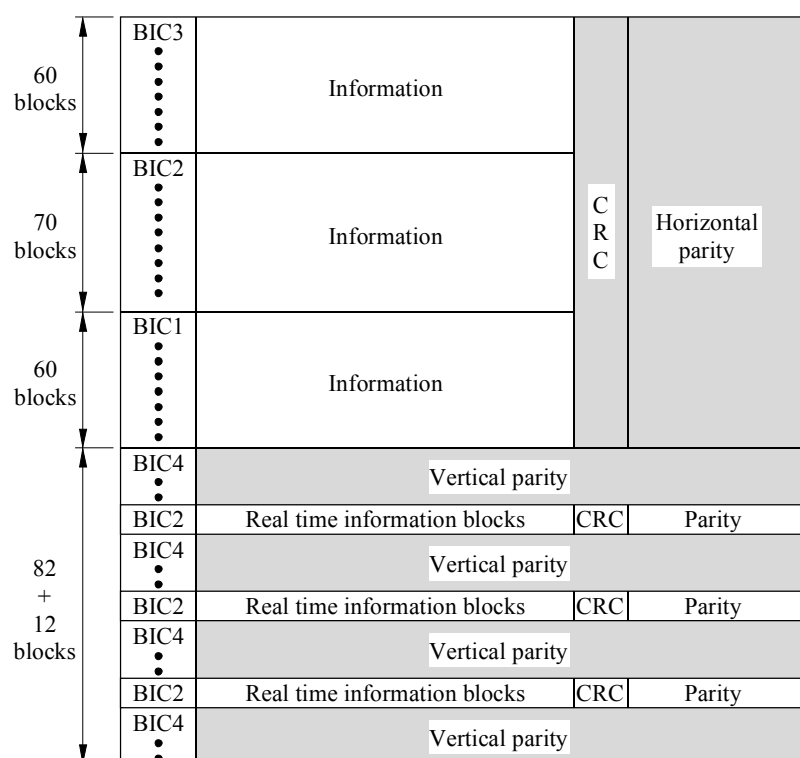
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The 12 inserted blocks are not a part of the product coded frame. They are placed at fixed positions, four blocks at a time at three positions (see Figure 4). The first four blocks are placed after 20 parity blocks, the next four after another 21 parity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

The BIC for the inserted blocks is BIC2. The receiver extracts such blocks and decodes them immediately.

FIGURE 4

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



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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 Figure 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 $(272,190) \times (272,190)$ 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 $(272,190)$ is used for method C.

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

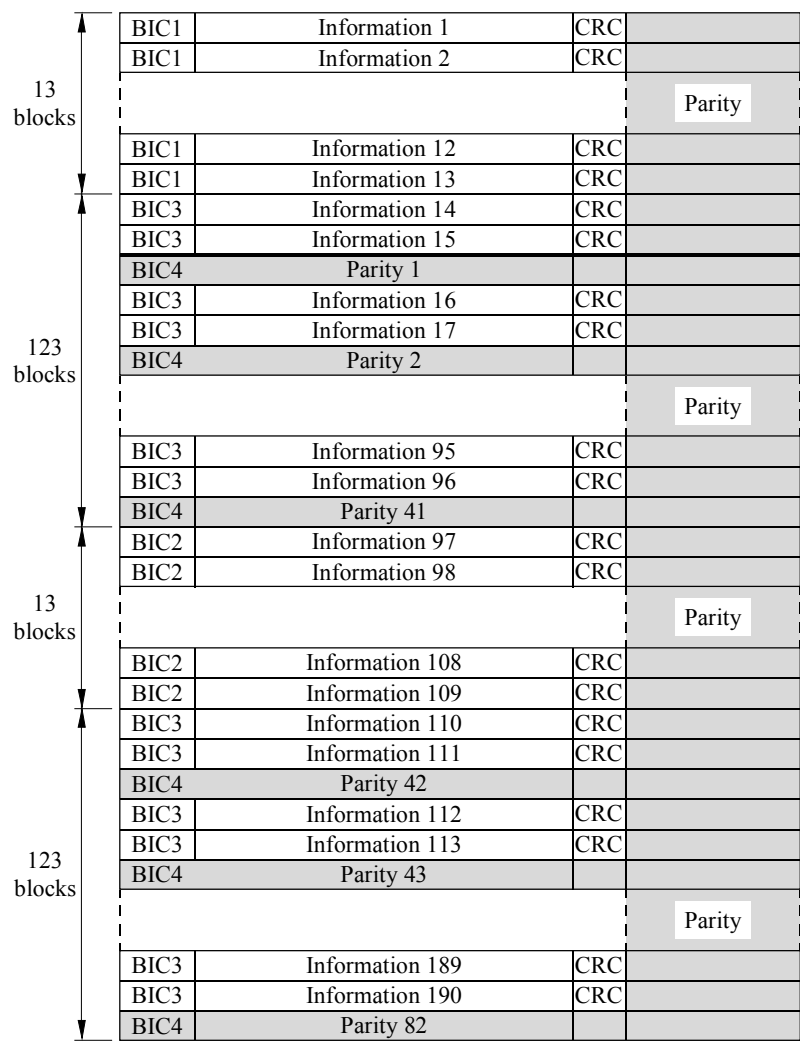
$$g(x) = x^{14} + x^{11} + x^2 + 1$$

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



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FIGURE 6
Frame according to method C, block code only

BIC3	Information	CRC	Parity
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3 Operational characteristics of the Data Radio Channel (DARC)

