Digital Predistortion of Power Amplifier Non-Linearities for Full-Duplex Transceivers

Andrew C. M. Austin, Alexios Balatsoukas-Stimming, and Andreas Burg

Telecommunication Circuits Laboratory, École Polytechnique Fédérale de Lausanne (EPFL), Switzerland

Predistortion of Power Amplifier Non-Linearities

Power amplifiers can introduce significant non-linear components into the transmitted signal

- For wideband signals, **memory effects** aggravate the problem

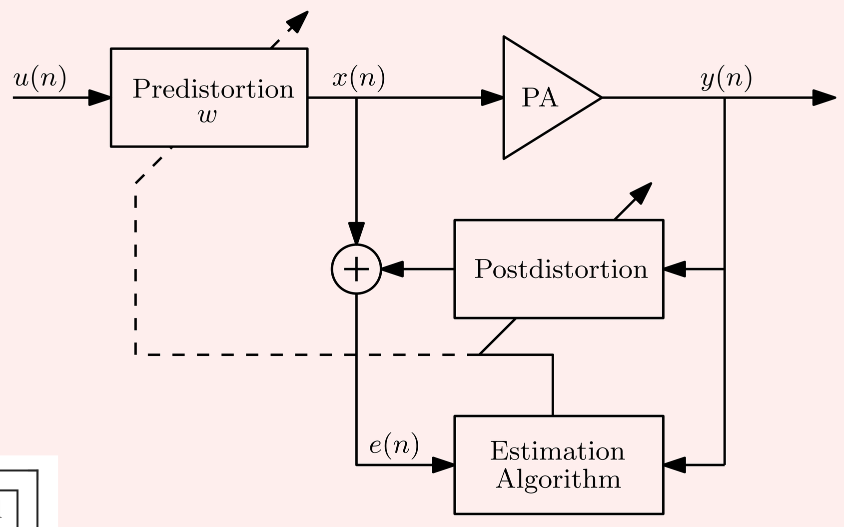
Digital predistortion compensates for non-linear compression and memory effects by appropriately pre-processing the **baseband** signal

Predistortion requires a model of the power amplifier to find the **inverse**:

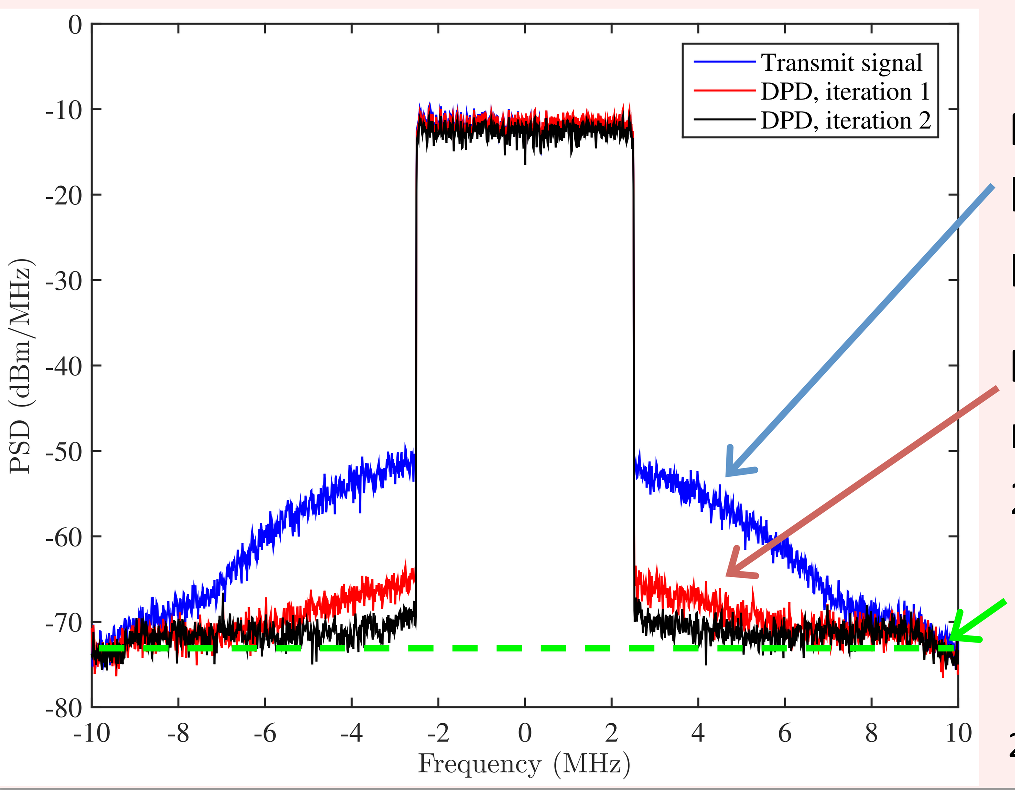
- Memory polynomial: $$y(n) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} \underbrace{a_{km}}_{\text{Coefficients}} \underbrace{x(n-m)\,|x(n-m)|^k}_{\text{Basis function}}$$

