RECOMMENDATION ITU-R BS.1547

Terrestrial component of systems for hybrid satellite-terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 1 400-2 700 MHz

(Question ITU-R 107/10)

(2001)

The ITU Radiocommunication Assembly,

considering

a) that there is an increasing interest worldwide for terrestrial and satellite digital sound broadcasting (DSB) to vehicular, portable and fixed receivers in the frequency range 30-3 000 MHz for local, regional and national coverage;

b) that the ITU-R has already adopted Recommendations ITU-R BS.774 and ITU-R BO.789 to indicate the necessary requirements for DSB systems to vehicular, portable and fixed receivers for terrestrial and satellite delivery, respectively;

c) that by operating the broadcasting-satellite service (BSS) (sound) in an hybrid configuration the service objectives listed in b) above can be more adequately met;

d) that Recommendations ITU-R BS.774 and ITU-R BO.789 recognize the benefits of complementary use of terrestrial and satellite systems, and call for a DSB system allowing a common receiver with common processing very large scale integration (VLSI) circuits and manufacturing of low-cost receivers through mass production;

e) that Digital System D_H described in Annex 2 meets most or all of the requirements of Recommendations ITU-R BS.774 and ITU-R BO.789, and that the system has been field tested and demonstrated in more than one country;

f) that Digital System E described in Annex 3, meets most or all of the requirements of Recommendations ITU-R BS.774 and ITU-R BO.789, and that it has been field tested;

g) that some systems included in Recommendation ITU-R BO.1130 have a terrestrial component which allows augmentation of the BSS (sound) part, hence creating a hybrid satellite/terrestrial system;

h) that at the 7th World Conference of Broadcasting Unions (Mexico, 27-30 April 1992), the World Broadcasting Unions unanimously resolved (literal quote):

"1. that efforts should be made to agree on a unique worldwide standard for DAB and

2. to urge administrations to give consideration to the benefits for the consumer of common source and channel coding and implementation of Digital Sound Broadcasting on a worldwide basis at 1.5 GHz";

j) that the World Administrative Radio Conference (Malaga-Torremolinos, 1992) (WARC-92) allocated the band 1 452-1 492 MHz to the BSS (sound) and complementary terrestrial broadcasting service for the provision of DSB. Also, additional footnote allocations were included for specific countries in the band 2 310-2 360 MHz and in the band 2 535-2 655 MHz in Radio Regulations (RR) Nos. 5.393 and 5.418,

noting

a) that a summary of the digital systems that allow hybrid operation is presented in Annex 1;

b) that condensed system descriptions for Digital System D_H and E are given in Annexes 2 and 3;

c) that complete systems descriptions of Digital System D_H and E are contained in the DSB Handbook,

recommends

1 that administrations that wish to implement hybrid satellite/terrestrial DSB services meeting most or all of the requirements as stated in Recommendation ITU-R BS.774 should consider either of the two Digital Systems, D_H or E, using Table 1 to evaluate their respective merits. (see Note 1). This should be done in conjunction with the consideration of Recommendation ITU-R BO.1130 for the satellite portion in view of the selection of an overall hybrid BSS (sound) system.

NOTE 1 – Technology in this area is developing rapidly. Accordingly, if additional systems meeting the requirements given in Recommendation ITU-R BS.774 are developed, they may also be recommended for use when brought to the attention of the ITU-R. Administrations engaged in the development of DSB systems should make efforts to bring about, as much as possible, harmonization with other systems already developed or currently under development.

TABLE 1

Performance of Digital Systems D_H and E evaluated on the basis of the recommended technical and operating characteristics listed in Recommendation ITU-R BS.774

Characteristics from Recommendation ITU-R BS.774 (condensed wording)	Digital System D_H	Digital System E
1. Range of audio quality and types of reception	Range is from 16 kbit/s to 128 kbit/s per audio channel in increments of 16 kbit/s. Each 16 kbit/s increment can be split into two 8 kbit/s services. MPEG-2 and MPEG-2.5 Layer III audio coding are used. The system is intended for vehicular, portable and fixed reception	Range is from 16 kbit/s to 320 kbit/s per audio channel in any increment size. MPEG-2 AAC audio coding is used. The system is intended for vehicular, portable and fixed reception

TABLE 1 (*continued*)

Characteristics from Recommendation ITU-R BS.774 (condensed wording)	Digital System D_H	Digital System E
2. Spectrum efficiency better than FM	FM stereo quality achievable in less than 200 kHz bandwidth; co-channel and adjacent channel protection requirements much less than that for FM. (QPSK modulation with concatenated block and convolution error correcting coding)	FM stereo quality achievable in less than 200 kHz bandwidth; co-channel and adjacent channel protection requirements much less than that for FM. (CDM based on QPSK modulation with concatenated block and convolutional error correcting coding)
3. Performance in multipath and shadowing environments	The system is a hybrid satellite/terrestrial system designed for diversity reception of a TDM signal via satellite complemented by a terrestrially retransmitted MCM signal. MCM is especially designed for multipath operation. It works by power summing the echoes falling within a given time interval	System is especially designed for multipath environment. It works on the basis of receiving power summation of multipath using a RAKE receiver. This feature allows the use of on-channel repeaters to cover shadowed areas. Also, more than 1 s blackout will be recovered using segmented convolutional bit wise interleaver
4. Common receiver signal processing for satellite and terrestrial broadcasting	Receivers are being developed for TDM-MCM reception in urban environments, including mobile applications. A TDM-MCM signal is radiated from terrestrial transmitters that repeat the satellite TDM. Circular polarization is used for satellite reception, vertical for terrestrial. External antennas are used for mobile	This system is based on the simultaneous reception from both satellite and complementary on-channel repeaters. Allows the use of the same receiver, from the RF front end to the audio and data output Adoption of MPEG-2 systems achieves maximum interoperability among the same kind of digital broadcasting receivers, e.g. ISDB-S, ISDB-T, and DVB-T, DVB-S through using future interconnection mechanism, i.e. IEEE1394

TABLE 1 (*continued*)

Characteristics from Recommendation ITU-R BS.774 (condensed wording)	**Digital System D_H**	**Digital System E**
5. Reconfiguration and quality vs. number of programme trade-offs	A flexible 16 kbit/s building block multiplex is employed. Up to 8 blocks can be assigned to each broadcast channel in order to trade off programme audio quality against number of services. Assignment to services is dynamically adjustable. FM-quality audio achieved at 64 kbit/s. All blocks are error protected. Data service transports streamed data and data packets	Multiplexing of payload data is based on MPEG-2 systems. Audio data rate can be selected in any step in order to trade off programme audio quality against the number of services. Higher-data rate service is possible using more than one CDM channel per programme audio stream
6. Extent of coverage vs. number of programme trade-offs	The system is optimized for diversity reception from satellite(s) and terrestrial repeaters. The trade off between extent of coverage and system throughput is fixed	Data rate of single CDM channel can be selected from 236 kbit/s to 413 kbit/s through using punctured convolutional coding. (Code rate can be selected from 1/2, 2/3, 3/4, 5/6 or 7/8)
7. Common receiver for different means of programme delivery:		
– Mixed/hybrid	– Allows hybrid use of satellite and complementary terrestrial transmissions in the bands allocated for BSS (sound) by WARC-92. A common receiver will receive the satellite TDM and the terrestrial MCM emissions that reinforce the satellite emissions.	– Allows the use of the same band as terrestrial sound broadcasting (mixed) as well as the use of terrestrial on-channel repeaters to reinforce the satellite coverage (hybrid) resulting in all these channels being received transparently by a common receiver.
– Terrestrial augmentations	– Allows local, subnational and national services with TDM-MCM modulation in terrestrial SFNs and TDM-QPSK in satellite line-of-sight via a common receiver.	– Allows local, subnational and national terrestrial services with the same modulation with a single transmitter or multiple transmitters operating in a SFN to take advantage of a common receiver.
– Cable distribution	– Signal can be carried transparently by cable	– Signal can be carried transparently by cable

TABLE 1 (*end*)

Characteristics from Recommendation ITU-R BS.774 (condensed wording)	**Digital System D_H**	**Digital System E**
8. PAD capability	PAD comprising text (dynamic labels) and graphics with conditional access control can be delivered	PAD multiplexing is based on MPEG-2 systems. Data services are available using any CDM channel and a part of CDM channel
9. Flexible assignment of services	The multiplex can be dynamically re-configured in a fashion transparent to the user	The multiplex can be dynamically re-configured in a fashion transparent to the user
10. Compatibility of multiplex structure with OSI	Multiplex structure is compatible with the OSI layered model	The system multiplex structure is fully compliant with MPEG-2 systems architecture
11. Value-added data capability	Capacity in increments of 8 kbit/s up to the full 1.536 Mbit/s capacity of the TDM can be assigned to independent data for the delivery of business data, paging, still pictures graphics etc. under conditional access control if desired. A data connector is provided on the receivers for interfacing to information networks	Capacity at any rate up to the full payload capacity (depends on the number of CDM channels multiplexed) can be assigned to independent data for the delivery of business data, paging, still pictures graphics etc. under conditional access control if desired
12. Receiver low-cost manufacturing	The satellite and MCM-TDM signal reception and digital processing will be embedded in microchips suitable for mass production	The system was specifically optimized to enable an initial low complexity vehicular receiver deployment. Standardization group has been established to achieve low cost receivers based on large scale integration mass production techniques

AAC: advanced audio coding
CDM: code division multiplex
DVB: digital video broadcasting
FM: frequency modulation
IEEE: Institute of Electrical and Electronics Engineers
ISDB: integrated services digital broadcasting
MCM multi-carrier modulation
MPEG: Moving Pictures Experts Group
OSI: open system interconnection
PAD: programme associated data
QPSK: quadrature phase shift keying
RF: radio frequency
SFN: single frequency network
TDM: time division multiplex

ANNEX 1

Summaries of digital systems

1 Summary of Digital System D_H

Digital System $D_{H,}$ also known as the hybrid satellite/terrestrial WorldSpace system, is designed to provide satellite digital audio and data broadcasting for vehicular, fixed and portable reception by inexpensive common receivers. The satellite delivery component of Digital System D_H is based on the same TDM broadcast channel transport used in Digital System D_S but with several significant enhancements designed to improve line-of-sight reception in areas partially shadowed by trees. These enhancements include fast QPSK phase ambiguity recovery, early/late time diversity and maximum likelihood combination of early/late time diversity signals.

It extends the system structure of Digital System D_S by adding the terrestrial delivery system component based on MCM. MCM is a multipath-resistant orthogonal frequency division multiplex (OFDM) technique that has gained wide acceptance for pervasive mobile reception from terrestrial emitters. The MCM extension improves upon the techniques which are common in systems such as Eureka 147, which is one standard utilized for terrestrial microwave digital audio broadcast services. MCM utilizes multiple frequencies to avoid frequency selective fades to avoid deleterious effects of delay spread.

2 Summary of Digital System E

Digital System E, also known as the Association of Radio Industries and Businesses (ARIB) system, is designed to provide satellite and complementary terrestrial on-channel repeater (hybrid) services for high quality audio and multimedia data for vehicular, portable and fixed reception. It has been designed to optimize performance for both satellite and terrestrial on-channel repeater service delivery in the 2 630-2 655 MHz band. This is achieved through the use of CDM based on QPSK modulation with concatenated block and convolutional error correcting coding. The Digital System E receiver uses state-of-the-art microwave and digital large-scale integrated circuit technology with the primary objective of achieving low-cost production and high-quality performance.

ANNEX 2

Digital System D_H

1 Introduction

Digital System D_H, also known as the hybrid satellite/terrestrial WorldSpace system, is designed to provide satellite digital audio and data broadcasting for vehicular, fixed and portable reception by inexpensive common receivers. It extends the system structure of Digital System D_S, described in Recommendation ITU-R BO.1130. Digital System D_S was designed to optimize performance for satellite delivery using coherent QPSK modulation with block and convolutional coding, and non-linear amplification at travelling wave tube amplifier (TWTA) saturation. It is now operating over Africa using the WorldSpace AfriStar satellite at 21° East and over Asia using the AsiaStar satellite at 105° East. The system provides for a flexible TDM of digitized audio and data sources to be modulated onto a downlink TDM carrier, and uses a hierarchical multiplex structure of three layers (physical, service and transport) that conforms to the OSI Model as recommended in Recommendation ITU-R BT.807.

Since the launch of AfriStar in October 1998 Digital System D_S system has been delivering a satellite direct digital broadcast service over Africa. With the launch of AsiaStar in March 2000 the same service has started over Asia. Both satellites are delivering direct digital broadcast signal reception with very high margins of 4 to 13 dB within their outer beam coverage contour areas of 28 million km^2. Digital audio signals are being uplinked to transparent and processing payloads from diversely located uplink earth stations in the satellite global beams and broadcast via AfriStar over three 5.7° to 6° width beams covering Africa and the Middle East, and three more beams via AsiaStar from Indonesia and India to Korea and China. Four differently manufactured 1.5 GHz receivers receive these signals.

Digital System D_H extends the reception performance of Digital System D_S to deliver robust mobile reception performance to urban regions that suffer severe blockage by buildings and trees. A Digital System D_H architecture has now been specified. It provides terrestrial augmentation for DSB services in a mixed satellite/terrestrial configuration to mobile receivers as well as static and portable receivers. The development work has reached the stage where system validation testing has taken place using the AfriStar Satellite and a three-transmitter SFN in Erlangen, Germany. Further tests are planned in Pretoria, Republic of South Africa.

The satellite delivery component of Digital System D_H is based on the same TDM broadcast channel transport used in Digital System D_S but with several significant enhancements designed to improve line-of-sight reception in areas partially shadowed by trees. These enhancements include fast QPSK phase ambiguity recovery every 1.4375 ms, early/late time diversity and maximum likelihood combination of early/late time diversity signals.

