ROHDE&SCHWARZ

BROADCASTING DIVISION

Application Note

C/N Ratio at Low Carrier Frequencies in SFQ

Products:

TV Test Transmitter *SFQ*

7BM09_0E

C/N ratio at low carrier frequencies in SFQ

Contents

Setting the C/N ratio in SFQ

1 Preliminaries

The main parameter for determining transmission quality is the C/N ratio, C representing the carrier power in the transmission channel and N the noise power added to the IF/RF signal. The noise normally has a Gaussian distribution and can be considered to be white noise. Since the noise is added to the total channel bandwidth during the transmission, there is no correlation between the noise components in the upper and the lower sidebands in the case of DVB. After demodulation, white noise is again obtained.

But what happens when transmission channels are simulated and noise with a bandwidth f_{noise} is added to the useful DVB signal with a bandwidth f_{signal} and when this signal mixture is converted to RF? As long as the carrier frequency f_c is high enough, $f_c > f_{noise}$ and $f_c >> f_{signal}$, no unwanted effects are to be expected.

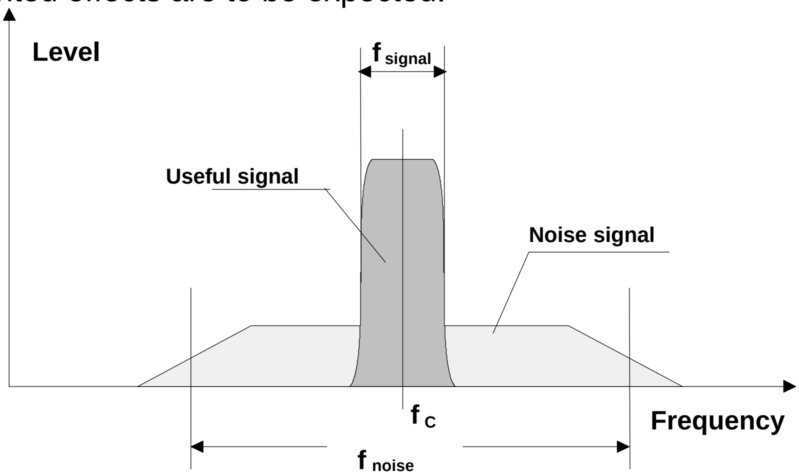

Fig. 1 Noisy DVB spectrum

The C/N ratio should, however, be capable of being varied over wide ranges with the aid of a TV test transmitter irrespective of the bandwidth f_{signal} that is selected. A number of different bandwidths f_{signal} are used for DVB:
With DVB-C and DVB-S, the signal bandwidth is linked to the selected symbol rate, with DVB-T precisely defined bandwidths are used depending on the bandwidth of the terrestrial channel. With DVB-C, signal bandwidths from 0.5 to 6.95 MHz could be used, with DVB-S a wider range from 0.5 to 60 MHz is realistic.
To create unambiguous and repeatable conditions, the C/N ratio should be referred to the signal bandwidth.[1] If the average level of C is to be constant, the absolute level of C must depend on the bandwidth. Corresponding bandwidths and levels are also required for the noise. TV Test Transmitter SFQ therefore produces a noise signal with a bandwidth of 15 MHz (only the central 10 MHz are used) with adequate level compensation (approx. 10xlog(60/10) = 7.8 dB) for narrowband signals in addition to the 100 MHz noise bandwidth for broadband signals (of which only the central 60 MHz are used to ensure that white noise is obtained).

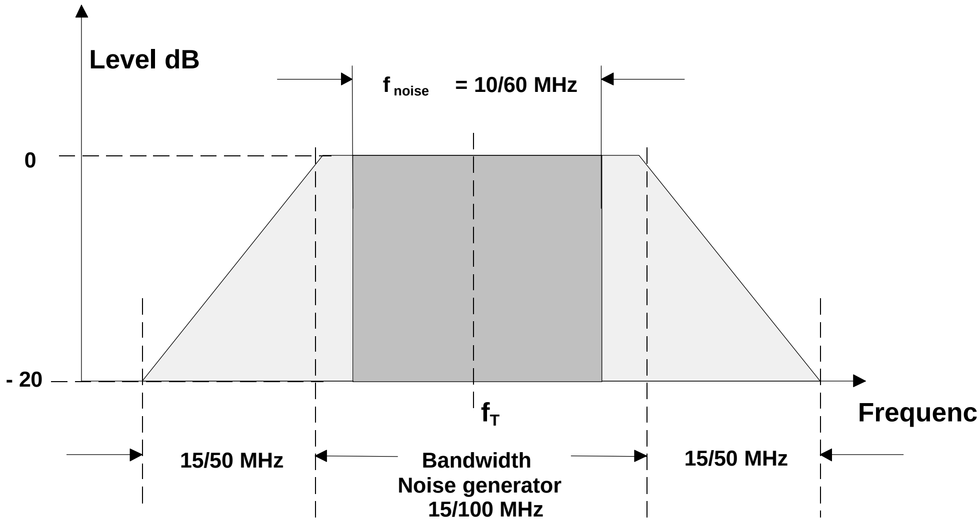

Fig. 2 Spectra of SFQ noise generator

The switchover thresholds between the two bandwidths are at the C/N reference bandwidths $f_{ref} \geq 10.1$ MHz for a utilized noise bandwidth of 60 MHz and $f_{ref} \leq 10.0$ MHz for a utilized bandwidth of 10 MHz.

