Ingegneria delle Telecomunicazioni
Satellite Communications

7. Digital Twins – Modeling of HPA

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- 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

Ku-band LTWTA Single Carrier Transfer Characteristics
(Measurement Frequency: 10992.5 MHz)

![Graph showing AM/AM and AM/PM characteristics with Pin (dB) on the x-axis and Pout (dB) and Output Phase Change (Deg) on the y-axis.](image-url)
Modelling AM/AM and AM/PM

\[ |y(t)| = \sqrt{P_{OUT,Sat}} g_{AMAM} \left( \frac{x(t)}{\sqrt{P_{IN,Sat}}} \right), \quad \angle y(t) = \angle x(t) + g_{AMPM} \left( \frac{x(t)}{\sqrt{P_{IN,Sat}}} \right) \]
TWTA Analytical Modeling (Saleh)

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

Here, \( x(t) \) is intended as ALREADY NORMALIZED wrt its saturation power \( P_{IN,Sat} \).
SSPA Analytical Modeling (Rapp)

\[
|y(t)| = \frac{|x(t)|}{\left(1 + |x(t)|^{2p}\right)^{\frac{1}{2p}}}, \quad \angle y(t) = \angle x(t) + 0
\]
$$IBO_{dB} \triangleq \frac{P_{in, SAT}}{P_{in}} \mid_{dB} = (P_{in, SAT})_{dB} - (P_{in})_{dB}$$

$$OBO_{dB} \triangleq \frac{P_{out, SAT}}{P_{out}} \mid_{dB} = (P_{out, SAT})_{dB} - (P_{out})_{dB}$$
Simplified Satellite Transponder Model

LO

IBO setting

HPA

Output Filter

Power Spectrum Density (dBm/MHz)

Frequency (MHz)
Efficiency vs. Distortion

In addition, larger OBO=less TX power

Receiver demodulation loss for a given IBO/OBO
High OBO means little or no distortion, but
- the SAT power is reduced wrt $P_{\text{OUT, Sat}}$
- 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
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.
1. HW (internal) linearization
2. Simple Constellation (Data) Predistortion
3. DSP-Based Dynamic Predistortion with memory
32-APSK

No Predistortion

Predistortion
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)

\[ OBO = \text{Output Back-Off} \]
0 dB means maximum satellite power - \( > 0 \) dB means unused onboard power

\[ \Delta = \text{SNR Degradation of the BER curve on the nonlinear channel @ target BER - Decreases increasing the BO} \]

\[ \text{TD (dB)} = OBO (dB) + \Delta (dB) \]

Optimum OBO value (operating point) to be found