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| Date issued:  | 29 March 2018 |
| Source:  | FAU and 450connect |
| Subject:  | Suggestions for “Effective IIP3” and “Effective Selectivity” for parameterization of SEAMCAT IM Plugin |
| Group membership required to read? (Y/N)N |
|  |
| Summary:  |
| This contribution suggests parameters for the SEAMCAT IM plugin concerning effective IIP3 and effective selectivity, which should be used for compatibility studies regarding wideband signals beside narrowband ones.  |
| Proposal: |
| FAU and 450connect invite Group toAdopt “Effective IIP3” and “Effective Selectivity” as basic parameters for simulations of IntermodulationAdopt an Effective IIP3 of +3.5 dB as default valueConsider the Effective Selectivity values suggested in section 6.2In case no consensus can be reached on a specific value for the Effective IIP3 and a specific value for the Effective Selectivity: to conduct compatibility studies selecting multiple parametersto revise the Annex 3 of the report accordingly |
| Background: |
| STG is currently implementing an algorithm for the prediction of Intermodulation response in victim link receivers. This will be done as an IM-Plugin for SEAMCAT. The Plugin will then be used to study the impact of wideband LTE Signals on TETRA receivers with compatibility studies of wideband signals beside narrowband ones. The IM plugin is generic. It needs to be parameterized based on a realistic victim receiver model, which is described by the parameters “Effective IIP3” and “Effective Selectivity”. |

# Introduction

STG is currently implementing an algorithm for the prediction of intermodulation (IM) response inside a victim link receiver (VLR). This algorithm is an approximation in the frequency domain avoiding extensive time domain computations. The algorithm is coded as a plugin for SEAMCAT. The plugin is generic and needs to be parameterized for the specific compatibility study in scope. SE7 intends to use this plugin for compatibility studies looking at wideband signals beside narrowband communication like TETRA in 400 MHz band.

The parameterization of the IM plugin reflects a receiver model for the VLR that is constituted of two parameters: the “Effective IIP3” and the “Effective Selectivity”. The methodology followed is reflected in Fig. 1 taken from [1].

**Task**

Extraction of wideband nonlinear

RX model

**Model parameters**

wideband non linear transfer function
or
effective wideband IP3, and selectivity

**Task**

SEAMCAT simulations

**Prerequisite**

stable and validated
IM Plugin

*Fig. 1: Methodology for compatibility study*

The receiver model derived by any of these methods, reflects a typical receiver, whereby this receiver must be compliant to all 4 specifications for testing receiver nonlinearity, being:

* Intermodulation response rejection
* Spurious response rejection
* Blocking
* Nominal error rate.

It is therefore not sufficient to derive the receiver model and thus the parameterization from one test alone.

# Non-linearity modelling

As discussed in [12] the signal scenario with testing RX intermodulation response for the case of narrowband interferer versus the case of wideband interferer are not comparable. The Signal scenarios are shown in Fig. 2, taken from [12].

f

-47 dBm

-47 dBm

wanted

@RefSens+3dB

25 kHz

narrowband

200 kHz Offset

2 x 200 kHz= 400 kHz Offset

Occupied Bandwidth

200 kHz

f

wanted

@RefSens+3dB

25 kHz

narrowband

Offset t.b.d.

Occupied Bandwidth

3…5 MHz

**a) narrowband case**

**b) wideband case**

*Fig. 2: Signal scenario containing narrowband versus wideband interferer with intermodulation response test*

The occupied bandwidth of 200 kHz with the narrowband case is much smaller compared to the wideband case, where it is 3 or 5 MHz. Furthermore the offset of the interferer to the wanted narrowband signal is 400 kHz in the narrowband case and in the order of several MHz in the wideband case. Because of these two reasons, nonlinearity behaviour assessed with the narrowband case cannot simply be extrapolated to the wideband case.

This fact has a major consequence on modelling the non-linearity of the receiver.

In [13] it was shown that a Taylor series expansion for non-linearity modelling, which is the basis for the IM plugin, is insufficient if the system is memory contained (NLTV system) [12]. For wider bandwidth and larger offset, memory effects become more and more significant and can no longer be neglected.

From circuit analysis of mobiles in the field, it was found that high order reactive networks are used with input filters, interstage filters and IF filters. All these filters contain memory, which makes it necessary to use Volterra series expansion for non-linearity modelling. Furthermore, Volterra series modelling is more complex than Taylor series modelling, a 3-dimensional non-linear transfer function is difficult to extract and Volterra Series modelling cannot be turned into a three-frequency algorithm easily. Hence, in order to account for the memory effects, the concept of “Effective IIP3” has to be implemented in the plug-in.

