ROHDE&SCHWARZ
BROADCASTING DIVISION

Digital TV
Rigs and Recipes
Part 4 DVB-T

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Contents

4.1 Introduction

The expansion of multi-frequency networks (MFNs) and single-frequency networks (SFNs) for terrestrial digital video broadcasting (DVB-T) means growing demand for measuring technology for this modern means of transmission. The instruments we know from analog TV are not suitable for DVB, with a few exceptions like spectrum analyzers and thermal power meters. Not only are the instruments for DVB quite unlike those for analog technology, the parameters and methods of testing them are different too. This paper presents measurement techniques especially developed by Rohde & Schwarz for DVB-T.

The first topic focused on is the DVB-T transmitter to familiarize you with the special features of such a system. This will be followed by a description of test parameters, methods and instruments.

4.2 DVB-T Transmitter

4.2.1 DVB-T Modulator, Non-Hierarchical

In what follows, the signal processing steps will be explained based on the block diagram of a DVB-T transmitter shown below.

It can be seen that the DVB-T modulator uses in part the same function blocks as the related modulators for DVB-C (cable) to EN 300 429 and DVB-S (satellite) to EN 300 421. So certain test methods and parameters can also be adopted for these two DVB standards.

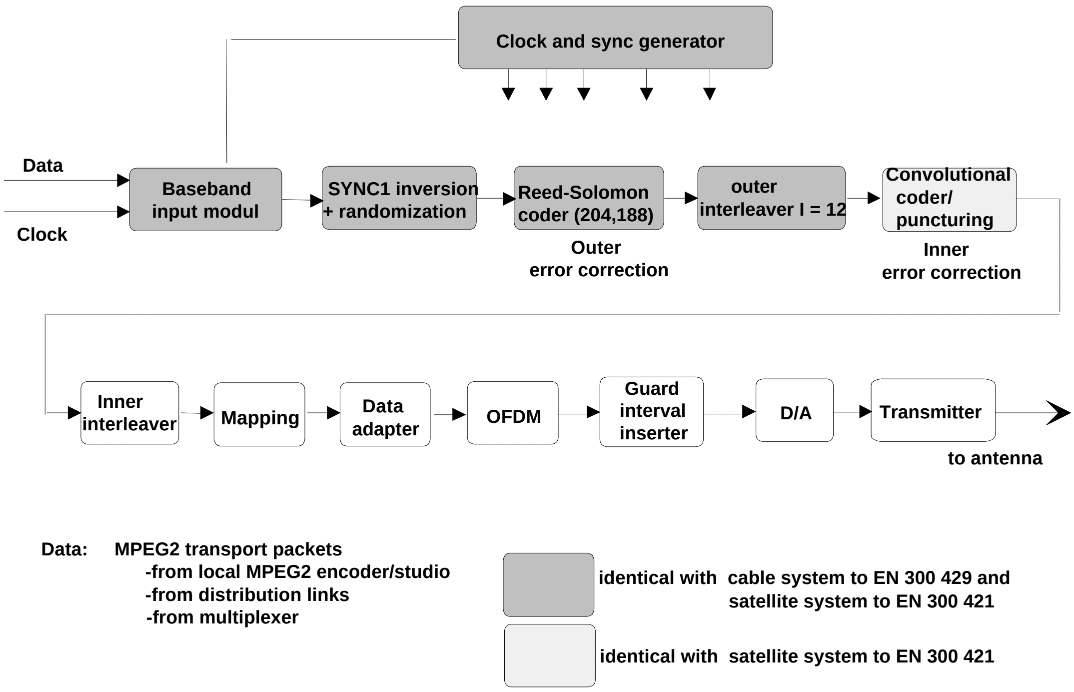


Fig 4.1 The DVB-T modulator / transmitter

4.2.2 Baseband Input Module

MPEG2-coded data are fed to the baseband input module in the form of a packetized transport stream (TS). Here the following parameters have to be aligned:

- Return loss (e.g. at the ASI interface if possible)
- Amplitude and phase response versus frequency
- Data amplitude

At the output of the module the regenerated TS packet data are available for distribution to the subsequent function blocks of the DVB-T modulator.
First the data are applied to the clock and sync generator. This module supplies the required clock and sync information to all function blocks of the DVB-T modulator
Next, the TS packet data are fed to the sync word inversion and energy dispersal block.

4.2.3 Sync Word Inversion and Randomization for Energy Dispersal

As a first processing step, the TS packets undergo sync word inversion and randomization for energy dispersal. The PRBS polynomial $1 + x^{14} + x^{15}$ disperses the data but not the sync words (0x47) of the TS packets. The sync word is the first byte of each TS packet. The polynomial has a length of 1503 bytes. This exactly corresponds to eight TS packets minus the bit-wise inverted sync word of the first TS packet, whose value is now 0xB8.

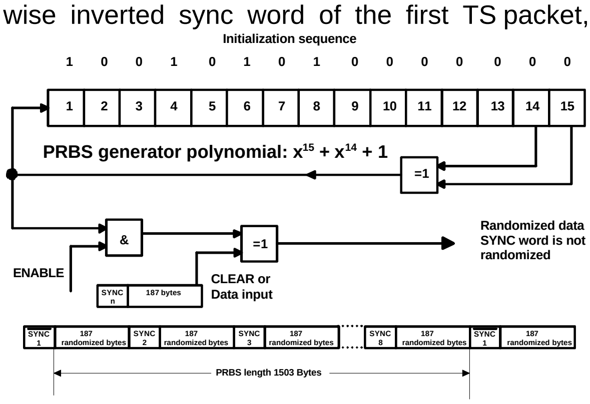


Fig. 4.2 Randomization for energy dispersal

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. Randomization ensures a constant average modulator output level.

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
Bit-wise inverted sync word	0xB8

Table 4.1

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

16 error control bytes are appended to the randomized TS packets. The extended TS packets now have a length of 204 bytes. The Reed-Solomon (204,188, t = 8) error control code allows correction of up to eight errored bytes per TS packet in the receiver/decoder. Using RS FEC, 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 $1*10^{-11}$.

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 4.2 Reed-Solomon forward error correction

4.2.5 Interleaver

Transmission errors 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 Reed-Solomon correction capacity of eight bytes per TS packet is usually insufficient in such cases. So an interleaver is used to insert at least 12 bytes from other TS packets between neighbouring bytes. This allows burst errors of max. 12 x 8 = 96 bytes to be corrected because only eight or fewer errored bytes per TS packet are obtained after the deinterleaver in the DVB receiver/decoder.

Interleaver

Paths	I = 12
Memory depth of FIFOs	M = 17 (= 204 / I) bytes
Sync bytes	Always via path 0

Table 4.3

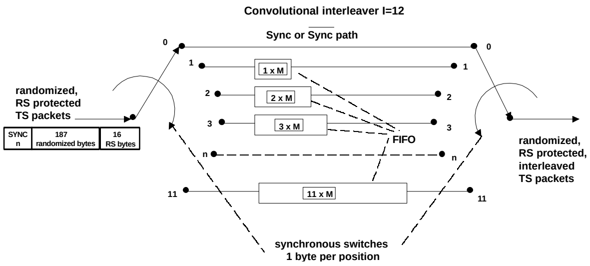


Fig. 4.3 Convolutional interleaver

Up to this point, the function blocks are identical for all DVB standards.

4.2.6 Convolutional Coder

In DVB-T, further error protection is added to the TS data by means of convolutional coding and (Viterbi) decoding.
The convolutional coder has the following characteristics:

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

Table 4.4

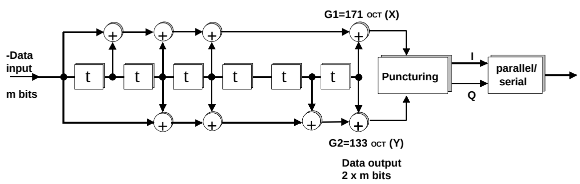


Fig. 4.4 Convolutional coder in DVB-T

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

From k bit input data, 2 x k bit output data are 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 are punctured. Defined bits of the output data are deleted, so reducing the output data rate in accordance with the puncturing scheme explained below.

4.2.7 Puncturing Scheme

The bit-serial data are 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 bits are sorted into a continuous data stream, and the puncturing rate P. The resulting serial bit stream is fed to the bit interleaver.

The Viterbi decoder of the DVB-T receiver can improve the BER based on the remaining redundancy. The puncturing rate, also referred to as code rate, indicates the ratio of input data rate to output data rate. Possible values are given in Fig. 4.5. The combined use of Viterbi FEC and RS FEC permits an input BER of about 2×10^{-2} depending on the puncturing rate:

The Viterbi decoder corrects the bit error ratio to
BER = 2×10^{-4} and
the RS FEC to BER = 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/Q inputs of the modulator, whereas the DVB-T coder has a bit-serial output.

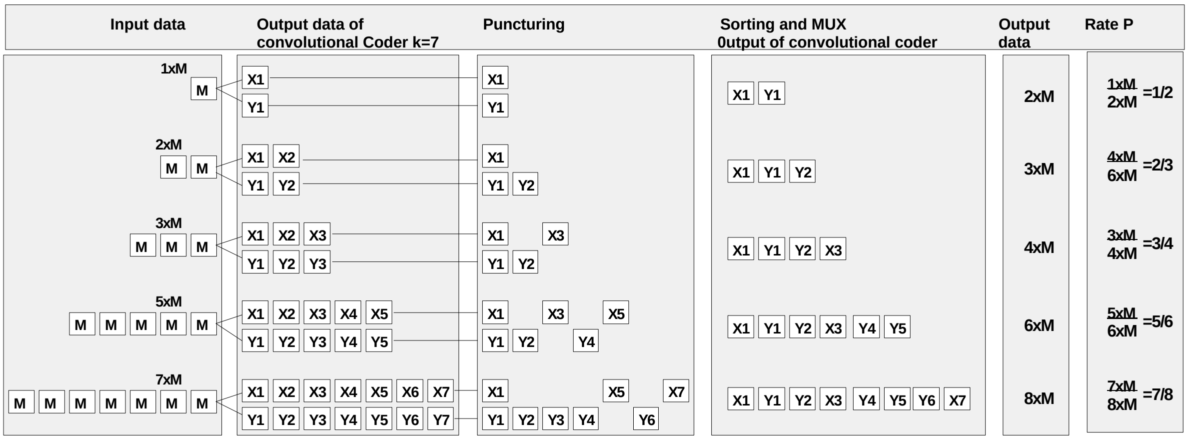


Fig. 4.5 DVB-T puncturing scheme

4.2.8 Byte-to-Symbol Mapping in DVB-T

Two modes are defined for the COFDM multicarrier method: 2k with 1705 carriers and 8k with 6817 carriers. COFDM can be optimally adapted to suit the conditions of terrestrial transmission. To ensure practically undisturbed reception even under extremely poor conditions (effects of weather, fading), further protection is added to the signal in the DVB-T modulator.

4.2.8.1 Inner Interleaver

In addition to the outer interleaver, which follows outer error correction (FEC) to Reed-Solomon, an inner interleaver is used in COFDM. Depending on the modulation mode – QPSK, 16QAM or 64QAM – the interleaver comprises two, four or six paths.

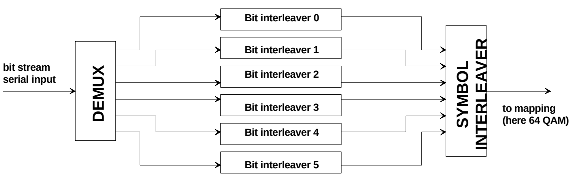


Fig. 4.6 Bit interleaver in 64QAM

In 8k mode, 48 blocks of 126 bits are processed in a 2-, 4- or 6-path bit interleaver using defined formulas for each path. In this way, all I/Q value pairs are defined for the 6048 data carriers in 8k.

In 2k mode, 12 blocks of 126 bits are processed in a 2-, 4- or 6-path bit interleaver using defined formulas for each path. In this way, all I/Q value pairs are defined for the 1512 data carriers in 2k.

The bit interleaver and the symbol interleaver in this way optimally support the bit-wise inner (Viterbi) error correction.

Note:
The designations "inner" and "outer" refer to the position of the function blocks relative to the antenna: "inner" designates the block closer to the antenna, "outer" the block further away from the antenna.

4.2.8.2 Symbol Interleaver

As described above, the interleaver output data words are grouped in 12 blocks of 126 bits in 2k mode and in 48 blocks of 126 bits in 8k mode. The symbol interleaver processes the bit groups to generate COFDM symbols.

At this point it is already defined on which useful carrier the I/Q value pairs should be modulated in QPSK or QAM. The mapping block that follows determines the constellation for each useful carrier.

The symbol interleaver already allows for the subsequent insertion of scattered pilots, continual pilots and transmission parameter signalling

(TPS) carriers at defined points of the COFDM symbol, i.e. it leaves these positions free.

The continual pilots are for receiver synchronization in frequency and phase, the scattered pilots for channel regeneration in amplitude and phase, and the TPS pilots transmit important information about the modulation mode to the receiver/demodulator.

The entire information on all carriers in COFDM is represented by a symbol.

The structure of DVB-T symbols and their combination into a transmission frame of 68 symbols is shown by Fig. 4.7.

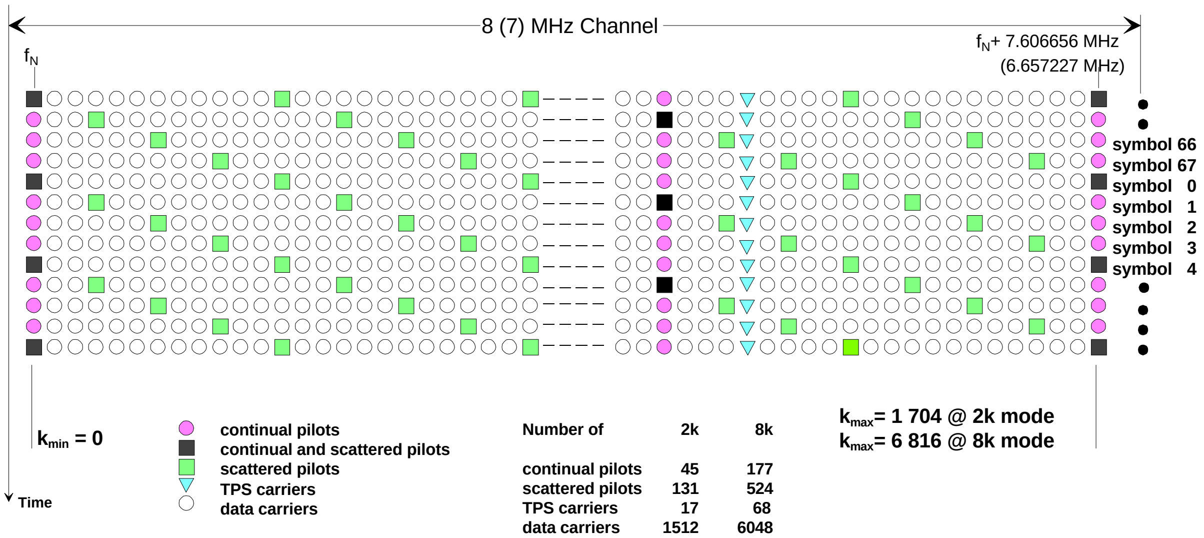


Fig. 4.7 Structure of DVB-T symbols

The number of scattered pilots is obtained with the following formula:

$$k = k_{min} + 3*(l \bmod 4) + 12*p \qquad \text{Equation 1}$$

where k is the index of the COFDM carrier defined as scattered pilot,

l is the index of the COFDM symbol with 0 < l < 67,

p is the index of the COFDM carriers, with $k_{min} < p < k_{max}$ and $k_{min} = 0$ and $k_{max} = 6816$ for 8k mode and $k_{max} = 1704$ for 2k mode. The resulting value for k must be within the range $k_{min} < k < k_{max}$.

The result of the calculation shows that for the symbols with (l mod4) = 0 the number of scattered pilots is 569, and for all other symbols it is 568.

In symbols with (l mod4) = 0, 45 scattered pilots in 8k mode and 12 scattered pilots in 2k mode overlap with the fixed continual pilots, whereas in the other symbols only 44 scattered pilots in 8k mode and 11 scattered pilots in 2k mode overlap with the fixed continual pilots.

4.2.9 Mapping
4.2.9.1 DVB-T Constellation Diagrams (Non-Hierarchical)

The values defined by EN 300 744 for the three modulation modes are shown in the Fig. below.

It should be noted that for DVB-T no differential coding is applied to the two MSBs (most significant bits). The value allocation does not therefore correspond to the definition applicable for DVB-C.

QPSK

10	00
11	01

16QAM

1000	1010	0010	0000
1001	1011	0011	0001
1101	1111	0111	0101
1100	1110	0110	0100

64QAM

100000	100010	101010	101000	001000	001010	000010	000000
100001	100011	101011	101001	001001	001011	000011	000001
100101	100111	101111	101101	001101	001111	000111	000101
100100	100110	101110	101100	001100	001110	000110	000100
110100	110110	111110	111100	011100	011110	010110	010100
110101	110111	111111	111101	011101	011111	010111	010101
110001	110011	111011	111001	011001	011011	010011	010001
110000	110010	111010	111000	011000	011010	010010	010000

Fig. 4.8 I/Q value pairs in constellation diagram

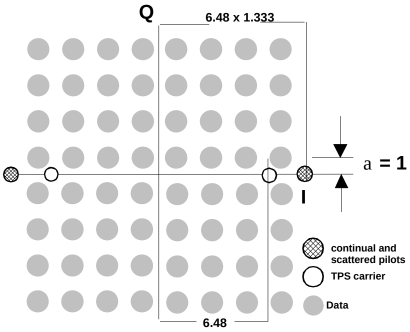


Fig. 4.9 Constellation diagram with pilots and TPS carriers, non-hierarchical

Although the carrier is suppressed in DVB, the phase information is easily recovered. The pilots and the TPS carriers are only modulated along the I axis and so are a direct indication of the phase. The amplitude of the TPS carriers corresponds to the average amplitude of the constellation (i.e. $U_{TPS} = \sqrt{42} = \mathbf{6.48}$) and are situated inside the constellation, while the amplitude of the pilots is boosted by the factor $\sqrt{\frac{16}{9}} = \mathbf{1.333}$ and are situated outside the constellation.

In the mapping block, assignment of the I/Q value pair takes place (Fig. 4.8).
If, for a given symbol, all I/Q value pairs modulated on the data carriers and pilots are projected on a plane, a non-hierarchical constellation diagram as shown in Fig. 4.9 is obtained for 64QAM.

4.2.9.2 Block Diagram and Operating Principle of Hierarchical DVB-T

What is the advantage of hierarchical modulation?
First, two independent transport streams can be transmitted in the same RF channel.
Second, as the clouds of I/Q value pairs move closer together in a quadrant, their distance from the quadrant's I and Q axes increases. Consequently, the noise margin between the quadrants (referred to the distance of the clouds of I/Q value pairs from the quadrant's axes) increases by a factor depending on α = 1, 2 or 4. The two bits of the high-priority path determine the quadrant of the I/Q coordinate system into which the clouds of I/Q value pairs of the low-priority path should be mapped. This means that the high-priority path is transmitted QPSK modulated via this quadrant, whereas the position of the I/Q value pairs in the quadrant represents the 16QAM modulated low-priority path.
Therefore, at least for α = 2 and 4, the QPSK modulated clouds of I/Q value pairs have a distance from the I and Q axes 7/4 or 14/5 times greater than that of the 16QAM modulated clouds, which can easily be derived from the geometry of the constellation diagrams. This considerably enhances reliability of reception.

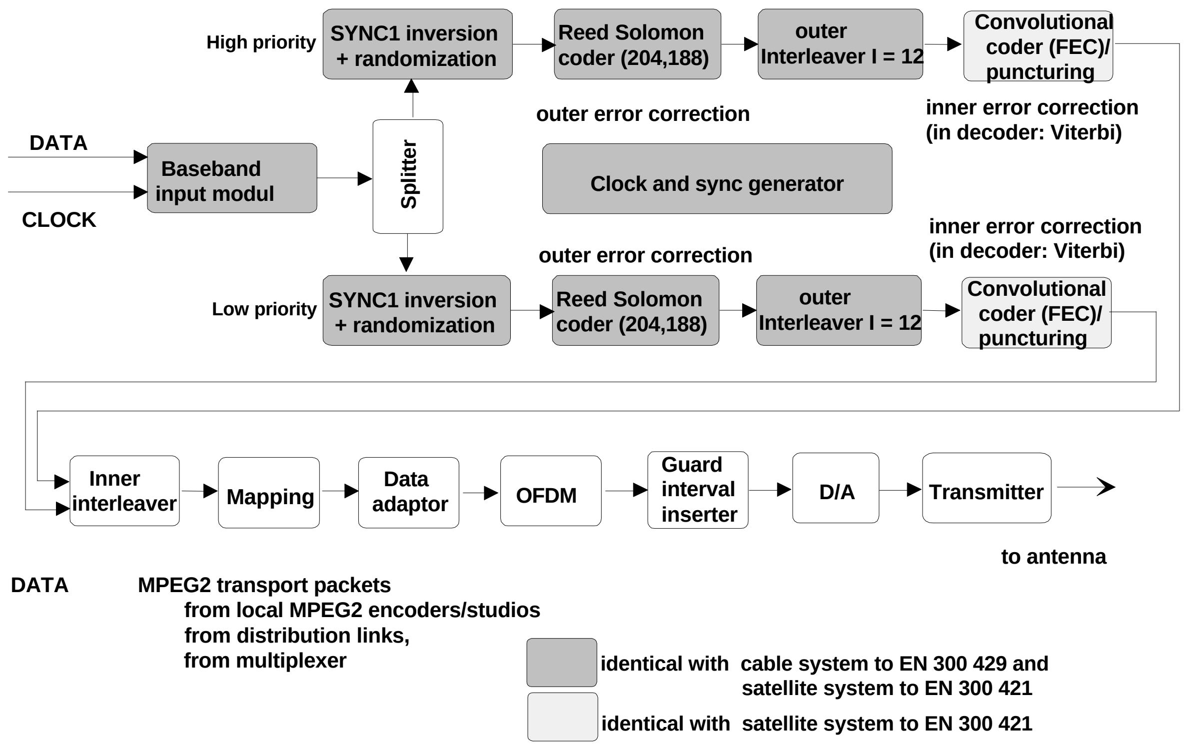


Fig. 4.10 Block diagram of hierarchical DVB-T transmitter

The TS packets are routed via the input module to a splitter, which separates the packets according to programs and assigns them to the high-priority and the low-priority path. It is also possible to feed two transport streams to be synchronized to the subsequent signal processing stages via two separate baseband input modules.

As in the non-hierarchical system, the signal processing modules in the high-priority and the low-priority path (from sync inverter and dispersal through to convolutional coder and puncturing) are in part identical with DVB-C and fully identical with DVB-S.

Hierarchical modulation is possible only with 16QAM or 64QAM in the DVB-T system. With 64QAM, two of the six bits of each I/Q value pair are used for the high-priority path and the remaining four bits for the low-priority path. With 16QAM, two out of four bits are allocated to each path.

The two paths, coded independently up to this point, are combined in the inner interleaver, which is made up of demultiplexers, bit interleavers and the symbol interleaver.

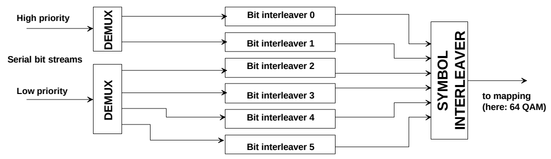


Fig. 4.11 Inner interleaver of hierarchical DVB-T transmitter

In the mapping block, hierarchical modulation is performed, which for 64QAM produces a constellation diagram over all carriers of a symbol as shown in the example below:

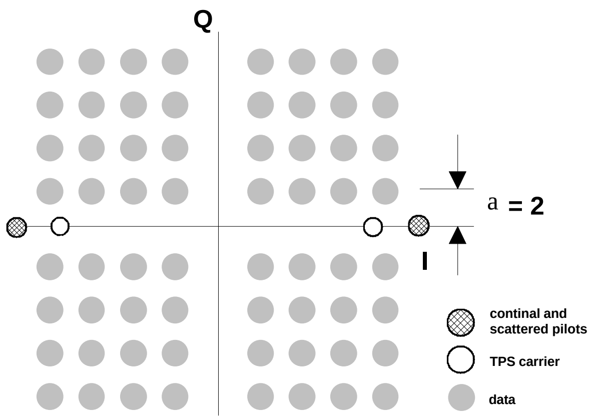


Fig. 4.12 Constellation diagram with pilots and TPS carriers, hierarchical, $\alpha = 2$

The distance of the clouds of I/Q value pairs from the I and Q axes is determined by the parameter α, which may take the value 1, 2 or 4.
So, α = 1 too is permissible in hierarchical modulation.

4.2.10 Data Adapter

In the symbol interleaver, gaps are left in the spectrum for the pilots and the TPS carriers. The data adapter fills these gaps. As to the pilots, a distinction is made between continual pilots, which are used for frequency synchronization of the DVB-T symbols in the receiver, and scattered pilots, which are used for channel estimation in amplitude and phase of the symbols.
The continual pilots are defined in a table in the EN 300 744 DVB-T standard, whereas the position of the scattered pilots is obtained by means of equation 1:

$$k = k_{\min} + 3*(I \bmod 4) + 12p$$

where

- k is the index of the COFDM carrier defined as scattered pilot,
- I is the index of the COFDM symbol with 0 < I < 67,
- p is the index of the COFDM carriers with $k_{min} < p < k_{max}$ and $k_{min} = 0$ and $k_{max} = 6816$ for 8k mode and $k_{min} = 0$ and $k_{max} = 1704$ for 2k mode. The resulting value for k must be within the range $k_{min} < k < k_{max}$.

The result of the calculation shows that in 8k mode the number of scattered pilots is 569 for the symbols with (I mod4) = 0 and 568 for all other symbols, and in 2k mode the number of scattered pilots is 142 for the symbols with (I mod4) = 0 and 141 for all other symbols.
In symbols with (I mod4) = 0, 45 scattered pilots in 8k mode and 12 scattered pilots in 2k mode overlap with the fixed continual pilots, whereas in the other symbols only 44 scattered pilots in 8k mode and 11 scattered pilots in 2k mode overlap with the fixed continual pilots.
The TPS carriers too are defined in a table in EN 300 744. With 17 carriers in 2k mode and 68 carriers in 8k mode, DVB-T transmission parameters are signalled with maximum error protection.

