Measuring ACPR of W-CDMA signals with a spectrum analyzer

When measuring power in the adjacent channels of a W-CDMA signal, requirements for the dynamic range of a spectrum analyzer are very challenging. This is due to the stipulations of the W-CDMA standard and also due to the nature of the W-CDMA signal. To achieve optimum results an understanding of the signal and also of the internal structure of the spectrum analyzer is necessary.

This paper presents an overview of the spectral behavior and the amplitude distribution of W-CDMA signals. Referred to the signal properties the dynamic range limitations of spectrum analyzers with ACPR measurement of W-CDMA signals will be shown. Next the internal structure of the spectrum analyzer is discussed with reference to its influence on the power measurement of W-CDMA signals, in particular the signal path and power detection. To overcome some limitations software correction of the measured power in the adjacent channels can be used. Methods, prerequisites, limits and the additional error due to the correction are discussed. Results achieving about 80 dBc adjacent channel power ratio are presented.

ROHDE & SCHWARZ

Introduction

With the emergence of the 3rd generation of mobile communication (W-CDMA) different proposals exist to make it suitable for high speed transmission. Based on the experimental system of the Japanese network operator NTT DoCoMo, standardization activities of the Japanese ARIB and the European ETSI are at present taking place. The common feature of the different proposals is a higher RF bandwidth used for transmission to cope with the data rates needed, e g for data and video transmission.

Equipment suppliers as well as test instrument manufacturers are faced with RF signals becoming more broadband in comparison with existing analog systems of the 1st generation and digital systems of the 2nd generation. This creates new requirements in the generation and analysis of the signals at the air interface and at module level. At a first glance the wideband CDMA signal looks like an IS-95 signal except for the bandwidth. However the W-CDMA signal is more complex in terms of its internal structure.

Structure of W-CDMA signals

The structure of the physical channels, the modulation and spreading are in parts different from IS-95. Only QPSK modulation is used with W-CDMA. The baseband filter is a root raised cosine filter. Its roll-off factor of 0.22 results in a similar steep decay in the frequency domain as the FIR filter with IS-95. The crest factor with one W-CDMA code channel is 5.5 dB compared to 7 dB with the IS-95 forward link and 5 dB with the IS-95 reverse link.

An important difference is the use of a socalled pilot symbol, which is repeated every 625 µs. It is identical for all code channels. If several channels transmit this pilot symbol at the same time, a high peak power can occur periodically. For this reason with W-CDMA a data offset is defined, which allows a delay of the data of the different code channels. Fig. 1 shows the effect of the data offset on the complementary cumulative probability distribution function (CCPDF) of the power levels for a forward link signal with 8 code channels.

With the use of a suitable data offset the probability for the occurrence of power levels higher than 5 dB above the average power is reduced considerably.

Fig. 2 shows the CCPDF for 2, 4, 8 and 15 code channels with equal power and data offset.

As expected the crest factor increases with an increasing number of code channels. But a comparison of the curves for 8 and 15 code channels shows that up to 11 dB and an associated probability of 3×10^{-5} the curves are very similar.

Compared to IS-95, requirements for W-CDMA mobile station transmitters are more critical. For transmission of high data rates multicode transmission is specified. The mobile station has to transmit several code channels. Although less channels have to be transmitted compared to a base station in Fig. 2, it is shown that the CCPDF is almost as critical as for the downlink signal.

