ROHDE&SCHWARZ
BROADCASTING DIVISION

Digital TV
Rigs and Recipes
Part 3
DVB-S

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Contents

3 Introduction

For optimal transmission, data not only has to be coded to MPEG2 (Motion Picture Experts Group), which reduces the data rate of the ITU-R BT.601 interface from 270 Mbit/s to typically 3 Mbit/s to 5 Mbit/s, but also subjected to a special type of modulation (see "Digital TV Rigs and Recipes" – Part 1 "ITU-R BT.601/656 and MPEG2"). A comparison of analog modulation with the modulation used in digital video broadcasting (DVB) reveals that DVB modulation yields a flat spectrum with a constant average power density across the channel bandwidth.

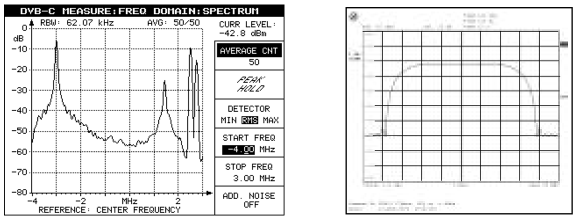

Fig. 3.1 Comparison of B/G PAL spectrum and DVB-S spectrum

This modulation mode results in optimal utilization of the transmission channel in all DVB modes, i.e. DVB-C (cable), DVB-S (satellite) and DVB-T (terrestrial). In this chapter, the special characteristics of DVB-S will be discussed.

3.1 DVB-S Modulation (Satellite)

to EN 300 421

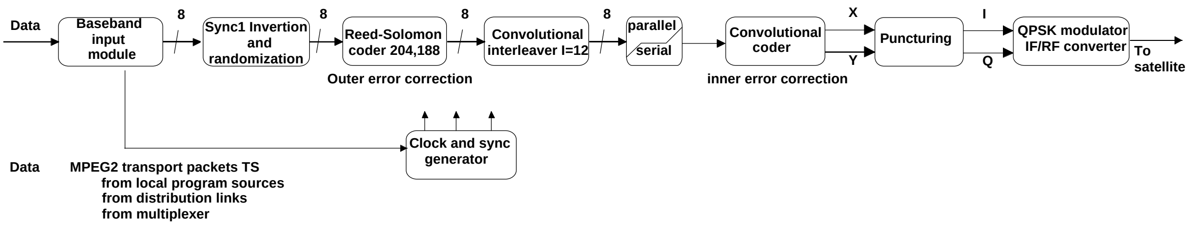

Fig. 3.2 Block diagram of DVB-S modulator/converter

3.1.1 Baseband Input Module

The MPEG2 transport stream (TS) packets are routed to the "DVB room" of the "digital TV house" via one of the following interfaces (see also "Digital TV Rigs and Recipes" – Part 1 "ITU-R BT.601/656 and MPEG2", "Introduction"):

SPI (synchronous parallel interface)
ASI (asynchronous serial interface)
SSI (synchronous serial interface)
SDTI (serial digital transport interface)
HDB3 (high density bipolar of order 3)
ATM (asynchronous transfer mode)

The baseband input module reconstructs the original TS data, optimizes return loss, and corrects amplitude and phase response versus frequency. It supplies all the required information to the clock and sync generator block, which acts as a central clock generator for all blocks of the DVB modulator. Information includes, for example, the data rate, which is derived from the incoming TS data, and in the case of the SPI interface, also sync byte signalling for the TS packet and data valid signalling via the data valid line. The reconstructed TS packets are taken from the baseband input module to the next block, i.e. sync word inversion and randomization.

3.1.2 Sync Word Inversion and Randomization for Energy Dispersal

After the input module, the TS packets undergo the first processing step: sync word inversion and randomization for energy dispersal.
Data randomization – or rather scrambling – ensures a constant average output level of the modulator signal.

The PRBS polynomial $1 + x^{14} + x^{15}$ disperses the data, but not the sync words (0x47), of the TS packets (for TS packet structure refer to "Digital TV Rigs and Recipes" – Part 1 "ITU-R BT.601/656 and MPEG2", section 1.8 "Transport Stream (TS)"). The polynomial has a length of 1503 bytes. This exactly corresponds to eight TS packets minus the bitwise inverted sync word of the first TS packet, whose value is now 0xB8. The 15-bit PRBS register is loaded with the sequence 100101010000000 after each 8-packet cycle. The inverted sync word marks the beginning of the randomized sequence.

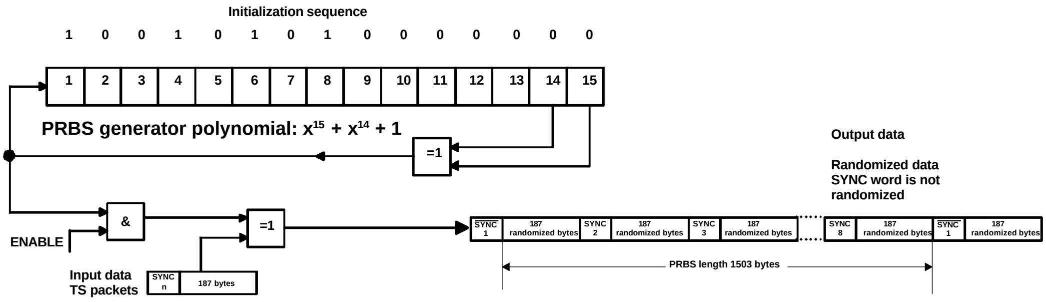

Fig. 3.3 Sync 1 inversion and randomization

This TS processing step is identical for the three DVB systems, cf Part 2 "DVB-C" and Part 4 "DVB-T".

Sync word inversion and randomization

PRBS polynomial	$x^{15} + x^{14} + 1$
Initialization of PRBS register	100101010000000
Length of polynomial	1503 bytes
Length of randomized sequence	1503 bytes + inverted sync byte = 8 TS packets
Sync word	0x47
Bitwise inverted sync word	0xB8

Table 3.1

3.1.3 Reed-Solomon (RS) Forward Error Correction (FEC)

Following randomization, 16 error control bytes are appended to the TS packets, which are thus enlarged to 204 bytes.

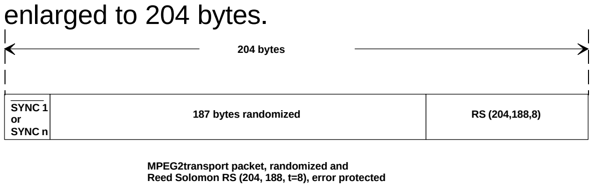

Fig. 3.4 204, 188, t = 8 Reed-Solomon error control coding

Using Reed-Solomon (204, 188, t = 8) error control coding, up to eight errored bytes per TS packet can be corrected in the receiver/decoder. Moreover, a bit-error ratio (BER) of $2*10^{-4}$ can be corrected to obtain a quasi-error-free (QEF) data stream with residual BER of $<1*10^{-11}$.

Note:
The BER of $2*10^{-4}$ is used as a reference in all quality measurements in digital TV (DTV).

This TS processing step, too, is identical for the three DVB systems, cf Part 2 "DVB-C" and Part 4 "DVB-T".

RS FEC

TS packet length	188 + 16 = 204 bytes
Correction	Up to 8 errored bytes per TS packet
Corrective capacity	BER of $2*10^{-4}$ to $1*10^{-11}$

Table 3.2 Reed-Solomon forward error correction

3.1.4 Convolutional Interleaver

Transmission errors usually corrupt not only a single bit but many bits following it in the data stream. Consequently the designation error burst, which may comprise up to several hundred bits. The bits may even be deleted. The Reed-Solomon correction capacity of eight bytes per TS packet is insufficient in such cases. So an interleaver is used to insert at least 12 bytes (the convolutional interleaver has 12 branches, see Fig. 3.5) and at most 2244 bytes from other TS packets between neighbouring bytes of a TS packet. This allows burst errors of max. 12 x 8 = 96 bytes to be corrected if only eight or fewer errored bytes per TS packet occur after the deinterleaver in the receiver/decoder.