4.2.11 OFDM Modulator and Guard Interval

OFDM modulation by IFFT (inverse fast Fourier transform) in conjunction with Hilbert transformation suppresses the image carrier of each carrier in 2k or 8k mode. The result is a time-domain signal in line with appropriate standards with defined length of 896 µs per useful symbol in 8k mode and 224 µs per useful symbol in 2k mode. Insertion of the guard interval extends symbol duration by 1/4, 1/8, 1/16 or 1/32 to give the total symbol duration T_{SYMBOL}. The time signal of length T_{SYMBOL}, so far still digital, is applied to the D/A converter.

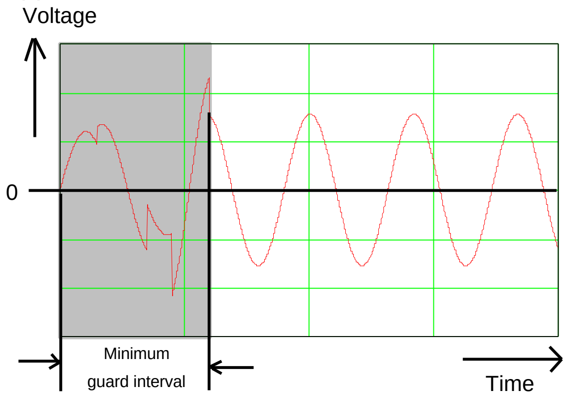


Fig. 4.13 Guard interval

Fig. 4.13 shows a direct incident sinewave starting at t = 0 to which four echoes with different delay and reflection phase are added. The start of the superimposed echoes can be recognized clearly and so the point until which the guard interval should extend at least.
By the end of the guard interval, all echoes caused by multipath reception, reception of other transmitters in the SFN or Doppler effects in mobile reception, i.e. all fading effects, must have settled or decayed. Only then can the transmitted symbol be evaluated.

The analog signal is converted to the RF, amplified and put on the air.

4.2.12 Table of Major DVB-T Parameters and Data

Table 4.5 shows that the signal bandwidth is identical for the two modes. The first and the last carrier of a symbol is a pilot carrying constant information, i.e. pure sinewaves of theoretically infinitely narrow bandwidth. So the overall bandwidth is determined only by the n-1 carriers.

The pilots and the TPS carriers reduce the number of carriers for useful data transmission by 11.3 %, the guard intervals additionally by 20 % (τ = 1/4), 11.1 % (τ = 1/8), 5.9 % (τ = 1/16) or 3.0 % (τ = 1/32). This means a substantial reduction of useful data transmitted, but a considerable improvement of transmission reliability.

General DVB-T data	S carrier	Scattered pilots	Continual pilots	TPS carriers	Number of useful carriers C_{useful}
DVB-T 2k mode	1705	131	45	17	1512
DVB-T 8k mode	6817	524	177	68	6048

General DVB-T data	Distance from carrier Hz	Overall bandwidth Hz	Useful symbol duration µs	Symbol duration T_{symbol} µs for guard interval		Guard interval µs
DVB-T 2k mode	*4 464.286*	1704 x *4 464.286* *=7 607 142.9*	224	280 252 238 231	1/4 1/8 1/16 1/32	56 28 14 7
DVB-T 8k mode	*1 116.071*	6816 x *1 116.071* *=7 607 142.9*	896	1120 1008 952 924	1/4 1/8 1/16 1/32	224 112 56 28

Table 4.5

4.2.13 Achievable Net Data Rates

Achievable net data rates can be determined fast and easily by means of equation 2:

$$BR_{net} = C_{useful} * ld(M) * P * \frac{188}{204} * \frac{1}{T_{symbol}} \quad \text{Equ. 2}$$

Identical values are obtained for the 2k and 8k DVB-T modes. This is due to a factor of 4 being applied for the distance from carrier and a factor of 1/4 for the useful symbol duration and the guard interval, which balance each other.

Net data rates BR_{net} Mbit/s	Guard interval	Puncturing rate P				
		1/2	2/3	3/4	5/6	7/8
QPSK (M = 4)	1/4	4.9765	6.6353	7.4647	8.2941	8.7088
	1/8	5.5294	7.3725	8.2941	9.2157	9.6765
	1/16	5.8547	7.8062	8.7820	9.7578	10.2457
	1/32	6.0321	8.0428	9.0481	10.0535	10.5561
16QAM (M = 16)	1/4	9.9529	13.2706	14.9294	16.5882	17.4176
	1/8	11.0588	14.7451	16.5882	18.4314	19.3529
	1/16	11.7093	15.6125	17.5640	19.5156	20.4913
	1/32	12.0642	16.0856	18.0963	20.1070	21.1123
64QAM (M = 64)	1/4	14.9294	19.9059	22.3941	24.8824	26.1265
	1/8	16.5882	22.1176	24.8824	27.6471	29.0294
	1/16	17.5640	23.4187	26.3460	29.2734	30.7370
	1/32	18.0963	24.1283	27.1444	30.1604	31.6684

Table 4.6

The number of carriers, the guard interval, QPSK and QAM mode and the code rate (also referred to as puncturing rate) are precisely defined in DVB-T. For this reason, only precisely defined data rates are possible as listed in Table 4.6.

4.3 Digital Terrestrial TV - from Studio to Transmitter

In the previous sections, the principle of operation of a DVB-T transmitter was discussed in detail based on the individual function blocks. The special features of a terrestrial transmitter for MPEG2-coded signals were described. In the following, the test points of a DVB-T transmitter network from the studio to the antenna will be described together with test instruments and methods, which considerably differ from those used in analog TV.

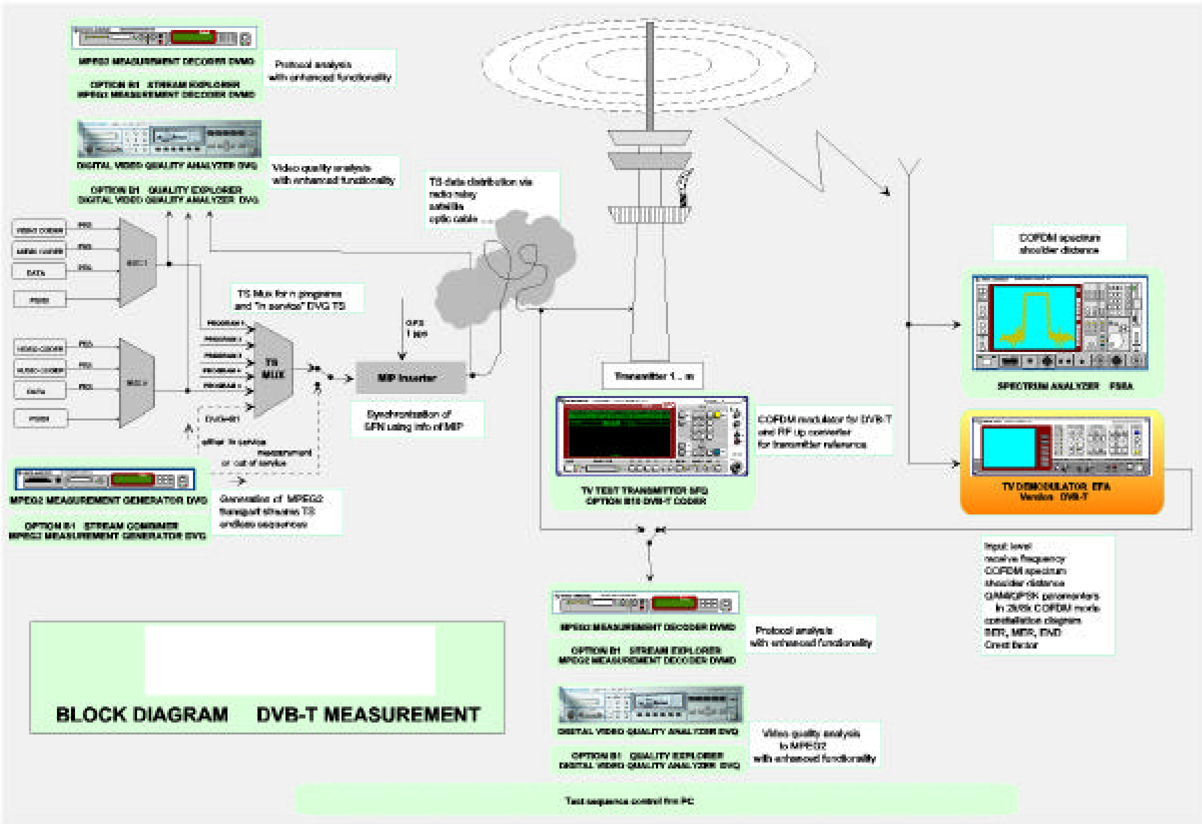


Fig. 4.14 DVB-T transmission scenario

Rohde & Schwarz offers suitable instruments for each test point and test parameter of a DVB-T transmitter network. To refresh your memory, refer to Part 1 of this paper, where MPEG2 measurements are described. The corresponding scenario is shown in the left part of Fig. 4.14.

The parameters described in Part 1, "MPEG2 Measurements", have already been measured and the MPEG2 protocol is monitored with the aid of the MPEG2 instruments from Rohde & Schwarz (plus corresponding software options for detailed status display):

DVMD MPEG2 MEASUREMENT DECODER or
DVRM MPEG2 REALTIME MONITOR,

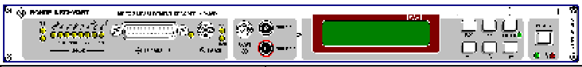
DVQ DIGITAL VIDEO QUALITY ANALYZER and
DVG MPEG2 MEASUREMENT GENERATOR.

Likewise, the measurements on the feeder link between the studio output and the transmitter input are considered performed. What remains to be done is measuring the DVB-T transmitter.

First, the test points and associated parameters have to be defined.

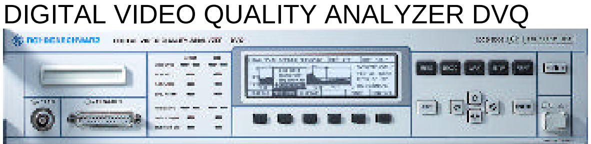
Condensed data of MPEG2 instruments whose functions are described in Part 1, "MPEG2 Measurements".

MPEG2 MEASUREMENT DECODER DVMD



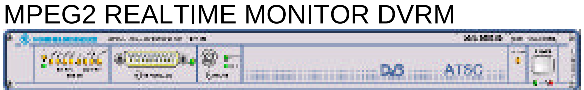
Input signals	TS to ISO/IEC 13 818-1
Length of TS	
DVB	188/204 bytes
ATSC	188/208 bytes
Data rates of TS	up to 54 Mbit/s
Signal inputs	
DVB	1x SPI 2x ASI
ATSC	1x SPI 1x ASI 1x SMPTE 310
Measurements	parameters to ETR290 (adapted for ATSC), TS protocol, data rates of overall TS, programs, substreams (PID), monitoring of TS_ID, "other" tables (DVB), paradigma condition (ATSC only), trigger on error
Decoder outputs	
Video	2x CCVS, 1x Y/C 1x ITU 601
Audio	1x AES/EBU 2x analog audio R/L
Interfaces	RS232C

DIGITAL VIDEO QUALITY ANALYZER DVQ



Signal inputs	ASI (active loop-through) SPI ITU-R BT. 601 and AES/EBU
Video formats	MPEG2 MP@ML 422P@ML
Audio formats	MPEG1 layers 1 and 2 Dolby® AC-3
Events recorded	sound loss R/L, separately, picture loss, picture freeze, quality below threshold
Realtime measurements	temporal activity (TA), spatial activity (SA), digital video quality level unweighted and weighted corresponding to subjective assessment
Buffer for ES	32 Mbits
Remote control interfaces	RS232C 10BaseT (Ethernet)
Alarm outputs	12 relay contacts

MPEG2 REALTIME MONITOR DVRM



Input signals	TS to ISO/IEC 13 818-1
Length of TS	
DVB	188/204 bytes
ATSC	188/208 bytes
Data rates of TS	up to 54 Mbit/s
Signal inputs	
DVB	1x SPI 2x ASI
ATSC	1x SPI 1xASI 1x SMPTE 310
Measurements	parameters to ETR290 (adapted for ATSC), TS protocol, data rates of overall TS, programs, substreams (PID), monitoring of TS_ID, "other" tables (DVB), paradigma condition (ATSC only), trigger on error
Decoder outputs	
Video	2x CCVS, 1x Y/C 1x ITU 601
Audio	1x AES/EBU 2x analog audio R/L
Interfaces	RS232C
Alarm outputs	12 relay contacts

MPEG2 MEASUREMENT GENERATOR DVG

Output signals	TS to ISO/IEC 13 818-1
Length of TS	
DVB	188/204 bytes
ATSC	188/208 bytes
Data rates of TS	0.6 to 160 Mbit/s
Overall data rate of ES	up to 32 Mbit/s
Overall data volume of ES	up to 228 Mbits
Signal set	live picture sequences, moving picture sequences, static test patterns with audio test signals, special test signals, TS with several programs
Signal outputs	
DVB	1x SPI 2x ASI
ATSC	1x SPI 1x ASI 1x SMPTE 310
Interfaces of integrated PC	keyboard, VGA monitor, 2x RS232C, parallel printer interface, PCMCIA

4.3.1 Measurements at Transmitter Input

The first point of measurement is the transmitter input, from where the incoming MPEG2 transport streams (TS) received via radio relay, satellite, fiber-optic cable, etc are routed to the DVB-T modulator. For optimal transmitter monitoring, the MPEG2 parameters and the TS protocol should be evaluated. It must be ensured that the data intended for transmission contain the correct programs and data and that the quality of the outgoing picture meets appropriate standards. Especially in statistical multiplex mode, certain minimum quality standards as determined by the MPEG2 coding have to be met even under extremely poor conditions of reception. The following parameters are measured at the transmitter input:

- all events recorded in monitoring/report,
- PAT, CAT, NIT, PMT, SDT and EIT, which may reveal TS routing errors,
- MIP with relevant SFN synchronization data and modulator settings,
- agreement of NIT and MIP information,
- identification of TS, transmission media and transmission networks,
- data rates of incoming TS and elements of the individual programs,
- picture quality determined from MPEG2 artifacts.

In an SFN with m transmitters, the above tasks can be handled by a small, PC-controlled remote monitoring system.

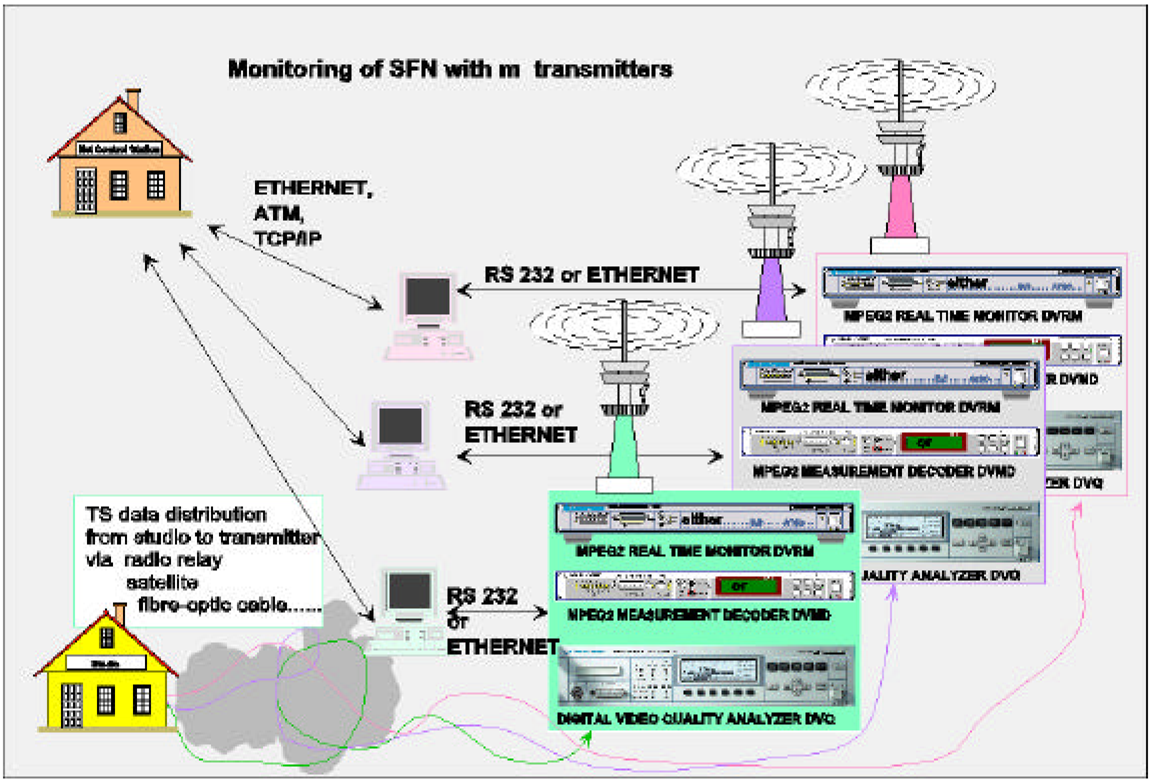


Fig. 4.15 Transmitter input monitoring in SFN

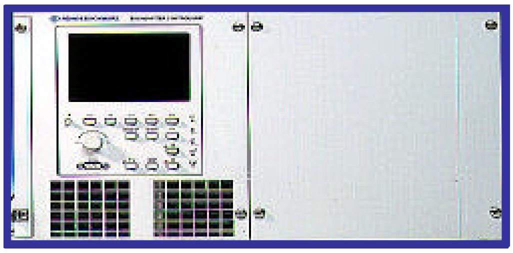
Each transmitter in an SFN is assigned such a monitoring system, which consists of a PC, MPEG2 Measurement Decoder DVMD or MPEG2 Realtime Monitor DVRM, and Digital Video Quality Analyzer DVQ. This configuration provides optimal monitoring of the TS at each transmitter input to ensure compliance with a program provider's specifications. At the transmitter input it is sufficient to analyze the programs and data of the TS one after the other by calling the PIDs of the associated PMTs. At the studio output, on the other hand, each program should be assigned a Decoder DVMD or Realtime Monitor DVRM or Video Quality Analyzer DVQ to provide comprehensive monitoring (see also Part 1, "MPEG2 Measurements"). To analyze the picture quality of several programs, it is advisable to use Multichannel Video Quality Analyzer DVQM, which integrates up to 12 DVQs in a highly compact configuration.
The measurement and monitoring data are taken via remote-control interfaces to the station computer. This not only manages the TS input

data but also controls all other measurement and organization tasks of the station. From here the data are transmitted in ATM mode, using SDH or PDH protocols, by the Internet or another medium to the SFN master station for central analysis. This gives the operator an overview of the status of the entire network.
Not only the protocol of the MPEG2-coded programs and data of the TS are evaluated in this way, the MIP (megaframe initialization packet) contents too are subjected to a final check at the transmitter input before they are put on the air. Decoder DVMD opens the TS packets with the address 0x15 and displays the information required for synchronization of the SFN in interpreted form, e.g. in plain-text tables (see also Part 1, "MPEG2 Measurements").

4.4 Measurements on DVB-T Exciter

The transport stream to be transmitted is routed to the input of the DVB-T exciter via an ASI interface. First the contents of the MIP are decoded. The packet includes the configuration data for the DVB-T coder and modulator. So this information can also be used to set the operating mode. This requires due care, however, since the NIT (network information table) also transmits these data, and agreement between the MIP and NIT data is essential. This is checked already at the transmitter input (see section 4.3.1). The DVB-T receiver evaluates the NIT data and, if they differ from the MIP data, can neither demodulate nor decode.
The DVB-T modulator synchronizes to the SFN timing conditions by means of the STS (system time stamp) of the MIP. This is followed by signal processing in conformance with EN 300 744. The digital baseband signal generated by the above procedure is applied in the form of real and imaginary components to the digital precorrector of the exciter. The precorrector ensures optimal equalization of amplitude frequency response, group delay and linearity of the power amplifiers. By varying the instantaneous amplitude and phase, the required high linearity of the DVB-T transmitter characteristic and frequency response is obtained at the output of the power amplifiers. The digitally precorrected DVB-T signal is D/A converted and then directly converted to the RF without any intermediate IF stage.

DVB-T Exciter SV700



Condensed Data of SV700

DVB-T encoder	
Input signal	MPEG2 transport stream
Coding/modulation	To EN 300 744
Bandwidth	6 MHz, 7 MHz or 8 MHz
Parameter setting	by RS232C or MIP
Input signal monitoring	TS present, TS synchronized, TS data rate
SFN capability	to TS 101 191
Delay correction	max. 1000 ms, automatic or manual for LP and HP data streams
Hierarchical coding	optional
Digital precorrector	
Group delay equalizer	in baseband (optional)
Linearity precorrector	in baseband
Synthesizer	
Frequency bands	III, IV and V
Internal stability	1.2×10^{-7} / 4 months
Reference	internal: OXCO (10 MHz) external: GPS external reference
I/Q modulator	
Modulation	direct conversion to RF
Inputs	
HP LP	ASI ASI
Outputs	
RF	DVB-T, band III, IV or V, 13 dBm thermal power, SMA, 50 Ω
Monitoring outputs	
RF	DVB-T, band III, IV or V, -7 dBm thermal power, SMA, 50 Ω
Frequency reference	10 MHz OXCO, 0 dBm, SMA, 50 Ω
I/Q	complex analog baseband signal, 0 dBm, SMA, 50 Ω
Interfaces	RS232C

4.4.1 Theoretical DVB-T Spectrum

Looking at the theoretical DVB-T spectrum in Fig. 16, you see a flat trace with a ripple of about 3 dB in the useful region, this ripple depending on the guard interval used.

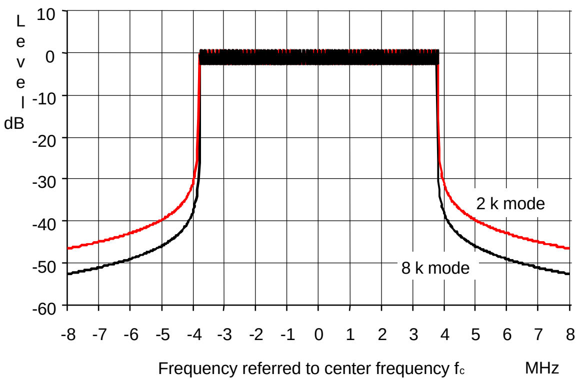


Fig. 4.16 DVB-T spectrum for 2k and 8k mode with guard interval τ = 1/4

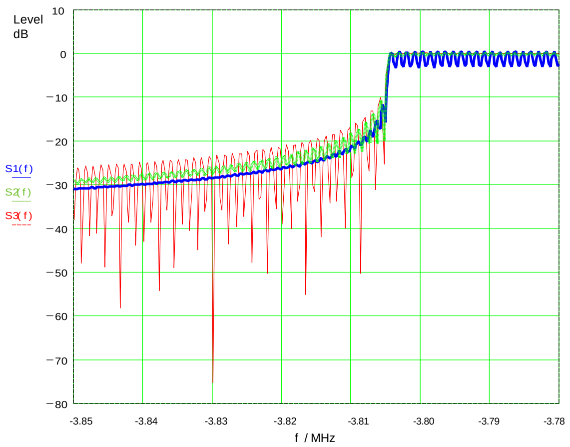


Fig. 4.17 Detail of spectrum with different guard intervals:

intervals:	τ = 1/4	S1(f)
	τ = 1/32	S2(f)
	τ = 0	S3(f)

At the band limits, the signal drops sharply over the width of a carrier spacing, then the trace is relatively flat again. In 2k mode the knee is located about 10 dB higher than in 8k mode.

With higher frequency resolution, the inserted guard intervals are clearly discernible. Fig. 4.17 shows the range from -3.85 MHz to -3.78 MHz in 8k mode, where the single carriers can be recognized.

The blue curve shows the signal characteristic for τ = 1/4. In the useful band the single carriers are distinguishable, even though the dips between them are just about 3 dB. By contrast, the out-of-band components are markedly flatter.

The green curve is the signal characteristic for τ = 1/32. In the useful band the single carriers can hardly be distinguished, the dips between them are less than 1 dB. The out-of-band components in this case have much more pronounced ripple.

The red curve shows the characteristic for τ = 0, i.e. without any guard intervals. In the useful band the spectrum is absolutely smooth, whereas the out-of-band components are characterized by deep dips at carrier spacing.

Fig. 4.17 illustrates that orthogonality between the single carriers exists only for τ = 0. As soon as the guard interval is added, this condition is no longer fulfilled. The guard interval is blanked in the receiver, thus restoring orthogonality.

Figs 4.16 and 4.17 demonstrate a basic problem in DVB-T spectrum measurement: in the useful region there is always a certain amount of ripple as a function of the guard interval.
How, then, do you measure the useful spectrum?

And there is another problem: the out-of-band components always have a basic ripple as well as a steep decline by about 15 dB at a spacing of one carrier from the last useful carrier. Then the out-of-band spectrum is relatively flat and, with a guard interval of τ = 1/32, has up to 10 dB deep dips at carrier spacing.
Where do you measure the shoulder distance?

SPECTRUM ANALYZER FSP

Condensed data of FSP

Frequency range (FSP 3/7/13/30)	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 bandwidths	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 (FSP 3/7/13/30)	10.5/11.3/12/12 kg

SPECTRUM ANALYZER FSEx

Condensed data of FSEA/FSEB

Frequency range	20 Hz/9 kHz to 3.5 GHz/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 bandwidths	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
Dimensions (W x H x D)	4127 mm x 236 mm x 460 mm
Weight	21.5/23 kg

4.4.2 Useful Spectrum

Modern spectrum analyzers provide the answer to the above problems: with resolution bandwidth much wider than the carrier spacing, the dips of the useful spectrum are averaged to obtain a smooth characteristic. In this way, satisfactory results are achieved even with a medium-priced analyzer. However, it must be remembered that the reference for all measurements is the positive envelope of the spectrum; so the analyzer must have a peak detector.
State-of-the-art spectrum analyzers like FSP and FSEx from Rohde & Schwarz fully meet the requirements for transmitter measurements.

