RECOMMENDATION ITU-R BS.1350

SYSTEMS REQUIREMENTS FOR MULTIPLEXING 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)

(1998)

The ITU Radiocommunication Assembly,

considering

a) there is an increasing requirement worldwide for a suitable means of multiplexing FM sound broadcasting with a sub-carrier data channel having a relatively large transmission capacity for stationary and mobile reception;

b) that FM sound broadcasting will support higher capacity data transmissions;

c) the capacity of current data systems in common use in FM sound broadcasting is limited;

d) that technical developments in large capacity data systems for multiplexing with FM sound broadcasting have demonstrated the technical feasibility of larger capacity data systems;

e) that field trials and demonstrations have confirmed the feasibility of large capacity data systems for use in FM sound broadcasting;

f) that compatibility has been achieved between the FM stereophonic services including the Radio Data System (RDS) services according to Recommendation ITU-R BS.643 and any new additional sub-carrier system has been demonstrated;

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

h) that sub-carrier data radio channel systems can provide relatively large transmission capacity compared to RDS and are capable of meeting compliance requirements of Recommendation ITU-R BS.412;

j) that relatively large transmission capacity data systems have already been put into operation,

recommends

1 that systems for multiplexing FM sound broadcasting with a sub-carrier data channel having a relatively large transmission capacity for stationary and mobile reception:

1) must comply with current ITU policy on intellectual property rights;

2) must not interfere with:

   – the main broadcast on the same carrier or on adjacent carriers as stated in Recommendation ITU-R BS.412;

   – RDS and/or other sub-carrier services on the same or adjacent carriers as stated in Recommendations ITU-R BS.412 and ITU-R BS.643;

   – aeronautical radio navigation services as stated in ITU-R IS.1009;

3) should be evaluated for selection taking into consideration the following characteristics and features relative to the needs of the particular application:

   a) system performance characteristics such as:

      • data reliability in Gaussian noise;

      • data reliability in multipath reception conditions;

      • data reliability with adjacent channel signals;

      • shortest end-to-end delay;

- message error rate for various message lengths in multipath conditions;
- synchronization acquisition time;

b) additional features of the system such as:

- minimum duty cycle for power savings;
- receiver addressability;
- conditional access;
- support for various data types;
- ability to operate in a network of data services;
- possibility for additional sub-carrier services;
- ability to operate independently of the radio network;
- multiple station access;
- capability for rebroadcasting;

c) system compliance with Recommendation ITU-R BS.450;

d) the ability of the system to minimize possible degradation to the audio main channel and/or RDS in multipath reception conditions; and

e) results of field tests of the system;

4) should be selected and specified with at least the following general features being identified:

– sub-carrier frequency;
– bandwidth;
– channel data rate;
– information data rate;
– modulation method;
– packet structure and framing (data structure);
– forward error correction and interleaving approach;
– error detection capability;
– injection level.

NOTE 1 – These requirements and considerations are discussed further in Annex 1. Examples of systems which may be suitable for various applications are discussed in the appendices of Annex 1.

ANNEX 1

Systems requirements for multiplexing FM sound broadcasting with a sub-carrier data channel having a relatively large transmission capacity for stationary and mobile reception

1 Introduction

1.1 Purpose

The purpose of this document is to assist in the selection of a specific system for providing relatively large data transmission capacity using sub-carriers multiplexed with FM sound broadcasts. This document presents a set of system characteristics that should be considered when selecting a system for the above purpose. These characteristics are divided into four aspects as follows:

– **General Features** is an overview of the basic parameters of the data systems (Section 3).
– **Additional Features** describes specifics of each data system that will tend to make it more or less suitable for special features of each system (Section 4).

– **Compatibility characteristics** which relate to the quantitative impact of the data system on existing services, both on the broadcast channel using the same carrier as well as on adjacent channels (Section 5).

– **System performance characteristics** which relate, in various terms, to the performance of the data system itself (Section 6).

It is recognized that, compatibility characteristics of a system are important regardless of the application. The system performance characteristics are dependent on the specific requirements of the intended application. This document identifies the important system performance characteristics for a number of different applications.

1.2 Special requirements

As for all systems recommended by the ITU, the system chosen should comply with the current ITU policy on intellectual property rights. In addition, proposed systems should be field tested prior to selection.

1.3 Document organization

Appendices 1, 2 and 3 of this document provide descriptions of several possible data systems with reverences to relevant TU-R documents which provide further information on these systems.

2 System applications

System applications are based on receiver characteristics, data types and transmission characteristics. These are discussed in Sections 2.1, 2.2 and 2.3 respectively. A particular system application involves the transmission of one or more data types from transmitters having various characteristics, to receivers with one or more characteristics. Because of the particular data types, transmitter characteristics and expected receiver characteristics which distinguish any given application, certain system performance characteristics will be more important than others.

2.1 Receiver characteristics

Receiver applications are distinguished in terms of the following characteristics. Some receivers may be good enough to meet low data rates or reliability requirements, but will not be adequate where high data rates and reliability are required.

2.1.1 Physical characteristics of the receiver application

– availability of prime power to the receiver (battery size and capacity);

– receiver antenna performance;

– receiver mobility and speed of motion;

– receiver noise figure;

– ambient electrical noise.

2.1.2 Data requirements of the receiver application

– required data integrity;

– receiver addressability options;

– data traffic types;

– networking functions.

Several receiver applications have been identified as shown in Table 1.

TABLE 1

Receiver applications

Application	Power availability	Receiver antenna performance	Mobility
Vehicular	High	Fair to good	0 - 150 km/h
Portable	Low	Fair	0 - 5 km/h
Personal	Extremely low	Poor	0 - 300 km/h
Fixed	Very high	Good to excellent	0 km/h

2.2 Data types

There are two data types. Firstly, packetized data which involves communication of information that is naturally separated into data segments or messages for some reason. Usually this segmentation is associated with a header of some type which may be used for addressing the data to a specific user or otherwise designating something unique about that segment of information. Packetized data may be further categorized based on the length of the message. Some may be as short as a few tens of bits while others may be as long as hundreds or thousands of bytes.

Secondly, continuous data, which involves the communication of data at a fixed rate in a way that presumes that, if there is any segmentation of the data, it is accomplished in a higher layer in the protocol stack and frequently consists of a sequence of packets.

2.3 Transmission system characteristics

– signal strength and intended service area;
– ability of transmitters to address specific receivers;
– transmitter networking functions.

3 General features and parameters

The following general characteristics should be considered when selecting a system:

– sub-carrier frequency;
– bandwidth;
– channel data rate;
– information data rate;
– modulation method;
– packet structure and framing (data structure);
– forward error correction and interleaving approach;
– error detection capability;
– injection level.

4 Additional features

The following additional features should be considered when selecting a system:

– minimum duty cycle for power savings;
– receiver addressability;

– conditional access;
– support for various data types;
– ability to operate in a network of data services;
– possibility for additional sub-carrier services;
– ability of operate independently of radio network;
– multiple station access;
– capability for rebroadcasting.

5 Compatibility characteristics

The following compatibility characteristics should be considered when selecting a system:

– interference to main broadcast service (on the same carrier);
– interference to RDS and/or other sub-carrier services (on the same carrier);
– protection ratio for broadcast services (on adjacent channels);
– protection ratio for RDS and/or other services;
– Recommendation ITU-R BS.450;
– protection ratio for aeronautical radio, Recommendation ITU-R IS.1009;
– degradation to audio main channel in multipath reception conditions.

6 System performance characteristics

The following system performance characteristics should be considered when selecting a system:

– data reliability in the presence of Gaussian noise;
– data reliability in multipath reception conditions;
– data reliability in the presence of impulse noise;
– data reliability with adjacent channel signals;
– shortest end-to-end delay;
– message error rate for various message lengths in multipath conditions;
– synchronization acquisition time.

Data reliability deserves some discussion. These characteristics are determined by the methods of modulation and coding as well as other features of the system. Data reliability performance is typically characterized in terms of Bit Error Rate (BER) or packet loss rate, Probability of Correct Message Received (PCMR) as a function of the conditions in the channel.

For noise, these conditions are normally described in terms of Signal to Noise Ratio (S/N). For multipath and noise, the conditions are described in terms of the multipath delay spread profile and fade rates as well as average S/N. For impulse noise, the channel is described in terms of peak pulse powers, pulse width and pulse repetition rate. Data reliability in general determines the coverage area and will be affected by the injection level.

7 Example applications

A number of items have to be considered as the minimum features required for defining a generic specification of a FM data broadcasting service.

– **I1 Service channels**: A service channel offers a powerful way of managing access to a given service by an end-user terminal (automatic tuning, service roaming, ...).
– **I2 File transfer services**: It is desirable that transparent file transfers are managed by the system in order to provide a large range of applications using, for instance, standard software on Personal Computers.

– **I3 Real-time services**: Some services may need real time or assured maximum delay (Differential Global Positioning System (DGPS)).

– **I4 Conditional access**: Conditional access is a key feature for commercial services.

NOTE – Service multiplexing: A service identification and management system offers flexibility for broadcasting several services together.

Compatibility with future DSB services has to be taken into account.

If we consider the generic definition of any broadcasting system (according to the ISO Open Systems Interface, seven layer model), these seven key items can be achieved by having a common understanding about the interfaces on layer 3 (I1), 4 (I3, I4) and 5 (I2).

This is the basis of a further discussion. As a summary, a worldwide standard should fulfil the required interfaces.

The following sections provide some examples of specific applications in operation or under test, along with a list of the characteristics from preceding sections which are most important for each of these applications.

7.1 Intelligent transportation system (ITS)

ITS requires several data types for transmitting transportation related information. Type 1 is for text, intended for portable receivers with small displays. Typically text ranges from 10 - 100 bytes in volume. Type 2 is for long text or graphical information with simple road maps for traffic congestion and is intended for mobile receivers (vehicular). Typical data volumes range from 100 to 5 000 bytes. Type 3 is for transparent data and coded information intended for navigation, including large memory (CD-ROM) equipment having detailed road maps.

Data requirements vary greatly. DGPS is an example of Type 3 data requiring short delivery delay (< 10 seconds), at a rate of 10's of bytes per second. A message of 10 to 20 bytes may be required for updating databases, perhaps of bus location or highway status. Since the database updates are used in the vehicle to help the driver determine the best route, and since delayed information can lead to incorrect route decisions for individuals and larger traffic problems for a highway network, end-to-end delay is an important metric for this ITS application. The database update messages will typically be repeated in a cyclic manner. However, since there is such a large volume of data, failure to receive a given update because of channel errors implies that the user must wait for the subsequent broadcasts. This would result in a larger effective delay, degrading vehicular traffic flow.

The following characteristics are most important to ITS applications:

– data reliability in multipath fading and noise;

– data reliability in the presence of impulse noise;

– end-to-end delay;

– information data rate;

– synchronization acquisition time;

– error detection and correction capability;

– implementation cost and risk;

– standardization.

In evaluating candidate systems for this application, the characteristics above should be given high priority. A comparison of candidate systems should be made, paying particular attention to these characteristics.

7.2 Paging applications

Paging applications require the broadcast of relatively short packets to personal receivers. One of the critical characteristic for paging applications is the effectiveness of any power saving feature. This is important because of the severely limited prime power available for personal receivers.

Typically personal receivers also, have very poor antenna performance. To provide reliable paging services, retransmission of the data is required, either on the same carrier or on other carriers. This reduces the effective throughput. However, the throughput requirements are not as stringent as for some other applications.

The following characteristics are important to paging applications:

– minimum duty cycle for power savings;

– implementation cost;

– receiver addressing;

– transmitter networking functions;

– error detection and correction.

7.3 Continuous data

For applications which may be characterized as "Continuous Data", the data to be sent will not require any segmentation at the physical or data link layer. Segmentation, if it occurs, is at a higher layer in the protocol stack. This data segmentation, associated with the application, will be transparent at the natural boundaries of the data at the physical and data link layers as dictated by the systems considered here. Continuous Data applications often, but not always, provide strong signals from high power transmitters with high antennas and large service areas.

Important System Performance Characteristics include the following:

– information data rate;

– data reliability in the presence of Gaussian noise;

– data reliability in multipath and noise;

– data reliability with strong adjacent channel signals;

– receiver addressability;

– conditional access features.

7.4 File transfer interface

A file transfer interface provides for the conveyance of data via a point to (multi-)point transmission from the information providers to one or more receivers. It may be affected by the following characteristics:

– receiver addressability;

– information data rate;

– conditional access;

– ability to operate in a network of data services.

7.5 Text information

Textual information, such as news, weather, music related and other programme related information, is one of the important applications for an FM multiplex broadcasting system. These information services require a high level of reliability against transmission errors and hence powerful error correction and detection methods.

7.6 Emergency information

Emergency information that gives notice of an earthquake, severe weather or tsunami wave is one of the important applications for an FM multiplex broadcasting system. When emergency information is transmitted through an FM broadcasting path, a receiver that may be receiving another program automatically displays the emergency information.