Interleaver

Branches	I = 12
Memory depth of FIFOs	M = 17 (= 204 / I) bytes
Sync bytes	Always routed in branch 0

Table 3.3

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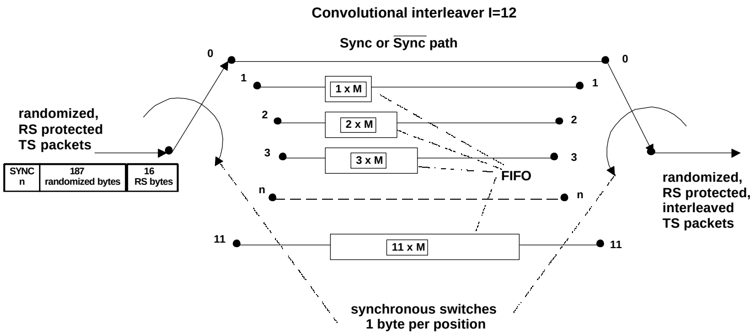

Fig. 3.5 Convolutional interleaver

This TS processing step, too, is identical for the three DVB systems, cf Part 2 "DVB-C" and Part 4 "DVB-T".

After the convolutional interleaver, TS processing is different for the different DVB standards.

3.1.5 Convolutional Coder

In DVB-S, further error protection is added to the TS data by means of convolutional coding and (Viterbi) decoding. This additional forward error protection is necessary because DVB-S signals are subject to additional interference during transmission in the form of atmospheric disturbances. Unlike DVB-C transmission, which relies on a fixed cable network with constant conditions, DVB-S transmission quality may be seriously impaired, for example by rain clouds gathering or a thunderstorm coming up. Yet, DVB-S should provide a clearly better reception quality than analog satellite systems. This is achieved through the second FEC, which is implemented by means of the convolutional coder in the DVB-S modulator.
The convolutional coder has the following characteristics:

Length (constraint length)	k = 7
Generator polynomials	G1 = 171 OCT (X) and G2 = 133 OCT (Y)

Table 3.4 Data of convolutional coder

The generator polynomials determine the outputs at the shift register with k = 7.

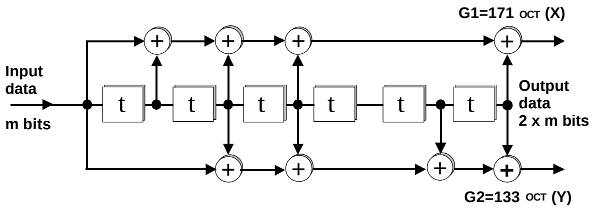

Fig. 3.6 Convolutional coder in DVB

From k bit input data, 2 x k bit output data is obtained, i.e. the useful data rate decreases by a factor of 2. To reduce this high redundancy at least in part, the output data is punctured, i.e. defined bits of the output data are deleted to reduce the output data rate.

3.1.6 Puncturing Scheme

The bit-serial data is doubled between the input and the output of the convolutional coder. The scheme shown below illustrates what bits of the X or Y output are deleted, how the remaining bits are sorted into two continuous data streams applied to the I and Q inputs of the DVB-S QPSK (quadrature phase shift keying) modulator, and the code rate P (also referred to as puncturing rate).

The Viterbi decoder of the DVB-S receiver can improve the BER based on the remaining redundancy. The code rate indicates the ratio of input data rate to output data rate. Possible values are given in Fig. 3.7. The combined use of Viterbi FEC and RS FEC permits an input BER of about $2 * 10^{-2}$ at the DVB-S receiver, depending on the code rate.

The Viterbi decoder corrects the bit error ratio to
$BER \leq 2*10^{-4}$
and
the RS FEC to $BER \leq 1*10^{-11}$

Note:
The BER of $2*10^{-4}$ before RS FEC is the reference value in all measurements of transmission quality.

Up to this point, the processing steps for DVB-S and DVB-T are almost the same. Both use a convolutional coder. The difference is in the sorting of the punctured bits: with DVB-S the two outputs are directly applied to the I and Q inputs of the modulator, whereas the DVB-T coder has a bit-serial output.

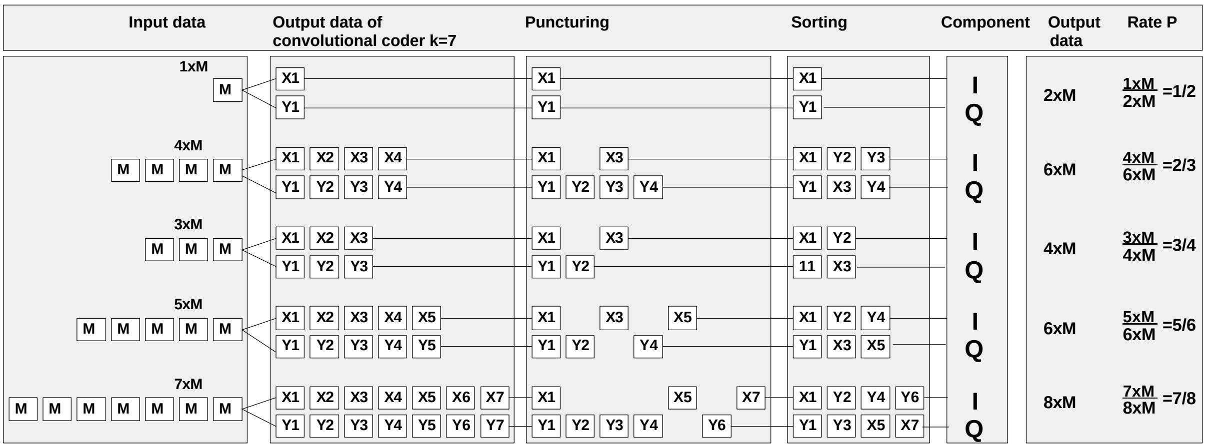

Fig. 3.7 DVB-S puncturing scheme

3.1.7 I and Q Components

Two bits – of the I and Q output data streams of the puncturing block – are mapped into a DVB-S symbol. This means that each symbol carries two bits of information. Gray coding is used to allocate the bits to the respective points of the constellation diagram. This is illustrated by the figure below:

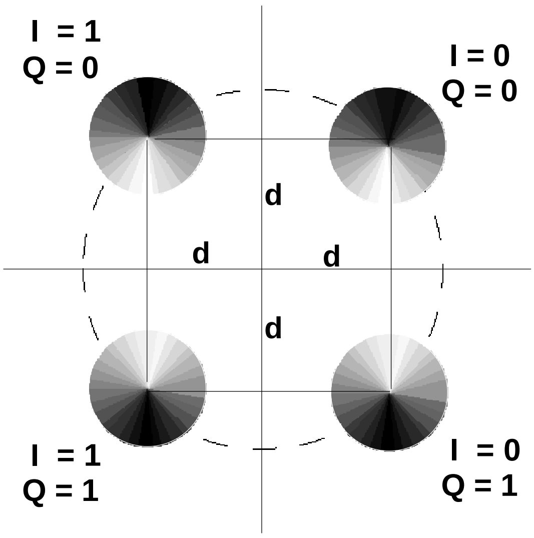

Fig. 3.8 QPSK constellation diagram

The symbols at the output of the DVB-S modulator are $\sqrt{\cos}$ roll-off filtered analog pulses with a spectrum approximating a sin (x)/x function and two amplitude levels each for the I and the Q component. The resulting signals, therefore, have a defined flat spectrum (see Fig. 3.1, right, and section 3.3 "QPSK Spectrum for DVB-S").

