*Ingegneria delle Telecomunicazioni*

Satellite Communications

# 7. Digital Twins – Modeling of HPA

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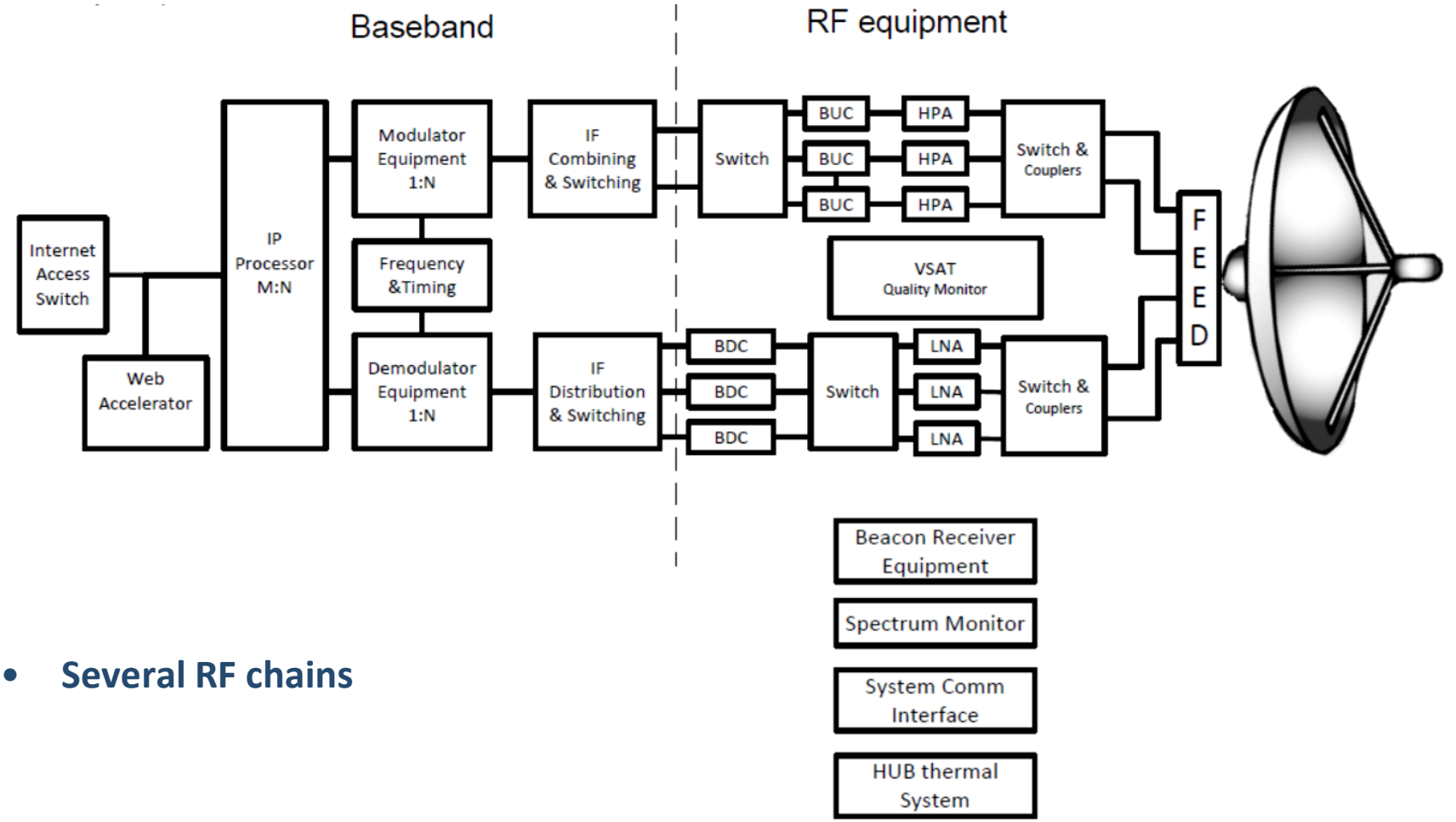
# Gateway Feeder Link







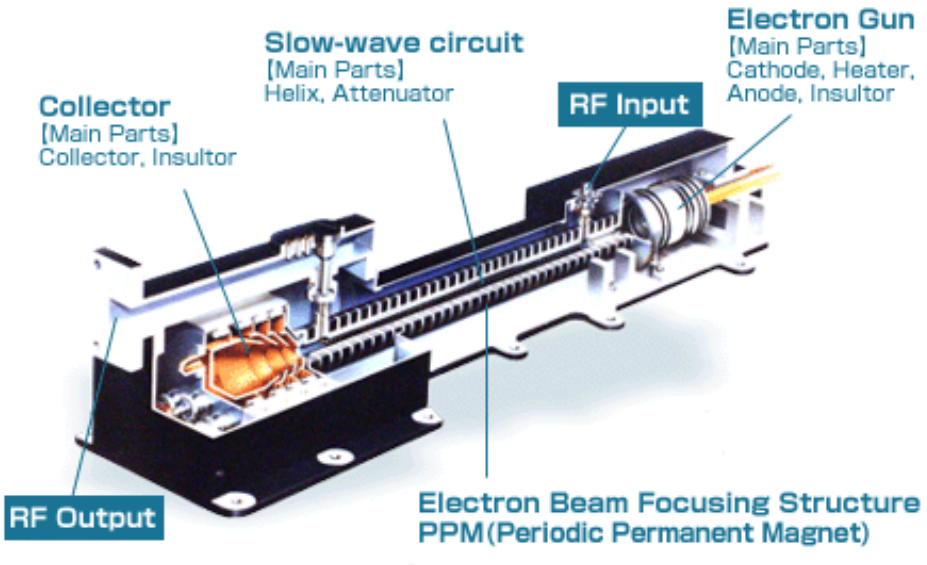

- **Several RF chains**

# HPA Technologies





- **Traveling-Wave Tube Amplifier (TWTA)**
  - High-Power
  - Mature Technology
  - Bulky

