Proceedings of the 10th WSEAS International Conference on COMMUNICATIONS, Vouliagmeni, Athens, Greece, July 10-12, 2006 (pp290-295)

Some Aspects Regarding the Measurement of the Adjacent Channel Interference for Frequency Hopping Radio Systems

PAUL BECHET, RADU MITRAN, IULIAN BOULEANU, MIRCEA BORA
Communications and Information Systems Training Center, Sibiu
MIRCEA VIRGIL POPA
Land Forces Academy, Sibiu
ROMANIA

Abstract – The paper presents an Adjacent Channel Interference (ACI) measuring method for Frequency Hopping (FH) radio stations using a digital spectral analyzer. The characteristics of the spectral analyzer can influence the measured value; that is why corrections are necessary. The paper proposes a measurement method which is in agreement with the signal statistics offered by the frequency hopping radio station.

Key-Words: - adjacent channel interference, frequency hopping, radio systems, signal spectrum measurements

1 Aci for frequency hopping equipments

The **A**djacent **C**hannel **I**nterference (ACI) is determined especially by the non–linear behavior of the **P**ower **R**adio **F**requency **A**mplifier (PRFA) of **F**requency **H**opping (FH) equipment. In mobile radio applications, the use of non–linear power amplifiers (AB, B and C functional classes) is preferred in order to optimize the energy consumption and to prolong the functioning period of the batteries. In the case of digital modulation (secure Fixed Frequency (FF) operation mode – digital FF), the non–linear functioning of the PRFA may determine the restoration of the side lobes.

Filtering the RF signals at the modulator output produces significant variations of the signal envelope and, implicitly, a greater volume of ACI.

The interference level can be limited using filters at the PRFA output. The parameters and the type of the filters establish the attenuation level for ACI, harmonics and intermodulation products. A strong filtering may lead to an increased **I**nter–**S**ymbol **I**nterference (ISI) and BER degradation at the reception side. Thus, it is necessary to optimize these filters in order to obtain equilibrium between the attenuation of unwanted interference and maintaining BER at an acceptable level.

In the digital FF operation mode, the synchronization is obtained by transmitting a synchronization sequence at the beginning of the traffic or by inserting synchronization sequences into the traffic. The first method prevents the increase of the information transfer rate (Rb) because the synchronization bits are transmitted only once. However, this method doesn't allow the synchronization of the radio stations accessing later the network. The second method allows the synchronization of the above mentioned radio stations, but increases the transfer rate because the synchronization bits are sent periodically.

Transmitting the synchronization sequence at the beginning of the data traffic determines the occurrence of discrete spectral components with a spacing of Rb/2 Hz (Fig. 1).

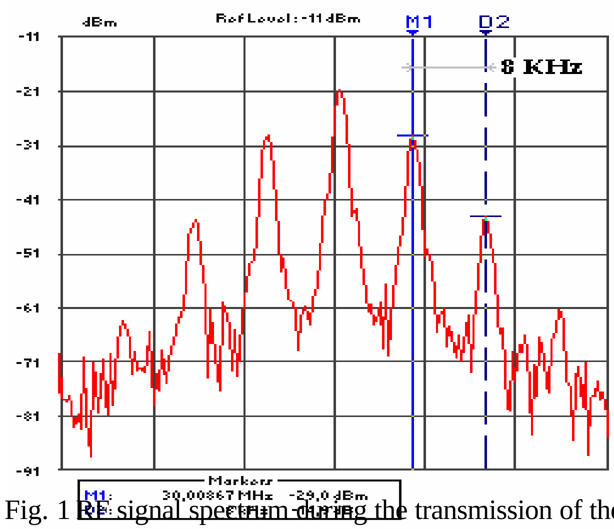

Fig. 1 RF signal spectrum during the transmission of the synchronization sequence (MSK signal, Rb = 16 kbps)

The discrete spectral components appearing during the transmission of the synchronization sequence may create interferences in the adjacent channels. A longer synchronization sequence determines stronger negative effects in the adjacent channels.

The Adjacent Channel Power Ratio (ACPR) characterizes an emitter's capability to concentrate the power in the transmission channel and to radiate as little power as possible in the adjacent channels.

2 Measuring ACI with spectral analyzers

The main parameters limiting a spectral analyzer's capability of correctly measuring ACI are: the **D**isplayed **A**verage **N**oise **L**evel (DANL); the analyzer's phase noise; the second order harmonic distortions; the intermodulation distortions; the analyzer's resolution (RBW).

