Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** **<http://grouper.ieee.org/groups/802/20/>**
Title	**Models for Signal Clipping in Evaluation of MBWA**
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Re:	Performance Evaluation by System and Link Level Simulation
Abstract	This document proposes a mathematical models for clipping effect and power back-off for the use by the simulation of MBWA proposals.
Purpose	Discuss and adopt.
Notice	
Release	
Patent Policy	

Models of Signal Clipping for the Evaluation of MBWA

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Introduction

Non-linear effect of power amplifier results in

- Clipping of signals $\Rightarrow$ distortion of the transmitted signals and adjacent channel interferences.

- Methods to compensate the loss due to non-linear charactersitcs

- Back-off of the transmit power $\Rightarrow$ linear characteristic, but less power

Amplifier

Base band signal

$$S(t) = I(t) + jQ(t) \tag{1}$$

RF signal

$$s(t) = I(t)\cos\omega t - Q(t)\sin\omega t = \Re[S(t)e^{j\omega t}] \tag{2}$$

where ω is the RF frequency.

Model of Amplification:

Power amplifier

$$P_{out}(t) = G[P_{in}(t) = S^2(t)] \tag{3}$$

Signal amplifier

$$S_A(t) = F[S(t)] \tag{4}$$

Hard Clipping

The clipped signal has the envelop

$$S_A(t) = \begin{cases} S(t) & \text{for } |S(t)| \leq A \\ A \cdot e^{j\theta(t)} & \text{for } |S(t)| > A \end{cases} \quad (5)$$

when normalized by $\sqrt{g}$, where

- g: power gain of the amplifier,
- $S(t)$: input signal,
- $\theta(t) = arg[S(t)]$,
- $A > 0$: ceiling of the output amplitude,
- $S_A(t)$: normalized output signal.

Back-off against Hard Clipping

- Metric for saturation $r := S_m/A$
  - $S_m = max\{|S(t)|; t \in [0, T]\}$,
  - $r^2 - 1$: saturated power fraction
  - Linear $r \leq 1$; Clipping $r > 1$.
- S_m^2: maximum input power within the observation window
- A^2: maximum output power of the amplifier.
- Δ: amplitude amount of back-off

$$r' := (S_m - \Delta)/A = r - \Delta/A \leq r \qquad (6)$$

- Complete back-off achieves $r' = 1$. In general,

$$S_m - \Delta \leq A \Leftrightarrow r' \leq 1$$

Soft Clipping

$$S_A(t) = \begin{cases} S(t) & \text{for } |S(t)| \leq A \\ (A + b(S - A)) \cdot e^{j\theta(t)} & \text{for } |S(t)| > A \end{cases}$$

where

- $b(x) = \alpha \cdot (1 - e^{-\beta \cdot |x|})$ characterizes the non-linear region,
- α determines the size of non-linear region and
- β determines the speed of (never !) reaching the
- upper bound $A + \alpha$.

Back-off against Soft Clipping

- Metric for soft saturation

$$r_s := \frac{S_m}{A + \alpha \cdot (1 - e^{-\beta|S_m - A|})}$$

  – Relation $r_s \leq r$ holds for $\alpha \geq 0$

  – Range between linear and "clipping":

$$A < \max_{|S(t)|, t \in [0,T)} |S_A(t)| < A + \alpha$$

$\Rightarrow$ $1/(1 + \alpha/A) < r_s < 1$: Soft-clipping.

- Back-off with $1 \leq r' \leq r$,

$$\Delta = (r - r') \cdot A \leq (r - 1) \cdot A \tag{7}$$

- Corresponding soft metric

$$r'_s = \frac{r'}{1 + (\alpha/A) \cdot (1 - e^{-\beta A \cdot |r' - 1|})} \tag{8}$$