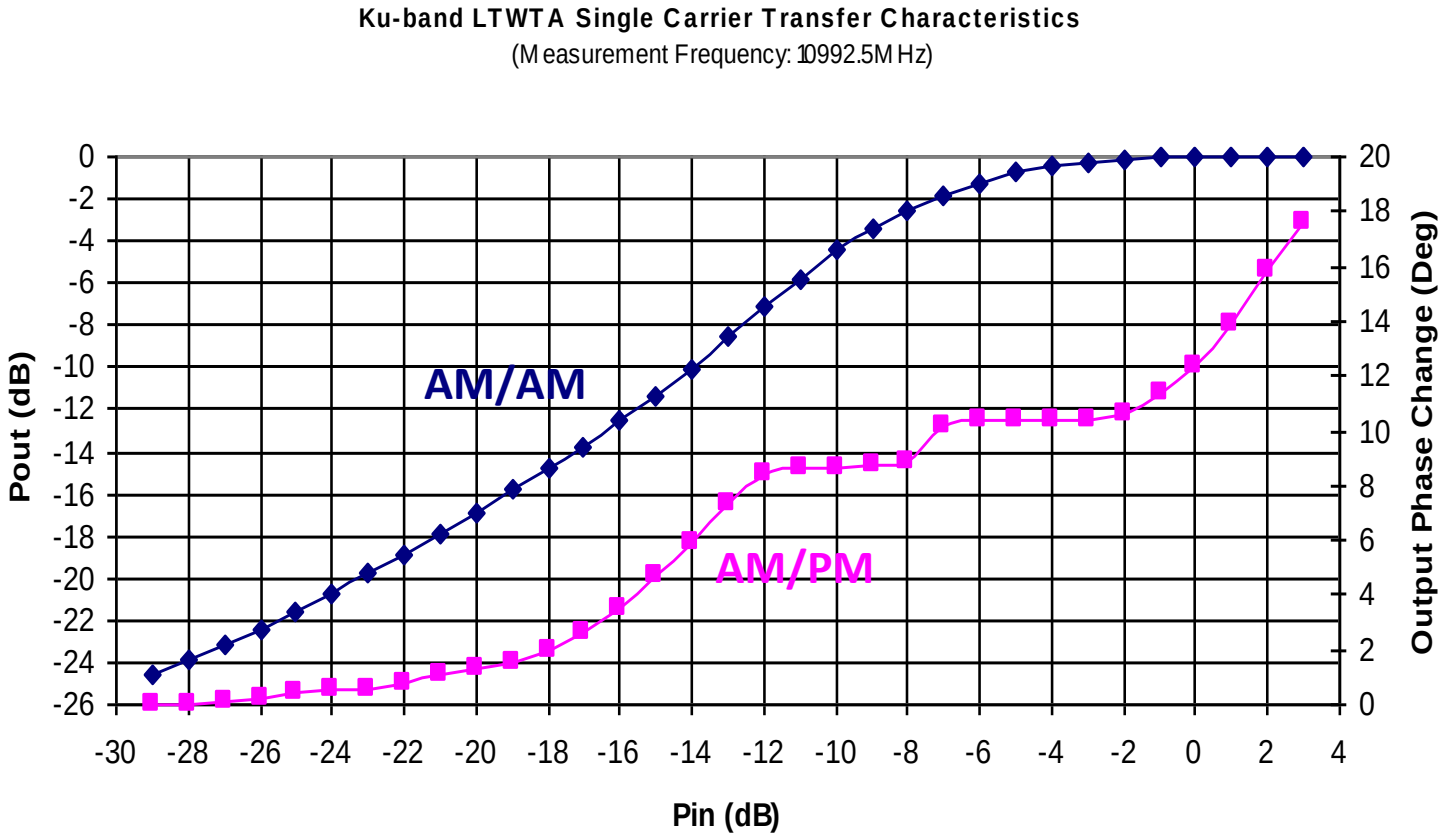



- **Solid-State Power Amplifier (SSPA)**
  - Medium Power
  - Some reliability Issues
  - Lighter than TWTA (especially suited on-board)