7.7 Differential GPS

[Information to be supplied.]

8 Example of systems

Table 2 provides a summary of three systems.

8.1 System A

The DARC (Data Radio Channel) 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 and detection provides virtually error-free data reception on all types of receiver.

Some multiplexed application 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 system exceeds the requirements of this ITU-R Recommendation. The DARC FM Sub-carrier specifications are a matter of record. See Recommendation ITU-R BS.1194, ETSI Standard ETS 300 751 and Appendix 1.

8.2 System B

The High Speed Data System (HSDS) is a flexible, one way, communications protocol that permits the use of very small receivers. Receivers, with duty cycles varying from 100% to less than 0.01%, provide the ability to select message delay, data throughput and battery life. HSDS can operate as a single or multiple transmitter system. Multiple transmitters are accommodated by frequency-agile receivers, time offset transmission and lists of alternative frequencies. Reliability can be enhanced through packet retransmission.

The system employs time division multiplexing with a system of master frames, subframes and time slots. Each timeslot is utilized to transmit a single data packet. In multiple transmitter systems, each HSDS master frame is synchronized to Universal Coordinated Time (UTC).

The error correction scheme varies with the application.

HSDS modulation and encoding provides a high data rate and a narrow bandwidth that has both high spectral efficiency and negligible impact on the main channel. The modulation method employed is that of Amplitude Modulation Phase Shift Keying (AM-PSK) with duobinary encoding. The channel data rate is 19 000 bit/s.

HSDS deviation can be set from 3.75 to 7.5 kHz. Sharp transmission filter skirts result in low impact on the main channel in multipath free situations. Pseudo-randomized data reduces the impact on the audio channel even in multipath situations. The narrow bandwidth of HSDS ensures compatibility with RDS and complies with Recommendation ITU-R BS.450. See Appendix 2 for more information.

8.3 System C

The Sub-carrier Transmission Information Channel (STIC) system was developed for the United States Department of Transportation in support of its Intelligent Transportation System (ITS) activities. The system has been optimized for use in broadcasting ITS data to vehicular receivers. It uses a version of DQPSK modulation on a 72.2 kHz sub-carrier with a symbol rate of 9 025 symbols per second (18 050 bit/s). A concatenated Forward Error Correction (FEC) coding approach is used which incorporates convolutional coding with Viterbi decoding, Reed-Solomon coding and two interleavers.

Because of this concatenated code, this system exhibits robustness in multipath reception conditions and noise, especially for long messages. The system provides a net throughput of 7 600 bit/s, plus some capacity for short delay data, depending on the frame structure selected. (This short delay data path is intended for Differential GPS (DGPS) and/or other high priority messages of an emergency nature.)

The system is compatible with RDS as well as with the main stereo channel. The system is compatible with, but does not explicitly include, conditional access and receiver addressability features.

The ability to support multiple service providers is made possible by the packet structure defined for the system. Because of the long packets used, service provider identification is highly efficient in terms of the data rate capacity.

Enhancements to the system are planned which will provide power saving features and options for higher data rate operation. See Appendix 3 for more information.

TABLE 2

Summary of systems

	System A (Rec. ITU-R BS.1194)	System B	System C
Parameters			
Sub-carrier frequency	76 kHz	66.5 kHz	72.2 kHz
Bandwidth	44 kHz (-40 dB)	16 kHz (60 to 76 kHz at -60 dB)	16 kHz (-50 dB)
Channel data Bit rate	16 kbit/s	19 kbit/s	18.05 kbit/s
Information data rate	Method A - 6.83 kbit/s Method B - 6.95 kbit/s Method C - 9.78 kbit/s	Packets - 10.51 kbit/s Small blocks - 8.3 kbit/s	7.6 kbit/s + short delay data
Modulation method	LMSK	Duobinary double-sideband suppressed-carrier amplitude modulation	π/4 shifted DQPSK
Error correction	(272, 190) product code	Packets - interleaved Hamming (12, 8) Small Blocks - time spread packets with additional Hamming	Reed-Solomon (243, 228) + 1/2 convolutional code
Error detection	14 bits of CRC	16 bits of CRC	Accomplished by Reed Solomon decoding
Injection level	varies from 3 kHz up to 7.5 kHz	3.75 kHz to 7.5 kHz nominally 7.5 kHz	nominally 7.5 kHz
Additional features			
Power saving	Yes, in current receivers	Yes, duty cycles from 0.01% to 100%	
Receiver addressability	Yes	Yes	Yes
Support of different data types	Yes	Yes	Yes
Possibility for additional sub-carrier services	No	Yes	Yes
Multiple station access	Yes	Yes, including time offset transmission for paging type data	Yes

TABLE 2 (*CONTINUED*)

Summary of systems

	System A (Rec. ITU-R BS.1194)	System B	System C
Compatibility characteristics			
Audio programme	see Recommendation ITU-R BS.1194 (Section 2, Annex 2)	see Appendix 2	see Appendix 3
Protection ratio	see Recommendation ITU-R BS.1194 (Section 4, Annex 2)	see Appendix 2	see Appendix 3
RDS	see Recommendation ITU-R BS.1194 (Section 3, Annex 2)	see Appendix 2	
Rec. ITU-R BS.450	(sub-carrier frequency, see Note 1)	completely	
Aeronautical radio navigation services			
Audio in multipath	see Recommendation ITU-R BS.1194 (Annex 2)	see Appendix 2	
Handle rebroadcasting	Yes	Yes	Yes
Performance characteristics			
BER (Gaussian)	see Recommendation ITU-R BS.1194 (Section 1, Annex 2)	see Appendix 2	see Appendix 3
BER (multipath and fading)	see Recommendation ITU-R BS.1194 (Section 1, Annex 2)	see Appendix 2	see Appendix 3
BER (impulse noise)			
Shortest end to end delay			
Message error rate for various length messages in multipath conditions		see Appendix 2	see Appendix 3

NOTE 1 – Guidelines for sub-carrier frequencies and injection levels can be found in Recommendation ITU-R BS.450. A large number of protection ratio tests have been carried out for System A.

APPENDIX 1

System description: System A

1 System A

The DARC (Data Radio Channel) 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 application 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 system exceeds the requirements of this ITU-R Recommendation. The DARC FM Sub-carrier specifications are a matter of record. See Recommendation ITU-R BS.1194 and ETSI Standard ETS 300 751.

APPENDIX 2

System description: System B

1 Introduction

The High Speed Data System (HSDS) is a flexible, one way, communications protocol and permits the use of very small receivers. Receivers, with duty cycles varying from 100% to less than 0.01%, provide flexibility to select message delay, data throughput and battery life. HSDS can operate as a single or multiple transmitter system. Multiple transmitters are accommodated by frequency-agile receivers, time offset transmission and lists of alternative frequencies. Reliability can be enhanced through packet retransmission.

The system employs time division multiplexing with a system of master frames, subframes and time slots. Each timeslot is utilized to transport a single data packet. In multiple transmitter systems, each HSDS master frame is synchronized to Universal Coordinated Time (UTC).

The error correction scheme varies with the application.

HSDS modulation and encoding provides a high data rate and a narrow bandwidth that has both high spectral efficiency and negligible impact on the main channel. The modulation method employed is that of Amplitude Modulation Phase Shift Keying (AM-PSK) with duobinary encoding. The channel data rate is 19 000 bit/s.

HSDS deviation can be set from 3.75 to 7.5 kHz. Sharp transmission filter skirts result in low impact on the main channel in multipath free situations. Pseudo-randomized data reduces impact on the audio channel even in multipath situations. The narrow bandwidth of HSDS ensures compatibility with RDS and complies with Recommendation ITU-R BS.450.

See also Doc. 10B/46, September 1995 for a short description of this system.

2 Physical layer

2.1 Modulation

The HSDS modulation scheme satisfies the following criteria:

– non-interference with FM radio receivers;

– compatibility with ITU-R Recommendations;

– simplicity in IC implementation of the demodulator;

– low-cost mobile receiver with a small form factor;

– adequate bit error rate performance in the presence of noise;

– commercially satisfactory coverage area;

– relatively high data rate.

The HSDS sub-carrier frequency is 66.5 kHz and is phase-locked to the pilot with a phase difference of 63°. Double-sideband suppressed-carrier amplitude modulation with duobinary encoding is used. Duobinary encoding employs controlled inter-symbol interference to achieve 1 bit/sec/Hz efficiency. The duobinary encoding technique achieves this result by using a filter to create inter-symbol interference that combines the current and previous data bit, creating a three level output signal in the demodulator.

2.2 Compatibility with main channel audio

HSDS is more than 60 dB below the pilot outside the sub-carrier envelope and uses data randomization to "whiten" any otherwise audible signal elements - avoiding generation of tones in the audio portion of the band. Lab tests showing the compatibility with main channel audio in a multi-path environment are summarized below.

For these tests the RF Channel Simulator was set to assume static multipath characteristics. Figure 1 shows a screen dump of the baseband spectrum in an unfaded situation, Figure 2 shows the same baseband in a faded situation having a Desired to Undesired ratio (D/U) of 5 dB, delay of 8 μs and Phase Shift of 120º.

Under these kind of conditions the audio Signal to Noise ratio (S/N) may be deteriorated by the sub-carrier.

Figure 3 gives the laboratory test configuration. A test receiver with a selective filter of 300 kHz is used in front of the audio analyser. The HSDS deviation was set to 5.5 kHz, unless stated otherwise.

During the test, different D/U values of 5, 10 and 15 dB were used during the measurements. The lowest D/U resulted in the worst S/N deterioration.

Figure 4 shows the audio S/N under faded conditions having a D/U value of 5 dB. The figure shows this with different multipath delays obtained by switching the HSDS on and off. The difference that HSDS makes in this is negligible.