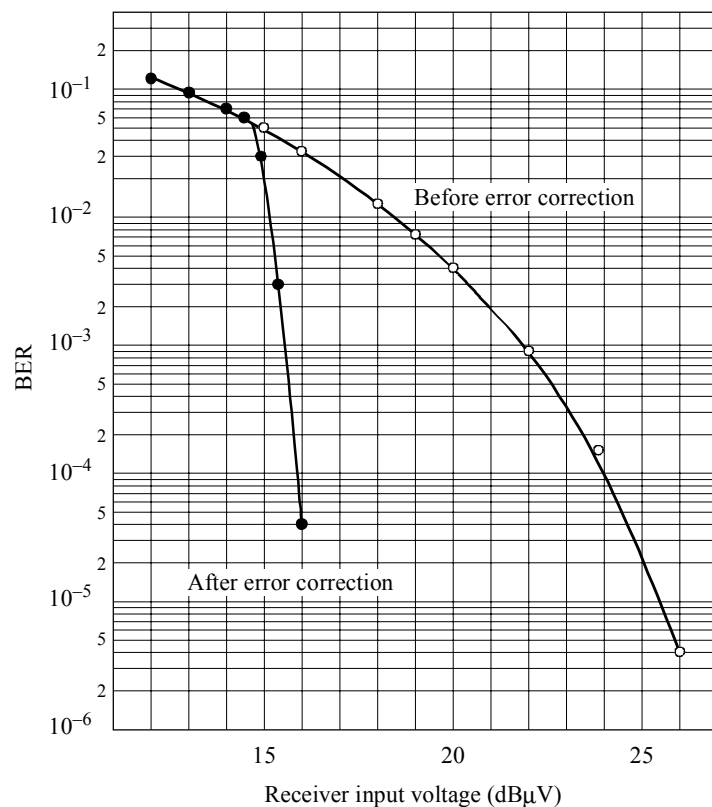
3.1 Transmission characteristics

3.1.1 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 dB μ V or above.

FIGURE 7
Bit error characteristics for random noise



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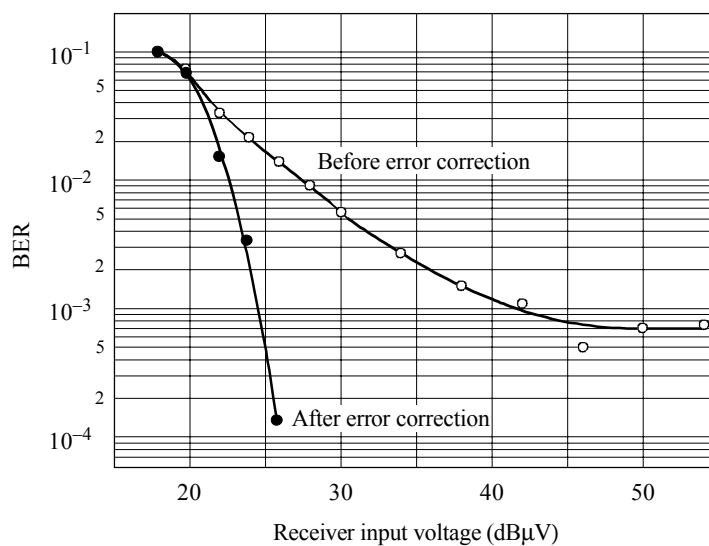
Figure 8 indicates BER characteristics under fading distortion. Without error correction, the error rate does not fall below about $7 \cdot 10^{-4}$ even if the receiver input voltage is increased. The use of error correction will enable the BER to be kept to an adequately low level for input voltages above 27 dB μ V.

3.1.2 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 more can be secured by using DARC Frame C shown in Figure 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

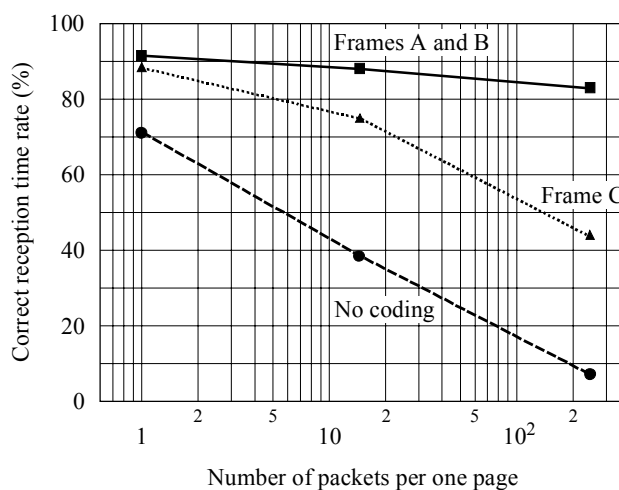


Fading frequency: 3.3 Hz
 Multipath D/U : 10 dB
 Delay time: 5 μs

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FIGURE 9

Effect of error correction code in the FM service area



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3.2 Compatibility with stereo sound broadcasting

3.2.1 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 people was conducted by changing the multiplexing level of the LMSK signals which were 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 the 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%.

3.2.2 Subjective assessment of sound quality

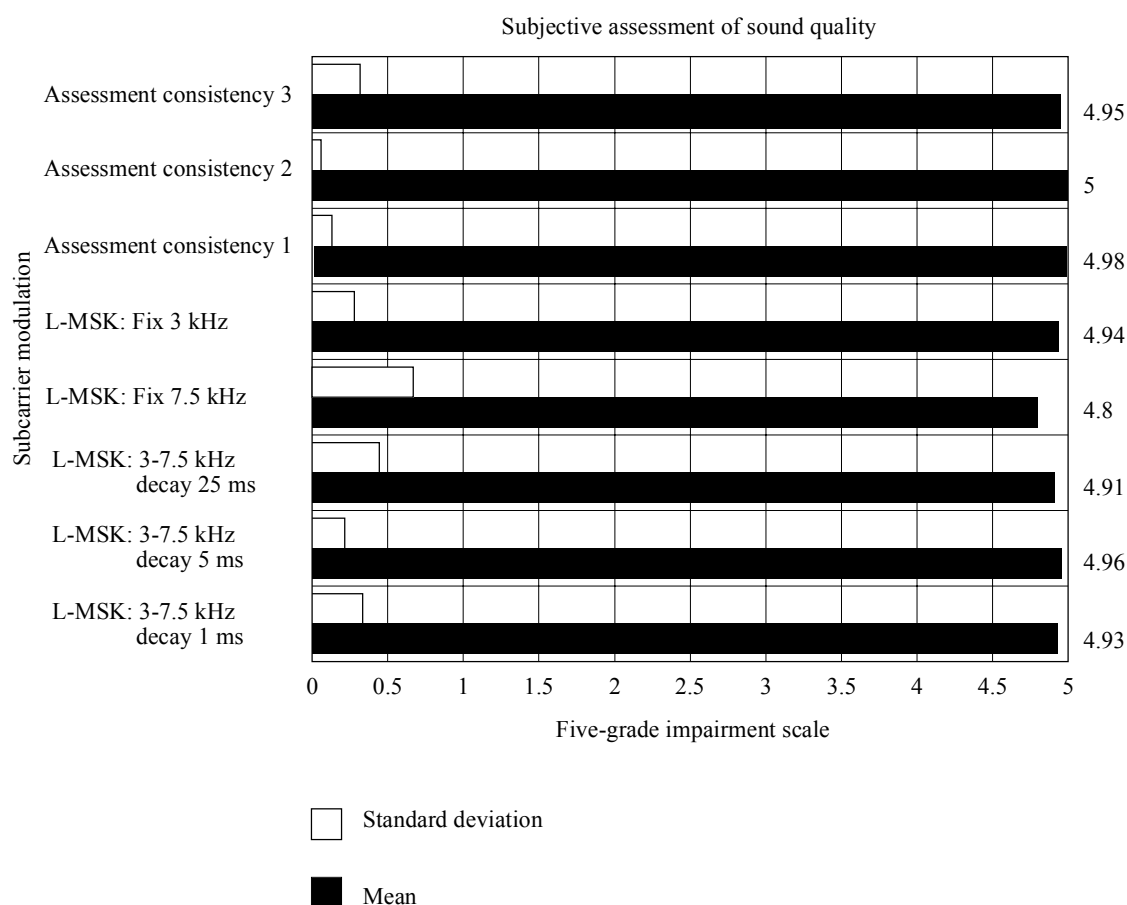
The test procedure was based on Recommendation ITU-R BS.562. Three types of programme material were used, namely piano music, pop music and female speech.

