CHAPTER

10

Contents

Digital transmission

10.1 Introduction

The introduction of digital transmission technology enables a dramatic decrease in required bandwidth per channel. In the context of television services this implies that more television channels will be available to provide the home user with programs and special services. Services such as pay-per-view and video-on-demand, for example, require a large number of television channels. Because of the increased number of available channels it is expected that the costs per channel will drop. However, this depends on the investments that have to be made to enable the actual implementation of the digital transmission technology. Standards can play an important role in the establishment of economies of scale in order to obtain a return on investment.

This chapter discusses the DVB specifications for digital transmission technology, which were standardized by ETSI. DVB has specified several systems for digital communications via satellite, CATV, and terrestrial networks. The basic elements and the several (sub)systems pass the revue per communication system. Moreover, the channel encoding and decoding processes are explained at a functional level. The presence of *additive white gaussian noise* (AWGN) is assumed for each channel, unless stated otherwise. Information concerning the system performance can be obtained from the ETSI standards papers. Consult [1] for a more detailed study of the main DVB digital transmission systems.

10.2 DVB satellite

Television signals can be provided via various transmission networks. This section discusses the DVB specifications for satellite communications, first explaining the basic elements of satellite communication and then describing the DVB channel encoding and decoding systems.

10.2.1 Elements of satellite communications

Several elements play a role in satellite communications. The several elements discussed in this section concern typical transmission characteristics, which have to be regarded when specifying a satellite communications system.

10.2.1.1 Transmission medium

By providing point-to-multipoint communications from a point in space, satellites typically have the ability to create simultaneous links to users on Earth. Moreover, with satellites, capacity can be dynamically allocated in correspondence to the users' needs.

Satellites that are used for broadcasting purposes are located in a *geostationary orbit* near the equator at an altitude of about 36,000 km. Because these satellites move as fast and in the same direction as the Earth rotates, perceived from the Earth's surface, they seem to hang still at a fixed point.

The energy needed for transmission is supplied by the satellite's solar system. As a result of the solar system's low efficiency, the power of the output signal is limited. However, the rich availability of bandwidth counters this limitation. Today's satellite systems use channel bandwidths from 26 MHz to 54 MHz.

The ITU, which acts under the authority of the United Nations (UN), has developed rules and guidelines called *Radio Regulations* [2]. Since 1903 a series of international radio conferences have been held. The most recent was the 1995 World Radio Conference (WRC-95). Table 10.1 lists the frequencies allocated to *broadcasting satellite services* (BSS), as well as the corresponding geographical areas.

10.2.1.2 Satellite uplink/downlink

The baseband signal is processed and transmitted to the satellite by a modulated *radio frequency* (RF) carrier. The RF carrier is transmitted from the Earth station to the satellite via the *uplink* frequency spectrum (Figure 10.1). Next, the RF carrier is sent back to Earth via the *downlink* frequency spectrum.

In order to avoid interference, the uplink and downlink are operated on different frequencies. Beside using BSS frequencies, sometimes frequencies allocated to FSSs are used for the uplink. A BSS, for example, could use a 14.0–14.5 GHz uplink (FSS) and an 11.7–12.5 GHz downlink (BSS). The function of the satellite itself can be thought of as a large repeater in space. It simply receives an RF signal, amplifies the RF signal, translates the signal frequency, and sends the signal back to Earth.

Table 10.1
Frequency Allocations to Broadcasting Satellite Services Related to Television (Downlink)

Frequency Range (GHz)	Restriction
2.52–2.655	c
11.7–12.2	1, 3 only
12.2–12.5	1, 2 only
12.5–12.7	2, 3c only
12.7–12.75	3c only
21.4–22	1, 3 only
40.5–42.5	
84–86	

Notes:
c = community reception only;
1 = (Region 1): Europe, Africa, former USSR, and Mongolia;
2 = (Region 2): North and South America and Greenland;
3 = (Region 3): Asia (except former USSR and Mongolia), Australia, and the Southwest Pacific.

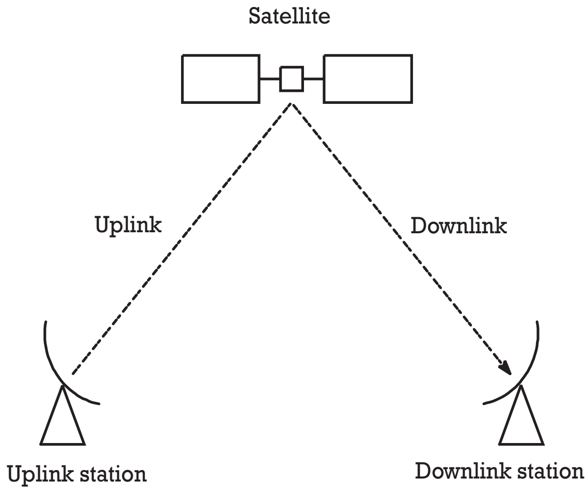

Figure 10.1 Satellite system.

10.2.1.3 Orthogonal polarization

The number of transponders can be increased by "reusing" frequencies. This is accomplished by means of orthogonal polarization, which allows two signals to be transmitted in the same frequency without interfering. The polarization of a radiated electromagnetic wave is the curve traced by the endpoint of the instantaneous electric field vector as observed along the direction of propagation. Polarization can be classified as linear, circular, or elliptical [3].

In case of linear polarization, the electric field vector oscillates along the horizontal or the (orthogonal) vertical line, respectively (Figure 10.2). As a result, the information capacity carried by the satellite can be doubled. EUTELSAT and ASTRA, among others, make use of this type of polarization. The electric field vector of a circularly modulated signal rotates clockwise or counterclockwise orthogonally in the direction of propagation. Hence, the electric field vector is constant in length but traces a circle. This type of polarization is applied in TV-SAT. In case of elliptical polarization, the electrical field vector describes a (counter)clockwise elliptical curve. At the receiving end the orthogonally polarized signals can be separated again.

In theory there is infinite isolation between orthogonal polarizations. Due to system imperfections and propagation influences, however, this is not the case in practical systems. Dual-polarized transmission requires a

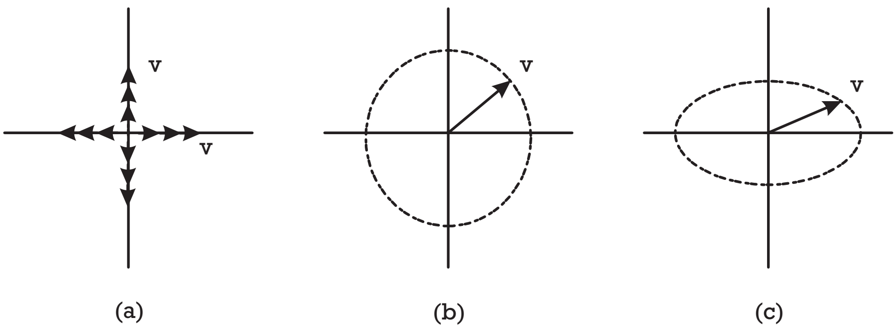

Figure 10.2 Types of orthogonal polarization: (a) linear, (b) circular, and (c) elliptical.

good level of isolation between two polarizations in order to keep the interference at an acceptable level. This can, for example, be achieved by employing an interleaved frequency plan as shown in Figure 10.3.