FIGURE 1

Unfaded baseband spectrum

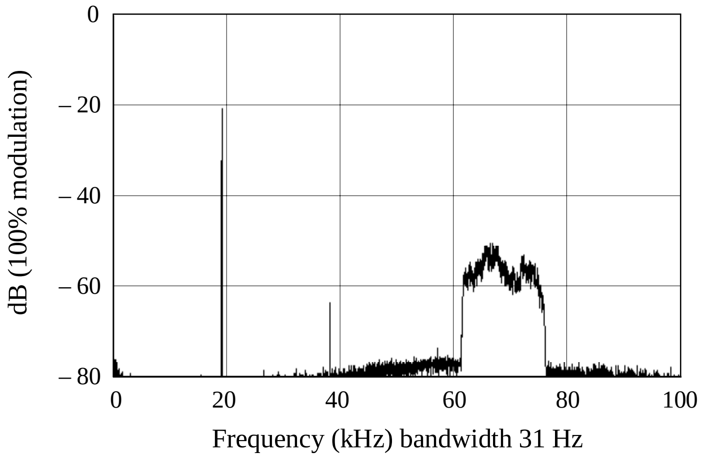


FIGURE 2

Unfaded baseband spectrum

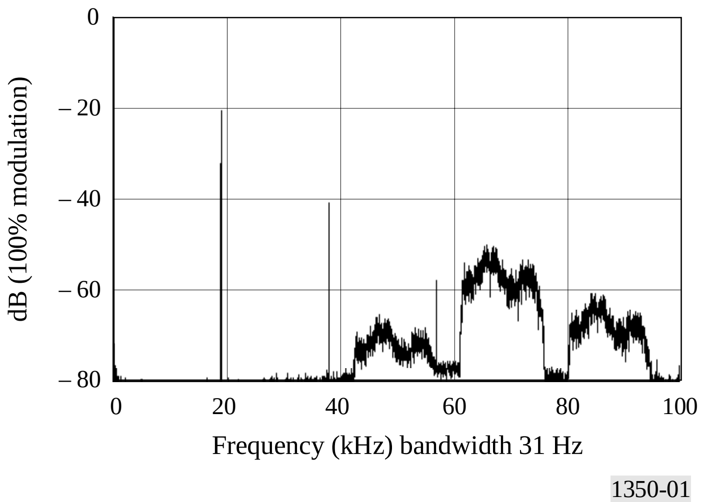


FIGURE 3

Audio *S*/*N* laboratory test configuration

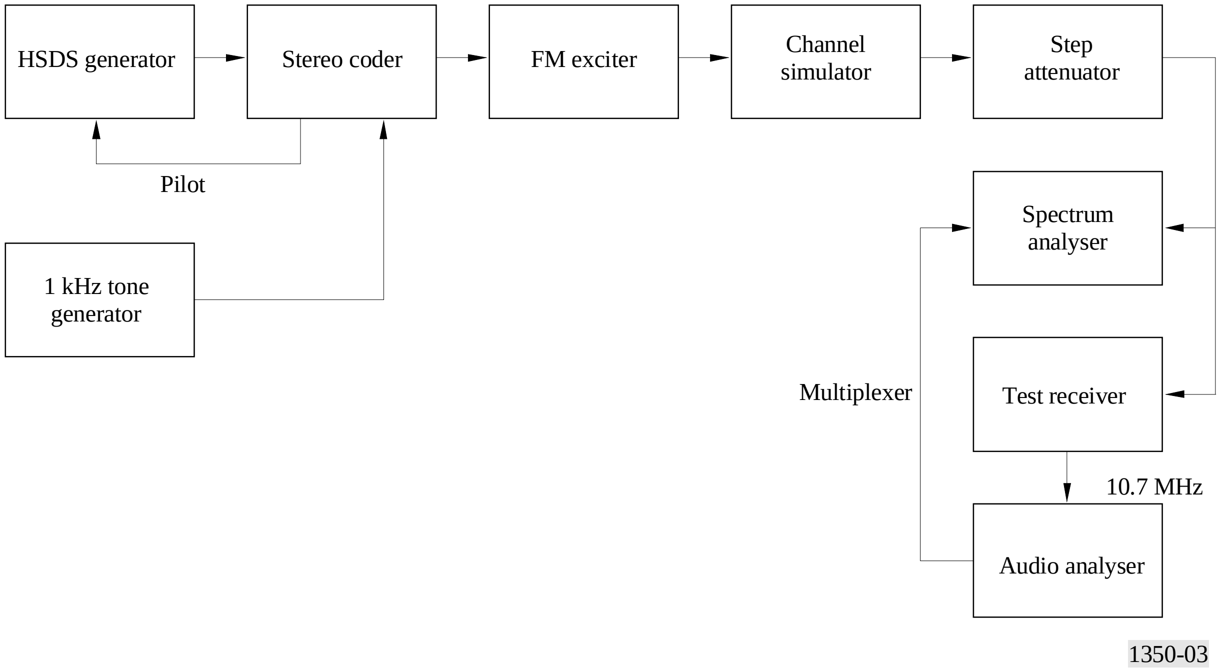
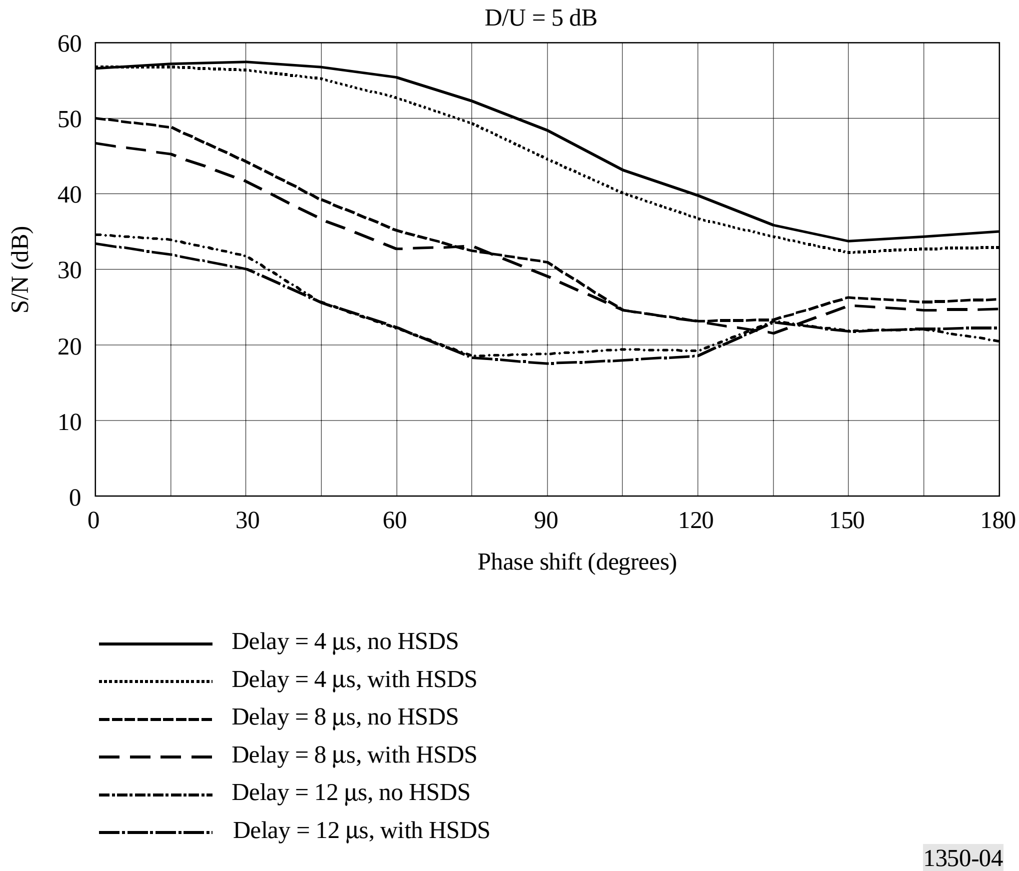


FIGURE 4

Audio *S*/*N* in multipath phase shift D/U = 5 dB



During the test different phase shifts of up to 180º were used during the measurements. As expected, the greatest phase shift resulted in the worst S/N deterioration.

Figure 5 shows the audio S/N having a phase shift of 180º as a function of the multipath delay. This was done for three different D/U values.

FIGURE 5

Audio *S/N* in multipath delay

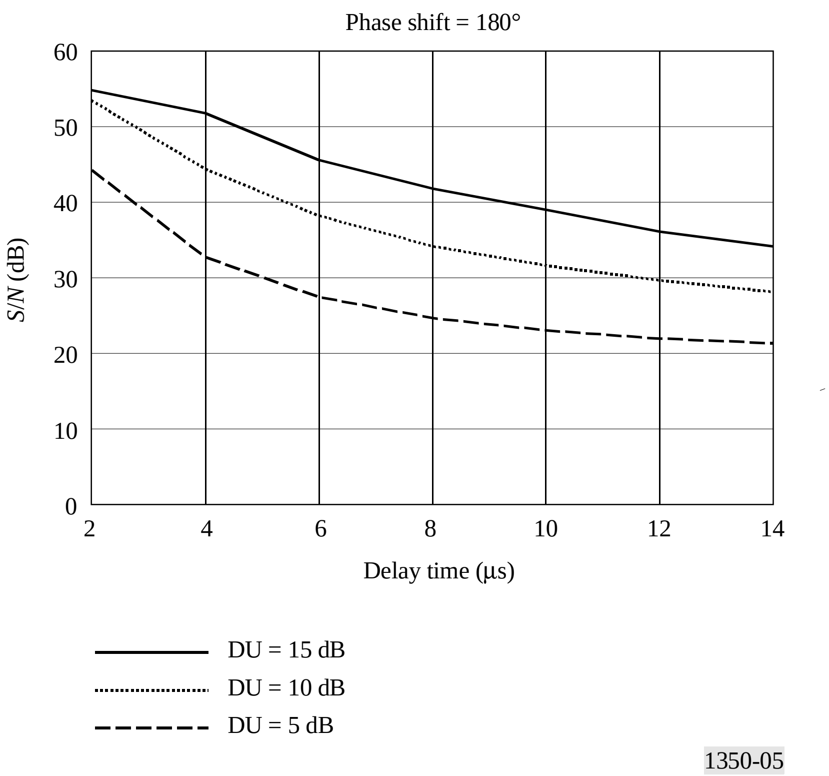
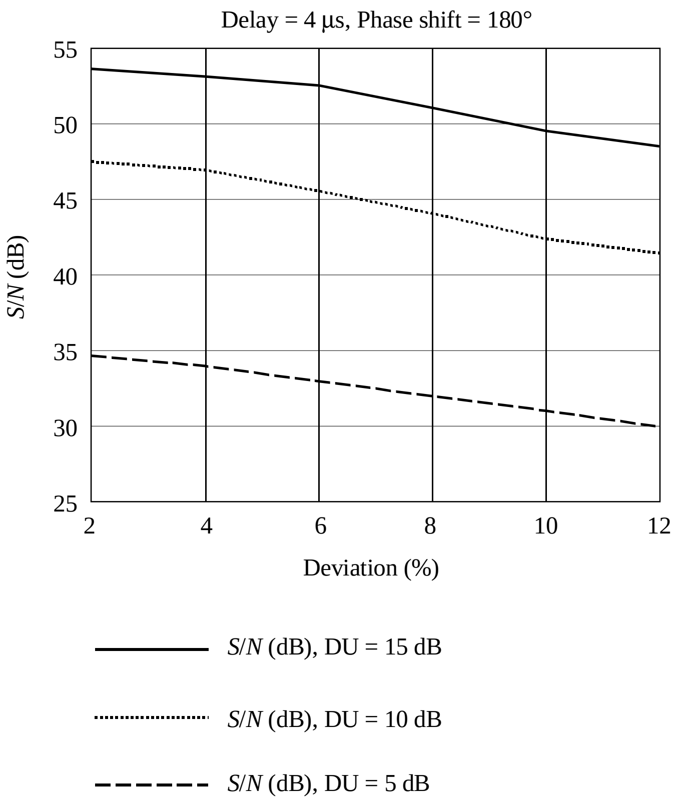


Figure 6 shows the audio S/N with a phase shift of 180º as a function of the deviation. This was done for three different D/U values.

FIGURE 6

Audio *S*/*N* vs. deviation in multipath



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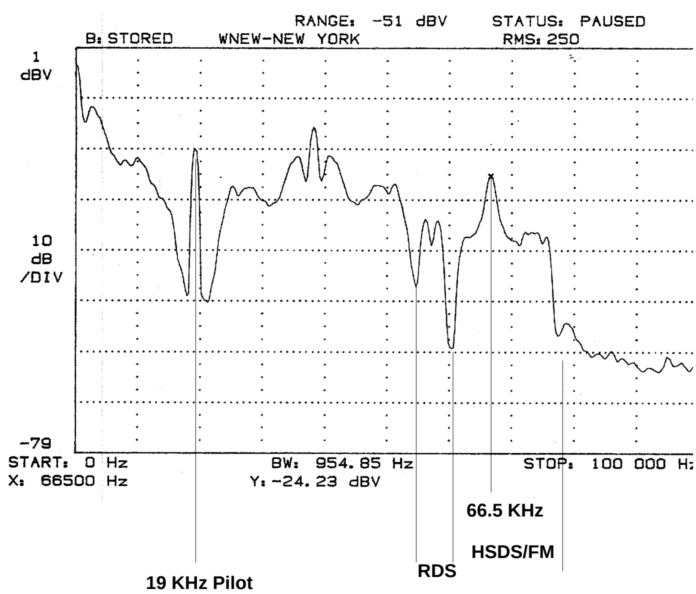
2.3 Compatibility with RDS (Recommendation ITU-R BS.643)

The chart in Figure 7 illustrates spectral compatibility with RDS.

FIGURE 7

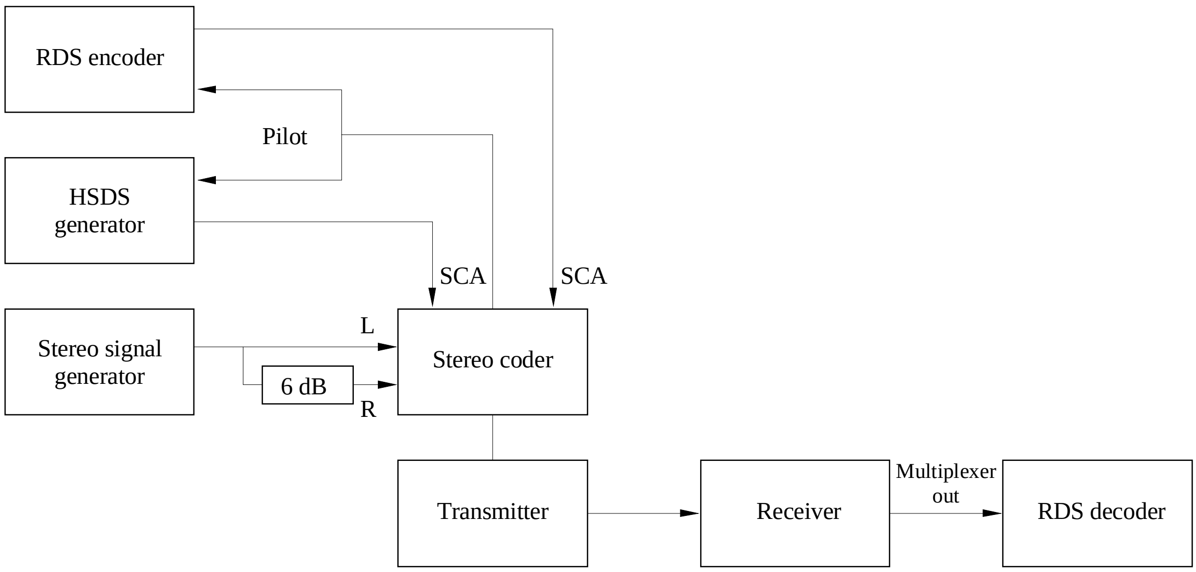
Compatibility with RDS (Recommendation ITU-R BS.643)



Lab tests showing the compatibility of HSDS with RDS are summarized below. Figure 8 illustrates the measuring system for a laboratory test on the HSDS compatibility with RDS. The transmitter was modulated with RDS, HSDS and coloured noise. A 6 dB attenuator caused an S-signal in the multiplex approximately 10 dB lower than the M-signal. The deviation was: audio 60 kHz, pilot 7.5 kHz and RDS 2 kHz. The multiplex output of the receiver was fed into the RDS decoder with a counter for the block error rate. The block error rate gives the percentages of fault blocks, during the preceding 100 blocks. Ten block error rates per measurement point were measured in a 20 second period and then averaged.