# Modling of HPA: Memoryless Nonlinearity

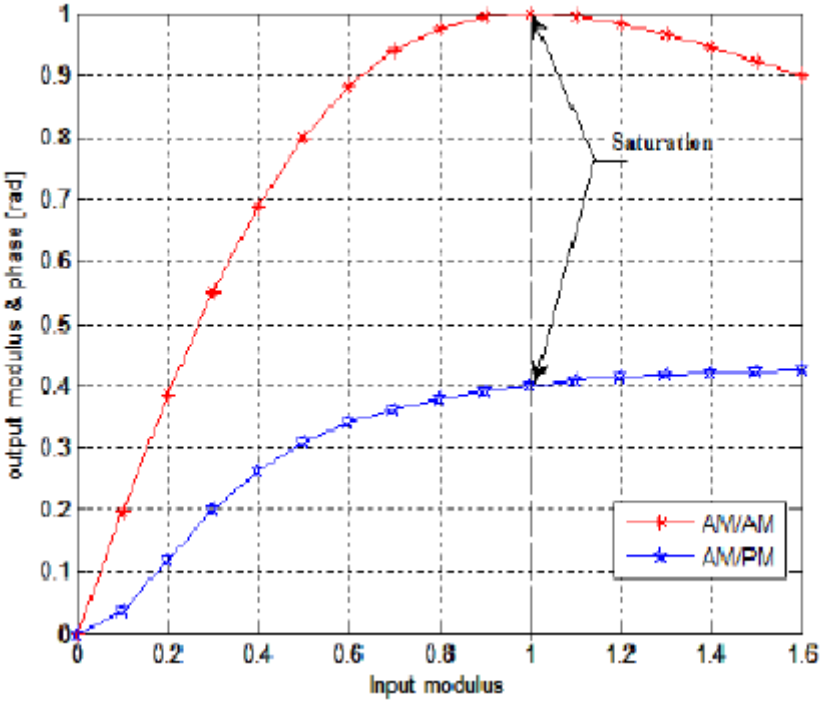


- **AM/AM and AM/PM Characteristics**



# Modling AM/AM and AM/PM

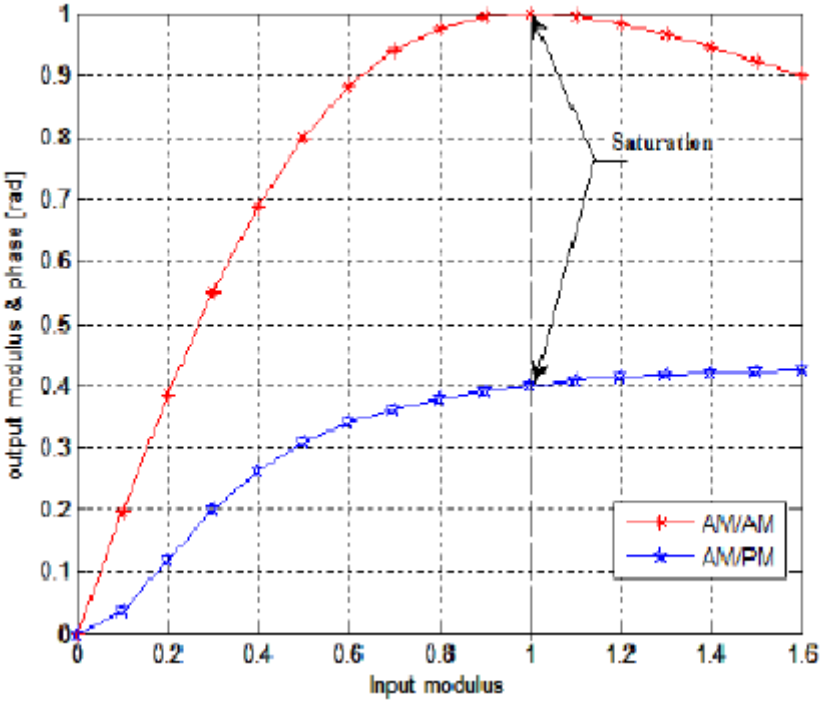
$$|y(t)| = \sqrt{P_{OUT,Sat}}\, g_{AMAM}\left(\left|\frac{x(t)}{\sqrt{P_{IN,Sat}}}\right|\right) \quad , \quad \measuredangle y(t) = \measuredangle x(t) + g_{AMPM}\left(\left|\frac{x(t)}{\sqrt{P_{IN,Sat}}}\right|\right)$$




# TWTA Analytical Modeling (Saleh)



$$g_{AMAM}\left(|x(t)|\right)=\frac{2|x(t)|}{1+|x(t)|^2} \quad , \quad g_{AMPM}\left(|x(t)|\right)=\frac{\pi}{3}\frac{|x(t)|^2}{1+|x(t)|^2}$$



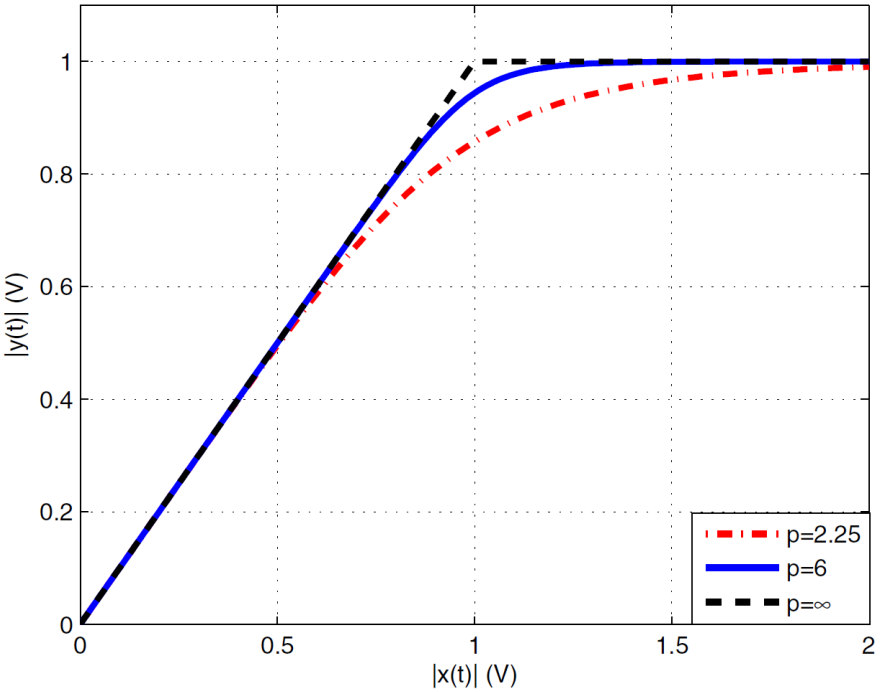


Here, $x(t)$ is intended as ALREADY NORMALIZED wrt its saturation power $P_{IN,Sat}$