10.2.1.4 Energy dispersal

In general, the power density of a DTV signal is equally divided over its own bandwidth. It might occur, however, that for a period of time the bit stream of a television signal contains a sequence of either all ones or all

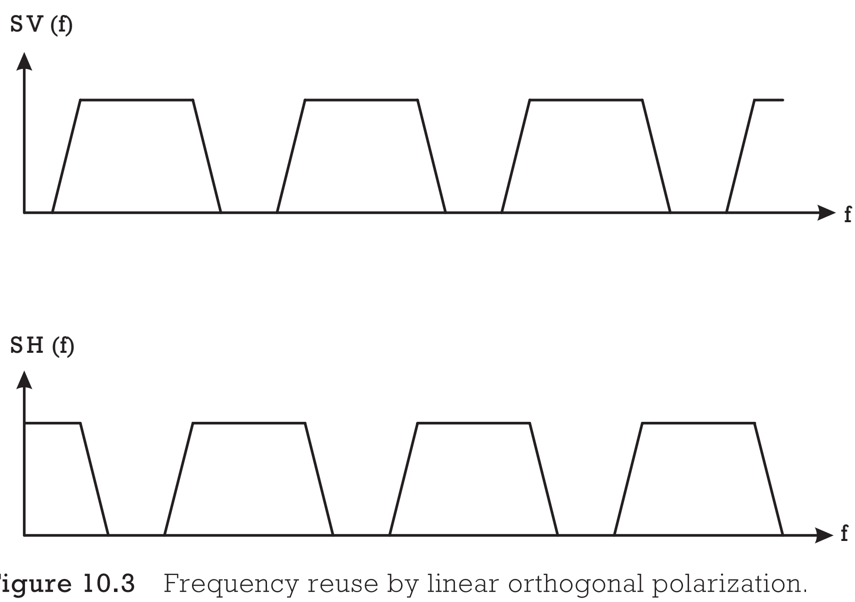

Figure 10.3 Frequency reuse by linear orthogonal polarization.

zeros. In case *phase shift keying* (PSK) is used as a modulation scheme (see Section 10.2.1.5), this results in a concentration of the power density around the carrier frequency. Because of this power peak in the frequency spectrum, a satellite channel, which operates in the same frequency range but is orthogonally polarized, may suffer from interference. If the satellite Earth station is unable to filter the interference, the user may notice disturbance of the television program.

In order to avoid a long sequence of ones or zeros and to distribute the transmitted frequency spectrum more evenly across the transponder bandwidth, the bit stream of the television signal is randomized. This means that the signal is more or less represented by alternating ones and zeros. A digital scrambling device changes the signal as it would concern a bit stream with a random structure. At the receiving end the signal is descrambled to obtain the original signal again.

10.2.1.5 Modulation

To transmit information over a bandpass channel, a baseband signal, which represents the information, is modulated on a carrier frequency. Digital information is assumed to be binary (1 and 0) and occurs at a rate of 1 bit per Tb seconds. Alternatively, the binary digits can be segmented into blocks consisting of m bits. Since there are $M = 2m$ blocks, M different signal values are required to represent the m-bit blocks unambiguously. Each m-bit block is called a symbol. The symbol duration is $T_s = mT_b$ seconds. This type of transmission is referred to as M-ary signaling.

The actual modulation can be achieved by varying the signal amplitude, frequency or phase. M-ary PSK is commonly used in digital satellite communications. The signal amplitude is constant and M different phases are used to represent M distinct symbol values. A constant amplitude is very important to the non- linear characteristic of the transponder. M-ary signaling allows transmission of m bit in a bandwidth of one Hertz.

10.2.2 DVB satellite systems

DVB has specified satellite systems for DTH satellite services, satellite services via cable television, and terrestrial broadcasting networks and SMATV. This section discusses the several DVB satellite systems at a functional level in which the application and the required bandwidths play an important role.

10.2.2.1 Direct-to-home system

Within DVB, satellite systems for digital multiprogram television and HDTV have been specified. One of these systems concerns the DTH system for consumer IRDs. The DTH system operates at 11/12 GHz and uses bandwidths in the range of 26 MHz to 54 MHz. Home users can receive the signal broadcast by the satellite directly, by means of a satellite dish (diameter 60cm). The specifications for this system have been standardized by ETSI (ETS 300 421 [4]).

10.2.2.2 Satellite services via cable television and terrestrial broadcasting networks

The same standard (ETS 400 421) applies to the transmission of satellite signals to a CATV head-end station. For various reasons, CATV network operators may want to decide for themselves which programs they want to provide to their users. At the cable head-end the signals are separated in a demultiplexer. Next, with the help of a remultiplexer the desired programs are compiled. Finally, the remultiplexed satellite signal is remodulated in order to be accommodated in an 8-MHz CATV channel to the home user IRD.

The same procedure also applies to terrestrial broadcasting networks. In this case, the satellite signal is remodulated in order to be provided to the home user IRD via, for example, an 8-MHz terrestrial channel.

10.2.2.3 Satellite master antenna television system

A SMATV system is defined as a system for the distribution of television and sound signals to households in one or more adjacent buildings [5]. These signals are received by a satellite receiving antenna and may be combined with terrestrial television signals. SMATV distribution systems are also known as community antenna installations or domestic television cable networks.

In correspondence to the CATV head-end, the desired satellite and terrestrial signals are demodulated, demultiplexed, remultiplexed, and remodulated according to the SMATV channel characteristics in the SMATV head-end. The DVB specifications (ETS 300 473 [6]) for the SMATV system offer two alternatives for providing signals to the home user IRD. The satellite signals can be distributed directly using frequency conversion (e.g., to the extended *intermediate frequency* (IF) band (0.95 GHz to 2.05 GHz)) or to the extended *super* (S)-band (0.23 GHz to

0.47 GHz)). The alternative is to first remodulate the satellite signal and distribute it via the SMATV network and second, use the same frequency conversion.

10.2.3 Channel encoding

This section explains how the constraints in the basic elements of satellite communication, which were discussed in Section 10.2.1, are respected by DVB in the specifications for channel encoding.

10.2.3.1 Encoding system

Before explaining the signal encoding process in more detail, a conceptual representation of the encoding system and modulation is provided in Figure 10.4.

The most important steps to adapt the TS to the satellite transmission medium are the following.

- Transport multiplex adaptation;
- Randomization for energy dispersal;
- Error correction coding and interleaving;
- Baseband shaping for modulation;
- Modulation.

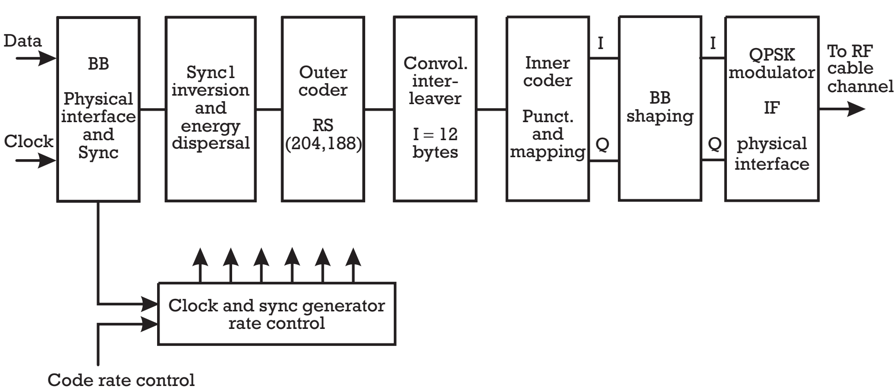

Figure 10.4 Conceptual encoding system description.

10.2.3.2 Transport multiplex adaptation

The satellite system is compatible with MPEG-2 coded signals [7]. This implicates that the modem transmission frame complies with the MPEG-2 multiplex transport packets. These packets consist of 188 bytes of which the first four bytes are used for the header. The header's first byte is reserved for the synchronization byte. The length of the packets, 188 bytes, was chosen to ensure compatibility with ATM transmission. ATM is considered to be an important future transmission technology and has already been introduced in some public broadcasting and telecommunications networks.

10.2.3.3 Energy dispersal scrambling

To avoid a concentration of the power density around the carrier frequency, the data of the MPEG-2 TS is randomized by a *pseudo random binary sequence* (PRBS) generator (Figure 10.5).

At the start of every eight transport packets, an initial sequence is loaded into the PRBS registers. Via an exclusive-or operation the first bit (i.e., MSB) at the output of the PRBS register is applied to the first bit of the first byte following the inverted MPEG-2 sync byte. The MPEG-2 sync bytes of the subsequent seven transport packets are not randomized in order to support other synchronization functions. Although the PBRS generation continues during this process, its output is disabled. The period of the PRBS sequence is 1,503 bytes.