FIGURE 8

RDS compatibility laboratory constellation



SCA: subsidiary carrier adapter

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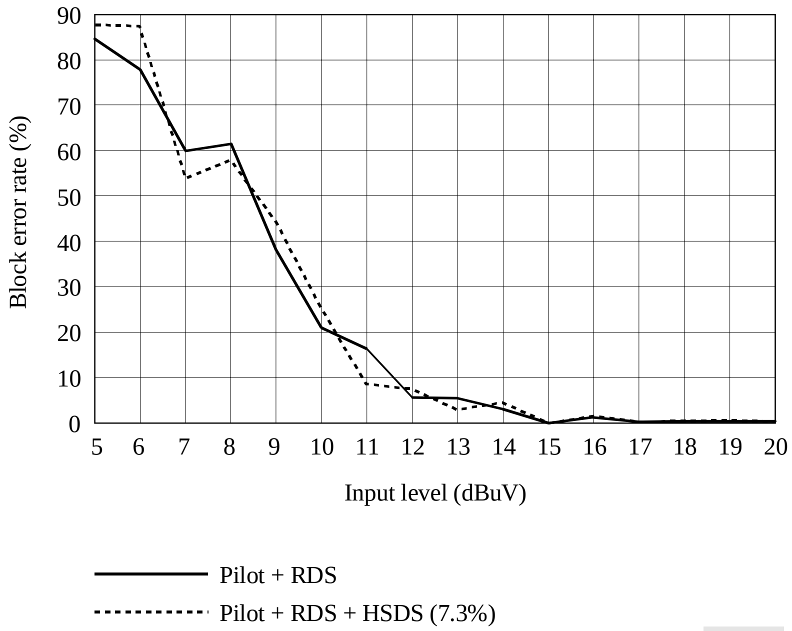
Figures 9 to 12 show the results of the test. The results show the influence of the HSDS deviation (5.5 kHz and 7.5 kHz) and the effect of the presence of the main audio channel. It can be seen that the HSDS system did not interfere with RDS.

FIGURE 9

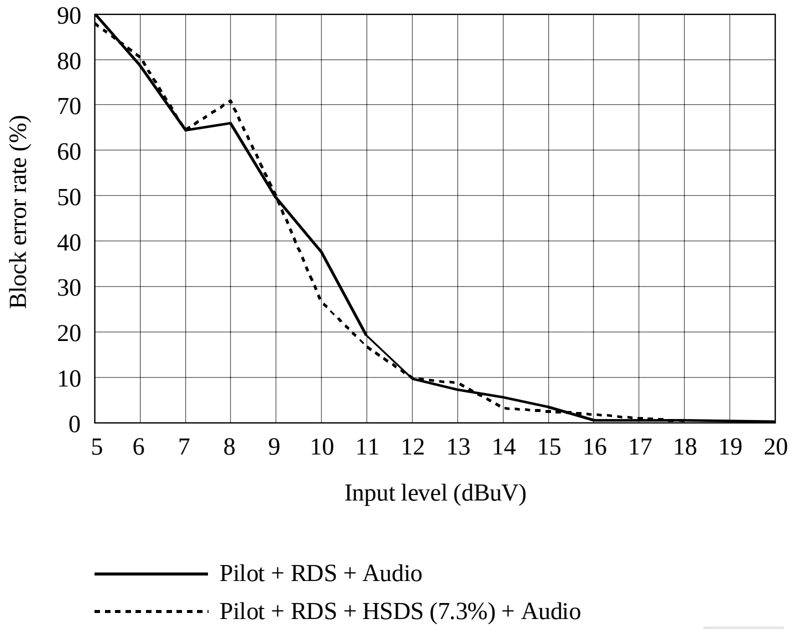
Interference HSDS on RDS



1350-09

FIGURE 10

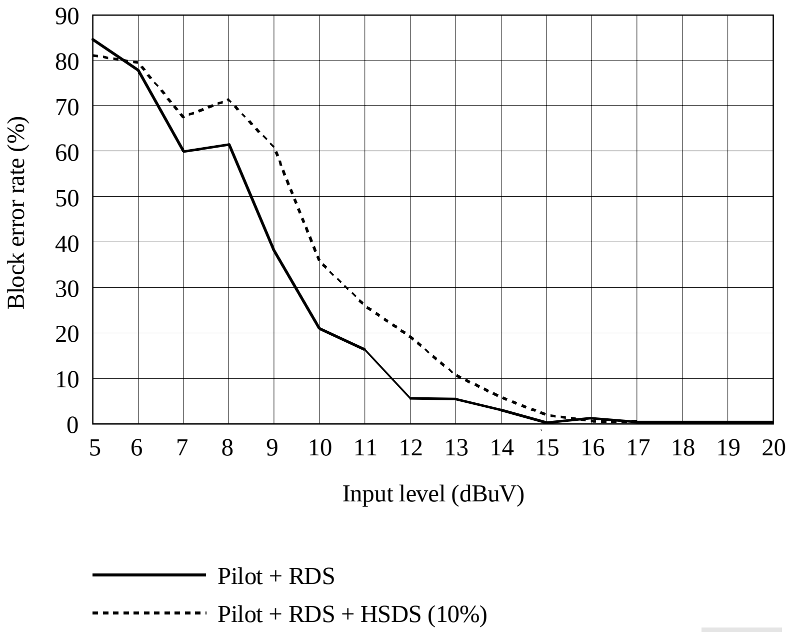
Interference HSDS on RDS



1350-10

FIGURE 11

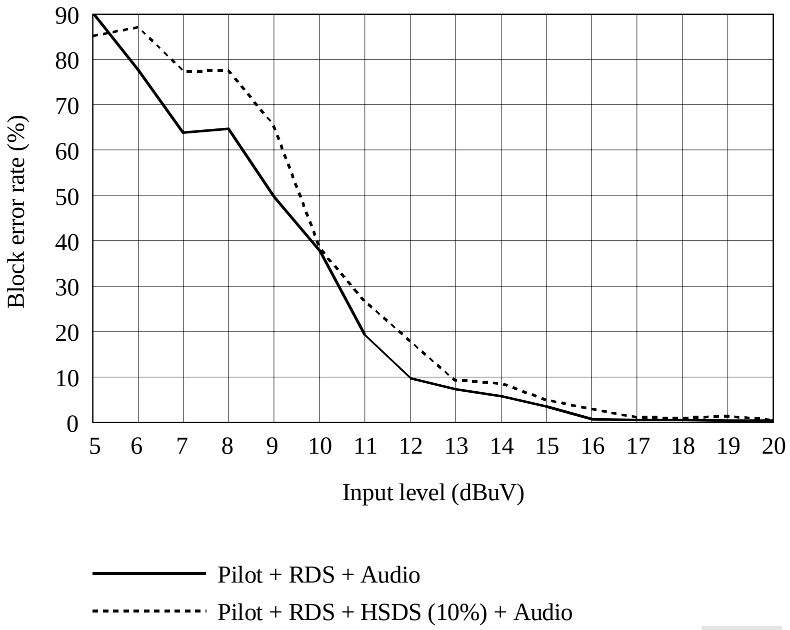
Interference HSDS on RDS



1350-11

FIGURE 12

Interference HSDS on RDS



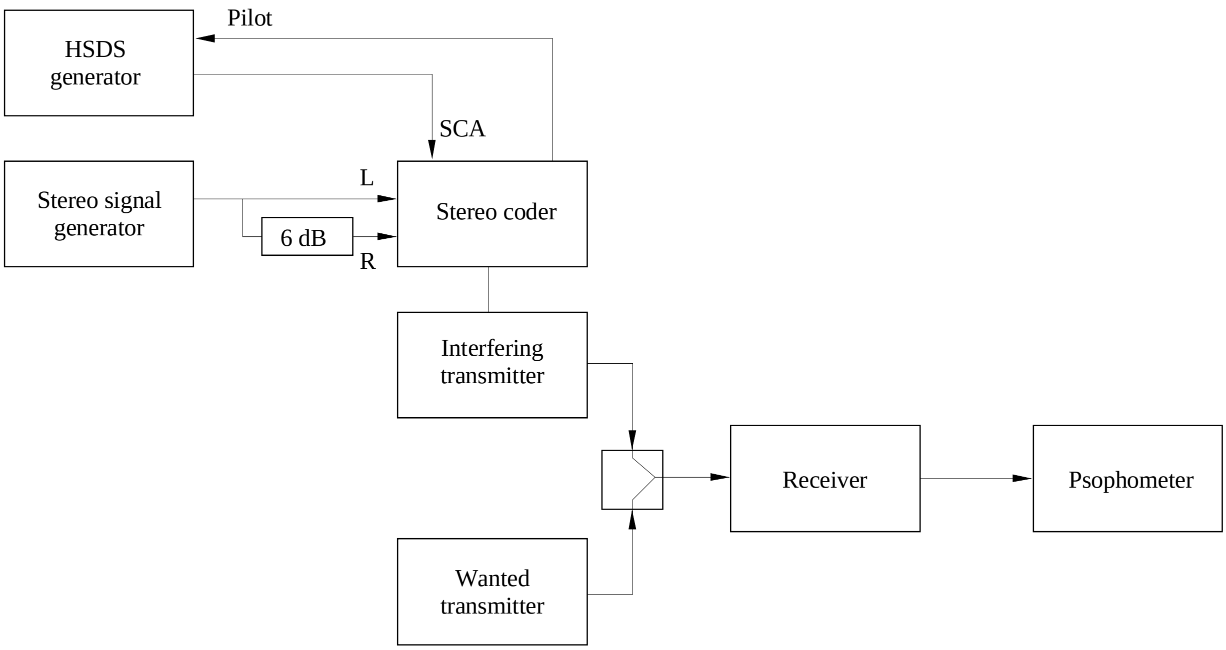
1350-12

2.4 Radio-frequency protection ratios

Laboratory tests showing the radio-frequency protection ratios are summarized below. The protection ratios for radio frequencies were calculated using stereophonic transmitters without limiters, in contrast to Recommendation ITU-R BS.641. The interfering signal is thus much stronger and leads to more stringent protection ratios. The conclusion drawn from the results of these tests is that the radio-frequency protection ratios were not influenced by the HSDS additional signal. Figure 13 illustrates the measuring system.

FIGURE 13

Frequency protection ratio test configuration



SCA: subsidiary carrier adapter

1350-13

The interfering transmitter was modulated with coloured noise (see Recommendation ITU-R BS.559) or with the HSDS signal. The interfering transmitter was operated in stereophonic mode, because this represents the actual broadcast situation. The frequency deviation of the interfering transmitter was adjusted using a 500 Hz sinusoidal tone causing a peak deviation of ± 19 kHz. This tone was then replaced with coloured noise having equal r.m.s. level at the input of the left-hand channel. The deviation of the wanted transmitter was adjusted using a 500 Hz sinusoidal tone which caused a peak deviation of ±40 kHz and was switched of during the tests. The deviation of the HSDS signal was set to 5.5 kHz, which is a practical value in the Dutch broadcast situation. The output level of the wanted transmitter was 57 dBμV. The first receiver used was a professional one from Studer (A764), the second receiver was a consumer product of Philips (FT9410). Figures 14 and 15 show the results of these tests. The conclusion drawn from the results of these tests is that HSDS does not influence the radio-frequency protection ratios.