A symbol consists of a pair of I and Q values arranged orthogonally through modulation. "I" stands for the inphase and "Q" for the quadrature component.

3.2 DVB-S Signal Bandwidth

The symbols are $\sqrt{\cos}$ roll-off filtered analog pulses similar to a sin (x)/x function with a 3 dB bandwidth B in Hz corresponding to half the symbol rate S in symbols/s. The roll-off factor for DVB-S is r = 0.35. After double-sideband modula-tion, the signal bandwidth is obtained as the symbol rate in Hz.

The bit rate R in Mbit/s of the TS packets can be converted to the symbol rate of a QPSK system by the following equation:

$$S = R * \frac{204}{188} * \frac{1}{2} * \frac{1}{P} \text{ Msymb/s} \qquad \text{Equation 3.1}$$

The factor 204/188 takes into account Reed-Solomon error control coding; P takes into account the effect of puncturing.
In satellite transmission, the bit rate

R = 38.014706 Mbit/s

is frequently used. This results in a Nyquist bandwidth f_N of

f_N = S = 27.5 MHz

for the QPSK symbols, applying the code rate of P = 3/4 commonly used in DVB-S.

The required bandwidth B_T for the transponder channel is calculated from the symbol rate and the roll-off factor as follows:

$$B_T = S * (1 + r) \text{ MHz}$$

For a roll-off factor of 0.35, the following transponder bandwidth is obtained:

$B_{transponder}$ = 27.5 ∗ 1.35 = 37.125 MHz

The new 1E generation of Astra satellites offers 36 MHz transponder bandwidth. This extends the 33 MHz bandwidth of Astra satellites 1A to 1D by 3 MHz, but still does not match the preferable DVB-S symbol rate of 27.5 Msymb/s. Investigations were, therefore, carried out with the aim of reducing the roll-off factor. It was found that a roll-off factor of 0.28 or 0.25 in the DVB-S modulator has hardly any impact on the demodulated signal in the DVB-S receiver. For this reason, a roll-off factor of 0.27 is mostly used today.

Applying a roll-off factor of 0.27, the following transponder bandwidth is obtained:

$B_{transponder}$ = 27.5 ∗ 1.27 = 34.925 MHz
i.e. < 36 MHz

For the 33 MHz transponders, lower symbol rates are defined. The maximum possible symbol rate in compliance with DVB-S specifications is:

S = 33 / 1.35 = 24.444 Msymb/s

3.3 QPSK Spectrum for DVB-S

The European Standard EN 300 421 defines the tolerances of the DVB-S spectrum as follows:

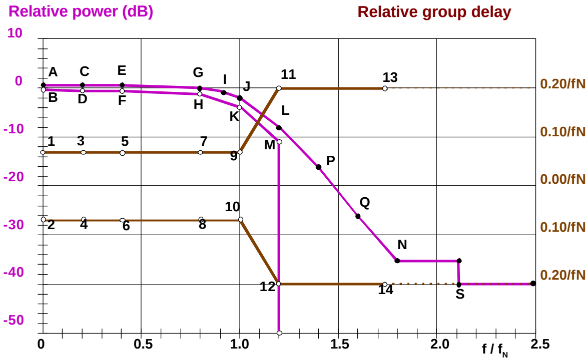

Fig. 3.9 DVB-S spectrum

Definition of points shown in Fig. 3.9

Relative power, upper tolerance limit		
Point	Frequency	Relative power (dB)
A	0.0 ∗f_N	+0.25
C	0.2 ∗f_N	+0.25
E	0.4 ∗f_N	+0.25
G	0.8 ∗f_N	+0.15
I	0.9 ∗f_N	-0.50
J	1.0 ∗f_N	-2.00
L	1.2 ∗f_N	-8.00
P	1.4∗f_N	-16.00
Q	1.6 ∗f_N	-24.00
N	1.8 ∗f_N	-35.00
S	2.12 ∗f_N	-40.00
Relative power, lower tolerance limit		
B	0.0 ∗f_N	-0.25
D	0.2 ∗f_N	-0.40
F	0.4 ∗f_N	-0.40
H	0.8 ∗f_N	-1.10
K	1.0 ∗f_N	-4.00
M	1.2 ∗f_N	-11.00

Relative group delay *), upper tolerance limit		
Point	Frequency	Relative group delay
1	0.0 ∗f_N	+0.07 / f_N
3	0.2 ∗f_N	+0.07 / f_N
5	0.4 ∗f_N	+0.07 / f_N
7	0.8 ∗f_N	+0.07 / f_N
9	0.9 ∗f_N	+0.07 / f_N
11	1.0 ∗f_N	+0.07 / f_N
13	1.2 ∗f_N	+0.2 / f_N
Relative group delay *), lower tolerance limit		
2	0.0 ∗f_N	-0.07 / f_N
4	0.2 ∗f_N	-0.07 / f_N
6	0.4 ∗f_N	-0.07 / f_N
8	0.8 ∗f_N	-0.07 / f_N
10	0.9 ∗f_N	-0.07 / f_N
12	1.0 ∗f_N	-0.07 / f_N
14	1.2 ∗f_N	-0.2 / f_N

*) The numerical values are expressed as (group delay ∗ f_N), i.e. for a "normal" satellite channel with 27.5 Msymb/s the group delay of $\tau \leq 5.1$ ns is defined up to the Nyquist frequency.

Table 3.5 DVB-S spectrum

3.4 $\sqrt{\cos}$ Filtering

The symbols shaped by $\sqrt{\cos}$ filters in the transmitter and the receiver yield a spectrum similar to a sin (x)/x function with a constant amplitude- and group-delay frequency response.

$\sqrt{\cos}$ filtering in the transmitter and the receiver, therefore, produces spectrum edges as shown in Fig. 3.11 "Spectrum obtained by cos roll-off filtering". The degree of approximation to an ideal sin (x)/x spectrum depends on the selected roll-off factor. The smaller this factor, the better the approximation to an ideal sin (x)/x spectrum.
Plotting the level along a linear scale, the following theoretical spectrum is obtained at the output of the DVB-S modulator:

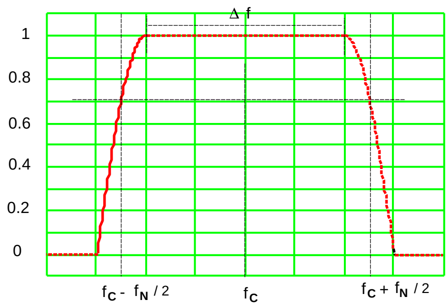

Fig. 3.10 Spectrum obtained by $\sqrt{\cos}$ filtering

Clearly discernible are the steep edges at low levels at the left and right boundaries of the spectrum produced by $\sqrt{\cos}$ filtering. Attenuation at the Nyquist frequencies of $f_C \pm f_N/2$ is 3 dB. The roll-off factor r is the ratio of the Nyquist bandwidth to the flat "rooftop" of the spectrum.

$$r = \frac{f_N}{\Delta f} - 1$$

$\sqrt{\cos}$ filtering in the transmitter and the receiver yields the cos roll-off edges:

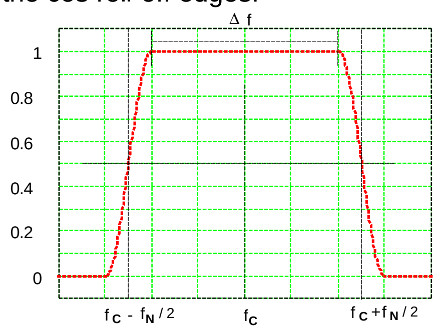

Fig. 3.11 Spectrum obtained by cos roll-off filtering

It can be seen that after cos filtering the edges at low levels at the left and right boundaries of the spectrum are flatter and rounder. Attenuation at the Nyquist frequencies of $f_C \pm f_N/2$ is now 6 dB.