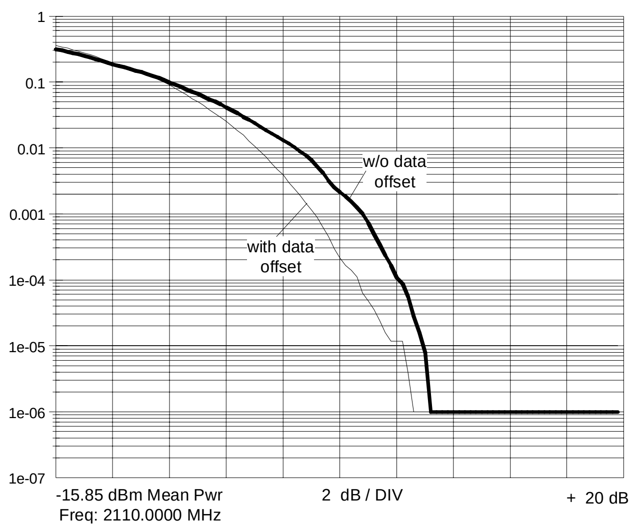

Fig. 1 CCPDF of a W-CDMA signal with 8 code channels with and w/o data offset generated with the signal generator SMIQ and the IQ source AMIQ

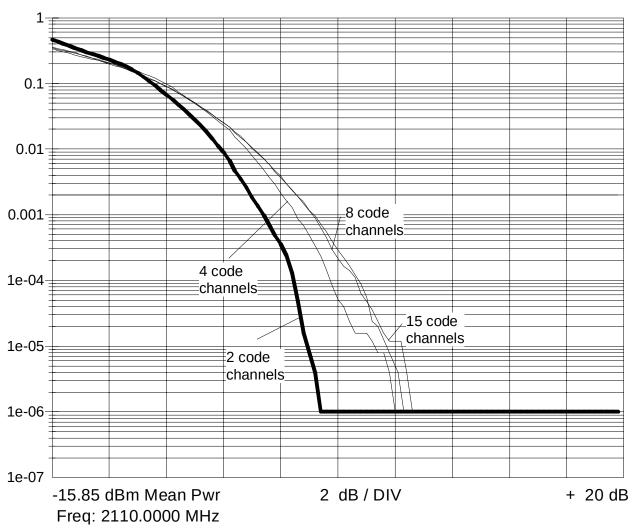

Fig. 2 CCPDF of a W-CDMA signal with 2, 4, 8 and 15 code channels generated with the signal generator SMIQ and the IQ source AMIQ

ACPR measurement

One important measurement on transmitter signals is the adjacent and alternate channel leakage power, in order to ensure interference-free communication on neighbouring channels. The standards set high demands on the adjacent and alternate channel power ratio. For a base station transmitter according to the NTT DoCoMo specification the adjacent channel power at the antenna connector should be 55 dB below the transmit power, both measured in a 4.096 MHz channel bandwidth. In the 1st alternate channel the leakage power should be even 70 dB below the transmit power. At the module level the requirements are even higher as many stages within a base station contribute to the total leakage power.

In order to measure the leakage power correctly a margin between the power to be measured and the inherent power of the spectrum analyzer in the neighbouring channels is needed. If the inherent power and the power from the device-under-test are of equal magnitude, the test result will be 3 dB above the true power of the device-under-test. With a margin of 6 dB the test result will be 1 dB above the true power. Fig. 3 shows the error due to the margin between the inherent power of the spectrum analyzer and the power of the device-under-test. A tolerable error of 0.5 dB requires a 9-dB margin between device under test and the inherent power indication of the spectrum analyzer.

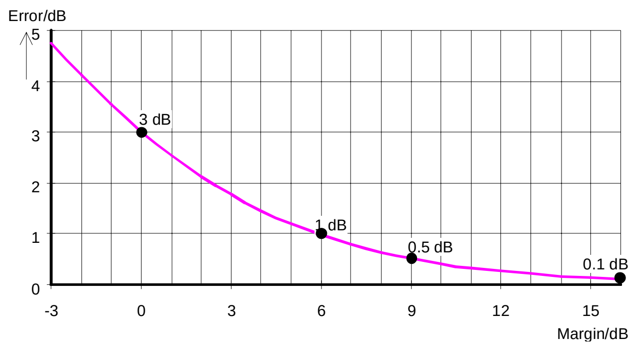

Fig. 3 Measurement error due to margin between device-under-test and spectrum analyzer

Referred to the base station transmitter minimum specification mentioned above for a 0.5-dB error the dynamic range of the spectrum analyzer has to be 64 dB in the adjacent channel and 79 dB in the 1st alternate channel. Dependent on the margin to be met on module level the requirements are higher, accordingly.

