

ML-Assisted Wideband Injection Pulling Mitigation in Wireless Transceivers

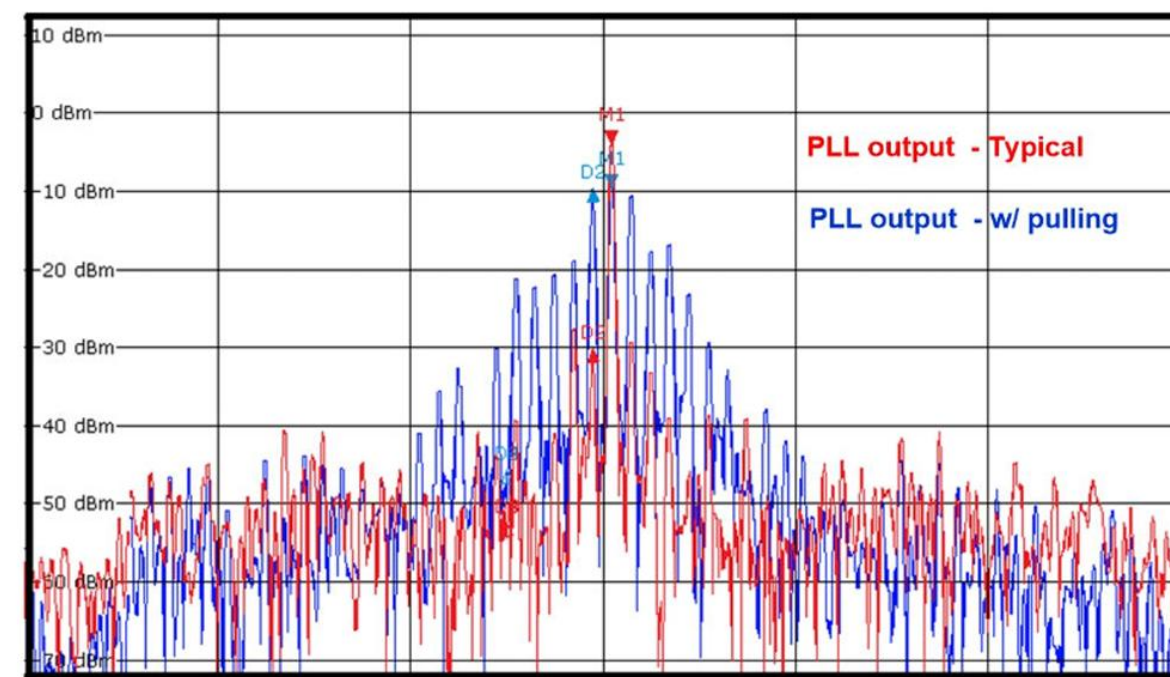


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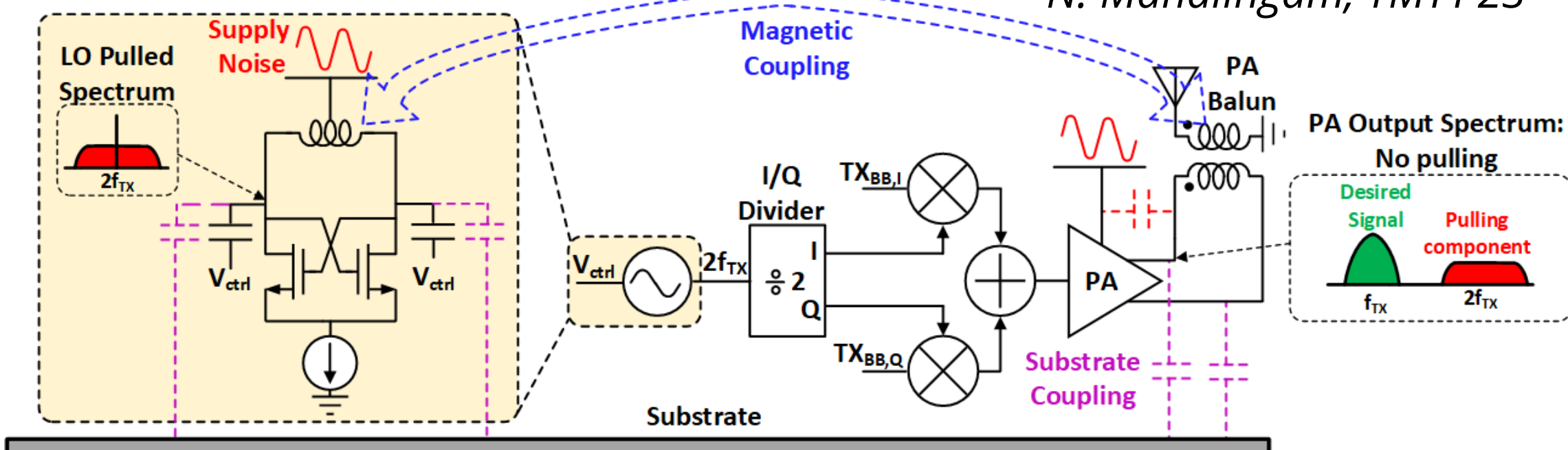
Motivation