To illustrate this, Fig. 3.12 shows the $\sqrt{\cos}$ and cos filter edges in greater detail:

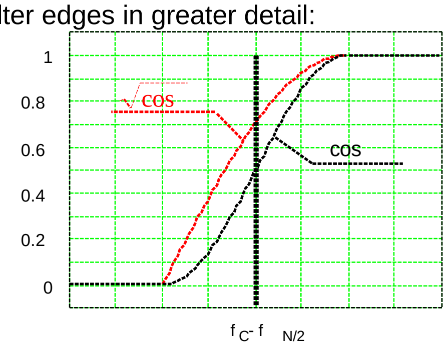

Fig. 3.12 Edges obtained with $\sqrt{\cos}$ roll-off and cos roll-off filtering

The combined filtering in the transmitter and the receiver serves two purposes:

1. optimal approximation to an ideal sin (x)/x spectrum and thus a flat useful spectrum;
2. signal filtering in the receiver and thus useful channel selection.

3.5 DVB-S Key Data

Modulation		QPSK
Symbol form		similar to sin (x)/x, $\sqrt{\cos}$ roll-off filtered
Roll-off factor		0.35 (0.28, 0.25)
Most frequently used bit rate R	Mbit/s	38.014706
Symbol rate S	Msymb/s	$S = R * \frac{204}{188} * \frac{1}{2} * \frac{1}{P}$
Most frequently used symbol rates S	Msymb/s	27.5 (at 36 MHz bandwidth) 24.44 (at 33 MHz bandwidth)

Table 3.6

3.6 Measurements in DVB-S Systems

An MPEG2 multiplexer or MPEG2 generator supplies video, audio and other data in the form of TS (transport stream) packets with a defined data rate R.

TV Test Transmitter SFQ modulates this data as required for the following standards:
DVB-C (digital video broadcasting – cable),
DVB-S (digital video broadcasting – satellite),
DVB-T (digital video broadcasting – terrestrial),
ATSC with 8VSB (advanced television systems committee with eight-level trellis-coded vestigial sideband)
and the American cable standard
ITU-T Rec. J.83/B.

TV Test Transmitter SFL was designed specially for applications in production. It comes in five models tailored to the above standards:
SFL-C for DVB-C (EN 300 429)
SFL-S for DVB-S (EN 300 421, EN 301 210)
SFL-T for DVB-T (EN 300 744)
SFL-V for ATSC/8VSB
SFL-J for ITU-T Rec. J.83/B

To optimally adapt to the TS signal parameters, TV Test Transmitters SFQ and SFL measure the data rate of the input transport stream and convert it to the current symbol rate as appropriate for the modulation mode used, or the data rate is calculated from a predefined symbol rate. Then the data is modulated in compliance with the DTV (digital television) standard in question and transposed to the RF.
For measurements to the DTV standards, SFQ and SFL modulate the TS data stream strictly in accordance with DTV specifications. Apart from this, defined modulation errors can be introduced into the ideal signal, so creating reproducible signal degradation. Such stress signals are indispensable in DTV receiver tests to determine system limits.

TV Test Transmitter SFQ

Condensed data of SFQ

Frequency range	0.3 MHz to 3.3 GHz
Level range	-99.9 dBm to +4 dBm
MPEG2 inputs	ASI SPI TS PARALLEL
Error simulation	
I/Q amplitude imbalance	±25 %
I/Q phase error	±10 °
Residual carrier	0 % to 50 %
Special functions	scrambler, Reed-Solomon, all interleavers can be switched off
DVB-C	
Modulation	16QAM, 32QAM, 64QAM, 128QAM, 256QAM
DVB-S	
Modulation	QPSK
Code rate	1/2, 2/3, 3/4, 5/6, 7/8
DVB-T	
Modulation	QPSK,16QAM, 64QAM non-hierarchical, hierarchical
FFT mode	8k and 2k
Bandwidth	6 MHz, 7 MHz, 8 MHz
Puncturing	1/2, 2/3, 3/4, 5/6, 7/8
ATSC	
Modulation	8VSB
Bandwidth	6 MHz
Data rate	19.392658 Mbit/s ±10 %
Symbol rate	10.762 Msymbol/s ±10 %
Internal test signals	null TS packets, null PRBS packets PRBS (2^{23} - 1 and 2^{15} - 1)
Options	fading simulator, noise generator, input interface, BER measurement, turbocoding

Condensed data of SFL-S

Frequency range	0.3 MHz to 3.3 GHz
Level range	-140 dBm to 0 dBm
MPEG2 inputs	ASI SPI TS PARALLEL
Error simulation	
I/Q amplitude imbalance	±25 %
I/Q quadrature offset (phase offset)	±10 °
Residual carrier	0 % to 50 %
Special functions	scrambler, Reed-Solomon, all interleavers can be switched off
Modulation	QPSK, 8PSK, 16QAM
Internal test signals	null TS packets, null PRBS packets PRBS (2^{23} -1 and 2^{15} -1)
Options (on request)	noise generator (SFL-N), turbocoding


TV Test Transmitter SFL-S

3.6.1 Important Requirements To Be Met By DVB-S Test Transmitter

This section deals in particular with the requirements to be met by TV Test Transmitter SFQ in DVB-S measurements. The statements made below also apply to TV Test Transmitter SFL-S.

Test transmitters are needed to simulate potential errors in the DTV modulator and distortions in the transmission channel. From the two types of signal degradation it is determined to what extent a receiver still operates correctly when non-standard-conforming signals are applied. For tests on a DVB-S set-top box (STB), for example, the test transmitter should be capable of producing defined deviations from the standard in addition to the common parameter variations of, for example, Tx frequency or output level.

STBs have to undergo function tests in at least three frequency ranges:

- in the lowest RF channel,
- in a middle RF channel, and
- in the highest RF channel.

TV Test Transmitter SFQ is capable of setting any frequency between 0.3 MHz and 3.3 GHz, thus offering a frequency range by far exceeding the range presently defined for DVB-S. Frequencies of interest can also be stored in the form of a channel table.

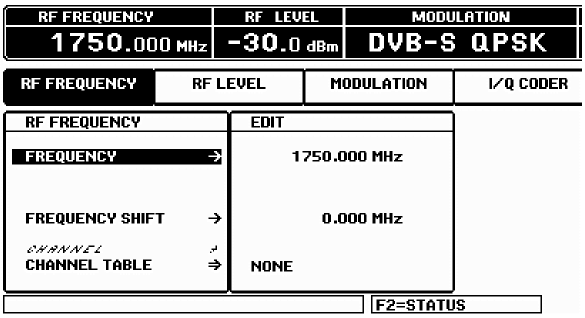

Fig. 3.13 Frequency setting on SFQ

Another test is for verifying error-free reception at a minimum level of typically -70 dBm. SFQ features a setting range between +6 dBm and -99 dBm, which in any case includes the required minimum level.

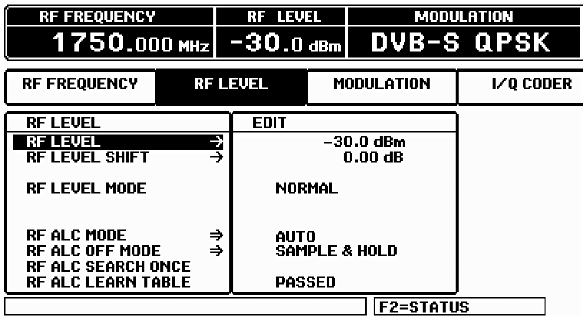

Fig. 3.14 Level setting on SFQ

In the DVB-S modulation mode, modulator- and transmission-specific settings can be made, including noise superposition and the generation of fading profiles. SFQ is thus capable of simulating all signal variations and degradations occurring in a real DVB-S system. The degraded signal generated by the "stress transmitter" SFQ is used for testing the STB's susceptibility to errors and interference.