The ACPR dynamic range of a spectrum analyzer is determined by three factors:

- the load capability of the signal path without distorting the CDMA signal
- the thermal noise floor of the spectrum analyzer and
- the phase noise of the internal local oscillators.

The load capability determines the maximum level, which can be applied to the input mixer of a spectrum analyzer without generating excessive spectral regrowth in the neighbouring channels. It is related to the third order intercept point.

(T.O.I.) known from two tone measurement. The T.O.I. is only a relative measure for the spectral regrowth as the structure of a W-CDMA signal is completely different from a two tone signal. But the relationship between leakage power in the adjacent channel and transmit power are similar to the level relation valid for third order intermodulation distortion. If the power of the transmit signal is increased by 1 dB the leakage power increases by 3 dB. As a rule of thumb found by measurements on W-CDMA signals the adjacent channel leakage power intercept point is about 8 dB greater than the third order intercept point. The 8-dB value is referred to a 11-dB crest factor of the W-CDMA signal. For other crest factors it can be different.

From this relationship the adjacent channel leakage power due to distortion can be estimated form the third order intercept specified in the data sheet of most spectrum analyzers and the power applied to the input mixer of the spectrum analyzer.

The Rohde & Schwarz Signal Analyzer FSIQ7 specifies a third order intercept point of 20 dBm in the W-CDMA band. On applying a W-CDMA signal with –10 dBm level to the input mixer the following adjacent channel leakage power ratio (ACPR) due to distortion can be expected:

$$\begin{aligned} \text{ACPR} &= (\text{T.O.I.} + 8\ \text{dB}) \times 2 - P_{in} \\ &= (28 \times 2 + 10) \\ &= 76\ \text{dBc} \end{aligned} \quad (1)$$

Note: The mixer level is the level applied to the RF input of the spectrum analyzer minus the set value of the input attenuator.

The absolute power due to distortion is –86 dBm (ACPR – input level)

The minimum measurable power is determined by the inherent noise floor

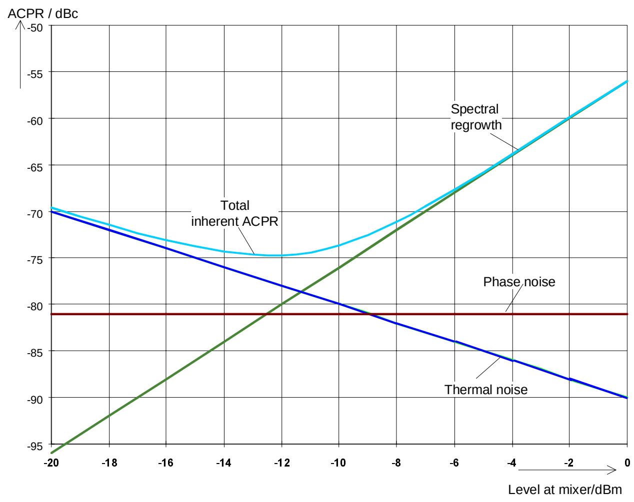

Fig. 4 Contributions to W-CDMA inherent ACPR of Signal Analyzer FSIQ7 dependent on channel power at the input mixer (5 MHz channel offset, 4.096 MHz channel bandwidth)