DANL determines the minimum measurable level of the signal. A signal having a level below DANL will not be displayed by the spectral analyzer. This parameter depends on the noise figure of the spectral analyzer, a value which can be measured by connecting a 50 Ω resistance to the analyzer RF input and measuring the noise level displayed on the analyzer's screen. DANL varies also with the spectral analyzer's resolution by the following formula:

$$\Delta = 10 \cdot \log \frac{RBW_1}{RBW_2} \qquad (1)$$

where ? is the difference between $DANL_1$ and $DANL_2$. Thus, by increasing the measuring resolution by 10, DANL will increase with 10 dB (Fig. 2).

A method of reducing the DANL value consists in coupling a preamplifier at the analyzer input. Some analyzers have incorporated preamplifiers, which can be switched on or off.

The choice of the analyzer resolution determines in a great extent the measurement errors. The choice of a too high resolution (wideband RBW filter) induces a reduced selectivity of the analyzer in extracting the channel of interest. In this case, the obtained value will be greater because the analyzer integrates also the signals outside the channel of interest. The recommended RBW value for the CHANNEL POWER operation mode is between 1 and 4 % of the channel bandwidth [1]. For instance, for 25 kHz FH radio channels, the optimum RBW value is between 250 Hz and 1 kHz. For the performed measurements, the RBW value was chosen to be 300 Hz.

The thermal noise and the phase noise have a Gaussian distribution, thus being incoherently combined with the useful signal. Combining these noises will determine a noise distribution which will limit the analyzer's possibility to measure small ACPR values. This minimum threshold depends on the spacing and the analyzer input level. Fig. 3 illustrates an example obtained for a 25 kHz radio channel.

ACPR can be measured up to a minimum level of –40 dB in the first adjacent channel, reaching –67 dB at 400 kHz spacing. The minimum threshold also depends on the signal level at the analyzer's first mixing stage input.

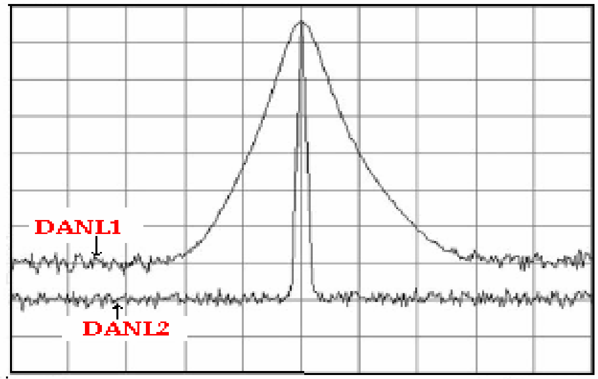

Fig. 2 Increasing RBW determines the increasing of DANL

For greater values, the dynamic range increases, implicitly permitting the measurement of smaller ACPR levels. Starting with –25 dBm, small ACPR levels are concealed by the analyzer's internal noise. Different minimum thresholds varying with the input level occur only at a spacing exceeding 100 kHz. Up to this value, the phase noise is the main factor limiting the analyzer's capability of measuring ACPR and this parameter does not depend on the mixer input level.

In Fig. 3 a minimum value of –40 dB was obtained for an input level smaller or equal with –12 dBm. In conclusion, maintaining the mixer input signal level below –12 dBm, ACPR can be measured in the first adjacent channel up to –40 dB.

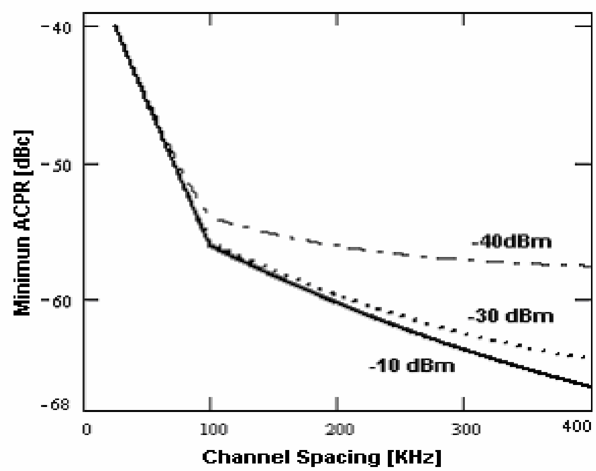

Fig. 3 Minimum measurable ACPR for 25 kHz channels varying with the spacing and the mixer input signal level

The phase noise is the main parameter limiting the dynamic range of the spectral analyzer in the first adjacent channel. Greater dynamic range values may be obtained by using spectral analyzers with a reduced phase noise.

