Non-Linear Digital Self-Interference Cancellation for In-Band Full-Duplex Radios Using Neural Networks

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In-Band Full-Duplex Communications

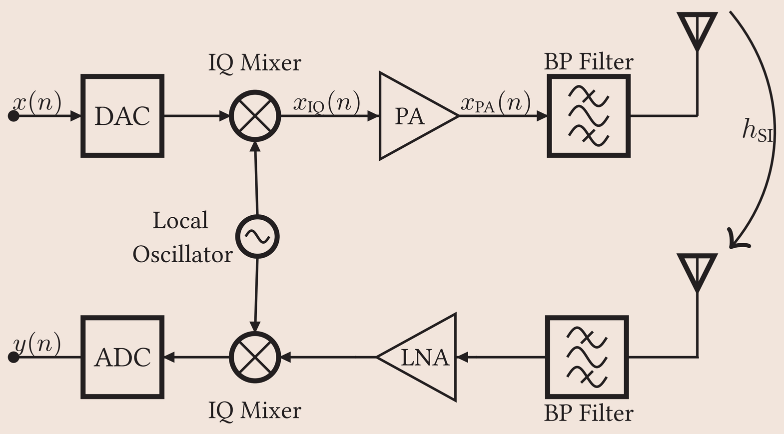
In-band full-duplex communications:

1. Up to twice the throughput wrt TDD & FDD
2. No additional bandwidth
3. No wasted time or frequency resources

Fundamental Challenge

Self-interference (SI) signal is **much stronger** than the desired signal and needs to be cancelled!

- **In principle**, SI cancellation should be easy since the digital transmitted signal is known
- **In practice**, the digital signal does not tell the whole story!



Why is Cancellation Difficult?

Analog components introduce strong **non-linear** effects!

Polynomial Non-Linear Digital Cancellation

Captures IQ imbalance, PA non-linearities (up to order P, memory M), and channel memory (L) using a complex polynomial model:

$$y(n) = \sum_{\substack{p=1,\\ p \text{ odd}}}^{P} \sum_{q=0}^{p} \sum_{m=0}^{M+L-1} h_{p,q}(m) x(n-m)^q x^*(n-m)^{p-q}$$

Number of parameters: $n_{\text{poly}} = (M+L)\left(\frac{P+1}{2}\right)\left(\frac{P+1}{2}+1\right)$

Complexity Analysis

Best-case scenario assumptions:

- Basis function computation is free
- Complex mults require 3 real mults and 0 real additions

Complexity:

1. Real additions: $n_{\text{ADD,poly}} = 2(n_{\text{poly}} - M - L - 1)$
2. Real multiplications: $n_{\text{MUL,poly}} = 3(n_{\text{poly}} - M - L)$

Neural Network Non-Linear Digital Cancellation

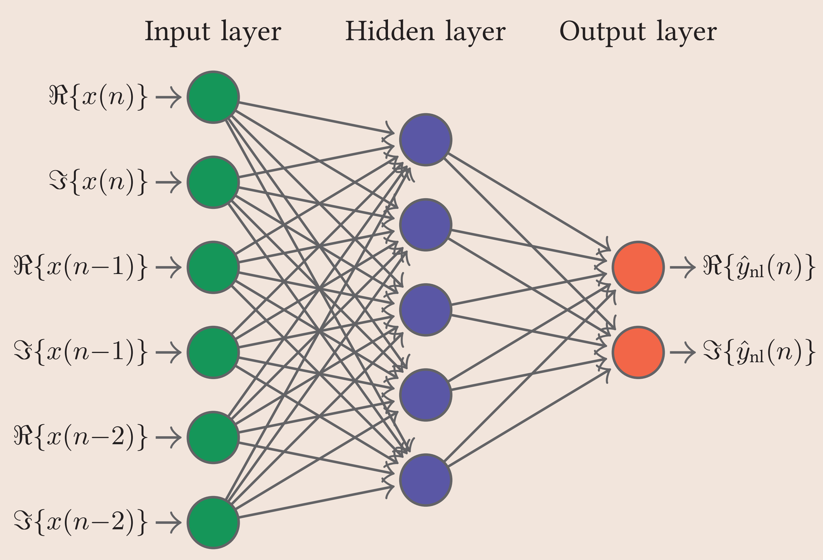
Two-step digital cancellation:

1. Linear digital cancellation: $\hat{y}_{\text{lin}}(n) = \sum_{m=0}^{M+L-1} \hat{h}_{1,1}(m)x(n-m)$
2. Train a neural network to cancel: $y_{\text{nl}}(n) \approx y(n) - \hat{y}_{\text{lin}}(n)$

Single-layer NN with n_h neurons and ReLU activation functions.