# SSPA Analytical Modeling (Rapp)

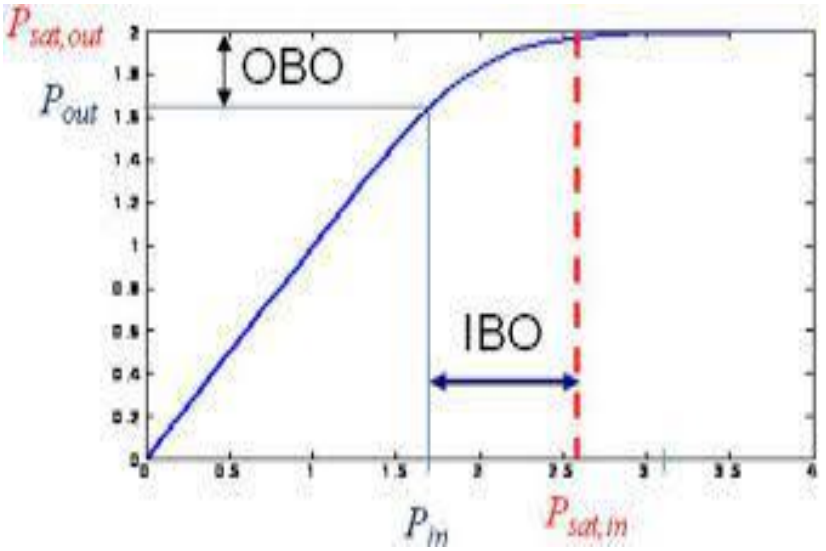


$$|y(t)| = \frac{|x(t)|}{\left(1+|x(t)|^{2p}\right)^{\frac{1}{2p}}} \quad , \quad \measuredangle y(t) = \measuredangle x(t) + 0$$



# IBO/OBO Definition





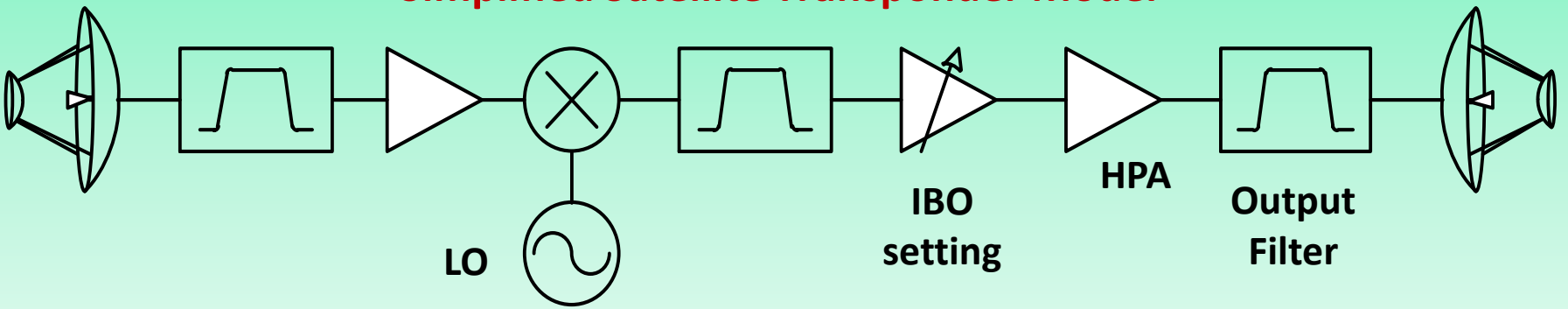

$$IBO_{dB} \triangleq \left.\frac{P_{in,SAT}}{P_{in}}\right|_{dB} = (P_{in,SAT})_{dB} - (P_{in})_{dB}$$

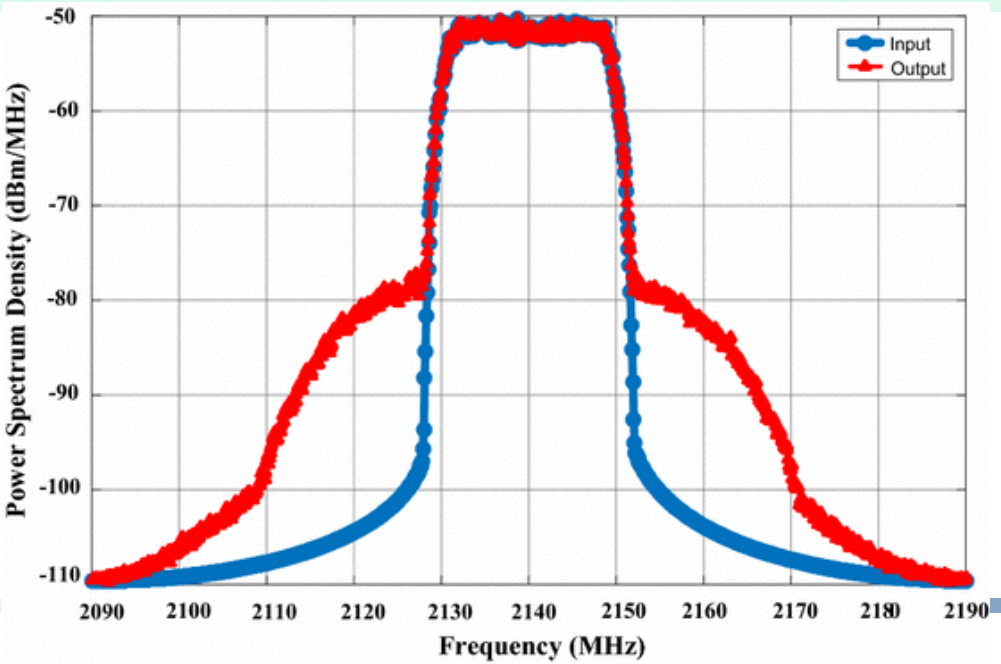
$$OBO_{dB} \triangleq \left.\frac{P_{out,SAT}}{P_{out}}\right|_{dB} = (P_{out,SAT})_{dB} - (P_{out})_{dB}$$

