Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**	
Title	**PA Model (Based on an ETSI-BRAN contribution)**	
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Re:	In response to the call for contributions on PA modeling	
Abstract	This document was presented by Ericsson in ETSI/BRAN-19 and one of its models has been adopted	
Purpose	Providing the information to the IEEE 802.16.1 working group	
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PA Model

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Abstract

This document describes a model suitable for a solid state RF power amplifier. It is proposed to adopt it as a reference model for the IEEE 802.16 group. The model has been used to simulate three different types of RF Power Amplifier (PA) non-linearity, in order to show the trade-off among symbol rate, roll-off and PA total *back-off*, for a given set of spectrum mask requirements. This document also aims at demonstrating the high sensitivity of total *back-off* to the amplifier model adopted (i.e. to the sharpness of the non-linearity on the top of PA dynamic). Finally, a set of parameters for the model is proposed, suitable for a typical MMIC PA non-linearity at the output power levels and frequencies of interest for IEEE 802.16.

General assumptions

For the evaluation of spectral spreading of M-QAM signaling passing thru a RF PA non-linearity, following system parameters have been used:

1. Symbol rate = 22 MHz (Equivalent gross bit rate for 4QAM: 44 Mbps)
2. Roll-Off (α) = 0.3
3. Spectrum masks:
   - Down-link: ETSI mask C (64-QAM option to be supported)
   - Up-link: ETSI mask B (16-QAM option to be supported)

Main goal of the evaluation has been to show that, without too much error, the most convenient way to model a RF non-linearity is by using of the corresponding "two-tone C/I3" value at the rated output power. This value determines well, independent of the precise behaviour of the non-linearity (in terms of AM/AM and AM/PM), the level of the spectral side lobes to be fit into the spectral mask.

PA model evaluation strategy

Three different 'AM/AM' non-linearities, paired with a common 'AM/PM' transfer function, have been used for model evaluation purposes:

1. "PA_SHRP": a 'theoretical' non-linearity with a very **sharp** limitation of P_{out} Vs P_{in}.
2. "PA_SOFT": a 'theoretical' non-linearity with a very **soft** limitation of P_{out} vs P_{in}.
3. "PA_MEAS": A '**measured**' non-linearity that (for any back-off down to approximately 2 dB) gives the same level of C/I3 measured on a physical MMIC PA device in the 28-31GHz band. The model coefficients used in this case have been extracted by experimental measurement following a simple procedure that will be explained later.

In order to assess the proposed model, the above-listed non-linearities have been used in three different link/spectrum mask configurations:

- 4-QAM Up-Link, (using ETSI-Mask B)
- 16-QAM Up-Link, (using ETSI-Mask B)
- 16-QAM Down-Link (using ETSI-Mask C)

For all these cases, the maximum ouput power allowed has been determined, and the corresponding C/I3 at that output power has been calculated[1] (as reported later on).

[1] T*he maximum power level allowed has been evaluated due to the spectral requirements only, i.e. not including the receiver sensitivity degradation due to signal distorsion.*

The corresponding C/I3 figures (at maximum power level) have some dependency of the type of non-linearity; the C/I3 range is reported hereafter:

- 4QAM-UL : 27.5 to 30.5 dB
- 16QAM-UL: 30.4 to 32.5 dB
- 16QAM-DL : 37.3 to 39.0 dB

On the other hand, for a given link/spectrum mask combination, the actual *back-off* required varies significantly in presence of different non-linearitiy types.

The simulation results for **back-off** requirements are summarised in the following table

PA Model	***4QAM UL***	***16QAM UL***	***16QAM DL***
PA_SHRP **(sharp AM/AM)**	Total BO = 3dB	Total BO = 4dB	Total BO = 5.5dB
PA_MEAS **('real' MMIC)**	Total BO = 4.4dB	Total BO = 5dB	Total BO = 7.2dB
	C/I3 = 28.6dB	C/I3 = 30.8	C/I3 = 37.6
PA_SOFT **(soft AM/AM)**	Total BO = 7.4dB	Total BO = 7.2dB	Total BO = 12dB

Non-linearity model description

A simple but effective non-linearity model is proposed for adoption in BRAN HA, which is based on the following four parameters.

1. Saturated output (and corresponding input) power level [dBm]
2. Amplitude-"non linearity" exponent (K_am/am).
3. AM/PM conversion (phase derivative) at the saturation point [deg/dB].
4. AM/PM conversion "roll-off" exponent (K_am/pm).