Slightly more than 100 people 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 along 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



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3.2.3 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 the conditions 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.

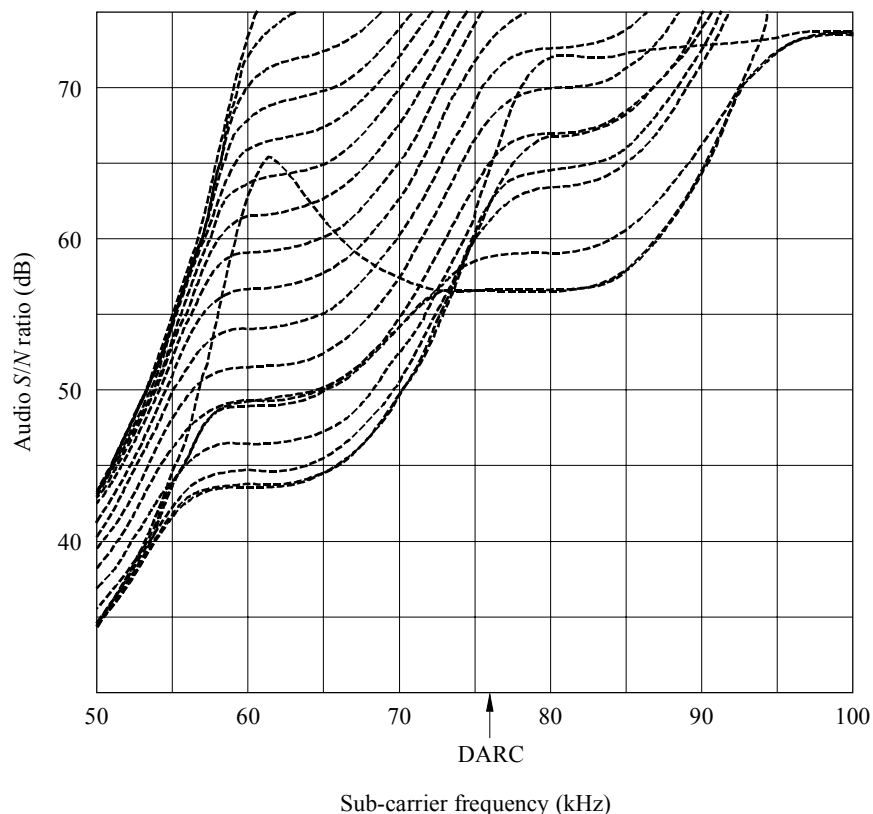
Figure 11 indicates the audio signal-to-noise (S/N) ratio for various sub-carrier frequencies in which the bit rate of 16 kbit/s and LMSK modulation scheme are used under multipath conditions. This figure shows that a better S/N ratio can be obtained when the centre sub-carrier frequency is higher than 73 kHz. This result shows that the DARC has a good performance since its sub-carrier frequency is specified as 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 an RF-phase shift of 180° and a multipath delay time of 9 µs.

Figure 13 shows the diagram of the laboratory tests. The receiver input level was set to -60 dBm and the noise level measured by a quasi-peak level metre with a weighting network in accordance with Recommendation 468. Figure 14 shows the audio S/N ratio versus multipath delay time. Delay times of between $7\text{ }\mu\text{s}$ and $10\text{ }\mu\text{s}$ 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 $7\text{ }\mu\text{s}$ delay multipath signal is greater than 15 dB and the $9\text{ }\mu\text{s}$ case 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 $7\text{ }\mu\text{s}$ and an RF-phase shift of 180° . Figure 15 shows the audio S/N ratio versus a lower injection level of LMSK under the worst multipath conditions. 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 conditions.

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 $7\text{ }\mu\text{s}$ and an 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.

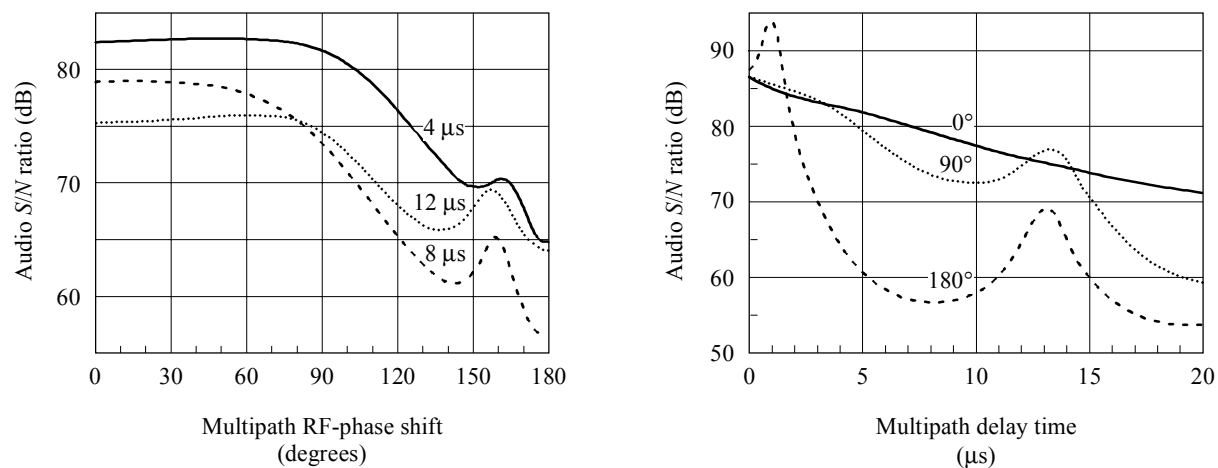
FIGURE 11
Audio S/N ratio for various sub-carrier frequencies