# Satellite Transponder with HPA



## Simplified Satellite Transponder Model

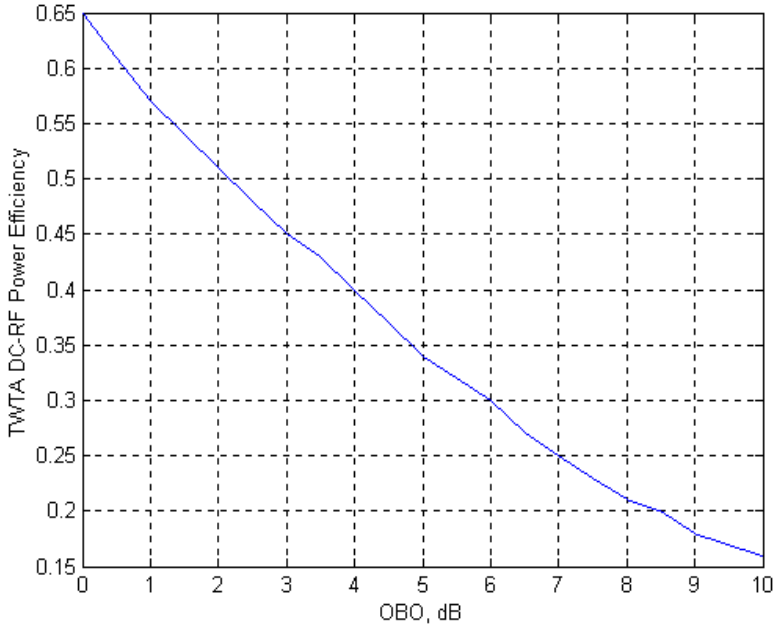


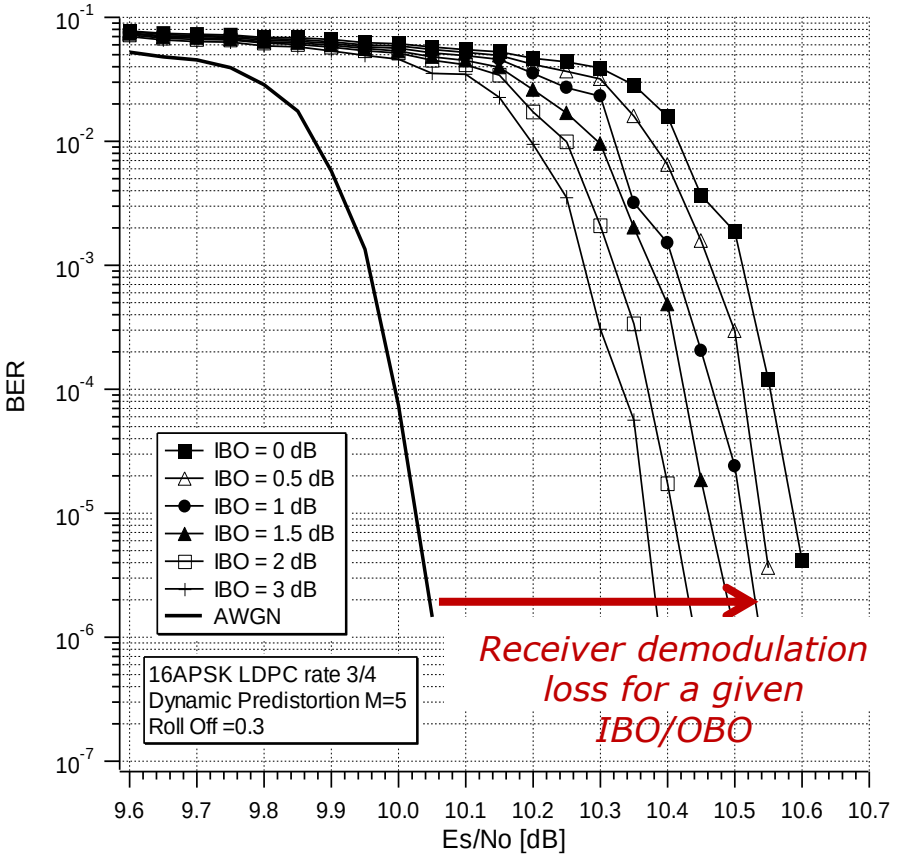



# Setting the IBO/OBO 1/2



- Efficiency vs. Distortion

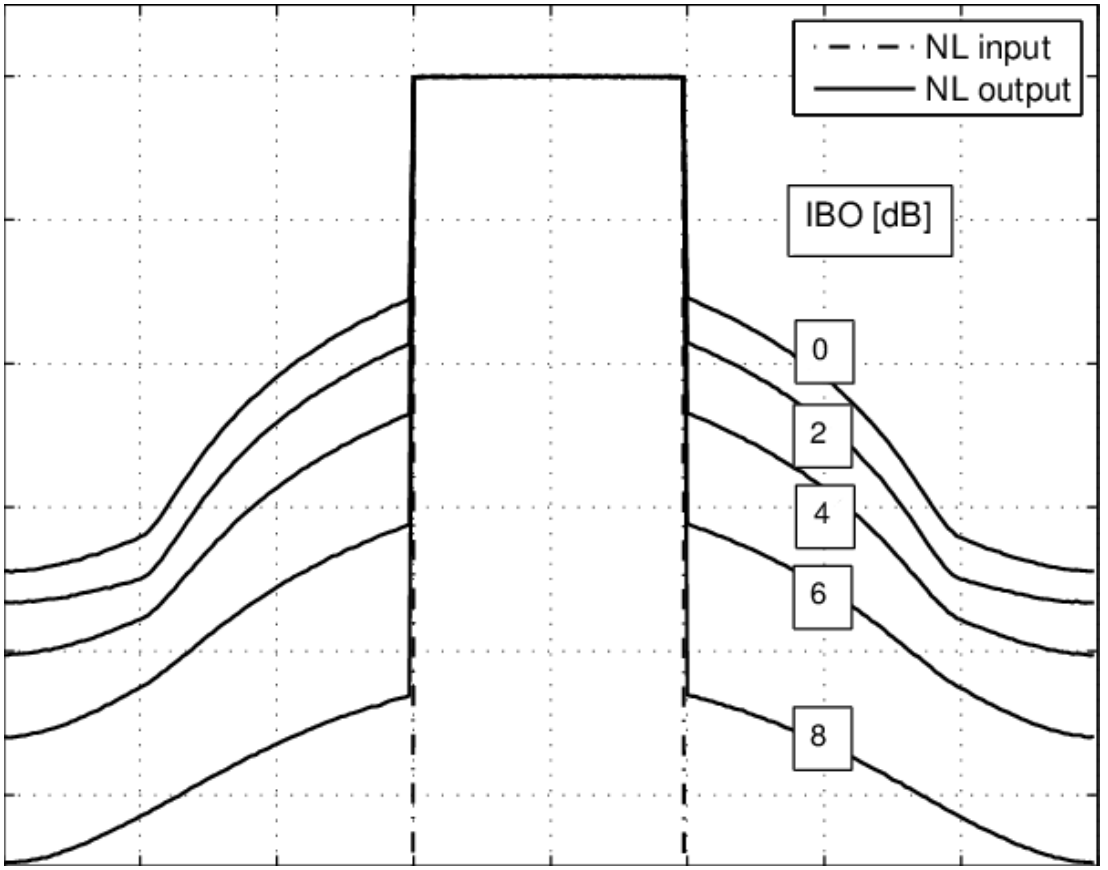


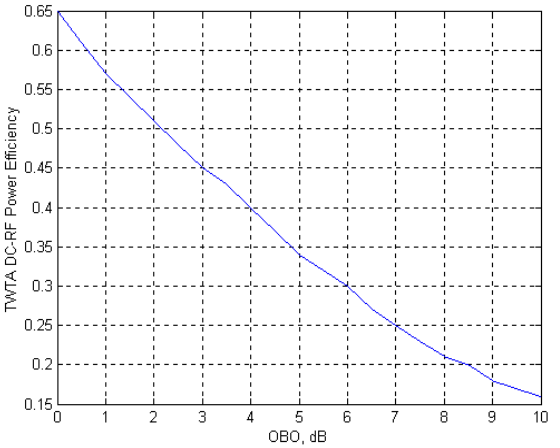




- In addition, larger OBO=less TX power

# Setting the IBO/OBO 2/2





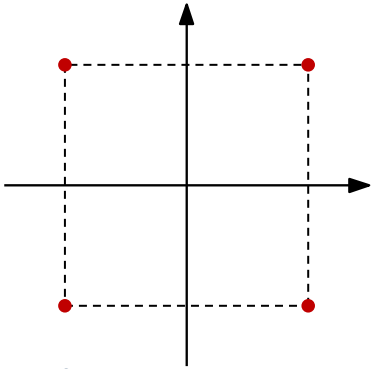



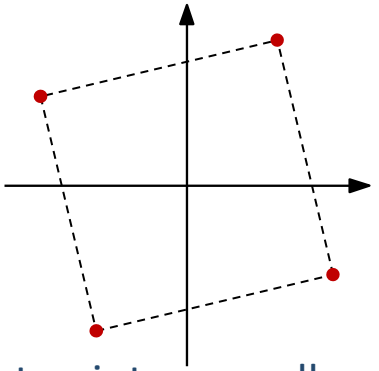

- High OBO means little or no distortion, but
  - the SAT power is reduced wrt $P_{OUT,Sat}$