If the utilized carrier frequency f_c is less than half the bandwidth of the noise or signal spectrum, parts of the spectrum are reflected about 0 Hz.

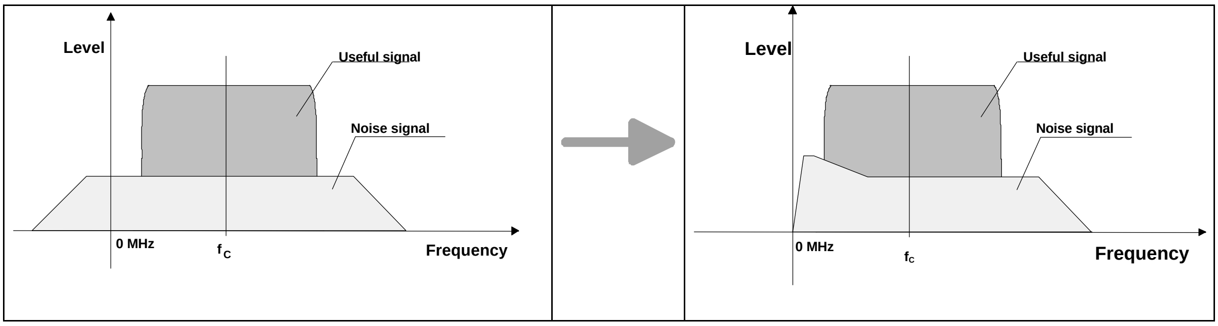

Fig. 3 Frequency reflection about 0 Hz

An example will illustrate the spectrum reflection: the section of the spectrum where the frequency is negative on the left of the diagram is folded onto the positive frequencies. As a reflection in the modulator always entails a highpass effect, a spectrum like that in the diagram on the left is obtained.

This means that there are spectrum ranges that have to be accurately investigated at low carrier frequencies f_c because of the spectral noise reflection about 0 Hz.

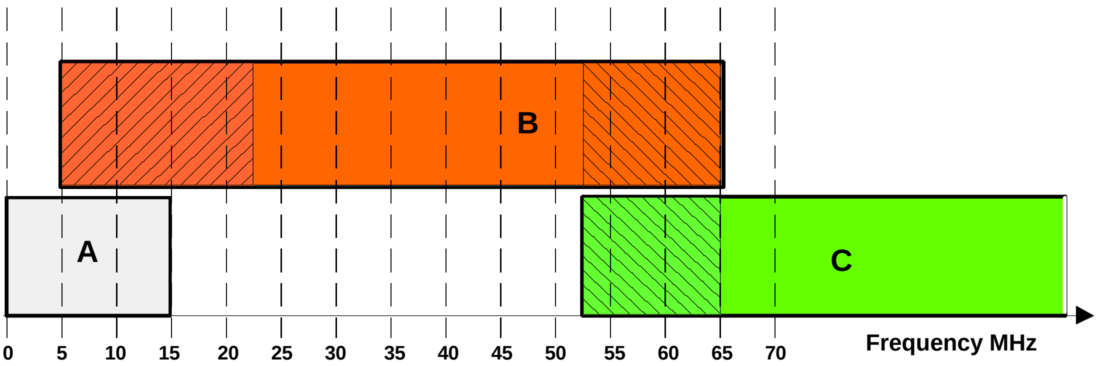

Fig. 4 Critical ranges for setting the C/N ratio in SFQ

The objective is to display accurate C/N values on TV Test Transmitter SFQ despite the noise reflections.

Range A:
For carrier frequencies f_c < 15 MHz, two cases must be investigated and described:
A1: The C/N reference bandwidth equals the symbol bandwidth and is ≤10.0 MHz.
A2: The C/N reference bandwidth is set to twice the symbol bandwidth and is ≥10.1 MHz.
Consequently, special settings are required for DVB-T.

Range B:
For carrier frequencies 5 MHz < f_c < 65 MHz, all C/N values for reference bandwidths f_{ref} ≤10.0 MHz are possible without any restrictions.
For reference bandwidths f_{ref} ≥10.1 MHz, three cases have to be investigated:

B1. Frequency range 5 MHz < f_c < 22.5 MHz: the C/N reference bandwidth has to be set to twice the symbol bandwidth in a limited range.
B2. Frequency range 22.5 MHz < f_c < 52.5 MHz: because of the spectral reflection of the broadband noise in 0 Hz, an undefined spectrum is obtained in this range.
B3. Frequency range 52.5 MHz < f_c < 65 MHz: whether a defined white noise spectrum is obtained depends on the current symbol rate.

Range C:
C1: As with range B3, the resulting noise spectrum in the range 52.5 MHz < f_c < 65 MHz depends on the available symbol rate.
C2: For carrier frequencies f_c > 65 MHz, all C/N values are possible without any restrictions for both reference bandwidths.

(Note: The frequencies specified for the three ranges are approximate.)

2 Description of Ranges

2.1 Range A

A1: The C/N reference bandwidth is equal to the symbol bandwidth at f_c < 15 MHz and f_{ref} £ 10.0 MHz.

With DVB-T in particular, the useful signal is converted to a relatively low IF and then demodulated. The carrier frequency f_c is often half the FFT sampling frequency. The carrier frequency in the 8 MHz channel is $f_c = \frac{1}{2} * \frac{64}{7} \approx 4.57\text{MHz}$.

