TV Digital Recipes Part4 DVB-T

Annex

Annex 4B

BROADCASTING DIVISION

APPLICATION NOTE

RF Level Measurement Accuracy of TV Test Receivers

Products:

TV Test Receivers, analog and DVB-C	***EFA***

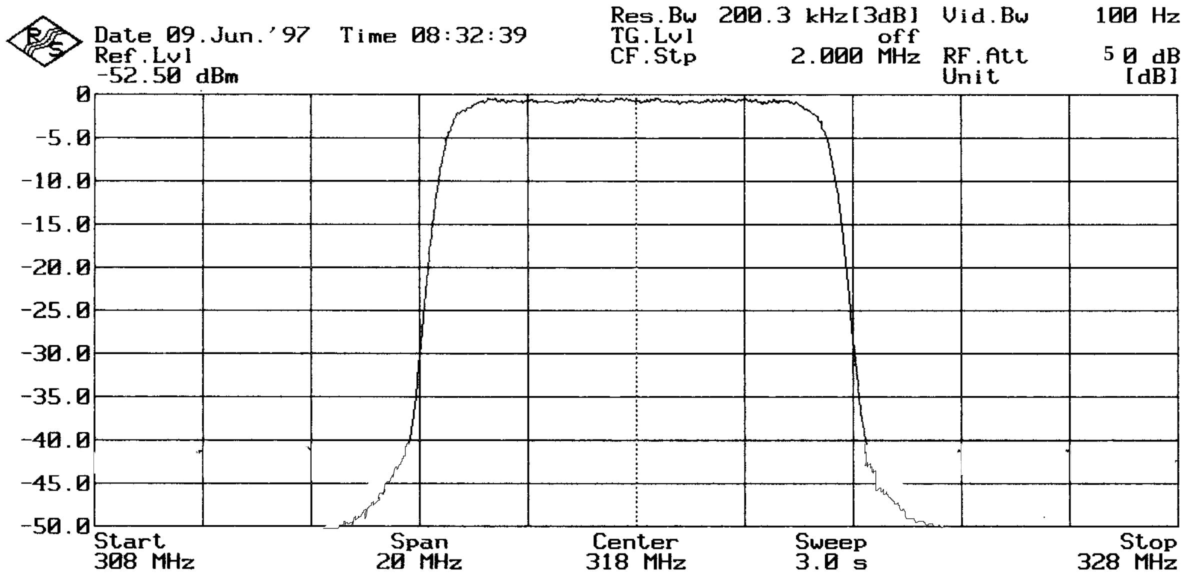
7MGAN15E

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

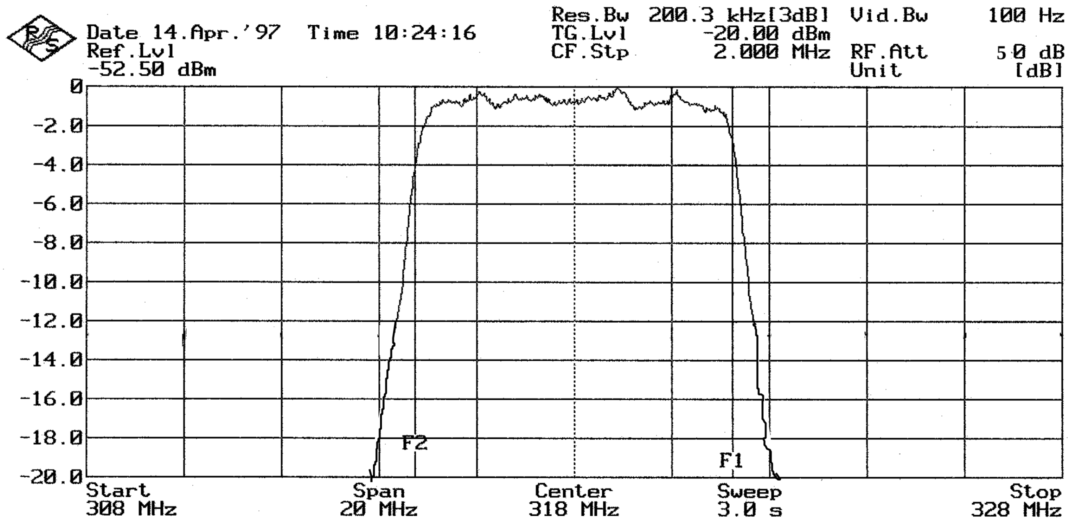
TV Test Receiver EFA uses a simple but highly accurate method for channel power measurement. This method however presupposes that the crest factor remains constant while the amplitude frequency response varies. The crest factor is the ratio of peak voltage to rms voltage of a signal. If it can be assumed 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

