ROHDE&SCHWARZ
BROADCASTING DIVISION

Digital TV
Rigs and Recipes
Part 1
ITU-R BT.601/656 and MPEG2

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Contents

1.1 Introduction

In analog television, pictures are recorded with a camera in the form of R, G and B colour signals. In the studio, these signals are converted to CCVS signals in conformance with the PAL, SECAM or NTSC standard. The signals are IF-modulated and converted to the RF in the transmitter, and then taken to the antenna, which emits one program per channel. Analog TV measurement systems are well known from the baseband in the studio to the RF signal in the transmitter.

But what about digital TV?
To understand digital TV measurements, it is necessary to know how digital television works. Therefore, a complete and detailed description of the digital television system will be given in the following. This will be followed by a description of the relevant test parameters, methods, and appropriate measuring equipment.

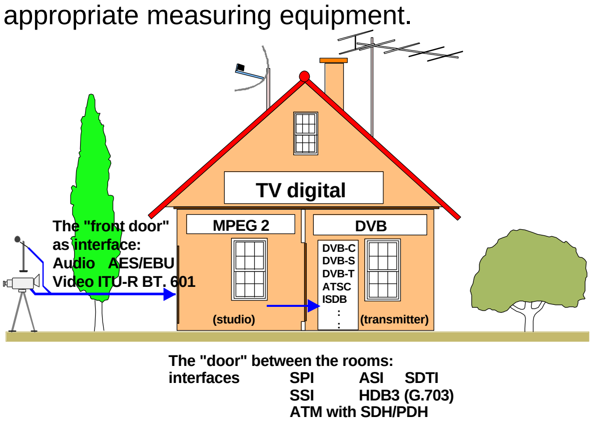


Fig. 1.1 "Digital TV house"

The RGB signals generated by the TV camera, as well as the corresponding audio channels, are immediately digitized in accordance with standards ITU-R BT.601/656 (International Telecommunication Union) for the video information and AES/EBU (Audio Engineering Society/European Broadcasting Union) for the audio information. The two signals are applied to the first "room", i.e. the MPEG2 (Motion Picture Experts Group) room of the "digital TV house", either via separate lines or with the audio information inserted in the digital blanking interval of the ITU-R BT.601/656 signal. At this point already, measurements are needed to verify and guarantee that digitization of the video and audio information is in line with relevant standards.

With the signals conforming to ITU-R BT.601/656 and AES/EBU, we enter the first room of the house, the MPEG2 room. Here we find the encoders for data compression of the video and audio signals. The digital ITU-R BT.601/656 video interface has a data rate of 270 Mbit/s, which is by far too high for TV channels of 7 MHz to 8 MHz bandwidth. Data can be compressed as required by means of video data coding to ISO/IEC 13818 (International Organization for Standardization/International Electrotechnical Commission), which provides detailed specifications of MPEG2 coding in nine parts, and audio data coding to ISO/MPEG 11 172 (this standard is referred to in ISO/IEC 13818-3 forr audio coding) using the MUSICAM (masking pattern adapted universal subband integrated coding and multiplexing) method. With MPEG2 coding, the data rate can be reduced from 270 Mbit/s to about 3 to 5 Mbit/s virtually without any visible degradation of picture quality. After digitization, MPEG2 coding and appropriate modulation, the above bandwidths are sufficient to transmit 6 to 12 programs in a channel.
As an alternative, sound may be Dolby AC-3 coded. In Australia, and possibly later in Europe too, both types of coding can be used. In the American ATSC system, only Dolby AC-3 coding is possible.
For video and audio information stored on DVD, the Dolby AC-3 system with Dolby surround up to the 5.1 mode (5 audio channels and one channel for very low frequencies) is used worldwide already now.

The video and audio signals are packetized to form packetized elementary streams (PES streams), multiplexed into transport stream (TS) packets, and information packets (tables) are added. Depending on the available data rate of the DVB (digital video broadcasting) system, several programs containing video and audio information may be combined in a transport stream.
The transport stream that leaves the "MPEG2 room" is monitored by means of suitable test equipment to verify compliance with the protocol and acceptable quality of the outgoing encoded video signal.

The transport stream thus generated is passed from the first room (MPEG2) of the digital TV house to the second room (DVB) via one of the following interfaces:

- SPI (synchronous parallel interface)
- SSI (synchronous serial interface)
- ASI (asynchronous serial interface)
- SDTI (serial digital transport interface)
- HDB3 (high density bipolar of order 3) to ITU-T G.703
- ATM with SDH/PDH (asynchronous transfer mode, synchronous digital hierarchy, plesiochronous digital hierarchy)

In the "DVB room" there are the modulators for the various types of modulation. Several systems are used worldwide today. These are

in Europe and other countries, e.g. Australia:

- DVB-C for cable transmission
- DVB-S for satellite transmission
- DVB-T for terrestrial transmission

in North and Central America:

- ITU-T J.83/B for cable transmission
- ITU-R BO.1294/B for satellite transmission (also known by the American designation of DirecTV or DSS (direct satellite system))

and

- DVB-S (common also in North America)
- ATSC with 8VSB (advanced television systems committee, vestigial sideband) for terrestrial transmission

in Japan:

- ISDB-T (integrated services digital broad-casting - terrestrial)
- ISDB-S (integrated services digital broad-casting - satellite)

Many countries in the world have not yet decided in favour of one of the above standards.