The noise signal to be added has a larger bandwidth however.
The bandwidth of the noise to be added does not satisfy the inequality $f_c > f_{noise}$. Since the noise should form a ”noise carpet”, it must have at least twice the bandwidth f_{signal} of the wanted signal. $f_{noise} > 2 \times f_{signal}$
The useful signal bandwidth f_{signal} is 7.607 MHz in the 8 MHz DVB-T channel so the noise bandwidth f_{noise} should be at least 2 x 7.607 ≈ 15 MHz.

To ensure that the added noise is white, TV Test Transmitter SFQ only uses the 10 MHz in the center of the 15 MHz (optional) noise spectrum when the reference bandwidth f_{ref} of the C/N ratio is ≤ 10.0 MHz.

This gives the following non-physical spectrum:

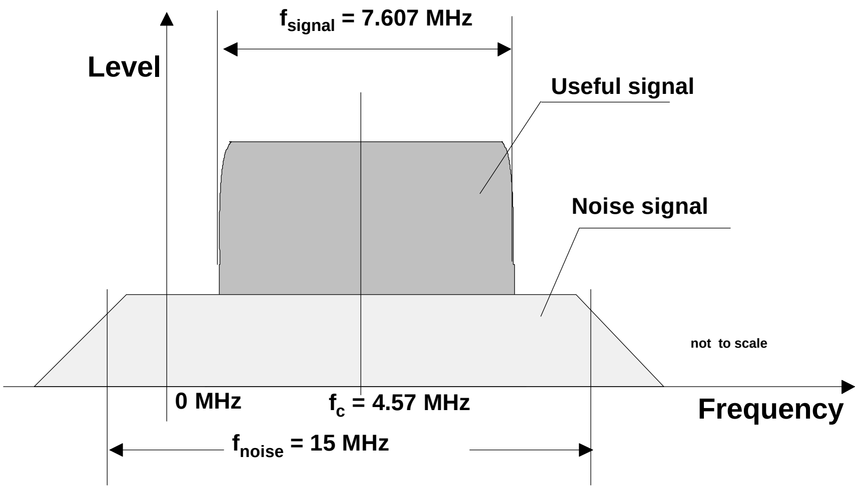

Fig. 5 Non-physical spectrum

After conversion to the carrier frequency f_c = 4.57 MHz, the spectral components of the 'negative' frequencies are reflected about 0 MHz into the positive range.

This real spectrum is obtained:

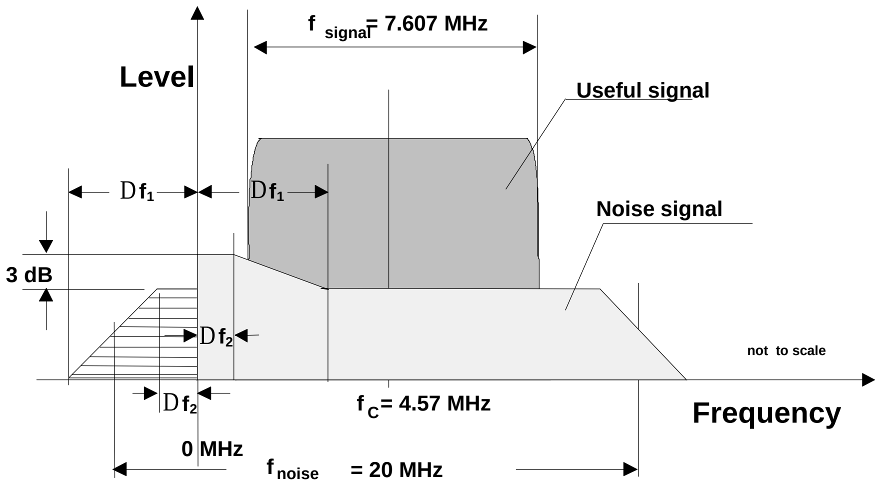

Fig 6 Real spectrum with noise reflection

Taking into account the highpass effect of the conversion, the following is obtained:

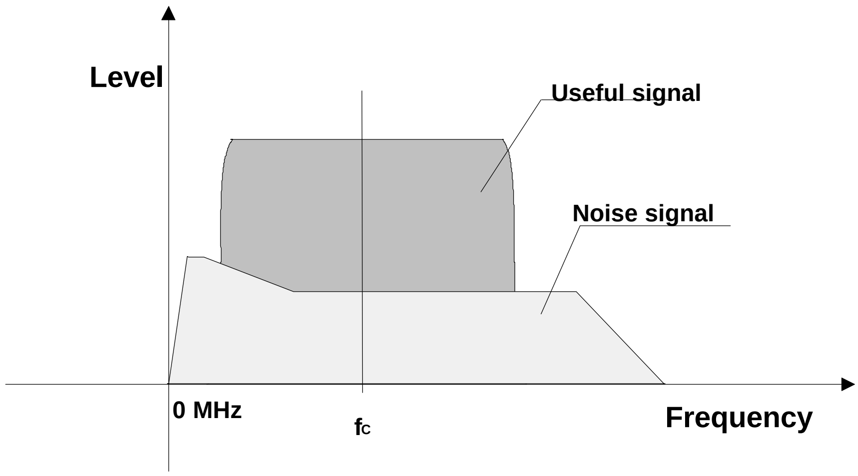

Fig. 7 Real spectrum

The complexity of the spectrum depends on the noise spectrum determined by the bandwidth and the slope of the band limiting filters. The noise added to the useful signal becomes coloured and its level cannot be determined satisfactorily.

The traces for measuring the bit error rate, BER, as a function of S/N (C/N = S/N + $k_{rolloff}$ [1] are no longer valid because the calculation assumes white noise.