The terrestrial delivery system component is based on MCM. MCM is a multipath-resistant OFDM technique that has gained wide acceptance for pervasive mobile reception from terrestrial emitters. The MCM extension improves upon the techniques that are common in systems such as Digital System A, which is one standard used for terrestrial digital audio broadcast services. MCM utilizes multiple frequencies to avoid frequency selective fades thereby avoiding deleterious effects of delay spread. The MCM modulation scheme is most suitable for reliable reception in urban mobile environments, and leads to spectrum efficient solutions when SFNs are used. A new Digital System D_H receiver design extends and improves upon the Digital System D_S design for satellite signal reception. It adds an MCM terrestrial reception branch to receive terrestrial signal single frequency network emissions. It uses two radio frequency tuner branches and demodulates the same TDM stream from both the satellite and terrestrial signal components. For its MCM extension, new terrestrial transport and physical layer specifications are added to the current service, transport and physical layers of Digital System D_S. Because the terrestrial transport directly modulates the TDM baseband symbols recovered by receivers at each terrestrial station of a terrestrial re-radiation network onto MCM carriers, the terrestrial transport is referred to as TDM-MCM.

The following sections describe in more detail the satellite and terrestrial retransmission components of Digital System D_H.

With the inclusion of the terrestrial delivery component, Digital System D_H can meet the service requirements stipulated not just in Recommendation ITU-R BO.789, but also Recommendation ITU-R BS.774 for satellite and complementary terrestrial delivery of digital sound broadcasting.

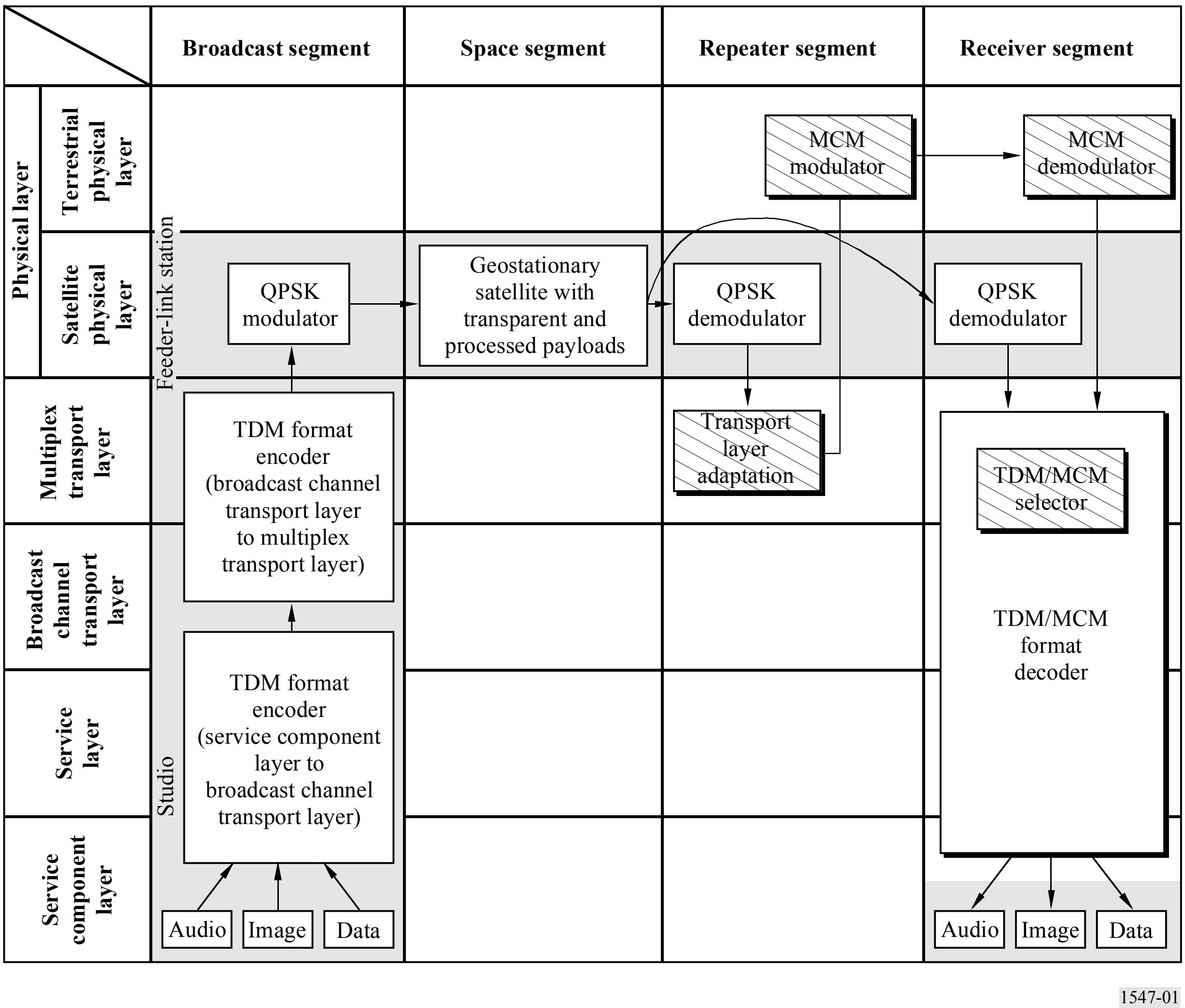
2 System overview

2.1 Layer structure of Digital System D_H

Digital System D_H uses the system layer structure illustrated in Fig. 1. It comprises service, transport and physical layers for both the TDM satellite segment and the TDM-MCM terrestrial repeater segment.

FIGURE 1

The WorldSpace Digital System D_H signal layers with the MCM extension



2.2 Satellite broadcast segment

2.2.1 Service layer

The service layer comprises audio, image and data source coders. WorldSpace uses a variation of International Organization for Standardization (ISO) MPEG 2 Layer III called MPEG 2.5 Layer III for audio and ISO Joint Photographic Experts Group (JPEG) for image. The source data is organized into 432 ms broadcast channel frames in prime rate increments of 16 kbit/s. Prime rate increments are the building bricks of the baseband multiplex architecture. A broadcast channel frame can support up to eight service components, each carrying a rate from 8 kbit/s to 128 kbit/s, that can be individually accessed at the receiver. Each prime rate increment can support two 8 kbit/s service components. The sum of service component rates in a broadcast channel must not exceed 128 kbit/s. A broadcast channel transports a mix of services such as music, talk in selectable multiple languages, images associated with the latter and data in the form of packets or streaming. Each broadcast channel frame carries a service control header (SCH) which at a receiver provides a broadcast channel frame synchronization preamble and the information needed to identify the type of information carried, the information rate, the identity of the various services carried, ancillary information related to the various services, alpha-numeric text display, narrow casting of services, selection of the accessed services and authorization to access restricted and subscription services to individual users.

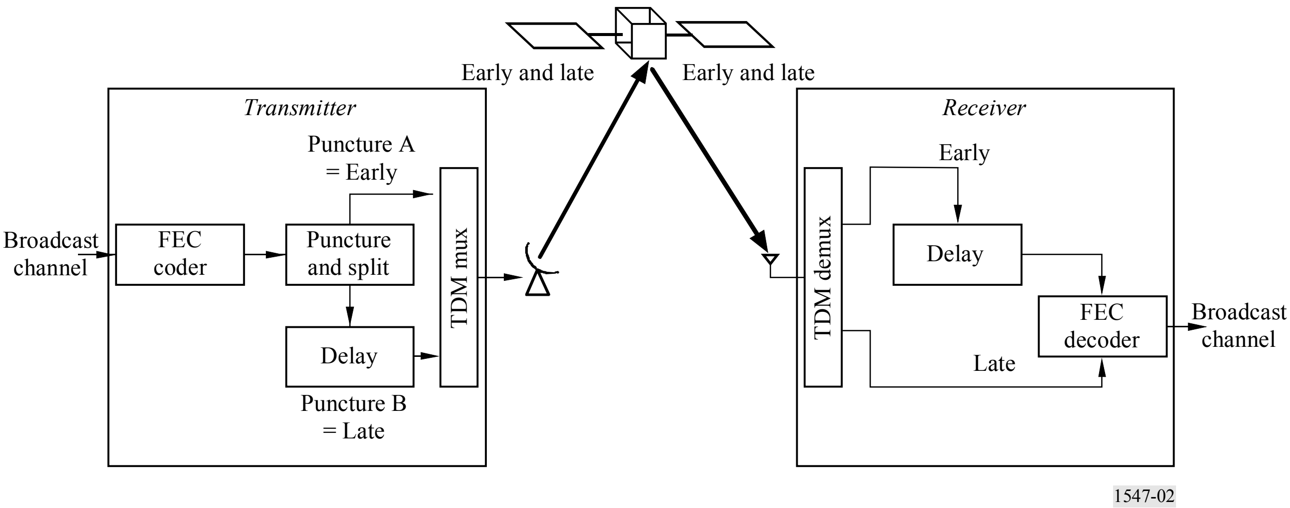
2.2.2 Transport layer

2.2.2.1 Time diversity only

For time diversity only using one satellite, the transport layer uses the architecture shown in Fig. 2. It accepts the bits of the broadcast channels from the service layer and first organizes them into symbols, each carrying two bits. Forward error correction (FEC), using the concatenation of a Reed-Solomon (RS) block coder and a convolution coder, next codes the symbols. Puncturing of the latter coder output creates two complementary companion error correction protected broadcast channels. One of the punctured broadcast channels is designated as the early channel. It is interleaved over a 432 ms frame to combat short term reception fades. Its companion punctured broadcast channel, designated as the late channel, is delayed for approximately 4.32 s. This channel is intended for reception by the current standard WorldSpace receivers as well as by the new mobile radios. Also, it is not interleaved because doing so would render it incompatible for reception by a conventional WorldSpace receiver. The 4.32 s delay between the early and late broadcast channels provides long delay protection to combat blockages of satellite signal reception by bridges, short tunnels and trees as a vehicle travels along highways at typical speeds. The two companion punctured broadcast channels are then division multiplexed into the TDM stream along with other mobile and non-mobile conventional broadcast channels. The system is intended to carry a mix of conventional broadcast channels for reception by the ordinary WorldSpace satellite broadcast receivers and complementary pairs of punctured broadcast channels, one early and one late, for reception by mobile receivers.

FIGURE 2

Time diversity with a single satellite

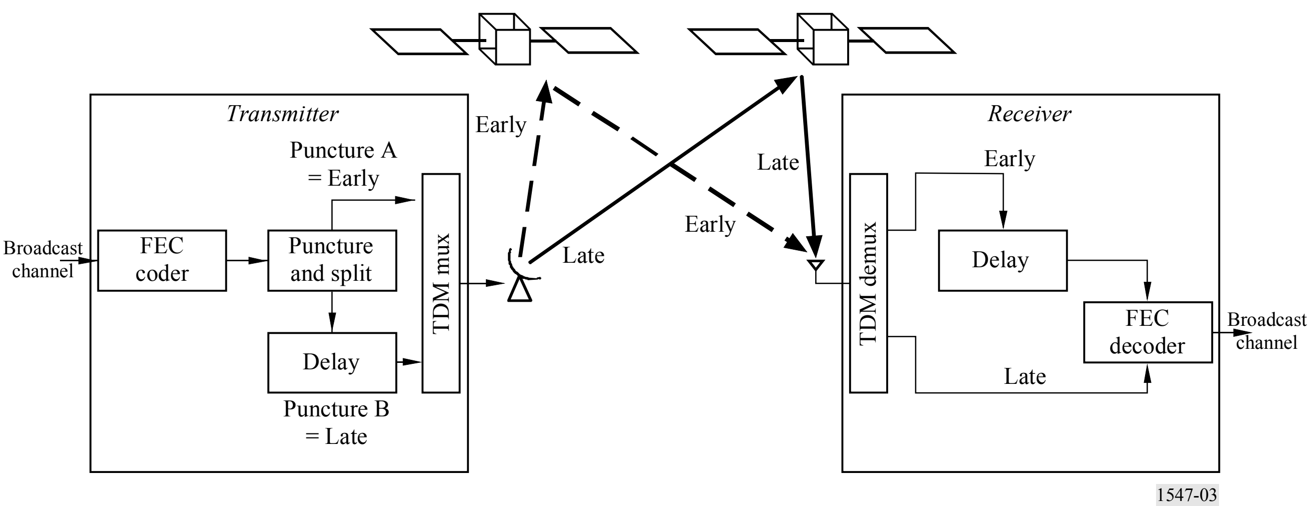


2.2.2.2 Time and space diversity

The satellite broadcast transport layer architecture for time and space diversity, illustrated in Fig. 3, uses two satellites spaced apart from one another by 15° to 35° along the geostationary orbit. It is best if the bisector between the satellites is centred over the intended earth coverage area. It uses the same early and late broadcast channel architecture described above for the time only diversity case. However, two TDM carriers are used, one transported by each satellite. Each may carry a mix of early and late broadcast channels or one can be designated to carry only early and the other only late. Also conventional broadcast channels not intended for mobile reception can be mixed with those for mobile. This is possible because every broadcast channel has its own broadcast channel identifier (BCID) that is used at the receiver to select specific broadcast channels from one or either of two received TDM stream(s).