Injection level : 4%
Desired-to-undesired signal (D/U) : 15 dB
Delay time : $8\text{ }\mu\text{s}$
RF-phase shift : $0^\circ, 10^\circ, 20^\circ, \dots, 180^\circ$

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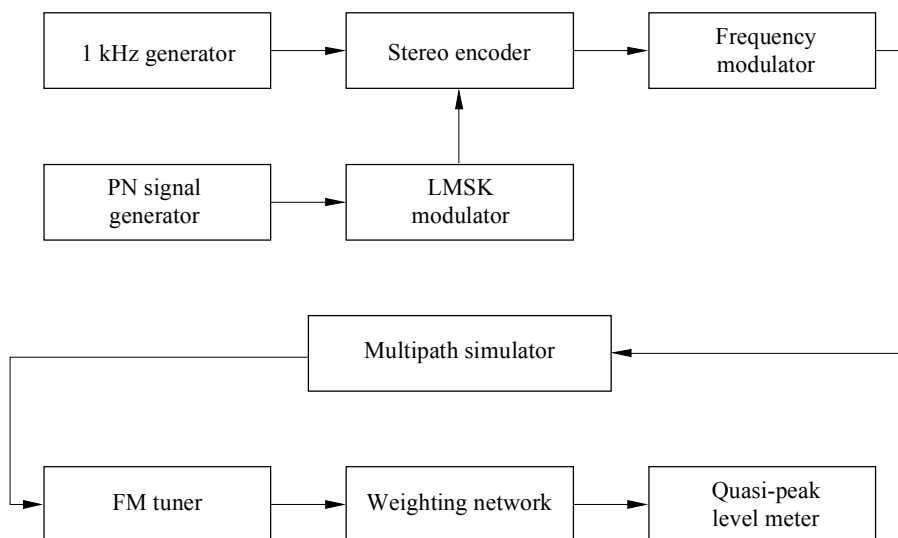
FIGURE 12

Audio S/N ratio versus multipath RF-phase shift and delay time $(D/U$ ratio: 15 dB)

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FIGURE 13

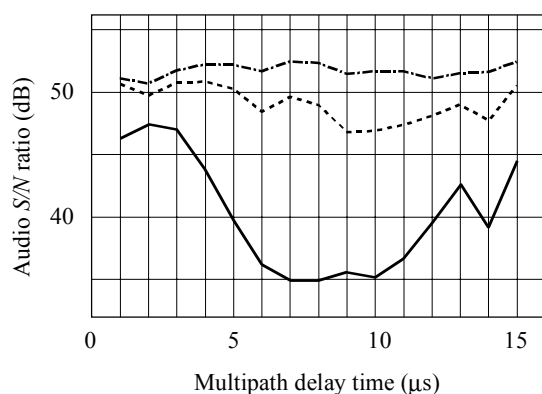
Diagram of the laboratory tests



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FIGURE 14

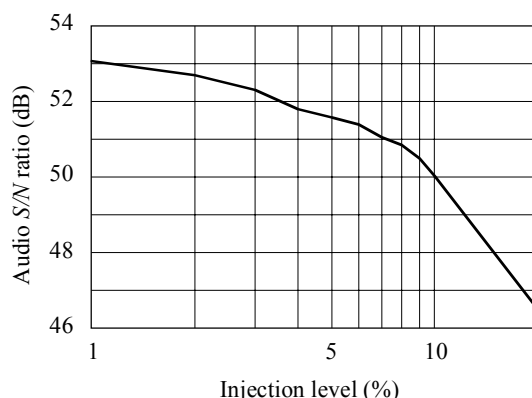
Audio S/N ratio versus multipath delay time



- - - - - $D/U = 15$ dB
 $D/U = 10$ dB
 ——— $D/U = 5$ dB
 RF-phase shift : 180°

FIGURE 15

Audio S/N ratio versus lower injection level of LMSK



D/U ratio : 15 dB
 Delay time : 7 μ s
 RF-phase shift : 180°

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3.3 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.

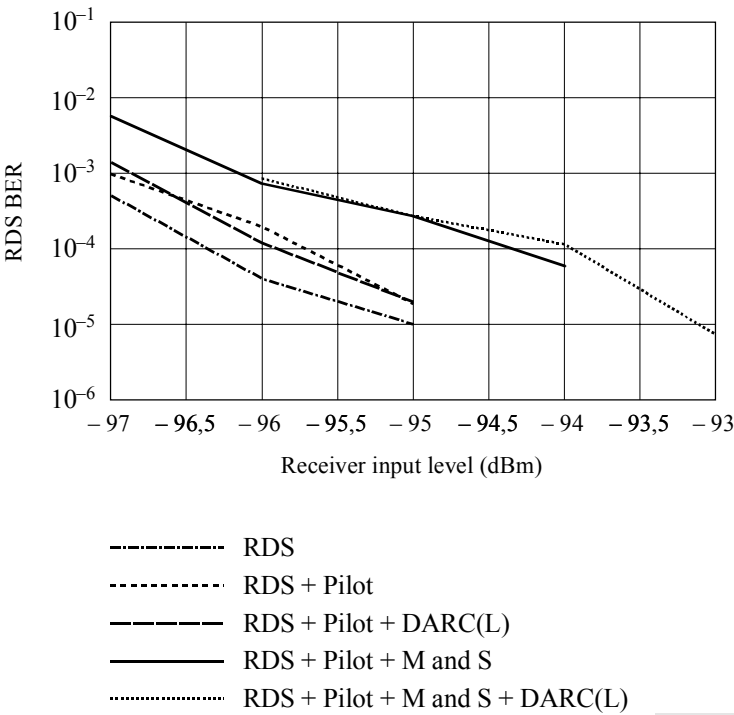
The results from the measurements with five combinations of multiplex components are shown in Figure 16.