For establishing the optimum mixer input signal level, the measurement errors were not observed, although they could significantly influence the measured results. Consequently, the optimum mixer input level has to be corrected in order to maintain BER at an acceptable level.

In order to establish the way these three types of internally generated signals (thermal noise, phase noise and intermodulations) are influencing the measured signal, it has to be determined how these signals combine with the measured signal. The internal noise and the phase noise are incoherently combined with the tested signal and the intermodulations generated by the analyzer's mixer are coherently combined with the tested signal [2].

The measurement errors caused by the incoherent combination of the tested signal with the phase noise and the thermal noise depend on the S/N ratio. The smaller this ratio is, the greater will the measurement errors be.

The intermodulations generated by the internal mixer are coherently combined with the distortions of the tested signal [3]. The power of the obtained signal may assume any value between the sum and the difference of the power values of the two signals, depending on the phase relationship of the two signals. Because the relationship between the tested signal intermodulation phase and the internal intermodulation phase is not known, a certain uncertainty value has to be applied to the measurement results. The value of this uncertainty is mathematically expressed by the following formula:

$$Uncert.[dB] = 20\log\left(1 \pm 10^{\frac{d}{20}}\right) \qquad (2)$$

where d is the ratio of the distortions of the tested signal to the internal distortions (in dB).

The error generated by the measurement uncertainty can not be eliminated because the addition value and sense can not be predicted any more as for the errors generated by the internal noise and the phase noise [4]. For a certain case, only the measurement uncertainty limits can be established.

In order to maintain the uncertainty value below 1 dB, the internally generated intermodulations have to be at least 18 dB below the tested signal intermoidulations level. The optimum signal level value at the mixer input is –25 dBm (Fig. 4). For this value, the maximum dynamic range for the first adjacent channel is –52.71 dB. The measurement errors in this dynamic range are below 2 dB.

Reducing the mixer input level and simultaneously increasing the spacing from the main channel causes the increasing of the maximum dynamic range. Thus, for channels with a spacing of 300 kHz from the main channel, ACPR can be measured up to –56 dB. The increasing of the dynamic range along with the increasing of the spacing was supported by the decrease of the phase noise. For a spacing value greater than 400 kHz, the phase noise is comparable with the thermal noise, and the increasing of the dynamic range along with the increasing of the spacing can not be sustained. For a spacing of 600 kHz, a dynamic range threshold value of –61 dB was obtained. Measuring ACPR below this value will determine the increasing of the measurement errors and of the measurement uncertainty above the value of 1 dB [5].

On hand of the previously obtained data for each spacing value, a maximum measurable ACPR value and a ACPR value measurable with an error below 1 dB and an uncertainty below 1 dB were obtained. The difference between these two values is approximately constant for every spacing (8 dB). The two curves resulting from the graphical representation of these values can be practically used for estimating the quality of the measurements (Fig. 5). If a measured value is situated above the first curve, the measurement errors will be below 1 dB. If the measured value is situated between the two curves, the measurement will show errors above 1 dB and the obtained result has to be corrected. The measured values situated below the second curve are values measured below the internal noise floor and the mixer generated distortions. In this case, irrespective of the error correction method applied, the uncertainty determined by the internal distortions can not be eliminated.

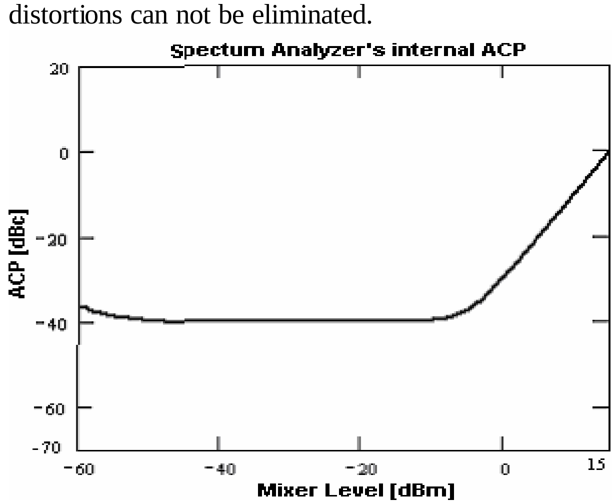

Fig. 4 Internal ACP generated by the spectral analyzer

3. Results and discussions

ACPR measurements for a FH radio station were accomplished by measuring the emitted power in a 25 kHz channel. The analyzer configuration is shown in Table 1.