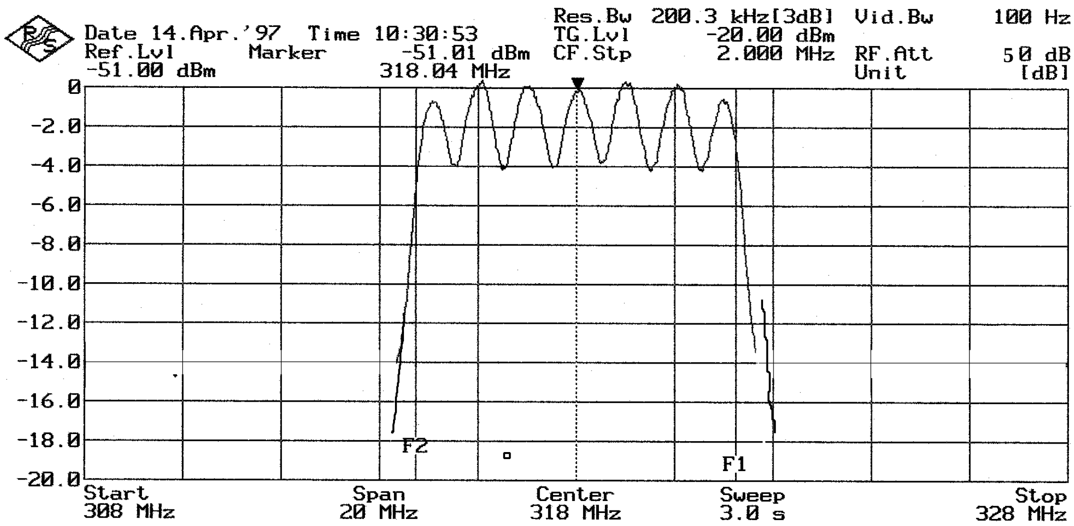
Associated amplitude frequency response



2. Echoes with 1000 ns and 10 dB Attenuation

Level measured with	NRV	EFA
	-34.58 dBm	-34.5 dBm

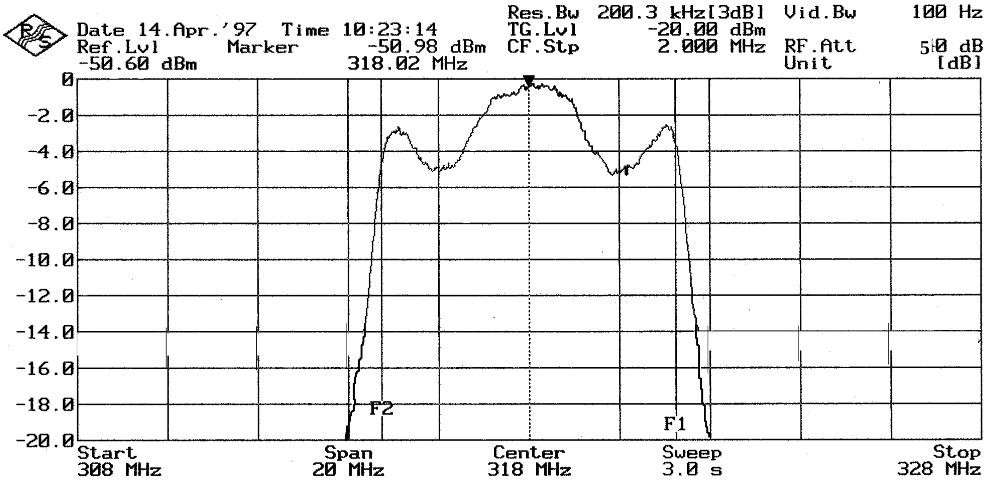
Associated amplitude frequency response



3. Echoes with 250 ns and 10 dB Attenuation

Level measured with	NRV	EFA
	-35.13 dBm	-35.0 dBm

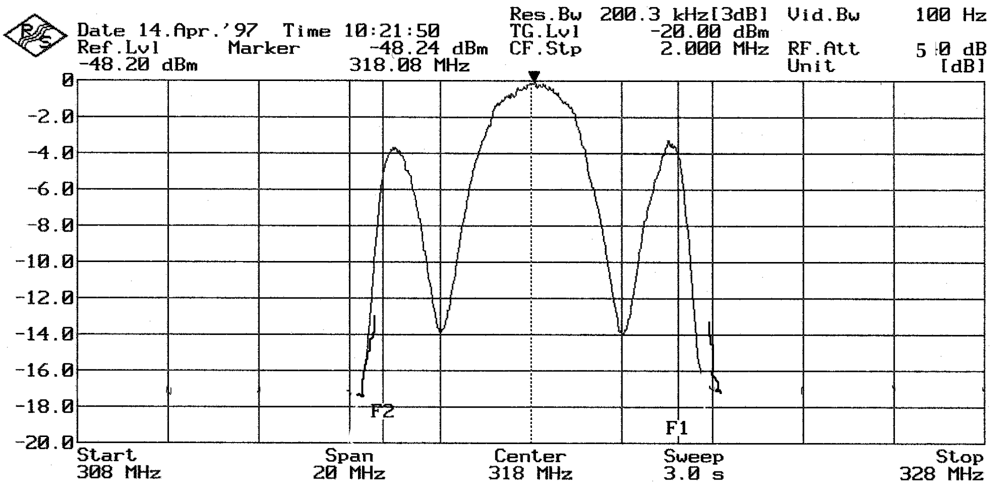
Associated amplitude frequency response



4. Echoes with 250 ns and 2 dB Attenuation

Level measured with	NRV	EFA
	-33.79 dBm	-33.0 dBm

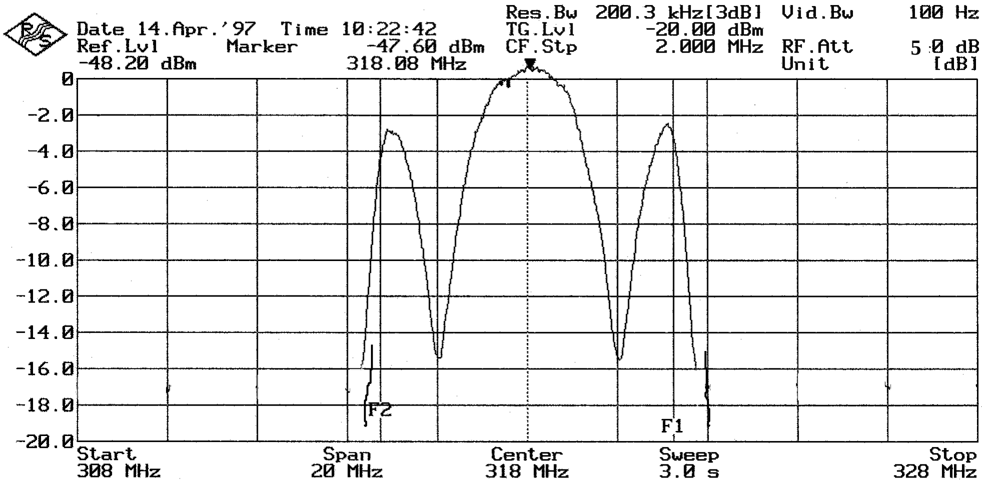
Associated amplitude frequency response