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 0.5-1 dB. The 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 itself.

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)

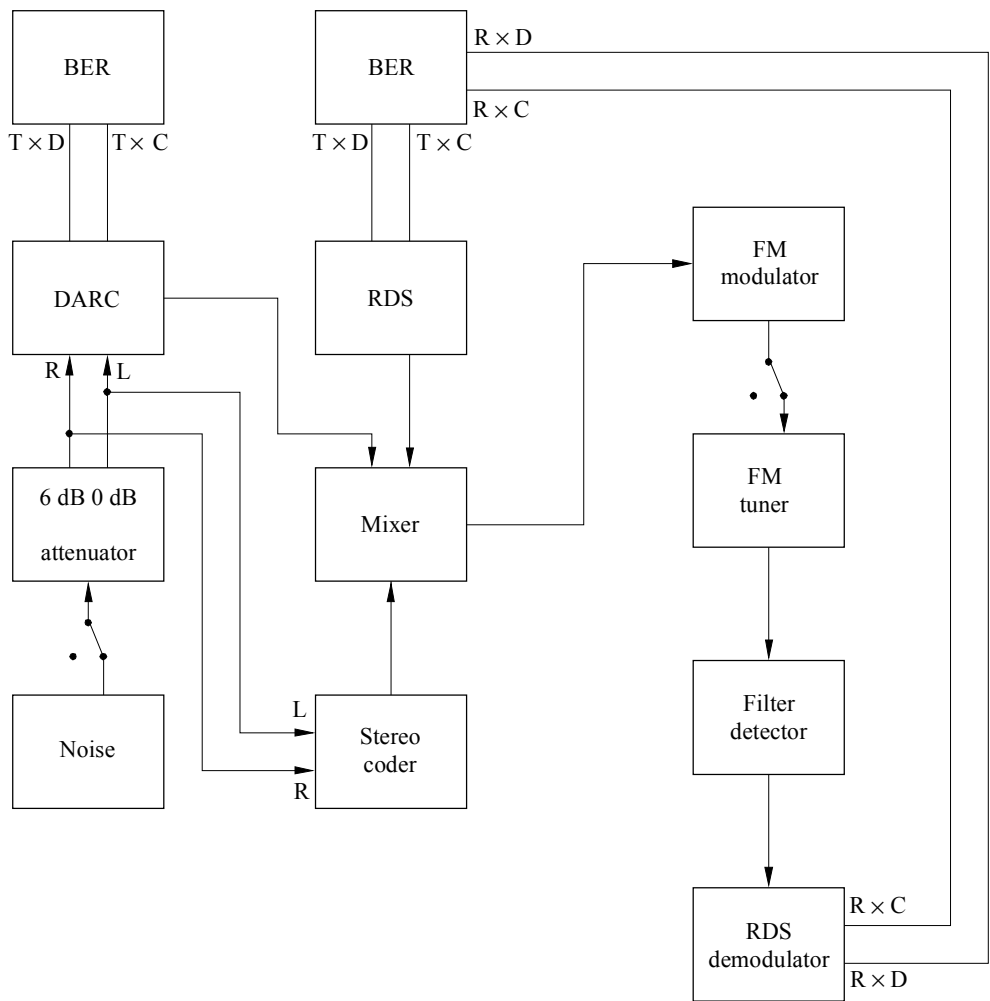
FIGURE 16
RDS BER as a function of receiver input level for
different multiplex content



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The measuring arrangement is shown in Figure 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 the recovery of RDS data (clock and data) a special bi-phase demodulator has been used.

FIGURE 17
Measuring arrangement for compatibility with RDS



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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.

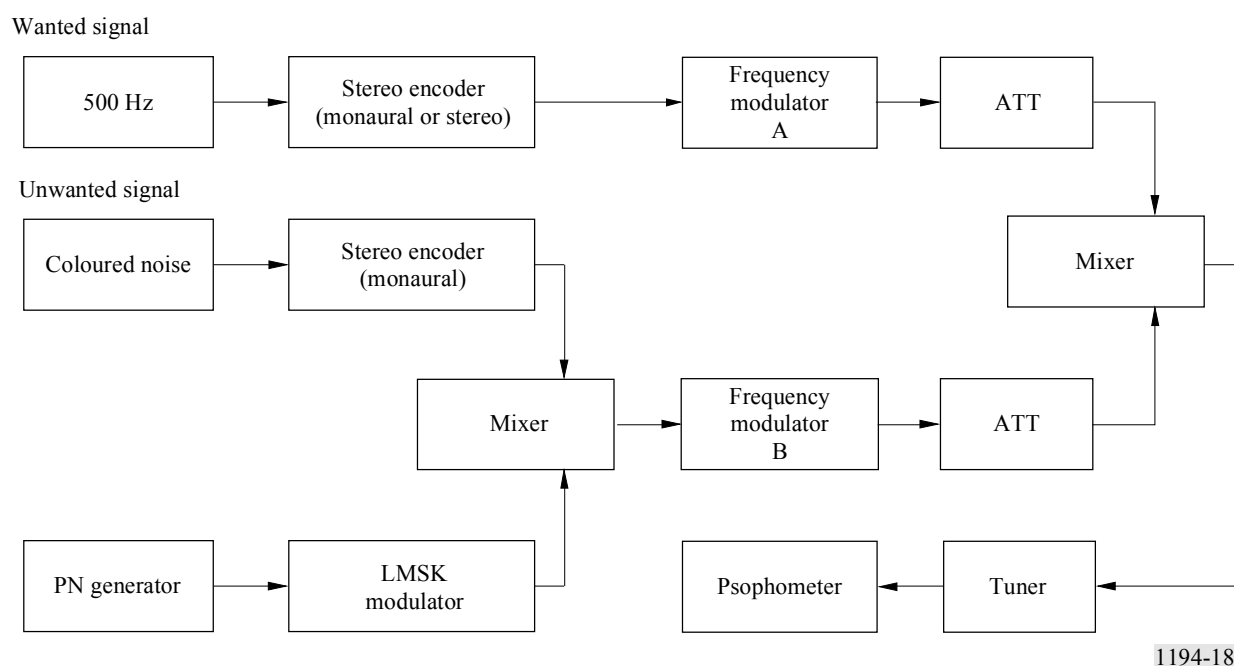
3.4 Protection ratios

Note that some 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 deviated the main FM carrier by ± 7.5 kHz, as well as an RDS signal which deviated 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.