Injection Pulling in Wireless TX:

- 2nd harmonic of PA couples to LO through various coupling mechanisms.
- Injection pulling causes deterministic LO phase error, spectral regrowth, EVM and ACLR degradation.
- For Wifi-7 Support: $f_{LO} = 5 - 6\text{GHz}$, $BW = 320\text{MHz}$

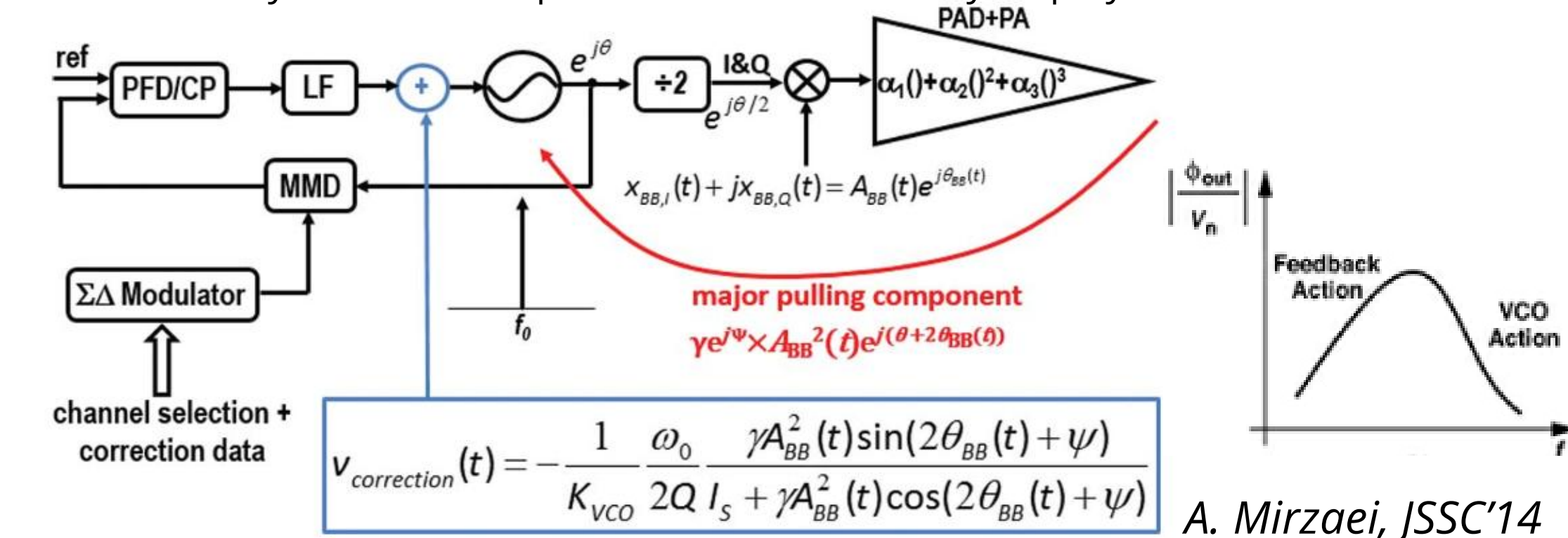


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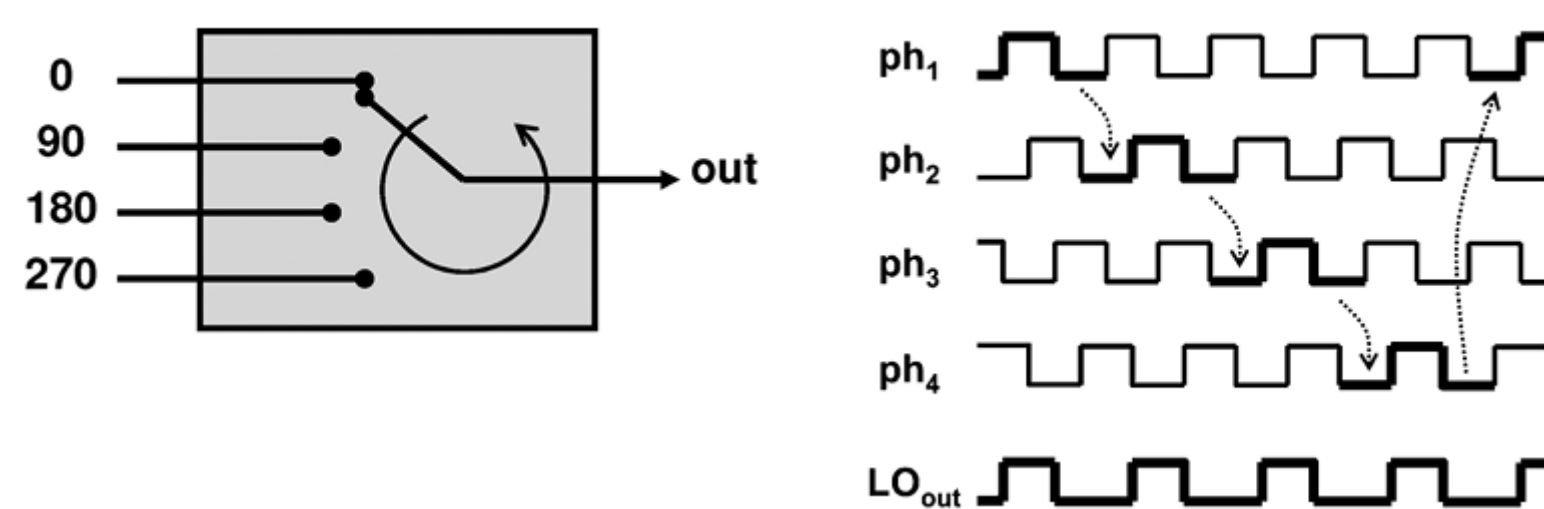


Limitations of Existing Mitigation:

- Act only inside PLL loop → Bandwidth limited by loop dynamics.



- Fractional dividers add power/complexity, still narrowband.