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

ROHDE&SCHWARZ

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.

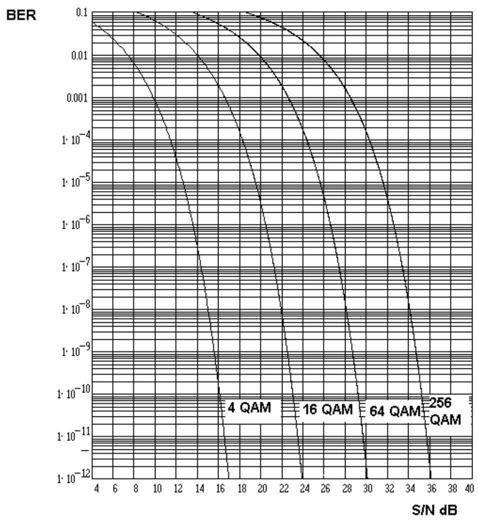


Fig. 1 BER as a function of S/N

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.

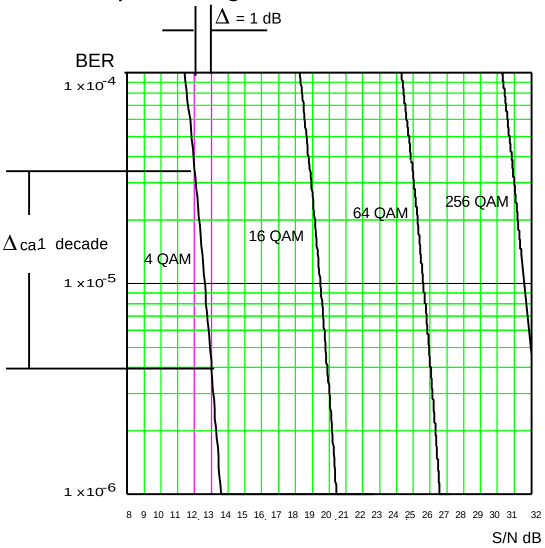


Fig. 2
BER in the range of 10^{-4} to 10^{-6} as a function of S/N in QAM

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.

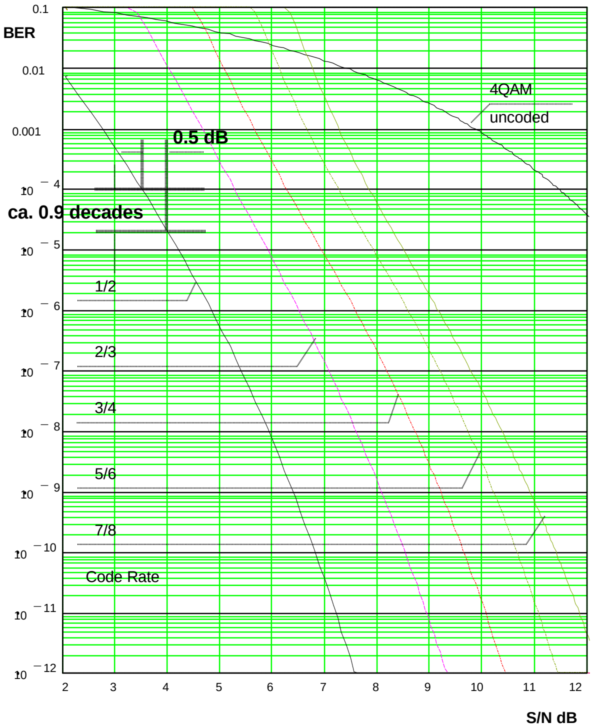


Fig. 3
BER as a function of S/N in QPSK Modulation with Viterbi correction for normally used Code Rates

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.