FIGURE 14

Radio frequency protection ratio

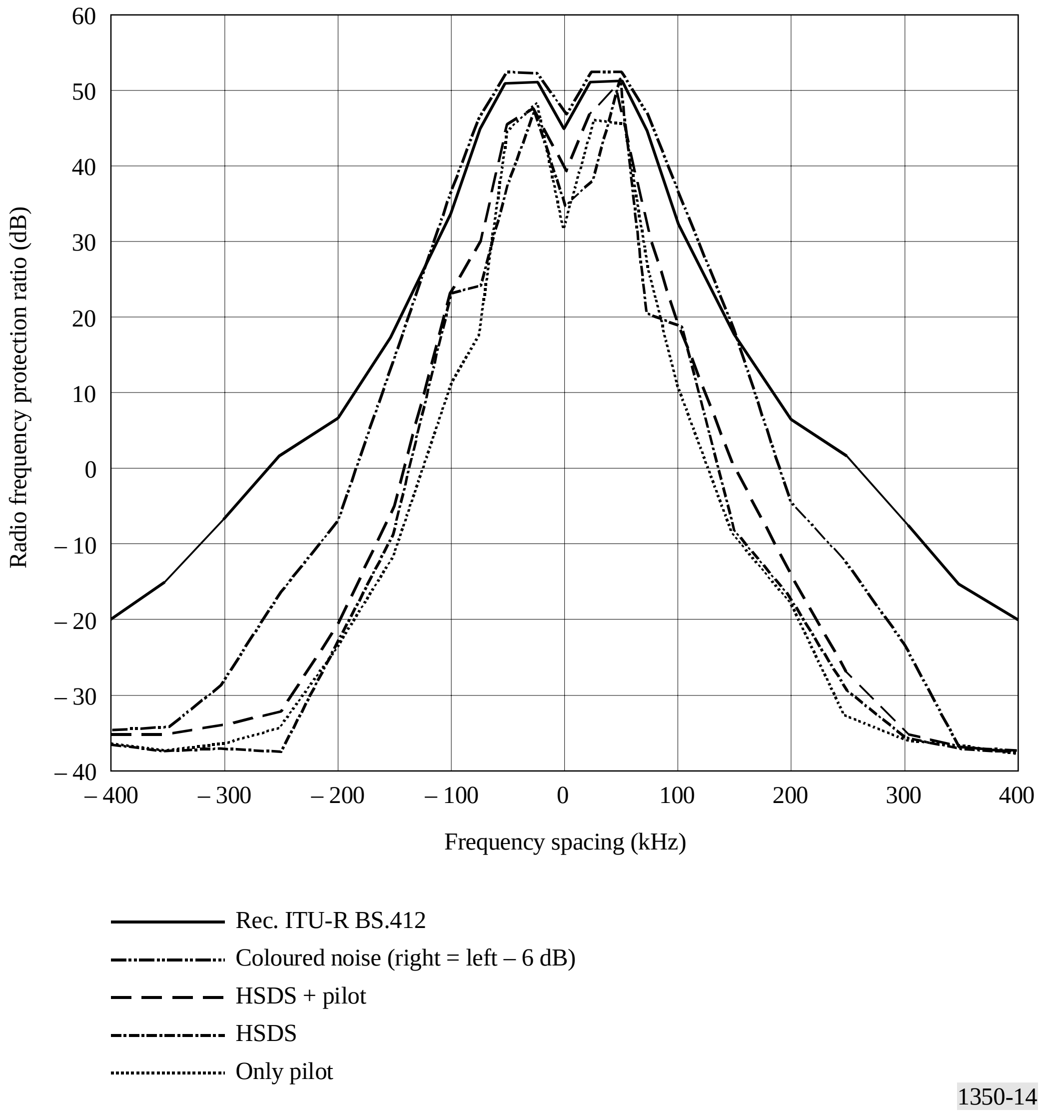
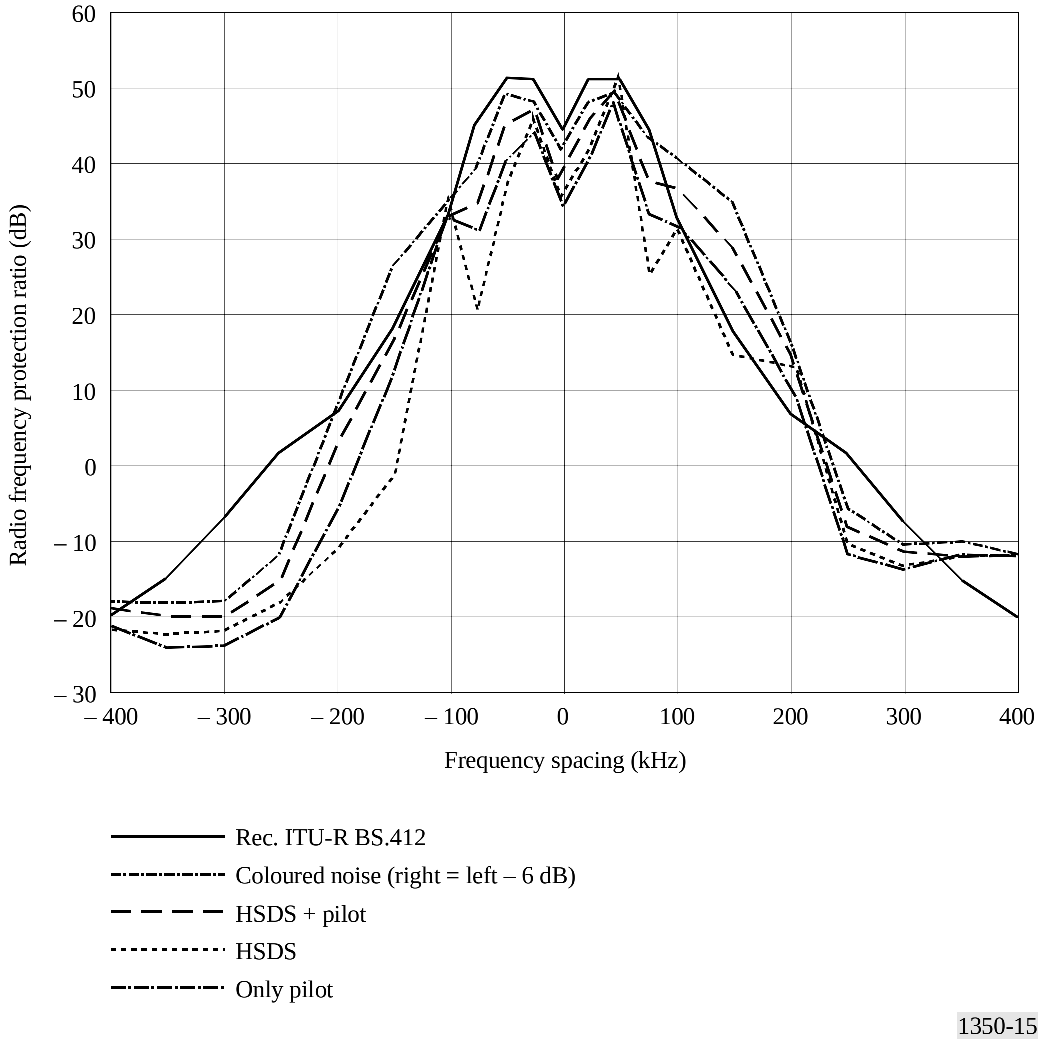


FIGURE 15

Radio frequency protection ratio



3 Link layer

The link layer incorporates the features required for a single transmitter data link to be reliable. These features include the frame and packet structure (size, word synchronization, error detection and correction).

3.1 Packet structure

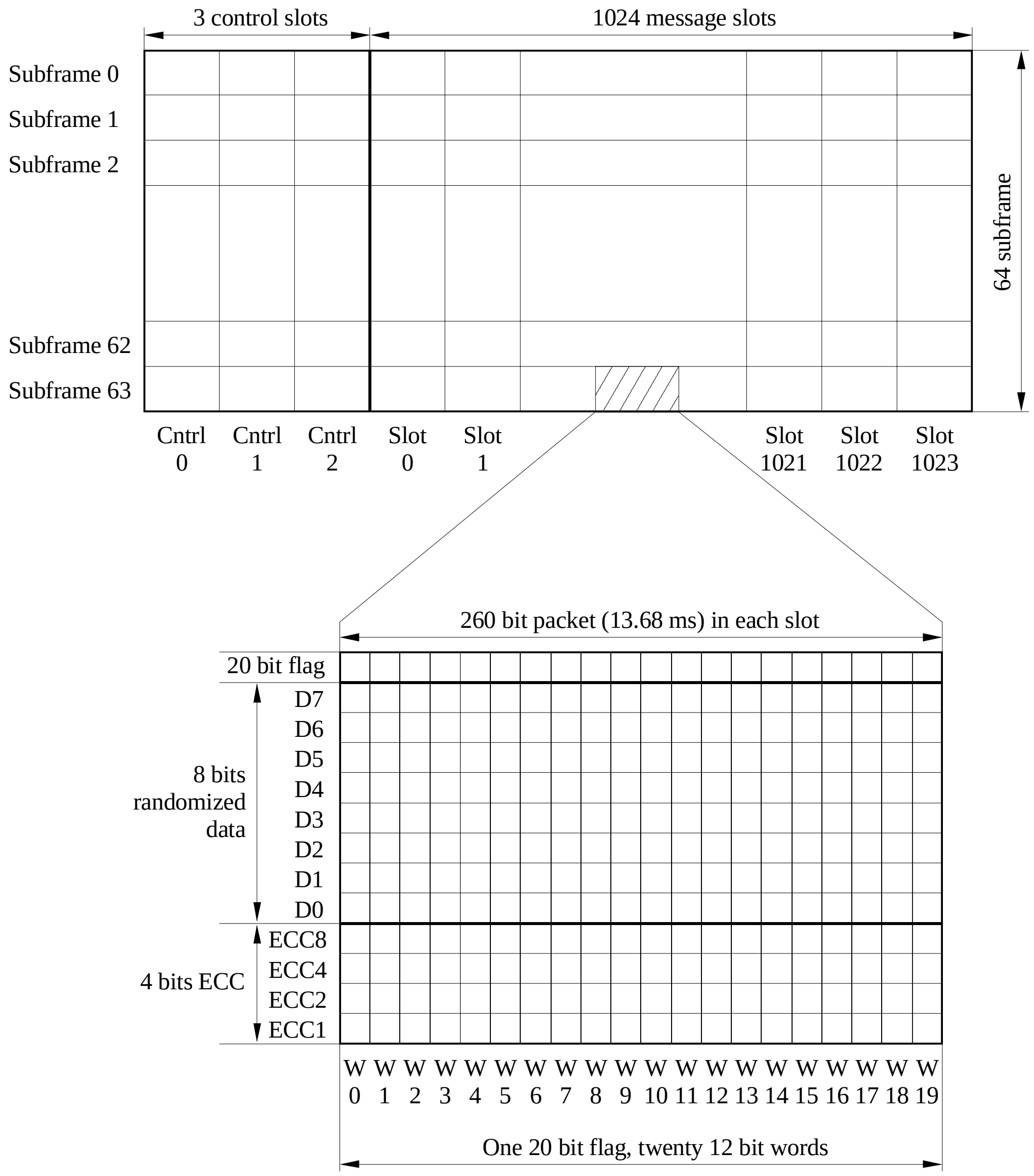
HSDS employs fixed-length data packets. Figure 16 illustrates the packet structure used in the HSDS Protocol. Each packet is 260 bits long. Packet format bits in each packet define the packet's structure. A typical packet consists of a word synchronization flag, Error Correction Code (ECC), information bits and error detection code.

Information bits from higher layers consist of 18 octets (8 bits per octet) per packet. A two octet ITU-T standard 16 bit Cyclic Redundancy Check (CRC) is generated from the 18 octets and appended to the packet, thus creating a 20 octet link data unit. The first octet (the incrementing slot number) of the 20 octet data unit is exclusive OR'ed with each of the remaining 19 octets thus creating pseudo-randomized data to minimize signal distortions due to multipath reception, etc.

Appended to each octet of randomized data is 4 bits of Hamming ECC. This error correction method provides single bit error detection and correction in 12 bits, or 8.3% correction capability, is reasonably efficient and provides for ease of decoding.

FIGURE 16

Frame and packet structure



1350-16

To increase burst error correction capability, data is interleaved providing immunity to 20 bit error bursts. Word synchronization is established by a 20 bit flag sequence at the beginning of the packet. Table 1 shows the steps performed by the link layer transmitter encoder and the reverse steps performed by the receiver decoder.

Double error correction on a stream of packets (small blocks) is under test for applications having less severe power constraints and with requirements for higher data reliability.