The transfer functions in terms of amplitude and phase non-linearity are described in the following two equations:

$$V_{out} = V_{in} - A\bullet(V_{in})^{k\_am/am} \quad (V_{in} < V_{in,sat}), \quad V_{out} = V_{out,sat} \quad (V_{in} >= V_{in,sat}) \quad (1)$$

$$\Phi_{out} = \Phi_{in} + B\bullet(V_{in}/V_{in,sat})^{k\_am/pm} \quad (2)$$

[2]

The coefficients A and B are calculated setting the requirements that the derivative of amplitude transfer function shall be zero at the saturation point and that the AM/PM (phase derivative) is at a defined level at the same saturation point.

Note that amplifier gain has been normalized to 0 dB in linear region.

Mapping a physical PA device into the model

As mentioned in a previous section, the proposed model can be used not only with 'theoretical' non-linearities but also to evaluate the behaviour of a specific amplifier, as in the case "PA_MEAS".

In the latter case the following procedure has been followed to calculate model parameters:

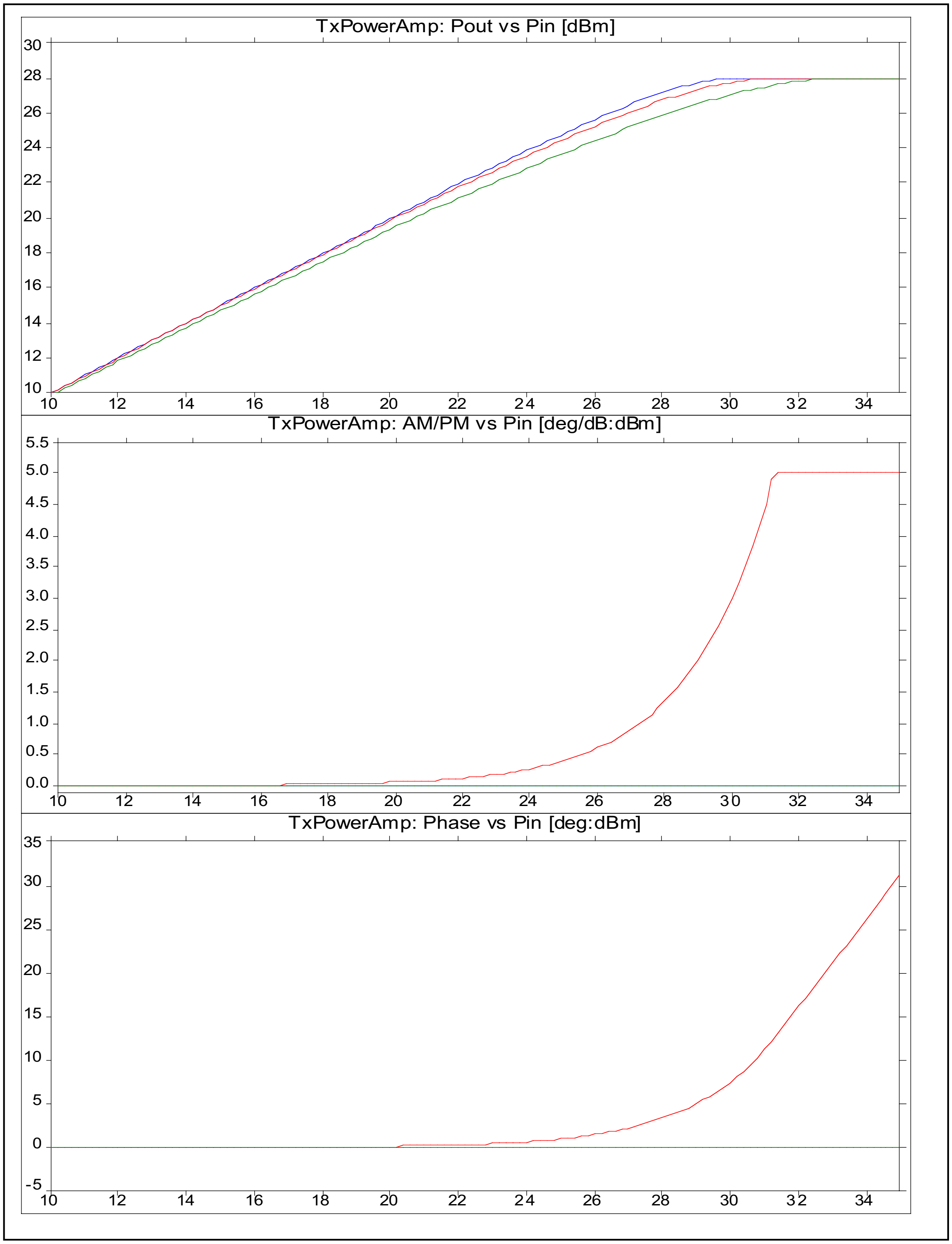
- the 'two-tone' C/I3 was measured at a number of output power levels, using two tones positioned at $f_c \pm f_{sym}/2$.
- the parameters in the model have been adjusted to give the same C/I3 at the same power levels.