Determining the Coefficients:

- Find predistortion coeffs by using PA output y to estimate the PA input x via least-squares
- After convergence: copy coeffs to predistortion stage and run open-loop



Experimental Verification:



No predistortion: strong out-of-band emissions 40 dB down from peak power

Predistortion with $K = 8$ and $M = 8$: rejection of out-of-band emissions by 20 dB to slightly above noise-floor

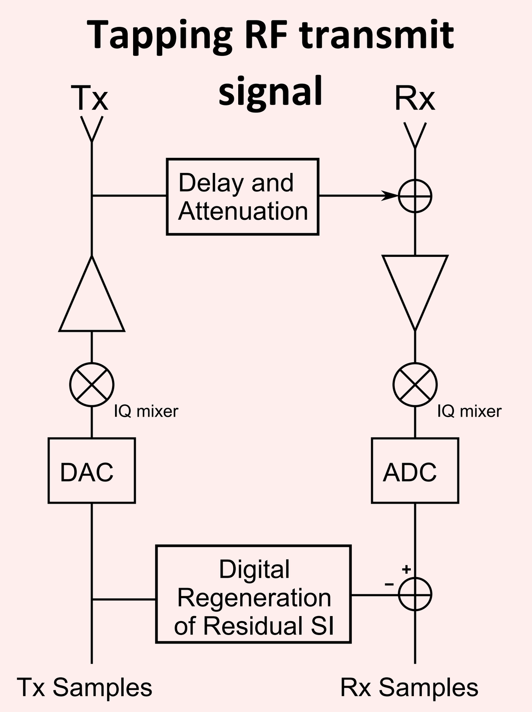
Noise-Floor: set by the approx 66 dB dynamic range of the receiver ADC

2.4 GHz carrier, 20 dBm, 5 MHz, 512-tone OFDM

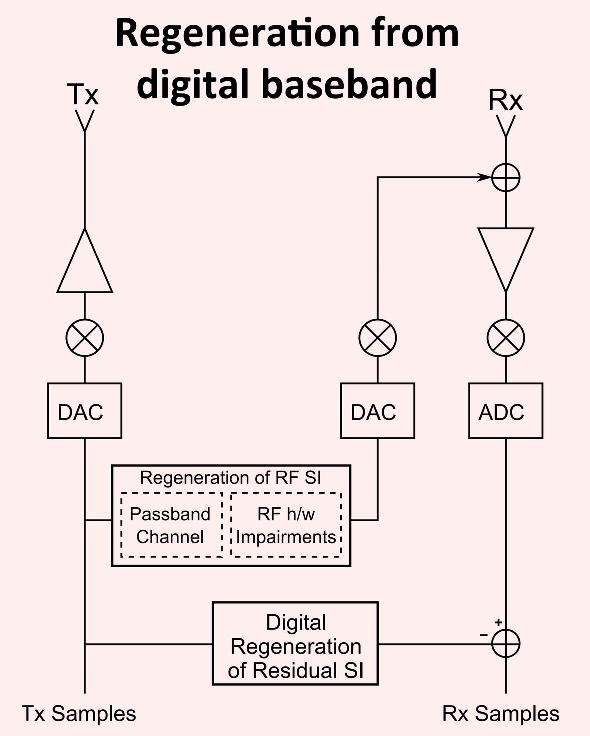
Application to Full-Duplex Transceivers

Full-duplex transceivers based on **digital regeneration:** more sensitive to PA non-linearities (and other impairments) than analog cancellation architectures