The current C/N value and the display on the SFQ are related but calculating one knowing the other is extremely difficult.

A 2: The C/N reference bandwidth is set to twice the symbol bandwidth at $f_c < 15$ MHz and f_{ref} 3 0.1 MHz.

What methods are now available to measure the system limits at very low carrier frequencies (e.g. DVB-T conversion of a 7.607 MHz or 6.656 MHz channel to the 4.57 MHz IF) with the aid of noise and BER?

TV Test Transmitter SFQ from R&S with a noise generator (option) featuring a real bandwidth of 100 MHz may offer a solution when a C/N reference bandwidth $f_{ref} \geq 10.1$ MHz is selected. Switchover from the 10 MHz noise bandwidth to the larger 60 MHz bandwidth at this frequency limit is automatic with the SFQ (see Fig. 2). In the case of DVB, this requirement is fulfilled when twice the signal bandwidth is used as the reference bandwidth. Consequently, the analysis of the spectrum changes:

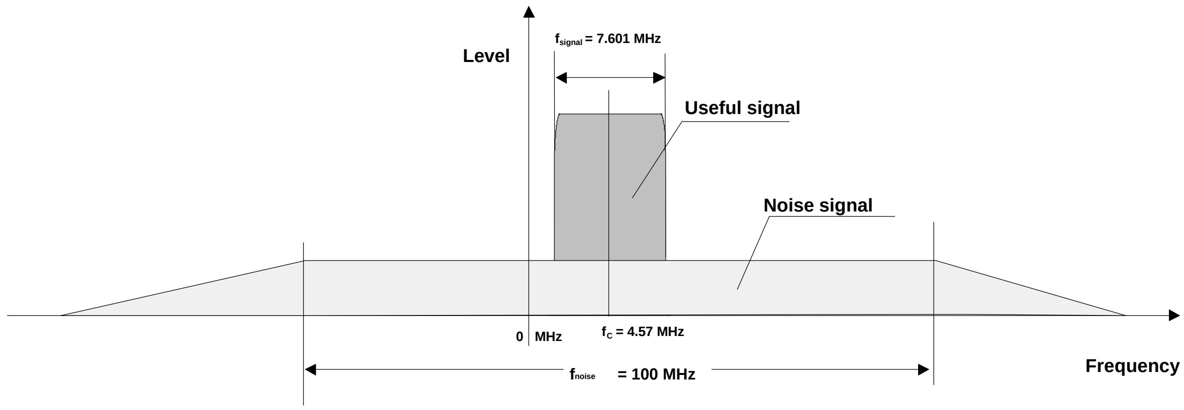

Fig. 8 Non-physical spectrum and broadband noise spectrum

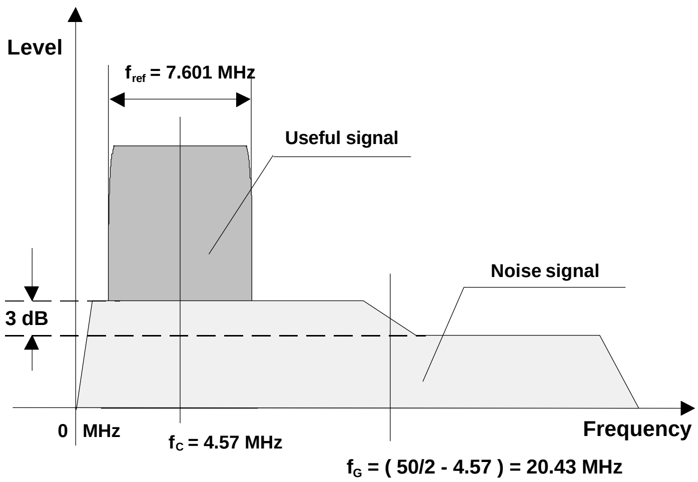

Fig. 9 Real spectrum and broadband noise spectrum

It can be seen that

- the sum of the directly added noise and of the noise reflected in the 0 MHz axis is again white in the useful frequency range,
- the noise level is higher by $k_{reflect} = 3.01$ dB
  as long as twice the symbol bandwidth is ≥10.1 MHz.

The calculated curves "BER as a function of S/N" again apply when the noise level is corrected.
This can be easily done in this case: select twice the symbol bandwidth as the noise reference bandwidth. This reduces the noise density by the 3.01 dB required and the C/N display on SFQ is again exact.

Which noise reference bandwidth is permissible for white noise at which carrier frequency f_c < 15 MHz is shown in Fig. 10:

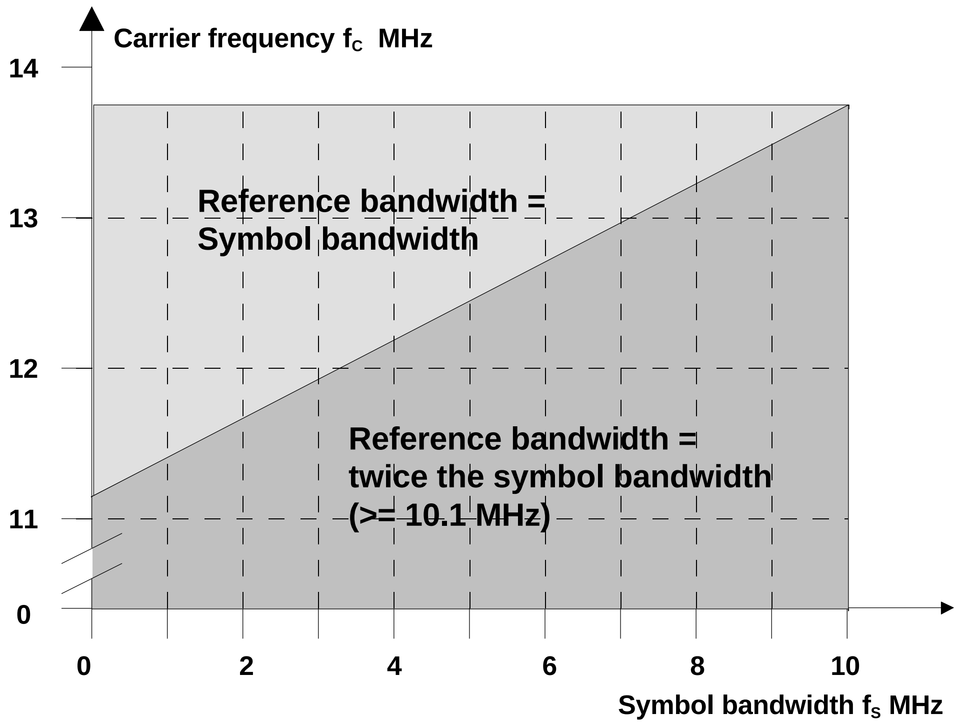

Fig. 10 Carrier frequency f_c < 15 MHz as a function of symbol bandwidth f_s ≤10.0 MHz or C/N reference bandwidth for white noise and correct C/N display on the SFQ

On the other hand, if twice the symbol bandwidth is ≤10.0 MHz, the correction for the SFQ display must be calculated. Sections 3 and 4 give a few examples.

2.2 Range B

B1 Frequency range 5 MHz < f_c < 22.5 MHz, symbol bandwidth f_s ³ 10.1 MHz: the C/N reference bandwidth has to be set to twice the symbol bandwidth over a limited range.

In the frequency range 5 MHz < f_c < 16.7 MHz, the possible symbol bandwidth f_s is equal to 2 x f_c MHz. If a greater symbol bandwidth is selected at these low carrier frequencies, the symbol spectrum is reflected in the 0 Hz axis and is, therefore, not correct.
In the range 16.7 MHz < f_c < 22.5 MHz, the white spectrum of the reflected 100 MHz noise limits the symbol rate with the 50 MHz filter edge until the level is reduced by -20 dB. The widest symbol bandwidth of f_s = 33.3 MHz is attained at the carrier frequency f_c = 16.7 MHz. The sum of the reflected and the directly added noise again gives white noise over the whole range but the noise level is 3.01 dB higher than the SFQ display reading. If twice the symbol bandwidth is selected as the C/N reference bandwidth, the level difference is compensated for. Correct C/N values are displayed by the SFQ.

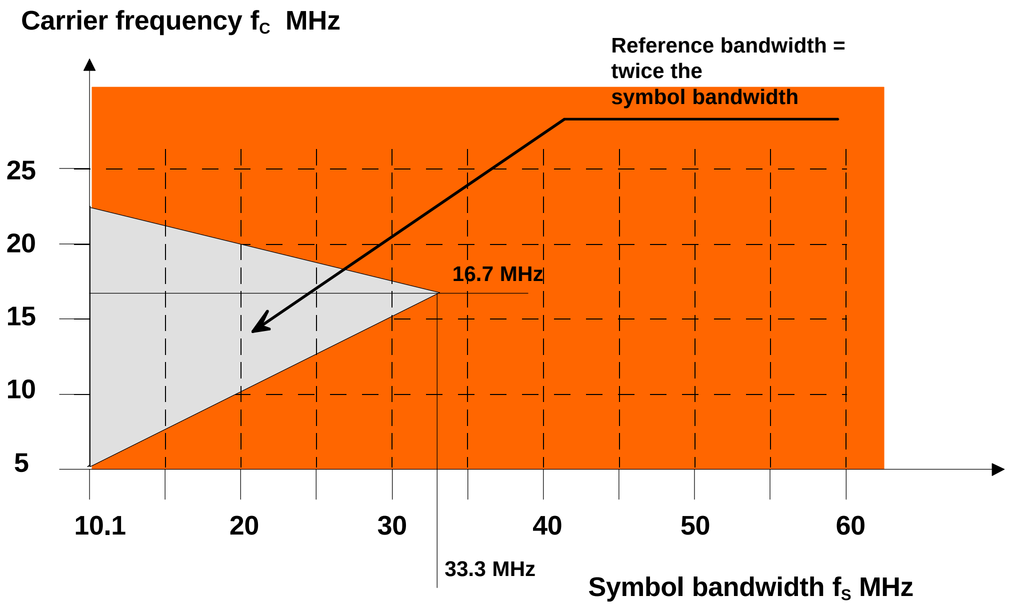

Fig. 11 Carrier frequency 5 MHz < f_c < 22.5 MHz as a function of symbol bandwidth $f_s \geq$ 10.1 MHz

In the B1 case, the "white noise" condition is not fulfilled outside the grey area and so B1 is not suitable for C/N setting on the SFQ for $f_s \geq$ 10.1 MHz. On the other hand, there are no restrictions for reference bandwidths (symbol bandwidths) ≤10.0 MHz.