[2] *For input levels above the corresponding input saturation point the, output level and the AM/PM conversion (Φout derivative Vs Vin) is kept constant.*

This approach has been choosen due to that it is difficult to measure amplifier performance in terms of amplitude and phase transfer with the accuracy that is required to determine these levels of spectral spreading.

In the first of following pictures the P_{out} Vs P_{in} curve is drawn, based on model equation (1), for the three non linearities discussed. Φ_{out} Vs Φ_{in} is reported in the third picture, based on model equation (2), while 2nd picture reports the phase derivative taken Vs Pin (in deg/dB Vs dBm).

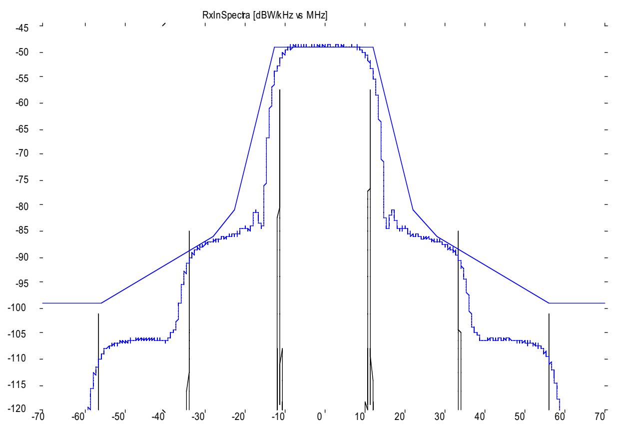
An ‘ideal' phase response (i.e. $\Phi_{out} = \Phi_{in}$) has been assumed for all models except ‘PA_MEAS', where a phase derivative of 5 deg/dB at saturation point has been calculated (to match the simulated C/I3 with measured one).



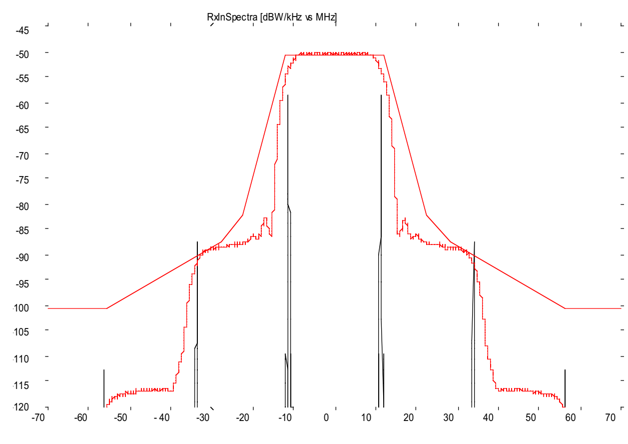
NOTE: if an amplifier needs to be measured and modeled within a simulator, a better way to measure the amplifier is in terms "partial-C/I3". In this case the C/I3 products are measured with one large signal and one small signal (lowered 20-30 dB). With this method it is possible to measure the AM/AM and AM/PM with sufficient accuracy at the power level determined by the large signal. These "partial-C/I3" are thereafter combined to a complete amplitude and phase transfer function.
Still, as in the end a practical specification for the power amplifier is needed, for single carrier operation the traditional C/I3 is sufficient for that purpose (talking the uncertainties shown above as a design margin).