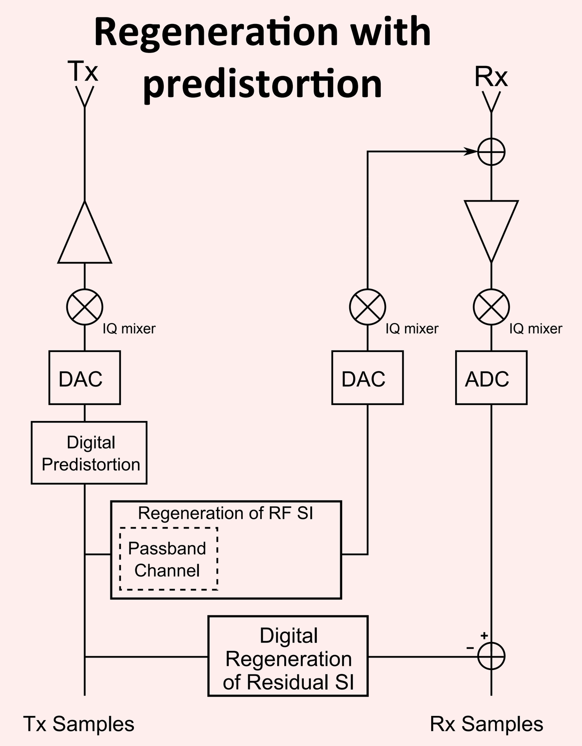
Predistortion reduces non-linearities in transmit signal: **reduces required complexity** of cancellation at the receiver



- Inherently captures all TX non-idealities
- Requires reconfigurable analog hardware: **does not scale well for MIMO**



- All signal processing done digitally: **scales well for MIMO**
- Requires precise modelling and reconstruction of TX non-idealities



- Linearizing the TX signal means less non-linear cancellation is required
- Avoid modelling the PA memory in digital cancellation

Memory polynomial predistortion **only** accounts for the power amplifier: mixer IQ-imbalance and DAC baseband non-linearities are also significant

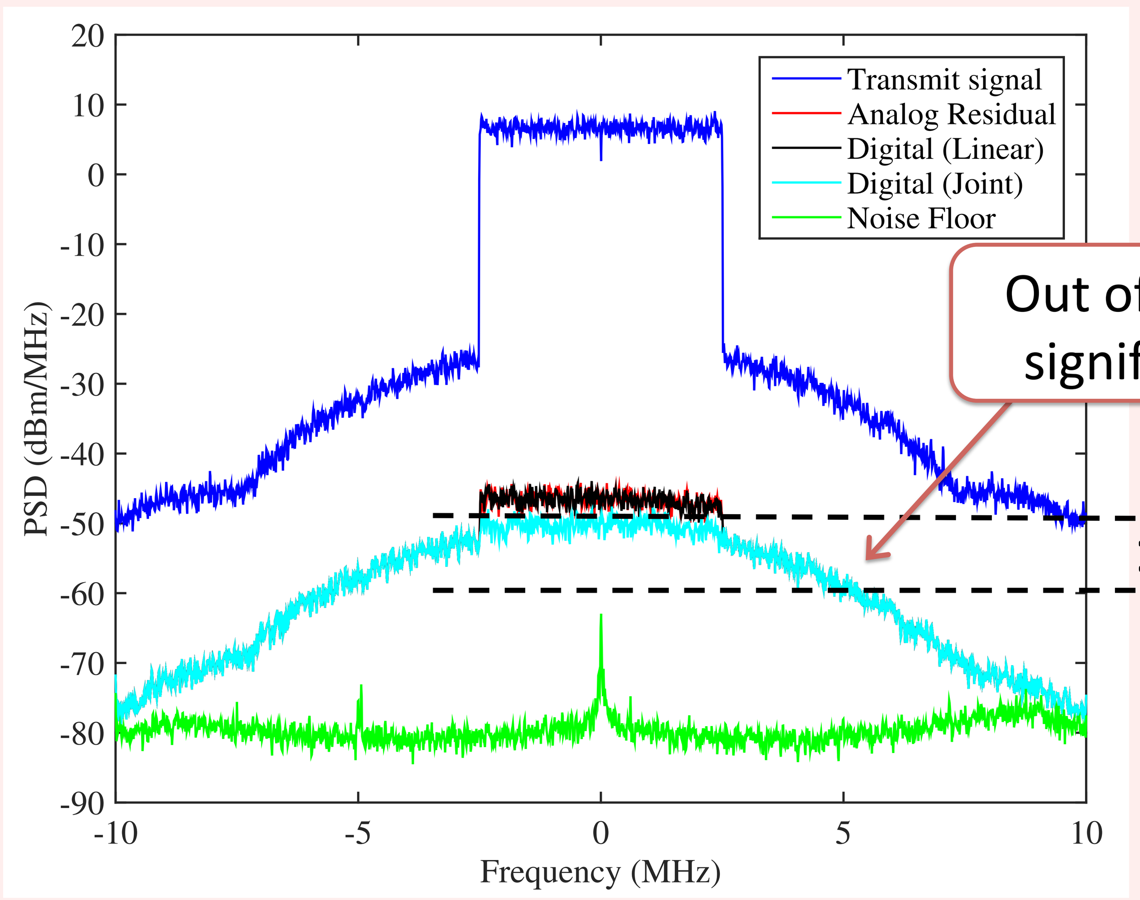
- **New predistortion IQ and PA basis** that includes mixer and DAC effects:

$$y(n) = \sum_{f=0}^{F} \sum_{g=0}^{G} \sum_{m=0}^{M} a_{fgm} \Re\{x'(n-m)\}^{\frac{f}{2}} \Im\{x'(n-m)\}^{\frac{g}{2}}$$

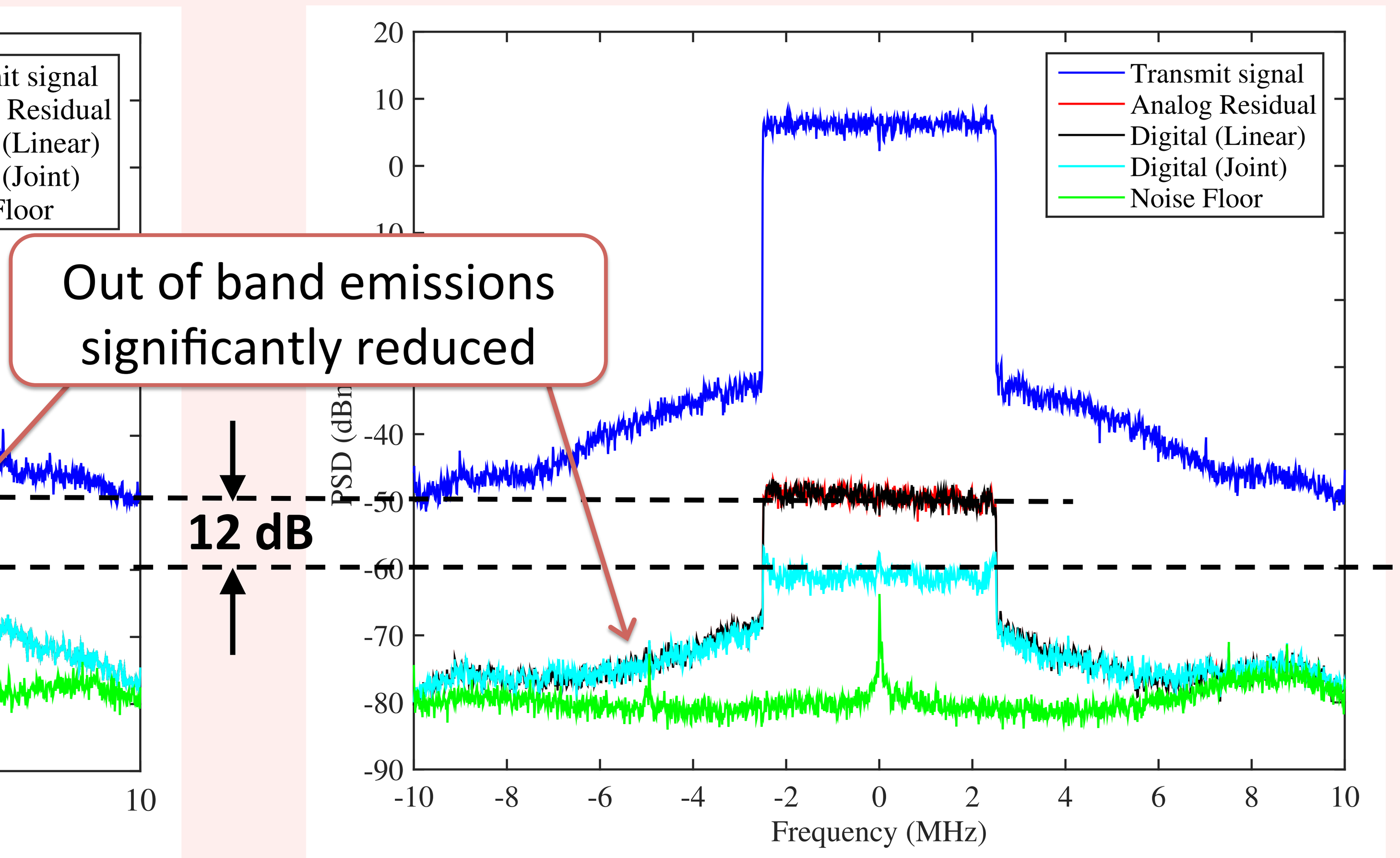
a_{fgm}: coefficients
M: memory depth
F: max. exponent of Real Part
G: max. exponent of Imaginary Part