They feature both a peak and an rms detector. The dynamic range exceeds the values stipulated in all the subsequent spectrum measurements. Even the most favourably priced model offers ample frequency range for LO (local oscillator) harmonics measurement.
Just as with analog transmitters, measurement of the second harmonic and determining LO phase noise are musts with DVB-T transmitters too.

4.4.3 Measurement of Phase Noise

A spectrum analyzer should be available at each transmitter site of an SFN so that the above measurements can be performed and LO phase noise determined unambiguously. These purposes call for a high-end analyzer. FSP and FSEx meet the stipulated requirements. The standards proposed by the European VALIDATE work group are very restrictive; see draft standard AC106 for phase noise in 2k mode illustrated by Fig. 4.18.

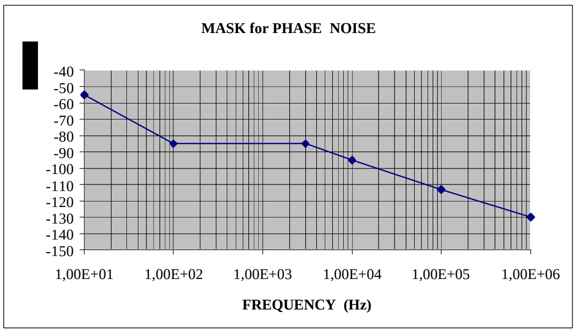


Fig. 4.18 VALIDATE draft standard AC106 for phase noise measurement in 2k mode

It shows that phase noise suppression as low as -55 dB/Hz is demanded just 10 Hz from the LO frequency. So the RBW (resolution bandwidth) must be much smaller than 10 Hz, the preferred value being 1 Hz.
Phase noise at a spacing of one carrier from the LO frequency is already defined as ENF (equivalent noise floor).

There are two types of phase noise in COFDM modulation:

- CPE (common phase error):
  signal distortions that are common to all carriers. This error can (partly) be suppressed by channel estimation using the continual pilots.
- ICI (inter-carrier interference):
  non-correlated noise superimposed on all carriers. This type of signal degradation cannot be corrected.

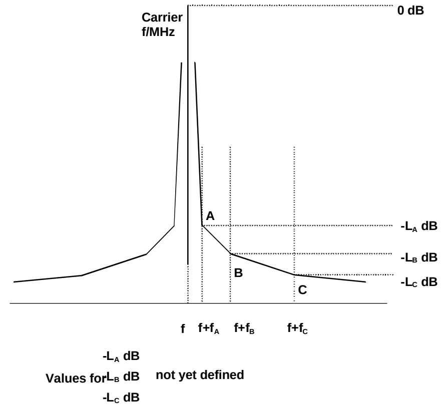


Fig. 4.19 Mask for phase noise

The frequencies for measuring ICI are defined by ETR290. However, the levels at points A, B and C of the mask are not yet defined. The frequencies are n times the carrier spacing in each case.

COFDM mode	f_A kHz	f_B kHz	f_C kHz
2k	4.464	8.928	13.392
8k	1.116	2.232	3.348

Table 4.7 Frequencies for measuring ICI

4.4.4 Mask for Out-of-Band Components (Minimum Shoulder Distance)

During the transition from analog to digital transmission, the protection channels between the present analog channels are used to start with DVB-T operation. Especially in Central Europe, there are hardly any other frequencies available.
Fig. 4.20 shows a possible spectral configuration during the transition from analog TV to DVB.

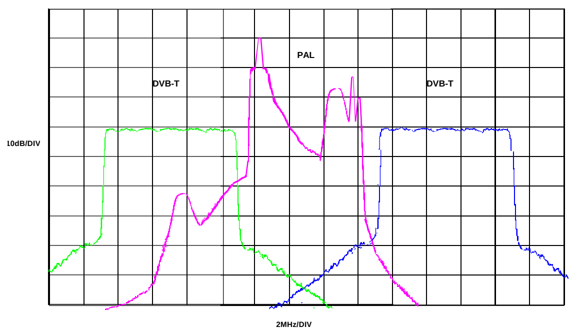


Fig. 4.20 Adjacent channel occupation, DVB-T and PAL

The DVB-T spectrum in the upper adjacent channel will have only little effect on the PAL signal if the PAL vision carrier frequency and the DVB-T center frequency conform to the standard. At most, the DVB-T shoulder in the lower adjacent channel may impair the second sound carrier of the B/G PAL signal, whereas in the upper adjacent channel it superimposes on the vestigial sideband like noise.
To prevent any interference to adjacent analog TV channels, EN 300 744 defines masks for the DVB-T spectrum. These are tables listing levels in the range ±12 MHz from the center frequency of the DVB-T channel when the upper and the lower adjacent channel are occupied by analog RF signals (G/PAL/A2 or G/PAL/NICAM or I/PAL/NICAM or K/L/SECAM/NICAM or K/PAL) emitted by co-sited UHF transmitters.

The tables in EN 300 744 specify levels versus frequency. The selected levels and frequencies orient on important points within the analog channels. Fig. 4.21 and Table 8, for example, show the values of the DVB-T mask when the upper and the lower adjacent channel are occupied by a G/PAL/A2 signal.

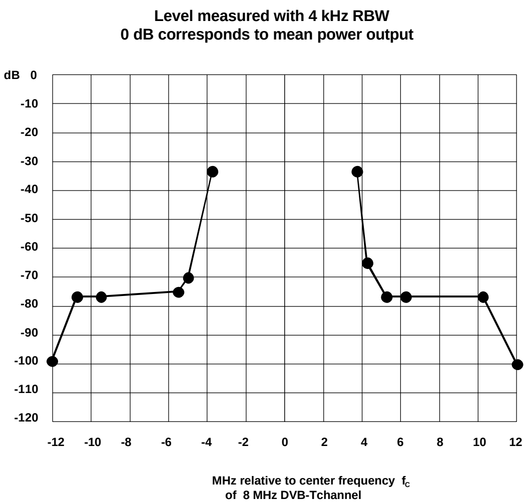


Fig. 4.21 Mask for out-of-band components

DVB-T out-of-band spectrum mask with standard G/PAL/A2 signals in the adjacent channels		
Frequency relative to center of DVB-T channel in MHz	Explanation of frequency	Level in dB[1])
-12.00	Lower end of lower adjacent channel	-100
-10.75	Vision carrier in lower adjacent channel	-76.9
-9.75	Vision carrier +1 MHz in lower adjacent channel	-76.9
-5.75	Upper end of (upper) sideband of lower adjacent channel	-74.2
-5.185	Upper end of RF bandwidth of first sound carrier in lower adjacent channel	[2])
-4.94	Upper end of RF bandwidth of second sound carrier (IRT A2) in lower adjacent channel	-69.9
-3.90	Lower end of RF bandwidth of DVB-T signal	-32.8
+3.90	Upper end of RF bandwidth of DVB-T signal	-32.8
+4.25	Vision carrier –1 MHz; lower end of vestigial sideband in upper adjacent channel	-64.9
+ 5.25	Vision carrier in upper adjacent channel	-76.9
+ 6.25	Vision carrier +1 MHz in upper adjacent channel	-76.9
+10.25	Upper end of (upper) sideband in upper adjacent channel	-76.9
+12.00	Upper end of upper adjacent channel	-100

[1]) Measured with 4 kHz RBW
[2]) Has no influence on shape of spectrum mask

Table 4.8

In critical cases, for example where channels adjacent to DVB-T channels operate in special modes like low-power analog TV transmission, a spectrum mask with higher out-of-channel attenuation of the DVB-T signal may be needed. For such cases a critical mask is defined by EN 300 744 (see Fig. 4.22 and Table 4.9).

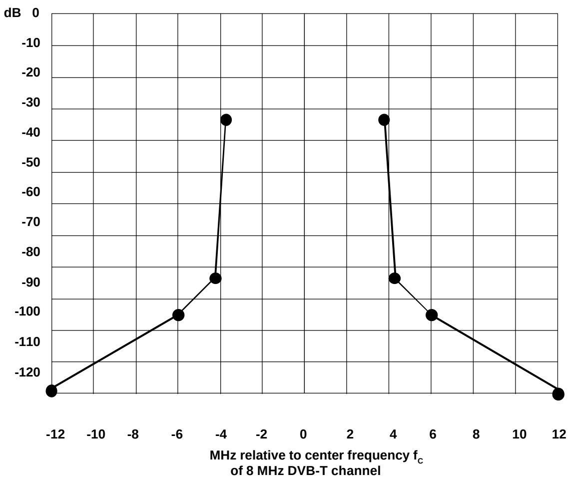


Fig. 4.22 Spectrum mask for critical cases

The breakpoints for the critical mask are likewise defined in a table:

Breakpoints for critical mask (UHF)	
Frequency relative to center of DVB-T channel (MHz)	Level (dB) *)
±12.0	-120
±6.0	-95
±4.2	-83
±3.8	-32.8

*) Measured with 4 kHz RBW

Table 4.9

4.4.5 Center Frequencies of UHF Channels

In contrast to analog TV which, at 8 MHz bandwidth in the UHF range, uses odd-numbered vision carrier frequencies offset by 250 kHz relative to the next integer MHz (e.g. 210.250 MHz for channel 10), even-numbered center frequencies are used in DVB-T. The UHF range starts at 470 MHz. From this frequency, the center frequencies f_{center} for DVB-T are calculated by:

UHF band IV/V

$$f_{center} = 470 + 4 + n \times 8 \text{ MHz}$$
$$n = 0, 1, 2, 3...49$$

So, the first channel in the UHF range has the center frequency f_{center} = 474 MHz and the last channel f_{center} = 866 MHz. This allocation is given by EN 300 744 for the UHF range only. Although no allocation is made for DVB-T for VHF with 7 MHz channel bandwidth, DVB-T is transmitted in the VHF range too. The above formula can therefore be used in a slightly modified form:

VHF band III

$$f_{center} = 174 + 3.5 + n \times 7 \text{ MHz}$$
$$n = 0, 1, 2, 3...7$$

So, the first channel in the VHF band III has the center frequency f_{center} = 177.5 MHz and the last channel f_{center} = 226.5 MHz.
For DVB-T transmission, special allocations of VHF channels used in some countries should be modified to match the above scheme.

4.4.6 Increasing Shoulder Distance

From 4.4.1, "Theoretical DVB-T Spectrum", it follows that the spectrum has to be bandpass-filtered to meet the requirements defined in the out-of-band spectrum masks. For the normal mask a 6-cavity filter is sufficient, whereas for the critical mask at least eight cavities are required.

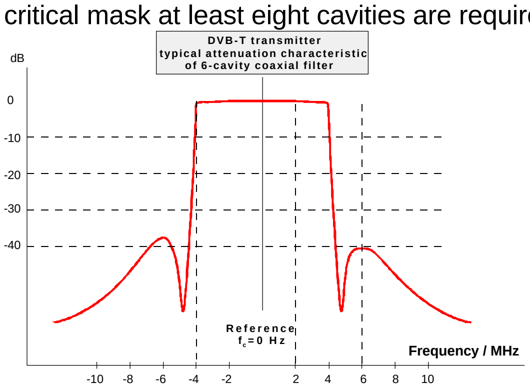


Fig. 4.23 Bandpass filter

The filter is connected between the transmitter power output and the antenna. With the bandpass filter the required shoulder distance is achieved. The output signal of the exciter of the DVB-T transmitter has a shoulder distance of about 50 dB. But this is reduced to values of near 30 dB by intermodulation products resulting from nonlinearity of the transmitter amplifiers. The effect is in part compensated by the exciter's digital linearity precorrector, producing intermodulation suppression of about 40 dB in the useful spectrum.
From Fig. 4.17 it can be seen that the DVB-T spectrum has to be additionally bandpass-filtered to attain the stipulated value of >36 dB.
This corresponds to the difference of 69.9 dB – 32.8 dB = 37.1 dB required at frequencies ±4.94 MHz and ±3.90 MHz in the normal mask. For the critical mask, the required shoulder

distance is correspondingly higher, i.e. 83.0 dB – 32.8 dB = 50.2 dB.

Very stringent demands are made for the out-of-band components of COFDM signals for DVB-T, which can be seen from the limit values of the relevant mask. As mentioned above, the shoulder distance at the transmitter output is not sufficient and so it is increased by bandpass filters. Filter attenuation rises especially close to the limits of the passband. The very steep attenuation characteristic in the stopband causes a correspondingly steep increase of group delay. The amplitude frequency response and the group delay shown are largely compensated by the digital precorrectors of the exciter.
Depending on the degree of suppression in the stopband of the bandpass filter, an extra filter may be required to suppress local oscillator harmonics.

In the absence of detailed specifications from official standardization bodies regarding permissible residual deviation from the ideal filter, preliminary values were laid down in 1998 in Great Britain for the installation of an MFN. These can be seen in Fig. 4.24.

Suitable measuring instruments:
Spectrum Analyzers FSEx and FSP (for data see page 19)

andDVB-T Test Receiver EFA model 40 or 43 (for data see page 23)

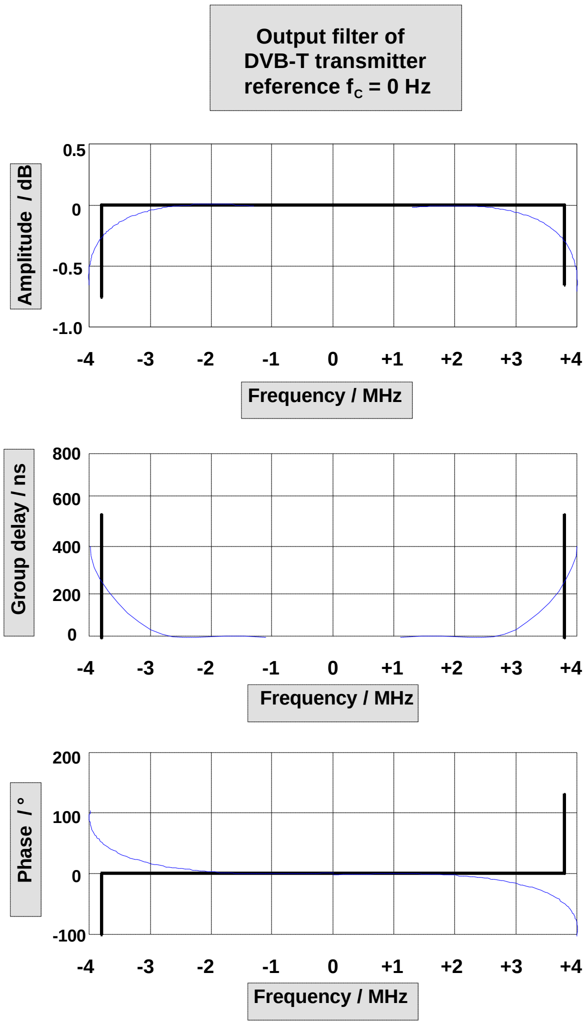


Fig. 4.24 Proposal for bandpass characteristic

Corrected amplitude frequency response with ripple ≤ 0.3 dB and group delay ≤ 250 ns (!)

Condensed data of EFA models 40/43

Frequency range	45 MHz to 1000 MHz, 5 MHz to 1000 MHz with RF preselection option (EFA-B3)
Input level range	-47 dBm to +14 dBm; -84 dBm to +14 dBm (low noise) with RF preselection option (EFA-B3)
Bandwidth	6/7/8 MHz
FFT mode	2k/8k
Modulation	QPSK, 16QAM, 64QAM; hierarchical/ non-hierarchical
Guard interval	1/4, 1/8, 1/16, 1/32
Puncturing rate	1/2, 2/3, 3/4, 5/6, 7/8
BER analysis	before Viterbi, before and after Reed Solomon
Measurement functions/ graphic display	level, BER, MER, carrier suppression, quadrature error, phase jitter, amplitude imbalance, FFT spectrum, constellation diagram, MER (f), I/Q (f), spectrum
Output signals	MPEG2 TS: ASI, SPI
Options	MPEG2 decoder, RF preselection

4.4.7 Measuring Shoulder Distance with DVB-T Test Receiver EFA

The FREQUENCY DOMAIN/FFT function of Test Receiver EFA makes it easy to determine the shoulder distance. For an 8 MHz DVB-T channel with frequency range –4.48 MHz (start frequency) to +4.48 MHz (stop frequency), for example, the shoulder distance can immediately be read from the spectrum displayed. EFA 40/43 determines the shoulder distance automatically and objectively in conformance with the ETR290 standard, which describes all test methods and parameters.

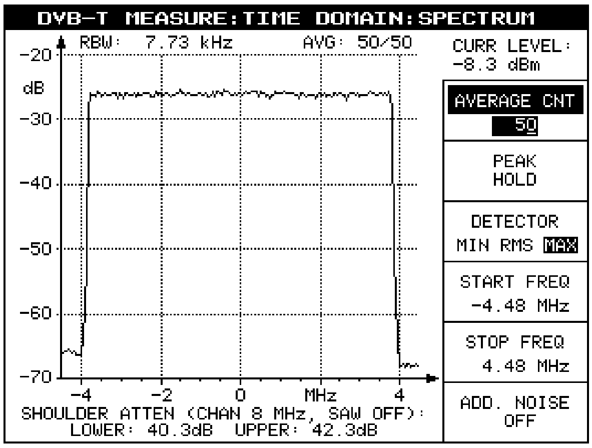


Fig. 4.25 Shoulder distance of COFDM signal

According to European Technical Report ETR290, the shoulder distance is to be measured between the maxima of the useful spectrum (approx. –26 dB in Fig. 4.25) and the (weighted) maxima of the out-of-band components at 300 kHz to 700 kHz from the last useful carrier (approx. –66 dB or –68 dB in Fig. 4.25). The MAX DETECTOR function greatly facilitates determining this value.
Measuring the suppression of local oscillator harmonics calls for a spectrum analyzer in addition.

4.4.8 Determining Shoulder Distance to ETR290

ETR290 describes a method for determining the shoulder distance that is rather time-consuming. Test Receiver EFA 40/43 delivers identical values provided that out-of-band components starting 300 kHz from the last COFDM carrier have a flat characteristic. This is almost always the case in COFDM.

Measurement to ETR290 works as follows (illustrated in Fig. 4.26):

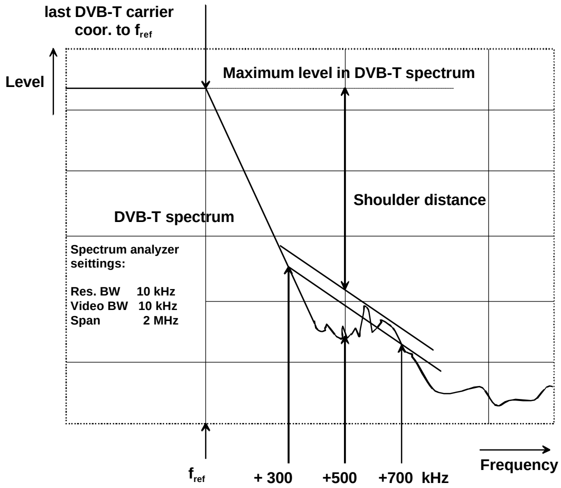


Fig. 4.26 Measurement of shoulder distance to ETR290

1. Determine the maximum level of the DVB-T spectrum (Max Hold).

2. Draw a line between the level value of the spectrum 300 kHz above (below) the frequency of the last (first) carrier in the DVB-T spectrum and the level value of the spectrum 700 kHz above (below) the frequency of the last (first) carrier in the DVB-T spectrum.

3. Draw a parallel to the above line that goes through the maximum of the DVB-T spectrum in the range 300 kHz to 700 kHz above (below) the frequency of the last (first) carrier in the DVB-T spectrum.

4. Measure the difference between the maximum level of the DVB-T spectrum and the level of the parallel line at 500 kHz above (below) the frequency of the last (first) carrier in the DVB-T spectrum. The lower of the two values is the shoulder distance.

This method requires a hardcopy of the spectrum as well as a protractor and a ruler, so its use will tend to be the exception. Deviations between this method and direct measurement with EFA 40/43 will rarely occur, i.e. where strong interference is superimposed on the out-of-band components. But even then, Test Receiver EFA supplies sufficiently accurate results because the FFT frequency range of -4.48 MHz to +4.48 MHz about the channel center frequency exactly corresponds to the range specified by ETR290.

4.4.9 Linearity Precorrector and Shoulder Distance

	Output signal	
Input signal	In-phase	Quadrature
0000	0.000	0.000
0.300	0.295	0.013
0.500	0.492	0.015
1.000	1.000	0.000
1.500	1.500	-0.070
3.000	2.300	-0.900
Crest factor 7.235 /dB (calculated from peak power)		

Table 10 Amplifier characteristic

Table 10 shows the linearity relationship of a typical power amplifier as used in a DVB-T transmitter. In the beginning there is a linear correlation between the input signal and the output signal, whereas at higher input levels there is a strong limitation of the output signal. The phase response can be determined from the in-phase and the quadrature component. A normalized output level up to 2.3 is possible referred to the normalized nominal value of 1. Higher output levels are limited. From the amplitude distribution and the limitation at 2.3 the crest factor in dB can be calculated.

4.4.10 How Is Crest Factor Defined?

The crest factor expresses a voltage ratio. The quotient of the peak voltage value (V_p) and the root-mean-square voltage value (V_{rms}) is formed and expressed as a logarithmic ratio (K_{CREST}):

$$K_{CREST} = 20 \times \log(V_p/V_{rms}) \text{ dB}$$

The linearity measurements, whose results are shown in Table 10, were made with a Spectrum Analyzer FSP using the CCDF (complementary cumulative distribution function). This function measures peak envelope power (PEP) rather than absolute peak voltage that occurs in the amplifier. So, with different weighting applied to the signal, the values stated in Table 10 have to be corrected by a factor of $\sqrt{2}$ or 3.01 dB. The actual crest factor is, therefore, 10.245 dB. When referring to the crest factor K_{CREST} in the following, this is understood to mean the value derived from the absolute peak voltage. The various types of signal weighting are discussed in Annex 4A.

The (typical) nonlinear characteristic of power amplifiers always leads to intermodulation products. Without filtering, these reduce the shoulder distance at the transmitter output to about 34 dB.

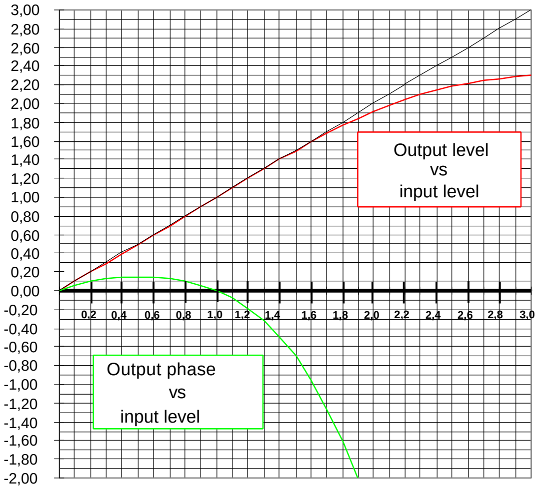


Fig. 4.27 Amplifier characteristic

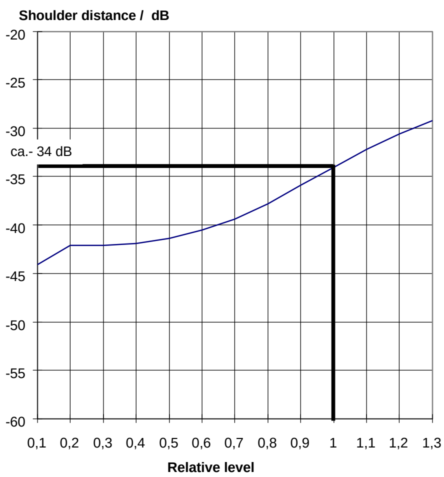


Fig. 4.28 Shoulder distance versus nominal input level

The digital precorrectors in the exciter make for optimal linearization not only of amplitude frequency response and group delay but also of the amplifier characteristic.

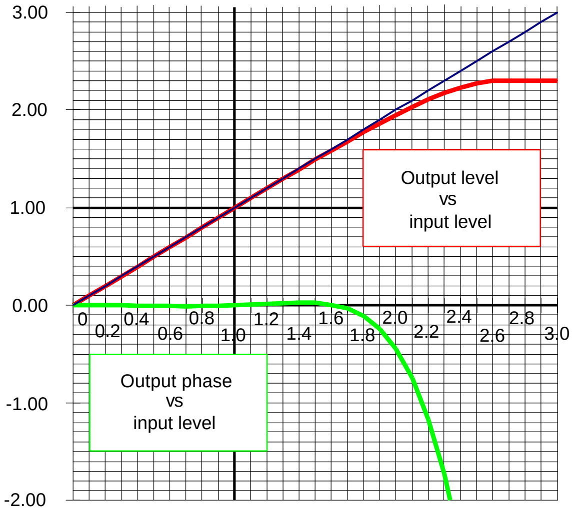


Fig. 4.29 Typical gain and phase characteristics of corrected amplifier

An amplifier with this typical characteristic (i.e. going into saturation at normalized output level of 2.3, and with corrected phase = 0 up to normalized input level of 1, then assuming negative values) attains a shoulder distance of approx. 42 dB at nominal input level.