Simulation results

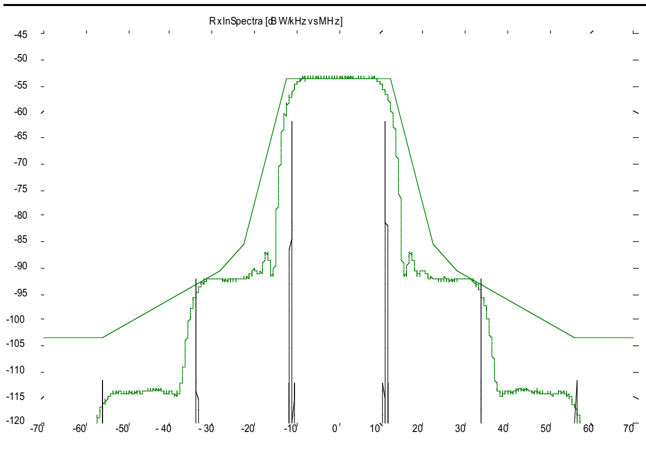
4-QAM Uplink



4QAM-UL, PA_SHRP



4 QAM-UL PA_MEAS



4QAM-UL PA_SOFT

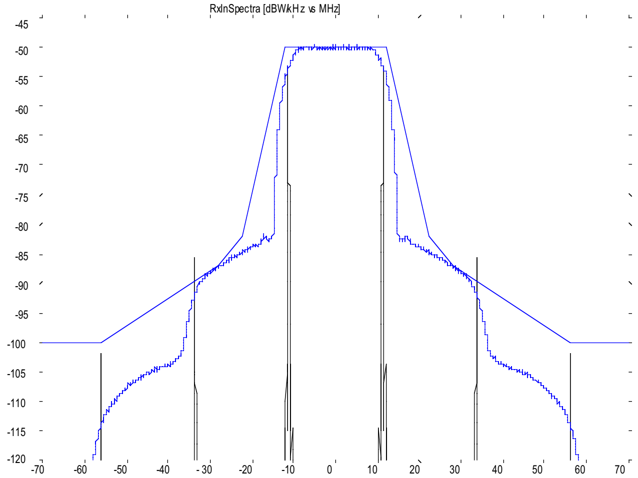
4-QAM / uplink: model parameters

Nonlinearity: "sharp saturation" (PA_SHRP)
Back-Off = 3.0 dB C/I3 = 27.5 dB

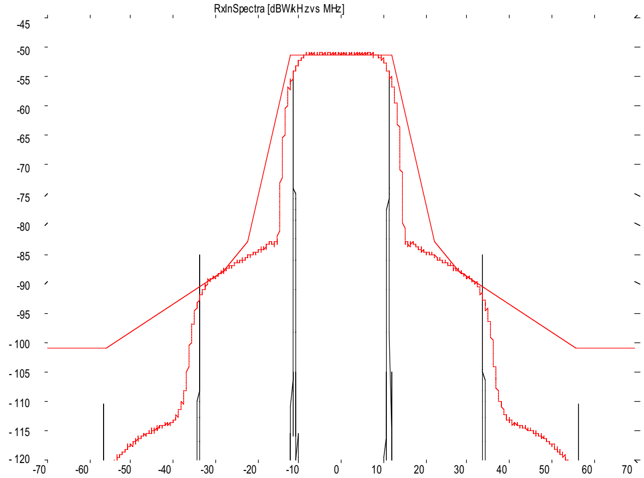
Nonlinearity: "Typical MMIC" (PA_MEAS)
Back-Off = 5.0 dB C/I3 = 30.8 dB