FIGURE 3

Space and time diversity with two satellites

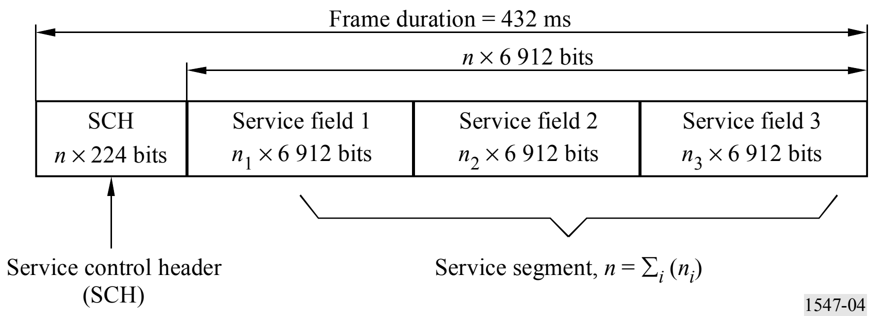


2.2.2.3 Broadcast channel frame and FEC

Figure 4 shows a broadcast channel frame containing three service fields. Each service field carries a rate that is an integer multiple n_i of the 16 kbit/s prime rate increment. Thus within each 432 ms frame, a service field i carrying a rate $n_i \times 16$ kbit/s has assigned to it $n_i \times 6\,912$ bits. The bit rate of a service field has a range from 16 kbit/s to 128 kbit/s. Also the bit rate of a broadcast channel has a range from 16 kbit/s to 128 kbit/s. A broadcast channel can carry a maximum of eight service components that have rates ranging from 8 kbit/s to 128 kbit/s. Note that service components are in multiples of 8 kbit/s. Hence, whenever a service component's rate is an odd multiple of 8 kbit/s, a dummy 8 kbit/s must be appended to produce an integer multiple of 16 kbit/s for the service fields in a broadcast channel. The total number of service fields in a broadcast channel is $n = \Sigma_i (n_i)$. To prepare for transport, each 6912-bit service field prime rate increment of a broadcast channel is assigned 224 bits in a SCH bringing the number of bits per broadcast channel frame to $n \times 7\,136$. The broadcast channel frame is next FEC coded by a 223,255 RS block coder to yield an output of $n \times 8\,160$ bits per frame. To prepare for mobile service, the output of the RS coder is next supplied to a R 1/4 convolution coder whose output is split into two R 1/2 convolution coded broadcast channels, one destined to be the early broadcast channel and the other the late broadcast channel. At this point there are $n \times 16\,320$ bits assigned to the n service fields in each broadcast channel. The n service fields are next demultiplexed into n prime rate channels (PRCs). Adding a 96-bit preamble to each PRC brings the total to 16416 bits per PRC.

FIGURE 4

Broadcast channel frame



2.2.2.4 Terrestrial transport

If an originating studio is remote from an uplink station, the PRCs of a broadcast channel are transported to the station over terrestrial digital telephony links. This is typically done via ITU-T Recommendation G.736 digital telephony multiplexes. If the originating studio is collocated at or near the originating studio, the signals are simply transported over a local cable. The signal transported is that generated at the output of the RS block coded level. At this point the broadcast channels are said to be carried in a protected form. At the uplink stations the PRCs of the protected broadcast channels arriving from a multiplicity of origins are synchronously aligned by means of a plesiochronous buffer to prepare them for uplinking to the satellite. Next the PRCs of the protected broadcast channels are R 1/4 convolution coded and split by complementary puncturing into the R 1/2 convolutionally encoded early and late broadcast channels. The latter PRCs of the broadcast channels are next uplinked to the satellite communications payload. The system has two ways to transport via the satellite communications payload. One is that via a processing payload and the other that via a transparent payload.

2.2.2.5 Uplinking to the satellite

For the PRCs of broadcast channels destined to the processing payload, the uplink signals are transported in a frequency division multiple access (FDMA) format. Each FDMA signal comprises a 38 kbit/s QPSK modulated digital stream operating on carriers separated by 38 kHz in sets of 48 contiguous band carriers. Thus each 48-carrier set occupies 1 824 kHz of bandwidth. Six of these sets are uplinked to the satellite at frequencies located between 7 025 and 7 075 MHz. Onboard the satellite 96 PRCs of the FEC coded broadcast channels are demodulated to their symbol level, synchronously aligned. The PRCs of each broadcast channel can be routed to one, two or three TDM multiplexers. The routed symbols are time division multiplexed into 2 622 sets of 96 symbols each in a 138 ms TDM frame period. At the start of each TDM frame there are attached a 96-symbol master frame preamble (MFP) and a 2 112 symbol time slot control word (TSCW) making the entire frame 253 920 symbols long and yielding a symbol rate of 1 840 000 symbols/s. Hence, each TDM carrier requires a bandwidth of 2.3 MHz. For improved robustness in transport and reception, a pseudo random symbol sequence is modulo-two added to scramble symbols of the TDM stream. Operationally, these TDM streams can support twenty-four 64 kbit/s broadcast channels for FM stereo quality audio service using the MPEG 2.5 Layer III source coder. Three processing payload TDM streams, QPSK modulated onto three carriers, are transmitted, one in each of three beams on different frequencies between 1 467 and 1 492 MHz. In each of the three downlink beams, the beam centre equivalent isotropically radiated power (e.i.r.p.) of each carrier is 53.5 dBW. The −3 dB beamwidth is approximately 6°.

For the transparent payload, at the uplink station the PRCs of the R 1/2 convolutionally encoded broadcast channel signals are multiplexed onto a TDM carrier. An aggregate of 96 PRCs, converted to 2-bit symbols, is time multiplexed into 2 622 groups. Each group contains one symbol of the 96 PRCs carried in a TDM frame period of 0.138 s. To this is added an MFP of 96 symbols and a time slot control channel of 2 112 symbols to yield a total TDM frame of 253 920 symbols and a rate of 1.84 Mbit/s. The bandwidth needed to accommodate this TDM stream using QPSK modulation is typically 2.3 MHz. The 96 PRCs carried in the TDM stream carry the traffic of the mix of broadcast channels for both mobile and non-mobile services.

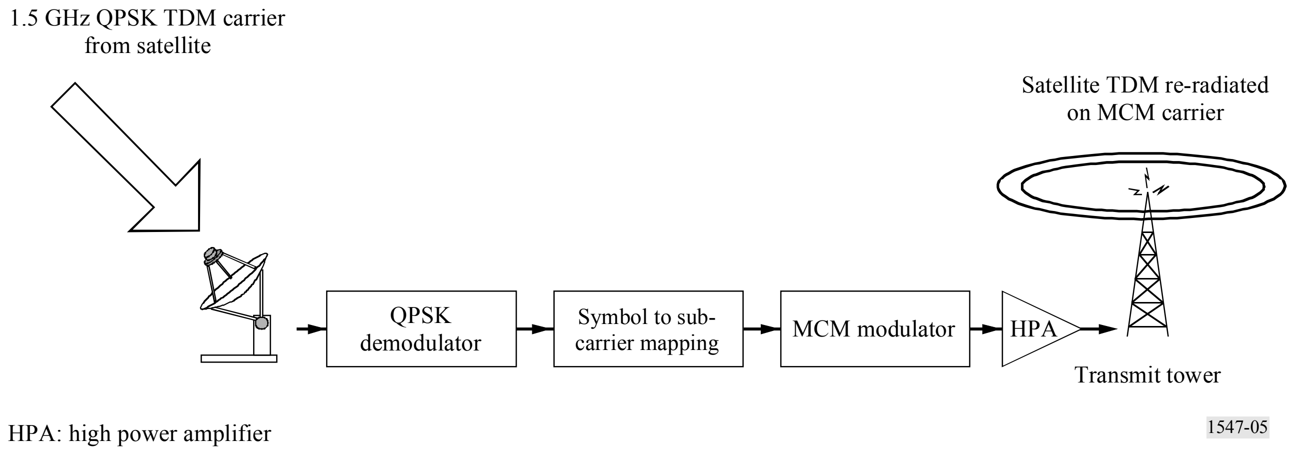
For broadcast channels intended only for non-mobile (direct-line-of-sight) reception, a R 1/2 convolutional coder is used after the RS coder. This R 1/2 convolution coder and the R 1/4 punctured to R 1/2 convolution coder used for the late mobile channel are compatible to the same receive side Viterbi decoder. In all other regards broadcast channel processing and TDM multiplexing for mobile and non-mobile receivers is the same.

2.3 MCM implementation

The TDM to MCM conversion of the satellite TDM symbol stream to a TDM-MCM signal for terrestrial re-radiation is illustrated in Fig. 5. For the time diversity only system, the resulting TDM-MCM signal is re-radiated by multiple terrestrial stations of a SFN.

FIGURE 5

TDM to MCM conversion and terrestrial re-radiation



Using a 1.2 m diameter off-set-feed parabolic antenna connected to a WorldSpace receiver, the satellite QPSK TDM carrier is demodulated to its baseband TDM symbol signal form. It is next converted to a TDM-MCM form using the processing steps shown in Fig. 6. The TDM symbols are mapped to MCM sub-carrier symbols by constructing a multicarrier signal in the frequency domain. To do this the TDM symbols are first ordered into a row-column format, each column corresponding to an MCM symbol. The TDM symbol row elements of the column correspond to the individual MCM sub-carriers of an MCM symbol. To create the time domain signal for each MCM symbol, an inverse fast Fourier transform (IFFT) operates on the row elements of each column to generate a multiplicity of differential QPSK (DQPSK) signals, one for each TDM symbol. To mitigate intersymbol interference (ISI), a guard interval is inserted between MCM symbols by time domain compressing and repeating parts of the output sequence of the IFFT.

A time domain view of an MCM frame comprises a sequence of MCM symbols as shown in Fig. 7. Each MCM frame starts with an amplitude modulated synchronization sequence (AMSS) that is used at the receiver to recover MCM frame timing synchronization and carrier frequency and phase recovery. Each MCM frame comprises 23 MCM symbols. Each MCM symbol carries 552 DQPSK modulated carriers, one for each 2-bit TDM symbol plus one more carrier that is the phase reference for the DQPSK modulation. Each MCM symbol ends with a guard interval in which a time segment of length equal to the guard time but sampled at the start of the MCM symbol is repeated. The MCM frames are themselves formatted into a frame of 138 ms duration that is equal to the length of a TDM frame. At the receiver, this AMSS accommodates synchronization of the TDM frames recovered from the satellite and terrestrial paths.

FIGURE 6

TDM to MCM conversion

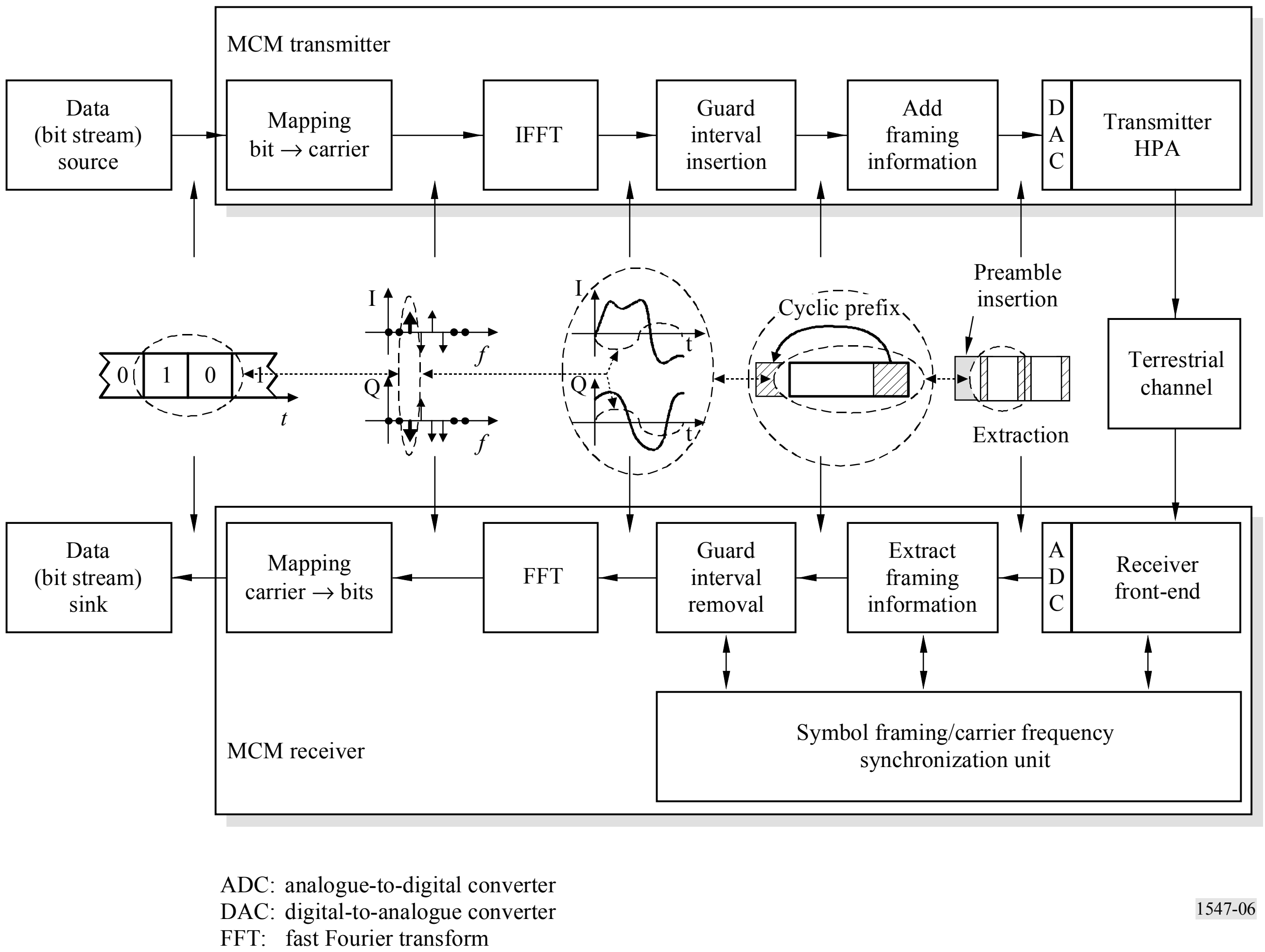
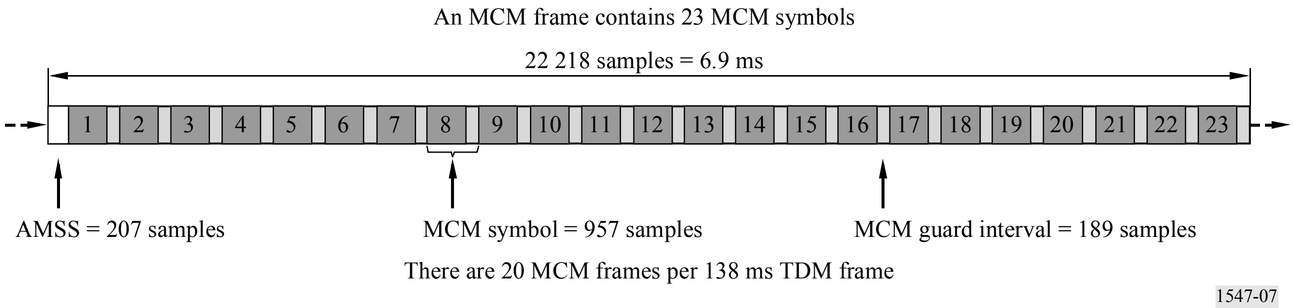


FIGURE 7

Time domain view of MCM frame



2.4 MCM waveform parameters

The MCM parameters being used for the mobile operations in the band 1 467-1 492 MHz are given in Table 2.