Summary

- Choose target saturation metric r'or r'_s

- Measure current saturation metric

$$r = \frac{max\{S(t')|t' \in [t, t+T)\}}{A} \quad (9)$$

or

$$r_s = \frac{max\{S(t')|t' \in [t, t+T)\}}{A+\alpha} \quad (10)$$

- Determine the input transmit signal

$$S_A(t)\sqrt{g} \cdot (r'/r) \quad (11)$$

where $r', r > 0$, or

$$S_A(t)\sqrt{g} \cdot (r'_s/r_s) \quad (12)$$

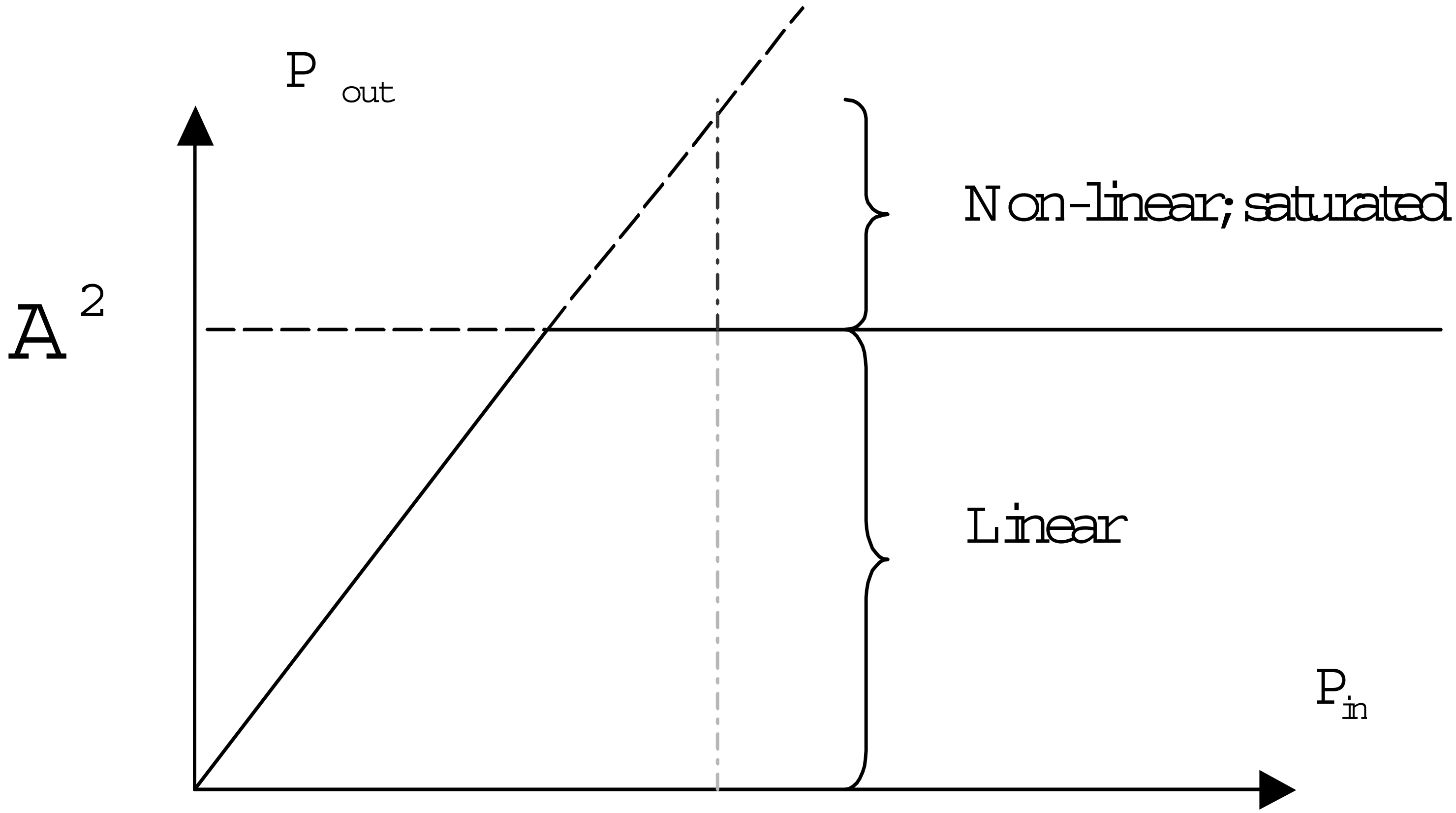

Fig.1: Non-linear model with hard saturation

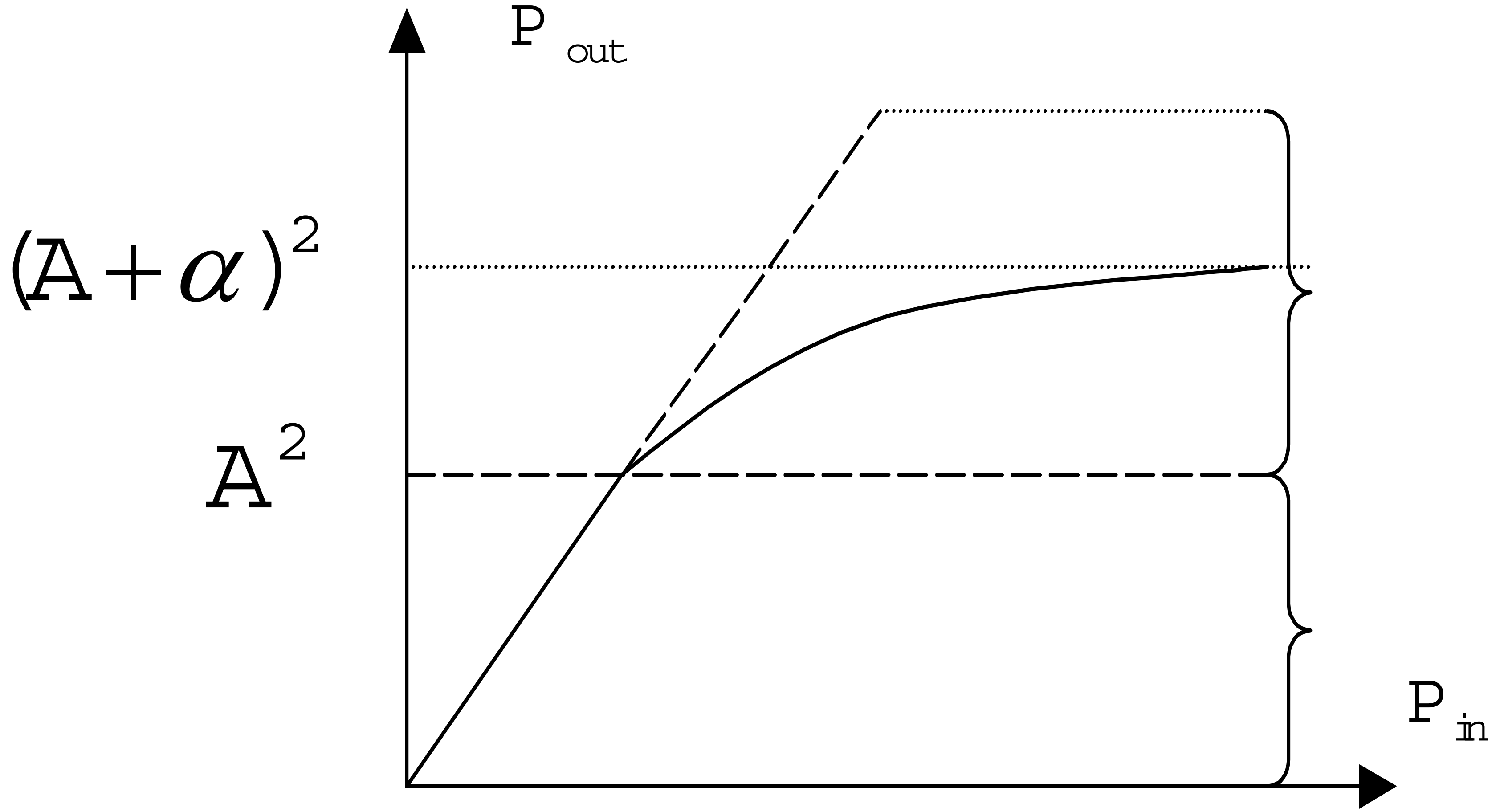

Fig.2: Non-linear model with soft saturation