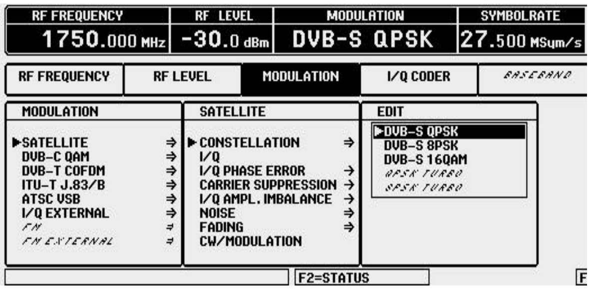

Fig. 3.15 Setting of modulator- and transmission-specific parameters in DVB-S mode

Detailed information on the above parameters will be found in section 3.6.3 "Error Sources in DVB-S".
Further important settings for the DVB-S system can be made in the "I/Q CODER" menu. Here the TS (transport stream) parameters for the modulator can be selected.

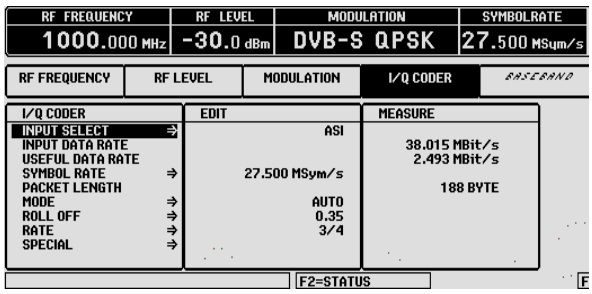

Fig. 3.16 DVB-S settings in I/Q CODER menu

3.6.2 Power Measurement

Measurement of the output power of a DVB transmitter is not as simple as that of an analog transmitter. In the analog world, the actual power of the sync pulse floor is measured at a sufficiently large bandwidth and displayed as the actual sync pulse peak power. A DVB signal, by contrast, is characterized by a constant power density across the Nyquist bandwidth (see Fig. 3.17), which results from energy dispersal and symbol shaping in the DVB modulator. Consequently, only the total power in a DVB channel is measured.

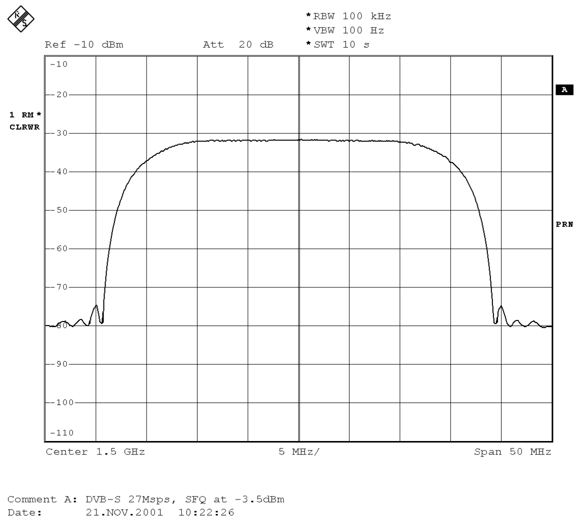

Fig. 3.17 Constant power density in a DTV channel (the $\sqrt{\cos}$ roll-off filter edges are clearly discernible)

The measurement bandwidths (resolution bandwidths - RBWs) of a spectrum analyzer are very small compared to the Nyquist bandwidth of a DVB-S signal. Information about the channel power can be gained by converting the measurement bandwidth to the signal bandwidth, taking into account the analyzer-specific correction factor. This method is, however, complicated and involves a considerable degree of inaccuracy.

Two more precise methods of measuring DVB-S signal power are known to date:

3.6.2.1 Mean Power Measurement with Power Meter NRVS and Thermal Power Sensor

Condensed data of Power Meter NRVS with Thermal Power Sensor NRV-Z51

NRVS	
Frequency range	DC to 40 GHz
Level range	100 pW to 30 W (depending on sensor)
Readout	
Absolute	W, dBm, V, dBmV
Relative	dB, % W or % V, referred to a stored reference value
Remote control	IEC 625-2/IEEE 488.2 interface
Max. input voltage	50 V
NRV-Z51	
Power sensor	thermal
Impedance	50 O
Connector	N type
Frequency range	DC to 18 GHz
Level range	1 µW to 100 mW

Thermal power sensors supply the most accurate results if there is only one DVB channel in the overall spectrum.
Plus, they can easily be calibrated by performing a highly accurate DC voltage measurement, provided the sensor is capable of DC measurement. To measure the DVB power, however, the DVB signal should be absolutely DC-free.

3.6.2.2 Mean Power Measurement with Spectrum Analyzer FSEx, FSP or FSU

If a conventional spectrum analyzer is used to measure power, its maximum measurement bandwidth will not be sufficient for a satellite channel. State-of-the-art spectrum analyzers, by contrast, allow broadband power measurements between two user-selected frequencies. The large Nyquist bandwidth of DVB transmission channels poses therefore no problems. Moreover, all kinds of amplitude frequency response that may occur in a satellite channel are taken into account, whether these are just departures from flat or caused by echoes. Based on this principle, the Rohde & Schwarz Spectrum Analyzers FSEx, FSP and FSU measure mean power in a DVB channel with an accuracy of ≤ 1.5 dB.

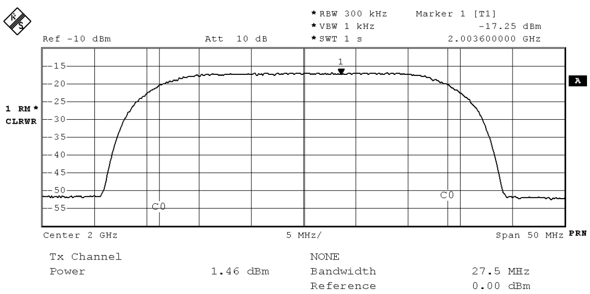

Fig. 3.18 a Power measurement with frequency cursors, Nyquist channel power (BW = 27.5 MHz)

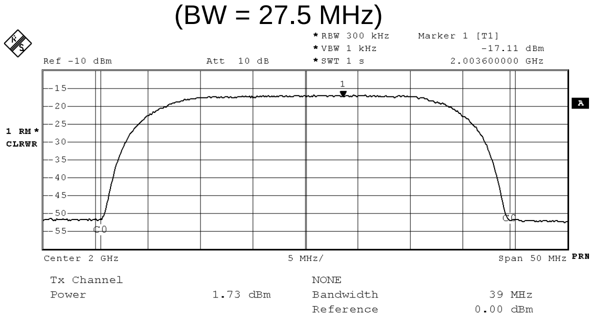

Fig. 3.18 b Power measurement with frequency cursors, total channel power (BW = 39 MHz)

A frequency cursor (C0) is placed on the lower and another one on the upper frequency of the DVB-S channel. The spectrum analyzer calculates the power for the band between the cursors. The method provides sufficient accuracy as long as the transponder channels are sufficiently spaced from each other in frequency and thus clearly separated. Given the normal DVB-S transponder assignment, i.e. without guard channels, results may be falsified however.