B2 Frequency range 5 MHz < f_c < 52.5 MHz, symbol bandwidth $f_s\ ^{3}$ 10.1 MHz:

As in case B1, the "white noise" condition is not fulfilled outside the triangular grey area. The noise, which has a bandwidth of approx. 200 MHz until it drops by -20 dB, is reflected into this frequency range and produces coloured noise, which makes it unsuitable for C/N setting on the SFQ. The bandwidth up to the -20 dB drop is selected as the limit because, after this drop, the effect of the reflected noise on the noise density is < 0.05 dB. This value can be ignored even when measuring BER as a function of noise.
On the other hand, there are no restrictions for reference bandwidths (symbol bandwidths) ≤ 10.0 MHz.

B3 Frequency range 52.5 MHz < f_c < 65 MHz, symbol bandwidth $f_s\ ^{3}$10.1 MHz:

At the carrier frequency f_c = 52.5 MHz, the effect of the reflected noise can be neglected at a symbol bandwidth of f_s = 10.1 MHz. Larger symbol bandwidths are again in the coloured noise range. The limit line for coloured noise is linear up to f_c = 65 MHz where the symbol bandwidth f_s = 60 MHz is reached (see Fig. 12). Above this limit, white noise is always obtained and there are no restrictions.

2.3 Range C

C1 Frequency range 52.5 MHz < f_c < 65 MHz, symbol bandwidth f_s ³10.1 MHz:

The C1 case is above the limit line described for B3 and therefore not subject to any restrictions in the symbol bandwidth used. To adapt the diagram for symbol bandwidths > 60 MHz, the limit line is extended.

C2 Frequency range f_c > 65 MHz, symbol bandwidth f_s ³ 10.1 MHz:

For carrier frequencies f_c > 65 MHz, all C/N values are possible for both reference bandwidths without restriction. The SFQ display is always correct within the specified tolerances.

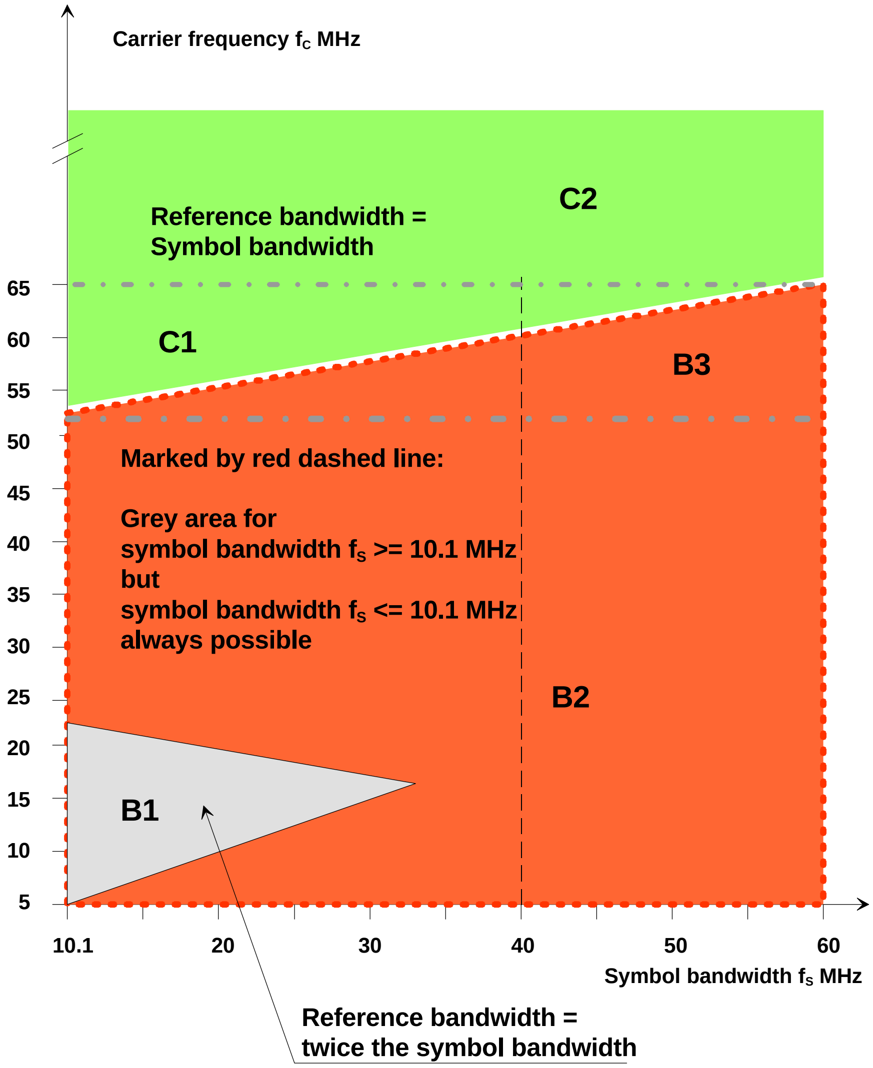

Fig. 12 Ranges B and C: f_c as a function of $_s$ ≥ 10.1 MHz
or of the C/N reference bandwidth for white noise with correct C/N display on SFQ