TABLE 2

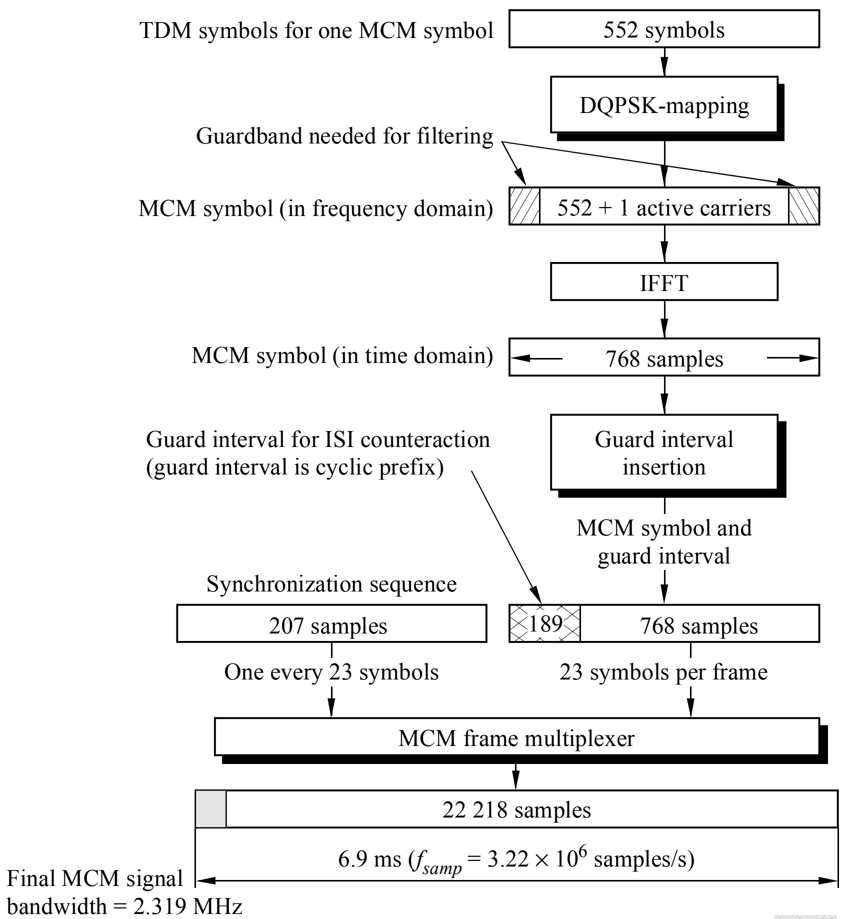
MCM parameters

Parameter	Value
FFT length	768
DQPSK active carriers	552
DQPSK reference carrier	1 per MCM symbol
TDM symbol → MCM symbol mapping	552 two-bit TDM symbols per MCM symbol using DQPSK
MCM symbols per MCM frame	23
MCM symbol frame length	6.9 ms
Symbol duration	297.21 μs
Guard interval	58.70 μs included symbol duration
AMSS synchronization preamble (at start of each MCM frame)	64.29 μs
Framing	20 MCM symbols (138 ms)
Sampling frequency	3.22 MHz
Bandwidth	2.32 MHz

Further details of the MCM signal construction are illustrated in Fig. 8.

FIGURE 8

TDM-MCM processing steps summary



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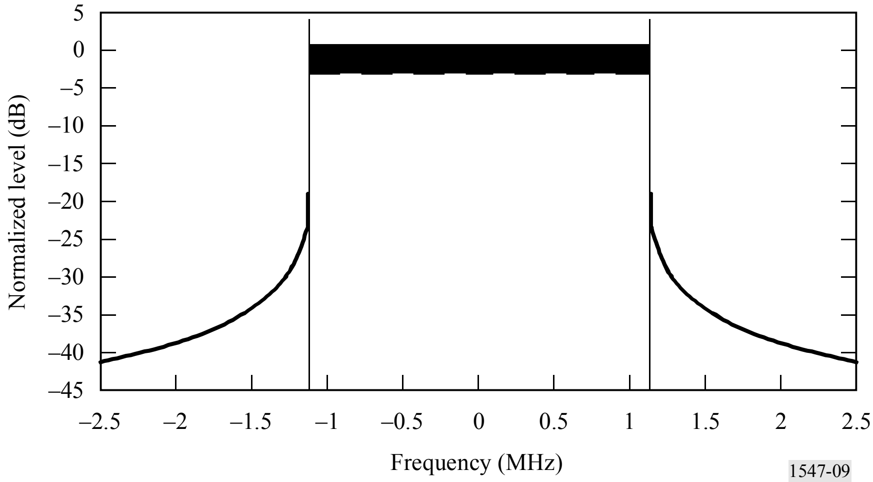
The theoretical spectrum of the MCM signal is shown in Fig. 9. Note the very rapid out-of-band fall-off that is typical of the MCM modulation process and aids in reduction of adjacent channel interference.

FIGURE 9

Theoretical MCM spectrum



2.5 Time diversity delay between early and late broadcast channels

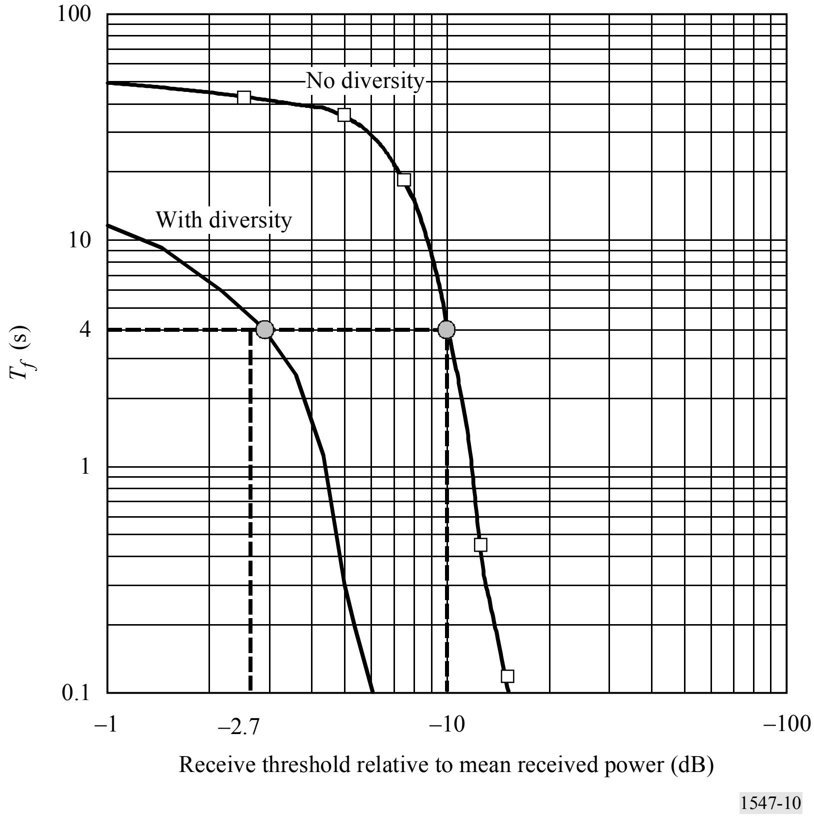
For time only diversity early and late boadcast channels may be transmitted as two different broadcast channels on one TDM carrier from one satellite and for time and space diversity from two separated satellites having, on two TDM carriers, one from each satellite.

Regarding the magnitude of the delay time needed for effective time diversity reception, experiment data from studies conducted by the German Aerospace Research and Test Establishment (DFVLR now referred to as DLR) in 1985 in Europe in connection with the Prosat/Prodat system and reported in the Proceedings of the Seventh International Conference on Digital Satellite Communications (ICDSC-7), Munich, Germany, 12-16 May 1986, p. 537-541 provide guidance. These experiments were performed via the MARECS-A satellite in geostationary orbit positioned at 15° West longitude. The data was collected for a vehicle travelling on rural highways at a speed of 60 km/h. Results of specific interest here are plotted in Fig. 3b of the reference cited. A subset of the data taken from the latter Figure is re-plotted here in Fig. 10.

Two curves are shown for mobile reception by a vehicle travelling on a highway at a speed of 60 km/h. One is without and the other with time diversity. They show the relationship between fade duration exceeded for 1% of the time in seconds on the vertical axis and receive threshold relative to mean received power in dB on the horizontal axis. The curve without diversity shows that for a receive threshold of −10 dB the fade duration exceeds 4 s less than 1% of the time. With diversity the receive threshold is reduced to −2.7 dB. Conversely, fades having a duration of 4 s or less occur 99% of the time for a receive threshold of −10 dB without time diversity and −2.7 dB with time diversity. The system described in this text will have a delay time of 4.28 s.

FIGURE 10

Fade duration ≥ T_f vs. ratio of receive threshold to mean received power (dB) for a time share of fade of 1% for highway mobile reception with and without time diversity



2.6 Receiving scenarios of hybrid satellite/terrestrial signals

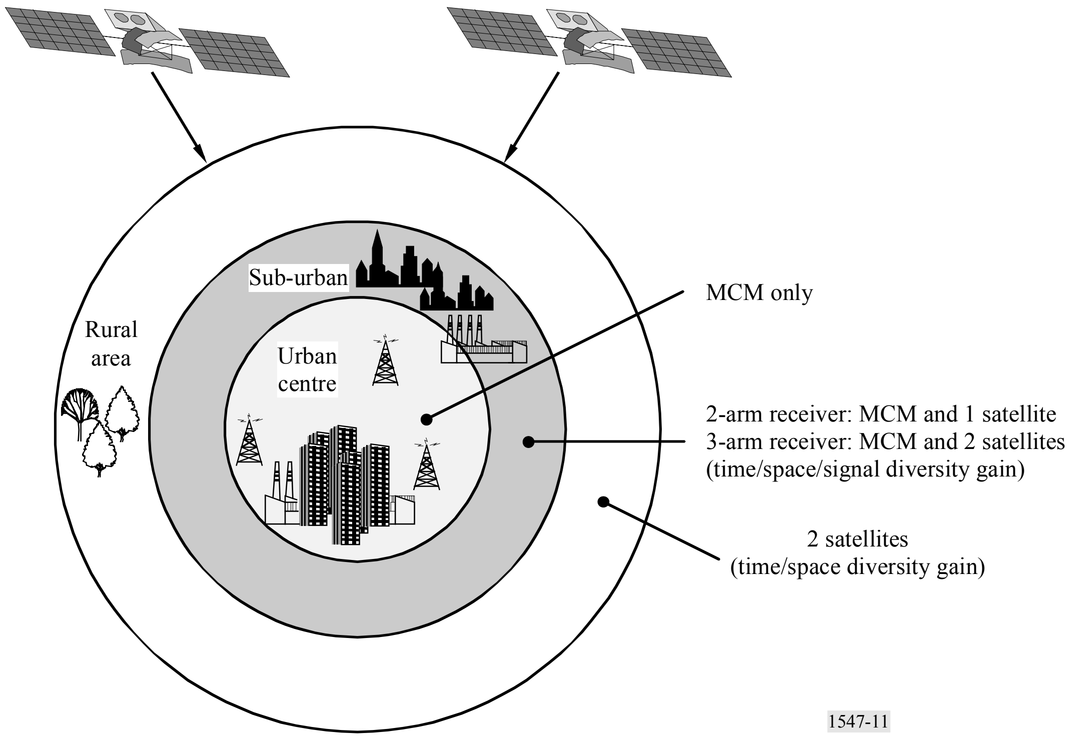
The overall scenario of the mix of satellite line-of-sight combined with terrestrial reinforcement for mobile reception is illustrated in Fig. 11. The scenario is composed of three regions which are discussed in the following.

2.6.1 Outer region – Dominantly satellite reception region

The outermost region, shown as the outer annulus around a large city in Fig. 11, comprises mostly wide-open rural areas across which highways interconnect major cities and rural roads interconnect small towns. Along most of the highways and roads, line-of-sight satellite reception will be possible for a large fraction of the time a vehicle moves along. However, inadvertently, a vehicle will encounter small regions where buildings and trees will interfere with direct line-of-sight satellite reception even if time and space diversity are available. Thus, in many such rural regions, terrestrial reinforcement stations re-radiating the TDM-MCM signal will be installed, particularly where the volume of service justifies doing so. These are likely to be 10 dBW to 20 dBW e.i.r.p. transmitters used principally for regions where the service availability using the satellite signals only would not be sufficient.

FIGURE 11

Reception scenarios



2.6.2 Intermediate region – Mix of satellite and terrestrial signals region

This is a transitional zone between intense urban and suburban/rural areas. It is composed of islands of tall housing and business clusters interspersed with a low rise suburban housing and rural settings. Thus, the satellite only signal is likely to be insufficient for full coverage. More intense use of terrestrial re-radiation is needed than in the rural region. As required by the topology, terrestrial repeaters radiating the TDM-MCM signal at power levels of 10 dBW to 20 dBW will be installed to provide the required service availability.

2.6.3 Inner region – Dominant use of the terrestrial signal

For urban centres only, terrestrial repeaters provide the coverage. Single frequency networks of multiple repeaters radiating the TDM-MCM signal at 30 dBW and higher are used to cover a complete urban centre if the coverage radius of one transmitter is not sufficient.

2.6.4 Vehicle transiting through the regions

As a vehicle transits toward the urban centre through the various regions of the scenario of Fig. 11, it will encounter various signal strengths and mixes of terrestrial re-radiated and satellite signals.

In open rural areas of the outer annulus, a vehicle will be a long distance, even over the radio horizon, from the nearest urban TDM-MCM re-radiators; hence, the satellite signal will dominate. In this case, a satellite receiver arm(s) will demodulate the TDM carrier(s), recover the early and late "tuned" broadcast channels and combine them by means of maximum likelihood FEC decoding to recover the broadcast channel bits.