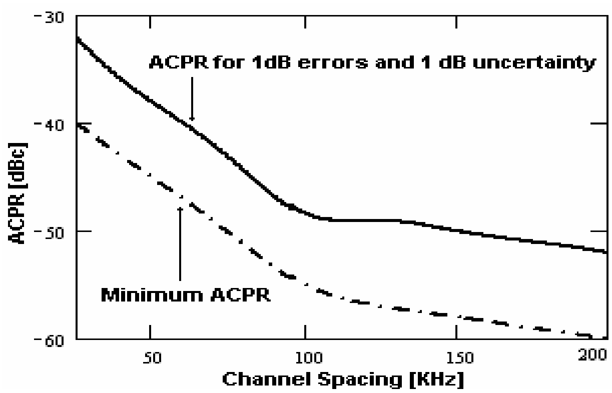

Fig. 5 Minimum measurable ACPR with (continuous line) and without imposed maximum error conditions

Table 1 Configuration of the spectral analyzer for ACPR measurements

Parameter	Value
RBW	300 Hz
VBW	3 kHz
Detector	RMS
Amp. Ref.	< –10 dBm
Sweep Time	2 s

The reference level (Amp. Ref.) was maintained below –10 dBm, as close as possible to the analyzer input power level. Thus, the analyzer's attenuator introduces no attenuation and the dynamic range is maximized.
The radio station was operated at the maximum power level (5 W; 37 dBm). Because the incorporated programmable attenuator wasn't used, an external attenuator was used instead. Hereby, the mixer input level was equal to the analyzer input level, which is known. The channel sweep time was chosen to be 2 s, so that the measured value takes into account a great number of samples, eliminating short term variations of the measured power.

ACPR was determined by measuring the emitted power values in the main channel, the adjacent channel and the first 8 alternative channels with a spacing of 25 kHz to 200 kHz from the main channel. ACPR was obtained by reporting the measured power values in the adjacent and alternative channels to the power measured in the main channel.
ACPR was measured in the above described conditions for different mixer input levels with the aim of establishing a relationship between ACPR and the mixer input level. ACPR of the radio station input signal should be independent of the signal level at the radio equipment input. If ACPR varies for different input levels, then the mixer introduces distortions on he measured signal.
According to Fig. 6, differences occur at spacing values greater than 150 kHz for power input levels of –2 dBm. For levels exceeding –10 dBm, the differences between ACPR measured for different levels are insignificant.