3.4.1 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 18
Diagram of the measuring system

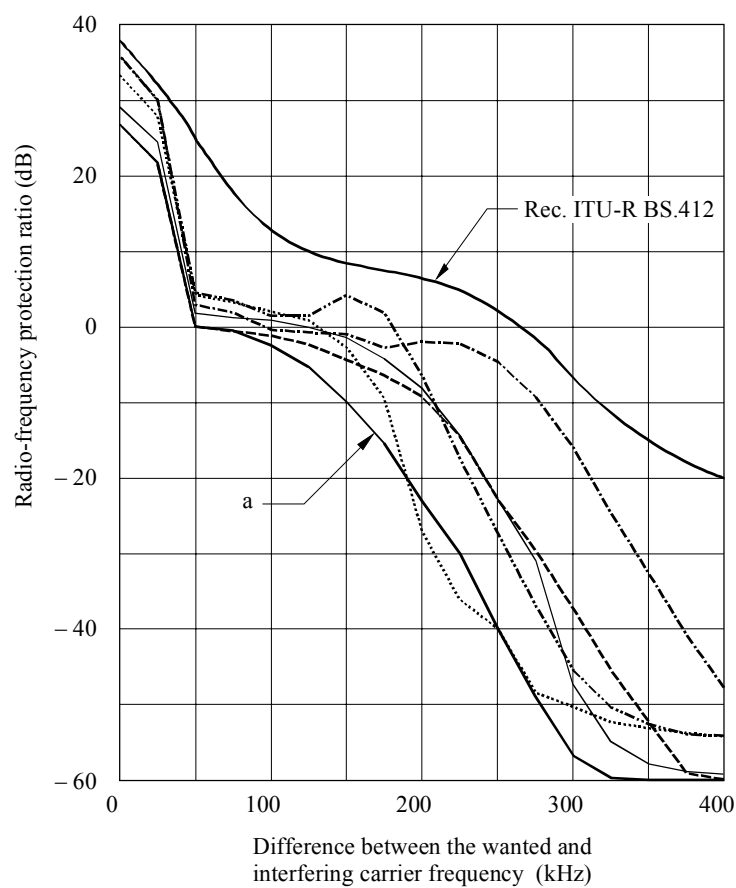


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Figure 19 shows the result of measurement for monaural sound signals. Figure 20 shows the result of measurement for stereo sound signals. The measurement results show that the interference from the DARC signal can be controlled to a level below the 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 19
Protection ratios of monaural sound signals interfered with by DARC signals