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SPECTRUM ANALYZER FSP

Condensed data of FSP

Frequency range (FSP3/7/13/30)	9 kHz to 3/7/13/30 GHz
Amplitude measurement range	-140 dBm to +30 dBm
Amplitude display range	10 dB to 200 dB in steps of 10 dB, linear
Amplitude measurement error	<0.5 dB up to 3 GHz, <2.0 dB from 3 GHz to 13 GHz, <2.5 dB from 13 GHz to 20 GHz
Resolution bandwidth	1 Hz to 30 kHz (FFT filters), 10 Hz to 10 MHz in 1, 3 sequence EMI bandwidths: 200 Hz, 9 kHz, 120 kHz
Detectors	Max Peak, Min Peak Auto Peak, Quasi Peak, Sample, Average, RMS
Display	21 cm (8.4") TFT LC colour display, VGA resolution
Remote control	IEC 625-2/IEEE 488.2 (SCPI 1997.0) or RS232C
Dimensions (W x H x D)	412 mm x 197 mm x 417 mm
Weight (FSP3/7/13/30)	10.5/11.3/12/12 kg

SPECTRUM ANALYZER FSEx

Condensed data of FSEA/FSEB

Frequency range	20 Hz/9 kHz to 3.5/7 GHz
Amplitude measurement range	-155/-145 dBm to +30 dBm
Amplitude display range	10 dB to 200 dB in steps of 10 dB
Amplitude measurement error	<1 dB up to 1 GHz, <1.5 dB above 1 GHz
Resolution bandwidth	1 Hz/10 Hz to 10 MHz in 1, 2, 3, 5 sequence
Calibration	amplitude, bandwidth
Display	24 cm (9.5") TFT LC colour or monochrome display, VGA resolution
Remote control	IEC 625-2/IEEE 488.2 (SCPI 1997.0) or RS232C

3.6.3 Error Sources in DVB-S

Digital TV has a clearly defined range in which it operates correctly. Transition between the operational range and total failure of a DVB-S system is very distinct. DVB-S uses outer and inner forward error correction (Reed-Solomon and Viterbi), which makes this transition even more pronounced than in DVB-C, while it renders the system much more error-tolerant. The sources of the errors determining the BER values before and after Viterbi, which serve as indicators for system operability, are known. A distinction is made between errors originating from the DVB modulator/transmitter and errors occurring during transmission.

The following errors occur in the modulator/ transmitter:

- different amplitudes of the I and Q components,
- phase between I and Q axis deviating from 90 °,
- phase jitter generated in the modulator,
- insufficient carrier suppression in DVB modulation,
- amplitude and phase frequency response distorting the I and Q pulses being shaped during signal filtering, and
- noise generated in the modulator and superimposed on the QPSK signals.

Amplitude and phase frequency response are aggravated during transmission by:

- nonlinearities of the satellite's transponder cause distortions of the DVB-S signal,
- intermodulation with adjacent channels degrading signal quality,
- interference and noise superimposed on the useful signal, and
- reflections distorting amplitude and phase frequency response.

Whereas the errors produced outside the modulator can be simulated by means of auxiliary equipment, the distortion introduced by the modulator itself can only be generated with a professional test transmitter. Here, TV Test Transmitter SFQ comes into its own as a stress transmitter. Tests reveal that a single parameter will not cause failure of the DVB-S system, even if degraded to the point of maximum error. As an example, the table below lists the limit values for modulator parameters that may occur simultaneously without errors resulting after the outer and inner FEC.

Parameter	Deviation from ideal value set on test transmitter
I/Q IMBALANCE	25 %
I/Q QUADRATURE ERROR	10 °
PHASE JITTER	(cannot be set with SFQ alone, see also Application Note 7BM30)
CARRIER SUPPRESSION	50 %

Table 3.7 Tolerable modulator errors in DVB-S with code rate 3/4

The BER before RS FEC resulting for the above values and the code rate 3/4 remains below the measurement limit of $0.0*10^{-9}$. In addition to these grave errors, noise may be superimposed on the useful signal. The additional carrier-to-noise (C/N) ratio is still 6.5 dB for a BER < $2.0*10^{-4}$.
When switchover is made to the code rate 1/2, the C/N ratio increases to 3.8 dB, including all modulator errors listed in Table 3.7 (see also Table 3.8 "Maximum SNR for the different code rates").

This demonstrates the high reliability of DVB-S transmission systems. Test and measurement requirements in STB production, DVB-S transmission, etc are, for this reason, not very stringent. The measurements to be performed will be described later.

TV Test Transmitter SFL-S, which was specially designed for production, offers the same range of settings as the SFQ and therefore also allows acceptance tests at the end of the production line.

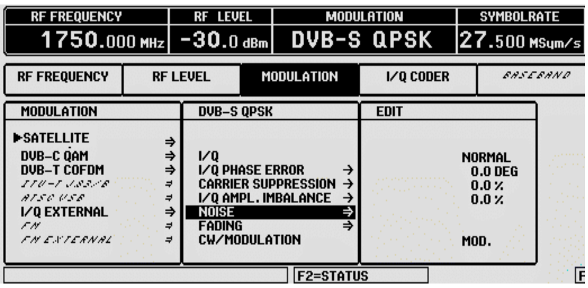


Fig. 3.19 SFQ menu for QPSK parameter setting

3.6.4 Bit Error Ratio (BER)

A defined BER can be generated by means of a noise generator with selectable bandwidth and level. The theoretical BER as a function of the signal-to-noise (S/N) ratio is described by calculated graphs for the five code rates in the QPSK mode.

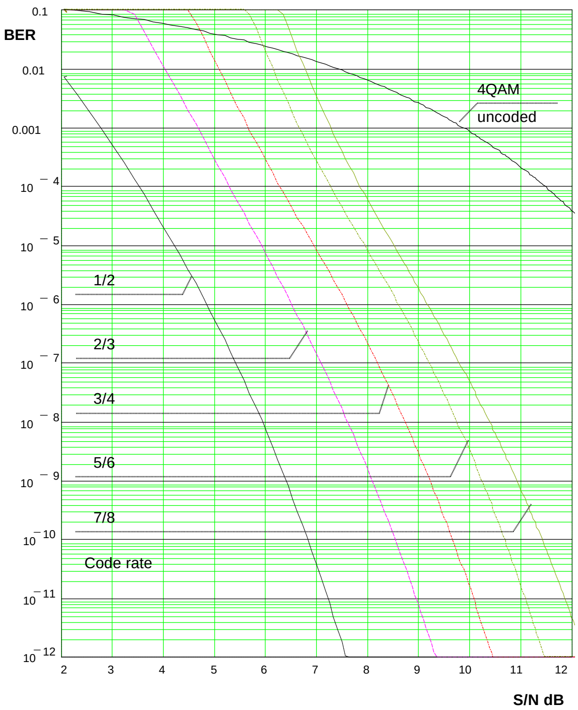


Fig. 3.20 Theoretical BER(S/N) for the five code rates in QPSK mode

Note: The theoretical curves shown in Fig. 3.20 present the BER as a function of the S/N ratio. The following relationship exists between S/N and C/N for DVB-S with a roll-off factor of r = 35 %:
S/N = C/N + $k_{roll\text{-}off}$ *= C/N - 0.398 dB*

TV Test Transmitter SFQ as well as the members of the SFL Test Transmitter family have integrated, optional noise generators (e.g. SFL-N for SFL).
The curves being very steep in the range BER $\leq 2*10^{-4}$, which is the reference value in all measurements connected with BER, the noise level can be determined very accurately.

This is done either using the method described in Application Note 7BM03 *(see Annex 4C to Part 4 (DVB-T) of the "Digital TV Rigs and Recipes")*, or by a direct measurement with TV Test Receiver EFA.
7BM03 also explains C/N to S/N conversion.

When one compares error susceptibility of DVB-C and DVB-S, it will be noticed immediately that the decision fields of the two DTV systems are very different in size. The "area" of a decision field in DVB-C with 64QAM is smaller by a factor of 16 than that of a DVB-S decision field. This factor alone means an extra margin of error tolerance of 10∗log(16) = 12 dB. Inner FEC (Viterbi) additionally improves the BER by two more decades. These two factors together guarantee, for example, quasi-error-free (QEF) reception for the lowest code rate of ½, even if an S/N ratio as low as 3.7 dB is obtained in the receiver after $\sqrt{\cos}$ filtering. This is valid even on the assumption of an equivalent noise degradation (END) of 0.4 dB. The improvement in quality over analog reception is evident.

