Measurement Techniques for CNR, CSO, CTB and Spurious signals

1. Document STATUS

Document: Technical Note TN981110

Revision	Date	Responsible	Remarks
00	13.11.98	Dr. Seidenberg	Document created

Required Equipment

To perform CNR, CSO, CTB and spurious signal measurements on a transmission system a multi channel generator generating a variety of unmodulated carriers and a RF Spectrum Analyzer (=RSA) with channel bandpass filters are required. The channel bandpass filters should provide a bandwidth larger than the channel bandwidth (e.g. 10 MHz) and should be able to suppress all other channels besides the measurement channel sufficiently in order to avoid intermodulations generated by the spectrum analyzer itself. It is important to keep in mind that CATV systems are 75 Ohms systems and matching pads or matching transformers (75 to 50 Ohms) may be needed when measuring with 50 Ohms components.

Setting up the multichannel generator

The transmission system has to be tested with a multi channel signal. There are 2 mesurement techniques:

- Using unmodulated carriers
- Using modulated carriers

In the lab in general unmodulated carriers are used because the measurements are much easier to perform and most multi channel generators are not offering modulated carriers.
In the field in general modulated carriers are used since rather often already a big number of subscribers are connected to the transmission system. There is a big difference in the measurement results of both methods since the spectrum of unmodulated carriers is composed out of sinewave signals whereas modulated carriers show a much broader spectrum.
In this technical note only the unmodulated carrier method is introduced.
The leveling of carriers of the multi channel generator has to be in accordance with the input signal specification of the transmission system. If a transmission system requires a flat input signal for all carriers (e.g. 20 dBmV = 80 dBµV into 75 Ohms) the adjusted signal flatness directly gives the achievable accuracy of the measurement results. If all carriers are levelled flat to ±0.5 dB the final measurement accuracy for CNR, CSO, CTB and spurious signals will be ±0.5 dB. However, if the flatness is only ± 3 dB (e.g. all carriers between 17 dBmV and 23 dBmV) the measurement accuracy will be only ± 3 dB. Therefore it is very important to have a proper input signal levelling of the transmission system. Further unaccuracies result from the performance of the used measuerment equipment like bandpass filters and RF spectrum analyzer. See appendix 2 for a discussion on measurement accuracy.
The input signal to the transmission system may be checked with a RF spectrum analyzer (RSA). If no RSA with 75 Ohm input impedance is available external matching pads for 50 Ohms (6 dB insertion loss) or matching trannsformers (0.8 dB insertion loss) have to be used.
Especially for CTB measurements it is necessary to be able to turn on and off the carrier of the channel to be measured. A computer control simplifies and shortens the measurement procedure.

Setting up the RF Spectrum Analyzer

The spectrum analyzer should be operated in manual mode in order to get a full control over the spectrum analyzer settings:

Let´s assume that the channel to be measured provides an unmodulated picture carrier at the frequency fp. At the beginning of the measurement, this carrier has to be turned on. The center frequency of the RSA should be set to (fp + 2.75 MHz), with a span of 8 MHz = 800 kHz/div. The RF attenuator (ATT) of the RSA should be in auto mode, the reference level should be adjusted to have the picture carrier matching the top line of the RSA display. The vertical scaling should be scaled in 10 dB/div. The recommended vertical units are dBm or dBmV. The correspondence between dBm and dBmV in 75 Ohms systems is: 0 dBm = 48.7 dBmV).

The resolution bandwidth (RBW) should be 30 kHz, the video bandwidth (VBW) as small as possible (e.g. 100 Hz) to get a smooth, filtered graph on the display. If the RSA does not offer this small VBW, alternatively video avering could be used. The sweep time has to be set to auto mode.

Using all these settings the RSA display should look as given in the figure 1. This picture is an example for the spectrum of a perfect transmission system with negligible intermodulations and spurious signals. However in reality the display will be more as given in figure 2. Before starting the mesurements it is important to check that the RSA dynamic range does not limit the measurement result: Disconnect the input signal (RF input open at RSA). Now the RSA noise floor should be at least 3 dB below the system noise floor. Accurate results can be obtained by having more than 6 dB of margin. In case the RSA noise floor is too high, repeat the start procedure after increasing the input level to the RSA (internal or external amplifier).