Nonlinearity: "Soft saturation" (PA_SOFT)
Back.Off = 7.2 dB C/I3 = 30.4 dB

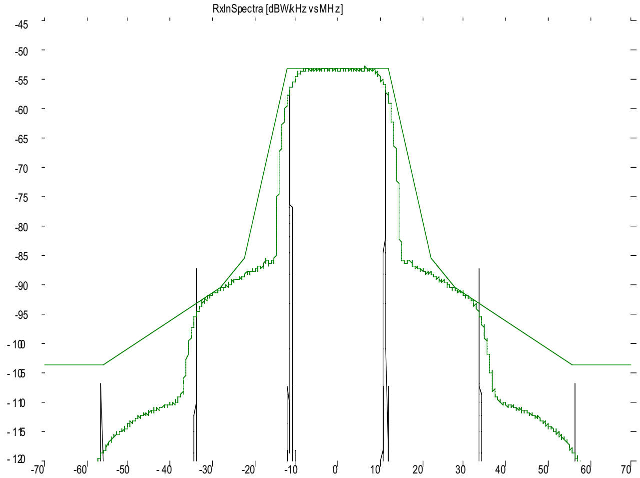
16-QAM Uplink



16QAM – UL PA_SHRP



16QAM-UL PA_MEAS



16QAM-UL PA_SOFT

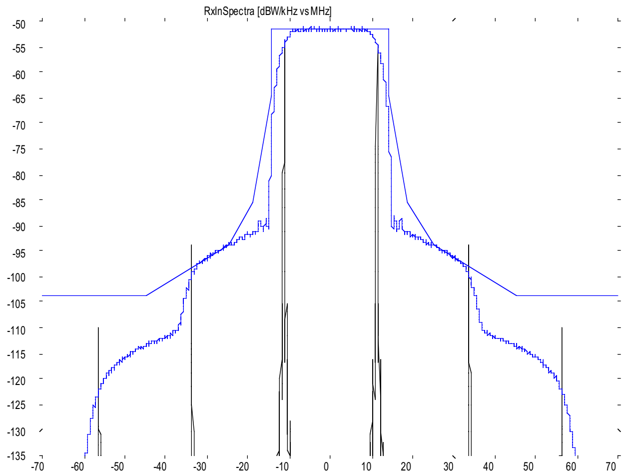
16-QAM / uplink: simulation summary

Nonlinearity: “sharp saturation” (PA_SHRP)
Back-Off = 4.0 dB C/I3 = 32.5 dB

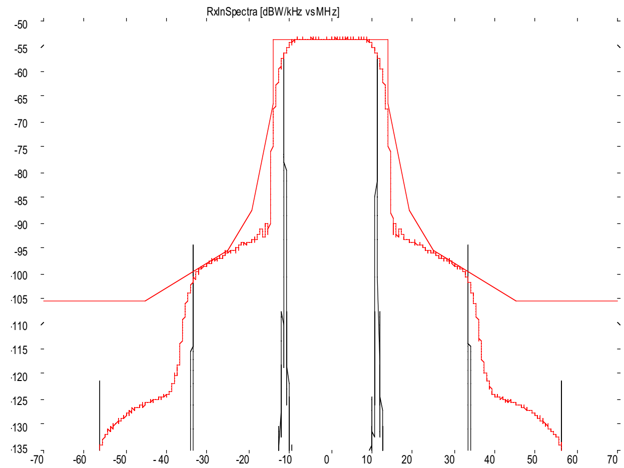
Nonlinearity: “Typical MMIC” (PA_MEAS)
Back-Off = 5.0 dB C/I3 = 30.8 dB

Nonlinearity: “Soft saturation” (PA_SOFT)
Back.Off = 7.2 dB C/I3 = 30.4 dB

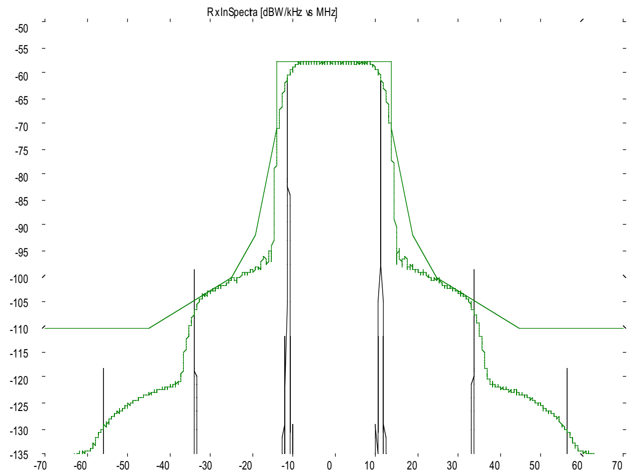
16-QAM Downlink



16QAM-DL PA_SHRP



16QAM-DL PA_MEAS



16QAM-UL PA_SOFT

16QAM / downlink: simulation summary

Nonlinearity: “sharp saturation” (PA_SHRP)
Back-Off = 5.5 dB C/I3 = 39 dB

Nonlinearity: “Typical MMIC” (PA_MEAS)
Back-Off = 7.5 dB C/I3 = 37.6 dB

Nonlinearity: “Soft saturation” (PA_SOFT)
Back.Off = 12.0 dB C/I3 = 37.3 dB

Model Parameters

Model	Sat. Pout [dBm]	Sat. Pin [dBm]	K AM/AM	AM/PM derivative [deg/dB]	K AM/PM
Sharp	28	30.3	4.5	0	3.5
Measured	28	31.2	3.2	5	3.5
Soft	28	33.1	2.2	0	3.5

Conclusions

ETSI-BRAN decided to adopt the model based on measured results as they matched better MMICs operating in the millimeter wave spectrum of interest.