3 Calculating the C/N Correction Factor Case A2

If noise is added to a wanted DVB signal, the signal bandwidth should always be used as the reference for determining the C/N ratio. To fulfill the "white noise" condition, select a noise bandwidth $f_{noise} > f_{ref}$.
The utilized SFQ noise bandwidth f_{noise} = 60 MHz satisfies the inequality if f_{ref} = 10.1 MHz is selected for C/N. 10.1 MHz is the lowest C/N reference bandwidth at which the SFQ automatically switches to the noise bandwidth f_{noise} = 60 MHz. Because of the spectral reflection in the 0 MHz axis, the correction factor $k_{reflect}$ is equal to 3.01 dB in the frequency range f < 25 MHz for carrier frequencies $f_c \leq 10$ MHz (see Fig. 12).
For C/N setting, the noise level is adjusted with the aid of the attenuator in the noise generator so that the desired C/N values are obtained at the various useful signal bandwidths.
Assuming the current maximum signal bandwidth of 7 MHz (6.95 MHz in the DVB-C channel with 64QAM), the C/N ratio in the SFQ is limited to -1.4 dB by the maximum noise density in the 60 MHz noise bandwidth, but because of the small bandwidth of the useful signal, the noise component is approx. $g = 10 * \log_{10}\left(\frac{10.1}{7}\right) = 1.59\,\text{dB}$, i.e. the true C/N value at the IF/RF output of the SFQ is initially -1.4 + 1.59 = 0.19 dB. However, because the reflected noise is added, C/N = 0.19 - 3.01 = -2.82 dB. If the signal bandwidth is reduced to 1 MHz, the noise would have to be amplified by the factor $g = 10 * \log_{10}\left(\frac{10.1}{1}\right) - 3.01 = 7.03\,\text{dB}$ to obtain the true value, C/N = -1.4 dB. In the A2 case, only C/N = -1.4 + 7.03 = 5.63 dB can be set on the SFQ because the maximum noise density of the 60 MHz noise does not allow a higher value. The theoretical limit in the cable channel with 64QAM is, however, 24 dB for a QEF transmission (quasi error-free transmission at BER $\leq 2 \times 10^{-4}$), i.e. it is nowhere near this limit.

If the selected C/N reference bandwidth f_{ref} is < 10 MHz, the A1 case described above will apply for carrier frequencies f_c < 10 MHz. In this operating mode, therefore, the calculated curves giving BER as a function of S/N are not valid.
If the carrier frequency f_c is < 10 MHz (see Table 2) and if a C/N reference bandwidth of f_{ref} = 10.1 MHz is selected, case A2, described above applies and the calculated curves are valid.
As shown in the examples, another correction factor k_{signal} has to be considered in addition to the correction factor $k_{reflect}$ = 3.01 dB because the following applies: f_{ref}. 1 f_{signal}

$$k_{signal} = 10 * \log_{10}\left(\frac{f_{ref}}{f_{signal}}\right) = 10 * \log_{10}\left(\frac{10.1 * 10^6}{f_{signal}}\right)\,\text{dB}\ .$$

Table 1
Correction factors k_{signal} for various signal bandwidths:

f_{signal} MHz	1	2	3	4	5	6	7	8	9	10
k_{signal} dB	10.043	7.033	5.272	4.023	3.054	2.262	1.592	1.012	0.501	0.043

and especially with DVB-T

f_{signal} MHz	7.607	6.656
k_{signal} dB	1.231	1.81

Table 2
Signal bandwidth f_{signal} as a function of carrier frequency f_c

Carrier frequency f_c in MHz	Signal bandwidth f_{signal} in MHz
1	2 - Δf
2	4 - Δf
3	6 - Δf
4	8 - Δf
5	10 - Δf
6	12 - Δf
7	14 - Δf
8	16 - Δf
9	18 - Δf
10	20 - Δf
12	24 - Δf
14	22 - Δf

- Δf takes into account the highpass effect at 0 MHz
- the C/N reference bandwidth f_{ref}, which is symmetrical about the carrier f_c, must not exceed the max. frequency $f_{white} \approx 25$ MHz

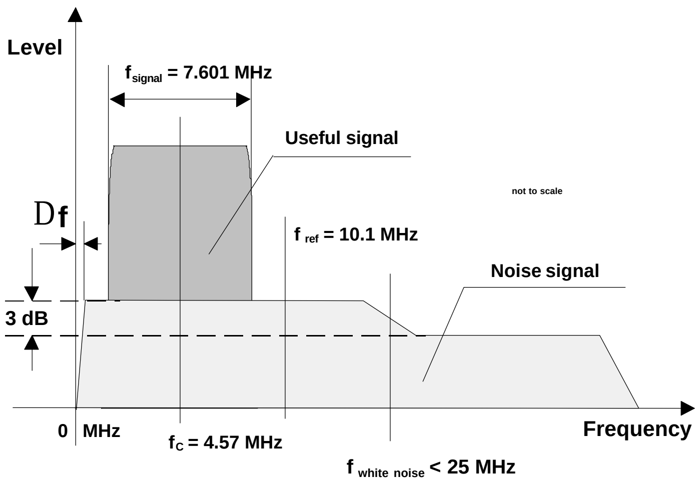

Fig. 13 Signal bandwidth f_{signal} as a function of f_c < 15 MHz for white noise

Since the noise spectrum with f_{noise} = 100 MHz drops at the band limits, case A2 should only be used up to f_{ref} < 25 MHz.

As long as the SFQ settings comply with the values in Table 2, the **total correction factor k** is given by the following equation:

$$k = k_{signal} - k_{reflect} = 10 * \log_{10}\left(\frac{10.1 * 10^6}{f_{signal}}\right) - 3.01 \text{ dB}$$

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4 Examples:

Example 1: DVB-T VHF channel

For demodulation of DVB-T signals in the 7 MHz VHF channel with a signal bandwidth f_{signal} = 6.656 MHz, the IF carrier frequency is
f_c = (64/8) x 0.5 = 4 MHz after conversion.
The C/N reference bandwidth is f_{ref}. = 10.1 MHz (case A2).
The level correction factor is calculated as follows:
$k = k_{signal} - k_{reflect}$ = 1.81 - 3.01 = -1.2 dB
If a C/N ratio of 25 dB is selected on the SFQ, the true C/N value is
C/N = 25 - 1.2 = 23.8 dB.