Measurement procedures for CNR

Measuring the CNR using the phase noise function

The most accurate measurement procedure to measure the carrier to noise ratio is to use the phase noise marker function (measurement of noise signals referred to a bandwidth of 1 Hz) when present in the RSA. Typically this function is offered in one of the marker menus of the RSA.

- read the carrier level using the marker: (e.g.: C = –10 dBm)
- turn on the phase noise function
- move the marker to the bottom of the total noise
- read the system noise (e.g.: N_{tot} = -128 dBm/Hz)
- Calculate carrier to total noise in 1 Hz: (e.g. $CNR_{tot} = C – N_{tot}$ = (–10 + 128) dB/Hz = 118 dB/Hz)
- disconnect the input of the RSA in order to measure the RSA noise floor (e.g. N_{RSA} = –135.5 dBm/Hz)
- Get correction factor from appendix 1 to determine correction factor for inhibiting RSA noise: (e.g.: $N_{tot} – N_{RSA}$ = 7.5 dB => corr. = -0.9 dB)
- Calculate $CNR_{sys} = CNR_{tot}$ - corr. (e.g.: = CNR_{sys} = (118 + 0.9) dB/Hz = 118.9 dB/Hz)
- Adjust result for TV-channel noise bandwidth B_{TV}: e.g. 5 MHz => B_{TV} = 67 dB, 4 MHz => B_{TV} = 66 dB
- Calculate CNR: CNR = CNRsys – BTV (e.g. CNR = 118.9 – 67 = 51.9 dB)

Measuring the CNR without the phase noise function

If the RSA does not offer to measure noise in 1Hz bandwidth directly, it is necessary to know the noise bandwidth of the spectrum analyzer for a given resolution bandwidth (RBW). The noise bandwidth depends on the shape of the filter used in the RSA. For a resolution bandwidth of 30 kHz the noise bandwidth is typical around 18.2 kHz. Now all measuremnts are performed with this setting of RBW = 30 kHz:

- Read the carrier level using the marker: (e.g.: C = –10 dBm)
- Move the marker to the bottom of the total noise
- Read the system noise (e.g.: N_{tot} = -85.4 dBm)
- Calculate carrier to total noise in 1 Hz: (e.g. CNR_{tot} = C – N_{tot} = (–10 + 85.4) dBc = 75.4 dBc)
- Disconnect the input of the RSA in order to measure the RSA noise floor (e.g. N_{RSA} = –92.9 dBm)
- Get correction factor from appendix 1 to determine correction factor for inhibiting RSA noise: (e.g.: N_{tot} – N_{RSA} = 7.5 dB => corr. = -0.9 dB)
- Calculate CNR_{sys} = CNR_{tot} - corr. (e.g.: = CNR_{sys} = (75.4 + 0.9) dB/Hz = 76.3 dB)
- Convert result to 1 Hz bandwidth: noise bandwidth of RSA: 18.2 kHz => 42.6 dB (e.g.: (76.3 + 42.6) dB/Hz = 118.9 dB/Hz
- Adjust result for TV-channel noise bandwidth B_{TV}: e.g. 5 MHz => B_{TV} = 67 dB, 4 MHz => B_{TV} = 66 dB
- Calculate CNR: CNR = CNRsys – BTV (e.g. CNR = 118.9 – 67 = 51.9 dB)

Measurement procedures for CSO

Composite second order (CSO) beats are intermodulations caused by the nonlinearity of the transmission system in the presence of a pair of carriers. The frequency at which CSO beats of a pair of carriers with the frequencies f_p and f_q occur can be calculated with the formula:

f_{CSO-} = $f_q – f_p$
f_{CSO+} = $f_p + f_q$

The frequencies f_p and f_q of carriers follow the used frequency plan (e.g. PAL-D: 55.75, 119.25, 127.25, 135.25, ... integer + 0.25 MHz or integer + 0.75 MHz).
It is easy to understand that for PAL-D and also similar frequency plans like PAL-B, PAL-G and even NTSC, CSO beats are always located at frequencies following the formula

f_{CSO-} = r + 0.0 MHz , where r is integer
f_{CSO+} = s + 0.5 MHz , where s is integer

whereas all carriers are at the frequencies

$f_{p,q}$ = t + 0.25 MHz or t + 0.75 MHz, where t is integer

Obviously CSO beats are always located at least 0.25 MHz apart from the carrier frequencies. They appear only at the frequencies as given from f_{CSO} formulas. In an 8 MHz channel there are 17 possible locations for CSO beats. Figure 2 gives an example where just 2 CSO beats occur. The location of CSO beats can be simulated on a computer when the frequency plan is specified.