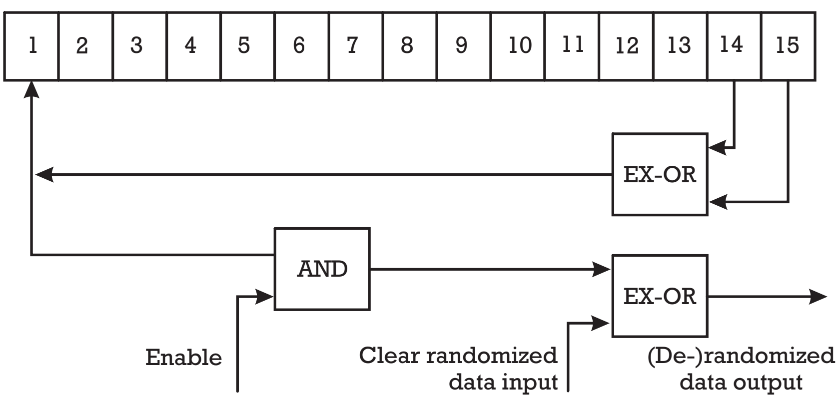

Figure 10.5 PRBS generator.

10.2.3.4 Inner coding

Digital transmission allows the use of *forward error correction* (FEC). The DVB satellite system requires a *quasi-error-free* (QEF) transmission. This means that less than one uncorrected error-event per hour is allowed. Hence, the *bit error ratio* (BER) must be within the range of $1*10^{-11}$ to $1*10^{-10}$ at the input of the MPEG-2 demultiplexer.

The satellite system incorporates two different error control procedures—an outer and inner coding. The latter is located closest to the satellite link. The outer coder uses a *Reed-Solomon* (RS) code. The 188 bytes packets are expanded with 16 redundant bits. Therefore this code is referred to as RS(204,188). The adding of these redundant bits allows up to eight erroneous bytes per packet. As a result, the BER may increase up to $2*10^{-4}$ at the input of the RS decoder in order to meet the required BER of $1*10^{-11}$ to $1*10^{-10}$ at the input of the MPEG-2 demultiplexer.

10.2.3.5 Convolutional interleaving

During satellite transmission lengthy burst errors for which the application of an error correction code is not sufficient may occur. By means of an interleaving process, adjacent symbols become separated. As a result mutilated packets are split up into individual errors. These errors can be corrected by the RS decoder at the receiving end. This procedure is referred to as convolutional interleaving. Figure 10.6 shows a conceptual representation of convolutional interleaving as applied by DVB.

The output packets from the outer coder are consecutively read into a *first-in, first-out* (FIFO) shift register, which contains M cells. The shift register is called a branch and the *interleaving depth* (I) refers to the number of branches the interleaver incorporates. DVB has specified $I = 12$ and $M = 17$ ($M = N/I$ and $N = 204$ bytes). As a result, adjacent mutilated bits in the channel are located at least 205 bytes apart from each other in the received TS after de-interleaving. In order to support synchronization, the (inverted) sync bytes are always routed in the branch corresponding to $I = 0$ of the interleaver. Next, the output of the FIFO shift registers are cyclically connected to the input of the inner coder by the output packet switch. This requires that the input and output switches are synchronized. At the receiving end, the whole process is reversed.

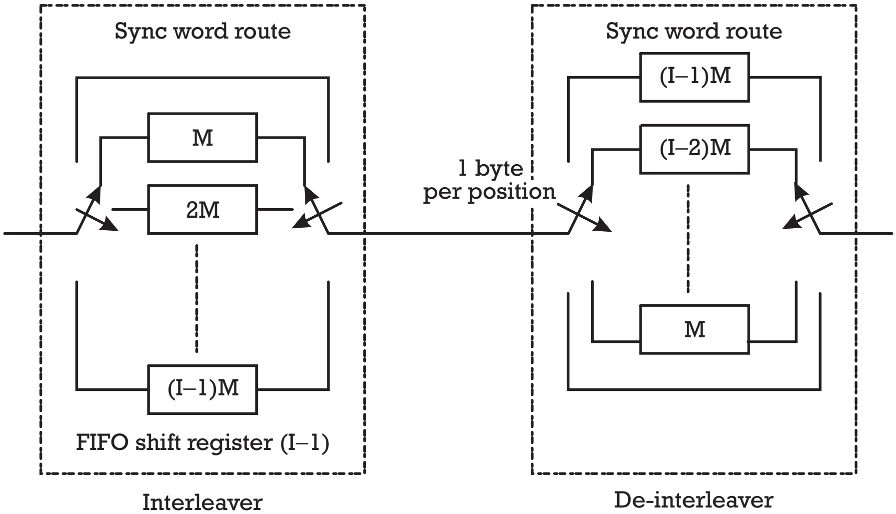

Figure 10.6 Convolutional interleaving.

10.2.3.6 Outer coding

A higher output power of a satellite signal has a beneficial effect on the BER. Because of technological and economical constraints, however, the satellite offers a medium power level. This is insufficient to achieve the required BER. To maintain the same BER, this implies that the Earth station satellite dish must have a larger diameter. However, especially in the case of DTH systems, the diameter of the satellite antennas must be small. A successful introduction of digital satellite technology requires low-cost home consumer antennas.

If the satellite dish diameter has a given value and the BER turns out to be high, the alternative to guarantee a QEF quality is to add error correction bits according to a convolutional code (Viterbi code) that doubles the total amount of bits. A more economical coding can be achieved by an additional process called puncturing. The redundancy of bits with respect to the useful information, which is referred to as the code rate, can now be chosen. For example, a code rate of 3/4 indicates that the total data contains 25% error correction bits and 75% useful data. Depending on the specific needs of satellite transmission, different code rates can be applied (see Table 10.2). In case the satellite produces a relatively high output

Table 10.2
Inner Code Rate and Corresponding Carrier to Noise Ratio

Inner Code Rate	C/N [dB]
1/2 np	4.1
2/3	5.8
3/4	6.8
5/6	7.8
7/8	8.4

Notes:
np = no puncturing;
B = 33 Mhz;
BER = $2*10^{-4}$ after Viterbi;
QEF (BER = $1*10^{-11}$ to $1*10^{-10}$) after RS.

signal power, the number of redundant bits can be kept small. This allows maximum error protection efficiency and a flexible implementation of the DVB satellite specifications.

10.2.3.7 Filtering

Prior to modulation, the digital signal is filtered so that it does not exceed the satellite channel's bandwidth. Exceeding this bandwidth could lead to interference with adjacent channels. According to the Nyquist (pulse shaping) criterion, the bandwidth (B) occupied by the pulse spectrum is $B = (r_s/2)(1+\text{alpha})$, in which r_s represents the symbol rate, and alpha is the filters' roll-off factor, where 0<alpha<1. Theoretically, a channel bandwidth of at least $r_s/2$ is required to accommodate the signal. In practice, however, the signal is formed by a raised cosine, which implies that the signal bandwidth is larger than $r_s/2$. Hence, a guard interval between two adjacent channels is required. If the guard interval is sufficiently large, a raised cosine filter can be used (Figure 10.7). This results in an acceptable level of interference.

DVB has specified a square root raised cosine filter with roll-off factor alpha = 0.35.

10.2.3.8 Modulation

The DVB digital satellite system uses *quadrature PSK* (QPSK) where the amplitude has four phase states ($M = 4$), and together these phases can

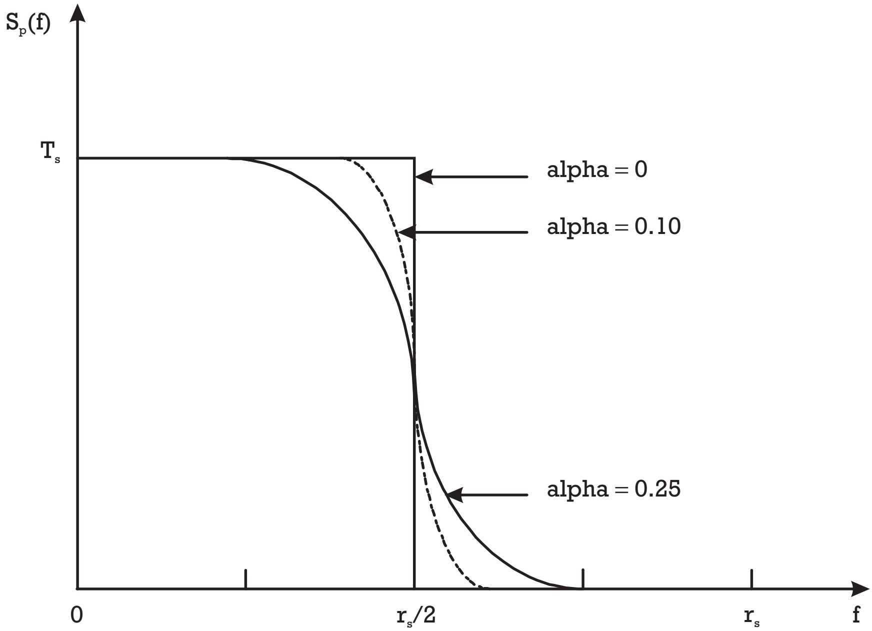

Figure 10.7 Raised cosine spectrum.

carry information that is represented by two bits ($m = 2$). This implies transmission of up to 2 bits in a bandwidth of one hertz. The actual transmission efficiency depends on the error coding applied. Figure 10.8 presents the QPSK constellation diagram. The Gray coding used defines that a phase shift of ±90 degrees implies that the digital representation of the phase changes one bit only.