Experimental Measurements of Self-Interference Suppression with Predistortion

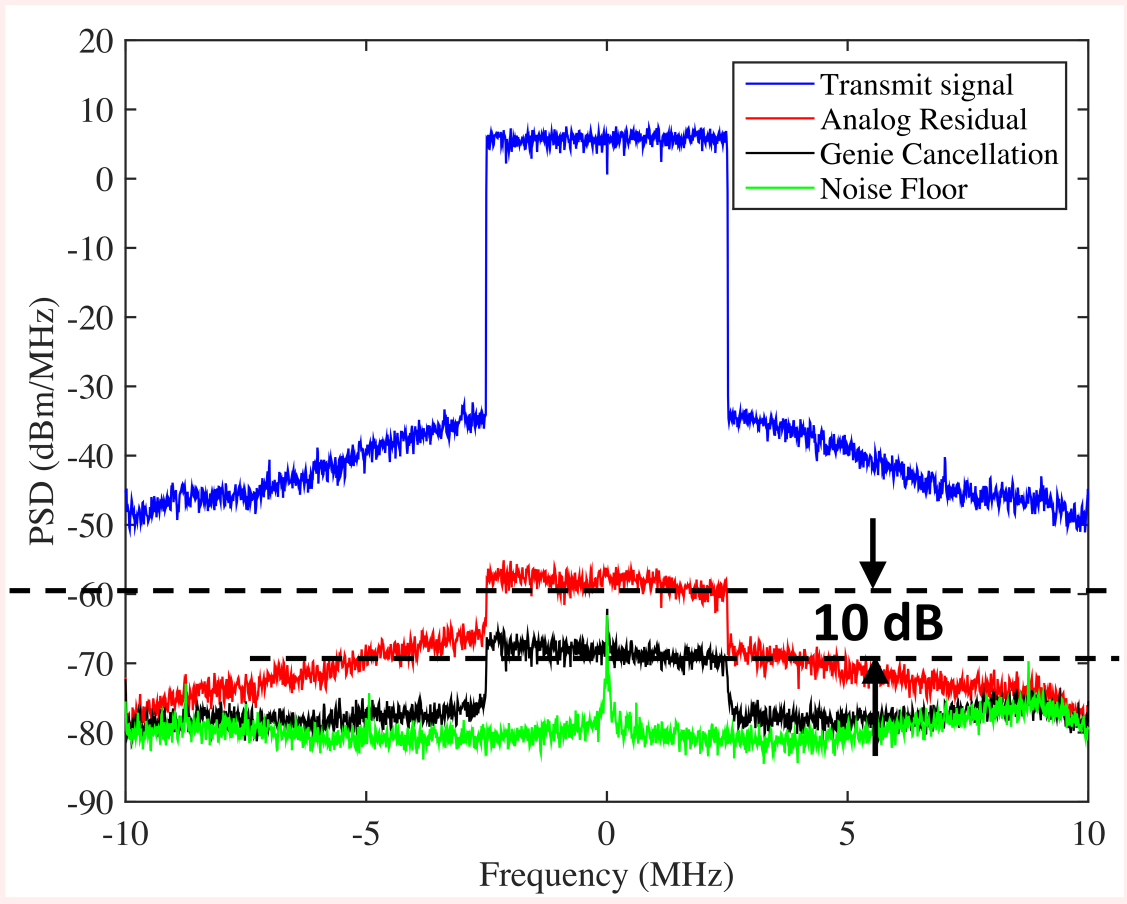
No predistortion



Predistortion with memory polynomial



Predistortion with IQ and PA basis



- Digital cancellation stage unable to reduce self-interference more than analog stage
- Self-interference approx 30 dB above the noise

PA predistortion allows digital cancellation stage to reduce self-interference further by 12 dB

- Analog cancellation stage **alone** reduces self-interference to within 20 dB of the noise-floor (on the same level as digital with PA linearization)

What is in the residual?

- A "feasible" genie removes all deterministic signal components by averaging over 10 frames