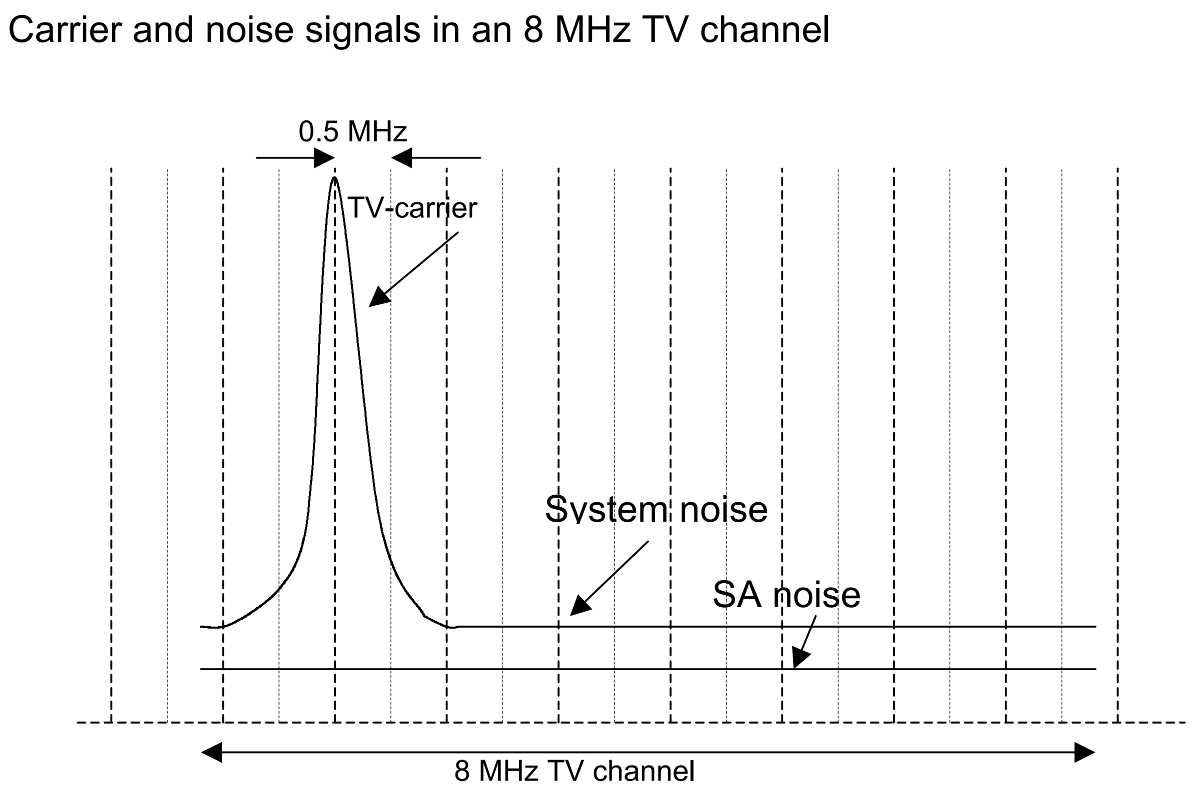

Figure 1: CNR measurement procedure

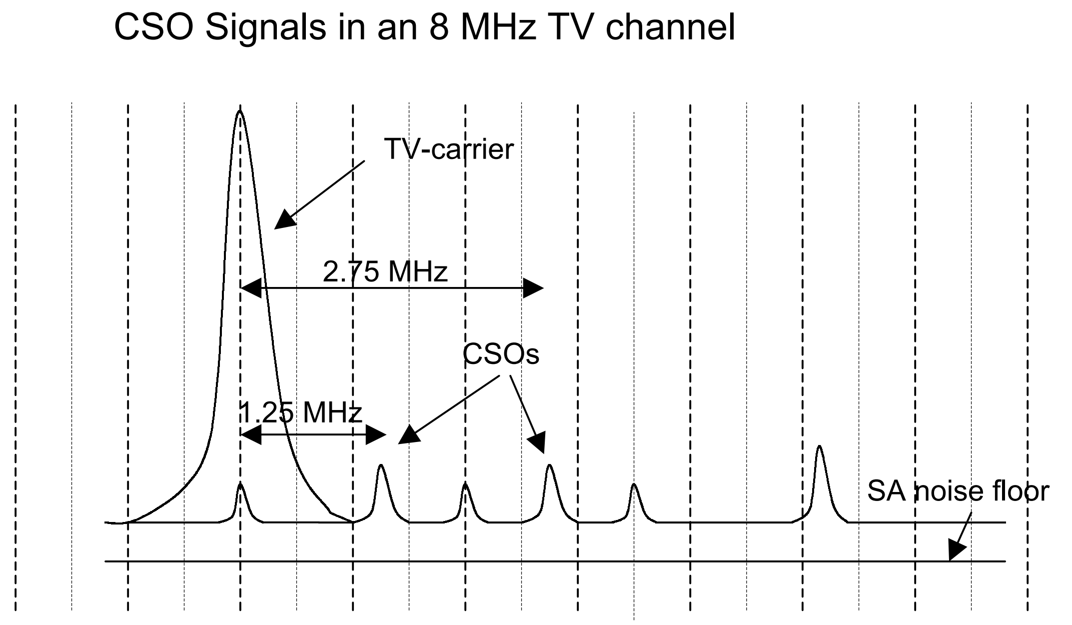

Figure 2: CSO measurement procedure

The measurement procedure is similar to the CNR measurement procedure. First of all the RF spectrum analyzer has to be set up as described in the section above.

Now a display as given in figure 2 should appear on the screen. It´s important to know where CSO beats are located. For PAL B, D,G and NTSC frequency plans all CSOs are always on frequencies as xxx.00 MHz or xxx.50 MHz (e.g. 120.00 MHz, 120.50 MHz, 121.00 MHz ...)).

The CSO reading is as follows:

- Read the carrier level using the marker: (e.g.: C = –20 dBm)
- Move the marker to the peak of the strongest CSO beat
- Read the CSO beat level (e.g.: CSO_{tot} = -87.0 dBm) including RSA noise floor
- Disconnect the input of the RSA in order to measure the RSA noise floor (e.g. N_{RSA} = –93.0 dBm)
- Get correction factor from appendix 1 to determine correction factor for inhibiting RSA noise: (e.g.: $CSO_{tot} – N_{RSA}$ = 6.0 dB => corr. = -1.3 dB)
- Calculate CSO beat level excluding RSA noise floor: $CSO_{sys} = CSO_{tot}$ - corr. (e.g.: = CNR_{sys} = (-87.0 - 1.3) dBm = 88.3 dB)