10.2.4 Channel decoding

Section 10.2.3 explained the DVB encoding system for satellite communications. At the receiving end the signal needs to be decoded again in order to obtain the original signal. Hence, this section discusses the DVB specifications for the channel decoding.

10.2.4.1 Decoding system

At the receiving end, with the help of the recovered carrier and clock signals and sync signal, the decoding system more or less reverses the coding

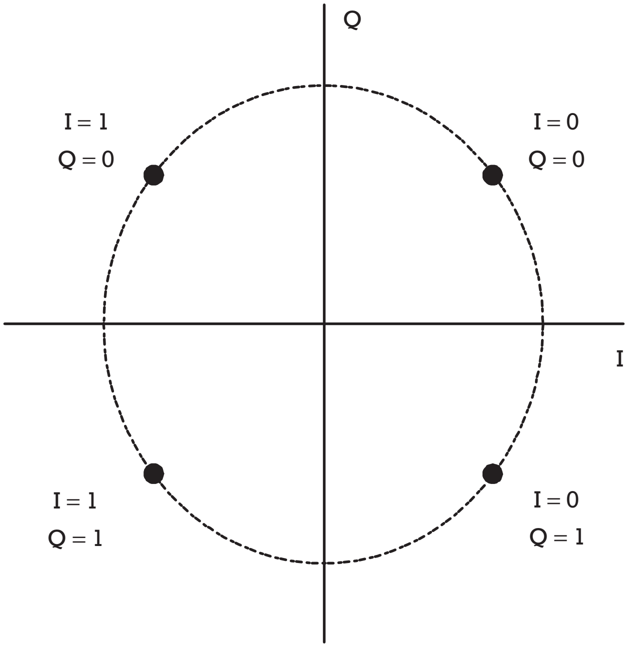

Figure 10.8 QPSK constellation diagram.

process. Hence, the decoding system (Figure 10.9) incorporates the following:

- Demodulation;
- Baseband reshaping and carrier and clock recovery;
- Inner error correction decoding;
- Synchronization decoding;
- Outer error correction decoding and de-interleaving;
- Derandomization for energy dispersal;
- Transport multiplex adaptation.

10.2.4.2 Demodulator

At the input of the receiving end the QPSK demodulator detects the phase of the carrier signal after which the symbol information can be

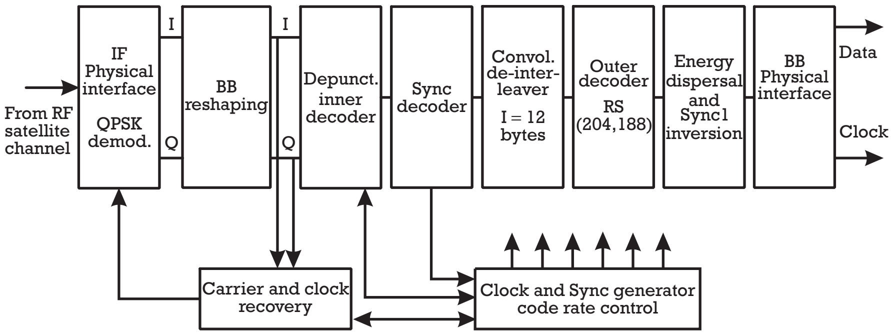

Figure 10.9 Conceptual decoding system description.

demodulated. Because the carrier signal can have four different phases (each with a 90-degree difference), a selection procedure is used to detect the correct phase in a maximum of two steps. The first step detects a phase error of ±90 degrees. In the next step a possibly remaining 180-degree phase error can be detected. The actual phase error detection and correction is executed in the following decoding process.

10.2.4.3 Filtering and carrier and clock recovery

The demodulated digital pulses are reshaped by means of a complementary square root raised cosine filter. In compliance to the filter at the transmitting end, the roll-off factor alpha is 0.35. This results in an acceptable level of interference with adjacent satellite channels. The demodulator synchronization is achieved by means of a carrier and clock recovery unit, which makes use of a *phase-locked loop* (PLL). The PLL functions as a feed back circuit in order to lock on to the rhythm of the clock signal.

10.2.4.4 Viterbi decoder

The filtered signal is then provided to the inner decoder, which incorporates a Viterbi [8] decoder with flexible depuncturing of error correction bits. In a trial and error process the correct code rate and depuncturing for the decoding process is selected. Moreover, a ±90-degree phase error can be detected. Depending on the adopted code rate, a BER in the order of $1*10^{-2}$ to $1*10^{-1}$ at the input of the Viterbi decoder is allowed so as to obtain the required BER of $2*10^{-4}$ at the input of the RS decoder for QEF quality in the end.

10.2.4.5 Sync decoder

To reconstruct the data stream with complete 204 bytes packets for further RS demodulation and energy dispersal descrambling, the preceding de-interleaving process has to be synchronized. At the transmitting end, synchronization bits were added for this purpose. Furthermore, if seven out of eight sync pulses are decoded as inverted, a 180-degree phase error is detected. This error cannot be detected by the Viterbi decoder. Next, at the output of the sync decoder, the data stream is inverted.

10.2.4.6 De-interleaver and Reed Solomon decoder

The interleaving process is reversed at the receiving end by means of a de-interleaver. As described above, the de-interleaver is synchronized to regain the complete data packets. As mentioned earlier, the (de)-interleaving and RS (de)coding process enables the correction of burst errors. The BER at the input of the RS decoder must be $2*10^{-4}$ at the most in order to obtain a BER in the order of $1*10^{-11}$ to $1*10^{-10}$. This complies to the required QEF quality.

10.2.4.7 Energy dispersal descrambler

The energy dispersal descrambler finally recovers the MPEG-2 Transport Stream by reversing the scrambling procedure. The descrambler is initiated by the inverted sync byte of the first transport packet into a group of eight packets. Next, the TS is provided to an MPEG-2 demultiplexer, after which MPEG-2 source decoding follows. In the TS an additional bit is inserted directly after the sync byte. This bit is to indicate whether an error has occurred during transmission but has not been corrected during the error correction process.

10.3 DVB cable

Beside satellite communication systems, television signals can be provided via CATV networks. This section discusses the DVB specifications for cable communication, first explaining the basic elements of cable communication and then describing the DVB channel encoding and decoding systems.

10.3.1 Elements of cable communications

This section discusses the several elements that play a role in cable communications, including typical transmission characteristics, which have to be regarded when specifying a cable communication system.

10.3.1.1 Transmission medium

Within CATV networks digital video signals are typically transmitted via 8-MHz channels. The theoretical maximum symbol rate ($r_{s,\max}$) depends on the roll-off factor (alpha) of the raised cosine filter. Hence, $r_{s,\max} = 8$ MHz/(1 + alpha). For alpha = 0.15 this implies $r_{s,\max} = 6.96$ MBaud.

In cable networks the transmitted signals attenuate after traveling a certain distance through the network. In order to obtain an adequate S/N at the receiving end, the cable network is equipped with repeaters. A repeater filters the noise and amplifies the digital signals to the required power level for further transmission through the network.