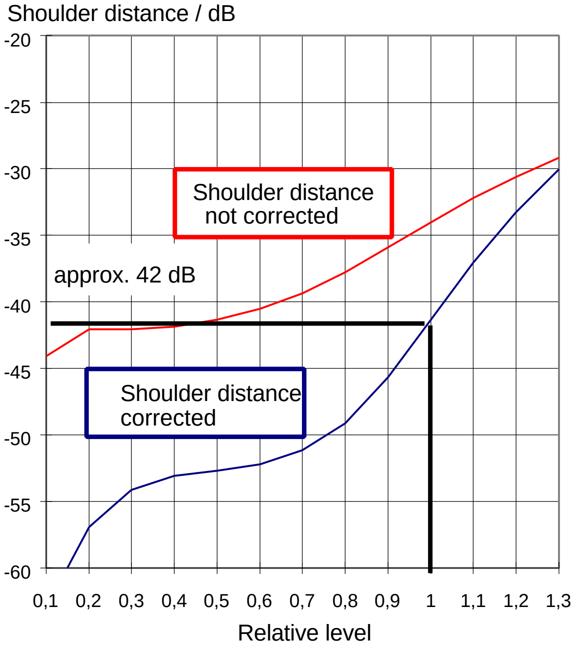


Fig. 4.30 Shoulder distance obtained with corrected/non-corrected amplifier

4.4.11 Crest Factor and Level Limiting in DVB-T Transmitter

For the theoretical case that all carriers of the COFDM time-domain signal, which is very similar to white noise, attain their maximum or minimum at the same time, all carrier amplitudes add up to give the maximum possible peak amplitude $V_{P\,MAX}$. In 8k mode this peak amplitude yields a crest factor of

$K_{CREST\,MAX}$ = 10 x log(6817)
= 38.3 dB

and in 2k mode

$K_{CREST\,MAX}$ = 10 x log(1705)
= 32.3 dB

These peak values will, however, not occur in practice. So, a realistic value of

K_{CREST} ≥15 dB

is assumed with a probability of 1 x 10^{-7} for both modes.

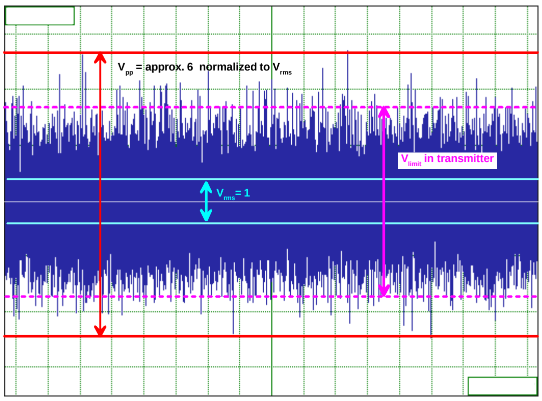


Fig. 4.31 Time-domain signal in DVB-T

This corresponds to a V_p / V_{rms} ratio of about 6. For the transmitter power this means that peak power 36 times that of the mean power must be provided as a safety margin. Using such a factor, all signal components would be transmitted, with favourable effect on the BER. This is not acceptable in terms of efficiency however. Investigations have shown that with a crest factor of K_{CREST} ~ 13 dB there will be no appreciable impairment of BER. But a safety margin of nine times the mean transmitter power is in any case economically impractical. For this reason the crest factor is limited to K_{CREST} = 10 dB...11 dB for all DVB-T transmitters, corresponding to a safety margin of about 7 dB.
This, however, does mean an appreciable degradation of BER. With channel filtering for boosting shoulder distance, a BER (before Viterbi) of 1 x 10^{-5} to 1 x 10^{-6} is in this case obtained at the transmit antenna.

The new solid-state amplifier generation employs high-linearity LDMOS transistors. This means that demands on digital precorrectors are less stringent than with predecessors using bipolar or MOS technology. To protect the transistors, the crest factor is limited to K_{CREST} = 10 dB. This prevents high voltage peaks from damaging the transistors.
Determining the crest factor at the transmitter output is, therefore, indispensable as it is crucial for power transistor lifetime. This measurement too can be performed with DVB-T Test Receiver EFA 40/43.

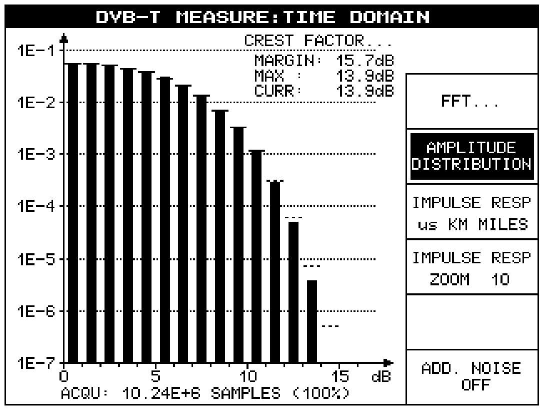


Fig. 4.32 Crest factor measurement with DVB-T Test Receiver EFA model 40 or 43

EFA calculates the crest factor based on the amplitude distribution or CCDF (complementary cumulative distribution function). The display indicates the current crest factor during the measurement (10.24 x 10^{-6} samples), the maximum crest factor since the beginning of the measurement, and the margin acive for the test configuration.

Note:
As set forth in 4.4.10, measurement of the crest factor with a spectrum analyzer (e.g. FSP) yields a value lower by 3 dB since in this case the peak power of the envelope is measured (see also Annex 4A).

4.5 Power Measurement on DVB-T Transmitters

Mean power measurement

In the case of analog transmitters, signal power is determined by measuring the peak power of the sync pulse floor of the modulated CCVS signal. The sync pulse floor is always the reference in analog TV because this signal component must be transmitted without compression or distortion.
In DVB this is different. The "*Sync 1 Inversion and Randomization*" block of the DVB modulator (see EN 300 421, EN 300 429 or EN 300 744) ensures constant mean power of the transmitter signal.
In DVB, therefore, it is not the peak power that is measured, based on the crest factor, but the mean output power. Three methods are available today:

a 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 TV 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.

b Mean power measurement with Spectrum Analyzer FSEx or FSP

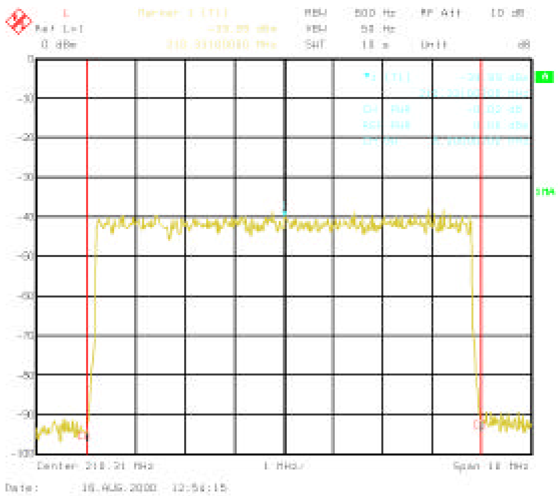


Fig. 4.33 Power measurement with frequency cursor

A frequency cursor is placed on the lower and another on the upper frequency of the DVB channel. The spectrum analyzer calculates the power for the band between the cursors. The method provides sufficient accuracy as in DVB-T normally no signals are put on the air in the adjacent channels.

c Mean power measurement with Test Receiver EFA

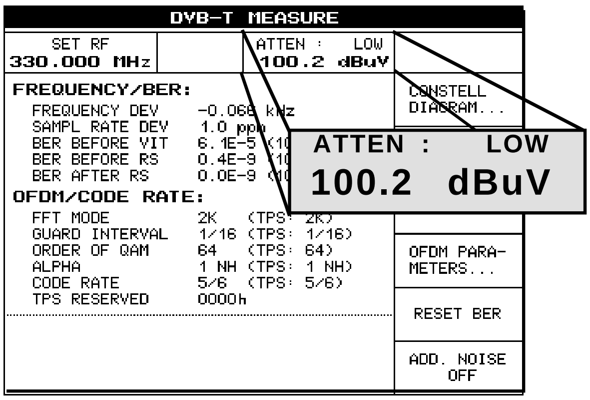


Fig. 4.34 Measurement menu of Test Receiver EFA model 40 or 43

EFA displays all important signal parameters in a status line. The righthand upper status field indicates mean power in various switchable units. Investigations on channel spectra revealing pronounced frequency response have shown the high accuracy of the displayed level. A comparison of the levels obtained with EFA and NRVS with thermal power sensor yielded a maximum difference of less than 1 dB – the comparison being performed with various EFA models at different channel frequencies and on different, non-flat spectra. Thanks to EFA's built-in SAW filters of 6 MHz, 7 MHz and 8 MHz bandwidth for the IF range, highly accurate results are obtained even if the adjacent channels are occupied.

The following example describes a measurement used in the above comparison.

An echo with 250 ns delay and 2 dB attenuation is generated by means of TV Test Transmitter SFQ with Fading Simulator option. This echo, plus the signal sent via the direct path, produces the channel spectrum shown in Fig. 4.35 with pronounced dips resulting from frequency response.

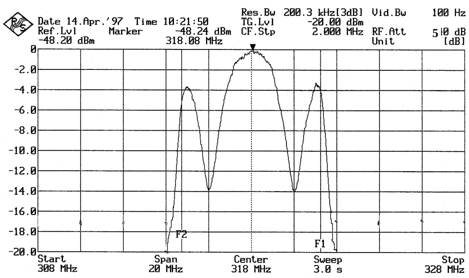


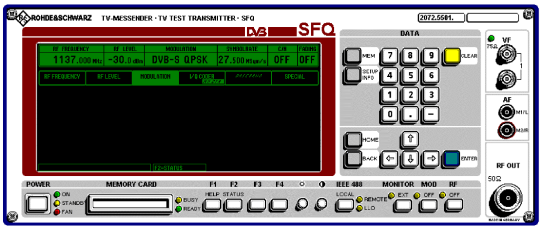
Fig. 4.35 Fading spectrum

Table 4.11 gives the results where the maximum difference between EFA and NRVS has occurred.

Level measurement with	NRVS	EFA
	-33.79 dBm	-33.0 dBm

Table 4.11 Comparison of results

Note:
The results of the level measurements are specified in detail in Application Note 7MGAN15E (see also Annex 4B).



Condensed data of TV Test Transmitter SFQ

Frequency range	0.3 MHz to 3.3 GHz
Level range	+4 dBm to -99 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	16, 32, 64, 128, 256QAM
DVB-S	
Modulation	QPSK
Puncturing	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

4.5.1 Amplifier Failure

Exciter SV700 feeds the DVB-T signal to the power splitter that drives the power amplifiers. These are designed as twin amplifiers. The amplifier output stages, likewise designed as twin stages, are LDMOS power transistors. Depending on the required transmitter power, a number of amplifiers operate in parallel. Two amplifiers are combined via a coupler in each case. The coupler output signal is bandpass-filtered to increase the shoulder distance and taken to the transmitting antenna. Depending on the degree of suppression in the stopband of the bandpass filter, an extra filter may be required to suppress local oscillator harmonics.

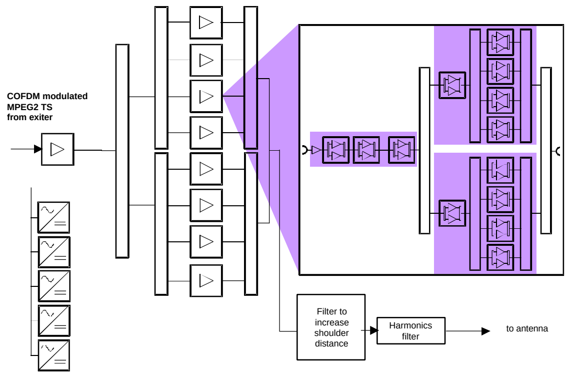


Fig. 4.36 Block diagram of power amplifier

Fig. 4.37 Power amplifier

4.5.1.1 Output Power in Event of Amplifier Failure

As mentioned above, twin amplifiers are used. Two amplifiers or, within one amplifier, two power transistors are combined via a coupler. If one of the *twins* fails, half of the power of the other twin is terminated by an absorber. Thanks to the absorber's very efficient cooling, overheating is prevented in the event of a failure. The following equation expresses the residual output power of a transmitter in the event of amplifier failure:

$$P_{out} = P_{nominal} * \left(\frac{m-n}{m}\right)^2$$

P_{out} = real output power
$P_{nominal}$ = nominal output power
m = number of amplifiers fitted
n = number of defective amplifiers

DVB-T Transmitter NV 7250, 2.5 kW, band IV/V

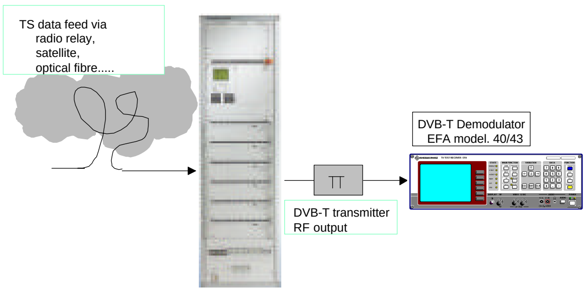
Condensed data of NV/NH 7xxx

Frequency range	470 MHz to 860 MHz
RF output power	0.4 kW to 5 kW (DVB-T) 2 kW to 40 kW (analog TV)
Interfaces	RS232C and RS485
Option	parallel interface (for messages and commands)
TV standards	
Digital	DVB-T, ATSC
Analog	B, G, D, K, M, N, I
Colour transmission	PAL, NTSC, SECAM
Sound transmission	dual-sound coding to IRT (-13 dB/-20 dB) or FM 1 sound (10 dB) and NICAM728

Example:
In a 2.5 kW DVB-T transmitter with a total of six amplifiers, one amplifier has failed. The transmitter continues operation with reduced power as follows:
$P_{out} = 0.694 \times P_{nominal}$ with m = 6 and n = 1

If an amplifier fails, transmitter power is reduced but the characteristic remains the same. The latter is merely shifted – parallel to the previous characteristic – towards the lower power value. This also means that all quality parameters (except reduced power) remain in compliance with specifications. This also applies if individual power transistors of an amplifier fail. As an important prerequisite, however, any overloading of an amplifier or power transistors must be prevented. The MTBF of the operational elements is not affected by this condition.

4.5.1.2 Amplifier Replacement



Longterm measurements with
Test Receiver EFA model 40/43

Fig. 4.38 Longterm measurement of transmitter power

A defective amplifier can easily be identified, also in remote monitoring, from the transmitter power histogram displayed on Test Receiver EFA model 40/43. If, in the case of DVB-T Transmitter NV 7250, transmitter power is reduced by a constant 1.59 dB, this means that one of the six amplifiers has failed. At higher transmitter powers the difference is smaller but still clearly identifiable from the histogram. The power drop can in any case be calculated with the above equation.

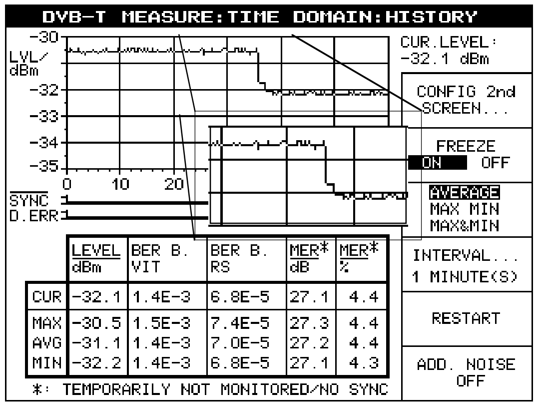


Fig. 4.39 Histogram generated by Test Receiver EFA model 40/43

What should be done if an amplifier fails?
First, remove the defective amplifier plug-in from the transmitter rack (also during operation) and insert a replacement.
Match the level and phase of the replacement amplifier to that of its twin amplifier. To do this, use a Spectrum Analyzer FSEx or FSP or a Test Receiver EFA 40/43 as employed in DVB-T transmitter monitoring. With optimally matched phase, the transmitter will output maximum power. The procedure is consequently very simple: adjust the phase until the instrument indicates maximum transmitter output power.

4.5.2 END Measurement

Each unit of a transmission chain contributes to degradation of the S/N ratio of the transmit signal. END (equivalent noise degradation) is a measure of the deterioration of signal quality. To determine END, another parameter, i.e. BER, is used. If the S/N ratio of a DVB signal decreases, BER increases. By adding white noise to the transmit signal before and after the device under test, signal characteristics can be degraded to the point where BER reaches a value of 2×10^{-4} after Viterbi decoding (or before Reed-Solomon decoding). Reed-Solomon forward error correction is capable of correcting BER of 2×10^{-4} to obtain a quasi-error-free (QEF) transport stream with BER $\tilde{}$ 1×10^{-11}.

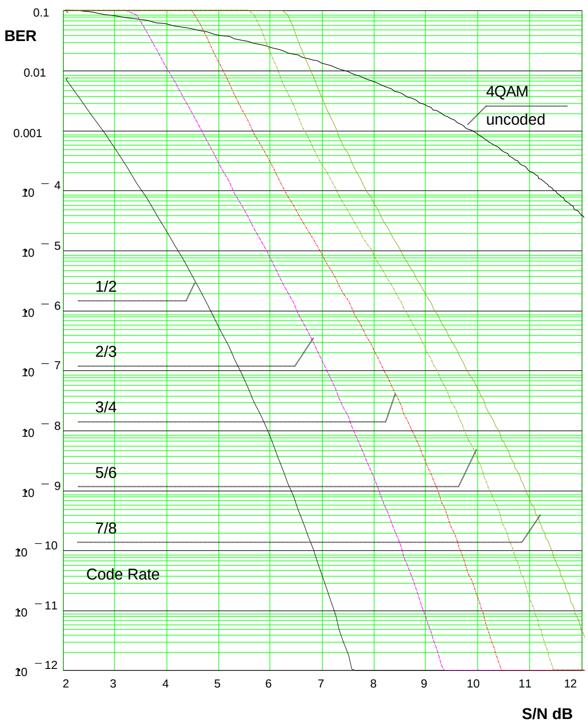


Fig. 4.40 BER (S/N) for QPSK modulation

The difference between the noise levels ahead and after the device under test for which BER of 2 x 10^{-4} is reached after Viterbi is the wanted END.

From the QPSK modulation diagram (Fig. 4.40) it can be seen that the curve for BER versus S/N (signal to noise) is very steep at BER = 2 x 10^{-4}. This is because Viterbi error correction has already been performed at this point. Minor errors in determining S/N therefore lead to strong variations of BER. Moreover, END values of < 0.3 dB should be measurable too. These requirements can be met only if S/N is determined with an accuracy of < 0.1 dB.

In the example below, the END measurement is described for a DVB-T transmitter amplifier. Fig. 4.41 illustrates the test setup:

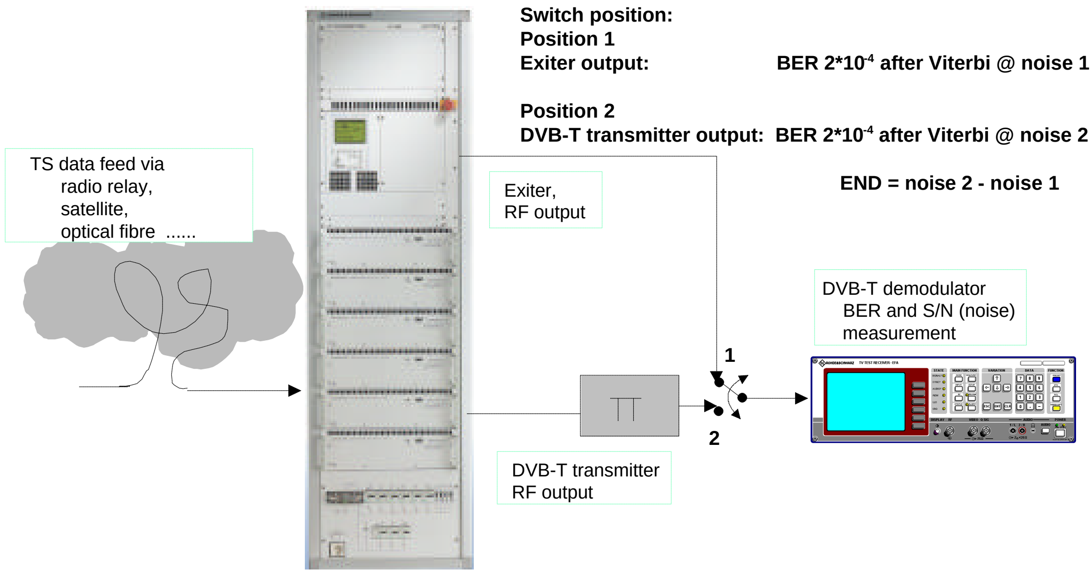


Fig. 4.41 Test setup for END measurement on solid-state transmitter amplifiers

The transport stream is fed to the exciter input and directly converted to the RF. Test Receiver EFA 40/43 demodulates the signal at the SV700 monitoring output and measures BER. In the demodulator, the signal is converted to the IF at 36 MHz and, with EFA's built-in noise generator, white noise is added until BER = 2 x 10^{-4}. Read this first C/N ratio – $(C/N)_1$ – from the EFA display.

Next, feed the transmitter output signal to the EFA RF input via a coupler and an attenuator. Adjust the input level via the coupler and the attenuator, so that a value identical with the first measurement is obtained, so establishing the conditions of reception existing at the exciter output. Again, add white noise with EFA's noise generator until BER = 2 x 10^{-4} is displayed. Read the second C/N ratio – $(C/N)_2$ – from the display.

The END for the transmitter amplifiers is calculated as follows:

$$END = (C/N)_2 - (C/N)_1 \text{ dB}$$

High-quality amplifiers should have an END not exceeding 0.4 dB. For this range, the 0.1 dB accuracy and 0.1 dB resolution of the EFA noise generator are sufficient.
Where more stringent demands have to be met, the C/N ratio has to be determined with much higher absolute accuracy. Application Note 7BM03_2E (see Annex 4C) describes how to do this. The method discussed there allows C/N ratio measurement with absolute accuracy better than 0.1 dB. The accuracy for END measurement is likewise typically 0.1 dB.

4.6 BER Measurement

Bit error ratio is the most important figure of merit in digital video broadcasting. In DVB-T, BER is measured at three points after demodulation:

a immediately after demodulation before any error correction, i.e. the raw-bit error ratio, generally referred to as "BER before Viterbi" (inner FEC);

b after the first error correction, generally referred to as "BER after Viterbi" or "BER before RS" (outer FEC);

c after the second error correction, generally referred to as "BER after RS" (outer FEC).

Test Receiver EFA 40/43 measures BER at these points during normal operation. The three values are displayed together in the MEASURE menu. To speed up display, a number of data blocks are selected for evaluation, each block comprising 10^7 bits. While BER calculated from these blocks is usually displayed with low resolution, e.g. 0.0E-5, the result is available immediately. EFA then performs *sliding* BER calculation until – after a corresponding waiting time – the result is obtained with the final accuracy. In the example shown in Fig. 4.42, the measurement before Viterbi starts with 10 data blocks. The corresponding 10×10^7 bits have already been processed, and the result is 2.0E-4. For BER before RS, sliding calculation is already active. Here, a total of 10000 blocks has to be checked, of which 881 have been processed so far.

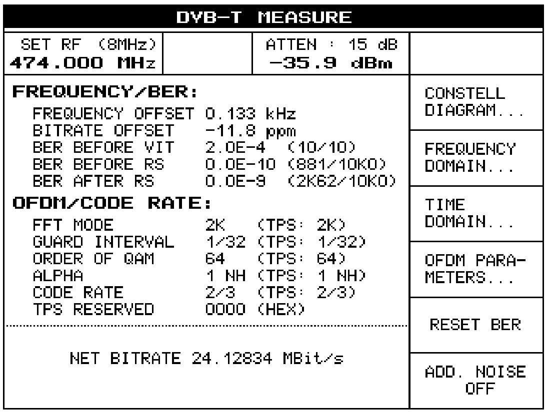


Fig. 4.42 MEASURE menu of EFA

This example shows the efficiency of Viterbi FEC: at a code rate of 2/3, it corrects BER of 2.0E-4 to 0.0E-10 before RS FEC. This value is very close to the QEF value, which is obtained after RS FEC.

For hierarchical modulation, Test Receiver EFA 40/43 can measure BER separately for the high-priority and the low-priority data stream. The path currently measured is indicated by the information "HP" (high priority) or "LP" (low priority) below the heading FREQUENCY/BER.

We again refer you to the note on page 6:

BER of 2×10^{-4} before RS FEC is the reference value in all measurements of transmission quality.

4.7 Other Measurements of MEASURE Menu

4.7.1 Measurement of Frequency Offset

In the status line of the MEASURE menu, the input level, the manually set channel center frequency (see also 4.4.5 Center Frequencies of UHF Channels) and the used channel bandwidth are displayed. The center frequency of the input signal is compared with the set frequency and the difference indicated under FREQUENCY OFFSET. The highly accurate, oven-controlled crystal used as a reference allows offset display down to 1 Hz. Test Receiver EFA 40/43, therefore, also replaces an extra frequency counter on the DVB-T transmitter.

4.7.2 Measurement of Data Rate Offset

DVB-T data rates are defined for each modulation mode (QPSK, 16QAM or 64QAM), guard interval and puncturing rate. Deviations from specified data rates have an effect on the DVB-T spectrum. The deviation from the specified data rate must therefore be known. On EFA, it is indicated in ppm under BITRATE OFFSET. The corresponding net data rate is displayed in the bottom line.

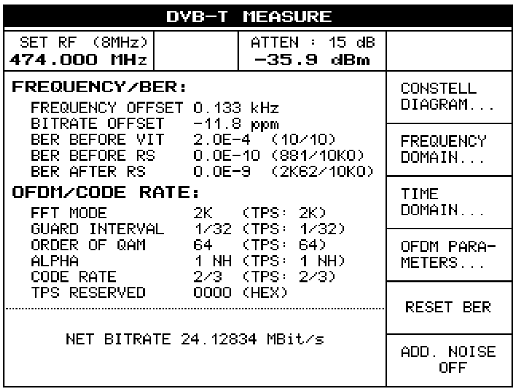


Fig. 4.47 MEASURE menu with frequency offset and data rate offset

4.7.3 Display Zoom Function

The MEASURE menu uses a relatively small type and so can be recognized only at a short distance. To read results from the DVB-T transmitter at a greater distance, i.e. a few meters, the following parameters can be zoomed:

LEVEL
BER BEFORE VIT
BER BEFORE RS
BER AFTER RS

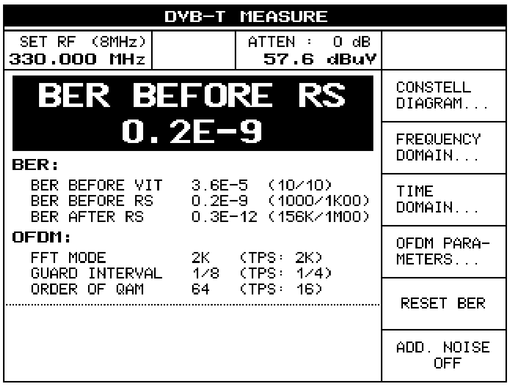


Fig. 4.48 Display zoom function

In this case however, the following parameters are not displayed as they are superimposed with the zoomed parameter:

FREQUENCY OFFSET
BITRATE OFFSET
ALFA (degree of hierarchy)
CODE RATE
TPS RESERVED

4.7.3 Display of DVB-T Modulator Settings

The transmitter operator must know the exact setting of his DVB-T transmitter at any time. The data determining the operating mode are fed to the transmitter in three ways:

via the NIT table of the PSI,
via the MIP,
by manual settings.