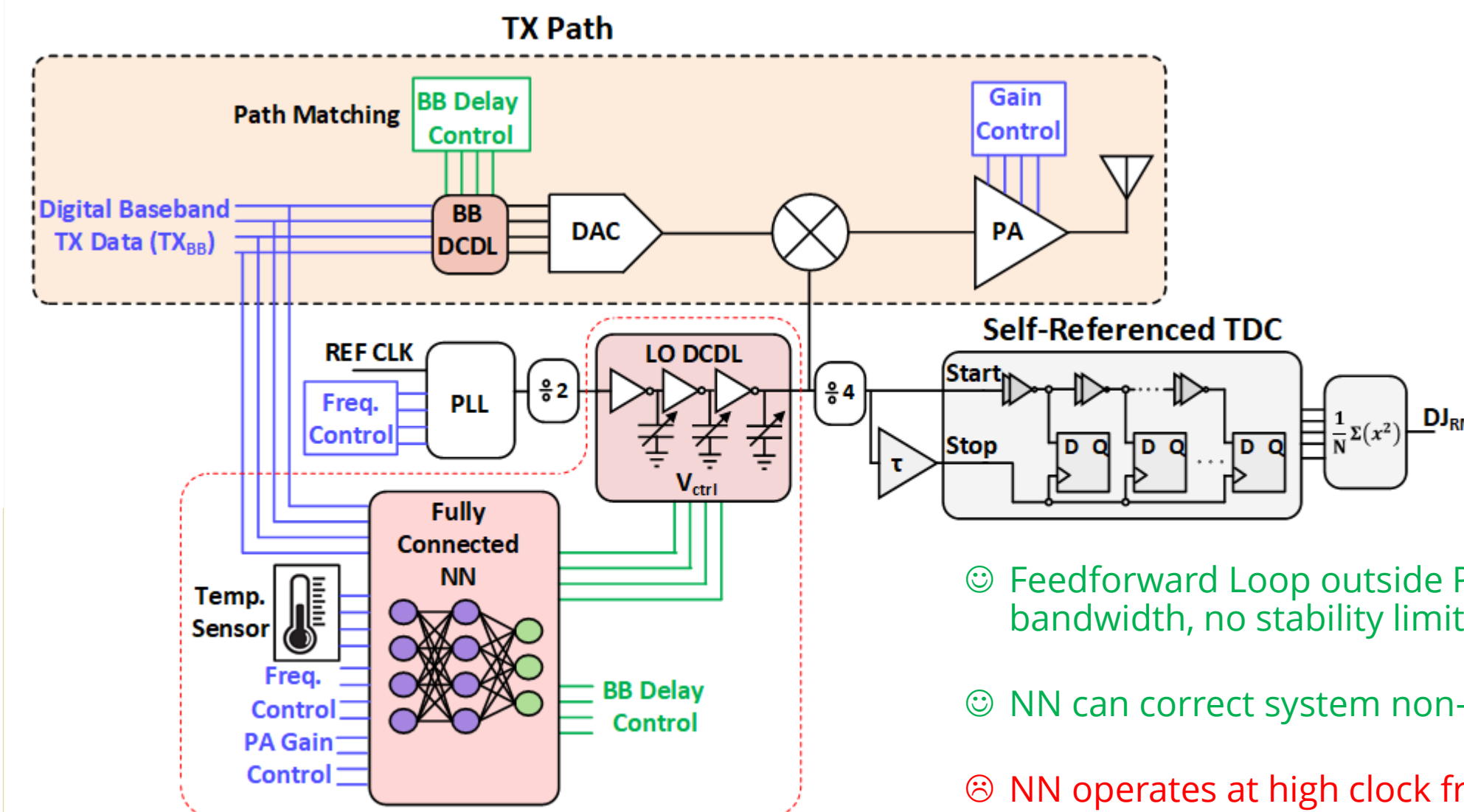


Div. By 1.25x

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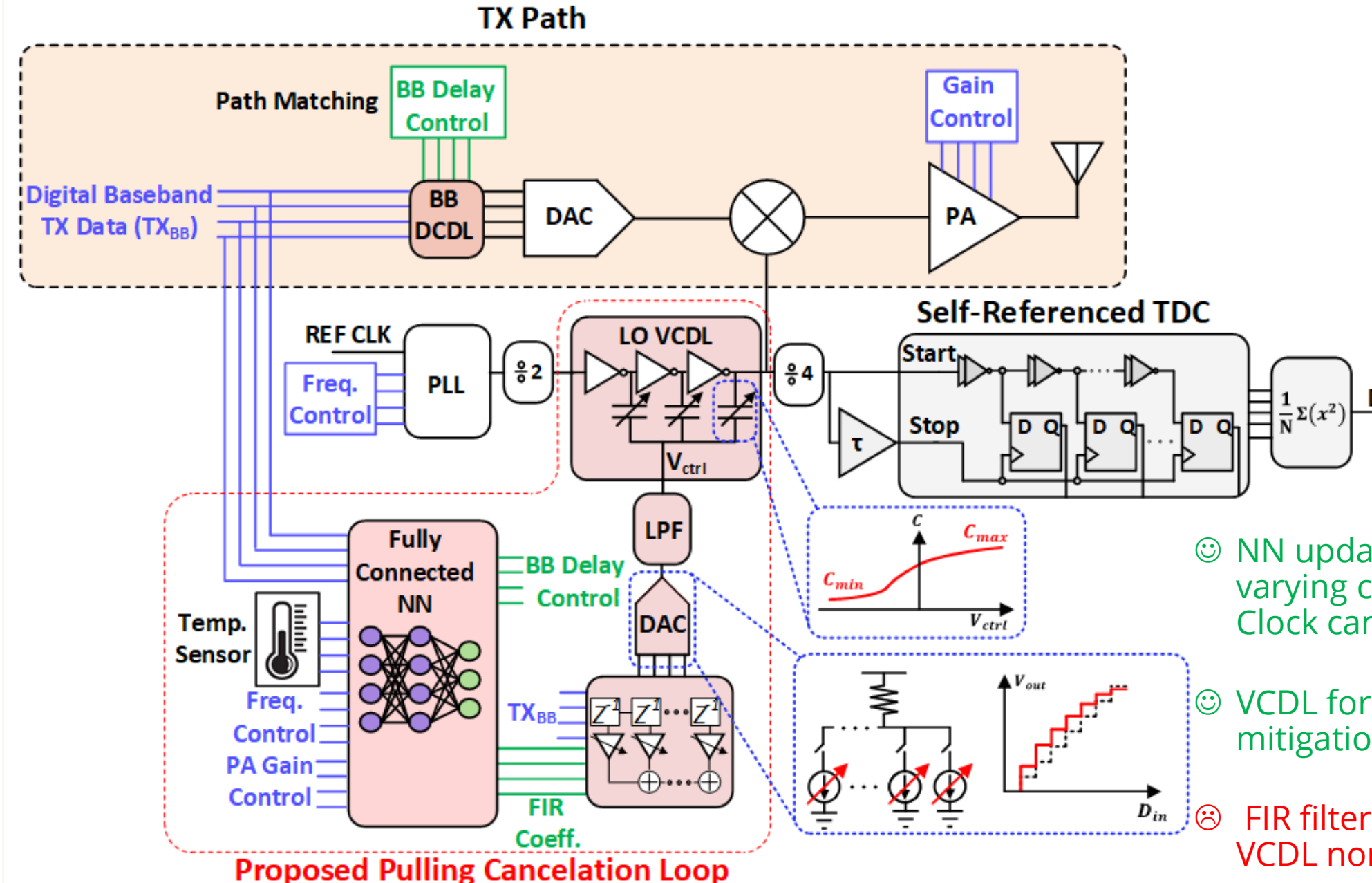
Proposed Architecture & ML Flow

Key Idea: Feedforward ML Phase Correction:



Proposed Pulling Cancellation Loop

- ML block learns mapping from baseband samples to LO timing error.
- TDC only used during offline optimization phase (Population mode).
- Idea can be extended to any form of DJ (e.g. PSJ in wireline systems.)



- FIR filter implements:

$$V_{ctrl} = \sum w_{1,i} A[n-i] + w_{2,i} B[n-i]$$

$$A = TX_I^2 - TX_Q^2$$

$$B = 2 TX_I TX_Q$$

- Only FIR filter and DAC run at Nyquist rate.