After modulation and conversion to the RF, the exciter outputs the signal to the power amplifiers. From there, the signal is fed to the cable system, the satellite uplink or the terrestrial transmitting antenna. The signal has now left the digital TV house and is on its way to the viewers at home.
At this point, too, measurements are indispensable to make sure that modulation and transmission parameters comply with specified requirements at any time, so guaranteeing unimpaired reception quality of the programs transmitted at any time.

1.2 Digitization of Video Signals to ITU-R BT.601/656

The cameras used in modern studios digitally encode the R, G and B colour signals immediately after the RGB sensors to yield the Y, C_B and C_R components. The picture delivered by the camera, therefore, is already in the ITU-R BT.601 format and contains the digitized Y, C_B and C_R components. The corresponding transmission interface to ITU-R BT.601/656 has the following characteristics:

Standard	ITU-R BT.601/656 (4:2:2) SMPTE 125M / 259 M
Systems	625 lines/50 Hz and 525 lines/59.94 Hz
Resolution in the studio in MPEG2 format	 10 bit 8 bit
Sync signals (timing reference signals – TRSs)	FF.C, 00.0, 00.0, XY.0
Parallel interface Level Connector	27 Msample/s ECL 25-pin D-SUB (ISO 2110 - 1980)
Serial digital interface (SDI) Level Impedance Connector Coding	270 Mbit/s in line with D1 format V_{PP} = 800 mV ±10 % 75 Ω BNC $G(x) = (x^9 + x^4 + 1)(x + 1)$, scrambled, NRZI

Table 1.1
Specifications of ITU-R BT.601/656 interface

Apart from the interface data, it is important to note the difference between the analog and the digital signal characteristic:

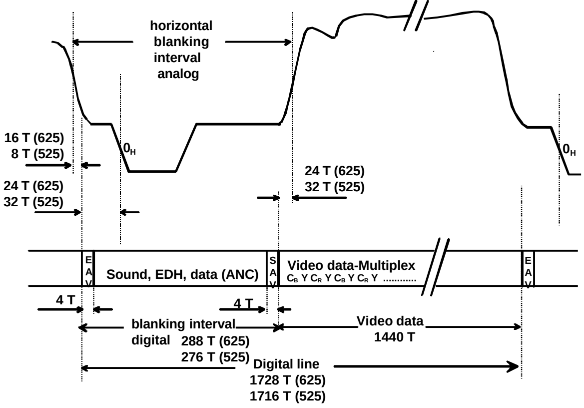


Fig. 1.2 Analog and digital signal in the time domain

Between the timing reference signals (TRV signals) EAV (end of active video) and SAV (start of active video), each comprising four cycles, there is the digital blanking interval, which is narrower than the analog one. In this interval, audio data, or any kind of data, or EDH data (error detecting and handling data) can be inserted for transmission along with the digitized video signal. The 10 (8) bit wide video data start at the beginning of the line with a C_B value, this is followed by a Y value and a C_R value, then by another Y value, and so on. This means that the luminance signal (Y) has double the bandwidth compared with the C_B and C_R colour components.

The sampling rates are as follows:

Y:	13.5 MHz
C_B and C_R:	6.75 MHz each

Number of samples within active digital line:

Y:	720
C_B and C_R:	360 each

Correct MPEG2 coding depends on the error-free digitization and conversion of the camera signal to the ITU-R BT.601/656 standard. This is, therefore, the first point where test equipment is required to measure and monitor the digital signal for compliance with the protocol and correct physical transmission data.

1.3 Test Equipment for ITU-R BT.601/656

The flexible generation of ITU-R BT.601/656 signals, including test signals recommended by ITU-R BT.801, is possible with CCVS GENERATOR SFF or CCVS+ COMPONENT GENERATOR SAF with the SxF-Z1 CCIR 601 option fitted in each case (CCIR is the old designation of ITU). The ITU-R BT.801 standard defines, with pixel accuracy, special signals for the measurements described in ITU-R BT.601/656. This includes, for example, the 100/0/75/0 colour bar signal, which enables reproducible, high-accuracy measurements of the time characteristic and time reference of the Y, C_B and C_R components.