  - efficiency is smaller

# Distortion of Constellations

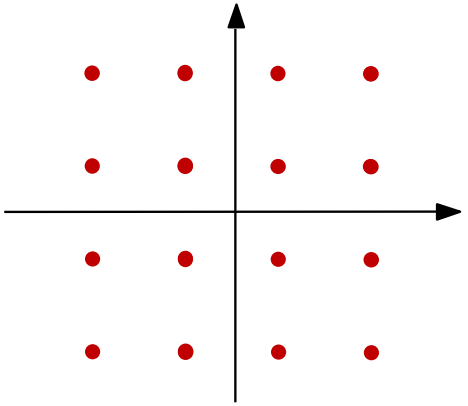


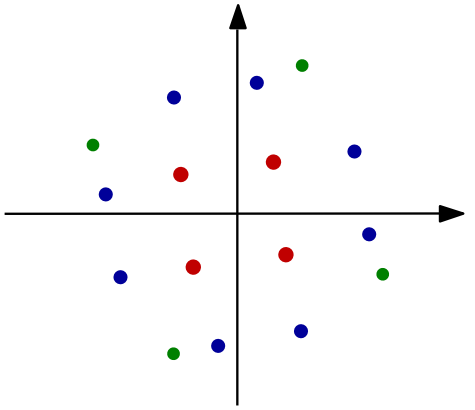
- QPSK: all points have the same amplitude, so the output amplitude by AM/AM and output phase rotation by AM/PM is the same for all – no distortion !





- 16-QAM: phase rotations are different for different points, as well as output amplitudes, since the different input points have different amplitudes







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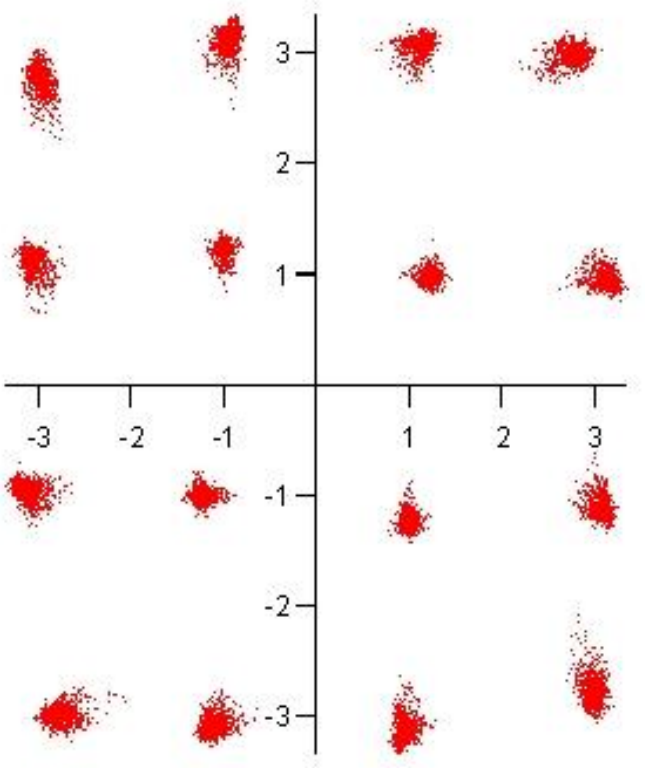
# Nonlinear Distortion & Filtering