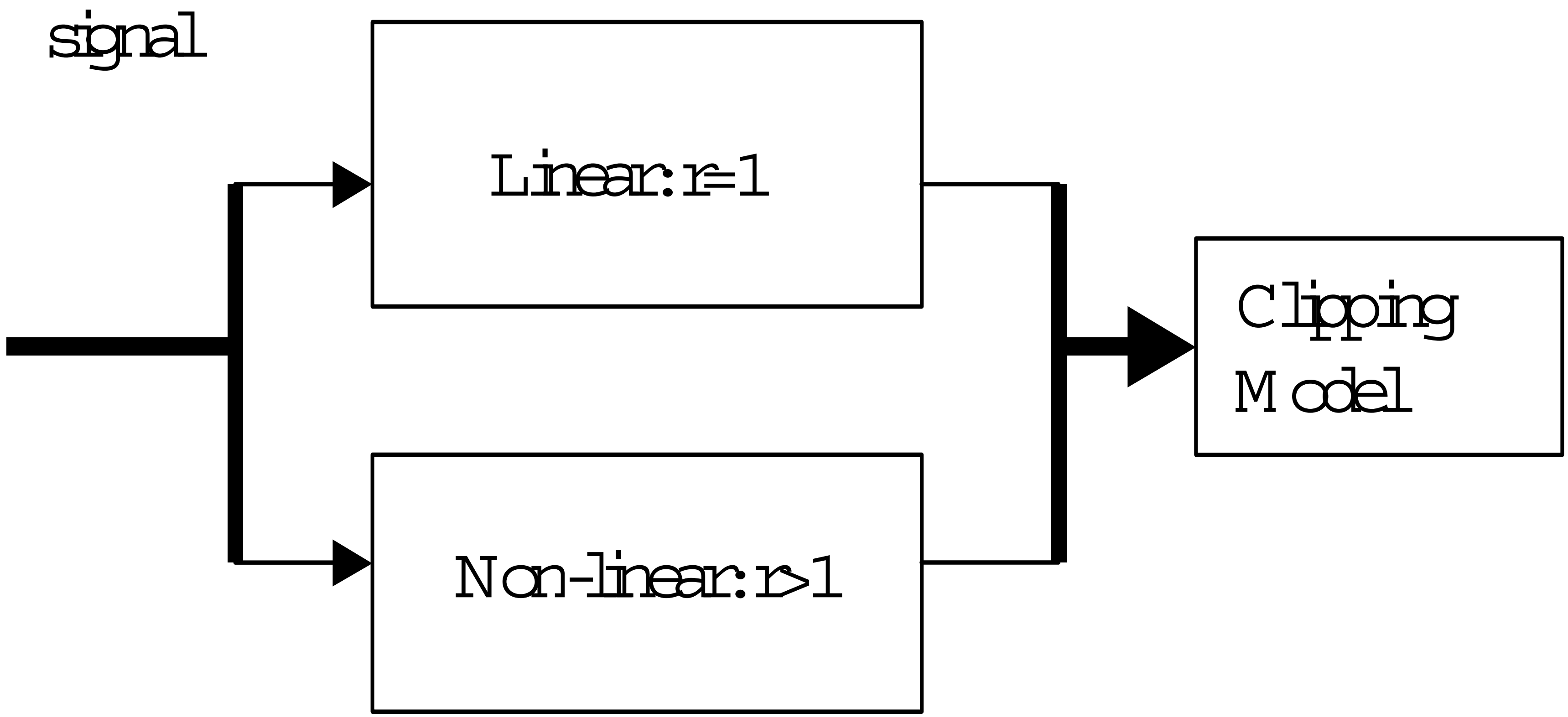

Fig.3: Model for the study of loss due to clipping

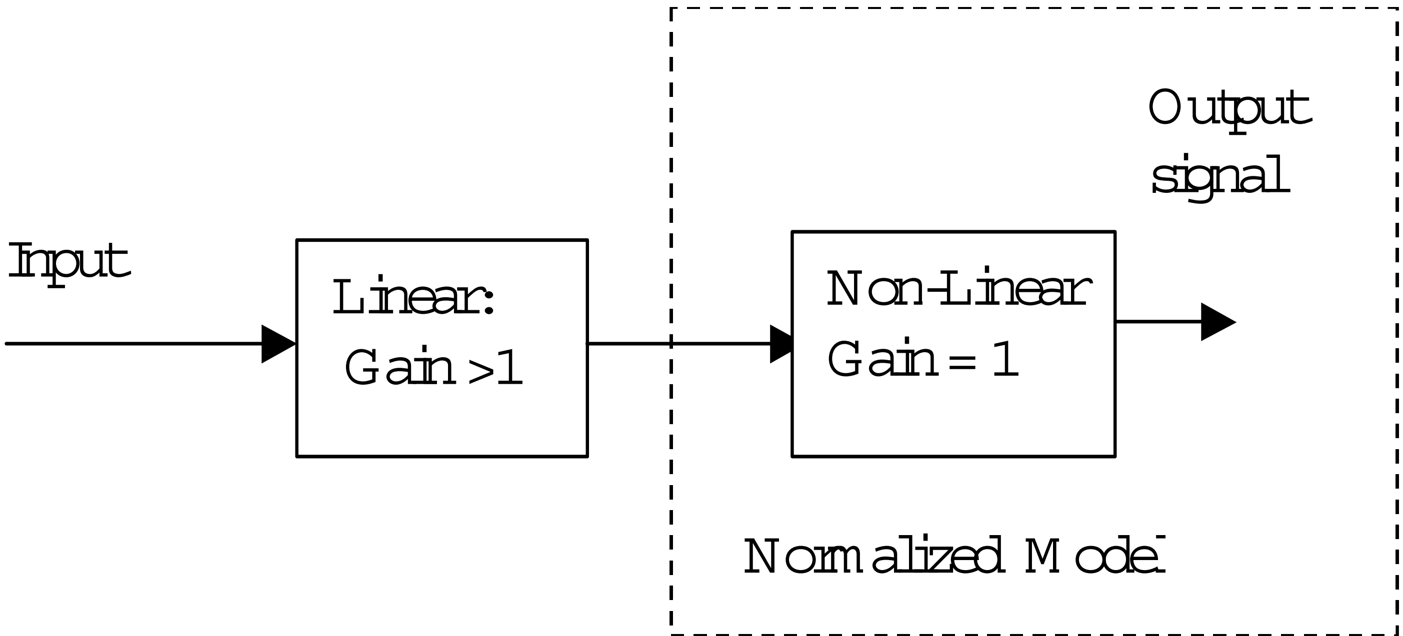

Fig.4 : Model of normalized amplifier