CCVS + COMPONENT GENERATOR SAF

Condensed data of SFF/SAF

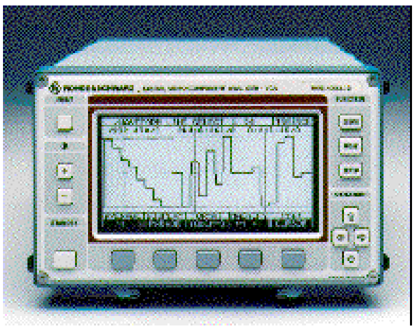
Basic unit	
Inputs	1 x program 2 x external data or test signals
Test signal outputs SAF SFF	 CCVS, Y/C (S-VHS), Y C_B C_R, R G B CCVS
TV standards	BG/PAL M/NTSC M/PAL N/PAL
Signals	approx. 500 fixed values, any number of user-programmable values can be added with MEMORY CARD option
Teletext Data line	5 pages, header can be edited user-programmable, direct input of VPS
Remote control	IEC 625 bus/IEEE488.2
SFF-Z1 and SAF-Z1 options: DIGITAL VIDEO INTERFACE	
Standards	ITU-R BT. 601/656 SMPTE 125M/259 M
Signals	to ITU-R BT.801; all predefined stored signals can be edited as required
Outputs Parallel Serial	 1x10 bit / 27 Msamples/s, 25-pin D-SUB connector (ISO 2110 - 1980) 2x270 Mbit/s 75 Ω BNC connector

Since the test signals recommended by ITU-R BT.801 are very important, they are listed in Table 1.2 together with the SAF/SFF-specific ITU-R BT.601 signals. A precise pixel-by-pixel definition of the signals is given in ITU-R BT.801. The signals printed *in italics* are special ITU-R BT.601 signals that can be produced by CCVS GENERATOR SFF or CCVS + COMPONENT GENERATOR SAF with SxF-Z1 CCIR 601 option fitted as part of the "CCIR 601" signal group. They include signals for testing cable equalizers or the subsequent PLL in the receiver section, as well as ramp signals for checking correct A/D and D/A conversion in signal processing. Signals not printed in italics are defined by the ITU-R BT.801 standard pixel by pixel and thus in the most accurate way possible.

ITU-R BT. 601	
1 GREY LEVEL	*21 PATHOL.SIGNAL Y=088h C=100h*
2 ALTERNATING BLACK/WHITE	*22 PATHOL.SIGNAL Y=044h C=080h*
3 EOL PULSE	*23 PATHOL.SIGNAL Y=022h C=040h*
4 BLACK/WHITE	*24 PATHOL.SIGNAL Y=011h C=020h*
5 RAMP YELLOW/GREY	*25 PATHOL.SIGNAL Y=008h C=210h*
6 RAMP GREY BLUE	*26 PATHOL.SIGNAL Y=198h C=108h*
7 RAMP CYAN GREY	*27 PATHOL.SIGNAL Y=004h C=300h*
8 RAMP GREY RED	*28 PATHOL.SIGNAL Y=0CCh C=180h*
9 RAMP CB Y CR Y	*29 PATHOL.SIGNAL Y=066h C=0C0h*
10 EOL BAR WHITE	*30 PATHOL.SIGNAL Y=033h C=060h*
11 EOL BAR BLUE	*31 PATHOL.SIGNAL Y=019h C=230h*
12 EOL BAR RED	*32 PATHOL.SIGNAL Y=00Ch C=318h*
13 EOL BAR YELLOW	*33 PATHOL.SIGNAL Y=006h C=18Ch*
14 EOL BAR CYAN	**34 DIG.COL.BARS 100/0/100/0**
15 *SEQUENCE 1010*	**35 DIG.COL.BARS 100/0/75/0**
16 *SEQUENCE 11001100*	*36 RAMP Y*
17 *SEQUENCE 111000111000*	*37 RAMP Y CB CR*
18 SDI CHECK FIELD	*38 RAMP CB*
19 PATHOL.SIGNAL Y=198h C=300h	*39 RAMP CR*
20 PATHOL.SIGNAL Y=110h C=200h	

Table 1.2 ITU-R BT.801 and SAF/SFF-specific signals

The ideal analyzer in an ITU-R BT.601/656 environment is
DIGITAL VIDEO COMPONENT ANALYZER VCA.



DIGITAL VIDEO COMPONENT ANALYZER VCA

Condensed data of VCA

Basic unit	
Inputs	1 x serial 1 x parallel
Outputs	actively looped through from inputs
Standards	ITU-R BT.601/656 SMPTE 125M/259M 8/10 bits 625/525 lines
Oscilloscope	waveform line select, waveform, numeric dump
Measurements	TRS error, reserved code error, video range error, CRC error C/L gain/delay error
Printer interface	RS-232-C/RS-422-A
Remote control (VCA-B1 option)	RS-232-C/RS-422-A
VCA-B11 option – DTL analysis (physical signal analysis)	
Additional input	1 x serial
Measurements	data jitter, amplitude spectrum, return loss (with external SWR bridge VCA-Z1), signal headroom, signal delay

VCA covers the complete range of protocol parameters and, with VCA-B11 DTL Analysis option, also the physical characteristics of a signal such as

spectrum,
signal amplitude,
jitter in time or frequency domain,
signal headroom

and other parameters. The VCA-B1 option enables remote control of the VCA as well as long-term monitoring of the TRS (timing reference signal), RCE (reserved code error), and CRC (cyclic redundancy check) information.