- The HPA distorts the whole *waveform* – the receive filter is no longer matched to the received signal and *nonlinear ISI* appears on top of the distorted constellation

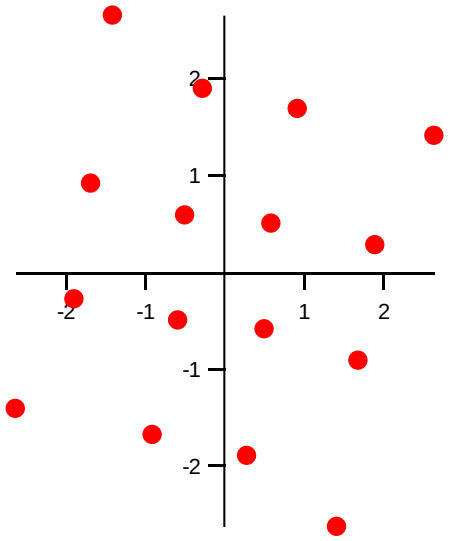
4 dB OBO

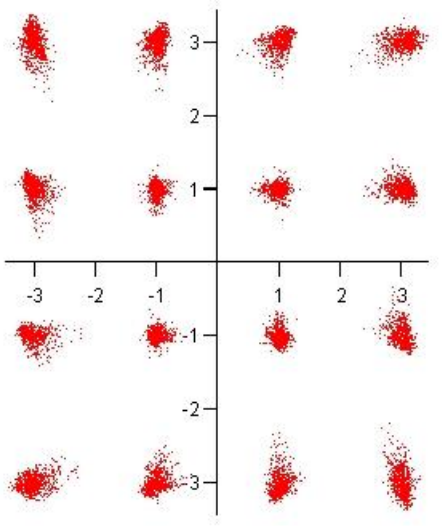


# PreDistortion



1. HW (internal) linearization
2. Simple Constellation (Data) Predistortion
3. DSP-Based Dynamic Predistortion with memory