Table 3.7 lists the minimum SNR values (SNR = signal-to-noise ratio) for the five code rates $P = \frac{1}{2}, \frac{2}{3}, \frac{3}{4}, \frac{5}{6}$ and $\frac{7}{8}$ for a BER $\leq 2*10^{-4}$ before Reed-Solomon forward error correction:

Code rate P	Max. SNR (dB)
1/2	3.3
2/3	5.1
3/4	6.1
5/6	7.1
7/8	7.7

Table 3.8 Minimum SNR for the different code rates

3.6.5 BER Measurement with SFQ

If TV Test Transmitter SFQ is fitted with options SFQ-B10 (DVB-T Coder) and SFQ-B17 (BER Measurement), the BER can be determined additionally with SFQ alone.

An SFQ-generated data stream (PRBS BEFORE CONVolutional coder) or the valid NULL PRBS PACKET MPEG2 transport stream is DVB-S-modulated and applied to the device under test (DUT).

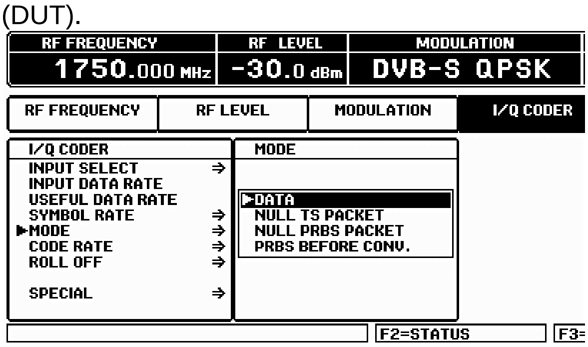


Fig. 3.21 BER measurement with SFQ-generated data

The TS packets are demodulated and output by the DUT, for example via the common interface (CI), and then re-applied to SFQ for BER measurement.

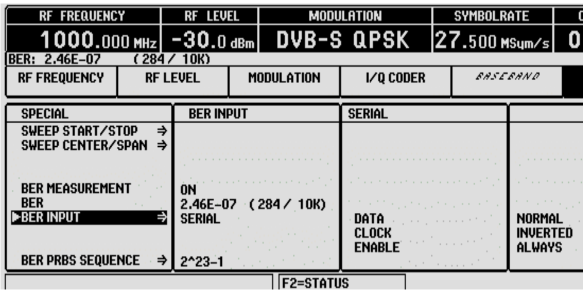


Fig. 3.22 BER measurement

In the following, this measurement will be explained by means of an example. The END (equivalent noise degradation) parameter of the front end of a DVB-S set-top box is to be determined.

Settings on SFQ

MODULATION	**NOISE ON** **C/N is being varied**
CODER	**REED SOLOMON OFF** **MODE NULL PRBS PACKET** **PRBS 2^{23} - 1**
SPECIAL	**BER MEASUREMENT ON** **BER INPUT PARALLEL** **MODE NULL PRBS PACKET** **BER PRBS SEQUENCE 2^{23} - 1**

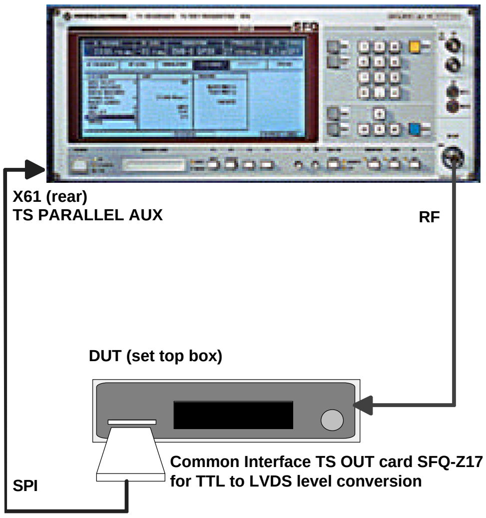


Fig. 3.23 Test setup and settings for BER/END measurement

TV Test Transmitter SFQ modulates the null PRBS packets (null packets with payload consisting of PRBS bytes). Channel coding is complete except that the Reed-Solomon encoder is switched off.

As a result, the Reed-Solomon decoder in the DUT detects more than eight apparently errored bytes, because the 16 error protection bytes are missing. The Reed-Solomon decoder sets the TEI (transport error indicator) error flag and allows the transport stream to pass unchanged. The BER before the Reed-Solomon decoder can thus easily be measured.

On a set-top box, the transport stream is brought out as a TTL signal at the common interface. An adapter card converts the TTL signal to an LVDS signal. This signal is taken to SFQ (TS PARALLEL AUX input) for BER measurement. The SFQ BER Measurement option (SFQ-B17) removes the four-byte header from the transport packets (SFQ is set to NULL PRBS PACKET mode, see left). The remaining 184 bytes of useful data contain the original PRBS of 2^{23} - 1, which is evaluated to obtain the BER.

To determine the END, the C/N ratio of the SFQ output signal is varied to a BER of $1{*}10^{-4}$. Using the method described in Application Note 7BM03, the C/N value is precisely determined and then converted to the S/N value by subtracting the roll-off factor. The difference between the measured S/N and the theoretical S/N shown in Fig. 3.20 "Theoretical BER(S/N) for the five code rates in QPSK mode" for DVB-S (or the corresponding diagram for DVB-C) at a BER of $1{*}10^{-4}$ is the wanted END in dB. It should not exceed 0.8 dB.

3.6.6 Crest Factor of DVB-S Signal

The structure of a DVB-S signal is determined by the four states it may assume in a QPSK constellation diagram. After settling, DVB-S signals have identical amplitude while the phases change by ±90 ° or ±180 °. Correspondingly, different level steps with different overshoots occur. Amplitude levels of $2{*}d$ or $2{*}d{*}\sqrt{2}$ are used (see Fig. 3.8 "QPSK constellation diagram"). The height of the overshoots depends on the roll-off factor. To detect limiting effects, the crest factor is measured. This factor is defined as the quotient of the peak voltage value and the root-mean-square (rms) voltage value. Spectrum Analyzer FSP measures the crest factor using the complementary cumulative distribution function (CCDF). If the factor so determined attains a value of K_{CREST} > 7 dB at a probability of $1{*}10^{-7}$, it can be assumed that there are no limiting effects in the DVB-S system under test.

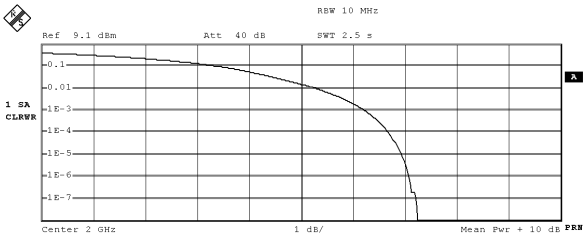


Fig. 3.24 Crest factor of a DVB-S signal

Any limitations of the DVB-S signal would mean that information is missing, with the consequence of increasing BER. Correct level adjustment, therefore, helps to avoid an unnecessary reduction of the system's safety margin.

3.6.7 DVB-S Spectrum and Shoulder Distance

For MPEG2 transport streams transmitted via satellite, the receive conditions must be monitored to guarantee constant, adequate coverage of the service area in question. Thanks to the robustness of the DVB-S system, all that is to be done is measuring the amplitude frequency response and shoulder distance using a well-aligned consumer satellite antenna. Although fading effects play a minor role in DVB-S reception, the effects of reflections with a constant phase, which produce a non-flat spectrum, should at least be examined. Such a spectrum is simulated by TV Test Transmitter SFQ.