The Effective IIP3 takes into account the additional effects introduced by memory, wideband behaviour and dispersive impedance terminations in all zones. Therefore, it deviates from an IIP3 that is extracted from the standard IM performance test in a narrowband regime.

# Extrapolation from given narrowband standards (method 1)

In the following, all 4 specifications for RX non-linearity are analysed and conclusions on Effective IIP3 and Effective Selectivity are derived. This approach is followed to extract a receiver model based on all 4 specifications, overcoming the error in case only one out of the four is considered.

## Intermodulation response test

If only an intermodulation response rejection test at a small occupied bandwidth is considered, ignoring the other three receiver specifications, a very low IIP3 of -9.5 dBm would be derived. Since there is no predictable relationship between the non-linear response close to the wanted signal and further away from it, this value can only be considered as a lower bound on IIP3. This value for the IIP3 is insufficient to be used in compatibility studies and must reflect a receiver that complies to all 4 non-linearity specifications.

## Spurious response test

A spurious response rejection test considers a wanted signal 3dB above the static reference sensitivity level. For TETRA, this is: -112 dBm + 3 dB = -109 dBm in the presence of sine tone at any offset, limited by the switching range, the local oscillator frequency and the sum of all the intermediate frequencies. In the TETRA standard the level of the sine tone applied is -45 dBm.

For example, Fig. 3 [15], the spurious response at the frequency defined by the relationship 2 x local oscillator frequency 2 x tone frequency is attenuated by 62 dB.



*Fig. 3: Mixer spurious table (rejections given in [dB])*

The noise floor of the receiver can be approximated roughly by -125 dBm, considering 18 kHz effective RX bandwidth and the receiver noise figure (NF) of 6 dB.

Hence, a -45 dBm signal would have to be attenuated by 80 dB to bring it down to noise level. With a spurious rejection of only 62 dB, an additional selectivity of 18 dB is required to overcome the spurious problem.

Depending on the choice of the IF frequency, the spurious will appear at a certain offset from the wanted signal within tuning range of the RX. Nevertheless this implies that at a certain offset selectivity must be implemented in order to attenuate the input signal at this offset by a value in the order of 18 dB.

## Blocking test

If the blocking specs of TETRA MS are analysed, a selectivity function can be derived indirectly.

|  |  |
| --- | --- |
| *Offset* | *Selectivity* |
| 50…100 kHz | 0 dB |
| 100…200 kHz | -5 dB |
| 200…500 kHz | -10 dB |
| >500 kHz | -15 dB |

*Table 1: Selectivity derived from blocking specification*

In some analysed receiver designs, preselectors providing such selectivity do not exist. The contribution SE7 (17)068 stated: *“The blocking response in a historical receiver would almost certainly be due to overload of the early stages in the receiver, the front end amplifier and the mixer. In a modern receiver blocking can be a combination of overload of these stages. Overload in the IF (both analogue and digital) but also can be a factor of the spurious emissions and noise generated in the receiver local oscillator synthesizer. Close to carrier, noise and spurious outputs from a synthesizer will mix with unwanted signals close to the wanted frequency to produce the intermediate frequency. This will in turn, desensitise reception of the wanted signal. And this can be a reason for a blocking response which is worse when it is close to the wanted signal.* “

But in the case of modern receivers linearity is much higher than defined by the narrowband IM test and therefore the blocking test can be passed without any implementation of this selectivity. Therefore, the application of a lower bound of IIP3 in the plug-in requires the use of this selectivity as derived from the blocking test.

## Nominal error rate (NER) test

An NER test assesses the capability of an RX to successfully receive very strong signals. For static conditions this test is conducted up to -20 dBm for the wanted signal without any interference.

An AGC (Automatic Gain Control) circuit can always reduce receiver gain to avoid an increasing BER due to an overdrive condition.

# RX design practice for other 400MHz receivers

The following figure highlights the required IIP3 for GSM 4xx MS based on GSM4xx standard specifications.

*Fig. 4: Required IIP3 based on RX design practice in 400 MHz band*

There are professional mobiles that are designed as SDR (Software Defined Radios), which can be operated either in TETRA or in GSM mode. In order to reflect this aspect, specs for GSM 4xx are also included in the graph [14].

The GSM specs require robustness due to strong signal levels present in the 400 MHz bands from different systems. Mobiles offering an IIP3 of +8 dBm are therefore deployed widely in the field. This proves that an IIP3 value of minimum +8 dBm can be guaranteed under all circumstances in mass production commercially considering also current constraints from battery operation.