Complexity Analysis

1. Real additions:
   $n_{\text{ADD,NN}} = (2M+2L+3)n_h$
2. Real multiplications:
   $n_{\text{MUL,NN}} = (2M+2L+2)n_h$

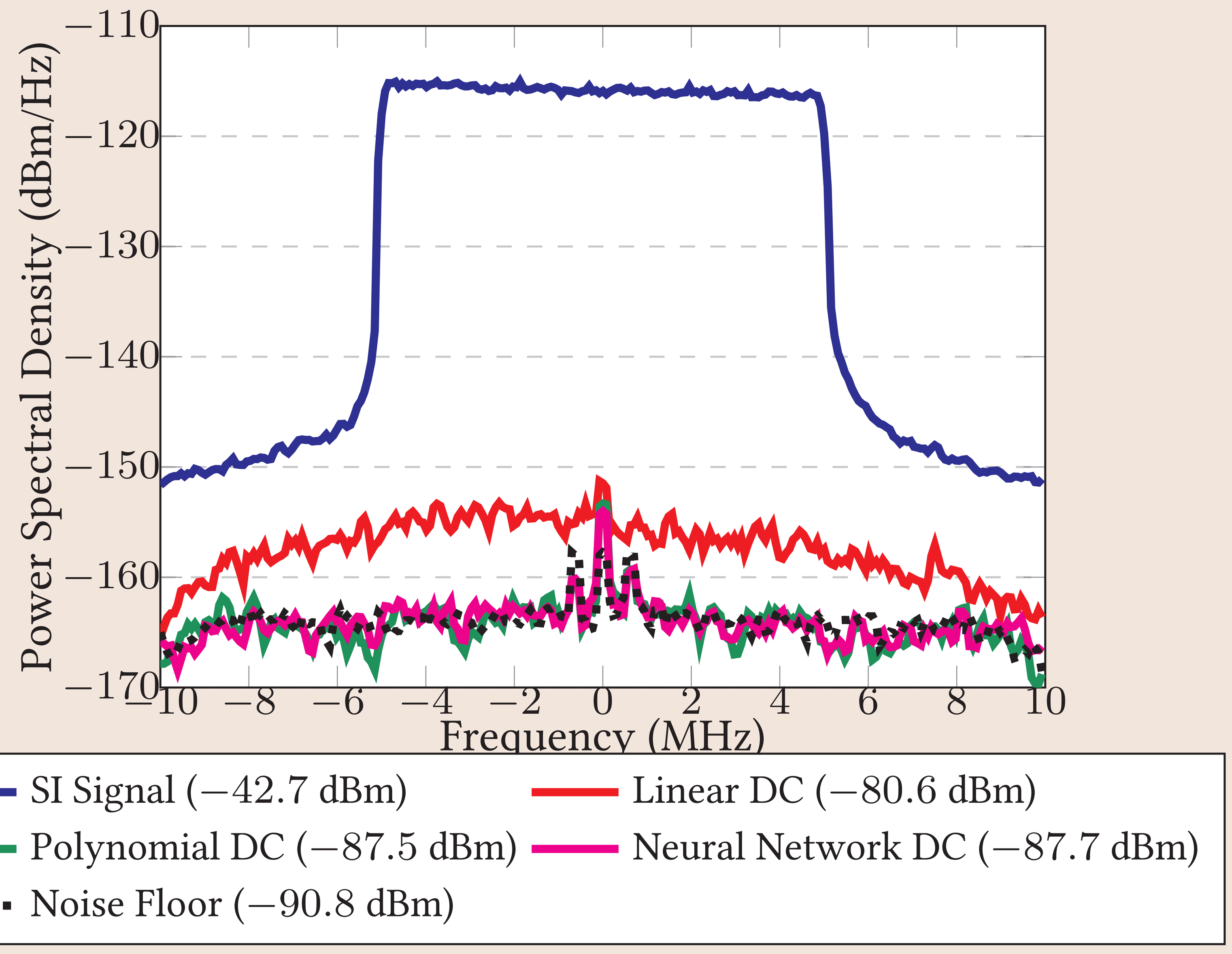


Experimental Setup

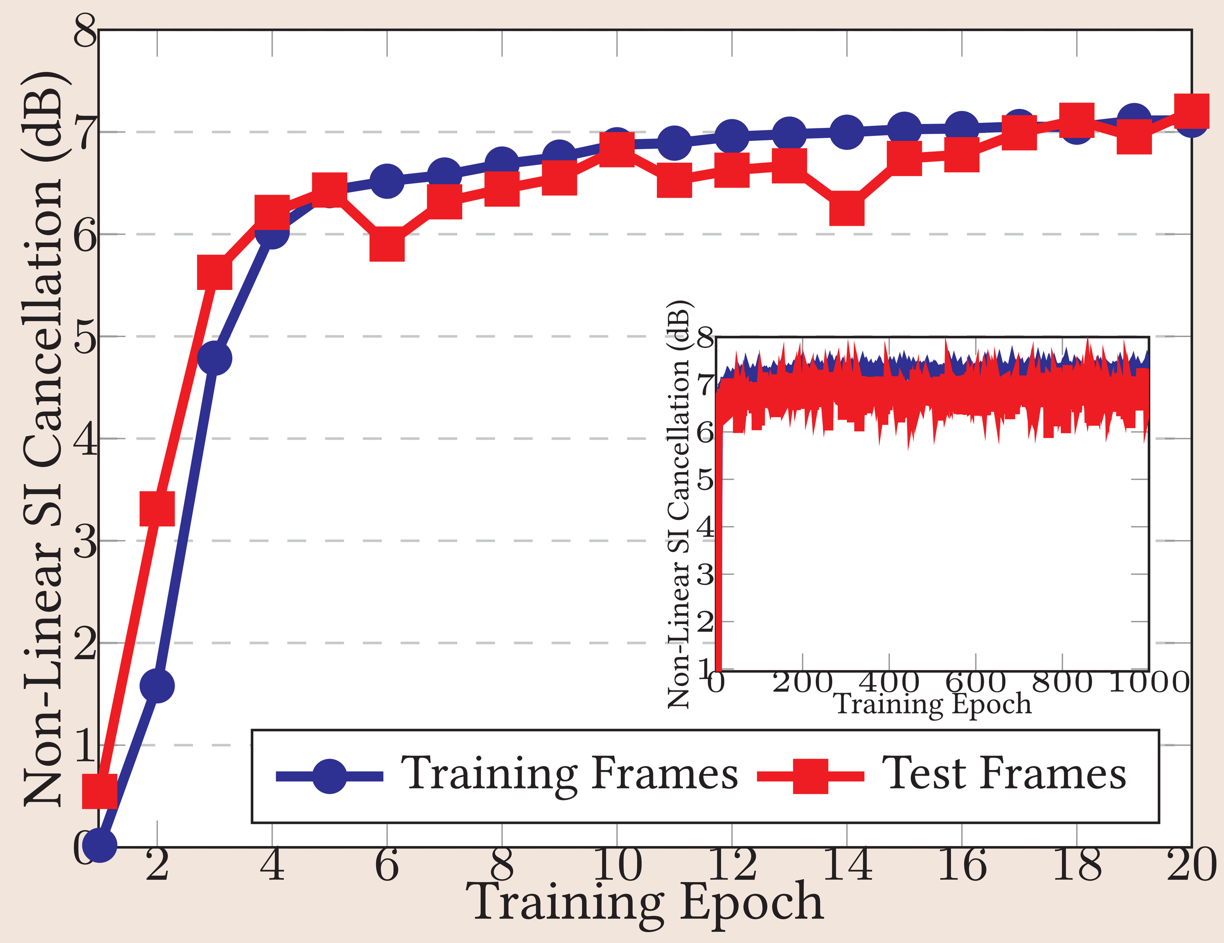
- **Dataset:** Full-duplex testbed with 53 dB analog cancellation
- **General:** 10 MHz OFDM signal, 10 dBm transmit power, $20,000$ samples (90% training, 10% test), $M+L=13$
- **Polynomial:** $P=7$, LS training
- **NN:** $n_h = 17$, MSE cost, Adam optimizer ($\lambda = 0.004$, $B=32$)

Self-Interference Cancellation Results

Cancellation performance:



NN training convergence:



Complexity Comparison

	Polynomial	NN	Improvement
Additions	492	493	0%
Multiplications	741	476	**36%**

Conclusions & Future Work

- Neural network seems **very promising**: same performance as the complex polynomial model, but with **lower complexity**
- Convergence and complexity of training need to be compared
- Scenarios with higher non-linear cancellation have to be examined
- Hardware implementations have to be compared

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