As the vehicle transits into the intermediate region, it will begin to encounter increasing levels of TDM-MCM signal. The receiver, using its FEC decoders, examines and compares the terrestrial and satellite signal quality in terms of estimated bit error ratios (BER_{ter} and BER_{sat}). Receiver reception stays with the satellite signal as long as it continues to deliver a $BER_{sat} = \Delta \times BER_{ter}$, $\Delta \geq 1$. When the latter condition becomes "not true" receiver reception switches to the terrestrial signal. Only when the satellite signal *BER* decreases such that $BER_{ter} = \Delta \times BER_{sat}$ will reception switch again to the satellite signal. If BER_{ter} and BER_{sat} are both too low for satisfactory reception, reception ceases. Values of Δ may be as great as 10.

A vehicle transiting in the intermediate region and also in the outer region will encounter towns, mountains and forests where line-of-sight to the satellite(s) is blocked. TDM-MCM terrestrial re-radiation repeaters are likely to be installed to achieve seamless coverage for travellers and local residents. Thus a receiver will cycle between terrestrial reception and satellite reception as the receiver performs the quality processing and switching in terms of BER. It is important that such switching occur with a minimum of interrupt to the continuity of service. For audio services, inaudible interrupts may be tolerated however, for data, such interrupts may cause the loss of service continuity. Measures to avoid such interrupts will be implemented.

When a transiting vehicle enters the centre region, reception is essentially 100% via the terrestrial signal. This is by design that involves the deliberate deployment of terrestrial re-radiators to accomplish pervasive coverage. Furthermore, once the receiver locks on to the terrestrial signal, the design of the signal quality comparator, as described above, is such as to inhibit return to satellite reception until the latter is dominantly the better. The value of Δ governs this aspect of the switching action.

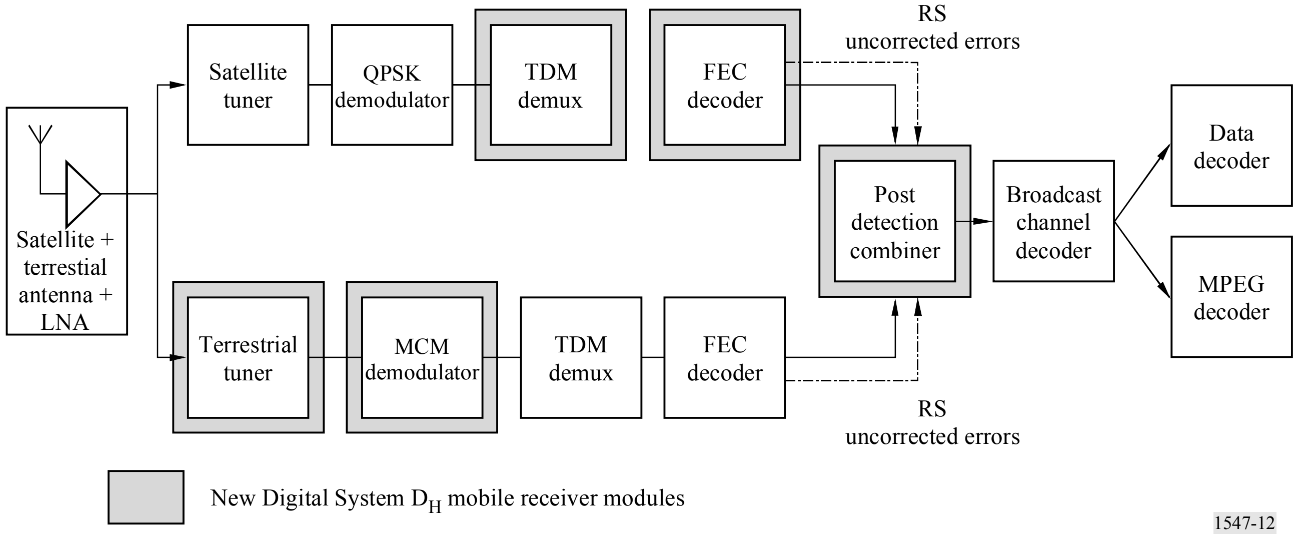
2.7 Receiver architecture

Two receiver architectures are described in the following, one for time only diversity and the other for time and space diversity.

The time-only diversity receiver is shown in Fig. 12. It employs a combined antenna for satellite and terrestrial reception that connects to two receiver arms, one for satellite and the other for terrestrial. The satellite arm comprises a satellite tuner that selects a desired TDM satellite carrier, a QPSK demodulator to recover the TDM symbol stream and a TDM demultiplexer that selects a desired pair of complimentary early and late broadcast channels. An FEC decoder that uses a Viterbi maximum likelihood FEC trellis decoder synchronously combines the delayed early signal and the late signal. Delay of the early signal is implemented in the TDM demultiplexer. Precise synchronization needed for the combining is accomplished by aligning the preambles of the early and late broadcast channel frames. The post detection combiner is a switch that selects the broadcast channel of either the satellite or terrestrial receiver arms based on the quality measurement previously described. The MCM arm of the receiver operates simultaneously and independently of the satellite. It tunes to the desired MCM carrier and demodulates it to the TDM symbol stream. From there on it operates precisely the same way as the satellite arm. The post detection combiner connects the terrestrial arm or the satellite arm to the output depending on its logic declaration as to which has the better quality. The selected broadcast channel is then demultiplexed into its constituent service components.

FIGURE 12

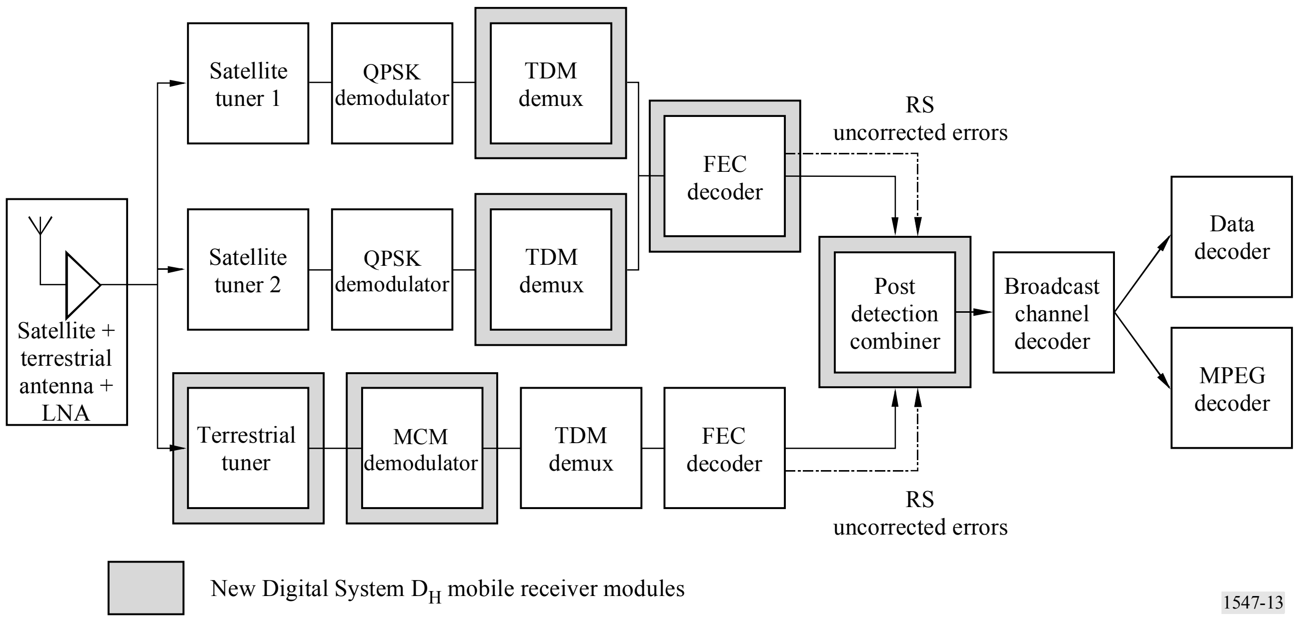
Time-only diversity receiver



The time and space diversity receiver is shown in Fig. 13. It uses three arms, two for satellite signal reception and one for terrestrial signal reception. All three arms share the same antenna and low noise amplifier (LNA). One satellite signal will carry only early broadcast channels and the other only late broadcast channels. The third arm receives the terrestrial signal that comprises a TDM-MCM carrier transporting the TDM. The TDM transported via terrestrial re-radiation is that carrying only early broadcast channels received at the terrestrial re-radiating station directly from the satellite. Each satellite arm comprises a satellite tuner that selects a desired TDM satellite carrier, a QPSK demodulator to recover the TDM symbol stream and a TDM demultiplexer. One arm delivers the desired early broadcast channel and the other the companion late broadcast channel to a FEC decoder that uses a Viterbi maximum likelihood FEC trellis decoder to synchronously combine the delayed early signal and the late signal. The required delay of the early signal is implemented in the TDM demultiplexer. Precise alignment needed for the Viterbi decoder combining is accomplished by aligning the preambles of the early and late broadcast channel frames. The MCM arm of the receiver operates simultaneously and independently of the satellite. It tunes to the MCM carrier and demodulates it to recover the TDM symbol stream, demultiplexes the TDM stream to recover the desired early broadcast channel and FEC decodes the latter in a Viterbi decoder. The latter broadcast channel will have to be delayed to bring it into synchronization with the broadcast channel recovered from the satellite arm. Some of the latter delay will have been introduced at the terrestrial re-radiating stations as incidental in the conversion from TDM to TDM-MCM. Precise synchronization needed for post detection combining is accomplished by aligning the preambles of the early and late broadcast channel frames. The post detection combiner connects the terrestrial arm or the satellite arm to the output depending on its logic declaration as to which has the better quality. The selected broadcast channel is then demultiplexed into its constituent service components.

FIGURE 13

Time and space diversity receiver



ANNEX 3

Digital System E

1 Introduction

Digital System E is designed to provide satellite and complementary terrestrial on-channel repeater services for high quality audio and multimedia data for vehicular, portable and fixed reception. It has been designed to optimize performance for both satellite and terrestrial on-channel repeater services delivery in the 2 630-2 655 MHz band. This is achieved through the use of CDM based on QPSK modulation with concatenated code using RS code and convolutional error correcting coding. The Digital System E receiver uses state-of-the-art microwave and digital large-scale integrated circuit technology with the primary objective of achieving low-cost production and high-quality performance.

The main features of this system are that:

– the system is the first digital sound broadcasting system to be tested in the field using the 2 630-2 655 MHz band that is assigned to BSS (sound) in some countries;

– MPEG-2 system architecture is adopted in order to achieve flexible multiplexing of many broadcasting services and interoperability with other digital broadcasting services. This is the first BSS (sound) system to adopt MPEG-2 systems;

– MPEG-2 AAC is adopted for audio source coding. AAC gives the most efficient audio compression performance for high quality audio broadcasting services;

– vehicular reception is the main target of this system. Stable reception was confirmed in high-speed vehicles in the course of corroborative testing;

– typically, satellite signals can be received using omni-directional single element antenna in the horizontal plane; for vehicles, two-antenna diversity reception is preferable.

2 System overview

Figure 14 shows the system overview. This BSS (sound) system consists of a feeder-link earth station, a broadcasting satellite, two types of terrestrial gap-fillers, and portable, fixed and vehicular receivers.

The signal is first transmitted from a feeder-link earth station to a broadcasting satellite, using a fixed-satellite service (FSS) uplink (the 14 GHz band for example). The signal is converted from the 14 GHz band to the 2.6 GHz band in the satellite. The 2.6 GHz band signal is amplified using a satellite transponder up to a desired level and this signal is broadcast over the service area using a large transmitting antenna on the satellite.

The main programmes broadcast by this system are high quality sound services in the first stage and multimedia services, including data broadcasting, in the following stage.

Listeners/viewers of this service can receive the broadcast signal via the satellite using small antennas with low directivity. To generate enough e.i.r.p. for vehicular reception, the space station will need to be equipped with a large transmit antenna and high-power transponders.

The major issues related to signal propagation in the 2.6 GHz band are shadowing and blocking of the direct satellite path. This system uses two techniques to cope with the various types of shadowing and blocking.

The first is a bit-wise de-interleaver in the receiver to counter shadowing and blocking caused by small objects. This shadowing and blocking is manifest in a vehicular reception environment as solid bursts of noise in the received signal of up to, approximately, a second.