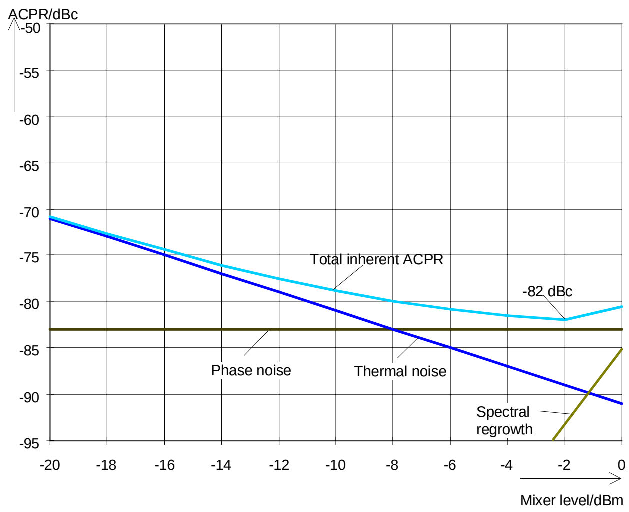

Fig. 5 Inherent ACPR of FSIQ7 in the 1st alternate channel dependent on mixer level

as well as the phase noise of the internal oscillators of the spectrum analyzer.

The inherent thermal noise power can be determined from the noise figure of the spectrum analyzer. Often the displayed average noise level (specified as DANL in data sheets) with 10 Hz or sometimes with 1 Hz resolution bandwidth is used instead of the noise figure. From DANL first noise power has to be calculated within the specified bandwidth. Due to averaging in the logarithmic display range DANL is 2.5 dB lower than the noise power (1.05 dB due to averaging plus 1.45 dB due to logarithmic scaling). The noise power within the specified bandwidth has to be scaled to the 4.096-MHz bandwidth for the W-CDMA channel.

This results in a channel power due to inherent thermal noise ($CHPWR_{noise}$) according to the following formula:

$$CHPWR_{noise} = DANL + 2.5\ dB + 10 \times lg(4.096 \times 10^6\ Hz/10\ Hz) \quad (2)$$

Signal Analyzer FSIQ7 has a DANL value in a10-Hz bandwidth of typically –148 dBm. This results in –89.4 dBm noise power in 4.096 MHz channel bandwidth. Assuming –10 dBm power at the input mixer the adjacent channel power ratio is –79.4 dBc.

The ACP due to the phase noise of the internal oscillators can be estimated from the phase noise specification of a spectrum analyzer at the offset range of the adjacent channel (2.952 MHz to 7.048 MHz). For accurate calculation of leakage power due to phase noise ($CHPWR_{phasenoise}$) it has to be determined over the 4.096 MHz adjacent channel bandwidth. However, for an estimation the phase noise value at the center of the adjacent channel can be used, e g at 5 MHz offset from the transmit channel center frequency.

$$CHPWR_{phasenoise} = L_C + 10 \times lg(4.096 \times 10^6) \quad (3)$$

where L_C = phase noise in 1 Hz bandwidth in dBc.

The typical value for the Signal Analyzer FSIQ7 is –147 dBc. This results in an adjacent channel power ratio of –81 dBc.

Regarding the three contributions to the inherent ACP of the FSIQ7 with –10 dBm mixer level, the distortion part is dominant, but also the thermal noise and to a lesser extent the phase noise contribute to the total inherent ACP. The power of all three contributions has to be added linearly.

Fig. 4 shows the contribution of all three parts to the inherent ACPR dependent on the mixer level.

The horizontal axis of Fig. 4 shows the channel power at the input mixer of the FSIQ7. If RF attenuation is set to be >0 dB then it is the signal power minus the RF attenuation. The vertical axis shows the adjacent channel power ratio (ACPR) with 4.096 MHz bandwidth of the transmit and adjacent channel.

With leakage power measurement in the 1st alternate channels the 5th order intermodulation products fall into the channel. 3rd order intermodulation products do not exist in the 1st alternate channel. However, 5th order products are much lower in level and do not contribute to the leakage power with the mixer level range regarded. This means that mainly thermal noise and phase noise of the spectrum analyzer influence the inherent leakage power.

Fig. 5 shows the inherent dynamic range of the 1st alternate channel power ratio with the FSIQ7.