Example 2: DVB-C back channel

The frequency range for the DVB-C back channel is between 5 and 45 MHz.
The C/N reference bandwidth f_{ref}. = 10.1 MHz (case A2).
Assuming a carrier frequency f_c = 7.5 MHz and a useful signal bandwidth f_{signal} = 1 MHz, the correction factor is given by
$k = k_{signal} - k_{reflect}$ = 10.04 - 3.01 = 7.03 dB.
If a C/N ratio of 20 dB is selected on the SFQ, the true C/N value is
C/N = 20 + 7.03 = 27.03 dB.

Consideration of limit conditions

Example 3:

The **carrier frequency f_c = 5 MHz**,
the **signal bandwidth f_{signal} = 10 MHz** (the highpass effect of the conversion and any "rolloff" are neglected),
the C/N reference bandwidth f_{ref}. = 10.1 MHz.
The signal bandwidth (almost) completely covers the C/N reference bandwidth

$$k = k_{signal} - k_{reflect} = 10 * \log_{10}\left(\frac{10.1 * 10^6}{10.0 * 10^6}\right) - 3.01 \text{ dB}$$

k = 0.04 - 3.01 = - 2.97 ≈ - 3 dB
The C/N value for the IF/RF signal is reduced by noise reflection. The C/N reference bandwidth is $f_{ref} = f_{signal}$.. A correction for different bandwidths is not performed, the reflected noise power degrades the C/N ratio without any reduction.
If a C/N ratio of 20 dB is selected on the SFQ, the true C/N value is
C/N = 20 - 3 = 17 dB.

Example 4:

The **carrier frequency f_c = 5 MHz**,
the **signal bandwidth** has the value **f_{signal} = 5 MHz** (assuming the highpass characteristic of the conversion and any "rolloff" is negligible),
the C/N reference bandwidth f_{ref}. = 10.1 MHz.
The signal bandwidth takes up half the reference bandwidth.

$k = k_{signal} - k_{reflect} = 10 * \log_{10}\left(\frac{10.1 * 10^6}{5.0 * 10^6}\right) - 3.01 \text{ dB}$

$k = 3.05 - 3.01 = - 0.04 \approx 0$ dB

Since $f_{ref.} \approx 2 \times f_{signal}$, the two correction factors compensate each other. In this configuration (case A2), the C/N display on the SFQ is correct.

5 Special Settings for DVB-T

The low IF carrier frequencies f_c referred to mainly occur when DVB-T signals are processed. To prevent discrepancies between the set and the displayed C/N values on the SFQ, DVB-T settings can be made as described in Example 4.

The 100 MHz bandwidth of the SFQ noise generator (option) allows the noise reflected in the 0 MHz axis to be utilized up to approx. 25 MHz. Up to this frequency, the sum of the 100 MHz noise (of which only the 60 MHz in the center are used) and the reflected noise produces the required white noise. Here all conditions of case A2 are met. The following conclusion can, therefore, be drawn:

If a reference bandwidth $f_{ref} = 2 \times f_{signal}$ is set on the SFQ ($f_{ref} < 25$ MHz), the displayed C/N value corresponds to the actual C/N value of the IF/RF signal at the SFQ output because, with DVB-T, twice the signal bandwidth is always greater than 10.1 MHz.

Remember: if the reference bandwidth $f_{ref} \geq 10.1$, the bandwidth of the noise generator in the SFQ is automatically switched to the utilized bandwidth f_{noise} = 60 MHz. The measurement "BER as a function of S/N" can again be performed without going into the details of the equations cited above.

The DVB-T signal bandwidths, the associated IF carrier frequencies and the C/N reference bandwidth selected on the SFQ are listed in Table 3.

Table 3

DVB-T mode	Signal bandwidth f_{signal} in MHz	IF carrier frequency f_c in MHz	Reference bandwidth for C/N $f_{ref} = 2 \times f_{signal}$ in MHz	**Settings on SFQ f_{ref} in MHz**
8 MHz, 8k	*7607143*	*4.57*	*15214286*	***15.2***
8 MHz, 2k	*7607143*	*4.57*	*15214286*	***15.2***
7 MHz, 8k	*6.656250*	*4.00*	*13.312500*	***13.3***
7 MHz, 2k	*6.656250*	*4.00*	*13.312500*	***13.3***
6 MHz, 8k	*5.705357*	*3.428571*	*11.410714*	***11.4***
6 MHz, 2k	*5.705357*	*3.428571*	*11.410714*	***11.4***

When the values in Table 3 are set on the SFQ, the displayed C/N value equals the actual C/N of the IF/RF signal at the SFQ output.

6 Tolerance Considerations

According to data sheet specifications, absolute noise accuracy is attained at 23 ±3°C. If reflection in the 0 MHz axis under the conditions in Table 3 is taken into account, the permissible tolerance is doubled to < 1 dB in the frequency range up to f_{white} = 25 MHz. As explained in [1], this accuracy is not sufficient for an accurate BER measurement. Therefore, the C/N or S/N ratio must be measured with an absolute accuracy of approx. 0.1 dB prior to all BER measurements (as described in the Application Note).

Reference

[1] Application Note 7BM03_2E Bit Error Ratio in DVB as a Function of S/N

19-Jul-01