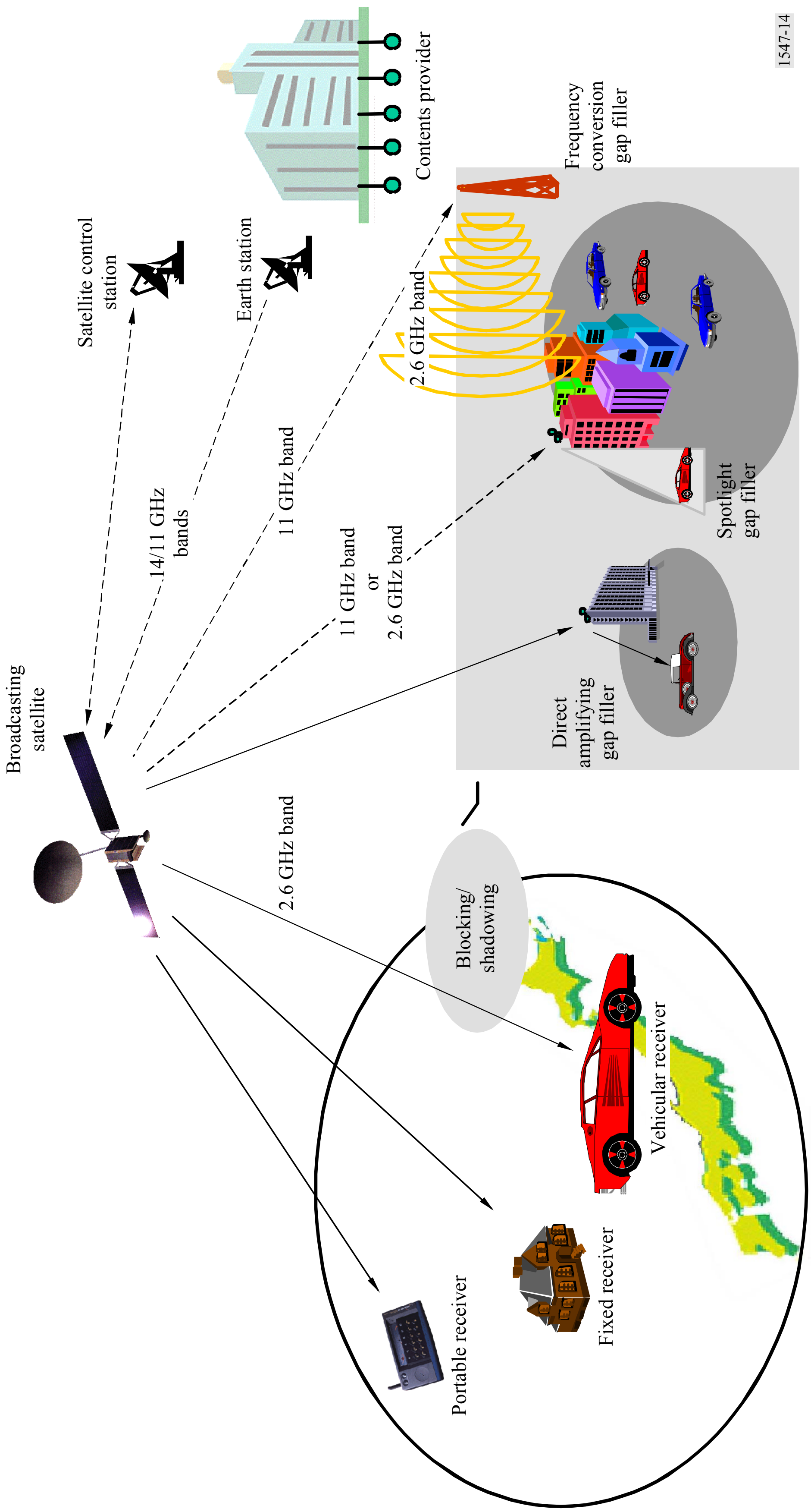
A solid burst of noise is distributed over a time period of several seconds using this de-interleaver to fit the error-correcting capabilities of this system.

The second method to alleviate signal fades caused by shadowing and blocking is the inclusion of gap-fillers in the system design. Such gap-fillers retransmit the satellite signal. These gap-fillers are expected to cover the area blocked by, for example, buildings and large constructions. There are two types of gap-fillers in this system, the so-called direct amplifying gap-filler and the frequency conversion gap-filler to cover different types of blocked areas.

The direct amplifying gap-filler only amplifies the 2.6 GHz band signal broadcast from the satellite. This type of gap-filler is inherently limited to low gain amplification to avoid undesired oscillation caused by signal coupling between transmitting and receiving antennas. This gap-filler covers a narrow area of direct path up to a 500 m long line-of-sight area.

FIGURE 14

System overview



However, a frequency conversion gap-filler is intended to cover a large area within a 3 km radius. The satellite fed signal uses a different frequency other than the 2.6 GHz band, for example, the 11 GHz band.

In such circumstances, multipath fading appears in the area where more than two broadcasting signals are received. In this broadcasting system, the CDM technique is adopted to secure a stable reception of the multipath-faded signal. By using a RAKE technique and antenna diversity in the receiver, a large improvement in the receiver's performance is expected in the limited multipath-fading environment.

The spotlight type gap-filler, also shown in Fig. 14, could improve the multipath environment where the CDM and RAKE receiver cannot decode properly without this gap-filler. This is a major feature of the CDM system. Spotlight gap-filler can either use amplification or frequency conversion to satisfy the specific requirement of the target area to be improved.

In CDM systems, different broadcasters will use different orthogonal codes for spreading the signal in order to broadcast their own programmes independently. Power flux-density (pfd) per unit bandwidth is relatively low because the CDM signal is spread over a wide frequency band.

3 Physical layer and modulation

Figure 15 shows the basic block diagram of the broadcasting system and Fig. 16 shows a detailed block diagram of the CDM part of Fig. 15. In the following, the basic parameters and capabilities of channel coding and modulation of this broadcasting system are provided.

FIGURE 15

Block diagram of broadcasting system

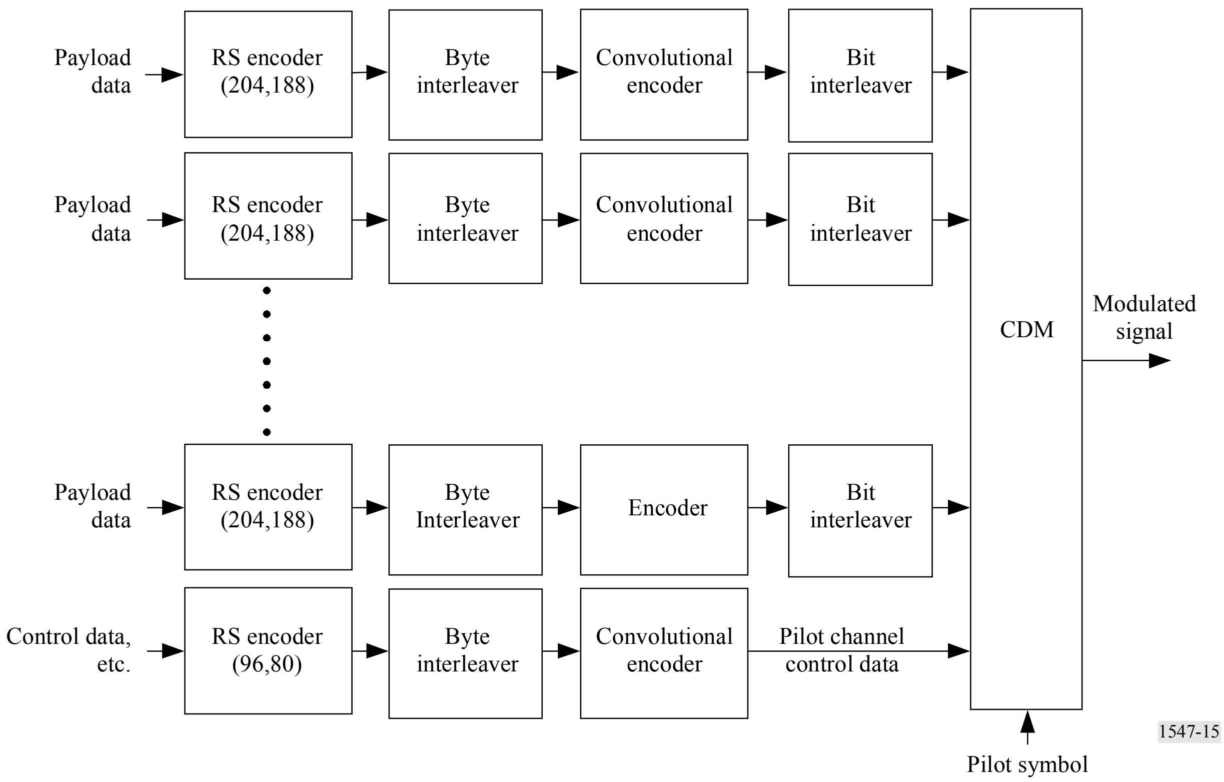
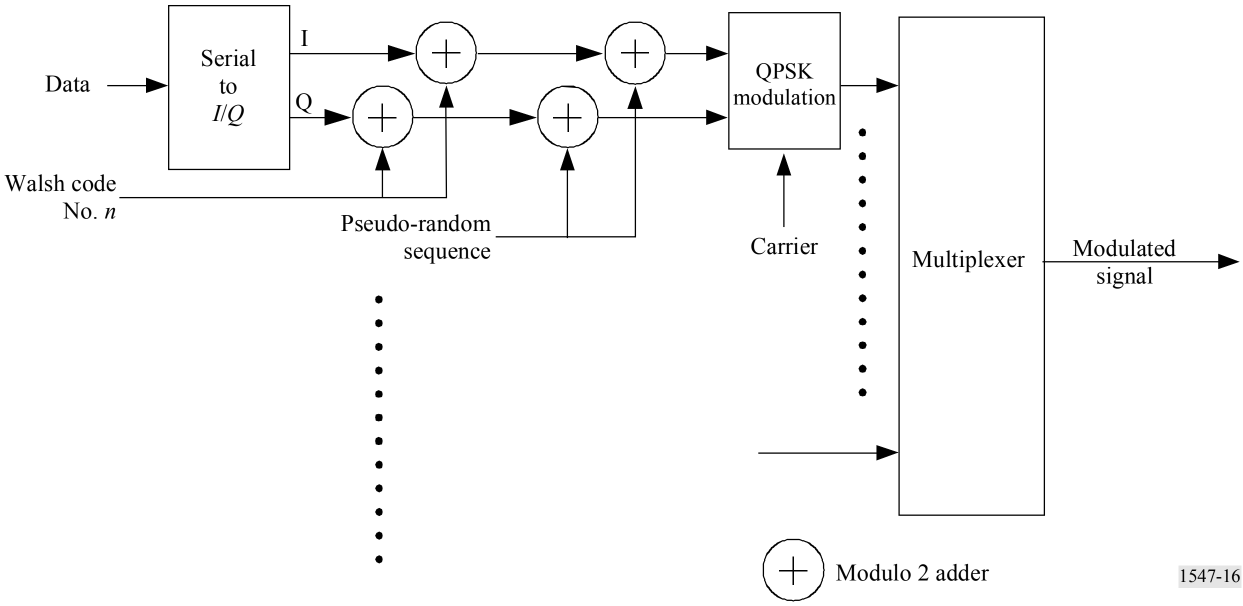


FIGURE 16

Detailed block diagram of CDM



3.1 Frequency band

This system can be used in various frequency bands, but the main target is the 2 630-2 655 MHz band. Since this is the highest frequency band allocated to BSS (sound), the received signals are likely to experience the highest Doppler shift.

3.2 Bandwidth

Basic bandwidth is 25 MHz.

3.3 Polarization

The system uses circular-polarization, however a complementary terrestrial repeater may use either circular-polarization or linear-polarization.

3.4 Modulation

The CDM scheme is adopted for modulation, both of the satellite link and the terrestrial gap filler link. As shown in Fig. 16, one data sequence is first converted from a serial bit stream to I and Q data sequences. Then each I and Q data sequence is spread by the same unique Walsh code (No. *n*) and a truncated *M*-sequence. These spread data are modulated into a QPSK signal. Modulated signals, each signal being identified by its Walsh code, are multiplexed with each other in the same frequency band.

3.4.1 Modulation of carrier

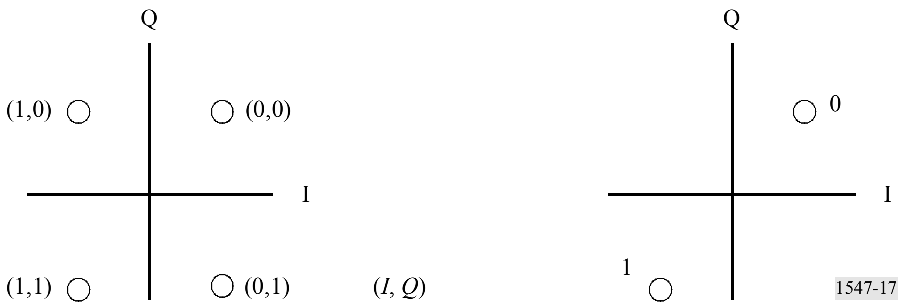
One pilot channel and several broadcasting channels comprise one whole CDM modulated broadcasting system as shown in Fig. 15. A broadcasting channel and part of the pilot channel data stream use QPSK modulation for the component modulation, while pilot symbols, frame synchronization symbol and a frame counter as defined in § 4.3, carried in the pilot channel data stream, are modulated using binary phase shift keying (BPSK).

3.4.2 Symbol mapping

Symbol mapping of QPSK and BPSK is shown in Fig. 17. In this system, QPSK is demodulated using coherent phase detection.

FIGURE 17

Symbol mappings of QPSK and BPSK modulation



3.5 Chip rate

Chip rate is 16.384 MHz and processing gain is 64.

3.6 Signature sequence and spreading sequence

Walsh codes of 64-bit length and a truncated *M*-sequence of 2 048-bit length are adopted as the signature sequence and the spreading sequence respectively. This spreading sequence is obtained by truncating maximum length sequences of 4 095-bit length generated, using 12-stage feedback shift register sequence.

3.7 Data spreading

Signature sequences and spreading sequences are modulo-2 added to the original I and Q sequence as shown in Fig. 16.

3.8 Roll-off factor

The transmitted signal is filtered by square-root raised cosine filter. The roll-off factor is 0.22.

3.9 The number of CDM channels

Theoretically, this system can multiplex 64 CDM channels because a 64-chip length Walsh code is adopted. In the corroborative testing, 30 CDM channels out of a possible 64 channels are multiplexed to achieve stable reception in multipath environments.

4 Channel coding

4.1 Error correction coding

Concatenated code, comprised of a K = 7 convolutional code as inner code and shortened RS (204,188) code as outer code, is adopted for forward error protection scheme.

4.1.1 Outer code

Outer code is the same as for other digital broadcasting systems. The original RS (255,235) code is defined as follows:

Code generator polynomial: $g(x) = (x + \lambda^0)(x + \lambda^1)(x + \lambda^2) \ldots (x + \lambda^{15})$, where $\lambda = 02_h$

Field generator polynomial: $P(x) = x^8 + x^4 + x^3 + x^2 + 1$

The shortened RS code can be implemented by adding 51 bytes, all set to zero, in front of the information bytes at the input of the RS (255,239) encoder. After the RS coding procedure, these null bytes are discarded.

4.1.2 Inner code

$K = 7$ convolutional code is adopted as the inner code of this system. Any code rate can be selected from 1/2, 2/3, 3/4, 5/6 and 7/8 by a puncturing technique for each broadcasting channel. These code rates are signalled using the control data of the pilot channel. Rate 1/2 convolutional code is used for the pilot channel.

