BROADCASTING DIVISION

Application Note

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

Products:

TV Test Transmitter	*SFQ*
Spectrum Analyser	*FSE*

7BM03_1E

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), i.e. 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.
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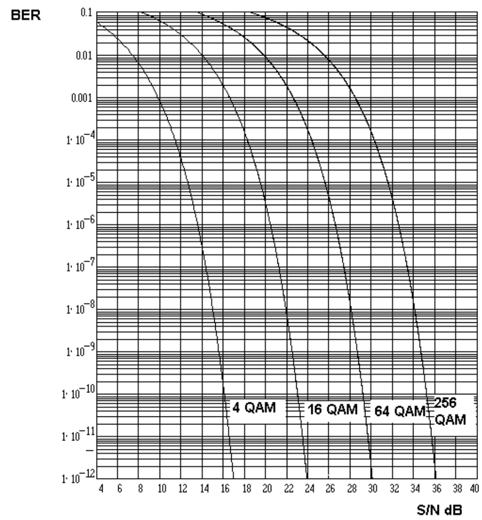

Fig. 1 BER as a function of S/N

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.

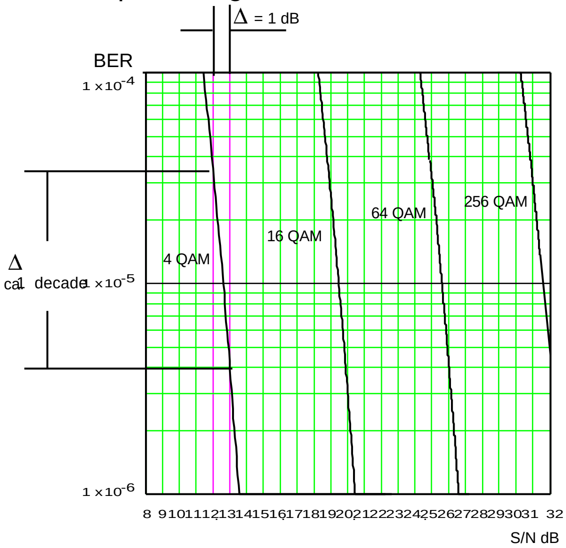

Fig. 2
BER in the range of 10^{-4} to 10^{-6} as a function of S/N in QAM

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 occurring 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.

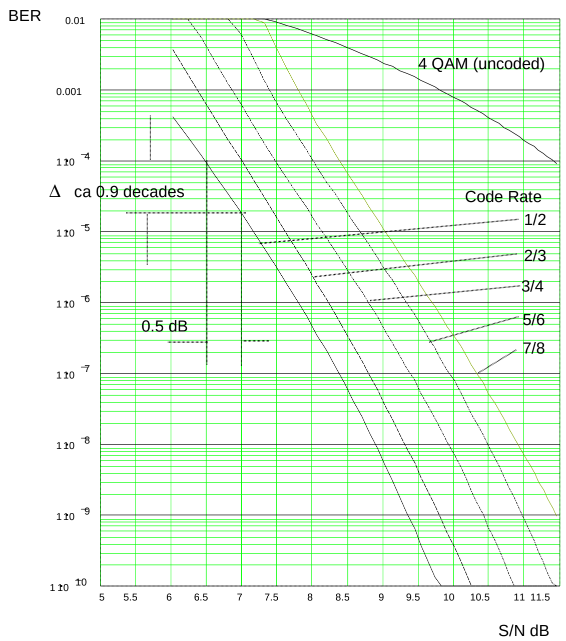

Fig. 3
BER as a function of S/N in QPSK Modulation with Viterbi correction for normally used Code Rates

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 data stream) 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.