- Calculate CSO: CSO = C – CSO_{sys} (e.g. CSO = (-20 +88.3) dBm = 68.3 dB)
- Check other CSO beats in the channel to be sure to measure the strongest one

Measurement procedures for CTB

Composite triple order (CTB) beats are intermodulations caused by the nonlinearity of 3^{rd} order of the transmission system. The frequency at which CTB beats generatred by the carriers at the the frequencies f_p , f_q and f_r occur can be calculated with the formula:

$f_{CTB--} = f_p – f_q - f_r$
$f_{CTB-+} = f_p + f_q - f_r$
$f_{CTB++} = f_p + f_q + f_r$
$f_{CTB2+} = 2f_p + f_q$
$f_{CTB2-} = 2f_p - f_q$
$f_{CTB3} = 3f_p$

The frequencies f_p ,f_q and f_r of carriers follow the used frequency plan. For PAL-B, D, G and NTSC frequency plans all carriers frequencies follow the formula

$f_{p,q,r}$ = t + 0.25 MHz or t + 0.75 MHz, where t is integer

It is easy to understand that CTO beats are always located at frequencies following the formula

f_{CTB} = r + 0.25 MHz , where r is integer or
f_{CTB} = s + 0.75 MHz , where s is integer

Obviously CTB beats are always located at the same frequency as any carrier (say: below the carrier) or a multiple of 0.5 MHz apart from the any carrier.