TABLE 1

Packet structure encode and decode steps

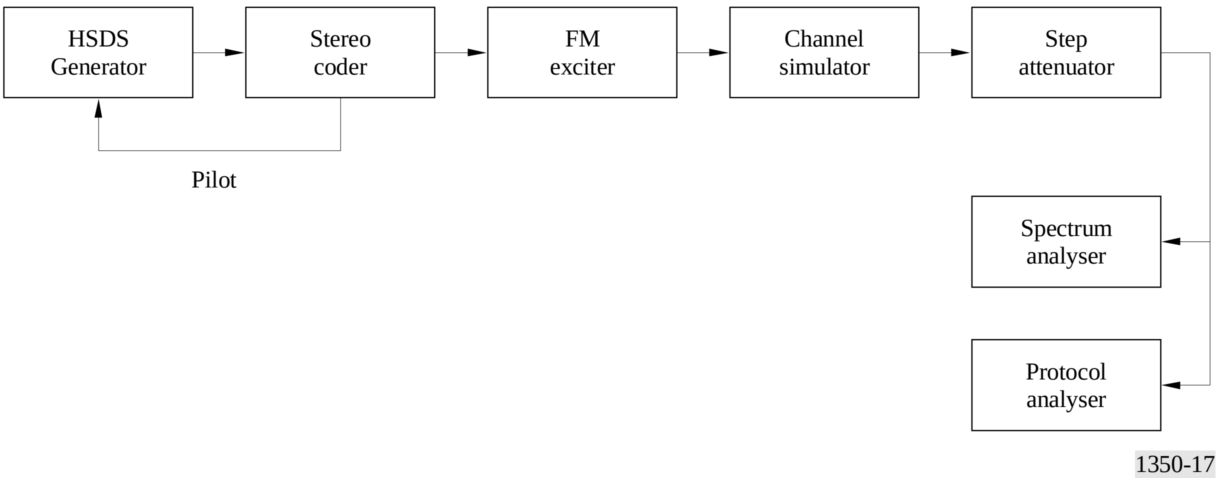
Step	Transmit encoder	Receive decoder
1	Compute and add CRC	Find flag
2	Randomize data	De-interleave data
3	Add error correction	Apply error correction
4	Interleave data	De-randomize data
5	Add flag	Compute and compare CRC

3.2 Bit error rate performance

The Bit Error Rate (BER) performance under faded and unfaded conditions was evaluated using the test configuration illustrated in Figure 17. During the tests the main carrier was without audio modulation.

FIGURE 17

BER laboratory test configuration



During the unfaded measurements the RF Channel Simulator (HP 11759C) was switched off. During the faded measurements a 4-tap Rayleigh channel was used, simulating a vehicle speed of 80 km/h. The tap settings are shown in Table 2 and are representative of the conditions observed whilst driving through rural Holland.

TABLE 2

RF channel simulator tap settings

Tap number	Tap delay (µs)	Tap attenuation (dB)
1	0	0
2	0.15	6
3	0.50	7
4	3.35	15

Figure 18 shows the unfaded BER of the HSDS system as a function of the signal input level for deviations of 5.5 kHz and 7.5 kHz. Figure 19 shows this under faded conditions, with averaging.

3.3 Packet completion rate performance

Because of the statistical spread of bit errors, data packets are affected with varying impact. These affected packets may still be recoverable using packet level error recovery. The packet structure is described before and Packet Completion Rate (PCR) is a measure of the success of the recovery of the transport data in the presence of bit errors.

The PCR performance of the HSDS system as a function of the signal input level under unfaded and faded conditions was evaluated using the same test configuration as illustrated in Figure 17. Figure 20 shows the unfaded PCR for deviations of 5.5 kHz and 7.5 kHz, Figure 21 shows this under faded conditions.

FIGURE 18

Unfaded BER performance

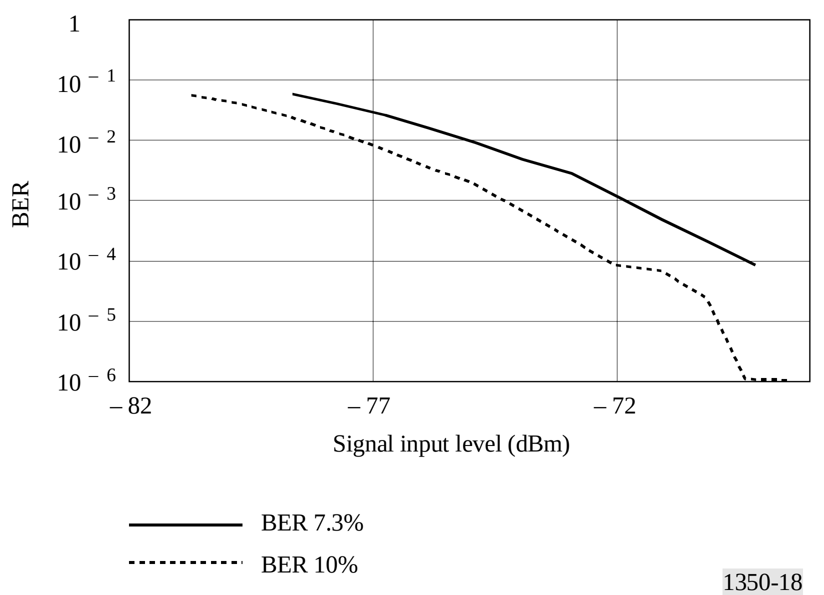


FIGURE 19

Faded BER performance

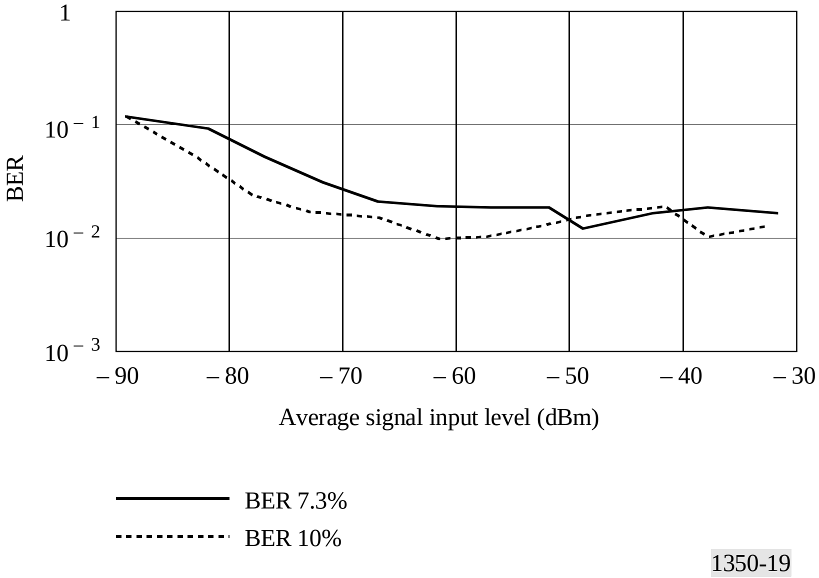


FIGURE 20

Unfaded packet completion rate

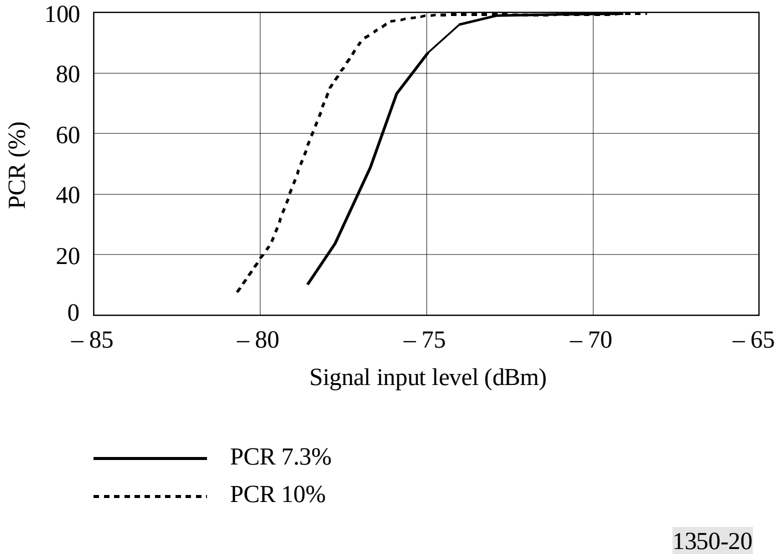
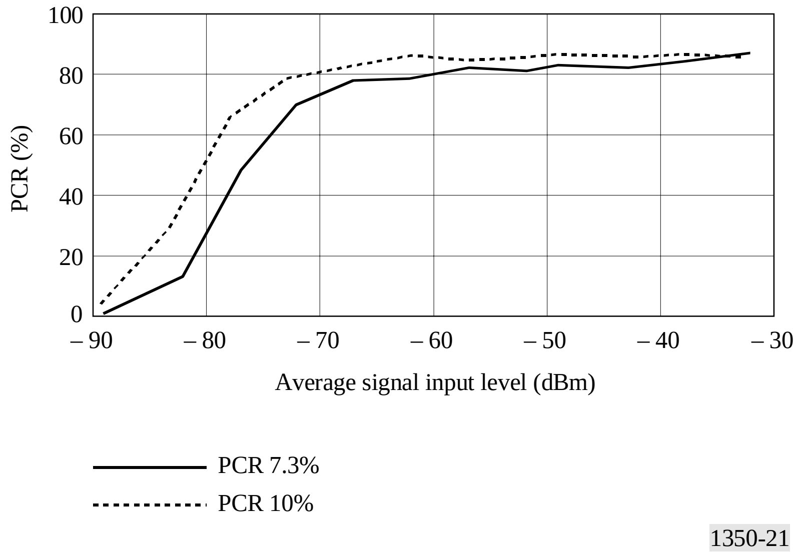


FIGURE 21

Faded packet completion rate

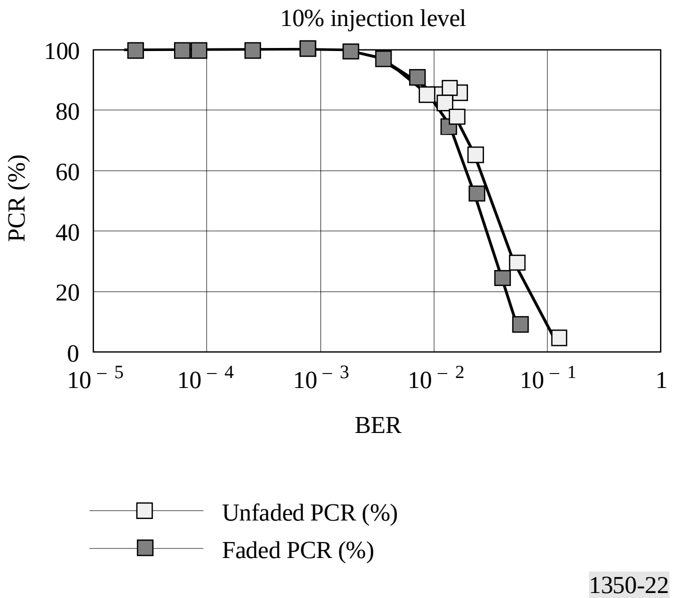


Combining the results from Figures 18, 19, 20 and 21 leads to an illustration of the PCR versus the BER which shows that the PCR remains within acceptable limits as the BER increases. Under the test conditions the PCR in Figure 21 never reached 100% and the BER in Figure 19 never exceeded 10^{-2}. This is illustrated in the PCR-curve below.

Figure 22 shows the results for a deviation of 7.5 kHz under unfaded and faded conditions. Under unfaded conditions the PCR and BER change with every step of the signal input level. Under faded conditions the performance stays longer around a certain point before it drops.

FIGURE 22

Bit error rate versus packet completion rate



3.4 Message completion rate performance

Repeated reception of the same original data packet can result in a higher data quality. If the receiver can receive packets from different transmitters, each with different propagation paths, then the receiver may receive messages even if some packets get lost. The HSDS receiver has the ability to switch between “k” time-shifted transmitters, each repeating the same packets “n” times.

The Message Completion Rate (MCR) is calculated by the formula:

$$MCR = 1 - [(1\text{-}PCR_1)^n * (1\text{-}PCR_2)^n * ... * (1\text{-}PCR_k)^n]$$

Because only one HSDS generator was available, the laboratory test configuration of Figure 23 was used. Two real time signals of local transmitters, each having an individual PCR of 100%, were received using two Studer FM receivers. The first receiver was set to receive a 96.8 MHz signal, heavily modulated by a pop station. The second receiver was set to receive a 92.6 MHz signal, lightly modulated with light music and additional information. These multiplex signals (including audio, RDS and HSDS) were modulated again and fed to the RF Channel Simulator.

FIGURE 23

MCR laboratory test configuration

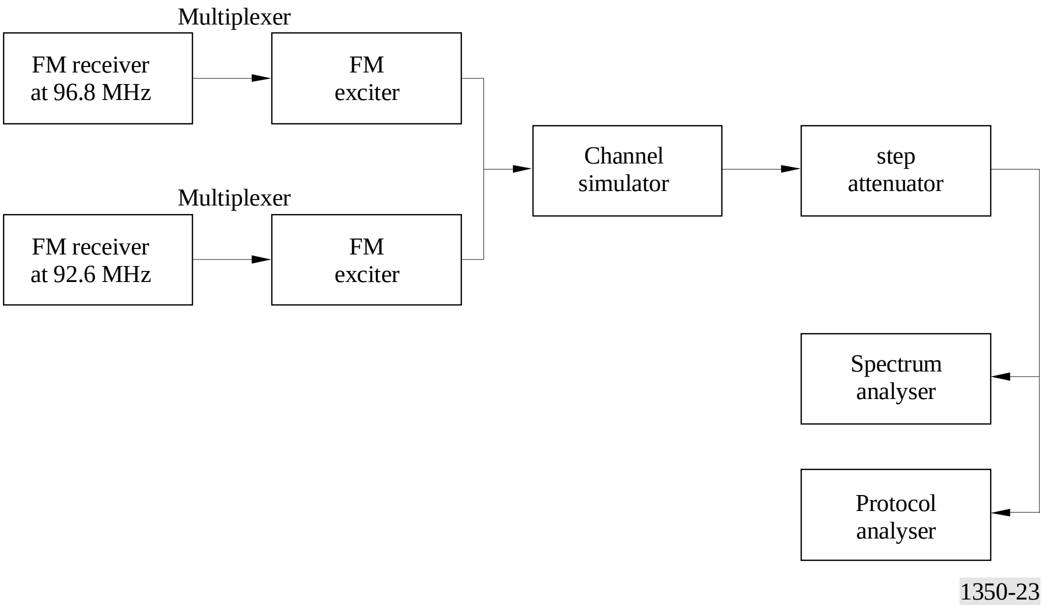


Figure 24 shows a screen dump of the HSDS protocol analyser. For the two transmitters the PCR and BER are shown under faded conditions for a deviation of 7.5 kHz.