An IIP3 of +8 dBm is therefore considered as a reasonable upper bound.

# Analysis of mobiles in the field (method 2)

FAU and 450connect have carried out an extensive study of mobiles that are in the field for more than 10 years, from 4 different suppliers [2-9]. The addressed questions during the analysis were:

* What Cascaded IIP3 figures are typical in the field for MS older than 10 years?
* What Noise Figures are typical in the field for MS older than 10 years?
* Are tunable preselectors in use?
* Is tunable preselection only done on the input filter or also on the interstage filter?
* What dominates non-linearity: the mixer or the LNA?

The Cascaded IIP3 is computed according to the following theory. The IIP3 of a system that contains multiple nonlinear stages can be computed by the following formula:

$\frac{1}{IIP3\_{cascaded}}=\frac{1}{IIP3\_{1}}+\frac{G1}{IIP3\_{2}}$ Eq. 1

This formula assumes nonlinear stages placed in series without any selectivity or dispersive termination in their harmonic zones [12]. If there is selectivity in front of the first stage and between the first and second stage, the Cascaded IIP3 will be higher. This is another reason why the concept of Effective IIP3 and Effective Selectivity was introduced.

The derivation of Cascaded IIP3 figures is based on nominal system design figures found in detailed service manuals. For computation of cascaded IIP3, nominal IIP3 figures for LNA and mixer and nominal losses by filters, transmission lines and attenuator pads were taken into account.

Nominal figures reflect average performance. In some cases, depending on temperature, battery level and component tolerances, a spread of the IIP3 in the order of +/- 2 dB is observed. The nominal design reflects a typical behaviour and does not reflect best or worst performance. It shows the centre of design target.

However, the approach to compute Cascaded IIP3 from system design serves as a lower bound on mobiles in the field. This is because Cascaded IIP3 formula ignores memory effects due to dispersive elements in the receiver design, which usually contribute to a higher linearity for a larger occupied bandwidth. The reason for that are IM products in other harmonic zones other than zone 1 which are filtered out in every design. Therefore the approach followed is a pessimistic approach. IIP3 figures in reality will be better (higher) than those derived from cascading the IIP3.

It can be seen that mobiles in the field older than 10 years offer Cascaded IIP3 values that are much higher than ‑9.5 dBm derived from intermodulation response alone. Indeed values of +2.7 dBm and the implementation of preselectors (which is not taken into account for this effective IIP3 figure) are found (see Annex).

Thanks to advancements in microelectronics over the last decades, high IIP3 values are not difficult to implement. LNA IIP3 Values of up to +17 dBm are offered [10] at low current. Even with mixers, high IIP3 values, e.g. up to +17 dBm, are widely available [11]. This also was observed during analysis of GSM400 MS.

The Cascaded IIP3 formula used during analysis of existing MS assumes no selectivity at the input and between the LNA and the mixer stage. It only considers the losses and gains in front of each stage. During analysis, mobiles with tuneable preselector filter and tuneable interstage filters were found. At least there is always a passband filter for zone 1 at input and interstage [12]. This proves that the Cascaded IIP3 computation on studied MS is a further lower bound on mobiles in the field. Effective IIP3 is thus higher thanks to selectivity.

The Cascaded IIP3 formula assumes that impedance is constant along the frequency axis, and all zones are terminated equally and in a non-dispersive manner. This is not the case with the studied MS. Shorts or reactive terminations in other zones [12] improve linearity, which is a further indication that real Effective IIP3 is higher than derived by Cascaded IIP3 formula.

# Suggestion for plugin parameterization

Based on above discussions FAU and 450connect propose the following parameters of the IM plugin:

## IIP3

Extrapolating from intermodulation response test alone has delivered an IIP3 value of -9.5 dBm. However, this value cannot be taken as standard parameter of plugin as it is only based on one out of the four specifications for the receiver nonlinearity. Analysis of GSM400 MS has revealed that an IIP3 of +8 dBm can be offered in mass production. Based on good RX design practice for TETRA mobiles found in the field for more than 10 years and the fact that Effective IIP3 is higher than derived by cascaded IIP3 formula the proposed conservative default value within the range from lower bound -9.5 dBm and upper bound +8 dBm is

IIP3 = +3.5 dBm

Nevertheless it has to be considered that components (LNA/Mixer) offering IIP3 of +17 dBm are widely available.