In an 8 MHz channel there are 16 possible locations for CTB beats. Figure 3 gives an example where just 3 CTB beats occur. Like CSO the location of CTB beats can be simulated on a computer when the frequency plan is specified.

CTB Signals in an 8 MHz TV channel

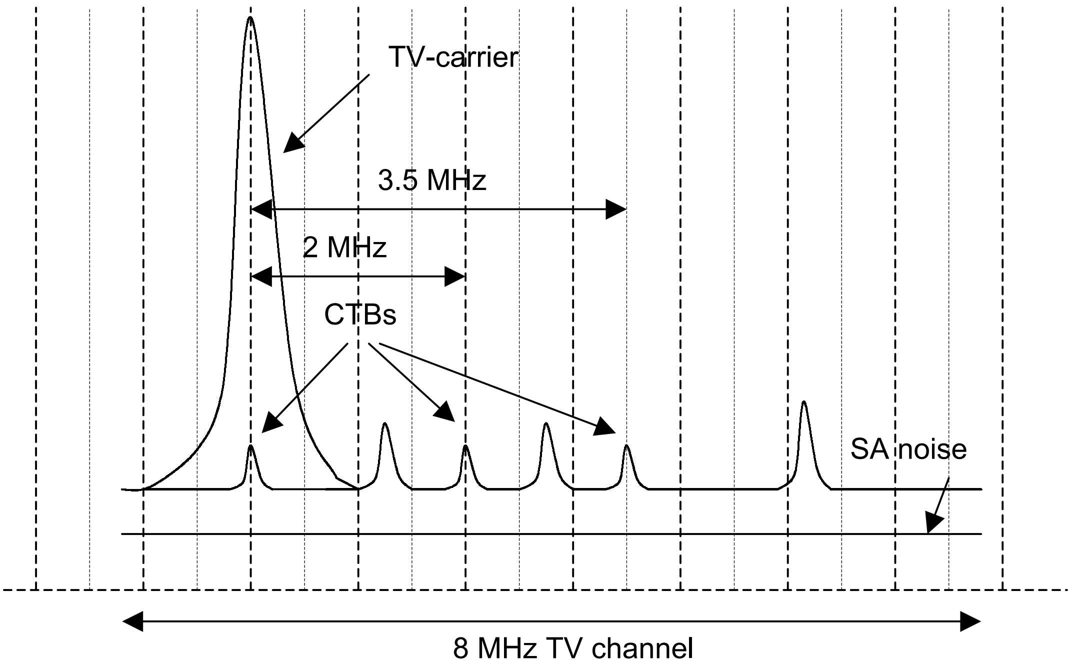

Figure 3: CTB measurement procedure:

The measurement procedure for CTB is similar to the CSO measurement procedure. First of all the RF spectrum analyzer has to be set up as described in the section above. Since there is one CTB beat which is always hidden behind the carrier. The CTB beat at the carrier frequency can only be measured by turning off the carrier in the multi channel generator after the carrier level has been measured.

A display as given in figure 3 should appear on the screen. It´s important to know where CTB beats are located. For PAL B, D,G and NTSC frequency plans all CTBs are always on frequencies as xxx.25 MHz or xxx.75 MHz (e.g. 120.25 MHz, 120.75 MHz, 121.25 MHz ...)).

The CTB reading is as follows:

- Read the carrier level using the marker: (e.g.: C = –20 dBm)
- Turn off the carrier at the multi channel generator
- Move the marker to the peak of the strongest CTB beat
- Read the CSO beat level (e.g.: CTB_{tot} = -89.0 dBm) including RSA noise floor
- Disconnect the input of the RSA in order to measure the RSA noise floor (e.g. N_{RSA} = –93.0 dBm)
- Get correction factor from appendix 1 to determine correction factor for inhibiting RSA noise: (e.g.: CTB_{tot} – N_{RSA} = 4.0 dB => corr. = -2.2 dB)
- Calculate CTB beat level excluding RSA noise floor: CTB_{sys} = CTB_{tot} - corr. (e.g.: = CTB_{sys} = (-89.0 - 2.2) dBm = 91.2 dB)
- Calculate CTB: CTB = C – CTB_{sys} (e.g. CTB = (-20 +91.2) dBm = 71.2 dB)
- Check other CTB beats in the channel to be sure to measure the strongest one