Therefore, with control data fed by different sources, the transmitter's operating mode is not unambiguously defined.

Test Receiver EFA 40/43 finds the relevant settings in the AUTO mode of the OFDM/CODE RATE MODE of the STATUS menu. Apart from this, EFA can be configured via the TPS carriers inserted in the DVB-T modulator.

The measured and accepted DVB-T transmitter settings are listed in the MEASURE menu in addition to the decoded parameters assigned via the TPS carriers (TPS values in brackets).

If automatic setting or TPS decoding does not produce stable results, the settings can be made manually.

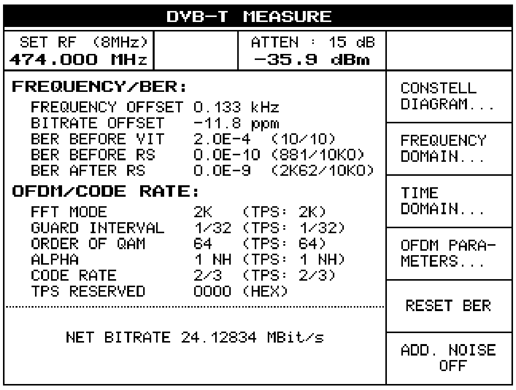


Fig. 4.49 MEASURE menu listing OFDM/CODE parameters

Test Receiver EFA 40/43 immediately tracks any change in configuration data, so keeping the transmitter operator informed at all times of current DVB-T transmitter status.

4.8 Measurements in Frequency Domain

4.8.1 Channel Amplitude and Phase Response

The theoretical amplitude and phase values of the scattered pilots of the COFDM symbol are stored in Test Receiver EFA and compared with the actual values of the pilots received. The resulting values yield the channel transfer function. Based on this function, the amplitude and phase response or group delay of the transmitter's RF output is to be measured, including all filters between the transmitter output and the antenna. So, EFA also verifies compliance with the requirements for amplitude and frequency response or group delay specified in 4.4.6, "Increasing Shoulder Distance".

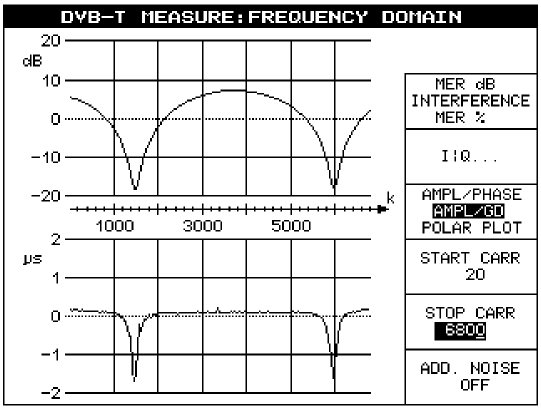


Fig. 4.50 Linear distortion (amplitude and phase) due to fading in transmission channel (with carrier number k plotted along abscissa)

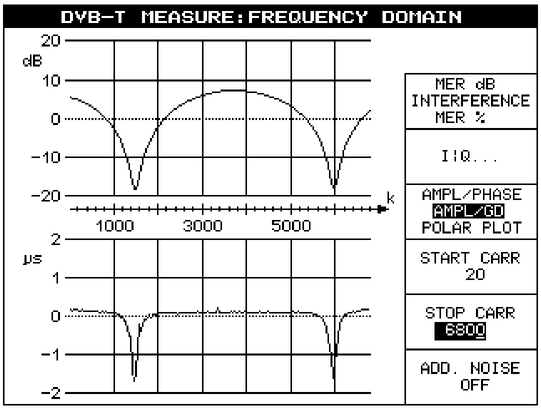


Fig. 4.51 Linear distortion (amplitude response and group delay) due to fading in transmission channel (with carrier number k plotted along abscissa)

Another way of presenting the above information is a polar diagram. Although this representation provides no reference to frequency, it does combine amplitude and phase information in a single diagram, so offering a fast overview of the conditions prevailing in a channel.

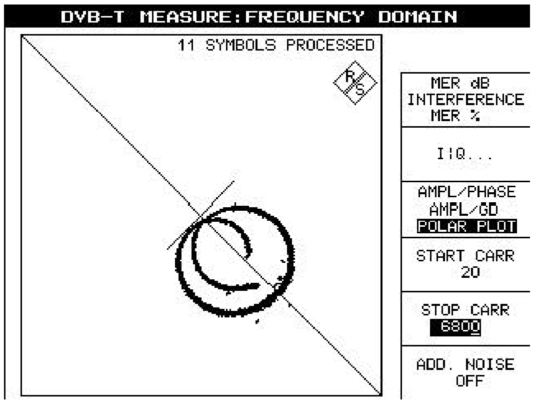


Fig. 4.52 Polar plot of chart shown in Fig. 4.50. Long diagonal: real component, short diagonal: imaginary component

In the ideal case of an undistorted channel spectrum, only a point would appear on the positive real axis.

4.8.2 Frequency Response Calculated with FFT

Calculating channel frequency response by means of FFT furnishes level deviation with much higher resolution than the complex comparison of pilots described above. Although FFT is not a full equivalent to spectrum analyzer measurement, it is adequate for analyzing the spectrum of a transmission channel and for determining out-of-band components as described in 4.4.6, "Increasing Shoulder Distance" above.

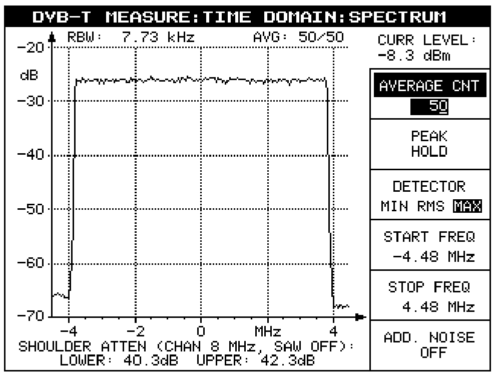


Fig. 4.53 Spectrum of DVB-T channel

Maximum level resolution is obtained by analyzing only the useful range of the spectrum (from -3.8 MHz to +3.8 MHz in the above example). EFA automatically selects maximum level resolution in this case, i.e. 2 dB/division, depending on the frequency response.

4.9 Constellation Diagram

Test Receiver EFA 40/43 maps each DVB-T carrier to its baseband by means of FFT. All I/Q value pairs thus obtained are projected into the decision fields for QPSK, 16QAM or 64QAM (hierarchical or non-hierarchical), so producing a constellation diagram.

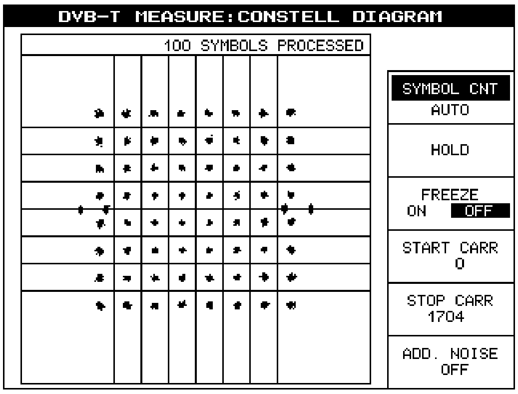


Fig. 4.54 Constellation diagram for 64QAM, 2k mode

The I/Q values of all carriers between START CARR and STOP CARR are included, so the pilots and TPS carriers too are plotted along the I axis. The TPS carriers show the mean power in a given constellation diagram, whereas the pilots appear with power higher by a factor of 16/9 = 1.777.

From the constellation diagrams of the individual carriers, various OFDM parameters can be determined.

4.9.1 MER Measurement

MER (modulation error ratio) summarizes all errors that can be measured within a constellation diagram. The definition of this parameter is illustrated by Fig. 4.55.

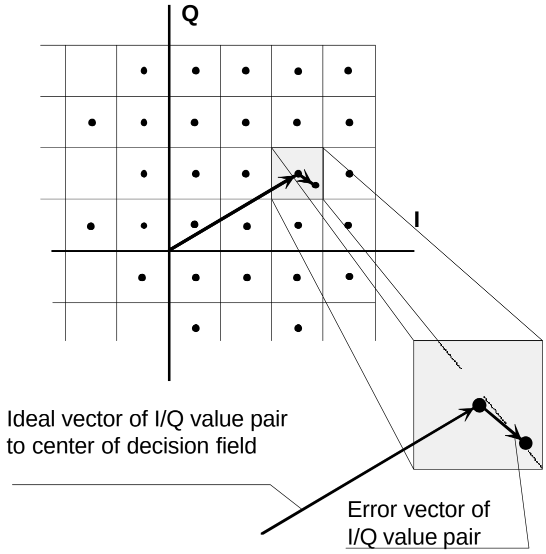


Fig. 4.55 Definition of MER

For each I/Q value pair of a constellation diagram there is exactly one theoretical target point located at the center of each decision field. But the actual point is not always located at the center. This is due to the effect of quantization in A/D conversion involving a limited number of bits, rounding errors in calculation, D/A conversion in the modulator, phase jitter of the converter clock and superimposed noise in transmission. From this an error vector can be formed combining all these effects. MER is calculated from the sum of the squares of ideal vectors and that of the error vectors (see Measurement Guidelines for DVB Systems ETR 290).

Test Receiver EFA 40/43 not only measures MER but also presents it as a function of frequency (MER(f)), i.e. MER is shown for each individual carrier of a COFDM channel, which is much more conclusive. Errors concerning just a few carriers of a COFDM symbol can immediately be located in this way.

This is illustrated by the following example:

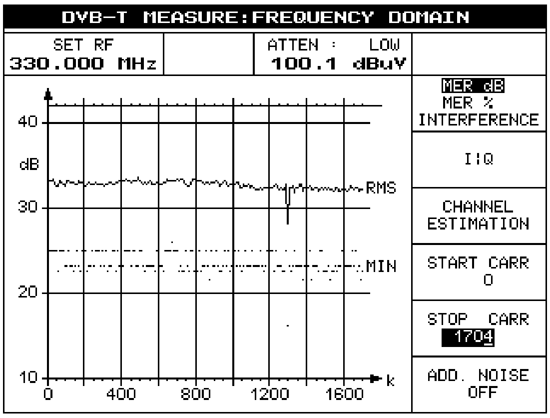


Fig. 4.56 MER(k) characteristic with narrowband interference

Fig. 4.56 shows a pronounced dip of MER in the carrier region about k = 1300 (k = index of COFDM carrier). To determine the disturbed carrier, select the start carrier a little below k = 1300 (e.g. k = 1280) and the stop carrier a little above (e.g. k = 1320). The disturbed carrier can thus be exactly identified; in this case it is k = 1299.

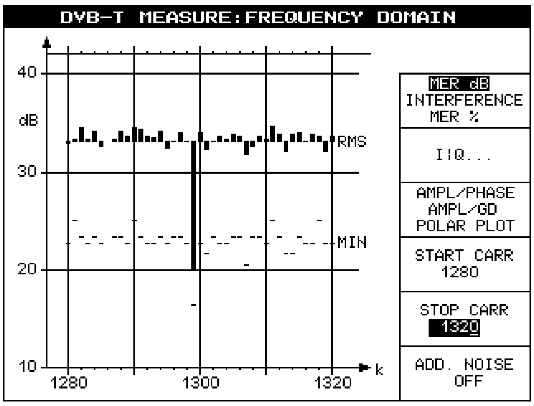


Fig. 4.57 Zoomed MER representation of 2k COFDM signal; the interference is on carrier 1299

DVB-T transmitter monitoring is therefore in the first place effected only by measuring MER in addition to BER. In the event of significant deviations from the linear characteristic, the cause of error will be examined in detail by zooming the carrier region in question or measuring the parameters defined in the COFDM menu.

MER, beside BER, is the primary parameter in a DVB transmission system as it provides information on transmission quality at a glance.

A good DVB-T transmitter should have

MER(f) > 35 dB.

4.9.2 I/Q Analysis

Another way of locating errors in the COFDM signal is by presenting I/Q versus frequency. The I component is shifted by 90° and superimposed on the Q component. Depending on the modulation (QPSK, 16QAM or 64QAM), two, four or eight I/Q bars are produced that directly indicate any deviation from ideal modulation and from which selective interferers can be determined. These bars should ideally be equidistant, parallel, horizontal lines located in the middle between the inner decision thresholds.

The example below shows the same signal as above for MER measurement, this time in I/Q presentation. The selective interferer on carrier 1299 is again identified by zooming.

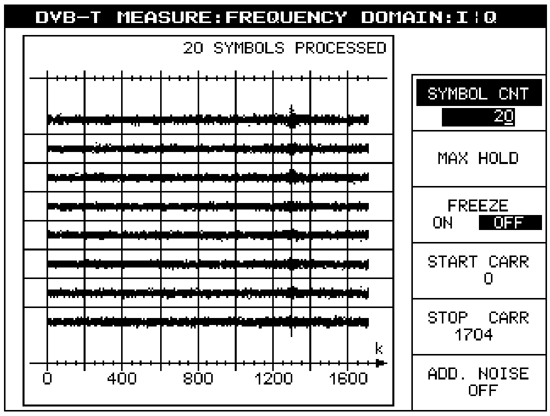


Fig. 4.58 I/Q analysis of 2k COFDM signal

In Fig. 4.59 a gap can be recognized at carrier k = 1286. At this point a TPS carrier is located that is not taken into account in the I/Q analysis. This is due to the modulation, i.e. the information is carried by the I component only; this method is, therefore, not comparable with the data carrier method.

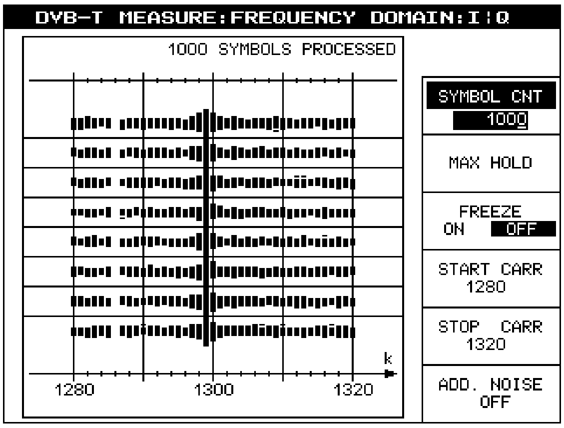


Fig. 4.59 Zoomed I/Q presentation of 2k COFDM signal; the interference is on carrier 1299

4.9.3 Measurement of I/Q Parameters in OFDM

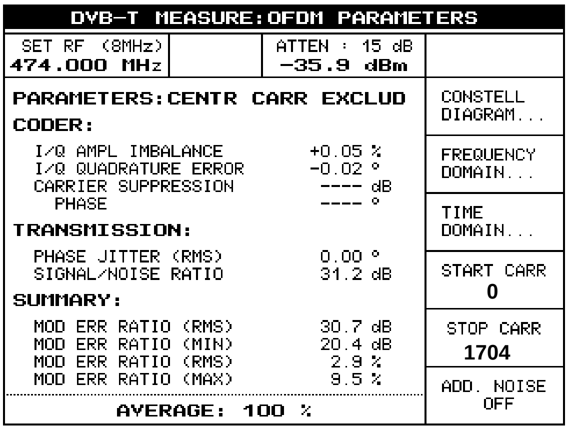


Fig. 4.60 Measurement of OFDM parameters without central carrier

Just as in DVB-C and DVB-S, any interference or disturbance in DVB-T is caused by the modulator and during transmission.

The parameters

I/Q IMBALANCE,
I/Q QUADRATURE ERROR,
CARRIER SUPPRESSION and
(RESIDUAL CARRIER) PHASE

are typical performance parameters of the exciter, whereas during transmission noise-like disturbance like

PHASE JITTER and
NOISE (S/N RATIO)

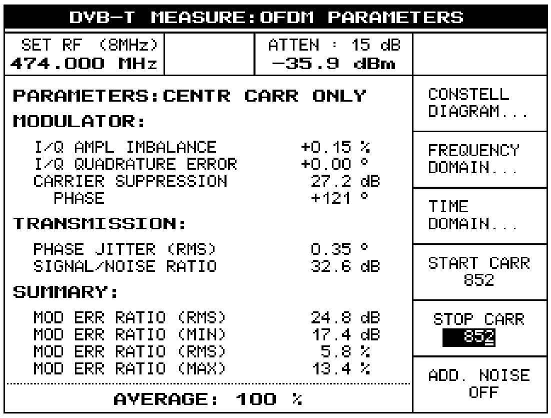
is superimposed on the useful signal.

MER is again obtained as a sum parameter (see also 4.9.1, "MER Measurement") and displayed under different designations.

4.9.4 Measurement of Residual Carrier

In residual carrier measurement some special features have to be taken into account. The residual carrier is a very narrowband interferer. Requirements regarding its spectral purity have already been described under 4.5.1, "Measurement of Phase Noise". Being very narrowband, the residual carrier has an effect only on the central carrier and so can only be measured on this carrier.
In 2k mode, the central carrier is a scattered pilot inserted in every fourth symbol whose index can be calculated by means of equation 1 (see 4.2.8.2). In 8k mode, the central carrier is assigned a continual pilot.

Fig. 4.61 Measurement of OFDM parameters on central carrier only



Despite these restrictions, Test Receiver EFA 40/43 measures the residual carrier with high accuracy using a patented computation standard. To determine the residual carrier, simply select the central carrier (852/2k or 3408/8k) in either 2k or 8k mode. The measurement is then performed automatically.

In DVB-T, the residual carrier is referred to the signal power of a single OFDM carrier in accordance with ETR 290. By contrast, in DVB-C and DVB-S, the residual carrier is referred to the mean power of the overall spectrum. For this reason, the logarithmic ratio obtained for the residual carrier in DVB-T is much smaller than that for DVB-C or DVB-S at the same absolute residual-carrier level:

2k mode $\Delta = 10 \times \log(1705) = 32.3$ dB
8k mode $\Delta = 10 \times \log(6817) = 38.3$ dB

Example:
While typical residual carrier suppression of about 60 dB can be expected in DVB-C, a value scarcely exceeding 20 dB will be measured in 8k mode in DVB-T.

4.10 Alarm Report

The above measurements cannot only be carried out manually at the transmitter site, results can also be queried from a remote control center via an RS232C interface and the IEC625/IEEE488 bus. Monitoring by single queries is time-consuming however, plus there is a large quantity of measured data to be handled.
Remote monitoring with Test Receiver EFA 40/43 greatly simplifies this procedure.
This is implemented by the ALARM menu.

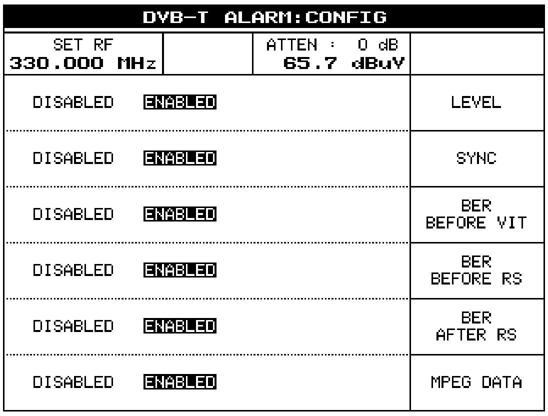


Fig. 4.62 Alarm configuration menu:
a variety of parameters can be monitored

Table 4.12 lists the parameters selectable in the ALARM CONFIGURATION menu:

Parameter	Explanation	Abbrev.
LEVEL	Input level	LV
SYNC	Indicates synchronization of OFDM symbols and MPEG2 transport stream	SY
BER BEFORE VIT		BV
BER BEFORE RS		BR
BER AFTER RS		BM
MPEG DATA	Data errors not correctable by Viterbi and RS	DE

Table 4.12

After selecting the parameters in the ALARM CONFIGURATION menu, the alarm thresholds have to be set. Thresholds can be set for LV, BV, BR and BM. Non-correctable data and synchronization failure are absolute events and are not assigned a threshold.

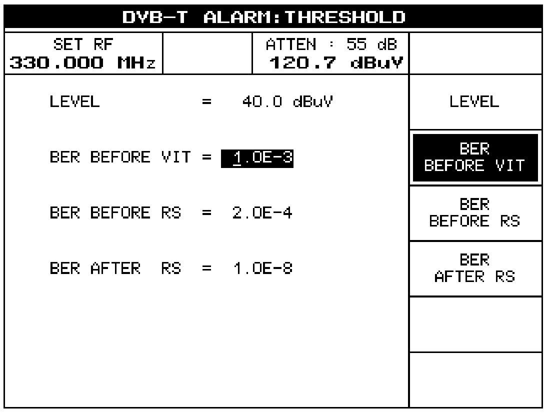


Fig. 4.63 Setting alarm thresholds

The activated alarms are combined to a sum signal brought out at a pin of X34 (USER PORT) on the rear of EFA. In the event of a sum alarm, the single alarms can be queried via the remote control interfaces.

On pressing the ALARM hardkey on the EFA front panel, the alarm list is displayed. The list may comprise up to 1000 lines in which each event is entered with its number, date and time and the parameter triggering the alarm. The time indicated is when a parameter first went out of tolerance or returned to tolerance.

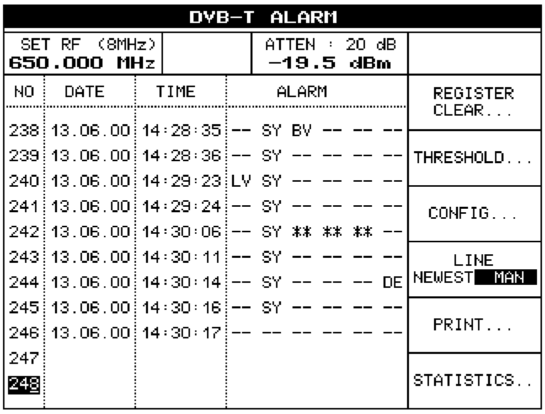


Fig. 4.64 Alarm list

If more than 1000 events occur in a monitoring period, the initial events are cleared and the current events added at the end of the list.
It may sometimes be necessary, for statistical purposes, to know the duration of the individual errors and the percentage taken up in overall monitoring time. This information is given under STATISTICS.

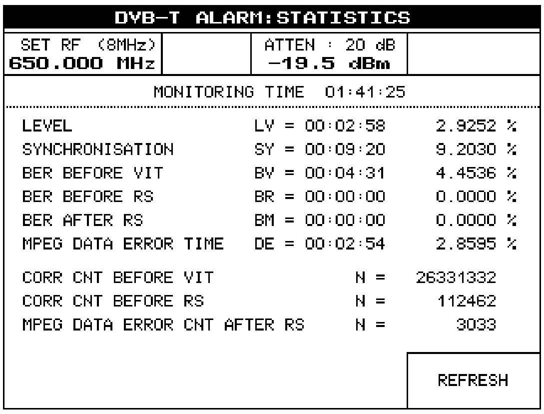


Fig. 4.65 Statistical evaluation of error periods

4.11 Measurements in VHF Band I and Band III

The European standard EN 300 744 has specified DVB-T so far only for the UHF band and 8 MHz channels. In notes, however, reference is made to 7 MHz channels, which are defined for VHF bands I and III and, in Australia, also used in band IV/V. For a 7 MHz channel, the DVB-T system clock has to be lowered from 64/7 MHz to 64/8 MHz. This increases useful symbol duration to 896 x 8/7 = 1024 µs and reduces useful signal bandwidth to 6.65625 MHz (with 976.5625 Hz carrier offset), so accommodating the data stream in a 7 MHz band. The length of the guard intervals is calculated on the basis of the useful symbol duration of 1024 µs. The useful data rate decreases by a factor of 7/8. The data rates given in Table 4.6 have to be multiplied by 7/8 for 7 MHz bands.
For DVB-T in 6 MHz channels, the system clock has to be reduced from 64/7 MHz to (64/8) x (6/7) = 48/7 MHz. The useful symbol duration is then (896 x 8/7) x 7/6 = 896 x 4/3 = 1194.667 µs, and the data rates and guard intervals have to be corrected accordingly.

Test Receiver EFA 40/43 carries out selective measurements in the 7 MHz and 6 MHz bands by means of two options: 7 MHz SAW filter EFA-B12 and 6 MHz SAW filter EFA-B11, which can be fitted in addition to the internal 8 MHz IF SAW filter.
The system clock automatically adapts to the selected bandwidth.
The latter is displayed in the STATUS menu.

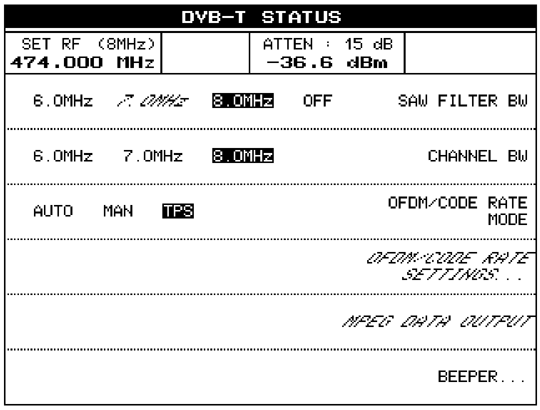


Fig. 4.66 STATUS menu

4.12 Measurements in DVB-T SFN or MFN
(Single Frequency Network,
Multi Frequency Network)

The guard interval takes up all signals reflected or directly received from other transmitters during DVB-T reception in a single frequency network. The path delay of such signals must not exceed the duration of the guard interval. Path delay is determined with Test Receiver EFA 40/43. Depending on the application, EFA calculates the path delay in µs or the path length in kilometers or miles.