10.3.1.2 Signal reflection

The reflection of signals is another typical aspect of cable communication. This occurs, for example, when cables are not ideally connected. As a result, the cable impedance is no longer characteristic. At the point of connection a part of the signal is reflected and travels back in the direction of its origin. The reflected signal may be reflected once again in the direction of the receiving end and is added to signals traveling in the same direction. Because of the attenuation of signals in general, the impact of these reflections at the receiving end is negligible.

10.3.1.3 Modulation

Satellite communication is subject to power limitations. These limitations do not apply to communication via CATV networks and therefore it is possible to modulate not only the phase, but the amplitude as well. For the DVB digital cable system an M-ary signaling (see Section 10.2.1.5) referred to as *quadrature amplitude modulation* (QAM) is applied. Hence, a larger number of bits/symbol is allowed. A modulation efficiency of 4 bits/symbol is achieved by 16-QAM, 5 bits/symbol is achieved by 32-QAM, and an efficiency of 6 bits/symbol is achieved by 64-QAM.

10.3.2 Channel encoding

This section describes how the constraints in the basic elements of cable communication are respected by DVB in the specifications for channel encoding.

10.3.2.1 Encoding system

The specifications for the DVB cable system (ETS 300 429 [9]) can be used transparently with the DVB satellite system (ETS 300 421). As described in Section 10.2.2.2, programs broadcast by satellite can be received in the CATV cable head-end. After channel adaptation, these programs can be provided to the home-user IRD. Hence, the conceptual representation shows much correspondence (see Figure 10.10). The common elements are presented in gray.

10.3.2.2 Byte to *m*-tuple conversion

Depending on the modulation efficiency of 2^m-QAM modulation, k bytes are mapped onto n symbols of m bits (m-tuple conversion), such that $8k = n*m$ because 1 byte consists of 8 bits. In case of 16-QAM, the modulation efficiency is 4 bits/symbol ($m = 4$) and two symbols ($k = 2$) of four bits each ($n = 4$) can be formed out of one byte. Before m-tuple conversion, the MPEG-2 transport packets contain 204 bytes. After the conversion, a transport packet contains 408 symbols (Figure 10.11). Correspondingly, for 32-QAM eight symbols can be formed out of every 5 bytes. For 64-QAM this results in four symbols out of every 3 bytes.

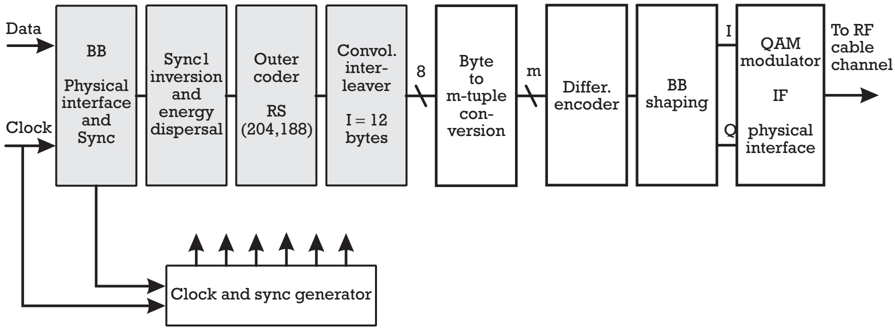

Figure 10.10 Conceptual encoding system description.

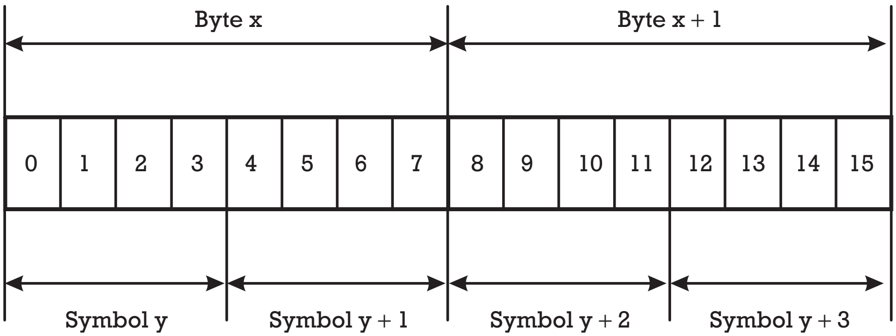

Figure 10.11 *m*-tuple conversion for 16-QAM.

10.3.2.3 Differential coding

After *m*-tuple conversion the symbols have to be prepared to be mapped in the QAM-constellation. This is achieved by the differential coding of the two *most significant bits* (MSBs) of each symbol. The MSBs define the quadrant in which the symbol is mapped (see Table 10.3).

10.3.2.4 Filtering and modulation

Before modulation, the digital signal is filtered. Corresponding to the DVB satellite system, a square root raised cosine filter is used. However, as a result of less available bandwidth per channel, for the DVB cable system a roll-off factor alpha = 0.15 is chosen.

In case of satellite communication, a maximum of four distinct symbol values can be distinguished in the QPSK(*quadrative phase shift keying*)-constellation diagram as result of QPSK modulation. These symbols all have the same frequency and amplitude, but have different phases. As

Table 10.3
MSBs Related to the Rotation in the QAM-Constellation Diagram

MSBs	Rotation	Quadrant
00	0°	1
01	–90°	4
10	+90°	2
11	180°	3

described in Section 10.3.1.3, CATV systems allow more bits/symbol. Hence, QAM is used. When, for example, 16-QAM is applied, 16 symbols are located in the constellation diagram (Figure 10.12).

The information in each of the 16 distinct amplitude/phase states is represented by 4 bits. This allows transmission of up to 4 bit/s in one hertz. For 32-QAM this implies 32 distinct states and a symbol length of 5 bits, which allows transmission of up to 5 bits/s in one hertz. Finally, when 64-QAM is applied, the transmission efficiency is 6 bits/s in one hertz.

10.3.3 Channel decoding

In Section 10.3.2, the DVB encoding system for cable communication is explained. To obtain the original signal again at the receiving end, the signal needs to be decoded. Hence, this section discusses the DVB specifications for the required channel decoding.

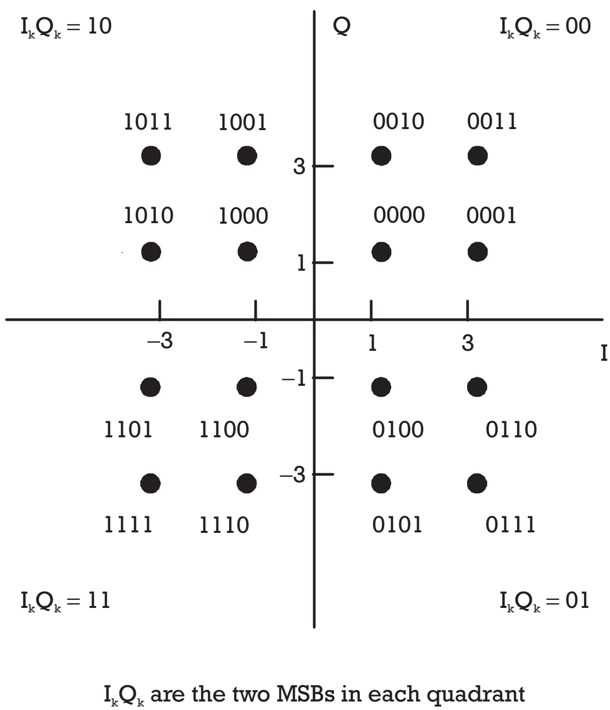

Figure 10.12 16-QAM constellation diagram. (I_kQ_k are the two MSBs in each quadrant.)

10.3.3.1 Decoding system

The signal encoding procedure is reversed at the receiving end with the help of the recovered carrier and clock signals and sync signal. Figure 10.13 presents the conceptual decoding system description.

10.3.3.2 Demodulation and filtering

The QAM demodulator now must regain the distinct symbols. Hence, the correct phase/amplitude states of the symbols are detected. In correspondence to the satellite system, phase errors are corrected in the following process.

Next, the digital pulses of the input signal are reshaped by means of a complementary square root raised cosine filter with a roll-off factor alpha of 0.15. Hence, the interference with adjacent cable channels is restrained.

10.3.3.3 Carrier and clock recovery

The demodulation process is synchronized by means of a carrier and clock recovery unit. Corresponding to the DVB satellite system, a feedback circuit (PLL) is used to recover the carrier and clock signals. In contrast with the satellite system, the correction of ±90-degree and 180-degree phase errors is achieved by comparing the original carrier phase and the phase at the receiving end within the same feedback circuit.