The MCR was calculated. Figure 25 shows a snapshot of more than 100 seconds of the MCR under faded conditions, receiving signals from the two transmitters.

It is clear that even with quite poor average transmitter performance, an acceptable combined MCR is achieved.

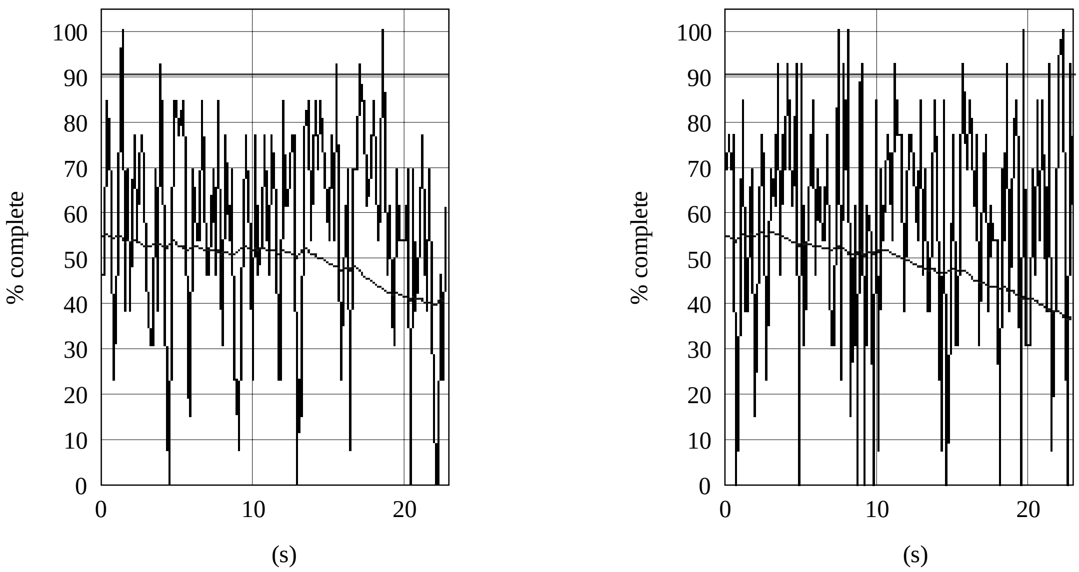
3.5 Frame structure

HSDS uses a packet oriented Time Division Multiplexed (TDM) scheme. The top section of Figure 16 illustrates the relationship between the timeslots and subframes. The largest structure used by the protocol is a master frame. Each master frame contains 64 subframes. Each subframe is divided into 1027 units called time slots. Each timeslot contains a data packet. The first three timeslots in each subframe are Control Slots and the remaining 1 024 are data timeslots. Control Slot packets carry the time of day, date, and lists of nearby related transmitters also carrying HSDS. Data timeslot packets typically include a slot number, receiver address, data format, packet format and the message data.

The pilot signal is used as the data clock. The frame structure provides for inaccuracy of the pilot signal through anticipation of bit padding. Since the stereo pilot frequency may not be exactly 19 kHz at the time of transmission, a single bit may be added (pad bit) between packets as required to maintain synchronization. This occasional addition of a pad bit ensures proper synchronization between transmitters and the receiver.

FIGURE 24

Message completion rate using HSDS protocol analyser



CRC:	5 436
ECC:	76 264
BER:	0.031381
MCR:	0.998081
PCR:	54.9
Flag:	203
RF input:	– 75.5 dBm
Pilot phase:	67.8°
Sub carrier injection level:	7.9%
Frequency:	95.2 test 2
Attenuator:	0 dB

CRC:	6 097
ECC:	86 942
BER:	0.033651
MCR:	0.998081
PCR:	54.8
Flag:	167
RF input:	– 73 dBm
Pilot phase:	85°
Sub carrier injection level:	7.1%
Frequency:	98.2 test 1
Attenuator:	0 dB

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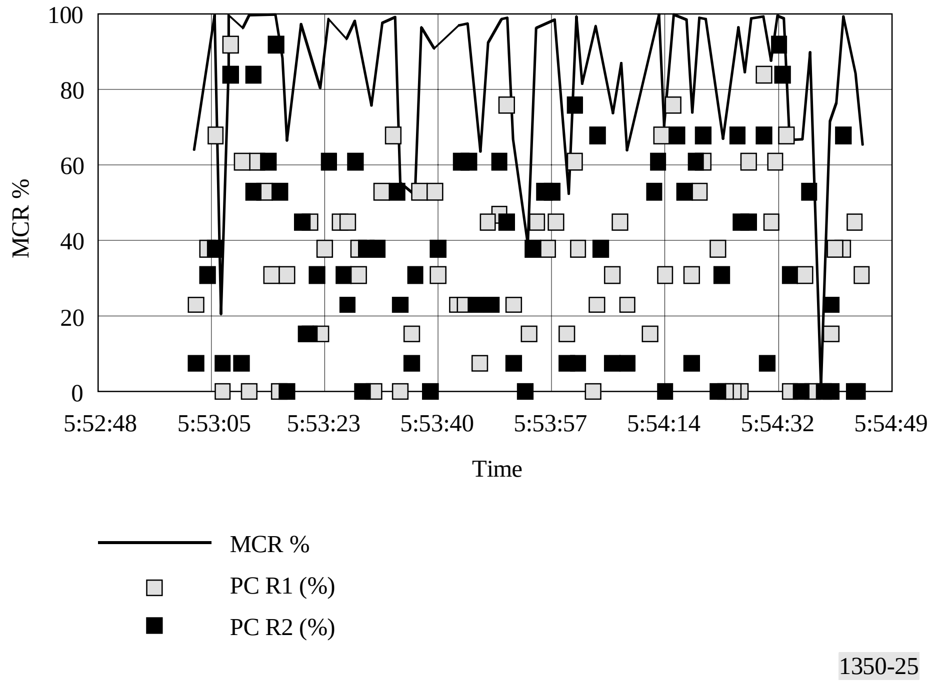
FIGURE 25

Faded message completion rate



4 Network layer

The network layer includes features required to make a number of individual transmitters act as a single system. This includes:

– receiver addresses;

– application multiplexing;

– alternative frequency lists;

– transmitter time offsets;

– time synchronization between transmitters.

4.1 Multiple transmitters

When multiple transmitter networks are required, master frames are synchronized and begin at the start of each quarter hour (plus an individual transmitter's time offset). The synchronized and time offset transmitters provide an opportunity for the receiver to change the tuned frequency and make subsequent packet reception attempts on the alternative frequencies with no loss of data synchronization.

4.2 System reliability

While extensive error correction techniques are useful for a moving receiver, they become ineffective when the receiver is stopped in an extremely low signal strength area or is moving very slowly through multipath nulls. HSDS addresses multipath and shielding effects with a combination of frequency, space and time diversity and, in the case of paging, message numbering.

5 Applications

HSDS implements up to 64 asynchronously multiplexed logical channels at the transport layer. The channels include 3 link packet types: Data Gram Packets, Data Stream Packets and Data Block Packets.

Data Gram Packets are stand alone packets consisting of 15 bytes of transport data. Data Gram Packets can be delivered in non-sequential order.

Data Streams are continuous streams of transparent data. Any segmentation of transport data is performed at a higher layer in this packet type. There are no transport level indications of the beginning or end of Data Stream Packets at the transport level. Order information is included in Data Stream Packets so that they may be interleaved with other data packets on the same channel. (Up to 128 Data Stream Packets may be delivered in a non-sequential order on a single logical channel, at any one time.) Data Stream Packets may include repeats of the same Data Stream Packet for enhanced reliability.

Data Block Packets provide the capability to send between 1 and 768 bytes of transparent transport data. Transport messages are broken down into multiple data blocks. Each data block is broken into multiple Data Block Packets. Each Data Block Packet carries up to 12 bytes of transport data. Up to 32 Data Block Packets may be delivered in a non-sequential order on a single logical channel, at any one time. Data Block Packets may be interleaved with other data packets on the same channel or other logical channels. At any one time on a single logical channel, up to 32 Data Block Packets may be delivered in a non-sequential order. Data Block Packets may include repeats of the same Data Block Packet for enhanced reliability.

APPENDIX 3

System description: System C

1 Introduction

The Sub-carrier Transmission Information Channel (STIC) system was developed for the United States Department of Transportation in support of its Intelligent Transportation System (ITS) activities. The system has been optimized for use in broadcasting ITS data to vehicular receivers. It uses a version of DQPSK modulation on a 72.2 kHz sub-carrier with a symbol rate of 9 025 symbols per second (18 050 bits per second). A concatenated Forward Error Correction (FEC) coding approach is used which incorporates convolutional coding with Viterbi decoding, Reed-Solomon coding and two interleavers. Modulation and coding parameters are summarized in Table 3.

Because of the powerful concatenated code, this system exhibits robustness in multipath reception conditions and noise, especially for long messages. The system provides a net throughput of 7 600 bits per second, plus some capacity for short delay data, depending on the frame structure selected. (This short delay data path is intended for Differential GPS (DGPS) and/or other high priority messages of an emergency nature).

The system is compatible with RDS as well as with the main stereo channel. The system is compatible with, but does not explicitly include, conditional access and receiver addressability features.

The ability to support multiple service providers is made possible by the packet structure defined for the system. Because of the long packets used, service provider identification is highly efficient in terms of the data rate capacity. Packet headers of 4 bytes in length will allow receiver addressability with a large address space (32 bits) for specifying various networks, service providers and packet formats, while utilizing only 1.75% of the 7 600 bit/s transmission capacity.

Further information on this system, including BER performance in the presence of Gaussian noise or multipath fading and also the message error rate, can be obtained from Document 10B/57 (1995). Enhancements to the system are planned which will provide power saving features and options for higher data rate operation.

TABLE 3

Summary of STIC design characteristics

Characteristic		Description
1	Modulation	π/4 shifted DQPSK
2	Baseband centre frequency	72.2 kHz
3	Baseband frequency spectrum	See spectrum analyser plot
4	Sub-carrier injection levels	Nominally ± 7.5 kHz
5	Sub-carrier channel symbol rate	9 025 symbols per second
6	Word synchronization	See frame structure
7	Error correction/detection	Reed-Solomon and convolutional coding with soft decision Viterbi decoding
8	Delay	Variable depending on interleaver depth and frame size
9	Information bit rate	7.6 kbit/s plus short delay data

2 Transmit end processing

The STIC system provides two data paths: a main data path and a data path reserved for short delay data. The main data path has four optional interleaver depths which correspond to four superframe durations: 46.08, 23.04, 11.52 and 5.76 seconds. These options allow trade-offs between system delay and system robustness in slow fading conditions.

From the point of view of the signals at the transmitter, the following processes are carried out for the main data path:

- An input data rate of 7 600 bit/s is assumed, and considered to be a continuous data stream based on one 228-byte data packet every 240 ms. Each byte consists of 8 bits.
- The message is block encoded using a (243, 228) shortened Reed Solomon 256-ary code.
- The Reed Solomon coded message is block interleaved by writing 8-bit bytes to a memory with 243 rows and 6 columns. Each cell in the memory contains one 8-bit byte and the message is written by columns and read by rows.
- The block interleaved message is convolutional encoded using a rate 1/2, constraint length 7 code with generator polynomial coefficients 554 and 744 (octal). The coder runs continuously without flushing.
- The encoded message is interleaved using a convolutional interleaver with 72 different paths. Each path has a different length shift register with an integer multiple of “J” stages as given in Table 4. Each stage represents one bit. The first path has 71*J stages, the second path has 70*J stages, ... , and the last path has zero stages. The switch arm changes once for each input bit and at the same time, the bits in the shift registers in that path shift one bit.
- The interleaved message is exclusive-OR'ed with a repeating Pseudo-Noise (PN) random pattern. The length of the PN pattern is given in Table 4. The PN pattern is synchronized to the interleaving and to the superframe. This process is called covering.
- The covered message is divided into subframes, frames and superframes. There are 72 data bits per subframe. The number of subframes per frame is given in Table 4. There are 72 frames per superframe. Framing is synchronized with the interleaver so that the first bit in a subframe comes from the first path in the convolutional interleaver. Four bits are appended as a suffix to each subframe to make each subframe 76 bits long. These four additional bits are called channel state bits.