Measurement procedure for Spurious Signals

Spurious signals are generated by transmission systems which introduce artificial signals into the CATV signal. Possible sources of spuriuos signals are pilot tones used to establish a pilot controlled function (e.g. AGC) or to improve power limits in single mode fibres (e.g. microwave carriers for SBS-suppression).
In standard CATV amplifiers in general no spurious signals can be found because no pilot signals are used at all. However, especially in 1550 nm optical transmission systems typically several pilot tones are used. Complicated efforts have to be taken in these systems to suppress spurious signals sufficiently.

One problem with spurious signals is, that their frequencies are not as easy to project as for CSO and CTB signals. The reason is that the pilot tone frequencies in general are not specified or show a temperature drift which causes a wandering of the spurious signals with temperature and time. At certain moments they even may coincide with CSO or CTB frequencies and may not be discovered as spurious but CSO or CTB signals. There are only two possibilities to recognize signals to spurious signals:

- If the frequency of a spurious signal is different from frequencies known for CSO and CTB beats it is a spurious signal. Example: CSO signals in general are found at xxx.00 MHz and xxx.50 MHz, CTB signals are found at xxx.25 MHz and xxx.75 MHz. If a signals occurs at a frequency xxx.4 MHz it´s a spurious signal!

- If all beats of a channel are observed for a certain time and one beat is moving in frequency with time/temparature it´s a spurious signal.

The measurement technique apart from the frequency issue is equivalent to the CTB technique. Figure 4 shows an example for a spurious signal.

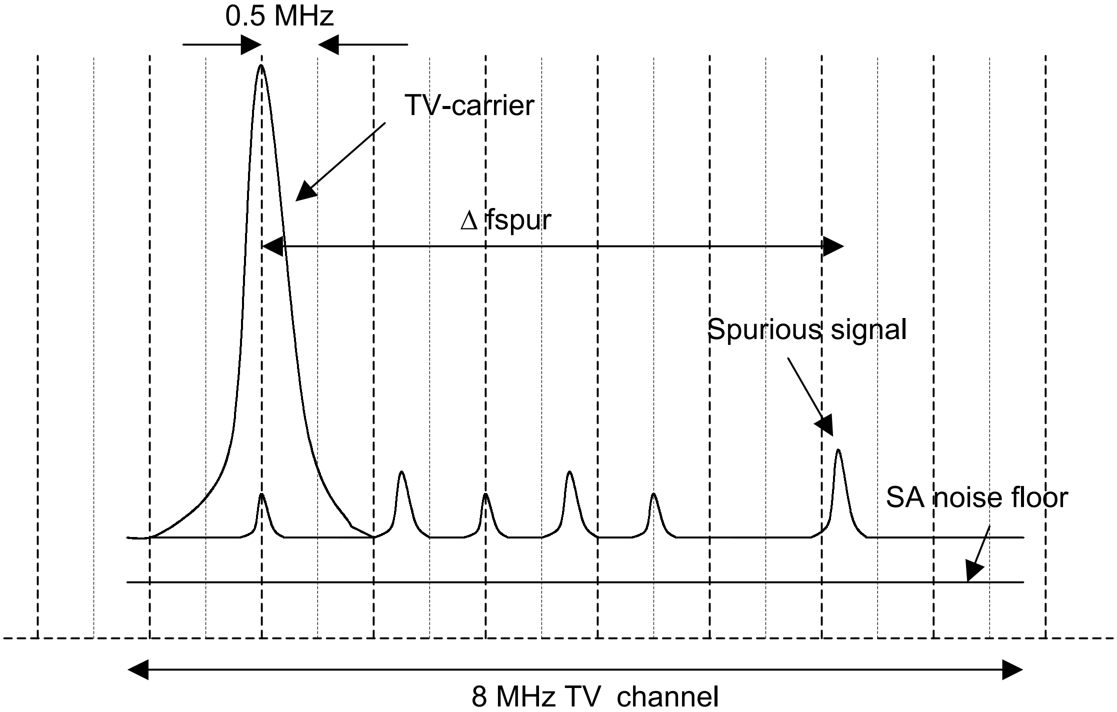

Figure 4: Measurement techniques for spurious signals

The spurious reading is as follows:

- Use RF spectrum analyzer (RSA) setting as described above
- Read the carrier level using the marker: (e.g.: C = –20 dBm)
- Turn off the carrier at the multi channel generator
- Look for spurious signal
- Move the marker to the peak of the spurious signal
- Read the spurious level (e.g.: $SPUR_{tot}$ = -86.0 dBm) including RSA noise floor
- Disconnect the input of the RSA in order to measure the RSA noise floor (e.g. N_{RSA} = –93.0 dBm)
- Get correction factor from appendix 1 to determine correction factor for inhibiting RSA noise: (e.g.: $SPUR_{tot}$ – N_{RSA} = 7.0 dB => corr. = -1.0 dB)
- Calculate SPUR level excluding RSA noise floor: $SPUR_{sys}$ = $SPUR_{tot}$ - corr. (e.g.: = $SPUR_{sys}$ = (-86.0 - 1.0) dBm = -87.0 dBm)
- Calculate SPUR: SPUR = C – $SPUR_{sys}$ (e.g. SPUR = (-20 +87) dBm = 67 dB)

Appendix 1: Correction factor for RSA noise limited measurements

For all measurements where the RSA noise is not significantly smaller than the signal to be measured, the measurement value read from the RSA is higher than without RSA noise since the RSA noise accumulates to the measured signal. Therefore the RSA noise contribution has to be subtracted. The table gives the correction factor in dB as a function of the distance between measured signal level and RSA noise floor.

Distance between signal level and RSA noise floor in dB	Correction factor in dB
-15,0	-0,1
-14,5	-0,2
-14,0	-0,2
-13,5	-0,2
-13,0	-0,2
-12,5	-0,3
-12,0	-0,3
-11,5	-0,3
-11,0	-0,4
-10,5	-0,4
-10,0	-0,5
-9,5	-0,5
-9,0	-0,6
-8,5	-0,7
-8,0	-0,7
-7,5	-0,9
-7,0	-1,0
-6,5	-1,1
-6,0	-1,3
-5,5	-1,4
-5,0	-1,7
-4,5	-1,9
-4,0	-2,2
-3,5	-2,6
-3,0	-3,0

Appendix 2: Achievable accuracy of CNR, CSO, CTB and spurios measurements

The achievable accuracy is limited by the carrier level accuracy of the multi channel generator, the flatness of the bandpass filter and the linearity error of the logarythmic section of the RF spectrum analyzer

The carrier levels can be adjusted at the multi channel generator. It is necessarey to achieve a carrier flatness < 0.5 dB to obtain reliable maesurement results.

The transmission loss of the bandpass should be constant. Otherwise an additional error will occur.

The linearity of the spectrum analyzer is the most important factor if the multichannel generator is properly levelled. To obtain the best possible accuracy it is important:

- to use a proper calibrated RSA
- not to change any setting like RBW and Reference Level during the measurement

By following these rules the remaining error is given by the linearity error of the RF spectrum analyzer. Please find some examples for widely used measurement equipment:

<u>Anritsu Spectrum Analyzer MS 2601A/J:</u>

Linearity error: ±1.0 dB for 0 to -70dB

<u>Anritsu Spectrum Analyzer MS 2663C:</u>

Linearity error: ±1.0dB for 0 to –70dB

<u>Hewlett Packard Spectrum Analyzer HP8560 E-Series:</u>

Linearity error: ±0.85dB for 0 to –90dB

<u>Tektronics Spectrum Analyzer Family R3271A, R3371A, R3265A, R3365A</u>

Linearity error: ±1.5 dB for 0 to –90dB

<u>Rohde und Schwarz Spectrum Analyzer Family FSE:</u>

Linearity error: ±0.50dB for 0 to –70dB

By summing up all possible errors it is very difficult to obtain an accuracy better than ±1.0dB.

Note: BKtel´s test results are measured with a generator levelled to ±0.5 dB , a bandbass calibrated to constant transmission loss and a Rohde und Schwartz Spectrum Analyzer.