ML Modes & System-Level Results

3 Modes of Operation:

1. Population Mode:

- Using supervised learning, an external optimizer (CMA-ES) is used to generate the FIR coefficients and the BB delay that minimizes the RMS TDC error.
- TDC_EN = 1, NN_EN = 0

2. Training Mode:

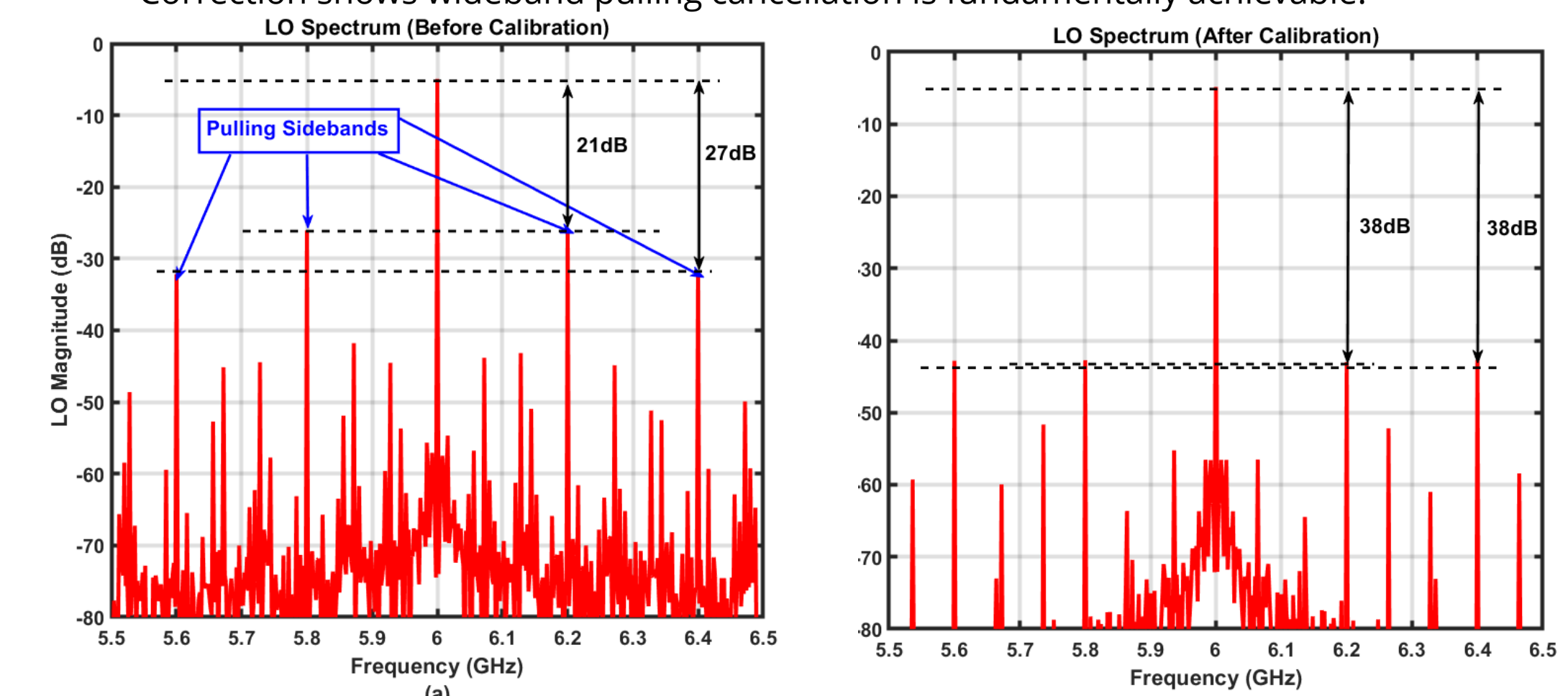
- The weights and biases are set using a python model for the NN. No interaction with the chip is needed.

3. Inference Mode:

- The NN is loaded with the trained weights and biases.
- FIR coefficients and BB delay are periodically updated (every T seconds - event based).