10.3.3.4 Differential decoder and symbol to byte mapping

After QAM-demodulation and pulse reshaping, the phase state, which corresponds to a certain quadrant (see Table 10.3), is provided to a

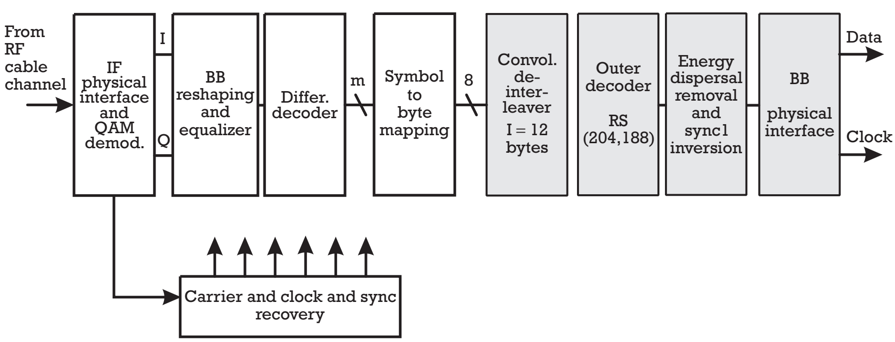

Figure 10.13 Conceptual decoding system description.

differential decoder. The output of the decoder delivers the corresponding two MSBs of the *m* bits symbol. Next, the *m* bits symbols are processed in order to regain the original symbols with a length of 8 bits each. The required synchronization for this process is enabled by the synchronization pulse in the TS.

10.4 DVB terrestrial

Television signals can be provided via terrestrial networks as well. This section first discusses the basic elements of terrestrial communications, then describes the several DVB systems for terrestrial communications at a functional level, and finally explains the specifications for the channel encoding and decoding process.

10.4.1 Elements of terrestrial communications

In case of terrestrial communications, specific elements play an important role. These elements concern typical transmission characteristics which have to be regarded when designing a terrestrial communication system.

10.4.1.1 Transmission medium

Digital terrestrial television services are expected to be provided via the *ultra high frequency* (UHF) band. The frequencies in this band range from 0.3 GHz to 3 GHz.

In contrast with satellite and cable systems, the terrestrial transmission of signals often suffers from multipath interference. A broadcast signal can be reflected, for example, by high buildings or mountains. The reflections are added to the main signal at the receiving end. Because the reflections travel via a different (and thus longer) route, these signals are delayed and therefore are called *echoes.* Hence, multipath interference occurs. Additionally, depending on the power used, cochannel interference may be caused when a different station transmits its programs via the same frequency.

In cities with high buildings and in mountain areas, echoes are likely to appear. When terrestrial signals are received by a fixed antenna, the antenna can be aimed at the strongest (main) signal. Hence, the influence of echo signals is minimized. This channel can be seen as a Rice channel. The Rice channel is described by the main signal and the sum of all echo signals together. However, in the case of portable reception, the power of the main signal drops more or less to the same power level as that of the echo signals. The channel can now be considered a Rayleigh channel, which is described by the sum of all (delayed) signals received.

10.4.1.2 Spectrum efficiency

For maximum spectrum efficiency within the UHF band a *single frequency network* (SFN) operation can be used. A SFN is built up out of broadcast stations which simultaneously transmit identical data streams via the same frequency. Neighboring broadcast stations support each other in their function. Moreover, if a large distance between neighboring broadcast stations is possible, national coverage can be achieved.

Beside the power level used, the distance between the broadcast stations mainly depends on the length of the guard interval. A relatively long interval allows a larger distance. For example, a guard interval of 200 μs corresponds to a distance of 60 km (200 μs*300,000 km/s = 60 km). The spectrum efficiency can be tailored to specific requirements by a flexible guard interval.

Terrestrial systems are designed for transmission via the same medium as satellite systems. Correspondingly, frequencies can be reused by the application of orthogonal polarization.

10.4.1.3 Modulation

In correspondence with digital satellite and cable systems, M-ary signaling is used for digital terrestrial services. Depending on the specific requirements, QPSK or QAM can be used. In case of QPSK energy dispersal scrambling has to be applied to avoid adjacent channel interference.

10.4.2 DVB terrestrial systems

DVB has specified several systems for terrestrial communication. Besides the digital terrestrial system, DVB specified a *multipoint video distribution system (*MVDS) and a system for *microwave multipoint distribution service* (MMDS). These systems are discussed at a functional level with their typical application and characteristics.

10.4.2.1 Digital terrestrial system

In general, terrestrial systems can provide local and national coverage in a more cost-effective way than satellite and cable systems. Moreover, the introduction of digital terrestrial systems enables a dramatic increase in available frequency spectrum. These frequencies, for example, can be used for the growing demand for mobile communications.

The DVB draft specifications (prETS 300 744 [10]) for a digital terrestrial system allow stationary and static portable reception via 8-MHz channels in the UHF band. Furthermore, these specifications include the use of large-area SFNs to allow maximum spectrum efficiency.

Different starting conditions in individual countries may lead to different introduction scenarios of digital terrestrial systems. This, for example, can depend on the spectrum availability and the number of existing analog services.

10.4.2.2 Multipoint video distribution system

The DVB specifications (ETS 300 748 [11]) for the MVDS are compatible with the 11/12 GHz satellite system (ETS 300 421) using QPSK modulation. The actual difference lies in the frequency band used for the transmission of digital terrestrial signals. Although the MVDS typically operates in the frequency band 40.5 to 42.5 GHz, the system is applicable to other frequency bands above 10 GHz. Moreover, the MVDS is suitable for use on different transmitter bandwidths varying from 26 MHz channels to 54 MHz channels. The frequency spectrum of the adjacent channels overlap each other in part but can be separated by the use of orthogonal polarization.

Typically, the MVDS is applied in areas where no cable system is provided. Moreover, it can be a competitive alternative for cable systems. An MVDS consists of (omni)directional transmitters and a number of stationary receivers. The maximum broadcasting distance of a digital MVDS is 6 km [12]. If one operator has been allocated the full 2-GHz frequency spectrum and the use of four broadcasting stations, 120 to 384 digital television programs can be received in an area of 200 km^2.

10.4.2.3 Microwave multipoint distribution service

At this moment DVB is working on the specifications of an MMDS (prETS 300 749 [13]). This digital terrestrial system is compatible with the DVB cable system (ETS 400 429). Hence, it uses 8-MHz terrestrial channels, and QAM modulation (16-QAM, 32-QAM, and 64-QAM) is applied. By using 32-QAM, a bit rate compatible with terrestrial *plesiochronous digital hierarchy* (PDH) can be retransmitted in an 8-MHz channel as well. The MMDS operates at frequencies below 10 GHz.

Analog to MVDS, this system is also typically applied as an extension of the CATV network and can serve as an alternative for cable systems in rural areas. Moreover, MMDS is perfectly suited to provide digital terrestrial television services within buildings with a large number of subscribers. This shows much correspondence with the digital SMATV system.

10.4.3 Channel encoding

This section describes the DVB specifications for the digital terrestrial system, explaining how the constraints in the basic elements of terrestrial communication (see Section 10.4.1) are respected by DVB in the specifications for channel encoding.

10.4.3.1 Encoding system

The specifications for MVDS and MMDS are the same as the DVB standards for digital satellite and cable systems. The specifications for the DVB terrestrial system, which are compatible with the DVB digital satellite system, are explained here. Figure 10.14 shows a conceptual description of the digital terrestrial system. The elements of this system which are common to the digital satellite encoding system are represented in gray.

The most important steps to adapt the TS to transmission via a terrestrial channel are the following.

- Transport multiplex adaptation;
- Randomization for energy dispersal;
- Outer error correction coding and outer interleaving;
- Inner error correction coding and inner interleaving;
- Mapping and modulation;
- OFDM transmission.

