Comparison of Traditional and AI-based Models for IMD2 Cancellation

A. A. Degtyarev, N.V. ,Bakholdin, A. Y. Maslovskiy, S. A. Bakhurin

Motivation

The use of **direct conversion receivers (DCRs)** in modern smartphones has become widespread due to their simplicity and ability to support multiple frequency bands. Self-interference cancellation is **essential** for these devices, and traditional approaches involve adapting behavioral models[1]. However, digital interference cancellation through neural network training has emerged as a promising alternative. Neural network-based models are capable of learning temporal information and accounting for the memory effects of nonlinearity[2]. This work focuses on researching second intermodulation distortion (IMD2) generated by the nonlinear distortion of a single RF mixer using complex data for transmission (Tx) and real-valued samples for reception (Rx).

Traditional and NN methods

Behavioral modelling is introduced by the **generalized memory polynomial (GMP)** model[3]. Polynomial model is known as a structure, which describes the PA physical properties for different PA kinds and modes. For the task of IMD2 cancellation special case of GMP is decided to be exploited. Moreover, currently we use orthogonal Chebyshev polynomials basis, which could be expressed mathematically as:

$$y_n = \sum_{k=0}^{K-1}\sum_{p=0}^{P-1} \theta_{k,p} T_p(|x_{n-d_k}|),$$
$$T_p(|x_{n-d_k}|) = \cos(n \cdot \arccos(|x_{n-d_k}|)),$$

where $\theta_{k,p} \in \mathbb{R}$ -parameters of Chebyshev polynomial model, x - samples of baseband (BB) signal d- signal samples delays, $T_p(\cdot)$- order Chebyshev polynomial of the first kind.

Neural network architecture for IMD2 cancellation is shown lower. Since non-linearity is inertial, NN structure is implied to take into account memory effects. In current work we realized really small non-linear model based on behavioral modelling approach. As an example architecture to follow we have chosen Wiener-Hammerstein model.

$$y_n = \boldsymbol{W}_{\text{out}}\sigma_{L-1}(\boldsymbol{W}_{L-1}\cdots\sigma_1(\boldsymbol{W}_1\sigma_0(\boldsymbol{W}_0\boldsymbol{f}_n))),$$
$$\boldsymbol{f}_n = (|x_{n-d_0}| \quad |x_{n-d_1}| \quad \cdots \quad |x_{n-d_{M-1}}|).$$

Explanation of IMD2 generation

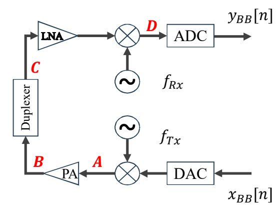
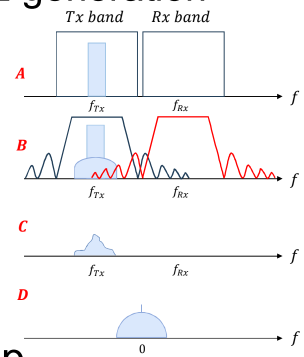


Fig. 1. Simplified scheme of FDD transceiver



Experimental Setup

The setup is shown in fig. 1. It has a computer where data are loaded. Then they go to the SMW200A generator. The signal is amplified by a PA ZRL-3500+. It has 26 dB gain and 24 dBm power at 1 dB. The PA has an OIP3 of 42 dBm. After the PA, there is a bandpass filter. It is like a duplexer. It has 30 dB stopband attenuation. The output of the BPF goes to an LNA ZRL-3500+. Its NF is 2 dB. There is also a ZX05-63LH-S+ mixer. It has 37 dB LO-to-RF isolation and 30 dB LO-to-IF isolation. It uses a complex valued OFDM signal. The bandwidth is 5 MHz. The transmit frequency is 814 MHz and the receive frequency is 859 MHz. The duplex spacing is 45 MHz.. The signal from the transmitter goes through the PA and leaks into the receiver. It has a frequency of 45 MHz. The receiver has a LO signal with power 10 dBm. The transmitter power is 8 dBm and the duplexer has an attenuation of 30 dB at 814 MHz. This makes the power on the mixer input 4 dBm.

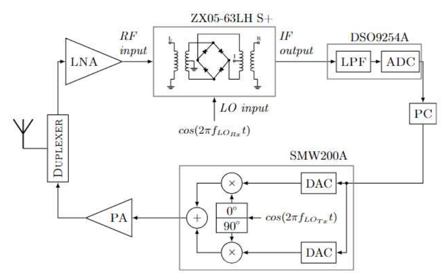
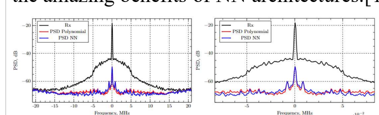


Figure 2: The scheme of testbench

Results

In the current article we researched NN and polynomial based models for IMD2 cancellation induced by Tx leakage signal in presence of limited stopband attenuation of duplexer.% Based on the achieved experiments there were shown that NN with SGD-like method can achieve better performance than polynomial with less resources: up to NMSE -23.6 dB with 17 coefficients. L-BFGS method showed us closest to the best performance which we can achieve for both traditional and NN based cancellation strategies.% The convergence speed of L-BFGS method is higher than for Adam method for both cancellation strategies, it can provide good performance starting from 1000 iterations whereas for Adam we need 5 times more counts to converge.% We found that after delay's search we can achieve performance better, but NN allowed us to find the best performance without any fine tuning.Current paper presents that both neural network and Chebyshev polynomial based models can achieve good performance but NN model can suppress IMD2 signal without any parameter tuning, whereas for polynomial model requires searching the set of optimal delays.The findings show that the L-BFGS approach delivers performance for both architectures near to the LS solution for polynomial NMSE=-23.59 dB. Furthermore, the L-BFGS simulation method for both structures requires fewer than 2000 epochs. Current findings demonstrate its use in the evaluation of models' performance in the interference cancellation domain.Due to neural networks' capacity for generalization, the first-order technique for NN-based models also demonstrates a greater convergence rate when compared to polynomial-based cancellers. For example, in 20000 epochs, the NN architecture achieves 0.44 dB performance gain over the polynomial. However, polynomial can reach full convergence performance by fine-tuning the first-order optimizer parameters. This demonstrates one of the amazing benefits of NN architectures.[1]



(a) IMD2 before and after cancellation (b) IMD2 before and after cancellation, magnified view

Model	Algorithm	Number of iterations		
		1000	5000	20000
Polynomial	LS	23.59	23.59	23.59
	Adam	21.96	22.76	22.91
	LBFGS	23.41	23.41	23.41
NN	LS	N/A	N/A	N/A
	Adam	21.00	22.03	23.35
	LBFGS	23.20	23.63	23.63

Table 1 . Comparison table for different models and optimization algorithms

[1] Shinil Chang and Hyunchol Shin. “2.4-GHz CMOS Bluetooth RF Receiver With Improved IM2 Distortion Tolerance”. In: IEEE Transactions on Microwave Theory and Techniques 68.11 (2020),
[2] Yann Kurzo, Andreas Toftegaard Kristensen, Andreas Burg, and Alexios Balatsoukas-Stimming. “Hardware Implementation of Neural Self-Interference Cancellation”. In: IEEE Journal on Emerging and Selected Topics in Circuits and Systems 10.2 (2020)
[3] Ville Syrjala, Mikko Valkama, Lauri Anttila, Taneli Riihonen, and Dani Korpi. “Analysis of oscillator phase-noise effects on self-interference cancellation in full-duplex OFDM radio transceivers”. In: IEEE Transactions on Wireless Communications 1