The maximum dynamic range is attained with a level of about 10 dB higher than the optimum mixer level for inherent adjacent channel power ratio. For the FSIQ7 the inherent dynamic range is about 82 dB mainly due to its phase noise at 10 MHz carrier offset (–149 dBc in 1 Hz bandwidth).

Settings of the spectrum analyzer

Consideration of level setting

Due to the amplitude distribution of the W-CDMA signal discussed and the relative narrow mixer level range for optimum ACPR the spectrum analyzer has to be set up very carefully in order to attain optimum performance. To set up a spectrum analyzer correctly some understanding of its internal structure is necessary. As an example Fig. 6 shows the structure of the signal path of the signal analyzer FSIQ7.

The bandwidths and the 1-dB compression points of Fig. 6 correspond to the values of the FSIQ. For the peak power levels of the W-CDMA signal a typical signal with a peak envelope power to mean power ratio of 11 dB is assumed. Actual values depend on the type and number of code channels available within the CDMA signal.

Following conclusions can be made regarding the different bandwidths and power levels of the signal path.

- Because the peak power is well above the mean power (11 dB in the example of Fig. 6), the input attenuator has to be set according to the peak power rather than the displayed trace or the measured mean power. This ensures that the peak power is within the linear range of the signal path up to the IF filter RBW1. As a rule of thumb the peak power should be about 10 dB below the 1-dB compression point of the signal path in front of the IF filter (RBW1, see Fig. 6).
- The trace shown on the screen (level in front of the log amp) is 21.3 dB below the mean power level or 32.3 dB below the peak power level of the W-CDMA signal. This is due to the decrease of power proportional to the bandwidth reduction from 4.096 MHz to 30 kHz.
- The narrow resolution bandwidth compared to the signal bandwidth alters the amplitude probability distribution of the CDMA signal to a white noise like Gaussian distribution.
- The reference level setting should be decoupled from the input attenuator setting because the step gain amplifier (see Fig. 6) which sets the reference level is loaded with a power 19 dB lower than the stages preceding the IF filter stage 1 (RBW1). Spectrum analyzers have coupled settings for the input attenuator which are optimized for CW signals with the same level independent of the bandwidth. Decreasing the reference level with a fixed input attenuator setting (e g increasing the gain of the last IF) leads to a lower noise floor as the stages following IF amplifier do not contribute to the overall noise floor.