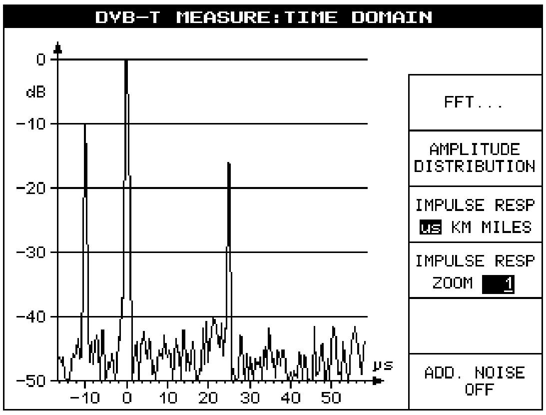


Fig. 4.67 Echo diagram

Fig. 4.67 shows that leading echoes too are possible in a DVB-T network, for example when receiving signals from a low-power gap-filler station located closer than a high-power transmitter. In this case the delay is -10 µs, i.e. the gap filler is about 3 km closer to the receiving station than the main transmitter, which is at 0 µs. At 25 µs, there is a lagging echo, which may result, for example, from reflection over a path of about 7.5 km. The above echo profile is valid for a DVB-T network with 8 MHz channel bandwidth and guard interval > 28 µs (2k guard interval: τ = 1/8; 8k guard interval: τ = 1/32).
Moreover, this measurement allows determination of the distance in km between the transmitters of an SFN, provided there is a line of sight between the transmitting antennas. The distance between transmitters in an SFN must not exceed the values specified in Table 4.13.

	Distance between transmitters (km)			
FFT	τ = 1/4	τ = 1/8	τ = 1/16	τ = 1/32
2k	16.8	8.4	4.2	2.1
8k	67.2	33.6	16.8	8.4

Table 4.13 Maximum distance between transmitters in SFN

4.13 Measurements with MPEG2 Decoder Option EFA-B4

The optional MPEG2 Decoder EFA-B4 covers only part of the functionality of MPEG2 Measurement Decoder DVMD and MPEG2 Realtime Monitor DVRM. The available measurement functions are adapted to monitor the demodulated MPEG2 transport streams at the transmitter. However, with EFA-B4 alone, the monitoring depth provided by DVMD or DVRM for MPEG2 specific parameters is not attained. If MPEG2 monitoring takes place already at the transmitter input, DVMD or DVRM is not needed at the output.
If Test Receiver EFA 40/43 is fitted with option EFA-B4 to analyze the MPEG2 protocol and the RF characteristics during DVB-T transmission, it alone will suffice to make the necessary measurements at the transmitter.
First, the time limits for the repetition rates of the tables and time stamps in the transport stream have to be set. The limits can be user-defined or selected in conformance with standards

ISO/IEC 13 818-1 for MPEG2
or
ETR 290 for DVB

for the parameters defined there.

Parameter name	**To DVB**		**To MPEG2**	
	MIN	**MAX**	**MIN**	**MAX**
PAT distance	25 ms	0.5 s	25 ms	0.5 s
CAT distance	25 ms	0.5 s	25 ms	0.5 s
PMT distance	25 ms	0.5 s	25 ms	0.5 s
NIT distance	25 ms	10 s	---	---
SDT distance	25 ms	2 s	---	---
BAT distance	25 ms	10 s	---	---
EIT distance	25 ms	2 s	---	---
RST distance	25 ms	---	---	---
TDT distance	25 ms	30 s	---	---
TOT distance	25 ms	30 s	---	---
PCR distance	0 ms	0.04 s	0 ms	0.1 s
PCR discontinuity	---	0.1 s	---	---
PTS distance	---	0.7 s	---	---
PID distance	---	0.5 s	---	---
PID unref. duration	---	0.5 s	---	---

Table 4.14 Limit values for parameters to DVB and MPEG2

In DVB all parameters are predefined, in MPEG2 only a few. Parameters not defined by the standard must be user-defined. The largest discrepancy between DVB and MPEG2 is in PCR distance with 40 ms for DVB and 100 ms for MPEG2.
Fig. 4.68 shows the menu for setting the limit values on Test Receiver EFA 40/43. The DEFAULT softkey activates the predefined MPEG2 or DVB values. To ensure reproducible and comparable results, it is recommended to select the DVB limit values.

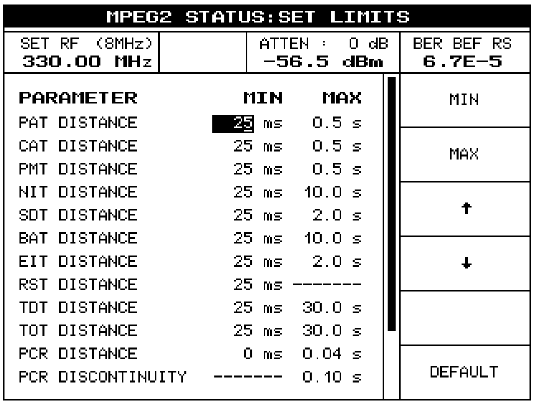


Fig. 4.68 Repetition rates for tables and time stamps

After defining the time limits, the parameters to be monitored for the MPEG2 alarm report have to be enabled. All parameters of the three priorities can be enabled.

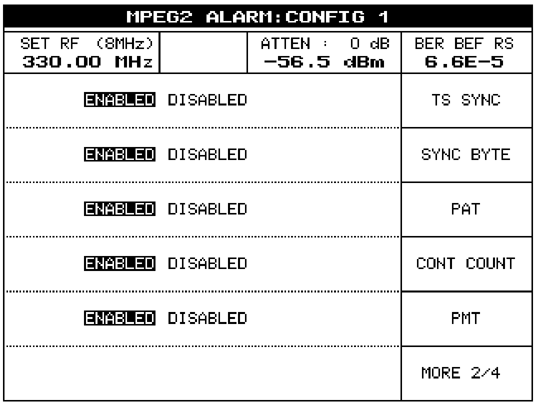


Fig. 4.69 First page of MPEG2 alarm menu

On pressing the ALARM key, the MPEG2 ALARM menu appears. In this menu, all results exceeding tolerances during the monitoring period are displayed.
For disabled parameters, "--" is indicated in brackets.

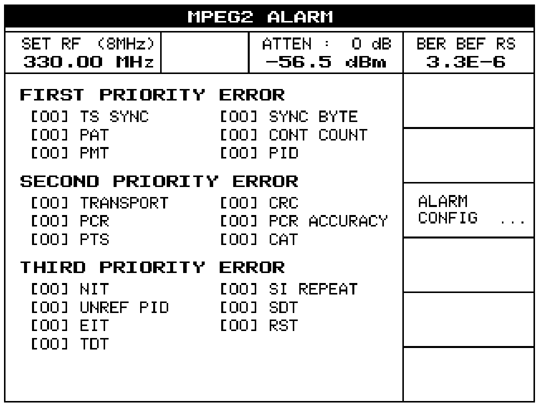


Fig. 4.70 MPEG2 ALARM menu

In the MEASURE menu, all parameters are evaluated in line with ETR290 irrespective of the settings made in the ALARM menu. An error counter can be started, stopped or cleared in this menu.

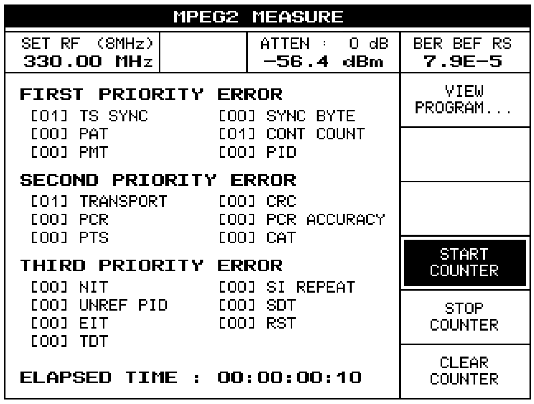


Fig. 4.71 MPEG2 MEASURE menu

The VIEW PROGRAM... softkey opens the PAT of the received transport stream listing the programs transmitted. The data rates of the overall transport stream, the individual programs, the tables and the null packets of the transport stream are displayed as well.

Test Receiver EFA 40/43 with optional MPEG2 Decoder EFA-B4 offers adequate functionality for MPEG2 monitoring, although it does not provide the same analysis depth as an extra MPEG2 Measurement Decoder DVMD or MPEG2 Realtime Monitor DVRM. The outputs for analog CCVS video and analog audio allow aural and visual monitoring of the programs put on the air.

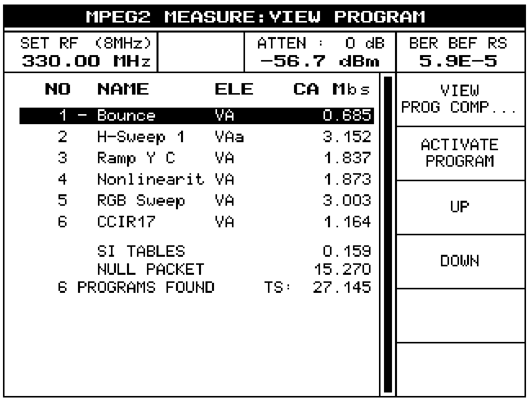


Fig. 4.72 PAT of transport stream with key parameters

ACTIVATE PROGRAM opens the PMT of the selected program with information on the number of video, audio, data and "other" data streams of the program including associated PID numbers. The PID numbers of the PMT and the PCR are listed too.

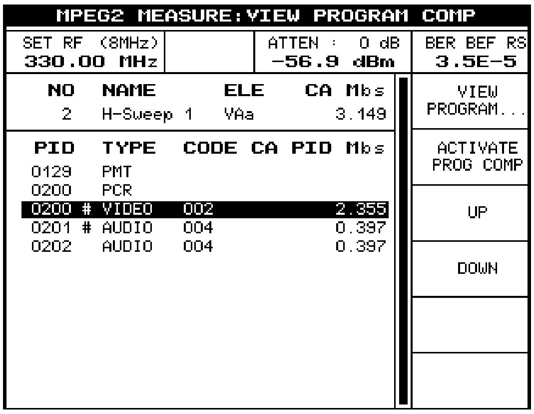
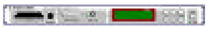
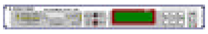
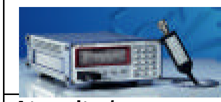
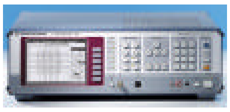
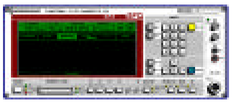


Fig. 4.73 PMT of program with key parameters

4.14 Overview of DVB-T Measurements

Instrument, Test Point	Test Parameter
At transmitter input DVG MPEG2 MEASUREMENT GENERATOR  DVMD MPEG2 MEASUREMENT DECODER  DVRM MPEG2 REALTIME MONITOR  DVQ DIGITAL VIDEO QUALITY ANALYZER 	Test signal generator for reproducible MPEG2 measurements, various test sequences Realtime MPEG2 transport stream protocol analyzer Realtime MPEG2 transport stream protocol monitoring Measurement of signal quality after MPEG2 coding and decoding
At exciter/ transmitter output SPECTRUM ANALYZER FSP or FSEx  	LO phase noise LO harmonics COFDM spectrum Shoulder distance Spectrum masks Crest factor Transmitter output power

Instrument, Test Point	Test Parameter
At exciter/ transmitter output NRVS Power Sensor NRV-Z51 	High-precision thermal measurement of transmitter output power
At exciter/ transmitter output EFA Model 40/43 DVB-T TEST RECEIVER with option EFA-B4 	**Basic unit** 2k and 8k 6 MHz, 7 MHz, 8 MHz channels Display of modulator settings COFDM spectrum Shoulder distance Spectrum masks Crest factor (to definition) Transmitter output power Amplifier failure END, BER, MER Offsets of frequency and data rate Channel transfer function Echo diagram Constellation diagram I/Q parameters in COFDM Residual carrier measurement Alarm report **Option EFA-B4** Measurements to ETR290: parameters of the three priorities alarm report, PAT and PMT
Simulation of DVB-T transmitter SFQ TV TEST TRANSMITTER Option NOISE GENERATOR FADING 	C/N setting for END measurement Simulation of defined receive conditions Simulation of transmitter defects

CCDF determination – a comparison of two measurement methods

Measurement of the CCDF (complementary cumulative distribution function) is often used for evaluating nonlinearities of amplifiers or transmitter output stages, for instance (see also refresher topic on page 44). This measurement indicates how often the observed signal reaches or exceeds a specific level. From a physical point of view, the CCDF measurement is the integral of the distribution function versus the level (integration of the observed level to infinity). Comparison of measured values and theoretical reference values (which can be determined for OFDM or mQAM/VSB) quickly yields information on the nonlinear response of all types of active elements. However, the great advantage of the CCDF measurement is that the useful signal itself is analyzed; as a result, it is not necessary to transmit complex test sequences. This test tip compares two different measurement methods.

CCDF determination – an important measurement in RF transmission systems

To minimize the overall signal degradation on the path to the receiver, amplification of the transmitted RF signal should be as pure as possible. However, it is necessary to limit the power of the transmitted signal (clipping) to avoid unnecessarily reducing the lifetime of the transistor output stages of the transmitter. For this reason, particular attention is given to the CCDF measurement as well as to the related crest factor $\hat{u}/u_{rms}$ in the development and operation of high-power transmitters. In practice, two different measurement methods are used, which produce different results.

Method 1: Sampling of the RF/IF signal – using the TV Test Receiver EFA, for example

In the TV Test Receiver EFA [1], the modulated signal is converted to an appropriate intermediate frequency and digitized (FIG 1, left). The digital samples are evaluated, and the CCDF represented. For an ideal CW (continuous wave) signal, this method yields a crest factor of 3 dB. The IF filtering occurs via a SAW filter adapted to the signal bandwidth; video filtering of the signal is not carried out, and thus the signal itself is not modified (FIG 2).

Method 2: Sampling the envelope – using the Spectrum Analyzer FSP, for example

The central element in a spectrum analyzer is the envelope detector. Via appropriate time filtering, the modulated signal is assigned a level value (FIG 1, right). The high-frequency modula-

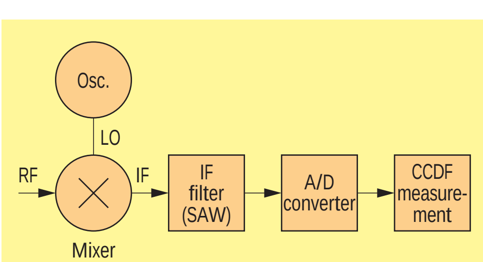
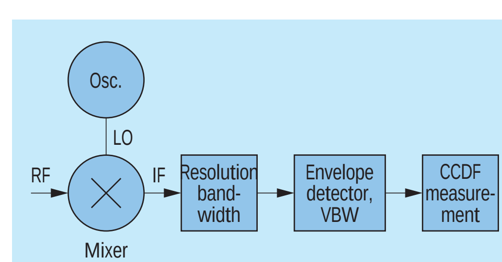


FIG 1
Simplified representation of the signal path to determine the CCDF via the TV Test Receiver EFA (left) and the Spectrum Analyzer FSP (right)



tion is eliminated from the signal; only the "envelope" signal is used (FIG 2). The measured values of a pure CW signal always have the same amplitude; it has thus a crest factor of 0 dB. In the case of IF and video filtering, it must be ensured that the resolution bandwidth (RBW) and the video bandwidth (VBW) do not distort the signal:

$$BW_{Resolution} > BW_{Signal}\,,\; BW_{Video} \geq 3 \cdot BW_{Resolution}\,.$$

Differences in the results of the two methods

The TV Test Receiver EFA analyzes the signal exactly as it is present at the RF input. According to its definition, a pure CW signal has a crest factor of 3 dB. The spectrum analyzer, on the other hand, analyzes the signal as it is present in the baseband (i.e. prior to modulation by the RF carrier), which in the case of the CW signal results in a DC voltage and consequently in a crest factor of 0 dB (ideally). Investigations have shown that the crest factors of both methods vary by 3 dB also in the case of random signals. However, the results of the CCDF measurements according to methods 1 and 2 cannot be converted one into the other simply by taking into account the difference of 3 dB. FIGs 3 and 4 show examples of the CCDF measurement using the Spectrum Analyzer FSP and the TV Test Receiver EFA.

Conclusion

Measuring the CCDF is a simple and effective method of determining the nonlinear characteristics of active elements. If the measurement of the CCDF is to be referred to the signal actually transmitted (instead of to the envelope), it is advisable to use the TV Test Receiver EFA.

Christoph Balz

REFERENCES

[1] TV Test Receiver EFA: see article on page 34 in this issue

[2] Spectrum Analyzer FSP: see article on page 20 in this issue

◆ The refresher topic "Measurements on MPEG2 and DVB-T signals" starting on page 44 covers the crest factor in detail

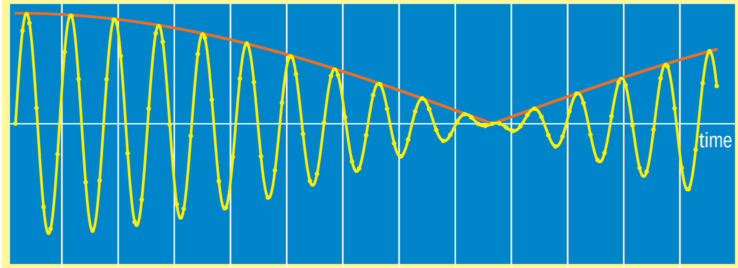


FIG 2 Time characteristic of a modulated signal; yellow: original signal, yellow dots: measured values used by the TV Test Receiver EFA to calculate the CCDF (measurement method 1); red: measured values used by a spectrum analyzer (measurement method 2).

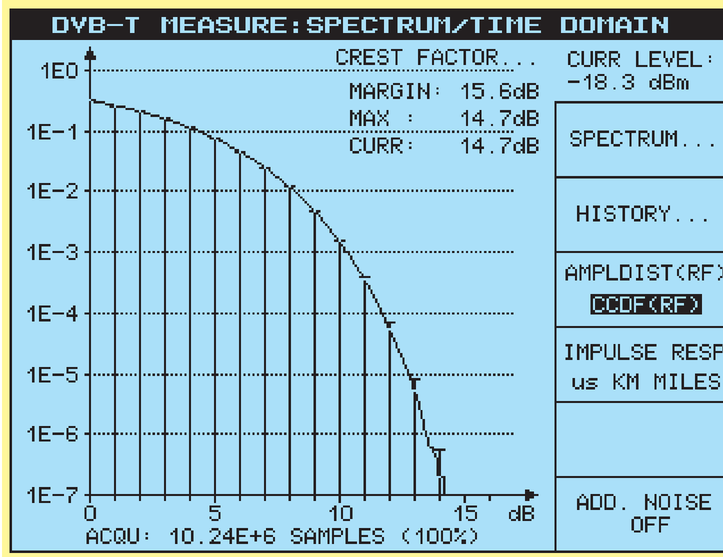


FIG 3 CCDF measurement with the TV Test Receiver EFA (method 1). Signal: OFDM with 64QAM; both the measured values (continuous line) and the theoretical values of an ideal signal are shown. The limitation of the signal in the case of high crest factors is clearly discernible.

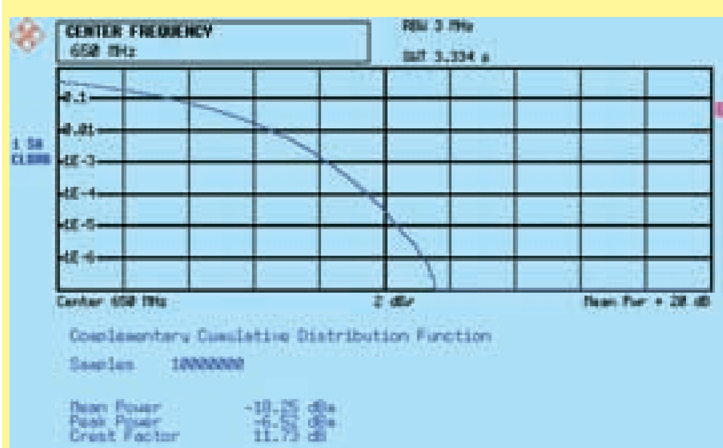


FIG 4 CCDF measurement with the Spectrum Analyzer FSP (method 2). Same signal as in FIG 3; the crest factor (11.73 dB) is 3 dB lower than in the measurement according to method 1 (14.7 dB, FIG 3).

TV Digital
Recipes
Part4 DVB-T

Annex

Annex 4B

ROHDE&SCHWARZ

BROADCASTING DIVISION

APPLICATION NOTE

RF Level Measurement Accuracy
of
TV Test Receivers

Products:

TV Test Receivers,
analog and DVB-C

EFA

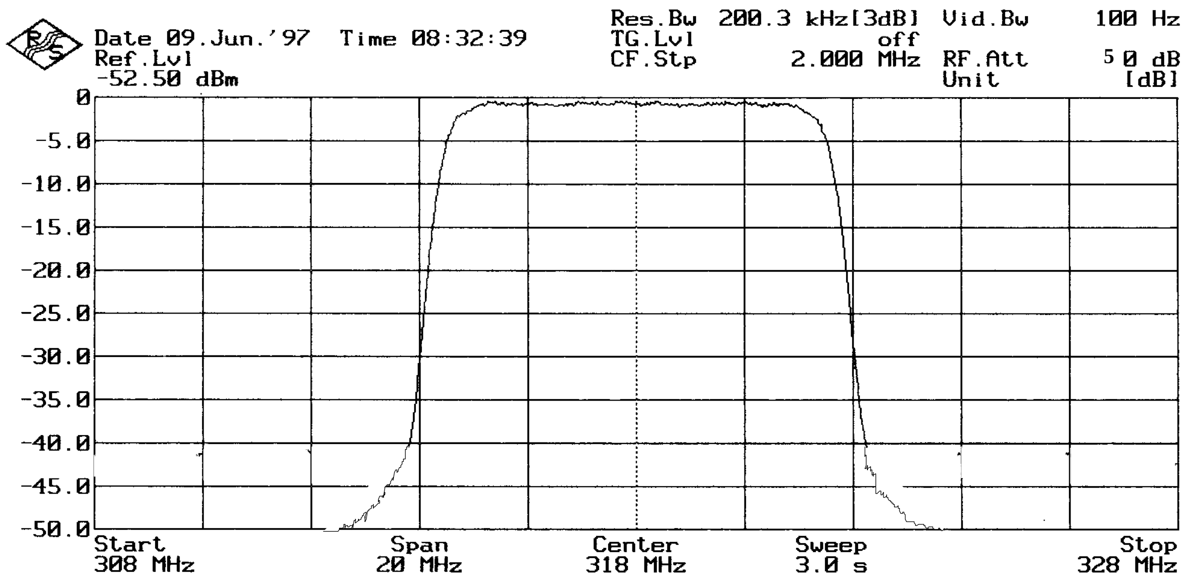
7MGAN15E

RF Level Measurement Accuracy of TV Test Receivers

One of the most important parameters for determining the transmission quality in an RF channel is the receive level. In analog TV, the peak level of the sync base line is measured for this purpose. As a precondition, the resolution bandwidth must be sufficiently wide to allow all filters to settle during the 4.7-µs base line period. The resolution bandwidth should be at least 1 MHz. The power distribution in the transmission channel is of no importance here. In any case, there will be maximum and constant power in the region of the sync base line. Nominal amplitudes are as follows:

300 mV, sync amplitude
700 mV, white amplitude
1124 mV, $CCVS_0$ amplitude
(corresponding to residual carrier of 11%).

This is different in the case of QAM or QPSK modulation. Due to energy dispersal in the digital modulator, constant power density is obtained throughout the channel width. Consequently, the average channel power is to be measured. The plot below shows a typical power distribution in a 8-MHz cable channel:



Power distribution in an 8-MHz channel with 64QAM modulation

If this broadband measurement is performed with a normal spectrum analyzer, a considerable amount of extra calculation has to be done if a maximum bandwidth of 1 to 3 MHz is involved. If the amplitude frequency response in the transmission band is flat, the average channel power can be determined by way of a simple conversion with only one measurement. The average power P_m is:

$P_m = P_{RB} + 10 \log_{10} (NB/RB)$ dBm
where
P_{RB} is the power measured at the resolution bandwidth,
NB is the Nyquist bandwidth and
RB is the resolution bandwidth.

If the measurement is made with the NOISE marker, which indicates power density in

dBm/Hz, the resolution bandwidth is 1 Hz. The Nyquist bandwidth must be specified accordingly in Hz.
As set out above, this applies only if the amplitude frequency response in the channel is flat. The two methods described do not however satisfy the accuracy requirements for measurements of this kind.
Another method of determining the power in a channel is by measuring the power between two selectable frequencies. The big advantage of this method is that the amplitude frequency response between the two frequencies is irrelevant. The spectrum analyzer used for the measurement determines the level characteristic over the selected frequency range, eg across a 64QAM-modulated 8-MHz channel. Since new analyzers perform all measurements digitally, power measurement is actually effected by calculating the partial power for each frequency step and integrating the results. This method yields very accurate results, provided the frequency steps are small enough, ie the spectral resolution in the channel is high enough. Absolute accuracy is less than 0.5 dB lower than the absolute accuracy of the analyzer. An example of this is Spectrum Analyzer FSE from Rohde & Schwarz, whose overall tolerance for this type of measurement is only 1.5 dB in the range $f < 1$ GHz.