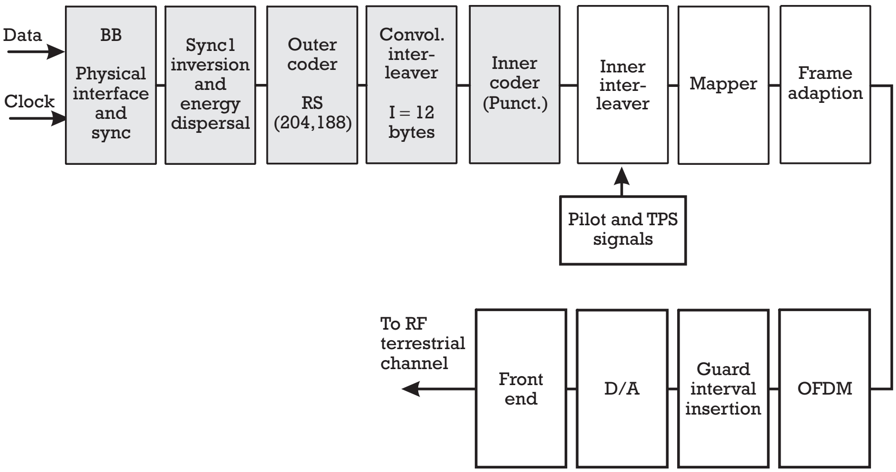

Figure 10.14 Conceptual encoding system description.

10.4.3.2 Inner interleaving, symbol mapping, and modulation

After the inner error correction procedure, the TS is demultiplexed into several substreams. When QPSK ($m = 2$) is used to eventually modulate the carriers, the data stream is demultiplexed into two substreams (see Figure 10.15). When 16-QAM ($m = 4$) or 64-QAM ($m = 6$) is used, it results in four or six substreams, respectively. Next, inner interleaving (bit-wise interleaving and symbol interleaving) is applied. A symbol is formed by the outputs of the *m* bit-wise interleavers. Hence, each symbol consists of exactly one bit from each of the *m* bit-wise interleavers. The purpose of the symbol interleaver is to map the *m* bit symbols onto the carriers. Finally, the carriers are QPSK, 16-QAM, or 64-QAM modulated and transmitted.

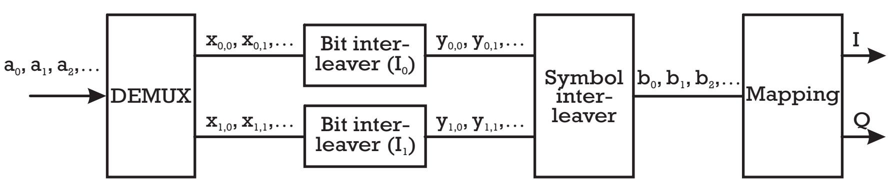

Figure 10.15 Mapping of input bits into QPSK modulation symbols.

10.4.3.3 OFDM transmission

In case of multipath interference, the delay of the echo is often longer than the symbol duration of the main signal. This results in a high level of interference. Echoes can be countermeasured by making the symbol duration longer. In turn, this would lead to more required bandwidth. However, a tradeoff between bandwidth and symbol duration is possible.

A method of achieving a larger symbol duration within the same bandwidth is to demultiplex a distinct symbol into several subsymbols. Next, the subsymbols are modulated in parallel onto different carriers. The total bandwidth (sum of all carrier frequencies) remains the same. Hence, the subsymbol duration is increased. Next, the modulated subsymbols are added, after which the newly obtained data stream can be transmitted.

DVB has chosen *orthogonal frequency division multiplex* (OFDM) as the technology for transmitting digital signals via the digital terrestrial system. OFDM is a multicarrier transmission technology that is currently being used in *digital audio broadcasting* (DAB). Typically, all adjacent carrier frequencies are orthogonally polarized.

The OFDM transmission system specified by DVB is able to operate in a 2k mode and 8k mode. In case of the 2k mode a maximum of 1,705 carriers per OFDM symbol can be used. The 8k mode is specified for a maximum of 6,817 carriers per OFDM symbol. The symbol duration in the latter is longer. Hence, a larger transmitter distance is allowed. Both modes are suitable for single transmitter operation. Furthermore, the 2k mode can be used in small SFN with limited transmitter distance. The 8k mode can be used in either large or small SFN.

10.4.3.4 OFDM frame structure

The OFDM signals are organized in a frame structure. Each frame consists of 68 OFDM symbols. Four frames together constitute a super-frame. As each symbol in its turn is modulated on a number of carriers, a matrix arises. The distinct elements of the matrix are referred to as cells. DVB has specified 1,512 active carriers for the 2k mode. In case of the 8k mode the number of active carriers is 6,048. The rest of the carriers is formed by reference data (i.e., scattered pilot cells, continual pilot cells, and *transmission parameter signaling* (TPS) carriers (see Table 10.4)).

By the application of pilot cells, frame synchronization, frequency synchronization, time synchronization, channel estimation as well as

Table 10.4
OFDM Frame Structure

Parameter	2k Mode	8k Mode
Maximum carriers	1,705	6,817
Active carriers	1,512	6,048
Scattered pilot cells	131	524
Continual pilot cells	45	177
TPS carriers	17	68

transmission mode identification are established. The pilot cells are always transmitted at a higher or "boosted" power level. (For example, in the case of QPSK, the amplitude is raised by a factor of 2.) The TPS carriers contain information concerning the applied channel coding and type of modulation.

10.4.3.5 Guard interval insertion

The DVB specifications include the use of a flexible guard interval between adjacent channels. A relatively long guard interval increases the transmitter distance but reduces the bit rate capacity (i.e., the symbol duration is longer). A flexible guard interval thus allows a tradeoff between transmitter distance and bit rate capacity. For the 8k mode with $T_g = 224\ \mu$s, this results in a maximum transmitter distance $d_{t,\max} = 67$ km (relevant for national coverage). In case the code rate is 7/8, this corresponds to a bit rate of 26.1 Mbps [14]. In Table 10.5, the guard interval related to the maximum transmitter distance and bit rate is presented for the 8k mode and 64-QAM is applied.

Table 10.5
Relation Between Guard Interval, Maximum Transmitter Distance, and Bit Rate

8k Mode		
T_g [μs]	dt,max [km]	bit rate [Mbps]
224	67	26.13
112	33.5	29.03
56	16.8	30.74
28	8.4	31.67

Notes: Code rate = 7/8; 64-QAM.

10.4.3.6 Hierarchical coding

CATV networks generally make use of coax cables. This results in minimal external interference at higher frequencies. When the CATV network topology is configured adequately, the transmission quality of the network can be considered constant and high. In case of satellite and terrestrial transmission external interference can be caused by rain if both polarizations are used. A digital satellite system (incorporating error correction) either performs at the required level or, when the external interference exceeds a certain threshold, the digital signal is interrupted. This can (partly) be countermeasured by accurately directing the antenna towards the satellite, a satellite dish with a larger diameter, or both.

The terrestrial transmission quality depends on local characteristics. A transmitter may, for example, cover a whole city, but because of obstruction the transmission quality in a lower located city area can be below the required level. In case of digital transmission this could lead to the interruption of the signal. Countermeasures are, for example, raising the transmitter power level considerably, the allocation of an extra transmitter, or the application of QPSK rather than 16-QAM or 64-QAM. Another possibility is the use of a lower code rate (i.e., more error correction information is added at the cost of a higher bit rate). These countermeasures, however, lead to an increase in costs or a decrease of the total transmission quality to serve only a fraction of the home users.

The solution for the problem described above is the application of hierarchical coding. DVB has specified two-level hierarchical channel coding. Technically, this implicates a “splitter” separating the incoming transport stream into a high-priority and low-priority transport stream. Both streams undergo their own inner/outer error correction coding process and inner/outer interleaving process. Next, these two bit streams are provided to the input of the mapper, after which modulation takes place (see Figure 10.16). Hierarchical coding is applied in case of 16-QAM and 64-QAM only.