- Each frame is provided with a 76-bit synchronization subframe as a prefix. This synchronization subframe consists of a 56-bit “correlation word”, a 15-bit frame identification word plus one unused bit and 4 channel state bits. The 56-bit correlation word is the same for every frame. The 15-bit frame identification word is the encoded frame number using a Bose, Chaudhuri and Hocquenghem (BCH) (15, 7) code. There is always one synchronization subframe per frame.

- Some subframes are reserved for the short delay data path. The number of subframes reserved in this way depends on the interleaver/superframe option as shown in Table 4. The number of total subframes per frame is also given in Table 4. There are always 72 frames per superframe.

- The formatted message is modulated on a 72.2 kHz sub-carrier using π/4 shifted Differential Quadrature Phase Shift Keying (DQPSK). The transmitted symbol rate is 9 025 symbols per second.

- The modulated signal is filtered using Square Root Raised Cosine (SRRC) filtering with a roll-off factor of 0.684. This results in a nominal bandwidth of 15.2 kHz (from 64.6 kHz to 79.8 kHz baseband).

Short delay subframes are provided to allow the transmission of data which must be processed quickly for applications which cannot tolerate the delay associated with interleaving. These subframes contain 76 bits and are multiplexed prior to covering as shown in Figure 1. The data rate available in the short delay data path is shown in Table 4.

The process described above produces the sub-carrier waveform that is frequency division multiplexed with the other signals prior to FM modulation at the broadcast transmitter. An injection level (in terms of the peak amplitude of the sub-carrier) of ±7.5 kHz is envisioned as typical. Other injection levels are possible with trade-offs in terms of Bit Error Rate (BER) performance and the performance of other sub-carriers sharing the transmission.

TABLE 4

Interleaver and framing options

Superframe duration (seconds)	5.76	11.52	23.04	46.08
Data packets per superframe	24	48	96	192
convolutional interleaver, “J” =	18	36	72	144
# stages in m-sequence	17	18	19	20
# bits from m-sequence	93 312	186 624	3 73 248	746 496
total subframes per frame	19	38	76	152
Short delay subframes per frame	0	1	3	7
Short delay data rate (bit/s)	0	475	712.5	831.25
synchronization subframes per frame	1	1	1	1
data subframes per frame	18	36	72	144

FIGURE 26

Example frame structure

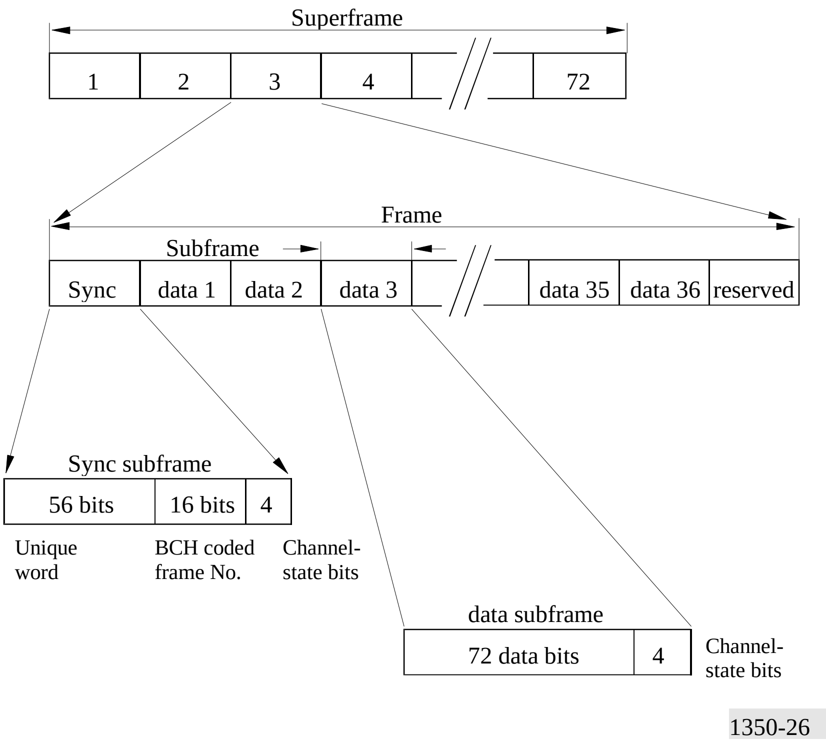


Figure 26 shows an example frame for the case of the 11.52-second superframe. The channel state bits are used for soft decision decoding. The inner convolutional code makes use of these bits by correlating with the known sequence and estimating the quality of the channel. This quality estimate helps in the Viterbi algorithm decoding process.

NOTE – Certain features of the STIC waveform and system are protected under United States patent law (United States Patent No. 5 442 646). The STIC system has been, and will be, licensed to interested users.

The Reed Solomon Code used for the STIC system is capable of correcting as many as 7-symbol errors but can also detect all 8-symbol errors. This feature is used in place of a Cyclic Redundancy Code (CRC) to reliably determine whether a packet has been received correctly.

Figure 27 shows a spectrum analyzer plot of the FM baseband from 50 kHz to 100 kHz. The baseband spectrum in this plot includes a 57 kHz RDS signal, the 72.2 kHz STIC signal injected at ±7.5 kHz and a 92 kHz analogue sub-carrier. The 50 dB attenuation at 64 and 81 kHz, is adequate to ensure that the STIC waveform does not impinge on the adjacent 57 kHz RDS or the 92 kHz sub-carriers.

3 Quantitative audio interference tests (same channel)

This test measured the degradation in stereo audio performance when the STIC sub-carrier is introduced. The results of this test are summarized in Table 5. Measurements were accomplished using a 15 kHz Low Pass Filter (LPF) as well as a Psophometric weighted filter. The results show that a degradation of approximately 1 dB would be perceived. This level of degradation is not objectionable as was validated by the qualitative test.

FIGURE 27

STIC spectral characteristics

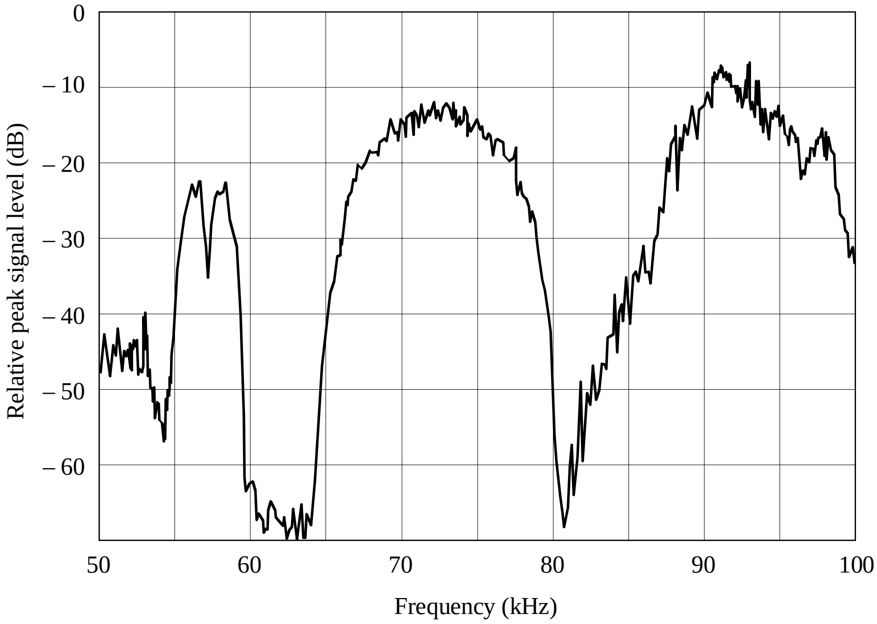


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TABLE 5

STIC effects on main channel

	Psophometric Filter	15 kHz LPF
Active Signals	SINAD (dB)	SINAD (dB)
1 kHz Tone	42.15	59.73
1 kHz Tone + STIC	41.02	55.01

4 Effect of RDS on STIC error rate performance

STIC channel error rate measurements were made with the RDS sub-carrier both on and off. The results are shown in Figure 28. This result indicates that the degradation due to RDS is insignificant.

5 Radio-frequency protection ratios

The STIC system performs well in terms of protection ratios, as shown in Figures 29 and 30. Protection Ratio performance for monophonic reception is shown in Figure 29 using an Alpine model 7502 car radio receiver.

FIGURE 28

Error degradation due to RDS

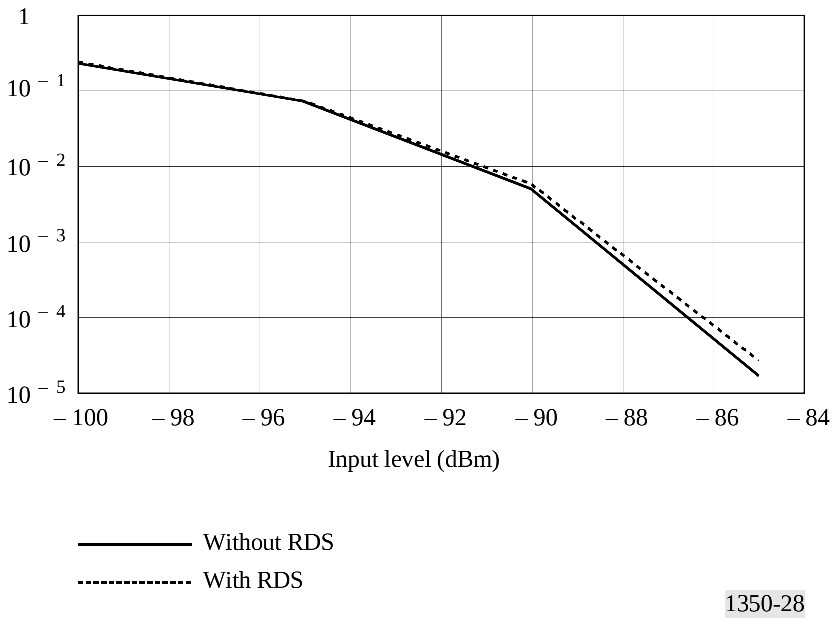
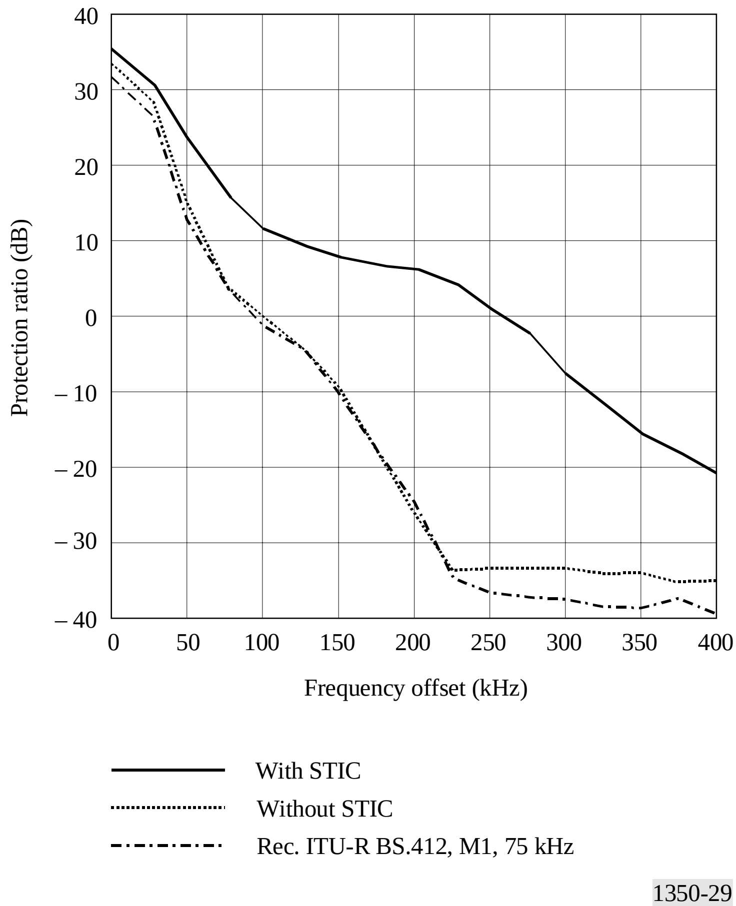


FIGURE 29

Protection ratios for main channel



The STIC system is also robust in the presence of alternate channel interference. Figure 30 shows protection ratios for the case of an alternate channel interfering with the STIC transmission at a 1% uncorrected channel error rate.

FIGURE 30

Protection ratios for STIC sub-carrier