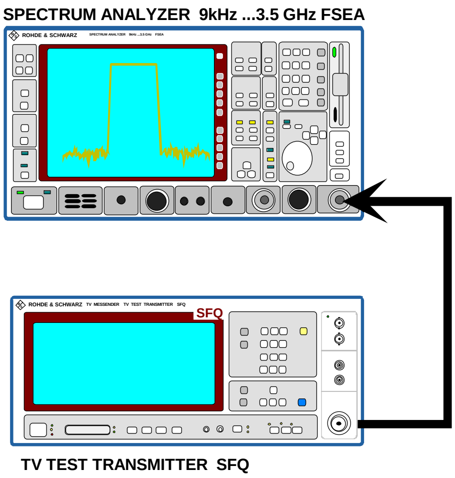

Fig. 4 Block diagram of SFQ and FSE

Inherent 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 9) defines 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 Analyser 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.

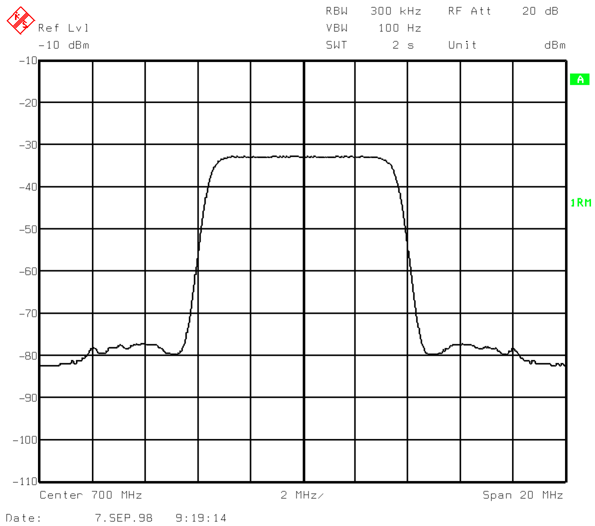

Fig. 5 PRBS spectrum

The spectrum of the PRBS at an RF power of P_{useful} = -33 dBm of SFQ, for example, is displayed on Spectrum Analyser 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).

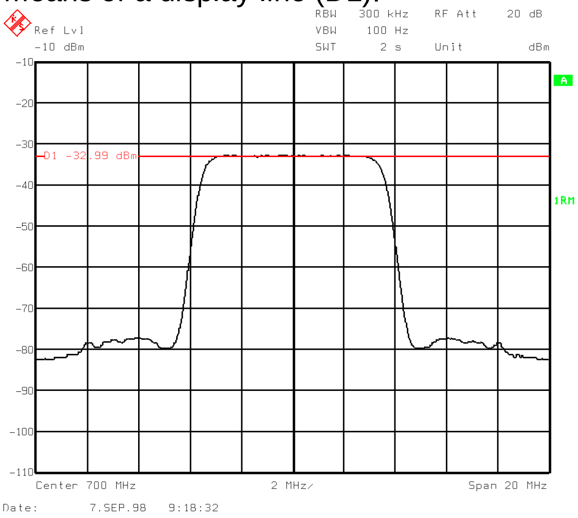

Fig. 6a PRBS spectrum: level marked with display line, 10 dB/div

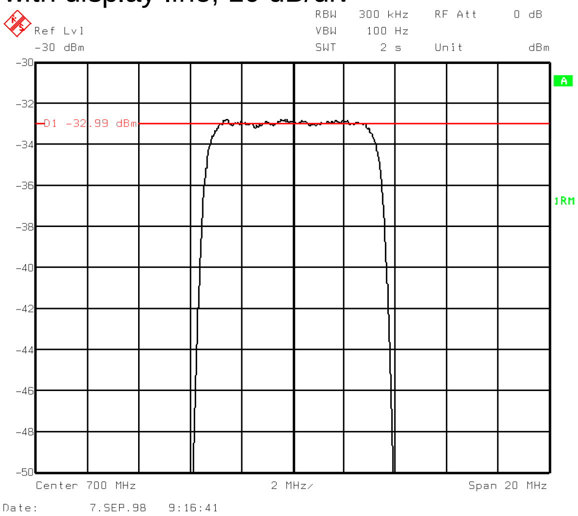

Fig. 6b PRBS spectrum: level marked with display line, 1 dB/div

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) referred 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.