Level measurement with TV Test Receiver EFA Model 20

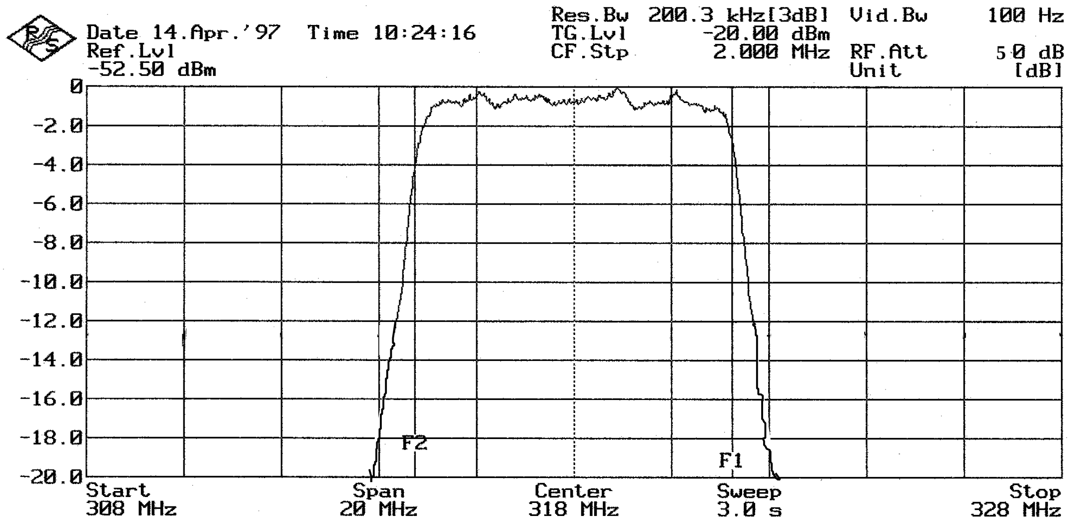
TV Test Receiver EFA uses a simple but highly accurate method for channel power measurement. This method however presupposes that the crest factor remains constant while the amplitude frequency response varies. The crest factor is the ratio of peak voltage to rms voltage of a signal. If it can be assumed that the symbol frequency with n QAM modulation (n = 4, 16, 32, 64, 128, 256) is evenly distributed across the frequency range under test, the crest factor will be different for the different orders of QAM but will be constant. The time interval for evaluating the crest factor must be long enough to have a sufficient number of symbols for evaluation. EFA performs level measurements at intervals of approx. 1 s so that the above assumption is valid.
The correctness of the above assertion is substantiated by the explanations given in the following and the subsequent series of tests.

The ready-to-send transport stream TS from the output of the TS multiplexer is applied to the input of a QAM/QPSK modulator. After the input module of the QAM/QPSK modulator, the signal passes a section that is important in this context: energy dispersal with the associated sync word inversion. Energy dispersal uses the polynomial $x^{15} + x^{14} + 1$ and generates from the input data a PRBS-like sequence. It is thus ensured that symbol frequency is evenly distributed and amplitude distribution is constant across the channel width depending on the order of QAM. From this it follows that the crest factor is constant, also depending the order of QAM, even with amplitude frequency response of whatever kind.
The average power of the QAM channel can therefore be determined with high accuracy by measuring the peak voltage of the QAM-modulated signal by means of a rectifier specially developed for this task. The crest factors for the different orders of QAM must of course be taken into account. QAM Demodulator EFA operates exactly in this way. To underline the above theoretical considerations, the subsequent test series was performed where the average channel power was determined with a precision Power Meter NRV from R&S as well as with EFA. Amplitude frequency response was simulated through echoes of different delay and level.

1. Echoes with 1000 ns and 50 dB Attenuation

Level measured with	NRV	EFA
	-35.08 dBm	-35.2 dBm

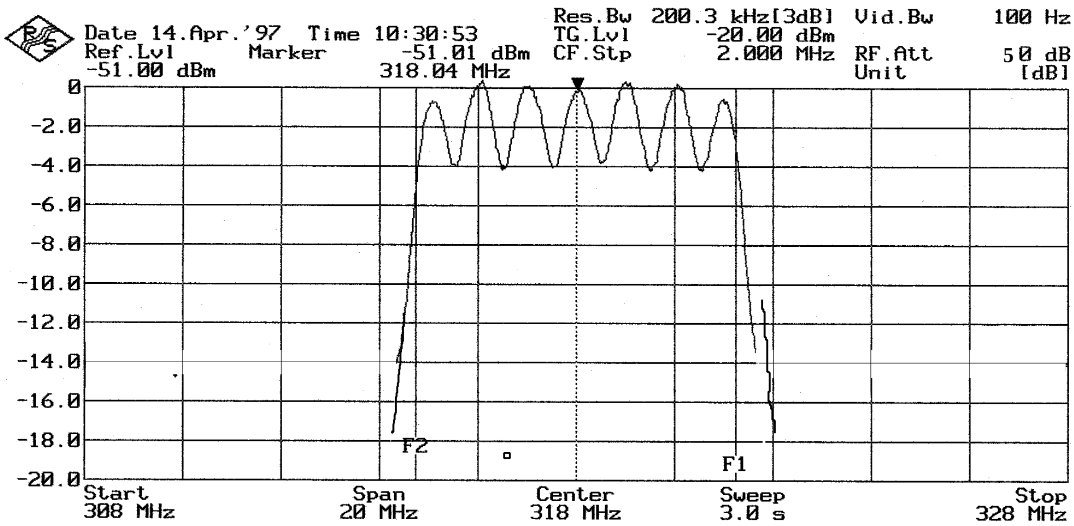
Associated amplitude frequency response



2. Echoes with 1000 ns and 10 dB Attenuation

Level measured with	NRV	EFA
	-34.58 dBm	-34.5 dBm

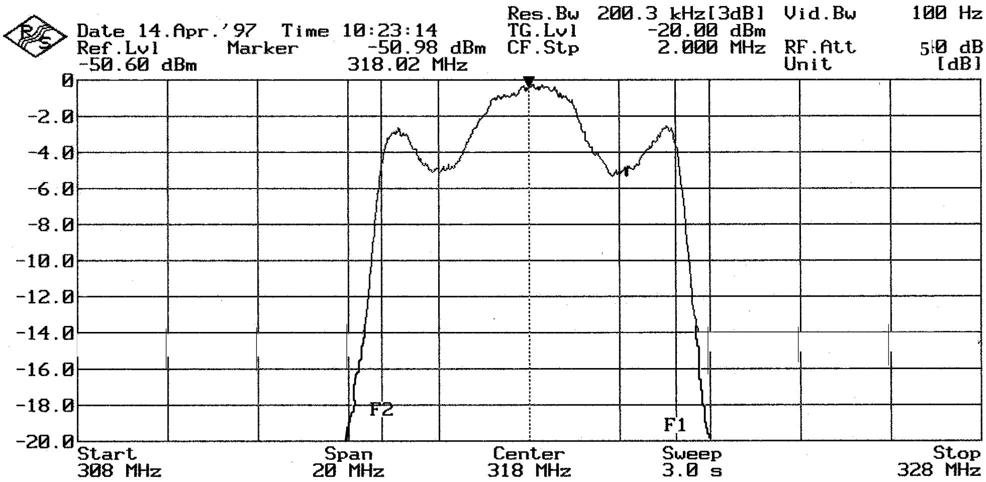
Associated amplitude frequency response



3. Echoes with 250 ns and 10 dB Attenuation

Level measured with	NRV	EFA
	-35.13 dBm	-35.0 dBm

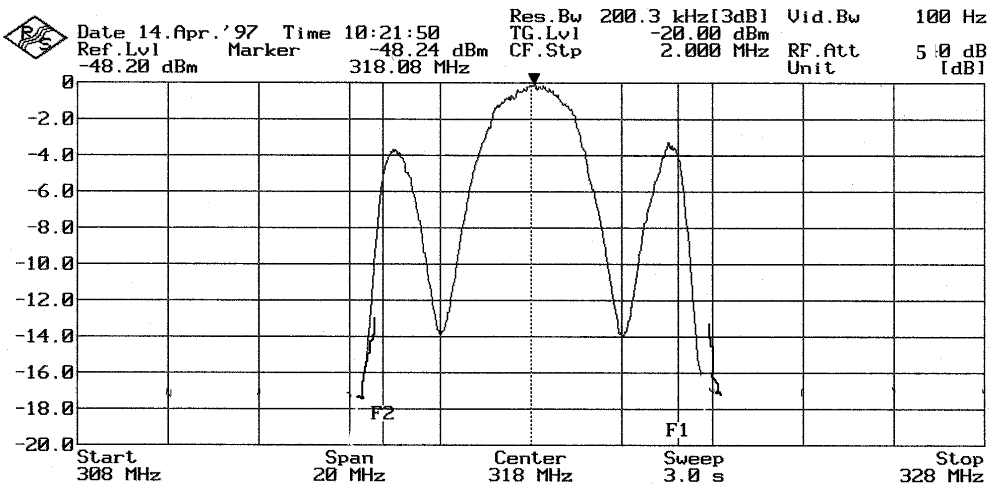
Associated amplitude frequency response



4. Echoes with 250 ns and 2 dB Attenuation

Level measured with	NRV	EFA
	-33.79 dBm	-33.0 dBm

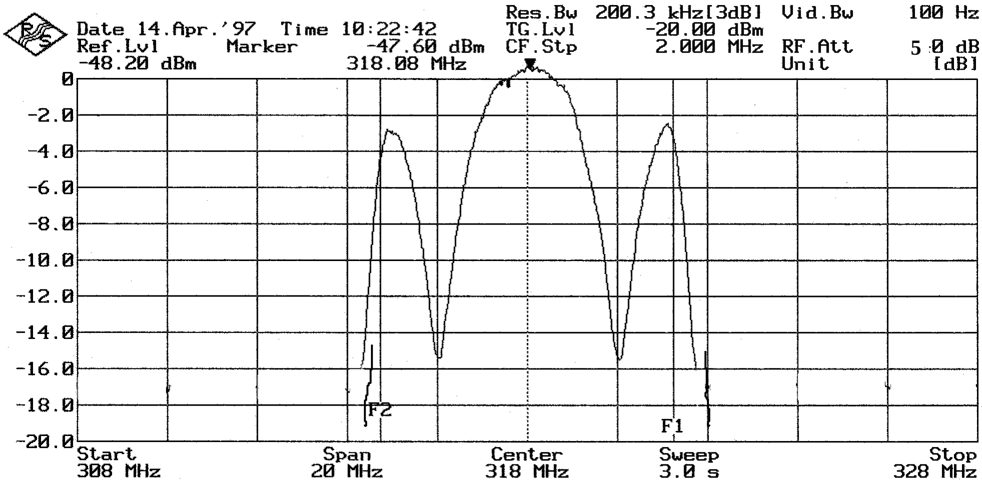
Associated amplitude frequency response



5. Echoes with 250 ns and 0 dB Attenuation

Level measured with	NRV	EFA
	-32.93 dBm	-32.0 dBm

Associated amplitude frequency response



The above diagrams show that the results obtained with NRV and EFA virtually coincide. This demonstrates the high precision of power measurements made with EFA in a QAM-modulated channel also under critical conditions.

Annex 4C

BROADCASTING DIVISION

Application Note

Bit Error Ratio BER in DVB as a Function of S/N

Products:

TV Test Transmitter	*SFQ*
Spectrum Analyzer	*FSE*

7BM03_2E

Contents

We would like to express our thanks to PHILIPS/Eindhoven for the support given us in the preparation of this Application Note.

1 Bit Error Ratio BER in DVB as a Function of S/N respectively C/N

At what C/N ratio does a set top box still operate properly? What system margin is available in the reception of DVB-C or DVB-S signals? How can the bit error ratio as a function of these parameters be determined exactly?
These questions have top priority in the development and production of equipment with DVB capability. In many cases, there is a defined BER margin for DVB equipment or chip sets, and the task is to find out to the limit up to which signal quality may deteriorate with the DVB system still operating properly. Different values are to be expected for DVB-S with QPSK modulation on the one hand and QAM on the other hand, because satellite transmission (QPSK) uses double forward error correction (FEC), ie Viterbi and Reed Solomon (RS), whereas for QAM simple error correction (RS) is used only. Determining the bit error ratio is, therefore, one of the most important measurements in DVB (Digital Video Broadcasting) on cable and satellite links. The difficulty is to generate an exactly defined BER.
One approach is to introduce, in FEC according to Reed Solomon, a known number of bit errors directly after the calculated error protection for the error-free MPEG2 transport stream (TS). If this approach is taken, it must be ensured that no further bit errors occur on the transmission path (modulation, frequency conversion, demodulation), caused by noise in the transmission channel or modulation errors in the data stream. This condition cannot however be met in practice: Each unit of a digital TV transmission chain has inherent errors. These errors are explicitly defined by the standard as ”implementation loss” (IL) or ”equivalent noise degradation” (END). The additional degradation of signal quality from transmission block to transmission block may be up to 0.8 dB per unit referred to the C/N of the DVB signal as defined by Standard ETR 290.

Each unit of a digital TV transmission chain has inherent errors. These errors are explicitly defined by the standard as ”implementation loss” (IL) or ”equivalent noise degradation” (END). The additional degradation of signal quality from transmission block to transmission block may be up to 0.8 dB per unit referred to the C/N of the DVB signal as defined by Standard ETR 290.

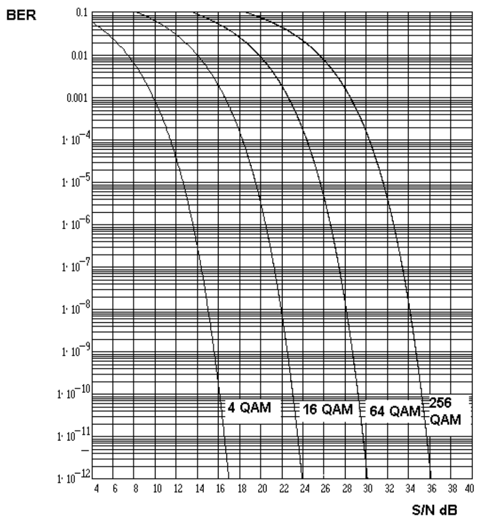


Fig. 1 BER as a function of S/N

For this reason, this application note describes a second, viable approach to generating a defined BER, taking into account S /N deterioration:
White noise of a defined power is superimposed on the DVB signal. From the noise and the modulated DVB signal, the S/N respectively the C/N ratio in dB (with consideration of the "roll off" factor) can be calculated. After conversion, the corresponding BER is obtained for each S/N value.
But there are some constraints using this method. Figure 1 shows the theoretically based restrictions as they occur with QAM transmission:

At BER values of about 10^{-4} to 10^{-6} - the real range of interest - the graphs for each QAM mode are very steep. This is also shown in figure 2 "BER in the range of 10^{-4} to 10^{-6} as a function of S/N" which is a zoomed part of figure 1.

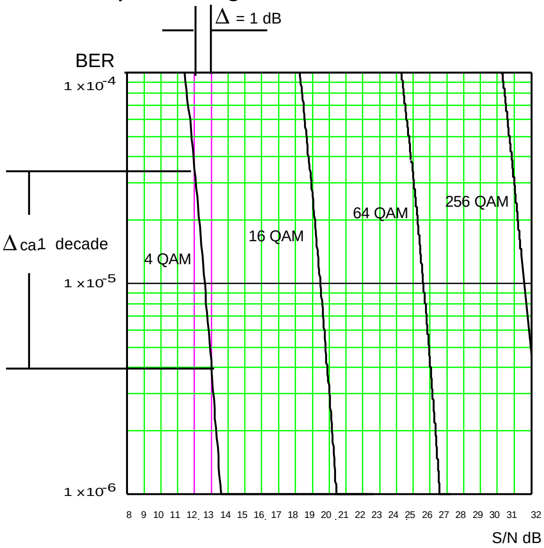


Fig. 2
BER in the range of 10^{-4} to 10^{-6} as a function of S/N in QAM

Changing the S/N value by 1 dB the BER alters about one decade. A precise noise source should have an accuracy of about 0.5 dB and as the diagram shows in this case the variation of the BER is again at least half a decade. This is too much in the QAM mode.

Regarding the QPSK modulation where two FECs in series correct occuring errors the situation is worse. The first FEC - the Viterbi correction - generates a much steeper slope in the diagram BER vs S/N depending on the Code Rate. This shows the figure 3, which presents the theoretical values for BER vs S/N for the coded signals referenced to the uncoded 4 QAM signal.

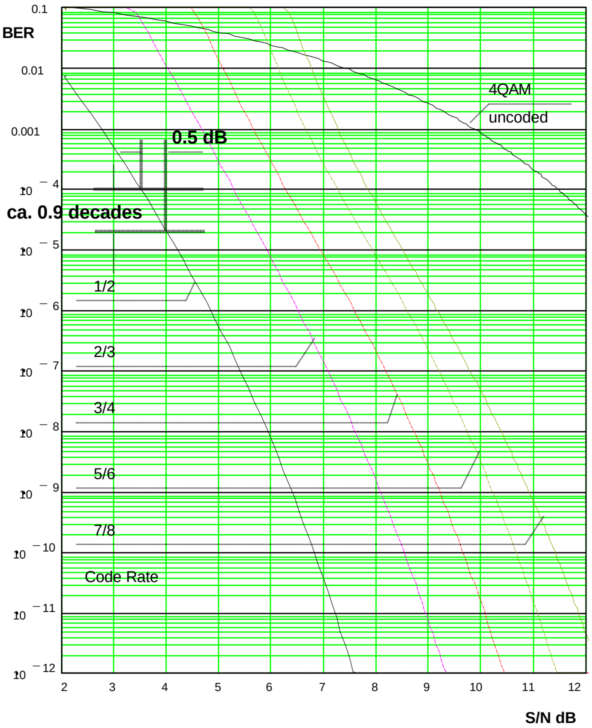


Fig. 3
BER as a function of S/N in QPSK Modulation with Viterbi correction for normally used Code Rates

It is obvious that the sensitivity of BER is nearly twice as in QAM. Changing the S/N value by only 0.5 dB the BER alters again about nearly one decade depending on the code rate.

As determining the Signal to Noise Ratio S/N for a predefined Bit Error Ratio BER = 2x 10^{-4} for a device under test is one of the most important measurements (the value BER = 2x 10^{-4} before Reed Solomon corresponds to the point where the FEC Reed Solomon is able to correct errors to the Quasi Error Free QEF datastream) the S/N value must be generated in highest precision. All deviation to the precise S/N value will cause either a too high Insertion Loss IL for the system to be tested or also indicate negative ILs. The accuracy 0.5 dB is therefore not high enough. To avoid false interpretations the S/N value corresponding to a given BER should be at least within the tolerance of 0.1 dB.
So far the theory.

The solution of Rohde&Schwarz

The TV Test Transmitter SFQ with the Noise Generator option supplies QAM or QPSK modulated TV signals with selectable C/N values dB. The generator furnishes analog noise signals and therefore does not produce a spectrum of discrete (although disper-sed) lines as obtained with digital noise generators. Moreover, the superimposed noise referred to the symbol rate has to be determined for a defined C/N ratio in dB. As the symbol rate in Hertz and the signal bandwidth coincide according to the modulation formula, the symbol rate is the only objective reference for the noise bandwidth and therefore recommended by Standard ETR 290.

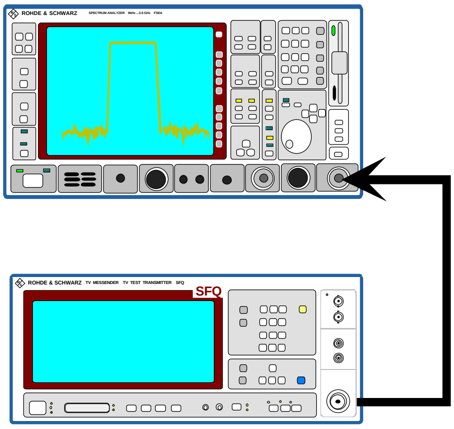


Fig. 4 Block diagram of SFQ and FSE

nherent noise of the measuring equip-ment has to be taken into account of course. The signal spectrum generated by TV Test Transmitter SFQ without superimposed noise has a C/N ratio of > 40 dB, so SFQ makes nearly no contribution to the superimposed noise in the range of interest < 35 dB (see Figure 1).
With 256QAM signals, a S/N value of 36 dB corresponds to a BER of $1*10^{-11}$, which is the value for the ”quasi error-free” (QEF) data stream. Here too the effect of SFQ can be neglected.
The equation $C/N = S/N + k_{roll\ off}$ dB (see page 64) defines the the corresponding C/N and S/N values. As the SFQ defines the C/N ratio there is the need to measure this value. The question is what measuring equipment is needed for accurate determination of the C/N value?
Because of the high accuracy of R&S equipment, only two instruments are required for this purpose: TV Test Transmitter SFQ and Spectrum Analyzer FSE are all that is needed to measure the C/N ratio with highest precision.
As a useful signal, a PRBS (pseudo-random binary sequence) signal of SFQ with 64 quadrature amplitude modulation (64QAM as example) is used. Alternatively, a ”live” signal can be fed in at one of the TS (transport stream) inputs - ASI or SPI – of SFQ and the output spectrum is displayed at the Spectrum Analyser FSEx.

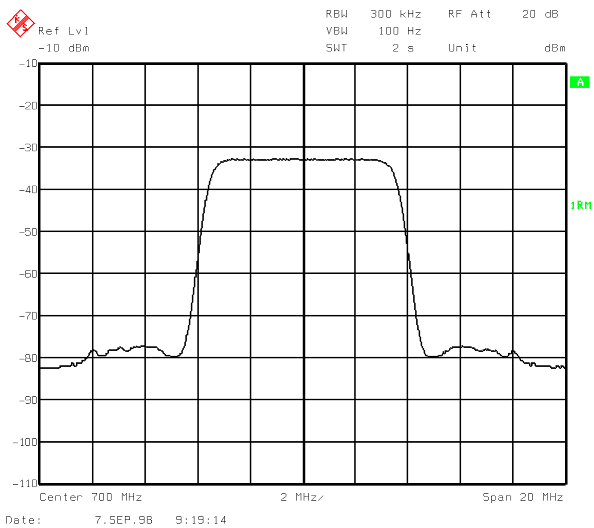


Fig. 5 PRBS spectrum

The spectrum of the PRBS at an RF power of P_{useful} = -33 dBm of SFQ, for example, is displayed on Spectrum Analyzer FSE with the following settings:

DETECTOR RND
RANGE 10 dB (1 dB/div)
SPAN 20 MHz
(for DVB-C with 8 MHz channel)
SPAN 50 MHz
(for DVB-S with 33 MHz transponder bandwidth)
RES. BANDWIDTH 300 kHz
VIDEO BANDWIDTH 2 kHz

After quadrature amplitude modulation, the PRB sequence has an optimally flat spectral distribution in the transmission channel. The displayed power, with the noise generator switched off, can therefore be marked very accurately by means of a display line (DL).

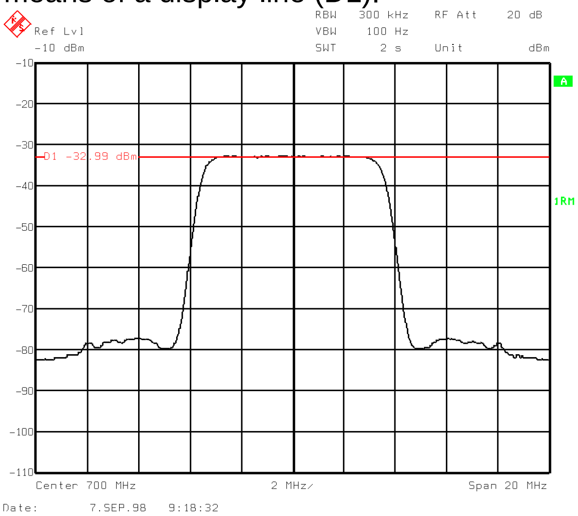


Fig. 6a PRBS spectrum: level marked with display line, 10 dB/div

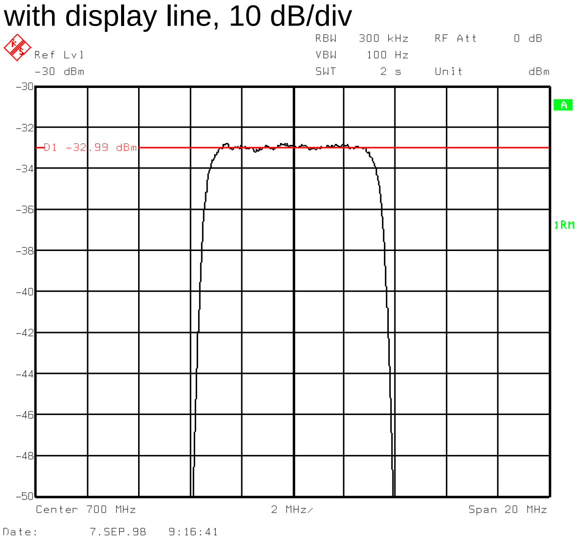


Fig. 6b PRBS sectrum: level marked with display line, 1 dB/div

After switchover to I/Q EXTERN in the MODULATION menu of the SFQ, the PRBS signal is switched off. The I/Q inputs should be terminated with 75 Ω. Now the noise generator is to be switched to the SFQ output by NOISE ON.

The power of the noise generator is

$P_{noise} = P_{useful}$ - 26 dB for C/N = 26 dB (example) rreferred to the signal bandwidth.

The noise is marked on the display of FSE by means of a line 26 dB below the useful signal line (see Fig. 5).

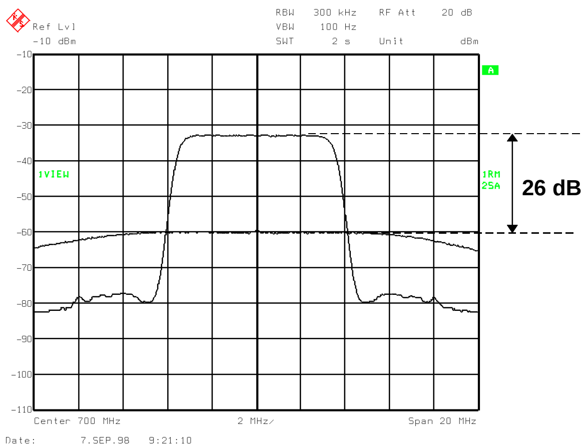


Fig. 7 PRBS useful signal and noise spectra with 10 dB/div

Now, is the noise exactly 26 dB below the useful signal?
This can be verified by changing the setting of the internal SFQ attenuator for RF level setting by 26 dB.

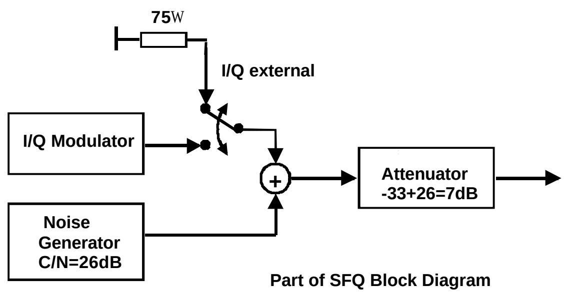


Fig. 8 Useful signal and noise paths in SFQ

The two display lines for the useful signal and noise should now coincide because both signals are routed via the internal attenuator. If there is no coincidence, the difference between the useful signal and the noise signal can be read from the two lines.