The basic unit performs the following measurements via the parallel and the serial interface:

data contents of signal in ITU-R BT.601 format (NUMERIC DUMP in hexadecimal or decimal notation), with Y, C_B, C_R or R, G, B components displayed as an oscillogram for the selected TV line (WAVEFORM)

TRS ERROR
RESERVED CODE ERROR (RCE)
VIDEO RANGE ERROR
CRC ERROR

(the last four parameters are displayed numerically or as a histogram)

C/L DELAY ERROR

(level and delay measurements on 75/0/100/0 or 100/0/100/0 colour bar to ITU-R BT.801 specifications)

1.4 MPEG2 Data Coding to ISO/IEC 13818-2

The ITU-R BT.601/656 and AES/EBU interfaces open the door to the digital TV house, whose first room accommodates MPEG2 data compression. Compression is aimed at reducing the video data rate of 270 Mbit/s of the ITU-R BT.601/656 interface to 2 to 6 Mbit/s without any visible degradation of picture quality. This applies analogously to the audio signal, whose data rate is reduced from 728 kbit/s to typically 192 kbit/s without any audible loss in sound quality. If several audio channels are to be transported in a program data stream, audio data rates from 64 kbit/s to 384 kbit/s are possible.
To reduce the video data rate, the ITU-R BT.601 picture is divided into blocks of 8 x 8 pixels. Each block consists of 64 pixels as shown in Fig. 1.3.

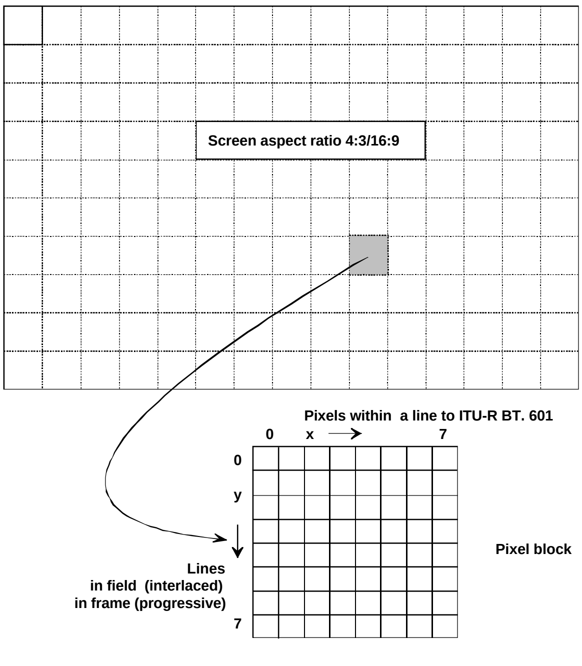


Fig. 1.3 Division of picture in 8 x 8 pixel blocks

The main elements of picture data reduction are:

DCT Discrete cosine transform with equation

$$G(f_x, f_y) = 0.25 * C(f_x) * C(f_y) * \sum_{x=0}^{7} \sum_{y=0}^{7} g(x,y) \cos((2x+1) f_x \frac{p}{16}) * \cos((2y+1) f_y \frac{p}{16})$$

$$C(f) = \begin{cases} 1/\sqrt{2} & \text{for } f = 0 \\ \text{and} & \\ 1 & \text{for } f > 0 \end{cases}$$

f_x, f_y = frequency coordinates
$G(f_x, f_y)$ = DCT coefficient
x, y = pixel/frequency coordinates
g(x, y) = pixel values

With the above equation, 8 x 8 DCT coefficients in the frequency domain are obtained from the 8 x 8 pixel blocks in the time domain.

Quantization based on standard quantization tables for

intraframe-coded pictures (I pictures)

$Q_I(x,y)$ = (→ x, ↓ y)

8	16	19	22	26	27	29	34
16	16	22	24	27	29	34	37
19	22	26	27	29	34	34	38
22	22	26	27	29	34	37	40
22	26	27	29	32	35	40	48
26	27	29	32	35	40	48	58
26	27	29	34	38	46	56	69
27	29	35	38	46	56	69	83

and

forward predicted and bidirectional predicted pictures (P and B pictures), and for C_B and C_R components.

$Q_{B,P}(x,y)$ = (→ x, ↓ y)

16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16

Zigzag scanning

The quantized DCT coefficients, after conversion to integers F(x,y) by means of equation

$$F(x,y) = INT\left[\frac{G(f_x, f_y)}{Q_{I,P,B}(x,y)} + 0.5\right],$$

are scanned so that sequences with a very high number of zeros are obtained.

Here is a typical example:

F(x,y) =

DC	-17	0	-1	0	0	0	0
-17	5	0	0	0	0	0	0
0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

The following coefficient sequences are obtained:

ZZ = (DC value
-17 -17 0 5 0 -1 0 0 -1 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0)

By means of variable length coding (VLC) and Huffman coding, the few DCT coefficients differing from zero and the typical, long zero sequences at the end of a zigzag row are reduced to transmit a minimum of information.