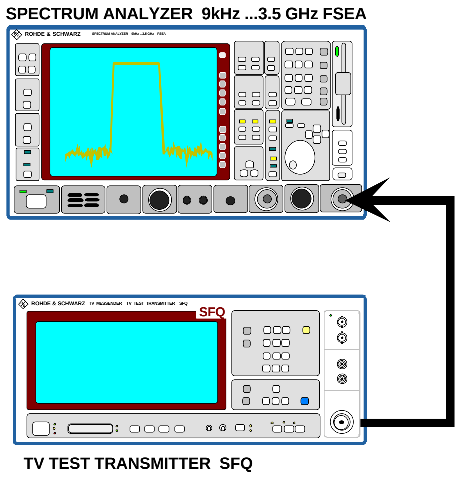


Fig. 4 Block diagram of SFQ and FSE

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 + $k_{\text{roll off}}$ 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.

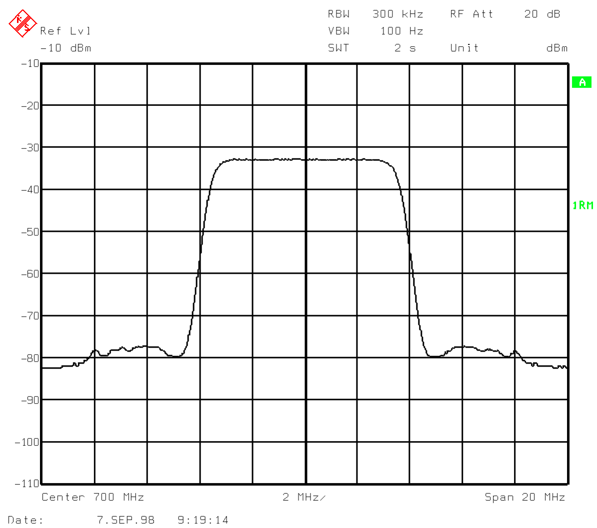


Fig. 5 PRBS spectrum

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).

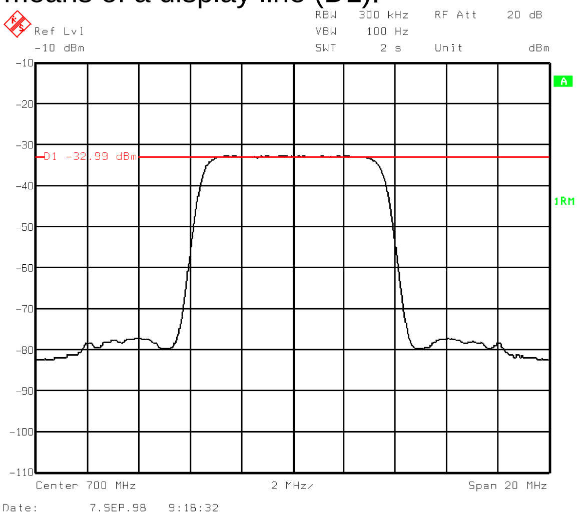


Fig. 6a PRBS spectrum: level marked with display line, 10 dB/div

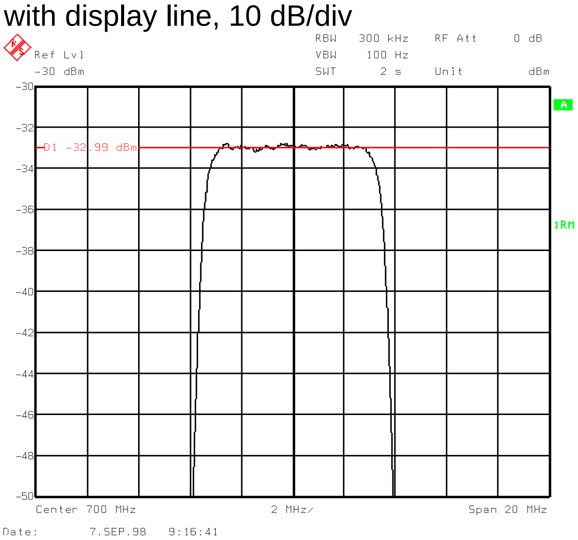


Fig. 6b PRBS sectrum: level marked with display line, 1 dB/div

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).