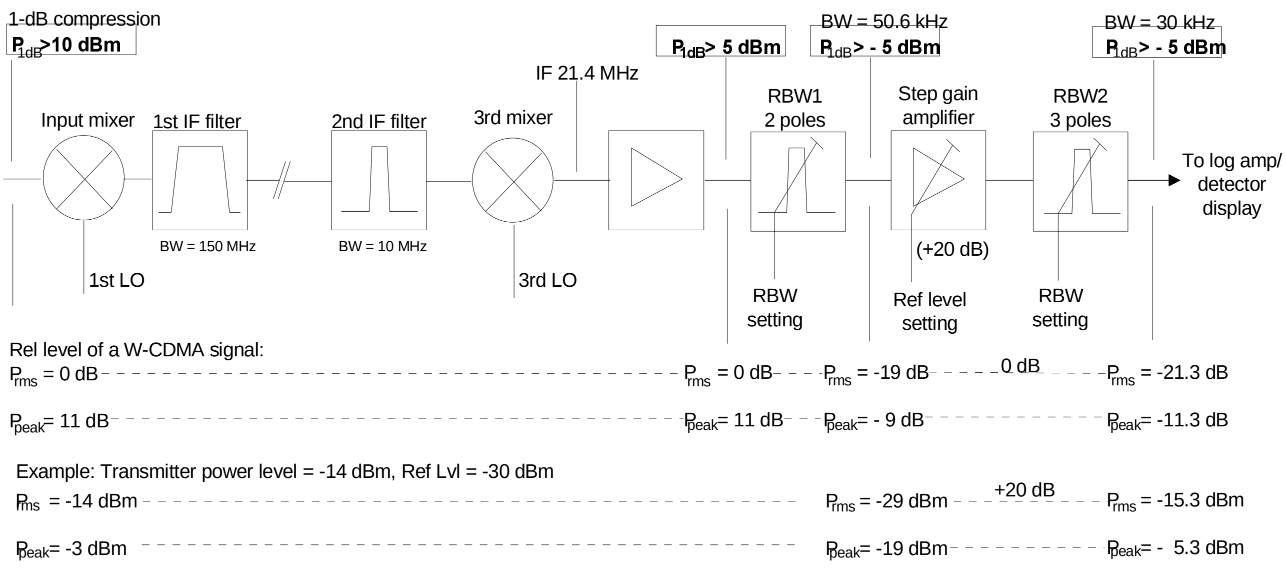

Fig. 6 Simplified spectrum analyzer block diagram of signal path (all levels referred to RF input, resolution bandwidth is 30 kHz)

- When measuring in the adjacent channel the amplifier setting the reference level (step gain amplifier in Fig. 6) is not loaded by the transmit power. This allows a further decrease of the reference level resulting in a higher trace level in a more linear region of the display. The measurement uncertainty of the power measurement in the adjacent channels is improved as the display linearity normally improves with higher display levels.

Selection of resolution bandwidth

For measuring the channel power or adjacent channel power, spectrum analyzers provide specific software routines. The channel filter is simulated by summation of the linear level of the pixels on the screen over the specified channel bandwidth.

The resolution bandwidth has to be set narrow compared to the channel bandwidth in order not to widen the channel bandwidth due to the high shape factor of the spectrum analyzer filters. Wide resolution filters result in poor selectivity of the channel filters and limit the dynamic range attainable for leakage power measurement in the adjacent channel as the transmit power is not attenuated sufficiently. The resolution filter to be used can be derived from the channel configuration. With 4.096 MHz channel bandwidth and 5 MHz channel spacing the gap between the band edges of the transmit channel and the adjacent channel is 904 kHz. The resolution filter used has to attenuate at 904 kHz offset sufficiently (e g 80 dB) in order not to influence the adjacent channel power by the transmit power. The spectrum analyzer´s 5-pole filters have a 60:3 dB shape factor of about 10 (12 guaranteed with most spectrum analyzers) and a 80:3 dB shape factor of about 16. This means that the attenuation at 10 x RBW/2 offset from the channel limit is 60 dB and at 16 x RBW/2 offset it is 80 dB, e g for 100 kHz RBW the 60-dB attenuation offset is 500 kHz and the 80-dB attenuation offset is 800 kHz. 100-kHz and 30-kHz resolution bandwidths are therefore the preferred settings. This assures that selectivity does not influence the power measurement in the adjacent channels.

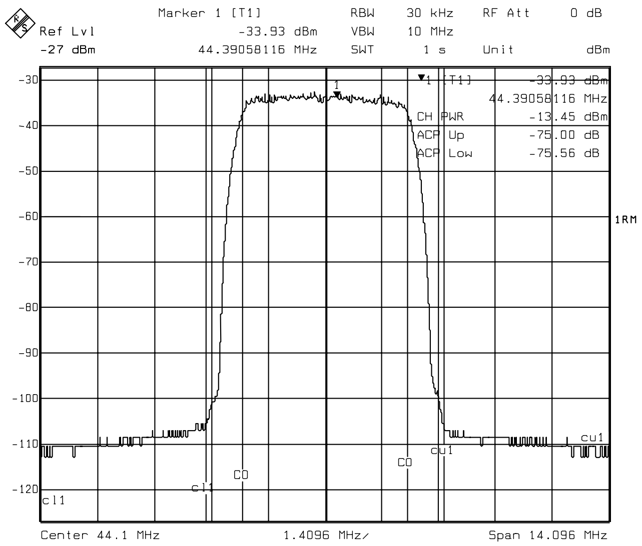

Fig. 7 Screen shot of an ACPR measurement using rms detector showing inherent ACPR of FSIQ7

Selection of the detector

In order to measure power the sample detector or rms detector should be used and the video bandwidth set 3 or 10 times the resolution bandwidth used. The sample and rms detector are the only two detectors available in spectrum analyzers capable of performing power measurements.