DVB has specified the high-priority stream with a high code rate, and thus results in a low bit rate. For the low-priority stream a low code rate is specified, which results in a high bit rate. Hence, a low bit rate, rugged version or a high bit rate and less rugged version of the same program can be received. It is also possible to transmit entirely different programs on both separate streams. This requires the provision of hierarchical source coding. The high-priority stream could, for example, be used for a normal

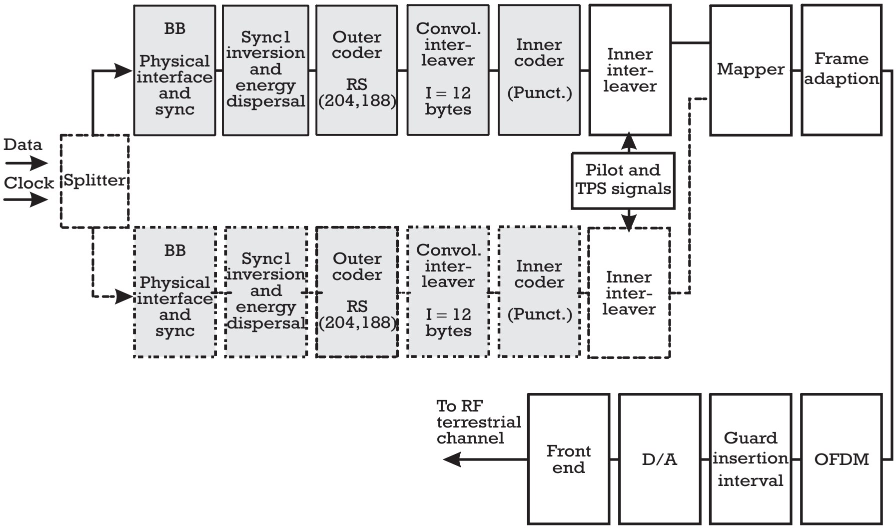

Figure 10.16 Hierarchical channel coding.

program, while the low-priority stream could be applied for the same program with HDTV-quality. DVB has decided not to adopt hierarchical source coding.

Hierarchical channel coding leads to a different constellation diagram. A high-priority stream makes use of a constellation with higher amplitudes. Three different levels (alpha = 1, 2, or 4) are specified by DVB. Figure 10.17 describes a 16-QAM constellation diagram with alpha = 2. An increase of alpha (i.e., a higher amplitude) implies a higher output power level of the transmitter. However, in case the transmitter power is constant and the value of alpha increased, the channel isolation has to be increased in order to maintain the same modulation quality. Moreover, a higher value of alpha results in more influence of phase noise. For each OFDM symbol the value of alpha and code rate are included in the TPS carrier.

10.4.4 Channel decoding

Section 10.4.3 explains the DVB encoding system for the digital terrestrial system. At the receiving end, the signal has to be decoded. This section discusses the DVB specifications for the required channel decoding.

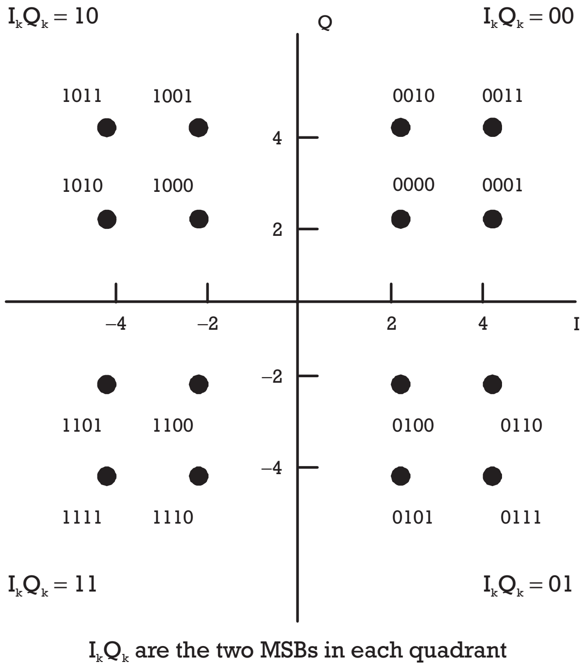

Figure 10.17 Constellation diagram 16-QAM and alpha = 2. (I_kQ_k are the two MSBs in each quadrant.)

10.4.4.1 Decoding system

In spite of the fact that the DVB specifications for the digital terrestrial system are in the final stage of becoming an ETSI standard, this system still has to evolve from the laboratory environment to a practical implementation. Tests have shown that portable reception in a car driving at 170 km/h is possible. This could make the system very interesting for all sorts of mobile digital broadband video services.

However, especially in the case of the 8k variant, the required sophisticated decoder technology is not yet being produced in mass production. Depending on the actual costs of the decoder's practical implementation, the requirements for the digital terrestrial system may still be subject to change.

10.4.4.2 Recovery of Reference Information

With the application of pilot cells, synchronization (frame, frequency, and time), channel estimation, and transmission mode identification are established. The TPS carriers contain specific information concerning the applied channel coding and type of modulation (see Table 10.6).

The reference information (pilots and TPS) can be recovered by means of a feedback circuit (PLL).

10.4.4.3 Demodulator and inner de-interleaver

The demodulator and the inner de-interleaver operate in a reversed way compared to the interleaving and modulation process at the transmitting end. The (high- and low-priority) bit streams are de-interleaved in order to be demodulated. Next, the demodulated bit streams are multiplexed into a single bit stream again in order to be applied to the inner decoder. The whole process is supported by the reference information.

10.5 Summary and conclusions

DVB has provided specifications for a broad variety of digital transmission systems concerning communication via satellite, CATV, and terrestrial networks. These systems have been or are currently being standardized by ETSI. Table 10.7 provides an overview of the typical parameters of the DVB digital transmission systems.

Satellite communication suffers from power limitations. For this reason, QPSK is used as a modulation method. The advantage of satellite communication is the rich availability of bandwidth, which in the end allows a high bit rate. After receiving the satellite signals, further transmission via a SMATV network is enabled by the DVB SMATV system. This allows the use of QAM, but the available bandwidth is limited. Hence, a

Table 10.6
TPS Carrier Information

Constellation including the value of alpha (QAM modulation)
Hierarchy information including inner code rate
Guard interval
Transmission mode (2k or 8k)
Frame number in a super frame
Synchronization word

Table 10.7
Typical DVB Digital Transmission System Parameters

DVB System	Modulation	Frequency Band (GHz)	Signal Bandwidth (MHz)	Bit Rate (Ru) (Mbps)
DTH	QPSK	11/12 (downlink)	26.0–54.0	18.7–68.0
SMATV	16-QAM	0.23–0.47 or 0.95–2.05	5.9–7.9	18.9–25.2
	32-QAM	0.23–0.47 or 0.95–2.05	4.7–8.0	18.9–31.9
	64-QAM	0.23–0.47 or 0.95–2.05	3.9–8.0	18.9–38.1
CABLE[1]	16-QAM	f	2.0–7.9	7.0–27.3
	32-QAM	f	2.0–8.0	8.7–34.6
	64-QAM	f	2.0–7.9	10.4–41.3
TERRESTRIAL[2]	OFDM (QPSK)	0.3–3.0	7.6	5.0–10.6
	OFDM (16-QAM)	0.3–3.0	7.6	10.0–21.1
	OFDM (64-QAM)	0.3–3.0	7.6	14.4–31.7
MVDS	QPSK	40.5-42.5	26.0–54.0	18.7– 68.0
MMDS[3]	16-QAM	f<10	2.0–7.9	7.0–27.3
	32-QAM	f<10	2.0–8.0	8.7–34.6
	64-QAM	f<10	2.0–7.9	10.4–41.3

Notes:
1. Frequency band is chosen by CATV operator;
2. Nonhierarchical coding;
3. Frequency band has not yet been allocated to MMDS.

lower bit rate is achieved. This last case more or less applies to the DVB cable system as well.

As a result of the different local characteristics, the DVB terrestrial system is the most complicated system of all. Multipath interference is countermeasured by means of the OFDM transmission technology. This multicarrier solution allows the application of QPSK as well as QAM. Due to the limited terrestrial frequency spectrum, this system has a lower maximum bit rate than the DVB DTH system.

MVDS, a terrestrial system that, for example, can be chosen as an alternative for transmission via CATV networks, is identical to the DVB DTH system. The only difference is the frequency band in which this system is operated. This enables a compatible use of both systems. The MMDS system provides the user with the same functionality as the MVDS. The system design, however, is based on the DVB cable specifications. This makes the DVB MMDS system compatible with the DVB cable system.

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