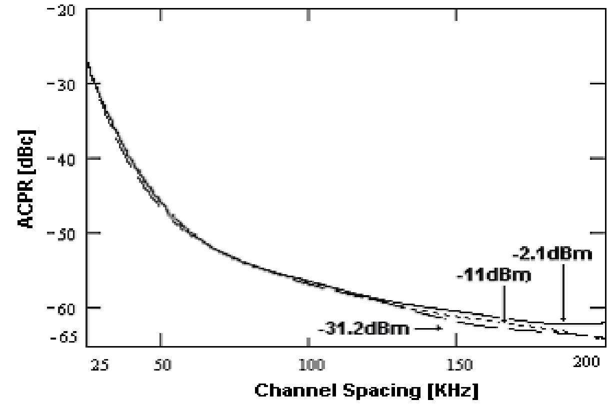

Fig. 6 ACPR varying with the spacing for different mixer input power levels

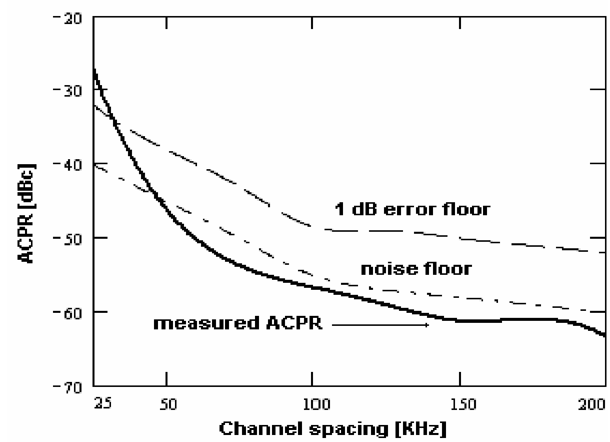

Fig. 7 ACPR varying with an error floor of 1 dB and with the noise floor

As a conclusion, for ACPR measurements, the mixer input should register values below –10 dBm. When the analyzer's attenuator is correlated with the analyzer input level, this requirement is automatically accomplished.
The measured values should be reported to the previously established measurement thresholds of the analyzer. The error floor of 1 dB determines the minimum values for which the measured ACPR is affected by errors below 1 dB and an uncertainty value below 1 dB (Fig. 7). The noise floor represents the power level of the phase noise and the thermal noise in the 25 kHz channel.
For the first adjacent channel, the ACPR value obtained was above the 1 dB threshold. For a spacing value greater than 40 kHz, the measured values are situated below the noise floor, assuming values up to 3 dB. Practically, the measured values can not be situated below the noise floor. The difference between the measured level and the noise floor occurs due to the

tolerances accepted for the analyzer's specifications values, these being used for establishing the noise floor. Hence it will be assumed that the values measured for a spacing exceeding 40 kHz are equal with the noise floor.

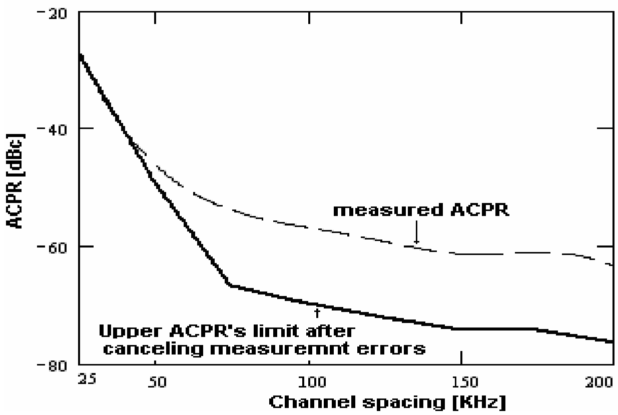

Fig. 8 Measured ACPR and corrected ACPR

In this case, according to the above specified observations, the real ACPR level is minimum 13 dB below the measured one (Fig. 8).

In the FH operation mode, the hopping rate was considered to be 100 hops/s. The transmission time on one frequency is smaller than 10 ms. This means that the spectral analyzer has to intercept the signal and measure its power during one hop. The above mentioned requirements can be accomplished by using the spectral analyzer in the TDMA Power operation mode and by employing an accordingly tuned trigger.

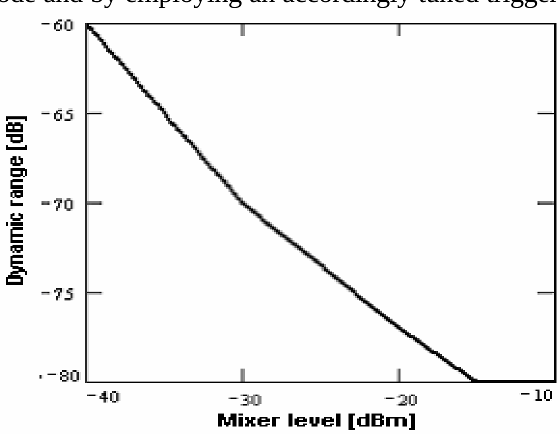

Fig. 9 Dynamic range due to the thermal noise level for a 30 kHz channel varying with the mixer input level

The phase noise shows the same behavior as for FF signals. Adding the thermal noise to the phase noise leads to the dependence of the dynamic range to the spacing and the mixer input level (Fig. 9). The obtained threshold represents the minimum measurable ACPR value (Fig. 10).

The radio station was programmed to hop on a single frequency.

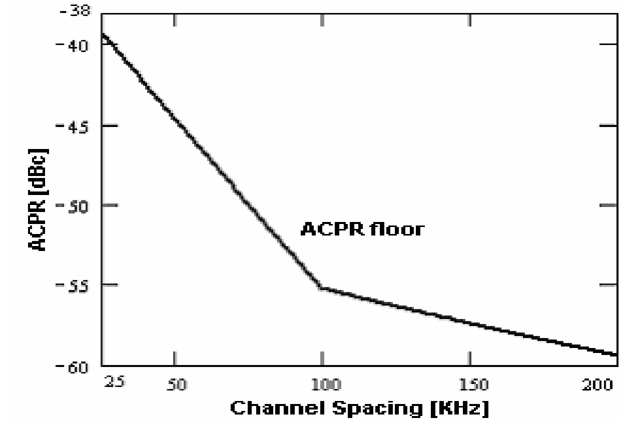

Fig. 10 Minimum measurable ACPR in the FH operation mode

The power of the main channel and of the adjacent channels was measured. The spectral analyzer's parameters for measuring the power are shown in Table 2.