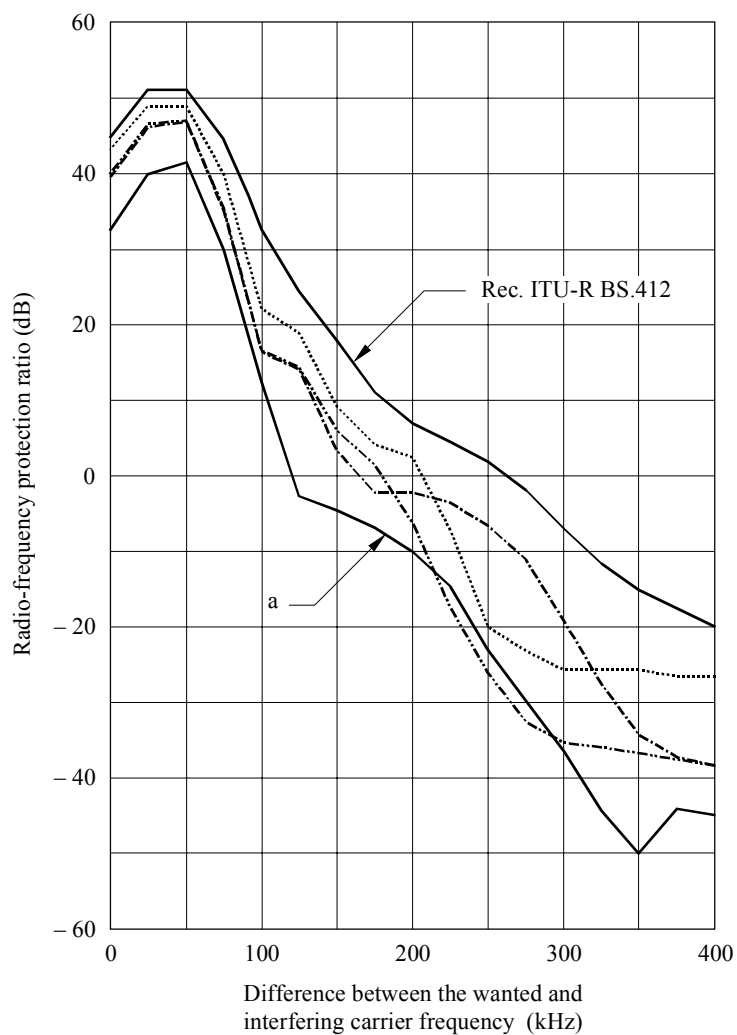


— a — Curve corresponding to the receiver used in Fig. 16

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FIGURE 20

Protection ratios of stereo sound signals interfered with by DARC signals

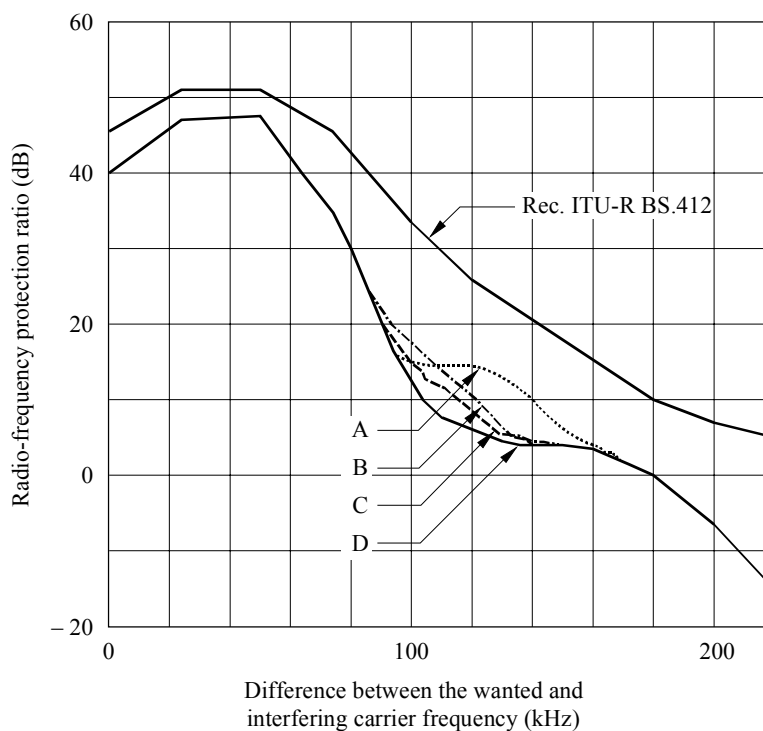


— a — Curve corresponding to the receiver used in Fig. 16

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FIGURE 21

**Protection ratios of stereo sound signals interfered
with by multiplexed signals**



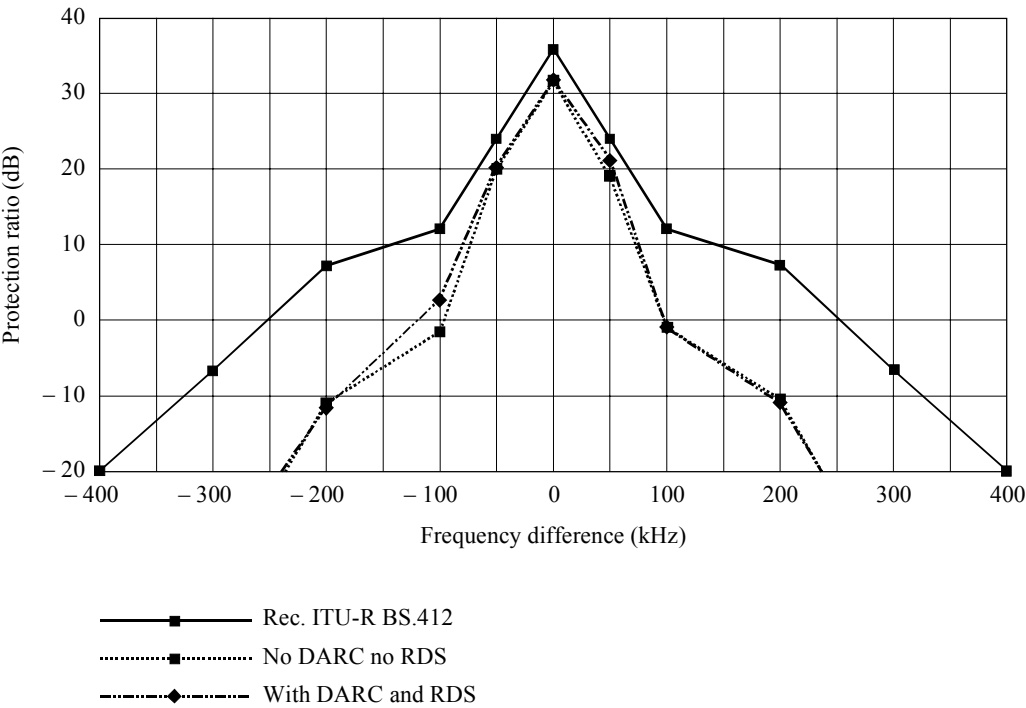
In this measurement, the receiver corresponding to curve a in Figs. 14 and 15 was used.

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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 Figure 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 Figure 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.

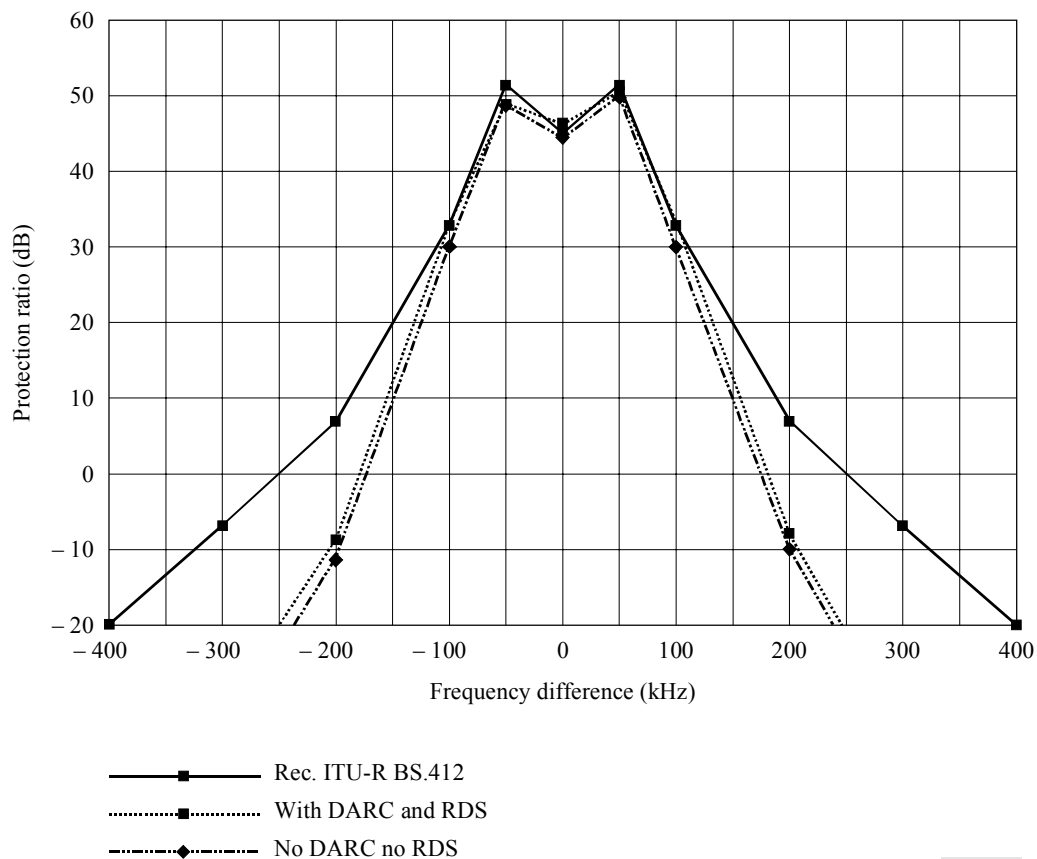
FIGURE 22
Protection ratios for monophonic sound interfered with by a monophonic broadcast



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FIGURE 23

Protection ratios for stereophonic sound interfered with by a monophonic broadcast



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3.4.2 Protection ratios for DARC signals

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 D/U ratio was measured at which the bit-error rate of the DARC signal was 1×10^{-2} .