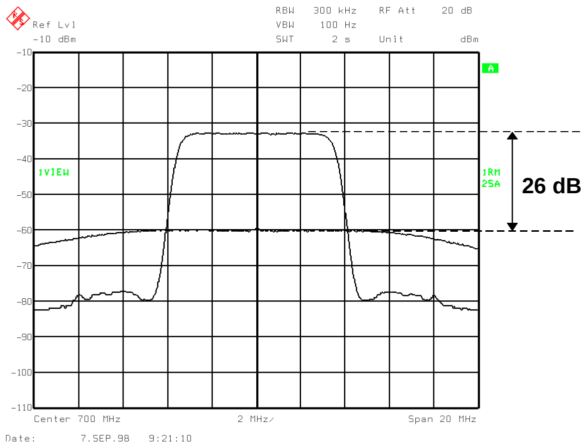


Fig. 7 PRBS useful signal and noise spectra with 10 dB/div

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.

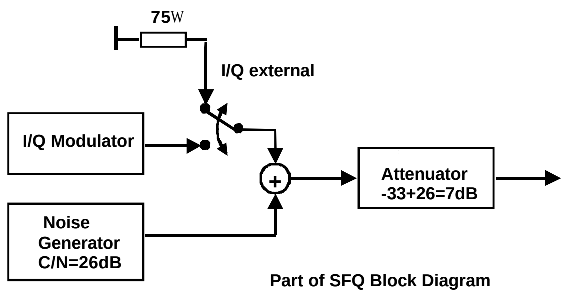


Fig. 8 Useful signal and noise paths in SFQ

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.

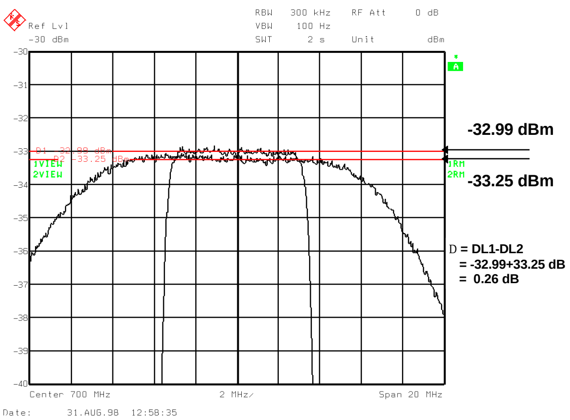


Fig. 9 Measurement of deviation from selected C/N value

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 - $k_{roll\ off}$ 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