Group of pictures (GOP) and prediction

Further, suppression of redundant picture information is attained by means of
forward predicted pictures (P pictures) and bidirectional predicted pictures (B pictures).

A GOP preferably consists of 12 pictures.
The first picture is intraframe-coded (I-coded). It removes all errors occurring at the end of the previous GOP as a result of lossy P and B coding. The I-coded picture is followed by forward predicted and bidirectional predicted (lossy) pictures (3 x P and 8 x B pictures). If and to what extent errors due to lossy coding become visible depends on the picture contents and the compression factor.

Possible types of picture coding in a GOP:

I coding	picture information is derived solely from the current macroblock or picture; only DCT, quantization and VLC are used for data compression
P coding	is based on prediction with reference to the preceding field or frame, with motion compensation
B coding	is based on prediction with reference to the preceding and/or subsequent field or frame, with motion compensation

Structure of a GOP with 12 pictures

Sequence: I-B-B-P-B-B-P-B-B-P-B-B
Duration: 12 x 40 = 480 ms
Typical data volume:
I picture 1000 kbit
P picture 300 kbit
B picture 100 kbit
Data rate of a coded program signal with good picture quality 5 Mbit/s to 6 Mbit/s
The data stream at the output of the video encoder is referred to as video elementary stream (video ES).

1.5 Audio Coding to ISO/IEC 13818-3 (ISO/MPEG 11172)

Not only the video data are compressed but also the accompanying audio data (mono, stereo, dual sound, as well as joint stereo for different audio channels). Masking effects obtained both as a function of time and frequency are utilized to compress data on the principle "Anything not audible is superfluous redundant information".

Table 1.3 MPEG1 layer 1 coding

Splitting of audio bandwidth in	32 subbands of equal width
Processing of blocks of	12 samples
Sampling rates	32 kHz, 44.1 kHz, 48 kHz
Duration of a block	32 x 12 / 48000 = 8 ms at typically 48 kHz sampling rate
Scale factor of a block	highest value of the 12 samples
Scale factor resolution	6 bit
Resolution of samples	2 bit to 15 bit (depending on permissible quantization noise)

The 12 values of each block are divided by the scale factor and quantized taking into account the masking effects (MPEG1 layer 1). The masking threshold as a function of frequency is calculated using Fourier transform with 512 samples. Masking as a function of time always occurs with blocks of a length of 8 ms to 12 ms (depending on the sampling rate).

Table 1.4 MPEG1 layer 2 coding

Splitting of audio bandwidth in	32 subbands of equal width
Processing of blocks of	36 samples
Sampling rates	32 kHz, 44.1 kHz, 48 kHz
Duration of a block	32 x 36 / 48000 = 24 ms at typ. 48 kHz sampling rate
Scale factors	2 to 3 per block and subband because of the short duration of masking as a function of time (premasking max. 20 ms)
Scale factor of a block	highest value of the 36 samples
Indicator for number of scale factors	2 bit
Scale factor resolution	6 bit
Resolution of samples	2 bit to 15 bit (depending on permissible quantization noise)
Quantization in subbands 23 to 26	0 (cancellation), 3, 5, 65535 quantizing steps
Subbands 27 to 31	suppressed because resulting frequency is > 20 kHz

The 32 values of each block are divided by the scale factor and quantized taking into account the masking effects (MPEG1 layer 2). The masking threshold as a function of frequency is calculated using Fourier transform with 1024 samples. Masking as a function of time is not always effective with block duration > 20 ms.

1.6 Audio Coding to Dolby AC-3

Dolby AC-3 audio coding incorporates Dolby surround audio processing. With data compression typically higher than a factor of 13, the Dolby AC-3 surround system allows for up to 5 quasi-transparent audio channels plus one channel for very low frequencies (subwoofer). AC-3 coding, therefore, is the ideal method to guarantee high audio quality in the home cinema.
This is one of the reasons why AC-3 coding has already been included in the Australian DVB standard as an alternative audio channel. In Australia, all of the above coding types are possible: MPEG1 layer 1 and 2, and AC-3. Table 1.4 shows some typical AC-3 data:

Table 1.5 Typical AC-3 data

Sampling rate	32 kHz, 44.1 kHz, 48 kHz
Maximum sampling width	24 bit
Bit rates	19 different rates between 32 kbit/s and 640 kbit/s
Channel coding without Dolby surround with Dolby surround	3 bit dual-sound, mono, stereo, stereo with center channel stereo, stereo with center channel, stereo with L/R surround, stereo with L/R surround and center channel
Length of AC-3 frame	1536 samples
Duration of AC-3 frame 32 kHz sampling rate 44.1 kHz sampling rate 48 kHz sampling rate	 48 ms *34.83* ms 32 ms

The data stream at the output of the audio encoder is referred to as audio elementary stream (audio ES).