Due to the integration method employed with the sample detector, stability of test results is dependent on the pixels available within the channel for trace display. If the number of trace pixels within the channel bandwidth is too low the repeatability of the test result is poor. For a repeatability of 0.1 dB about 1000 pixels are necessary [4].

Often trace averaging is used for smoothing the trace with noise like signals. But in the case of power measurement averaging of the trace is not an appropriate means. It has to be avoided as averaging of a trace in logarithmic scaling leads to lower test results compared to the actual power value. Also linear averaging leads to lower absolute test results. Some spectrum analyzers correct the test results for the errors introduced by averaging. This is possible to some extent, when the signal to be measured is uncorrelated.

A more straightforward method is the use of the rms detector. It needs no averaging of the trace pixels as it displays the power of the spectrum represented by each pixel. The time for power measurement is selected by setting the sweep time. A longer sweep time results in a longer measuring time per pixel leading to a stabilized test result. The test result is directly comparable to that of a thermal power meter. The rms detector is therefore the preferred detector for ACPR measurement.

Improvement of dynamic range by noise compensation

As mentioned above the spectrum analyzer´s inherent leakage power in the adjacent channels is the sum of three sources. It is added to the leakage power of the device-under-test in the respective channel. If the inherent leakage power would be known exactly, it could be subtracted from the measured leakage power in each of the adjacent channels. That way the dynamic range for ACPR measurement can be increased but also the measurement error can be reduced, as the test result is influenced by the inherent channel power to a lesser extent.

The only problem is to measure the inherent channel power with high accuracy and stability. This is not an easy task with a view to the distortion part and the phase noise part. Both require an ideal reference input signal normally not available. But this procedure is feasible with the thermal noise part, if the inherent thermal noise power of the spectrum analyzer can be measured with high accuracy. For inherent thermal noise measurement only the input signal has to be removed.

If the thermal noise power can be decreased for example by 20 dB, it hardly contributes to the total inherent adjacent channel leakage power. As shown in Fig. 8 with inherent thermal noise suppression for a mixer level >–12 dBm the spectral regrowth is dominant, below –12 dBm the phase noise is dominant. The dynamic range for ACPR measurement is increased to 80 dB in the adjacent channel.

If the inherent thermal noise is compensated in the 1st alternate channel, the leakage power is determined mainly by the spectrum analyzer phase noise (see Fig. 9). The optimum mixer level gets less critical as the minimum leakage power is attained at lower mixer levels.

Moreover, the same mixer level settings can be used for measurements in the adjacent channels and in the 1st alternate channels. Optimum for both measurements is a mixer level of about –16 dBm.

Prerequisite for compensation of the internal spectrum analyzer noise is a very high display linearity and high stability and repeatability of the power measurement. The reason is that for low signal-to-noise ratios two power values of nearly equal magnitude have to be subtracted linearly. For this purpose the rms detector is of great advantage, as it shows very stable and repeatable test results, especially if the sweep time is increased.

Assuming an overall error (repeatability and display non-linearity) of less than 0.1 dB, Fig. 10 shows the measurement error using noise compensation dependent on the signal-to-noise ratio.

The curves in Fig. 10 show a great improvement in the measurement accuracy for signal-to-noise power ratios down to –10 dB. At 0 dB S/N the error introduced by internal noise is negligible. Even at –10 dB S/N the error is only about 1 dB compared to more than 10 dB without noise compensation.