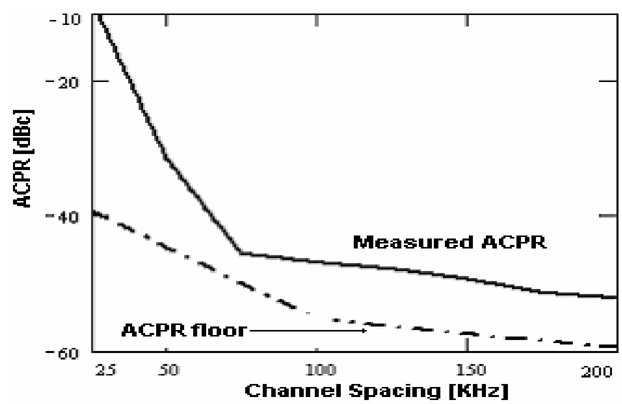

Fig. 11 ACPR measured in the FH operating mode compared to the minimum ACPR limit which can be measured with the spectral analyzer

Table 2 Configuration of the spectral analyzer for measuring the power in the FH operation mode

Parameter	**Value**
Mode	TDMA Power
Amp. Ref.	–21 dBm
RBW	30 kHz
SWT	10 ms
Trigger	Video
Meas. Time	8 ms
Detector	Sample
Trace	Average

The measured values represent the mean value obtained for 10 consecutive hops. The results were reported to the minimum ACPR limit measurable with the spectral analyzer in the above mentioned conditions.

According to Fig. 11, the obtained values are situated above the minimum threshold with values between 5 dB and 15 dB. For these values of the noise margin, the errors determined by noise are situated between 1.1 and 0 dB. The uncertainty determined by the distortions generated by the non–linear behavior of the spectral analyzer reaches a maximum level of 1 dB at a spacing value of 200 kHz. It results that, in this case, the values obtained by measurements exhibit a high degree of certainty.

4. Conclusions

On hand of the ideas expressed in the paper, we can estimate the errors of measuring the emitted power in an adjacent channel depending on:

- the performances of the spectral analyzer
  - phase noise
  - IP 2 and IP 3 (IP – Interception Point)
  - the chosen resolution
- the type of the measured signal
  - the signal level in the main channel at the mixer input of the spectral analyzer.

The measurements were performed in the Frequency Hopping (FH) operation mode, the FH list having a single frequency. Extrapolating the obtained data, we can build a mathematical model describing ACI for a real case, where the FH list comprises a set of frequencies.

For the 25 kHz channels used by FH radio stations, the phase noise is the main parameter limiting the ACPR measuring capability of the spectral analyzer. As the spacing increases, the phase noise decreases, thus enlarging the dynamic range and, implicitly, the capability of measuring small ACPR levels. When maintaining a level below –20 dBm, the distortion level is small, as is the measurement ACPR measurements in the proximity of the minimum limit are accompanied by errors and uncertainties.

The errors occurring due to noise may be eliminated if the noise margin is greater than 13 dB. The uncertainty due to the non–linear behavior of the mixer could be known, but not eliminated. For measuring ACPR for channels at spacing values exceeding 40 kHz from the main channel, an analyzer with reduced phase noise and a reduced noise figure is needed.

The values obtained for ACI in the FH operation mode are average values for the duration of a hop. During measurements, we noticed that, at the beginning of a hop, there is an ACI peak up to 20 dB higher than the average value. This peak short duration (below 1 ms). It is also useful to study the ACI distribution during a single hop in order to identify possible peaks, the moments they occur, their duration and value. Another subject of interest is establishing the ACI value varying with spacing, hopping duration and the tuning time.

References:

[1] *** – *Operating Manual: Handheld Spectrum Analyzer R&S FSH3, 2002.*

[2] John Barfus – *Test Spectrum Analyzer ACP Dynamic Range,* Microwaves RF, January 1997, pp. 55-60.

[3] *** – *Application Note 1303 – Spectrum Analysis Basics* , Agilent,

[4] *** – *Spectrum Analyzer Measurements Near the Noise Floor* , Tektronix, 2005.

[5] *** – *Measuring ACPR of W–CDMA Signals with a Spectral Analyzer*, Tektronix, 2000.