1.7 Packetized Elementary Stream (PES)

The elementary data streams are packetized to produce packetized elementary streams (PES streams). Each packet of a PES is preceded by a header which begins with a packet start code (24 bits: 0000 0000 0000 0000 0000 0001) and carries the following information:

Contents of PES (stream ID) 8 bits

The many different PES contents are listed in a table in the ISO/IEC 13818-1 specifications, for example:
1110 xxxx refers to the xxxxth video data stream, or
1111 0000 identifies an ECM (entitlement control message) data stream

Length of PES 16 bits

Defines the number of bytes of a PES that follow these 16 bits.

In an optional field, the header contains further information announced by flags, for example:

Counter reading for synchronization of system PLL with 27 MHz clock signal 42 bits

The lowermost 9 bits count up to 300;
the remaining 33 bits are clocked at
27 MHz/300 = 90 kHz
(SCR - system clock reference;
ESCR - elementary stream clock reference)

PTS and DTS time stamps 33 bits each
(PTS - presentation time stamp;
DTS - decoding time stamp)

Define the time of output or decoding of TS data.

Data rate of ES 22 bits

The packetized video and audio elementary streams are coded. Since MPEG2 coding does not take into account the horizontal and vertical blanking intervals, no insertion test signals, teletext or data lines are transmitted in the coded MPEG2 data stream.
To compensate for this, the analog TV teletext and data line information can be inserted in the packetized data elementary streams. Generally, data of any kind can be transported in the data PES containers.

1.8 Transport Stream (TS)

The multiplexer splits the video, audio and data PES streams and the additional information, i.e. the PSI and SI tables (program specific information and service information), into packets of 184 bytes and adds a 4-byte header to each packet. This yields transport stream (TS) packets with a length of 188 bytes.

The TS header contains the following information:

Synchronization byte 0x47

TEI (transport error indicator) to indicate any TS packet data that cannot be fully corrected by the demodulator 1 bit

PID (packet identification number, packet ID) 13 bits

Flags announcing the optional adaptation field 2 bits

CC (continuity counter)
Counter reading for monitoring continuous packet transmission 4 bits

and other signalling bits.

The optional adaptation field of the header contains, besides many flags, the following information:

PCR (program clock reference)
Program-related counter reading, derived from STC (system time clock), for synchronization of system PLL 42 bits

or

OPCR (original program clock reference)
Original program-related counter reading 42 bits

This information in the optional adaptation field is likewise announced with a one-bit flag. If the flags are not valid, normal data can be transmitted instead of the PCR and the OPCR.

1.9 MPEG2 Multiplexer

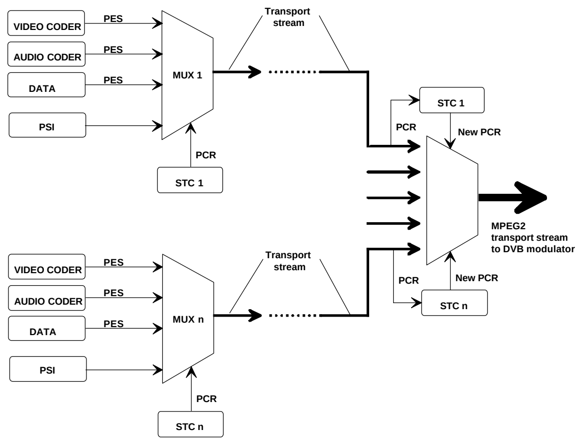


Fig. 1.4 MPEG2 multiplexer

A transport stream carrying one program has a data rate of about 4 Mbit/s to 7 (max.15) Mbit/s. This is made up of the following subrates:

Video	2 Mbit/s to 6 Mbit/s
Audio	32 kbit/s to 384(+64) kbit/s
Data	as required
PSI/SI tables	up to 1 Mbit/s
and stuffing packets	

The TS data rate varies according to the video and audio quality and the information entered in the tables.
At present, the following TS data rates are typically achieved for a DVB transmission channel:

Cable	38.153 Mbit/s (UHF)
Satellite	up to 38.015 Mbit/s for 27.5 Msymb/s
Terrestrial	4.98 Mbit/s to 31.67 Mbit/s

A transport stream can, therefore, carry between five programs of very high signal quality and ten programs of lesser signal quality via cable or satellite. For terrestrial transmission, this capacity is reduced to three to six programs. The actual data rate after program interleaving is normally always below the specified data rate for a given transmission medium to avoid data overflow. To use up the remaining data rate capacity, either TS stuffing packets with the PID 0x1FFF are inserted or "IP via DVB" packets for pure data transmission.
Program transmission efficiency can be boosted by means of **statistical multiplexing,** which balances the differences between the individual data rates of the programs transmitted in a transport stream. This means that programs requiring a low data rate at a given instant, for example because only frozen graphics are transmitted, make their extra capacity available to other programs requiring a high data rate. This method allows more programs of high picture quality to be packed into a transport stream.