The genie predicts an additional 10 dB analog or digital suppression is possible

- The remaining self-interference (10 dB above the noise-floor) comes from random components, e.g., phase-noise or timing jitter

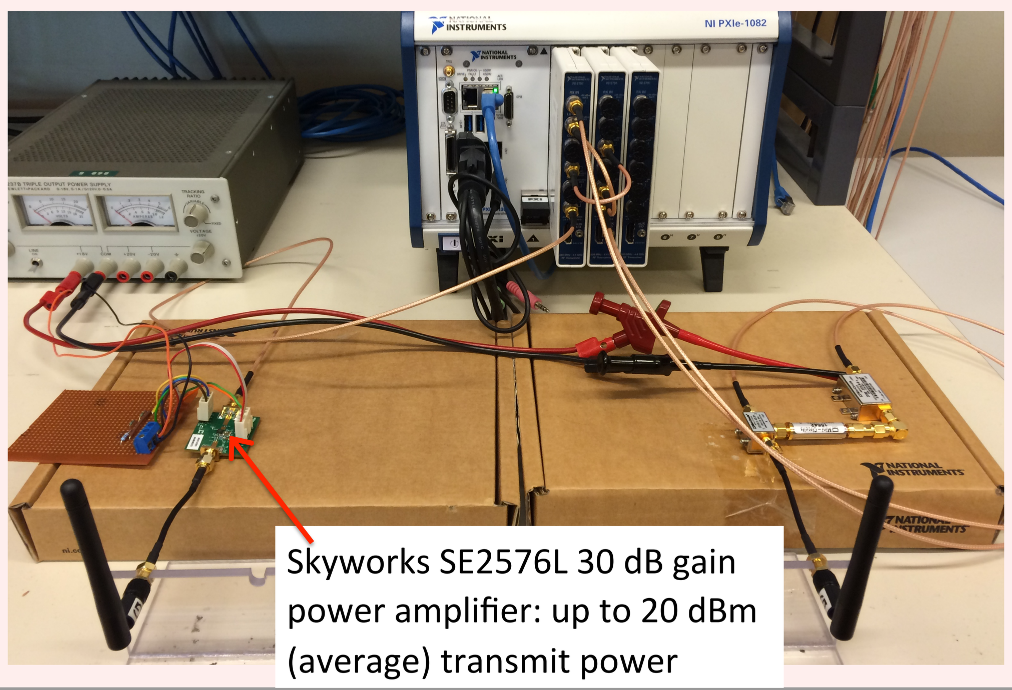
Hardware Testbed

NI FlexRIO PXIe-1082 with two NI-5791 RF modules

- Baseband signal processing performed in Matlab

Two stage self-interference suppression:

1. RF cancellation signal generated from digital baseband (by sounding self-interference channel)
2. Digital cancellation applied to the residual self-interference (joint model includes IQ-imbalance)



Skyworks SE2576L 30 dB gain power amplifier: up to 20 dBm (average) transmit power

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