The display lines should be placed on the respective channel spectra as accurately as possible. While this is a subjective setting, it may still be assumed to be correct with an absolute accuracy of < 0.05 dB since it is a ratio measurement which is performed with the aid of the display lines.

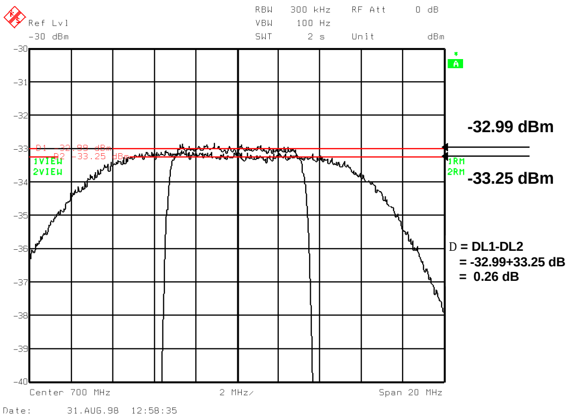


Fig. 9 Measurement of deviation from selected C/N value

The absolute overall accuracy of this measurement is, therefore, determined only by the accuracy of the SFQ attenuator. Any overload effects caused by the noise crest factor or similar factors are excluded through the use of the high-precision FSE as a spectrum analyzer.

And what about the accuracy of the SFQ attenuator?

The attenuator error has been shown to be < 0.01 dB in acceptance testing. This value is recorded and available together with the SFQ calibration report.

Level	Data sheet tolerance	Internal tolerance	Error
....	....	....	....
16 dB	≤0.50 dB	≤0.35 dB	-0.08 dB
17 dB	≤0.50 dB	≤0.35 dB	0.00 dB
18 dB	≤0.50 dB	≤0.35 dB	0.01 dB
19 dB	≤0.50 dB	≤0.35 dB	-0.01 dB
20 dB	≤0.50 dB	≤0.35 dB	-0.05 dB
....	....	....	....

Table 1 Extract from attenuator test report

If the minimum residual attenuator error plus the previously determined ENDs of the individual units are taken into account in setting the C/N for a defined BER, the total C/N value can be determined with an absolute accuracy of < 0.1 dB by means of the described method.
This accuracy fully meets the requirements for BER measurements even in the range 1*10-6 to 1*10-8 .

Tip:
Checking the exact C/N value at the output of SFQ in accordance with the above description is in itself a simple procedure. The easy calculation to arrive at the S/N value S/N = C/N - $k_{\text{roll off}}$ dB should not influence this proposal. However, the accuracy of the S/N value also at different symbolrates should be checked prior to every precision BER measurement.

Diagram for QAM

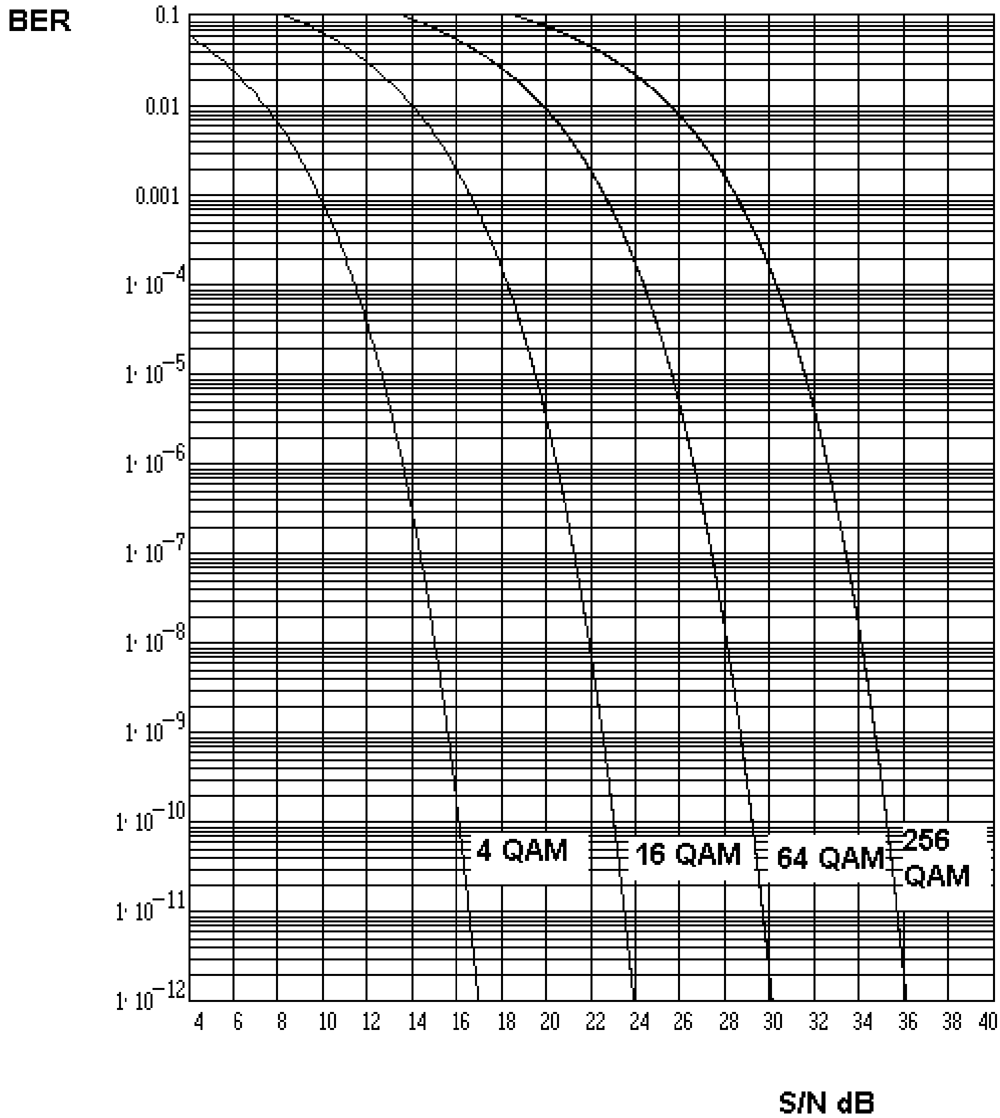


Fig. 10 BER as a function of S/N

Diagram for QPSK Modulation

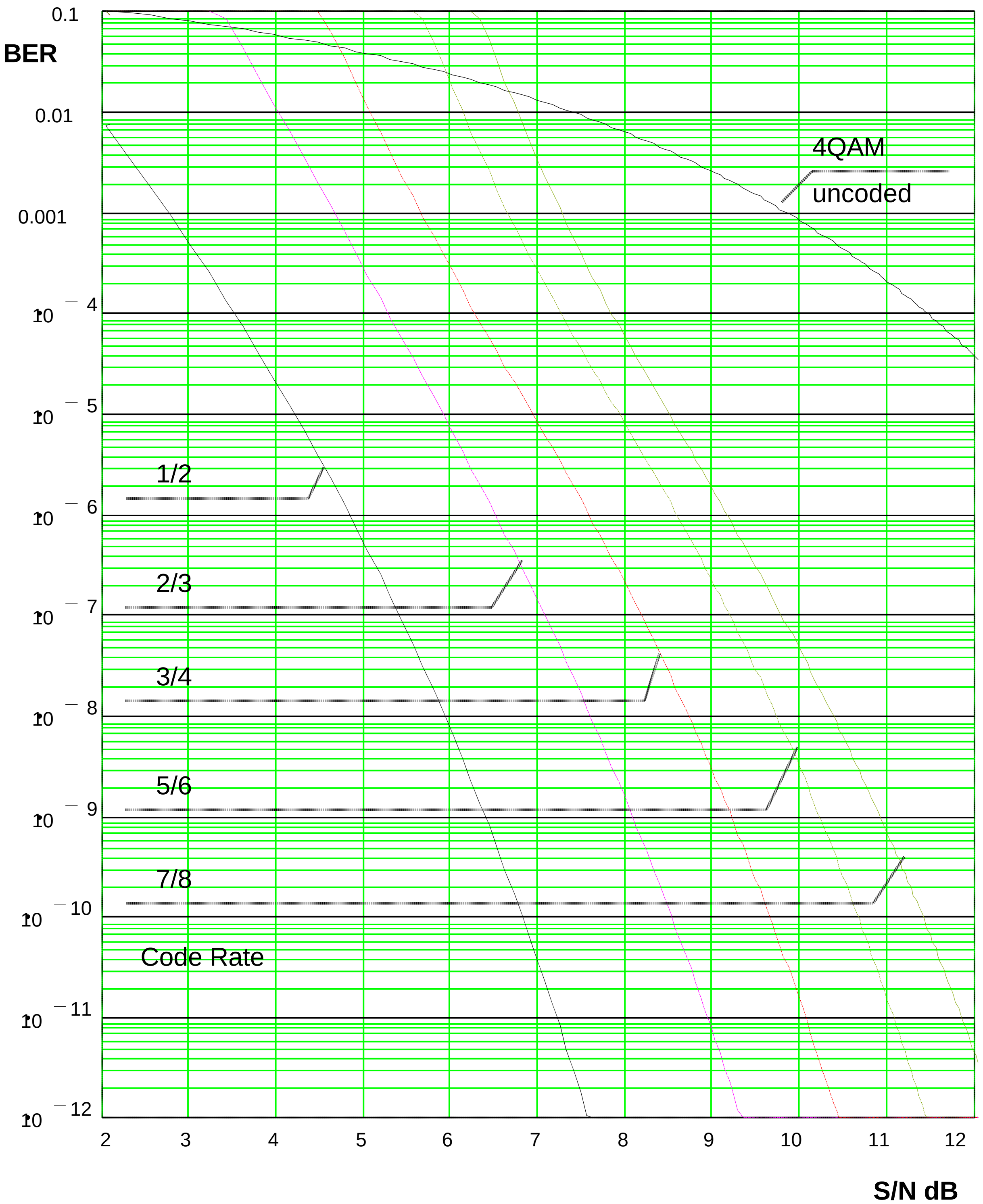


Fig. 11 BER as a function of S/N

2 Conversion of S/N (C/N) to E_b/N_0

Often, BER diagrams do not have S/N as abscissa but E_b/N_0, which is the energy per useful information bit E_b referred to the normalized noise power N_0. In converting the two quantities one to the other, some factors have to be taken into account as shown by the following equations:

$$C/N = E_b/N_0 + k_{FEC} + k_{QPSK/QAM} + k_P \quad \text{dB} \quad \text{or}$$

$$E_b/N_0 = C/N - k_{FEC} - k_{QPSK/QAM} - k_P \quad \text{dB} \quad \text{or}$$

$$E_b/N_0 = S/N + k_{\text{roll off}} - k_{FEC} - k_{QPSK/QAM} - k_P \quad \text{dB}$$

where: $C/N = S/N + k_{\text{roll off}}$ dB

To determine S/N dB respectively C/N dB, the logarithmic ratio E_b/N_0 is to be corrected by the following factors (this applies to the determination of E_b/N_0 vice versa):

$k_{FEC} = 10 * \lg \frac{188}{204}$ ie the factor for FEC to Reed Solomon

$\boxed{k_{FEC} = -0.3547 \text{ dB}}$

$k_{QPSK/QAM} = 10 * \lg(m)$ ie the factor for the QPSK/QAM modes

Mode	m	$k_{QPSK/QAM}$ dB
QPSK	2	3.0103
16 QAM	4	6.0206
64 QAM	6	7.7815
256 QAM	8	9.0309

$k_P = 10 * \lg(P)$ ie the factor for the puncturing rate (P=1 for QAM)

Mode	P	k_P dB
QPSK	½	-3.0103
	2/3	-1.7609
	¾	-1.2494
	5/6	-0.7918
	7/8	-0.5799
QAM	1	0

$k_{roll\,off} = 10 * \lg(1 - \frac{a}{4})$ ie the factor for the $\sqrt{\cos}$ roll-off filtering in the demodulator/receiver

Mode	α	$k_{\text{roll off}}$ dB
DVB-C	0.15	-0.1660
DVB-S	0.35 (nominal)	-0.3977
	0.27 (actual in transmitter)	-0.3035

The question of what correction factors are needed depends on whether

- E_b is to be treated as a pure information bit

and on whether measurement is made

- in the transmission channel,
- before or after Viterbi or Reed Solomon correction,
- with QAM or QPSK modulation.

Following are a few examples of conversion equations:

The following applies to *in-channel measurements* with QAM modulation:

$$E_b / N_0 = C / N - 10 * \lg \frac{188}{204} - 10 * \lg (m) \text{ dB}$$

The factors for

- $\sqrt{\cos}$ roll-off filtering and
- the puncturing rate (because only with QPSK necessary)

are not needed.

For measurements in the *QAM demodulator,* the $\sqrt{\cos}$ roll-off filtering has to be taken into account:

$$E_b / N_0 = S / N + 10 * \lg \left(1 - \frac{a}{4}\right) - 10 * \lg \frac{188}{204} - 10 * \lg (m) \text{ dB}$$

For measurements in the *satellite demodulator* with QPSK modulation (for determination of BER as a function of E_b/N_0 after Viterbi FEC), the equation is as follows:

$$E_b / N_0 = S / N + 10 * \lg \left(1 - \frac{a}{4}\right) - 10 * \lg \frac{188}{204} - 10 * \lg (m) - 10 * \lg (P) \text{ dB}$$

All correction factors are included in the equation

If a *pure PRBS* is used for BER measurements the RS FEC is not inserted and therefore the equation is as follows:

$$E_b / N_0 = S / N + 10 * \lg \left(1 - \frac{a}{4}\right) - 10 * \lg (m) - 10 * \lg (P) \text{ dB} \cdot$$

Diagram for QAM BER vs Eb/No

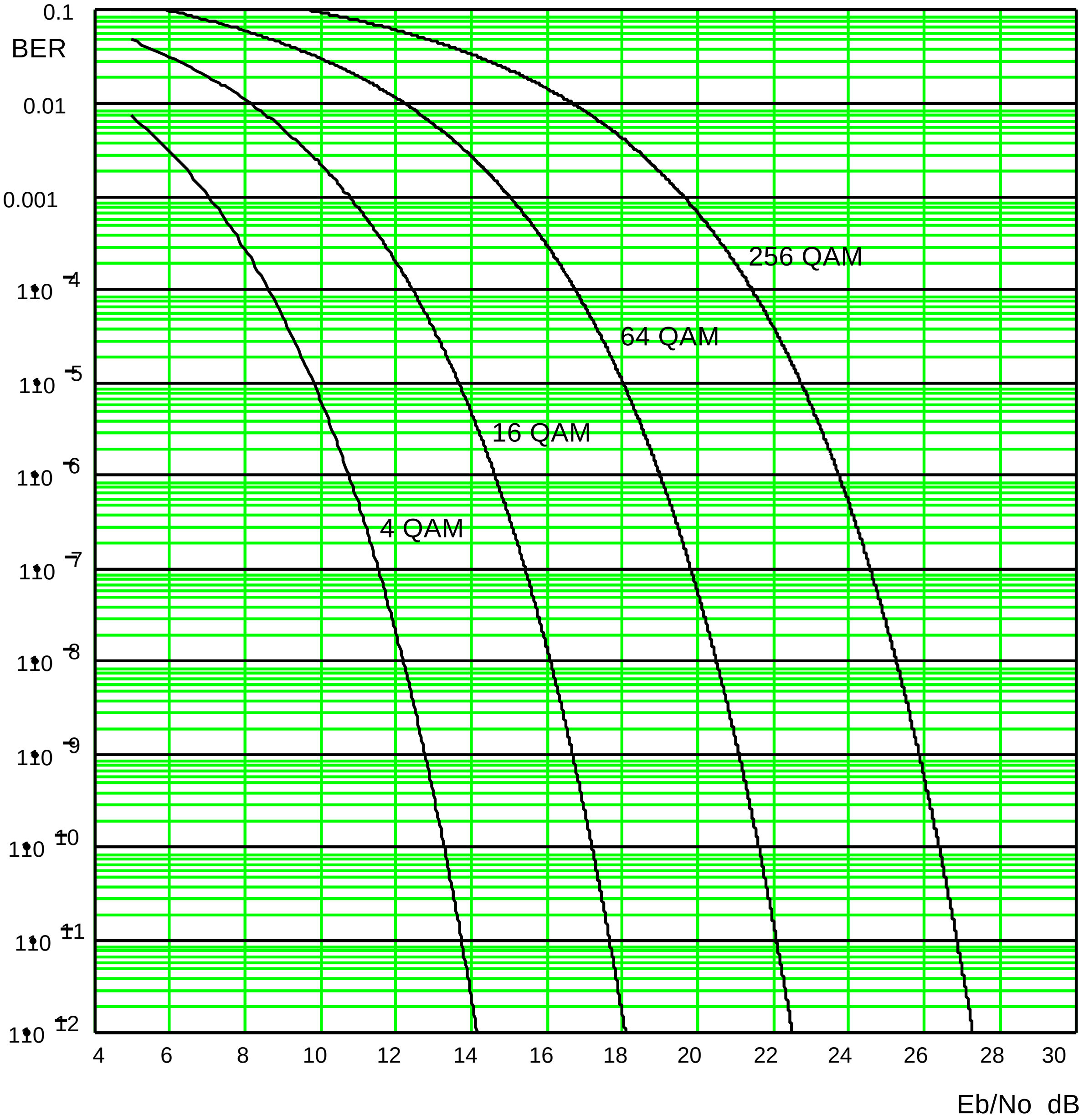


Fig. 12 BER as a function of Eb/No

Diagram for QPSK Modulation BER vs Eb/No

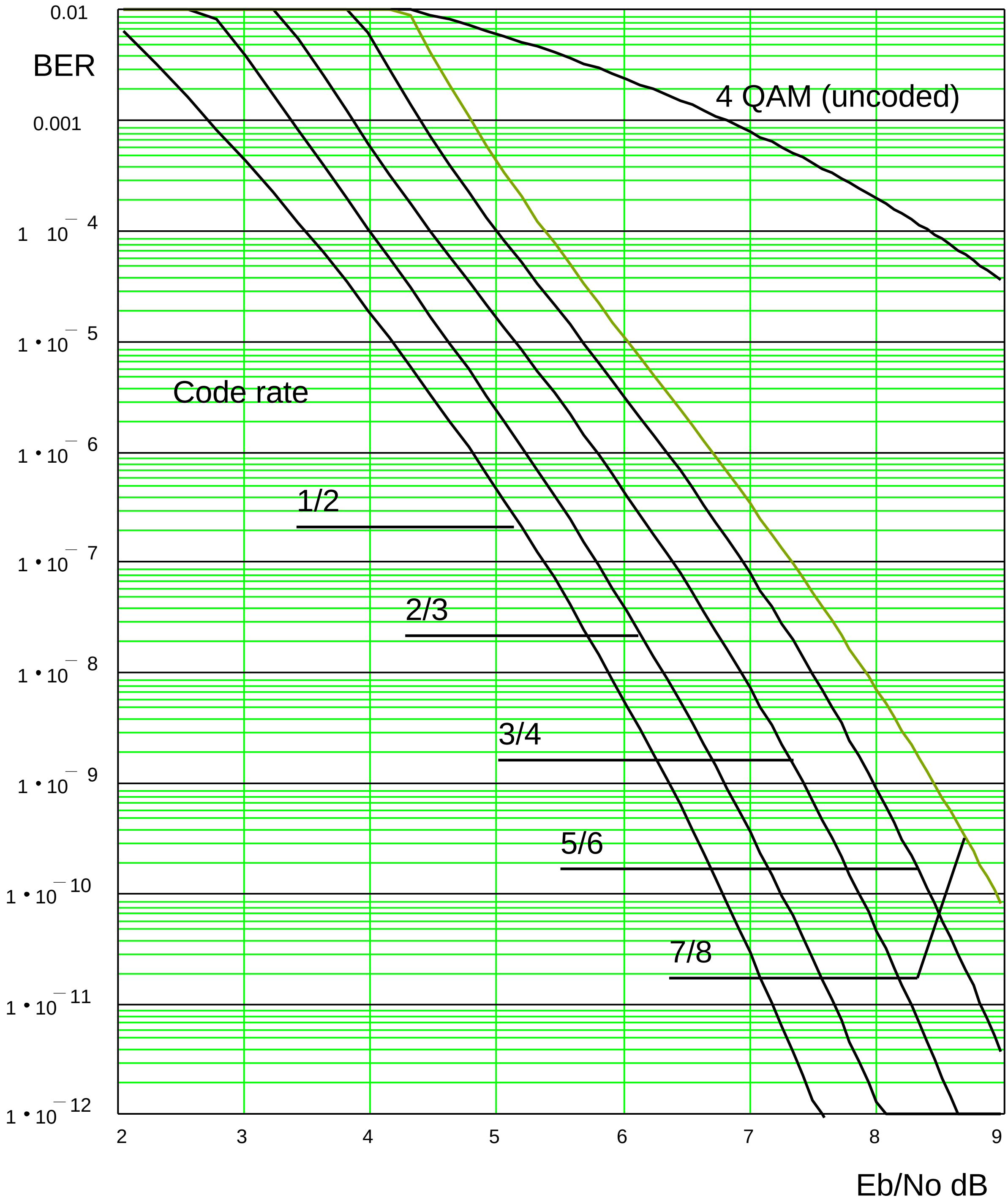


Fig. 13 BER as a function of Eb/No

ANNEX 1

Short form discription of SFQ and FSE settings for verifying a C/N of 6.8dB (as example):

First step:
Set the noise bandwidth.
This bandwidth corresponds always to the symbol rate and not to the bandwidth of the SAW filter of the STB. So using the normal symbol rate of a satellite system of 27.5 MSymbols/s the noise bandwidth set at the SFQ is 27.5 MHz.

Second step:
Set the SFQ to:

RF 200 MHz	Level x dBm.	In our case let's define x = - 26 dBm.
Modulation QPSK	Symbol Rate	27.5 MSymbols/s
Mode PRBS	Roll Off 0.25	
Noise Menue NOISE OFF		

Third step:
Set the spectrum analyzer FSE to:

Center Frequency 200 MHz	Span 50 MHz	Level Range 10 dB
Mode Low Distortion	VBW 30 Hz	RBW Coupled
Ref Level -26 dBm	Detector RMS	Sweep Time 1 s

Fourth step:
Set a display line exactly to the displayed channel power at FSE. The amplitude vs frequency response should of course be flat within the satellite channel. You should integrate the noise superposed to the displayed trace by your eye. The value of C (or better RF/IF power) is now marked at the FSE display.

Fifth step:
Set the SFQ to

RF 200 MHz	Level -26.0 + 6.8 ⇒ -19.2 dBm.		
Modulation I/Q EXTERNAL	and terminate the external I/Q inputs with 50Ω to avoid unwanted interference at these inputs. This means no RF is output!		
Symbol Rate 27.5 MSymbols/s			
Mode PRBS		Roll Off	0.35
Noise Menue NOISE ON	and select	C/N = 6.8 dB @ 27.5 MHz.	

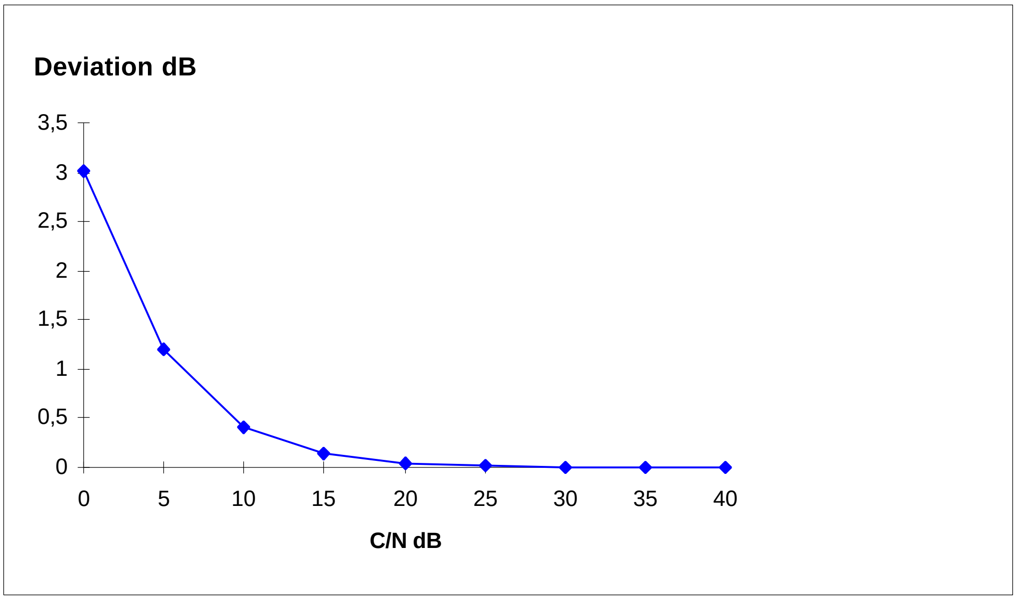
The now displayed NOISE FLOOR at the spectrum analyzer FSE should exactly meet the adjusted display line. If not so, the difference to the display line shows the deviation between the SFQ displayed value and the real generated C/N value. In order to calculate the corresponding S/N value correct the C/N value with -0.3977 dB.

Annex 2

Note: Transmitter Output Power

When determining the test transmitter output power, the effect of inherent or superimposed noise of the test transmitter must be taken into account very accurately because of the high sensitivity of the bit error ratio BER to even slight changes of C/N or E_b/N_0.
The table below shows the deviation of output power as a function of superimposed noise with the symbol rate in Hz as bandwidth.

Selected C/N in dB	Output power in dBm	Resulting power in dBm	Deviation in dB
0	-20	-16.990	+3.01
5	-20	-18.807	+1.193
10	-20	-19.586	+0.414
15	-20	-19.865	+0.135
20	-20	-19.957	+0.043
23	*-20*	*-19.978*	*+0.022*
25	-20	-19.986	+0.014
30	-20	-19.996	+0.004
35	-20	-19.999	+0.001
40	-20	-20.000	0



The above diagram shows that the effect of superimposed noise concerning the output power is negligible from a C/N value of >23 dB. For values <20 dB, BER measurement is error-prone already for 64 or 256QAM signals.