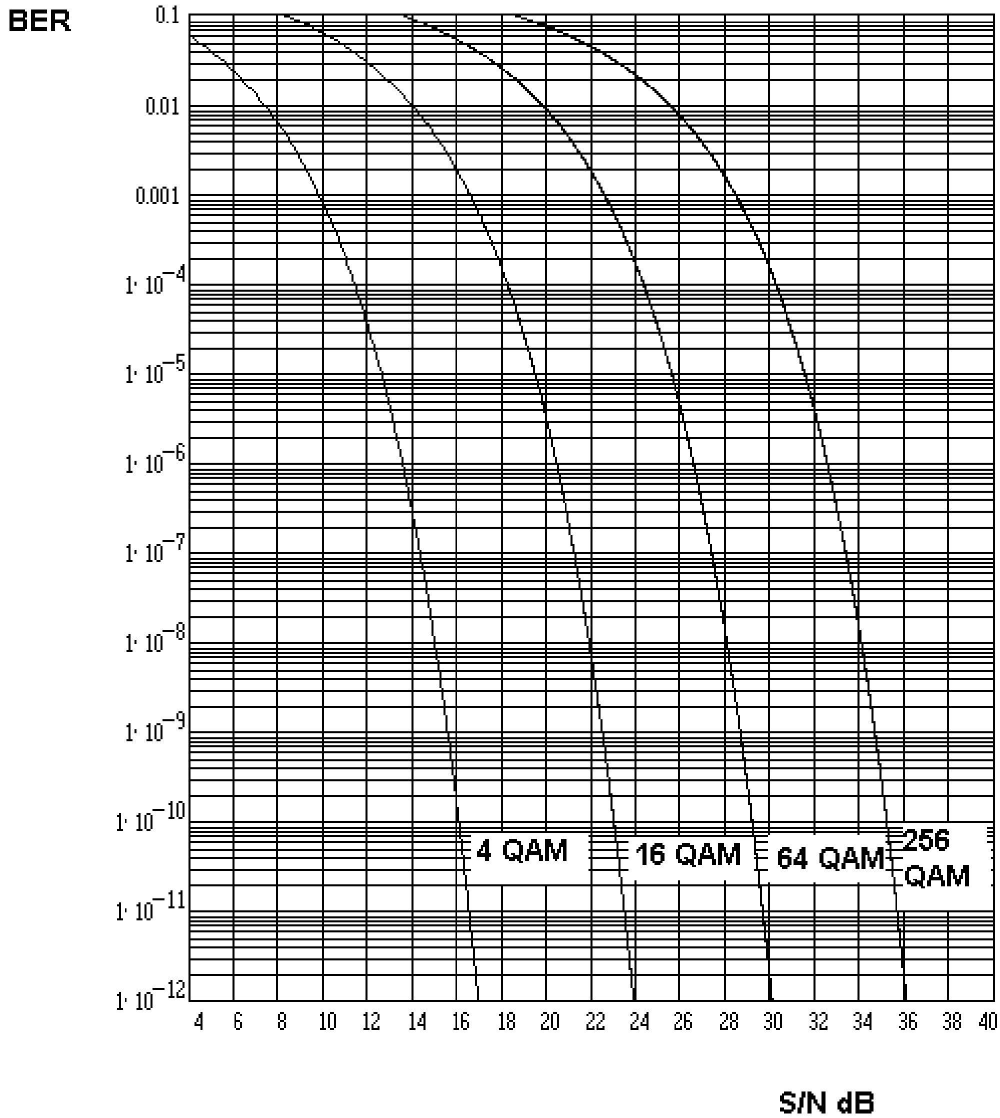


Fig. 10 BER as a function of S/N

Diagram for QPSK Modulation

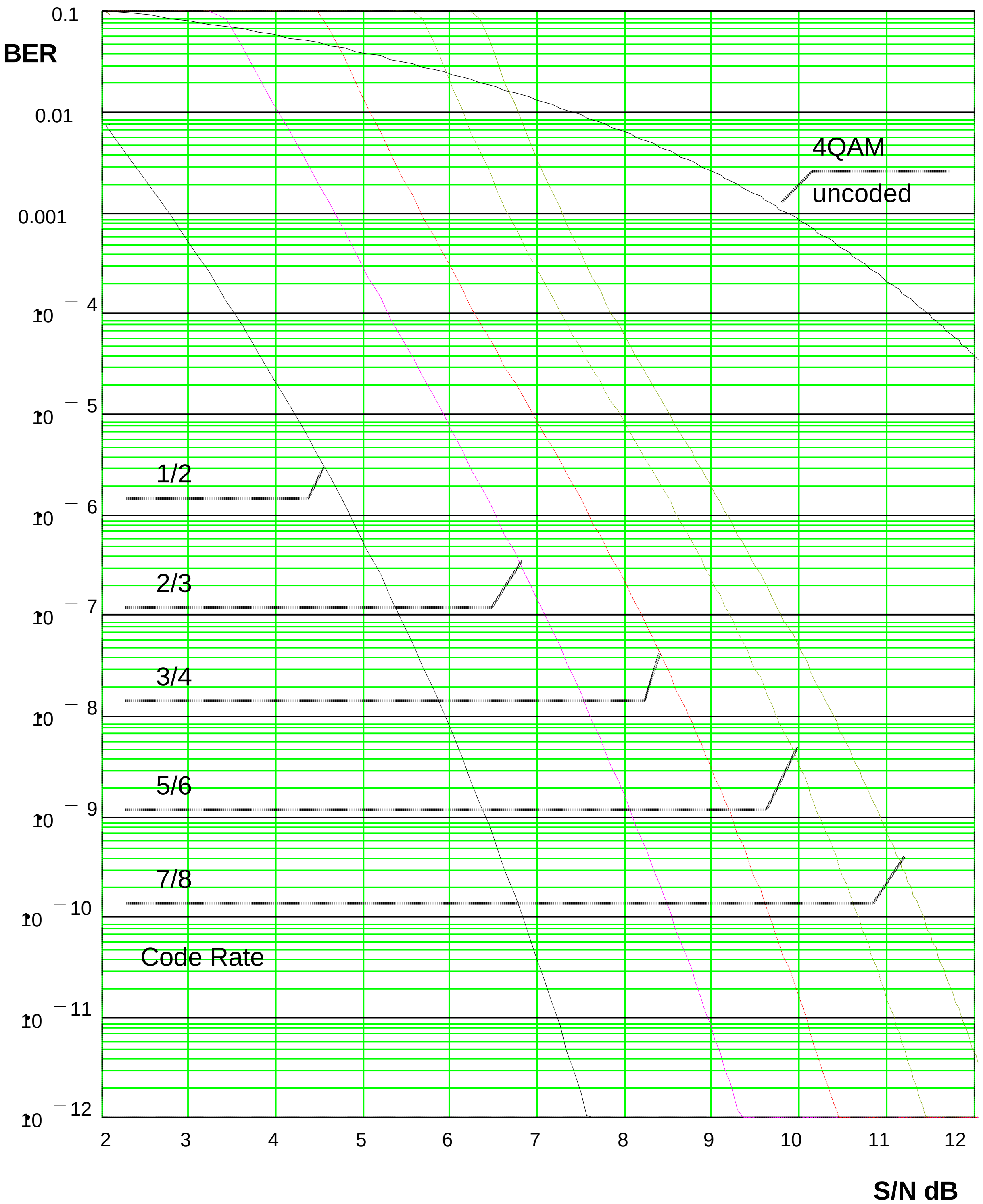


Fig. 11 BER as a function of S/N

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

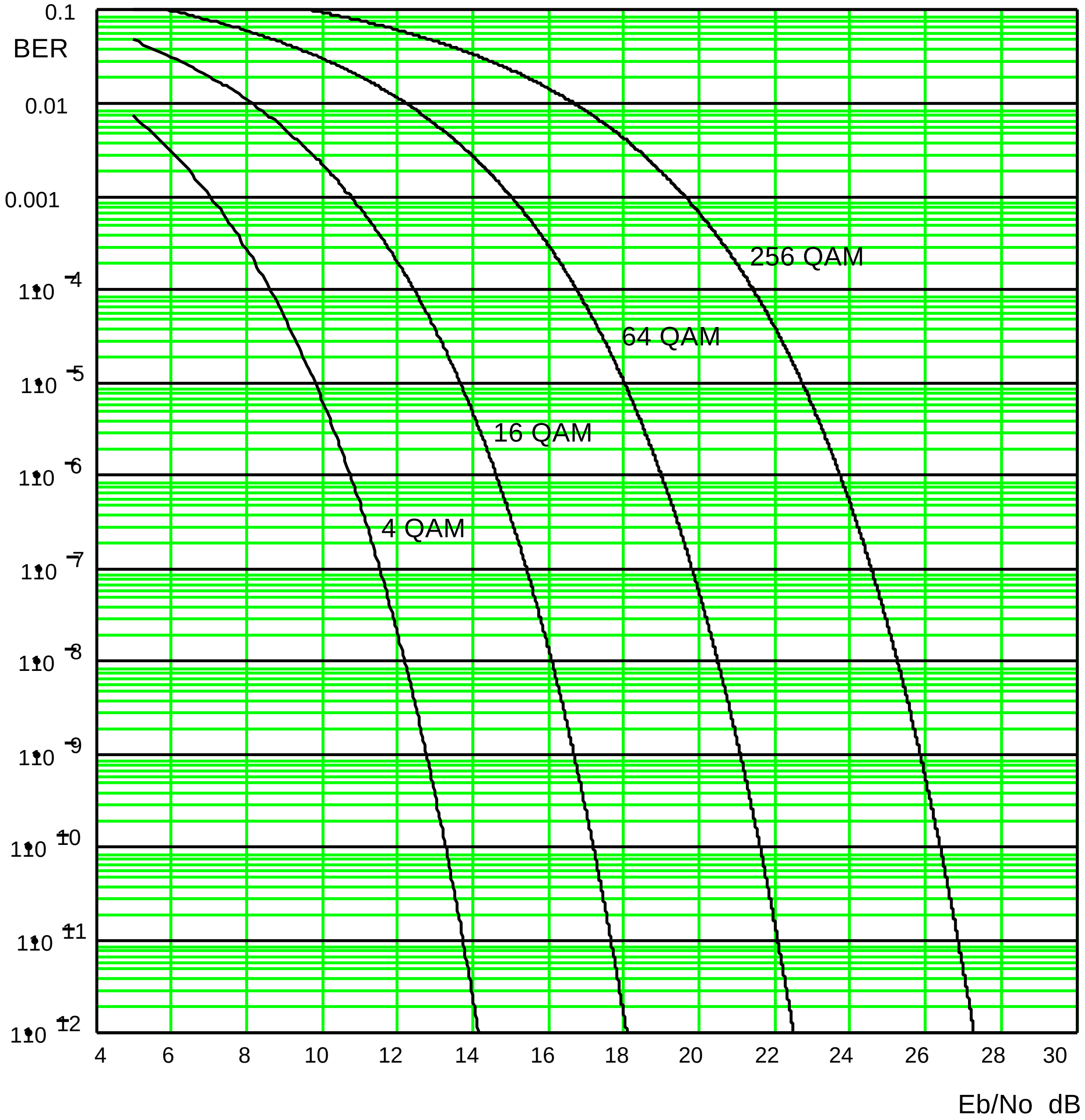