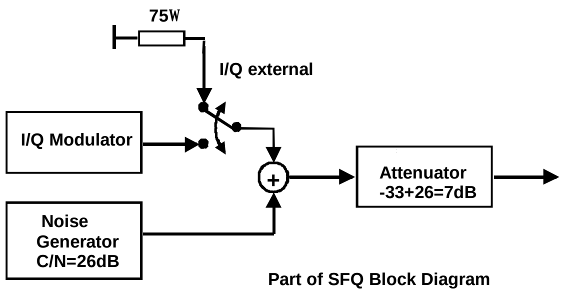

Fig. 8 Useful signal and noise paths in SFQ

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.

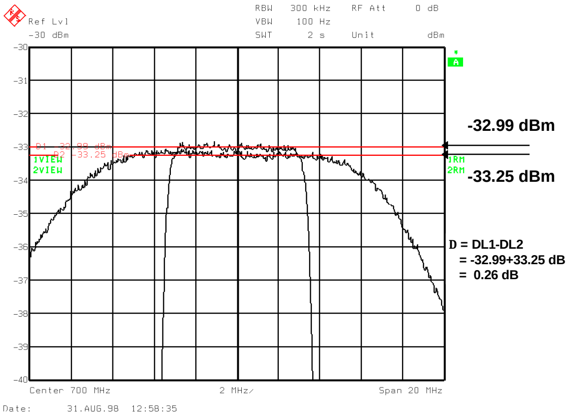

Fig. 9 Measurement of deviation from selected C/N value

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 analyser.

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 symbol rates should be checked prior to every precision BER measurement.