1.10 Tables

(**PSI** Programme Specific Information,
SI Service Information)

The tables provide the demultiplexer of the DVB or ATSC receiver with all the necessary information regarding the transmission channel and the transport stream contents. Although the tables carry in part DVB- or ATSC-specific information, they still come under the MPEG2 standard as they are carried in MPEG2 transport stream packets.

1.10.1 PSI Tables to ISO/IEC 13818-1

PAT **Program Association Table**
(PID = 0x0000, table ID = 0x00):
List of all programs multiplexed in the transport stream, including reference to the PIDs (packet identifiers) of the PMTs of these programs.

CAT **Conditional Access Table**
(PID = 0x0001, table ID = 0x01):
Provides information on encrypted (scrambled) programs and their descrambling codes
(EMM: entitled management message and ECM: entitled control message).

PMT **Program Map Table**
(PID = 0x0020 to 0x1FFE, table ID = 0x02):
Includes reference to packets containing the PCR (program clock reference), contains a list of program providers, a PID list of the program elements (e.g. video, audio and data channels), copyright and other information.

NIT **Network Information Table**
(PID = 0x0010, table ID = 0x40):
Provides information on the physical transmission network, in the case of DVB-S for example the orbit position, transponder number, satellite frequency, etc.

TSDT **Transport Stream Description Table**
(PID = 0x0002, table ID = 0x03):
Describes the structure of programs and program elements, e.g. aspect ratio, picture frequency in transport stream.

1.10.2 SI Tables to ETS 300 468 for DVB

BAT **Bouquet Association Table**
(PID = 0x0011, table ID = 0x4A):
Contains information on a provider's bouquet of programs.

EIT **Event Information Table**
(PID = 0x0012, table ID = 0x4E and 0x50 to 05F):
"TV guide" containing data such as start time and end time of events.

SDT **Service Description Table**
(PID = 0x0011, table ID = 0x42):
Describes the programs offered as well as the program providers.

RST **Running Status Table**
(PID = 0x0013, table ID = 0x71):
Enables the fast and precise response to any changes to the scheduled program sequence, for example if an event is to start at a later time.

TDT **Time and Date Table**
(PID = 0x0014, table ID = 0x70):
Contains the UTC (universal time coordinated) time and date information as well as the reference time at longitude 0.

TOT **Time Offset Table**
(PID = 0x0014, table ID = 0x73):
Contains the UTC time and date information and the local time offset.

ST **Stuffing Table**
(PID = 0x0010 to 0x0014, table ID = 0x72)
Deletes or invalidates other SI tables.

If a program provider transmits not only one transport stream but occupies two DVB-C or DVB-T TV channels, for example, for the transmission of different transport streams, the first channel may carry information on the programs and services transmitted in the second channel and vice versa.

This is effected by adding tables carrying the extra designation "OTHER":

NIT OTHER **Network Information Table OTHER**
(PID = 0x0010, table ID = 0x41):
Provides information on the physical transmission network (in the case of DVB-S for example the orbit position, transponder number, satellite frequency, etc.) in the other channel occupied by a program provider.

SDT OTHER **Service Description Table OTHER**
(PID = 0x0011, table ID = 0x46):
Describes the programs and services offered in the other channel occupied by a program provider.

EIT OTHER **Event Information Table OTHER**
(PID = 0x0012, table ID = 0x4F and 0x60 to 0x6F):
"TV guide" containing data such as start time and end time of events in the other channel occupied by a program provider.

1.10.3 Special Tables

The following table was created to support the multimedia home platform (MHP):

AIT **Application Information Table**
(PID = 0x20 to 0x1FFE, same as PMT, table ID = 0x74):
Provides information for the DVB receiver to locate and identify data services in the transport stream and process them as required for a given application.

Two tables are provided for "partial" TSs. These include recorded TSs that contain only a subset of the original data stream or in which time shifts occur relative to the original data. The two tables replace the original SI tables. PSI tables for "partial" TSs are restricted to the PAT and the PMT.

DIT **Discontinuity Information Table**
(PID = 0x001E, table ID = 0x7E):
The DIT is inserted at points where time shifts occur in the TS.

SIT **Selection Information Table**
(PID = 0x001F, table ID = 0x7F):
Defines the TS as a "partial" TS coming from the digital interface of a TS storage device.

The DIT and the SIT may be used in partial TSs only; they must not be used in TSs to be broadcast.

NST **Network Status Table**
(PID = 0x001D, table ID = 0x0x14):
(see also 1.10.4, "Special TS Packets")
If, at a monitoring point of the transmission chain, signal elements such as video, audio or data elementary streams, or subtitles or SI tables are found to be missing, or other errors (errors to ETR 290, BER values) are detected, a table with PID 0x1D is generated and inserted into the TS at this point. In this way, the error status within the transmission network is signalled, including error location, time and description.

RCT **Remote Control Table**
(PID = 0x001D, table ID = 0x0x12):
(see also 1.10.4, "Special TS Packets")
From the point of signal distribution, this table controls switchover between local and national programs (and between program time and advertizing time) by announcing the switchover time.