FIGURE 24

Diagram of the measuring system

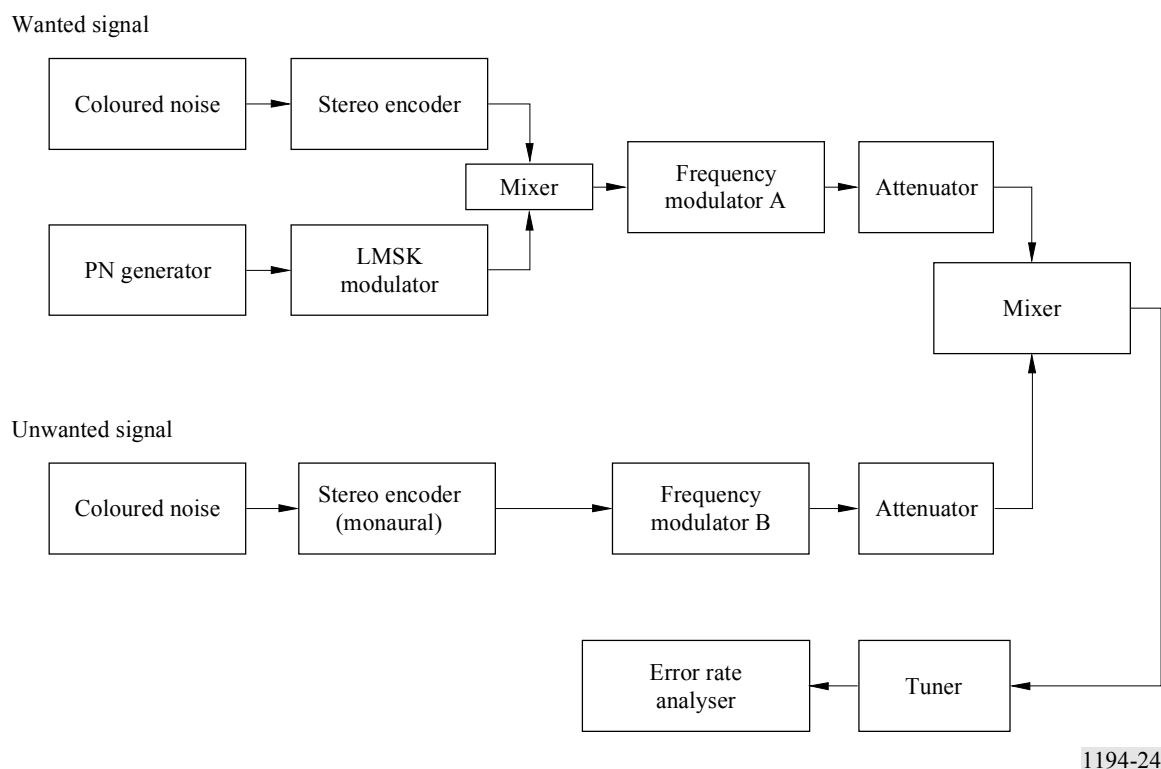
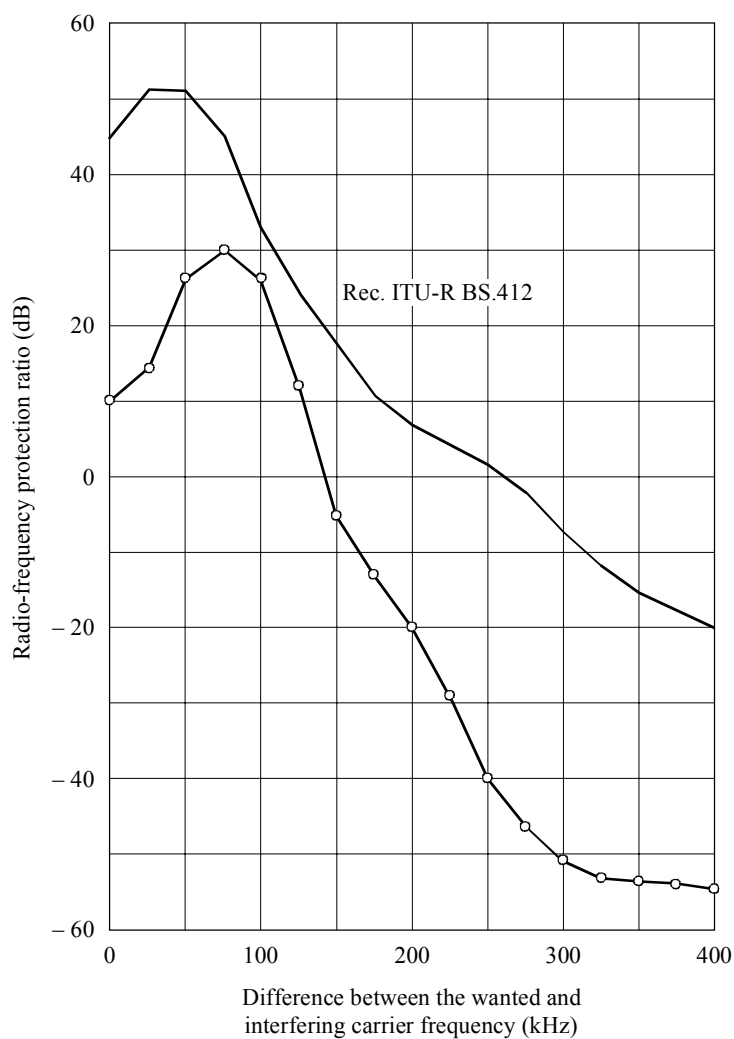


Figure 25 shows the result of measurements taken. The deterioration could also be controlled to a level below the criteria.

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



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