##  Selectiviyty

From spourios response tests a selectivity at large offsets in the order of -18 dB was found. The exact attenuation and offset frequency figure is dependent on the specific mixer used and on the IF frequency. Hence, it is suggested to take the selectivity function derived indirectly from blocking as a parameter, which is less stringent for large offsets, say -15 dB.

|  |  |
| --- | --- |
| *Offset* | *Selectivity* |
| 50…100 kHz | 0 dB |
| 100…200 kHz | -5 dB |
| 200…500 kHz | -10 dB |
| >500 kHz | -15 dB |

*Table 2: Suggested Selectivity parameterization*

## Further proposal

If no consensus can be reached on a default value for the Effective IIP3 and on Effective Selectivity, FAU and 450connect would suggest to

a) Study three IIP3 values to assess sensitivity [-9.5 / +3.5 / +8 dBm] considering lower bound, upper bound and pragmatic value found by TETRA MS in the field for more than 10 years,

b) Study selectivity [on / off]

by all permutations, which results in 6 different parameterizations.

# Conclusion

Suggestions on Effective IIP3 and Effective Selectivity have been made above. These are based on a complete analysis of all 4 specifications for testing receiver non-linearity and a study of mobiles in the field for more than 10 years. TETRA specifications therefore have served as the basis for the suggestions. The suggestions thereby reflect a well educated study based on rigorous analysis to the best knowledge of the authors and information openly available.

A useful next step to further prove these values is to conduct a measurement campaign and test mobiles’ reaction on wideband intermodulation. The suggestion made here can serve as a basis for parameterization of the IM plugin for outage simulations in SEAMCAT.

# References

[1] SE7(18)052, Methodology for assessing compatibility WB vs NB systems, source FAU & 450connect

[2] Motorola, MTP700, Detailed Service Manual, Nov 2006

[3] Motorola, MTH500, Detailed Service Manual, May 2002

[4] Motorola, MTP850, Detailed Service Manual, Feb 2010

[5] Motorola, CDM Pro Series, Detailed Service Manual, 1999

[6] Hytera, DMR, Service Manual, Sept 2010

[7] Hytera, PT580, Service Manual, Aug 2011

[8] Simoco, SRP8000 SERIES, Service Manual, Aug 1998

[9] EADS, THR880i Ex, March 2009

[10] Analog Devices, LNA table,
<http://www.analog.com/en/products/amplifiers/rf-amplifiers/low-noise-amplifier.html>

[11] Analog Devices, mixer table,
<http://www.analog.com/en/products/rf-microwave/mixers/single-double-triple-balanced-mixers.html>

[12] SE7(18)054, Dependence of IM products on tone spacing and occupied bandwidth, source FAU & 450connect

[13] SE7(18)053, Weak non-linearity models, source 450connect

[14] ETSI 3GPP TS 05.05, 3rd Generation Partnership Project; Technical Specification Group GERAN (GSM/EDGE Radio Access Network); Digital cellular telecommunications system (Phase 2+); Radio transmission and reception, (Release 1999)

[15] SE7(17)117, Good RX Design Practice, source FAU

# Annex

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| ***Nr.*** | ***Device vendor*** | ***Device Type*** | ***Date introduced*** | ***Tuning Range [MHz]*** | ***Preselector Tunable?*** | ***input loss [dB]*** | ***LNA G [dB]*** | ***LNA IIP3 [dBm]*** | ***LNA NF [dB]*** | ***Interstage loss [dB]*** | ***Interstage filter tunable?*** | ***Mixer G [dB]*** | ***Mixer IIP3 [dBm]*** | ***IF [MHz]*** | ***IIP3 by LNA [dBm]*** | ***IIP3 by mixer [dBm]*** | ***Cascaded IIP3 [dBm]*** | ***Cascaded NF [dB]*** |
| 1 | Motorola | MTP700 | 01.11.2006 | 50/64 | yes | 2,7 | 18,0 | 5,5 | 1,4 | 2,0 | no | -6,0 | 17,5 | 109,65 | 8,2 | 4,2 | 2,7 | 4,1 |
| 2 | Hytera | DMR | 13.06.2011 |   | yes |   |   |   |   |   | yes |   |   |   |   |   |   |   |
| 3 | Hytera | PT580 | 01.08.2011 | 64 | no |   |   |   |   |   | no |   |   | 73,35 |   |   |   |   |
| 4 | Simoco | SRP8000 | 01.08.1998 | 47 | yes |   |   |   |   |   | yes |   |   |   |   |   |   |   |

*Table 3: MS considered during study of mobiles in the field*