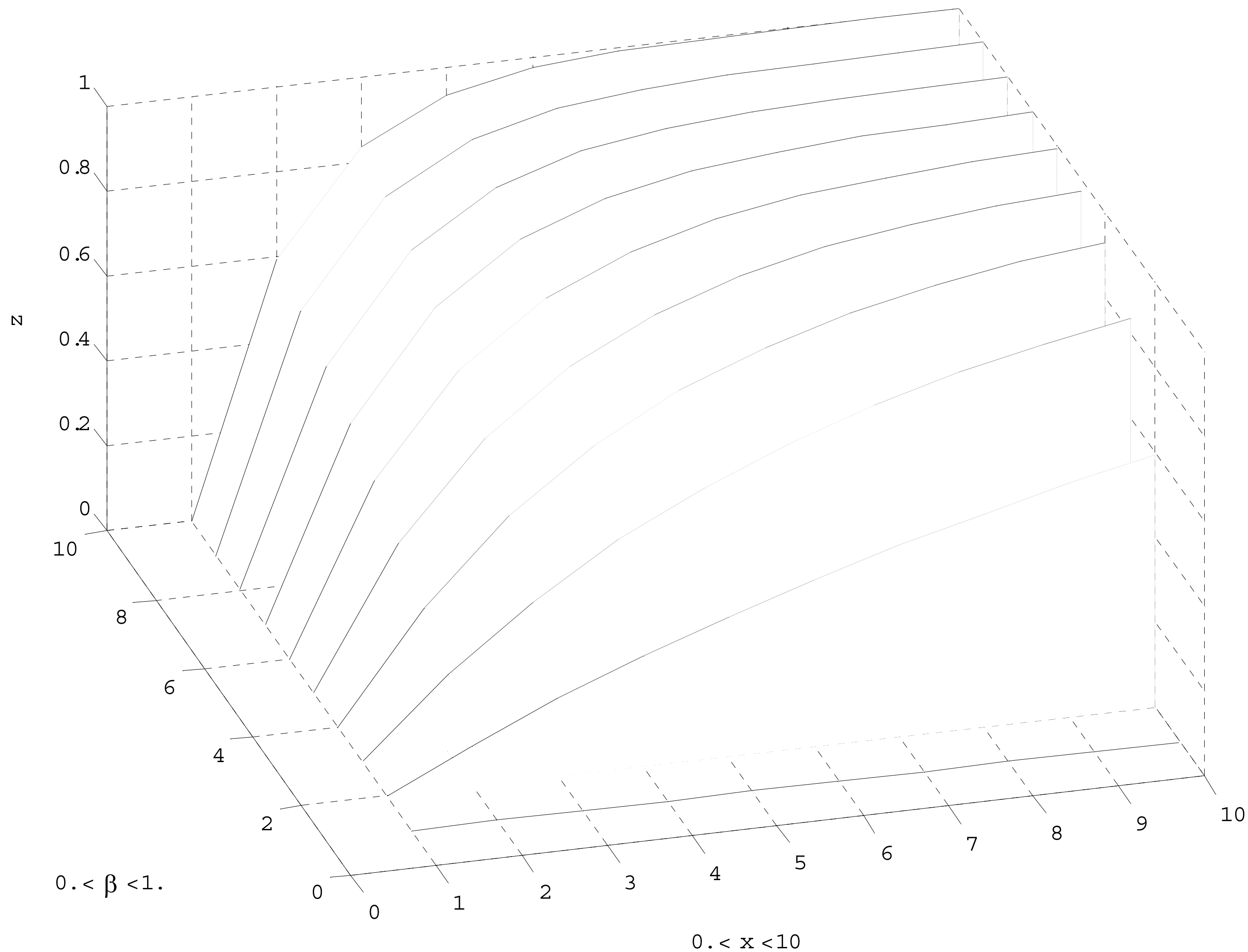

Fig.5: Non-linear part b(x) of the amplifier characteristic

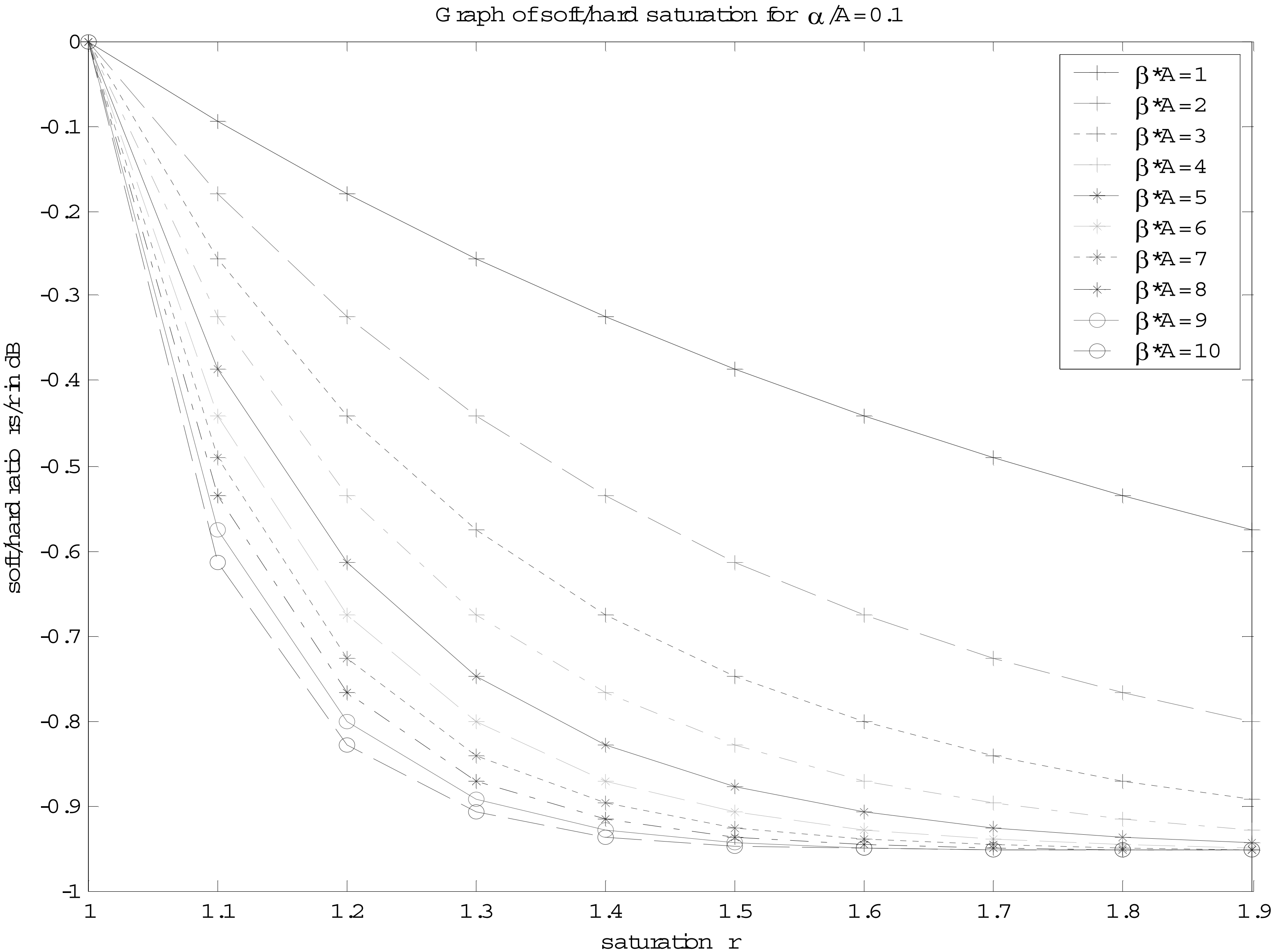

Fig.6: Saturation Distance 10*log(rs/r)