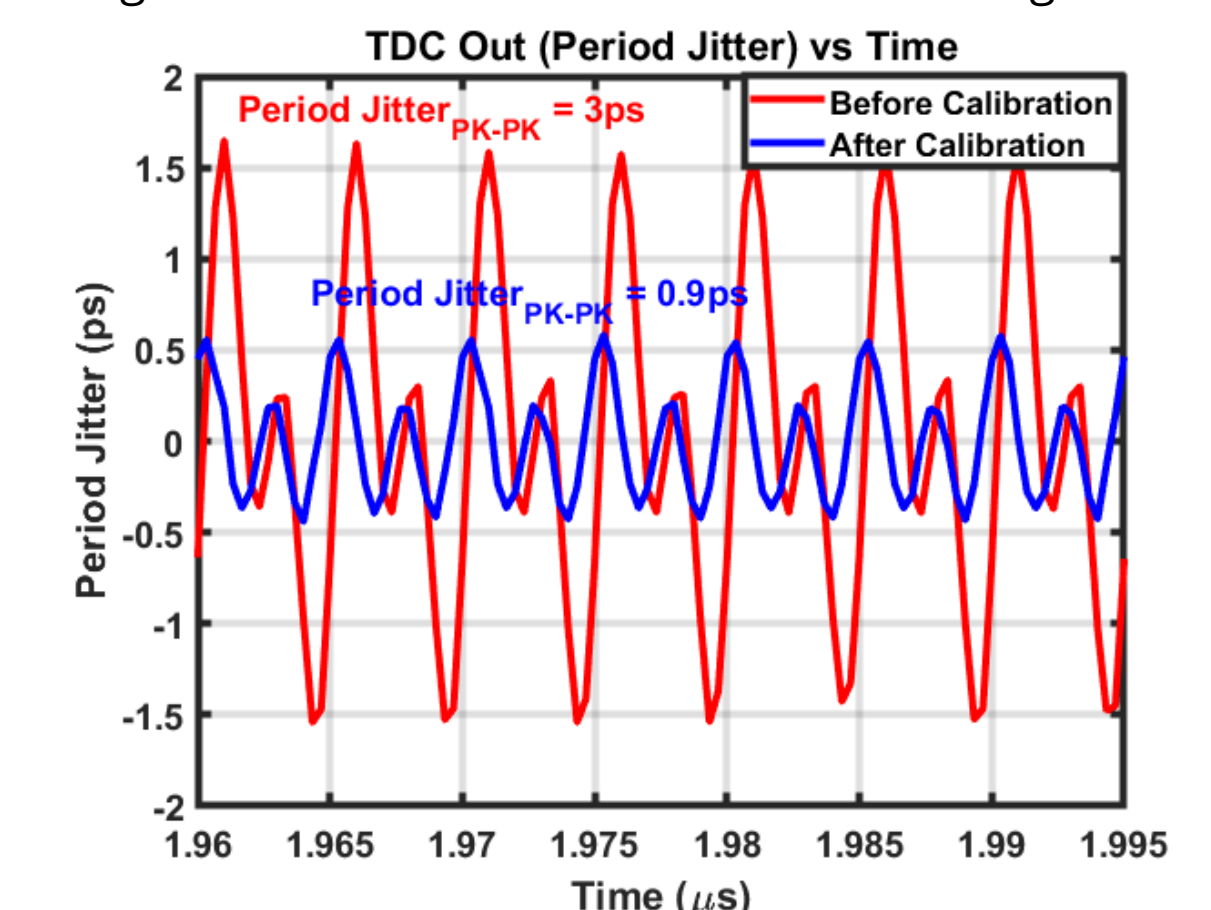
Behavioral results (6GHz LO)

- Verilog-A model of PLL, ideal TDC, multi-tone real baseband (100MHz, 200MHz).
- Correction shows wideband pulling cancellation is fundamentally achievable.



LO Output spectrum without calibration for a 6GHz LO signal

Output spectrum after calibration for 6GHz signal



Self-Referenced TDC output vs time