Fig. 12 BER as a function of Eb/No

Diagram for QPSK Modulation BER vs Eb/No

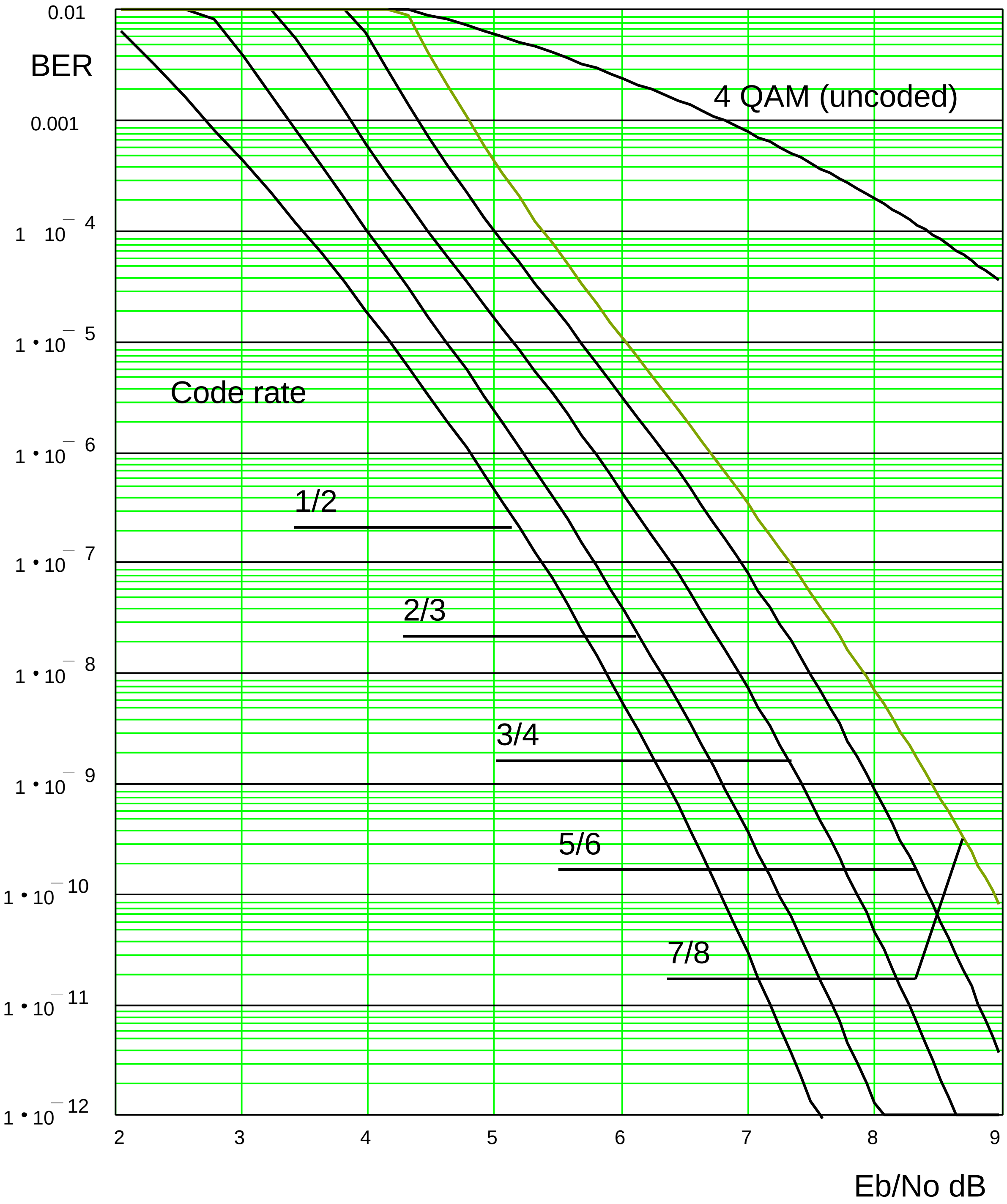


Fig. 13 BER as a function of Eb/No

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.	

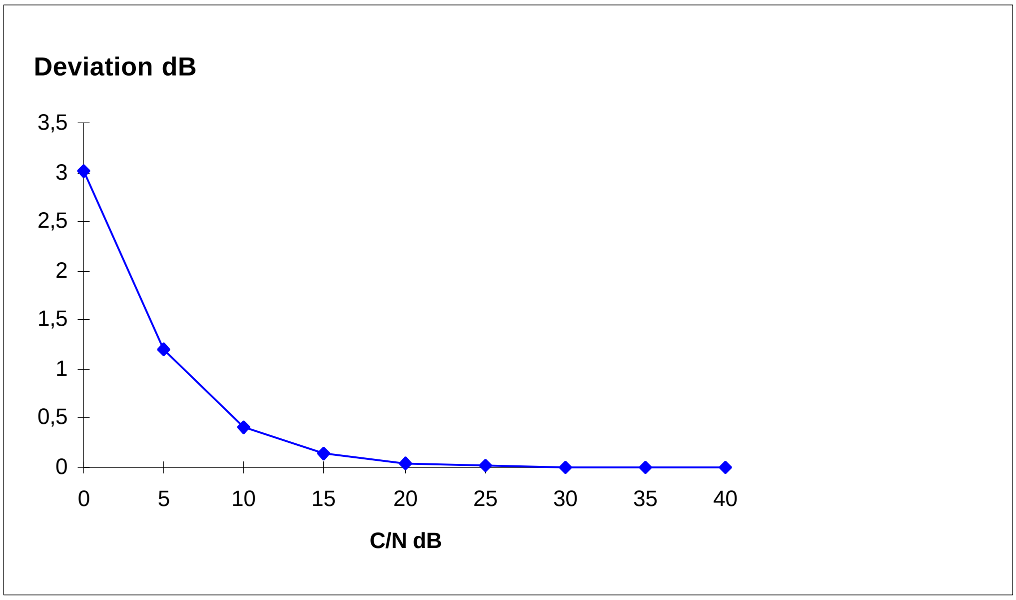
The now displayed NOISE FLOOR at the spectrum analyzer FSE should exactly meet the adjusted display line. If not so, the difference to the display line shows the deviation between the SFQ displayed value and the real generated C/N value. In order to calculate the corresponding S/N value correct the C/N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