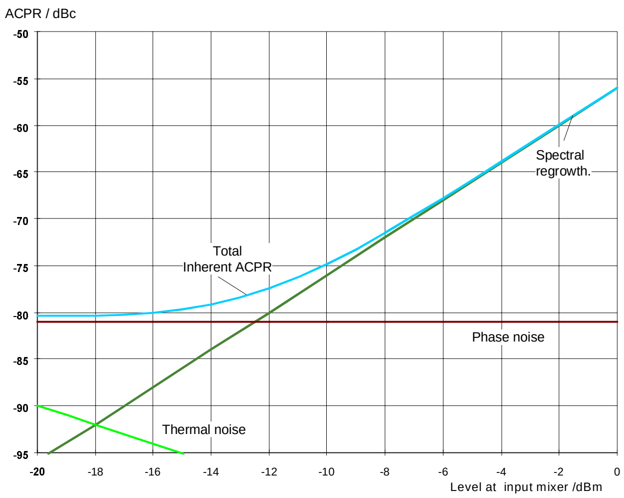

Fig. 8 Contributions to W-CDMA inherent adjacent channel power ratio of Signal Analyzer FSIQ7 dependent on mixer level with compensation of inherent thermal noise power

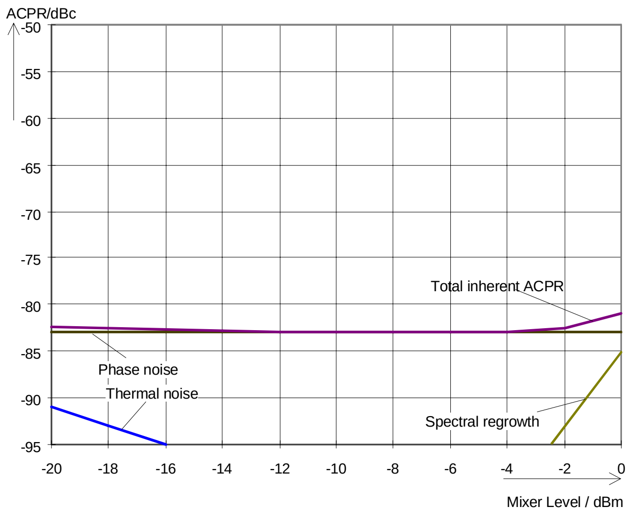

Fig. 9 Contributions to W-CDMA inherent 1st alternate channel power ratio of the Signal Analyzer FSIQ7 dependent on mixer level with compensation of inherent thermal noise power

Conclusion

The challenges in terms of the dynamic range for measuring the leakage power of W-CDMA transmitter signals with a spectrum analyzer were shown. Due to the amplitude statistics of the signal the optimum settings of the spectrum analyzer, optimum mixer level and achievable dynamic range were discussed using the specifications of the Signal Analyzer FSIQ7. An increase of the dynamic range to 80 dB in the adjacent channel and 83 dB in the 1st alternate channel was shown to be possible by compensation of the inherent broadband noise of the spectrum analyzer.

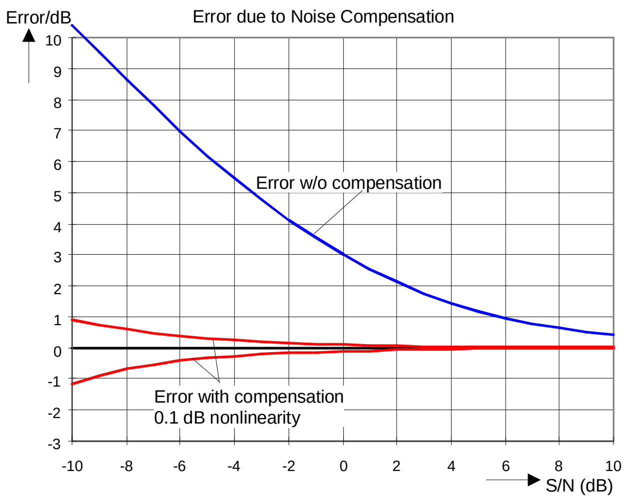

Fig. 10 Error for channel power measurement w/o and with noise compensation dependent on signal-to-noise ratio

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