4.2 Interleaving

Byte-wise convolutional interleaving is used between outer coding and inner coding. Furthermore, bit-wise convolutional interleaving with three-segment grouping is adopted after the inner coding.

4.2.1 Byte-wise interleaving

Byte-wise interleaving is the same as for other digital broadcasting systems, for example DVB-S, DVB-T, ISDB-S and ISDB-T.

4.2.2 Bit-wise interleaving

Figure 18 shows the working mechanism of the bit-wise interleaver and also Fig. 19 shows the conceptual diagram of the bit-wise interleaver and de-interleaver. The time delay of the bit-wise interleaver can be selected from eight possible positions defined in Table 3, for each broadcasting channel by using control data in the pilot channel. In the corroborative testing, position 5 was selected; hence the bit-wise interleaver has about 3.257 s delay to recover up to 1.2 s blackout of the received signal.

4.3 Pilot channel

Payload data is transmitted through broadcasting channels, whilst the system adopts a pilot channel to simplify receiver's synchronization and to transmit system control data.

The Pilot channel has three functions. The first is to transmit a unique word for frame synchronization and a frame counter for super frame synchronization. The second is to send the pilot symbol and the third is to transmit control data to facilitate receiver functions.

FIGURE 18

Bit-wise interleaver

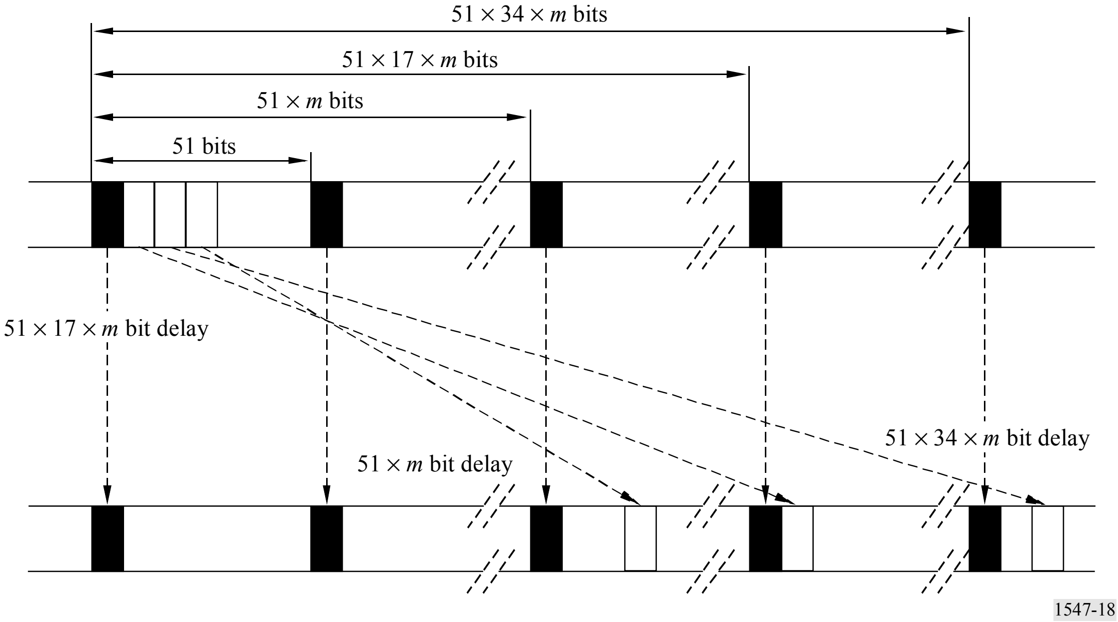


FIGURE 19

Conceptual diagram of bit-wise interleaver and de-interleaver

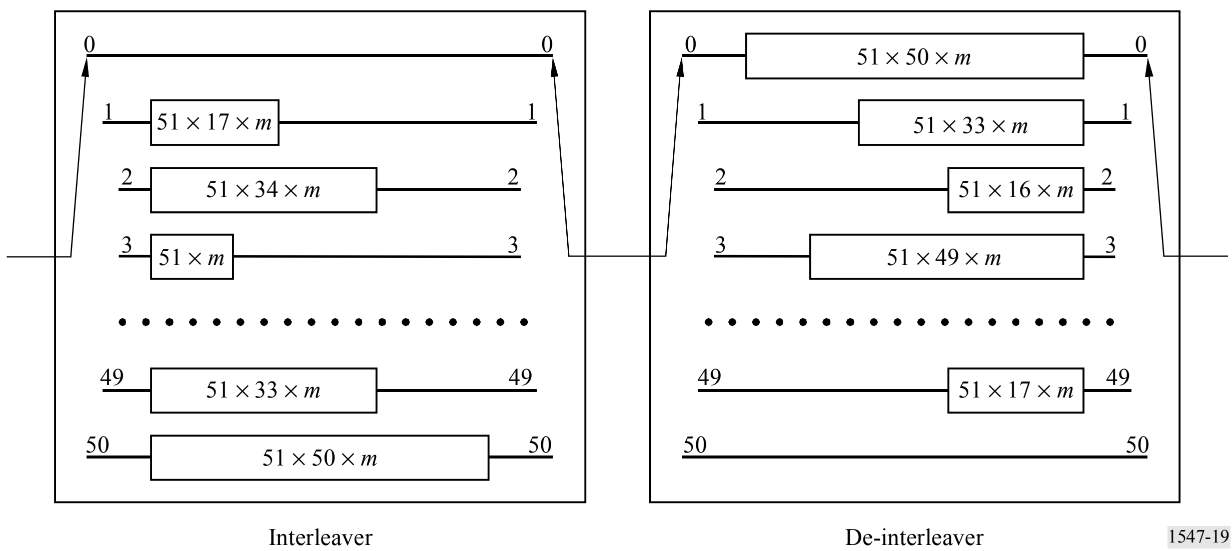


TABLE 3

Selectable positions of bit-wise interleaving size

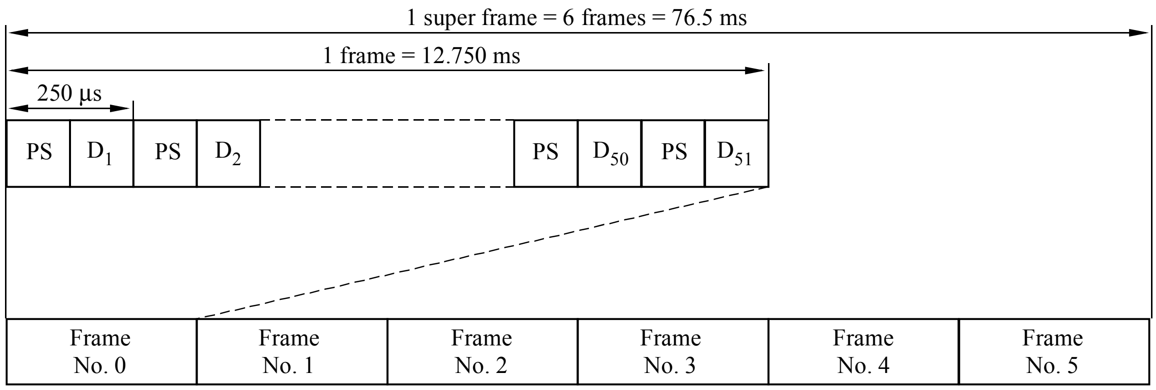
Position	Value of parameter *m*
0	0
1	53
2	109
3	218
4	436
5	654
6	981
7	1 308

4.3.1 Frame and super frame

Figure 20 shows the transmission frame and super transmission frame of this system.

FIGURE 20

Frame and super frame in pilot channel



PS: pilot symbol (32 bits)
D_1: unique word (32 bits)
D_2: frame counter (32 bits)
D_3 to D_{51}: control data, etc.

1547-20

A pilot symbol is inserted every 250 μs as described in the next section. One transmission frame comprises 51 times, one pilot symbol insertion period that has 12.75 ms time period. The first symbol D_1 (4 bytes or 32 bits), other than pilot symbols, is the unique word.

Six transmission frames give a super transmission frame that has a 76.5 ms time period. The second symbol D_2 is the frame counter, which assists the receivers to establish super frame synchronization. Any broadcasting channel with arbitrary puncturing rate can be synchronized in one super frame time period because this is the least common multiple of unit time intervals of each broadcasting channel with any possible punctured rate of convolutional code.

4.3.2 Pilot symbol

Special data embedded in the pilot channel are pilot symbols that are composed of 32-bit length continuing run of data 1. Using these pilot symbols, a receiver can analyse received signal profiles (path-search analysis) and these results are used to assist a RAKE receiver function. Pilot symbols are transmitted every 250 μs.

In order to improve the accuracy of path-search analysis, the pilot channel may have more signal power than a broadcasting channel. In corroborative testing, the pilot channel had twice the signal power of a broadcasting channel.

5 Service multiplexing

ISO/IEC 13818-1 (MPEG-2 systems) is adopted as the service multiplex. Considering maximum interoperability among a number of digital broadcasting systems, e.g. DVB-S, DVB-T, ISDB-S and ISDB-T, this system can exchange broadcasting data streams with other broadcasting systems through this interfacing point.

In this system some services, which are to come in the future, can be adopted if such future broadcasting services have adaptation capabilities for MPEG-2 systems.

6 Source coding

6.1 Audio source coding

MPEG-2 AAC (ISO/IEC 13818-7) is selected for this system. In order to use an AAC bit stream in MPEG-2 systems environment, the audio data transport stream (ADTS) is adopted.

6.2 Data coding

Various types of data broadcasting are applicable including mono-media (e.g. video source coding, text) and multimedia (mixture of audio, video, text and data) as long as these data structures are MPEG-2 systems compliant.

7 Example of an application of Digital System E

7.1 Satellite link

In this example, a geostationary satellite with a large transmission antenna is assumed. The feeder-link signal is fed from an earth station in the 14 GHz band while the service link (downlink) is to the Japanese service area using the 2.6 GHz band. Major characteristics of the satellite are given below:

– Feeder-link signal frequency: 14 GHz band

– Downlink frequency: 2 642.5 MHz

– Downlink bandwidth: 25 MHz

– e.i.r.p.: more than 67 dBW (within service area, including antenna-pointing losses)

7.1.1 Spectrum

The spectrum of the output signal from the satellite broadcasting station is shown in Fig. 21 in the case of 2 dB output back-off (OBO). In this case, an output signal is simulated using a non-linear amplifier which has similar input/output characteristic to a typical satellite transponder.

7.1.2 BER versus C/N_0 performances under an additive white Gaussian noise (AWGN) environment

BER versus C/N_0 performances under an AWGN environment were measured for various kinds of output back-off and frequency offset.

Figure 22 shows BER versus C/N_0 performances for different output back-off values of a satellite simulator. Unless otherwise noted, the following conditions were assumed in order to measure BER versus C/N_0 performances described in this section.

– BER was measured at the point after Viterbi decoding.

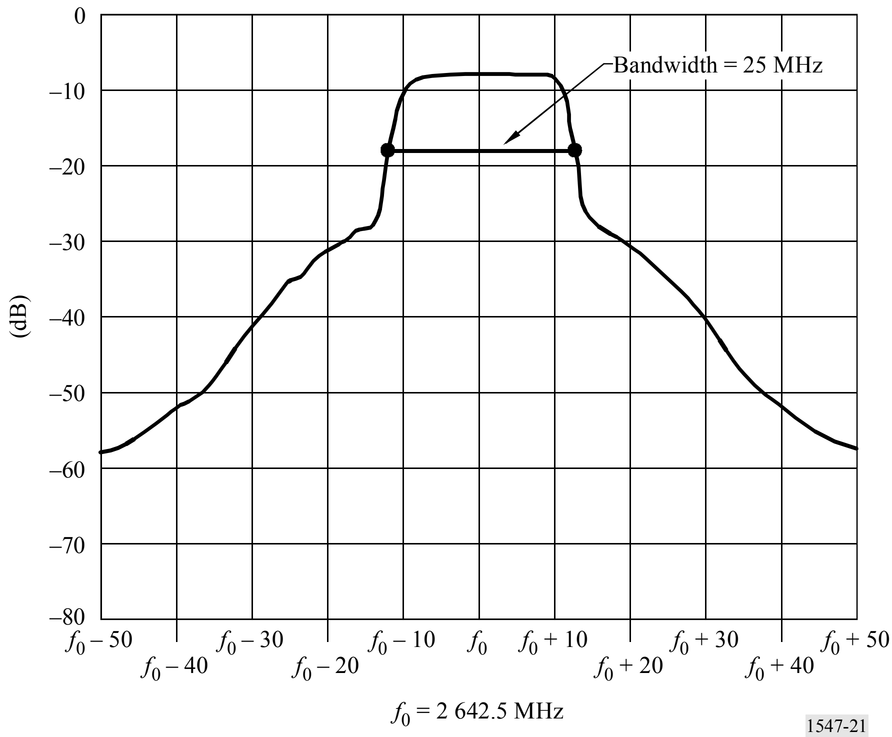
– Coding rate used in convolutional coding was 1/2.

– Data rate after Viterbi decoder was 256 kbit/s.

– Two-branch antenna diversity was used.

FIGURE 21

Spectrum of output signal from satellite (2 dB OBO)
(simulated using non-linear amplifier)



According to Fig. 22, when output back-off of a satellite simulator is set at the operating point (2 dB), the required C/N_0, which is defined in this system as C/N_0 where BER is equal to 2×10^{-4}, is 56.4 dB(Hz). Because the theoretical value of the required C/N_0 for an ideal reception is 54.3 dB(Hz), measured implementation loss is 2.1 dB.

When output back-off is set 1 dB below the operating point, the required C/N_0 is 0.1 dB higher. On the other hand, when OBO is set 1 dB above the operating point, the required C/N_0 is 0.1 dB lower. Hence, degradations of BER performance due to this non-linearity are very small but observable.

Figure 23 shows BER versus C/N_0 performances for different frequency offsets at the receiver. Note that the OBO is 2 dB and other conditions other than the frequency offset level are the same as in Fig. 22. According to Fig. 23, degradation of required C/N_0 is 0.3 dB for each case of ±264 Hz (= $\pm 1 \times 10^{-7}$ at 2 642.5 MHz) frequency offset, hence the measured degradation due to frequency offset up to ±264 Hz is small.