1.10.4 Special TS Packets

Two transport stream PIDs were defined to cater for special applications. These PIDs are used, on the one hand, to establish a channel for test data transmission in the DVB system and, on the other hand, to distribute all information necessary for synchronization of a DVB-T single-frequency network.

The first TS packet with PID 0x1D is defined by the European Standard TR 101 291.

The second TS packet with PID 0x15 (referred to as megaframe initialization packet – MIP) is defined by TS 101 191.

The 0x1D packet carries the following information:

signal type (video, audio, data) to which the transmitted test data belong,

origin of data,

test signal used,

time of insertion of packet into TS to determine signal delays,

place of measurement, GPS-based (GPS – global positioning system),

program in which measurement was performed

and, last but not least:

test data.

The MIP with PID 0x15 carries the following information:

number of TS packets to be sent until start of next megaframe (2-byte pointer),

periodic or non-periodic transmission of pointer,

time, in 100 ns steps, due to elapse from last 1 pps (pulse per second) signal from GPS system until first bit of next megaframe (system time stamp – STS),

operating mode of DVB-T network (tps_mip), described by transmission parameter signalling (TPS) data.

1.10.5 Repetition Rates of Time Stamps and Tables in DVB

To ensure correct signal decoding by the set-top box (STB), the repetition rates of all tables inserted in the transport streams must be complied with.
ETR 290 and ISO/IEC 13818 recommend the following minimum and maximum intervals for the transmission of tables. The values are selected so as to avoid, on the one hand, long waiting times for the key data describing the contents of the incoming TS after switch-on of the STB. On the other hand, undue loss of data rate capacity resulting from high table repetition rates is to be avoided.

Parameter	Minimum interval (ms)	Maximum interval (s)
PAT	25/25	0.5/0.5
CAT	25/25	0.5/0.5
PMT	25/25	0.5/0.5
NIT	25/25	10/10
SDT	25/25	2/2
BAT	25/25	10/10
EIT	25/25	2/2
RST	25/25	---/---
TDT	25/25	30/30
TOT	25/25	30/30
PCR	0/0	0.04/0.10
PTS	---	0.7/0.7

First value: recommended by DVB ETR 290

Second value: recommended by ISO/IEC 13818

Table 1.6

1.10.6 SI Tables for ATSC

The PSI tables meet the ISO/IEC 13 818-1 specifications also for the ATSC standard. Instead of the SI tables of the DVB standard, PSIP (program and system information protocol) tables are used in ATSC:

MGT **Master Guide Table**
(PID = 0x1FFB, table ID = 0xC7): Contains the version number, length in bytes and PIDs of all PSIP tables except for the system time table (STT), which is independent of the other tables.

TVCT **Terrestrial Virtual Channel Table**
(PID = 0x1FFB, table ID = 0xC8): "Private table" according to the protocol; describes all programs contained in the transport stream transmitted in the terrestrial virtual channel (TVC).

CVTC **Cable Virtual Channel Table**
(PID = 0x1FFB, table ID = 0xC9): "Private table" according to the protocol; describes all programs contained in the transport stream transmitted in the cable virtual channel (CVC).

RRT **Rating Region Table**
(protection of children and young people)
(PID = 0x1FFB, table ID = 0xCA): List of qualifications relating to the suitability of events for young viewers. This information is included in the MGT for all events. The RRT is valid for precisely defined regions (e.g. the whole of the USA or individual States).

EIT-n **Event Information Table**
(PID = 0x1FFB, table ID = 0xCB): EIT-0 to EIT-n (n is defined up to 127) describe the sequence of programs in a TS in a three-hour raster from 00:00 h to 24:00 h (universal time code – UTC), so providing an electronic TV guide.

ETT **Extended Text Table**
(PID = 0x1FFB, table ID = 0xCC): Each EIT-n is assigned an ETT, which gives a detailed description of each event.

STT **System Time Table**
(PID = 0x1FFB, table ID = 0xCD): Contains the current UTC time and date.

There are two optional tables:

DCCT **Directed Channel Change Table**
(PID = 0x1FFB, table ID = 0xD3)

DCCSCT **DCC Selection Code Table**
(PID = 0x1FFB, table ID = 0xD4)

The two tables support automatic channel switching if the viewer has signalled his interest in specific types of events from categorized services such as cinema, sports, age group, etc.

1.10.7 Repetition Rates of PSIP Tables in ATSC

Table 1.7 lists the repetition rates of PSIP tables as recommended by ATSC A/65.

PSIP table	Maximum interval (ms)
STT	1 000
MGT	150
VCT (virtual channel tables)	400
RRT	60 000
EIT-0	500

Table 1.7 Repetition rates of PSIP tables

VCT in this table is meant to comprise the two tables for terrestrial (TVCT) and cable (CVCT) transmission. The ETT is coupled to the EIT and should therefore have the same repetition rate as the EIT.