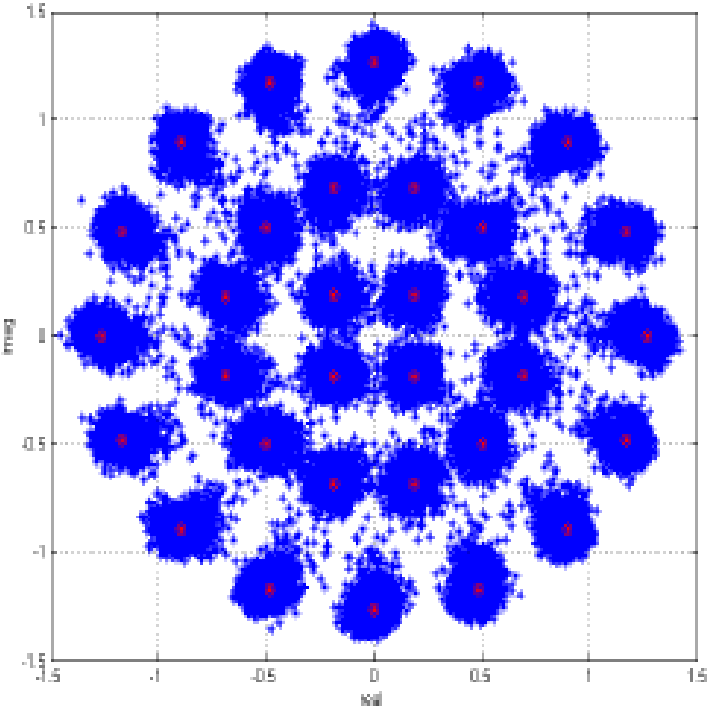


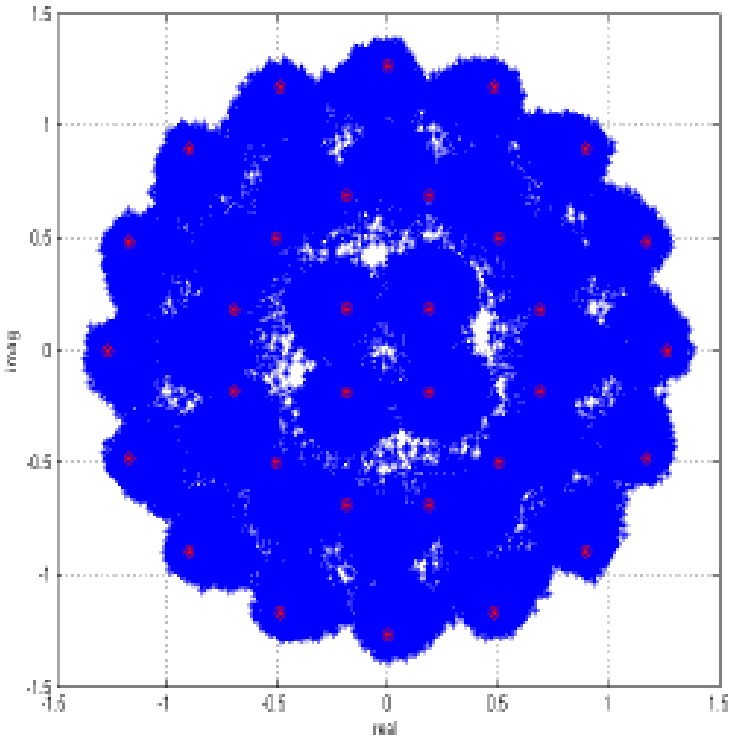



# 32-APSK



## Predistortion

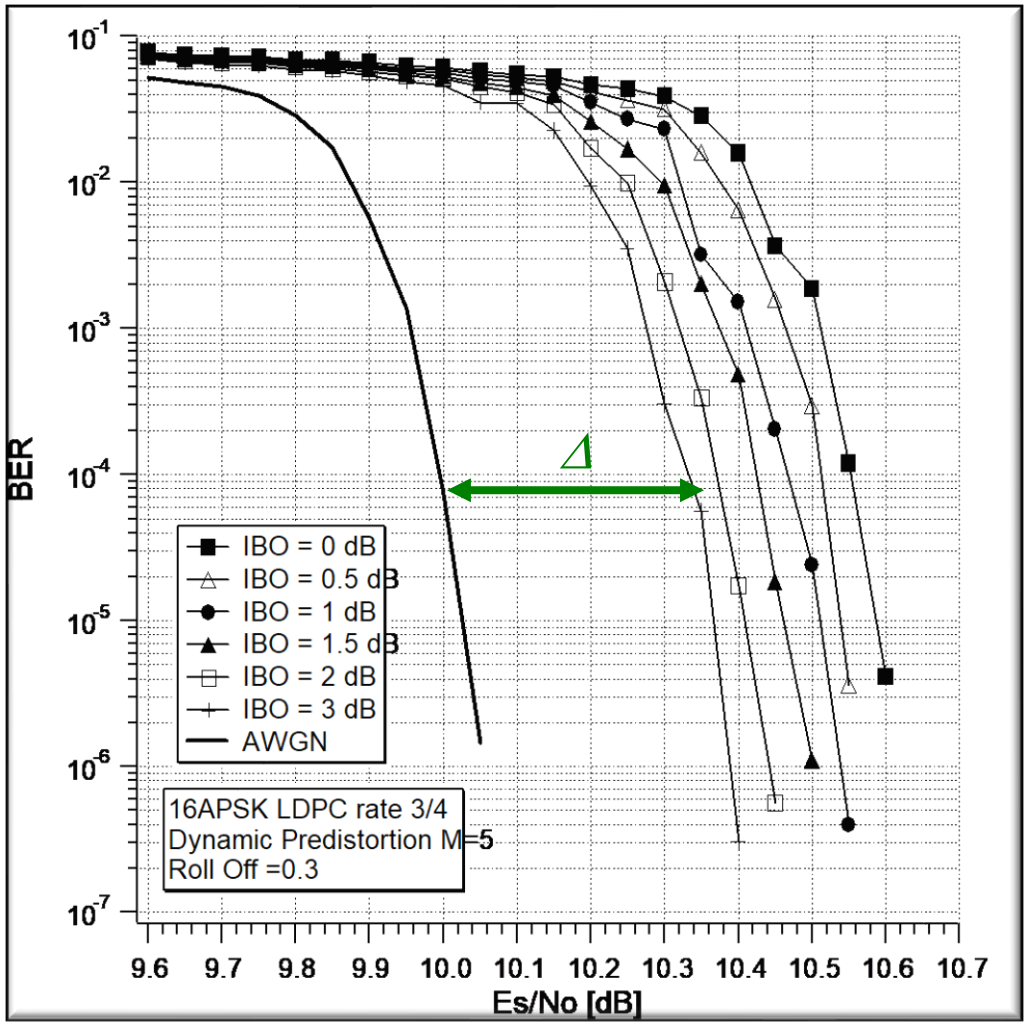



## No Predistortion

# Operating Point



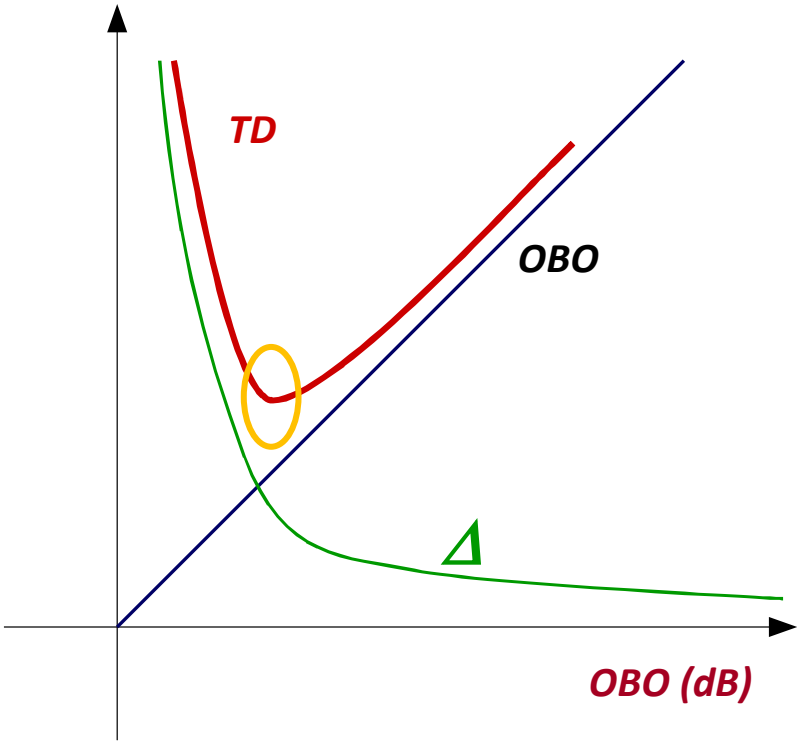



## Simulation Results

We can derive the SNR Degradation $\Delta$ due to nonlinear distortion in different operating conditions of the HPA (i.e., IBO/OBO)

# Performance Metrics: the Total Degradation (TD)






***TD (dB)=OBO (dB) + Δ (dB)***

***OBO* = Output Back-Off**

0 dB means maximum satellite power - > 0 dB means unused on-board power

**Δ = SNR Degradation**

*of the BER curve on the nonlinear channel @ target BER - Decreases increasing the BO*

***Optimum OBO value (operating point) to be found***