During these tests, the quality of received sound was monitored and it was confirmed that a degradation of less than perceptible grade was not observed, while the measured BER was less than 2×10^{-4} at the output of the Viterbi decoder. Programme selection was also checked and it was confirmed that changing to another programme worked successfully and the broadcast content was received correctly.

FIGURE 22

BER versus C/N_0 under AWGN environment for different levels of transponder OBO

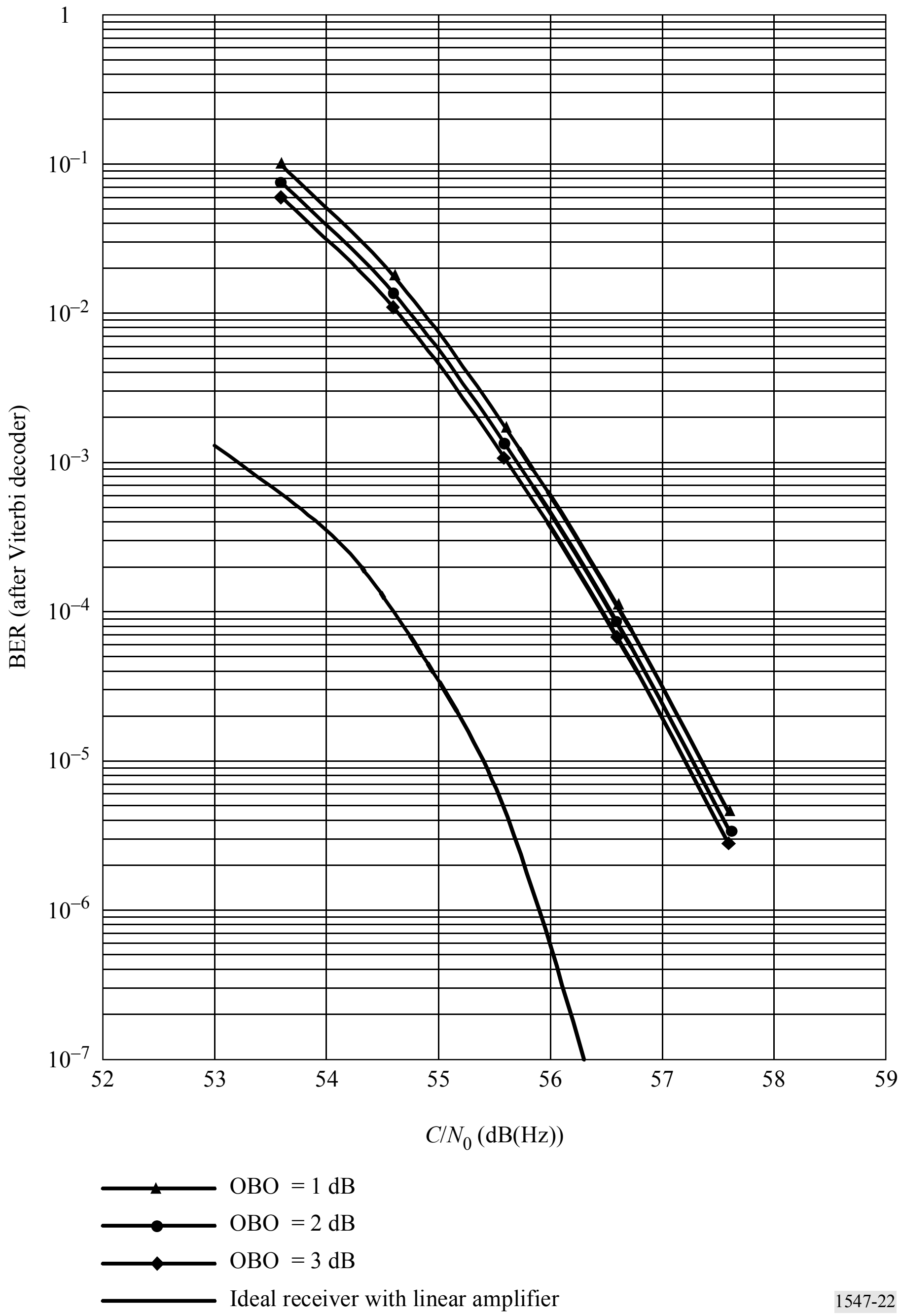
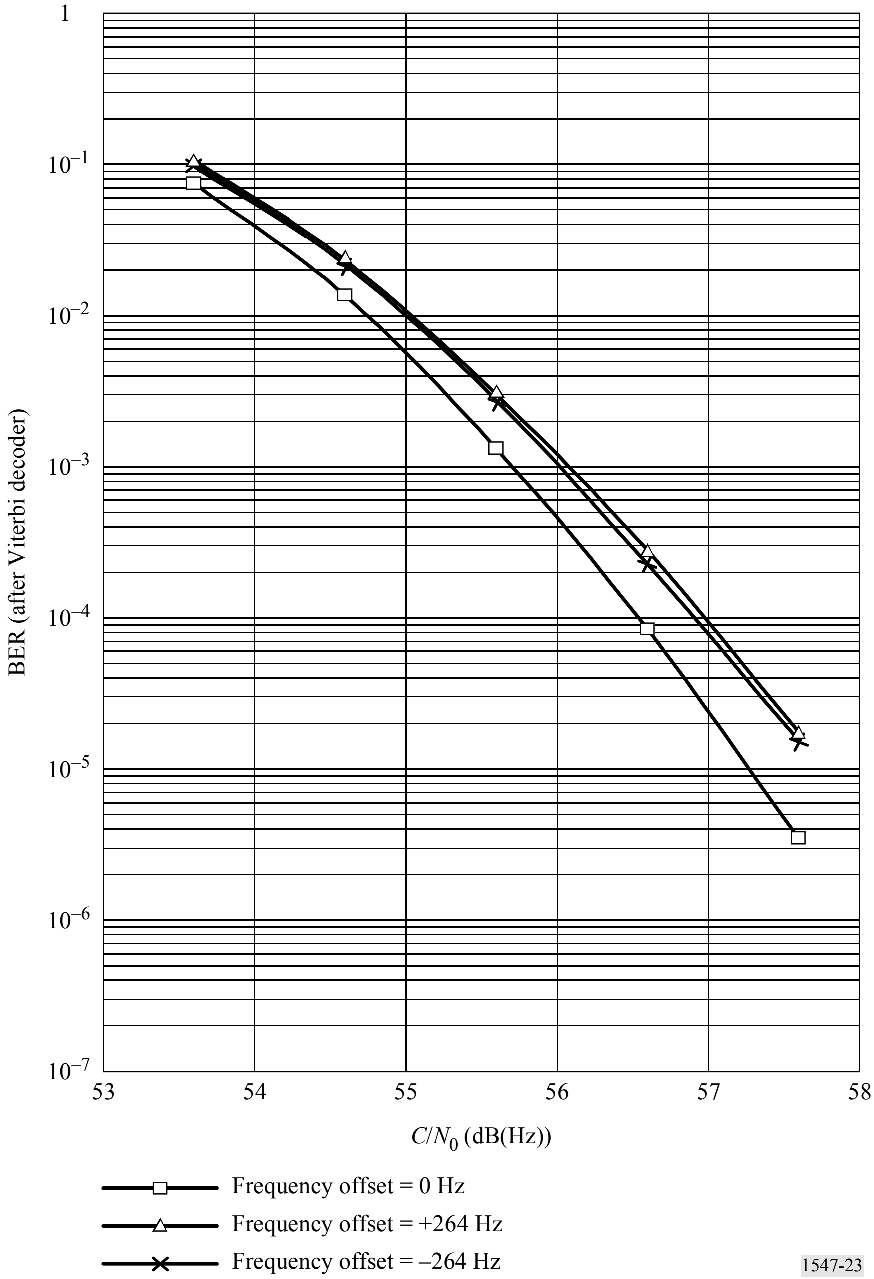


FIGURE 23

BER vs. C/N_0 under AWGN environment for different frequency offsets



7.2 Gap filler

7.2.1 Direct amplifying gap filler

The main purpose of the direct amplifying gap filler is to allow reception of the broadcast signal directly from broadcasting satellite, to amplify it and to transmit it to the signal blocked area.

– Receiving frequency: 2 630-2 655 MHz

– Transmitting frequency: 2 630-2 655 MHz

– e.i.r.p.: 1.7 dBm

– Coverage area: line-of-sight area up to 500 m from the station.

7.2.2 Frequency conversion gap filler

This equipment receives 11/12 GHz band feeder signals from the satellite, converts them to the 2.6 GHz band, amplifies up to the desired level, and transmits them to the signal blocked area. The major characteristics of the equipment are:

– Receiving frequency: 11/12 GHz bands

– Transmitting frequency: 2 630-2 655 MHz

– e.i.r.p.: 60.7 dBm

– Coverage: circular area up to 3 km radius.

7.3 Experimental results of high-speed vehicular receptions

One of the main features of this system is its capability for vehicular reception. In the corroborative testing, high-speed vehicular reception was examined carefully in laboratory and field tests. BER versus C/N_0 is shown in Fig. 24 for laboratory test results. There is only a small degradation of BER characteristics for 50 km/h, 100 km/h and 150 km/h. Field testing for high-speed vehicular reception was conducted at speeds of up to 100 km/h on the Chuo highway along the west side of the Tokyo metropolitan area.

7.4 Receiver model

Characteristics of typical vehicular receivers for this system are given below and Fig. 25 shows the block diagram of a typical vehicular receiver.

– Centre frequency: 2 642.5 MHz

– Input signal bandwidth: 25 MHz

– Figure of merit (G/T): more than –21.8 dB (K^{-1})

Antenna gain: more than 2.5 dBi for satellite reception
more than 0 dBi for terrestrial reception

Noise figure: less than 1.5 dB

– Demodulation: pilot symbol aided coherent demodulation and RAKE receiver with six fingers

– Diversity: two-antenna diversity

– Receiving filter: square-root raised cosine roll-off filter (roll-off factor is 22%)

– Decoding of convolutional code: soft-decision Viterbi decoding

– Implementation loss: less than 2 dB (degradation from the theoretical value at $BER = 2 \times 10^{-4}$).

FIGURE 24

BER vs. C/N_0 for high-speed reception (50 km/h, 100 km/h and 150 km/h)

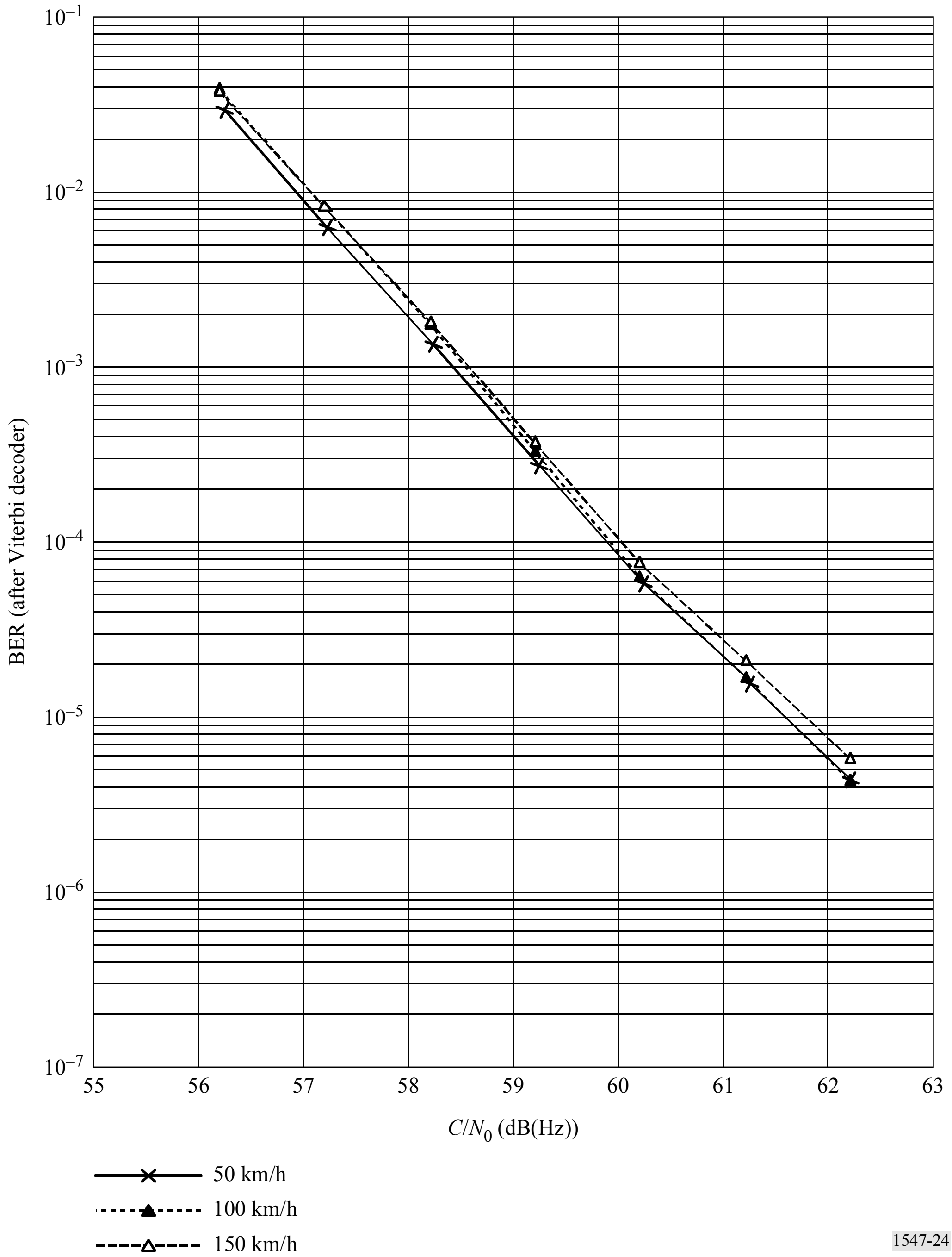


FIGURE 25

Block diagram of typical receiver