Diagram for QAM

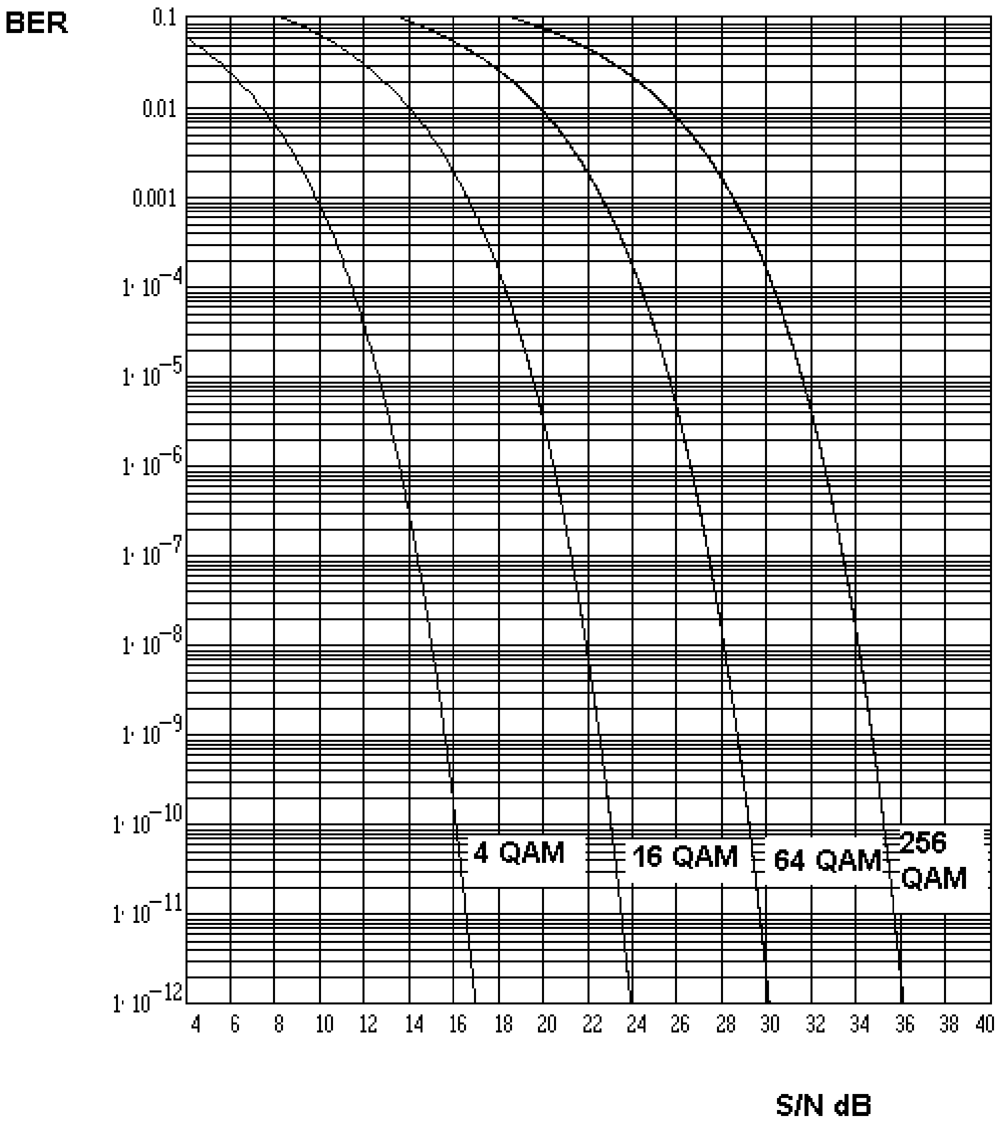

Fig. 10 BER as a function of S/N

Diagram for QPSK Modulation

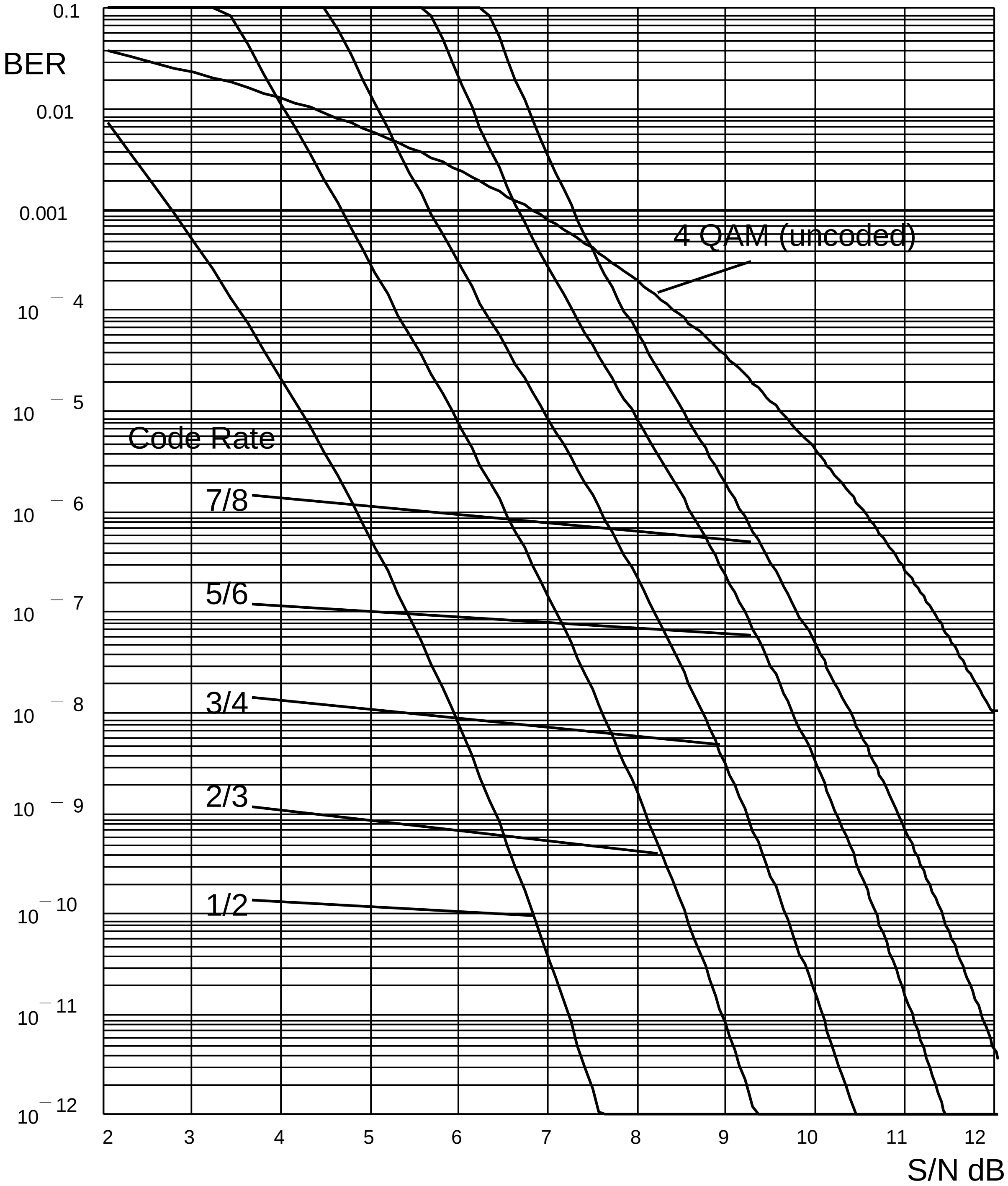

Fig. 11 BER as a function of S/N

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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 normalised 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):

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

$k_{FEC} = -0.3547$ dB

$k_{QPSK/QAM} = 10 * \lg(m)$ i.e. 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

$k_P = 10 * \lg(P)$ i.e. 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

$k_{roll\,off} = 10 * \lg(1 - \frac{a}{4})$ i.e. 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:

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

Diagram for QAM BER vs Eb/No

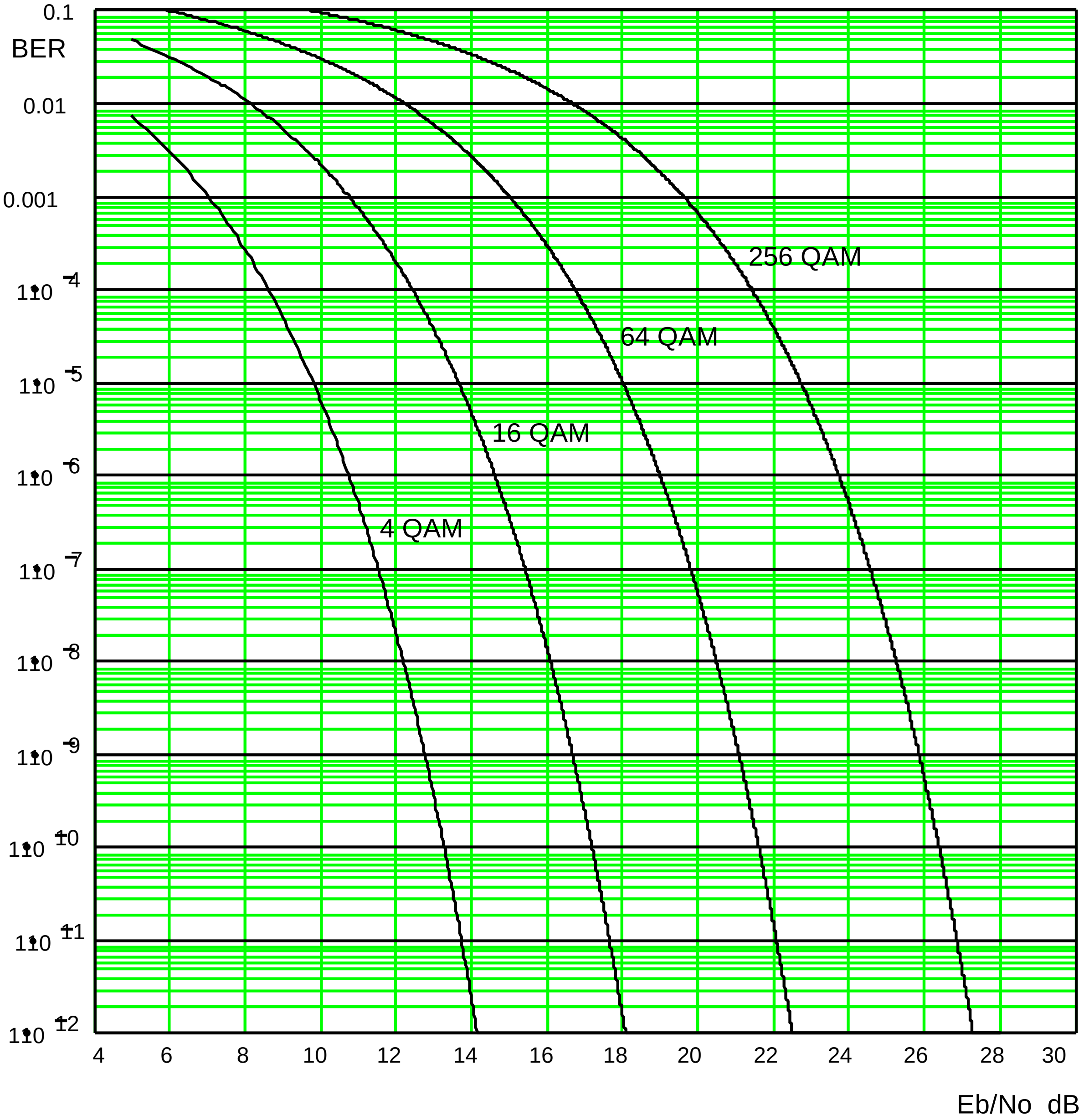


Fig. 12 BER as a function of Eb/No

Diagram for QPSK Modulation BER vs Eb/No

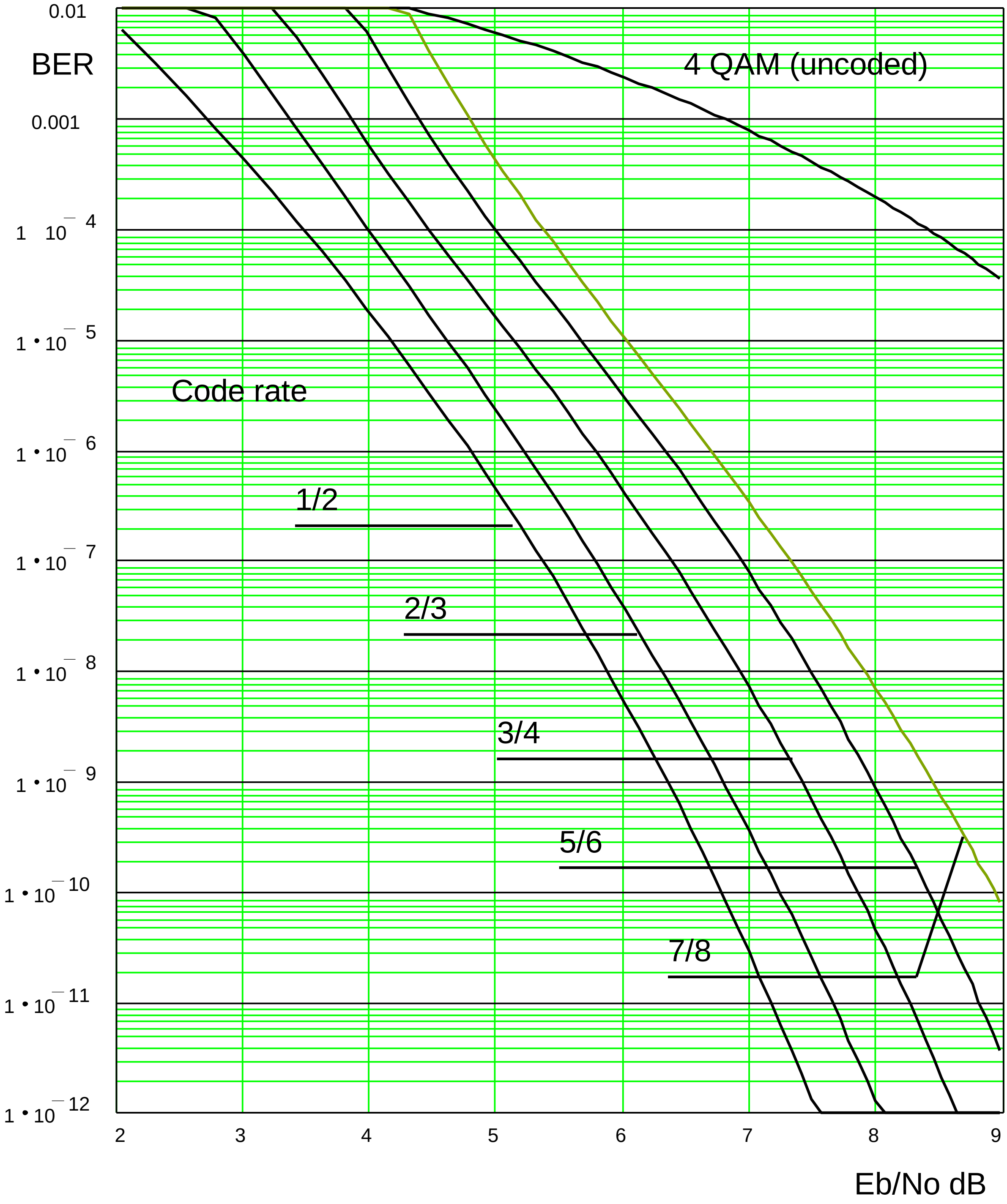


Fig. 13 BER as a function of Eb/No

ANNEX 1

Short form description 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 Menu NOISE OFF		

Third step:
Set the spectrum analyser 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 Menu NOISE ON	and select	C/N = 6.8 dB @ 27.5 MHz.	

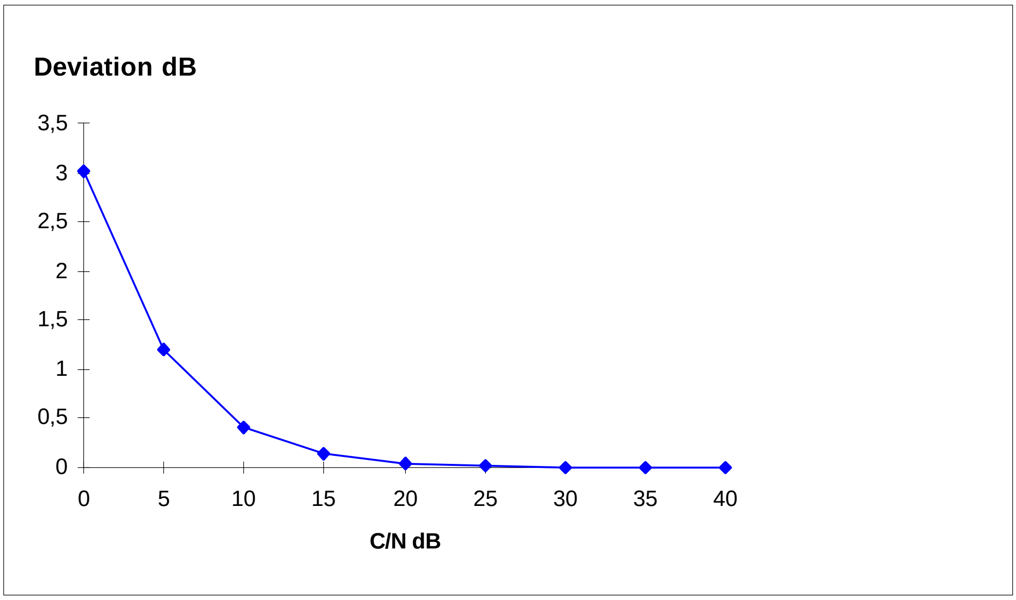
The now displayed NOISE FLOOR at the spectrum analyser FSE should exactly meet the adjusted display line. If not so, the difference to the display line shows the deviation between the SFQ displayed value and the real generated C/N value. In order to calculate the corresponding S/N value correct the C/N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