Fig. 3.25 shows the optimal amplitude frequency response for a symbol rate of 27.5 Msymb/s, which corresponds to a signal bandwidth of 27.5 MHz. The effect of $\sqrt{\cos}$ roll-off filtering with roll-off factor r = 0.35 is easy to recognize.
Fig. 3.26 illustrates the effect of an echo with constant phase. The notch in amplitude frequency response produced by the echo is clearly discernible.

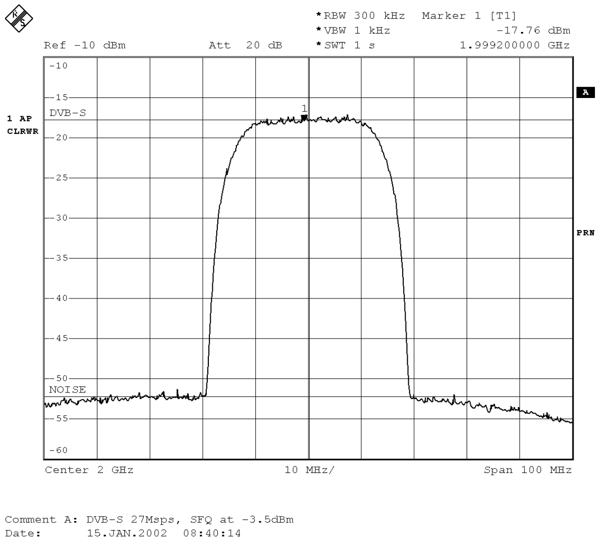


Fig. 3.25 Optimal amplitude frequency response for DVB-S

The shoulder distance in Fig. 3.25 is 47 dB. From Fig. 3.20 "Theoretical BER(S/N) for the five code rates in QPSK mode" it can be seen that a C/N (converted to S/N) of 47 dB will in any case yield a BER better than that of QEF reception.

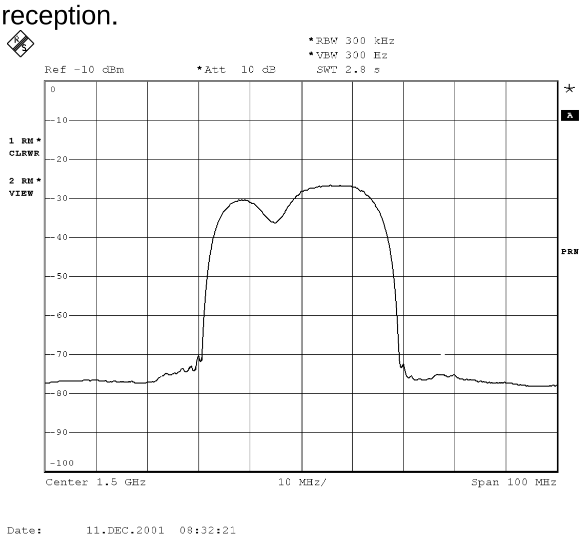


Fig. 3.26 Amplitude frequency response in DVB-S with 20 ns/6.5 dB echo

Echoes like those shown in Fig. 3.26 are quite likely to occur in the event of mismatch in the cabling system of a building or misalignment of the satellite antenna. It is therefore advisable to examine the reasons if a DVB-S set-top box produces a fading profile like the one shown above, although this profile should not cause a deterioration of the BER.

3.6.8 How to Generate a Defined Echo

By means of a defined mismatch, an echo is generated and superimposed on the RF output signal of TV Test Transmitter SFQ. The mismatch is introduced by a 50 Ω coaxial cable terminated with a short-circuit impedance and inserted in the RF feeder line to the set-top box via a T section. The notch in amplitude frequency response occurs at a defined frequency which depends on the length of the inserted cable. An echo delay of 2∗5 ns (forward and reflected) is assumed for each meter of length. In the above example, the notch comes at 1495 MHz, which corresponds to a delay of 20.067 ns.
The above spectrum was generated by means of a 2 m 50 Ω coaxial cable terminated with a short-circuit impedance, causing a delay of t = 2 x 2 x 5 = 20 ns. The frequency at which the first notch occurs is equal to f_1 = 1/ t = 50 MHz. The notch is repeated at f_n = n x f_1 (with n = 1, 2, 3,...).
For n = 30, for example, the notch should occur at f_{30} = 1500 MHz. The measured spacing from the center frequency is in this case only 5 MHz or 0.33 % (see fig 3.26). The depth of the notch depends on the quality of the cable.

Note: The optional Fading Simulator SFQ-B11 has a useful bandwidth of 14 MHz, which is too narrow for generating fading effects in DVB-S. Common DVB-S bandwidths are clearly larger than 20 MHz.

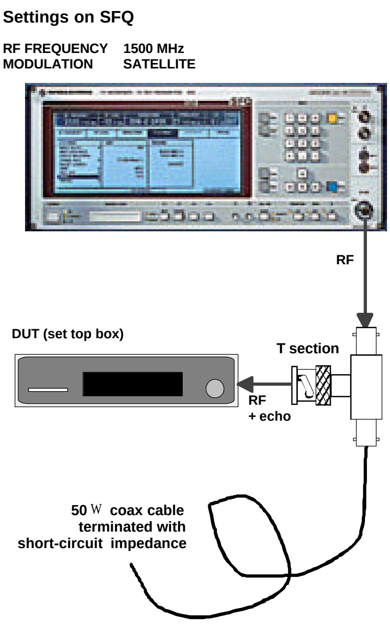
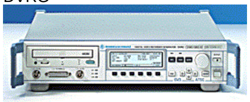
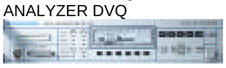
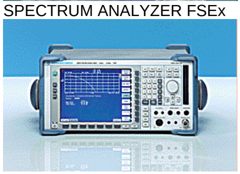
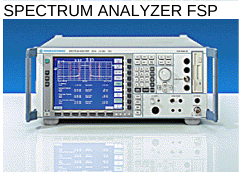


Fig. 3.27 Test setup for echo generation

3.7 Overview of DVB-S Measurements

Instrument, Test Point	Test Parameter
On satellite uplink **TS source for production**	
MPEG2 MEASUREMENT GENERATOR DVG 	Test signal generator for reproducible MPEG2 measurements, various test sequences
DTV RECORDER GENERATOR DVRG 	Test signal generator for reproducible MPEG2 measurements, various test sequences; recording of user-defined transport streams, recording of error events
TS output stream at common interface of STB	
MPEG2 MEASUREMENT DECODER DVMD 	Realtime MPEG2 transport stream protocol analysis
MPEG2 REALTIME MONITOR DVRM 	Realtime MPEG2 transport stream protocol monitoring
DIGITAL VIDEO QUALITY ANALYZER DVQ 	Measurement of signal quality after MPEG2 coding and decoding
At test transmitter/ **satellite uplink** **Reception via satellite antenna** **Analyzers for production**  SPECTRUM ANALYZER FSEx  SPECTRUM ANALYZER FSP  SPECTRUM ANALYZER FSU	DVB-S spectrum Shoulder distance Roll-off factor Crest factor Output power

Instrument, Test Point	Test Parameter
At test transmitter/ **satellite uplink**  **Power Meter NRVS with Thermal Power Sensor NRV-Z51**	High-precision thermal measurement of output power
Simulation of **DVB-S transmission**  TV TEST TRANSMITTER SFQ Option NOISE GENERATOR	C/N setting for END/BER measurement Simulation of defined receive conditions Simulation of modulator defects
DVB-S test transmitter **for production**  TV TEST TRANSMITTER SFL-S	Test transmitter for production Simulation of modulator defects for testing and adjustment of set-top boxes in production