

Motivation

• Spectrum Scarcity → Frequency Agile Standards

- Non-contiguous Transmission
- Carrier Aggregation (CA) in LTE-Advanced
- Cognitive Radio
- 5G Cellular

• Non-contiguous carriers intermodulate

- Caused by nonlinearities in power amplifiers (PAs)
- Undesired spurious emissions (spurs)
- Could interfere with nearby channels
- Self-interference to own receiver when using FDD

• Current 4G chipsets support up to 4 carriers

- Snapdragon 835
- 4x20 MHz carrier aggregation downlink, 2x20 MHz up-link

• *Need efficient way to linearize for this scenario*

Power Spectral Density

Related Works

• Reduce Power

- Operate in a more linear PA region
- Less range and less power efficient

• Full-Band Digital Predistortion (DPD)

- Computationally expensive
- Does not scale for noncontiguous carriers
- Requires large sampling rate as carrier spacing grows

• Sub-Band DPD

- Previously explored by the authors with the WARP SDR RF Board
- Observes and applies DPD to individual spurs
- Can reduce the necessary sampling rate and complexity
- Has only been considered for 2 carriers

Main Idea

• Learn DPD coefficient, α , for each spur

- Iteratively learn coefficients as necessary using adaptive, LMS algorithm.
- Apply them as in Equation 5 to reduce spurious emissions.

Mathematical Model

• PA Inputs and Outputs:

- Parallel Hammerstein baseband PA model
- Third order, memoryless

$$\text{Input: } x(n) = \sum_{i=1}^N x_i(n) e^{2\pi j n \frac{f_i}{f_s}}, \quad (1)$$

$$\text{Output: } y(n) = \beta_1 x(n) + \beta_3 |x(n)|^2 x(n). \quad (2)$$

• IM3 Spurious Signals and Their Locations

$$y_{IM3:i,j,k}(n) = x_i^*(n) x_j(n) x_k(n), \quad (3)$$

$$f_{IM3:i,j,k} = -f_i + f_j + f_k. \quad (4)$$

• DPD Processing

$$\begin{aligned} \tilde{x}(n) = & \sum_{i=1}^N x_i(n) e^{2\pi j n \frac{f_i}{f_s}} \\ & + \sum_{i=1}^N \sum_{j=1}^N \sum_{k=1}^N \alpha_{i,j,k} x_i^*(n) x_j(n) x_k(n) e^{2\pi j n \frac{-f_i + f_j + f_k}{f_s}}. \end{aligned} \quad (5)$$

MATLAB Simulation

• LTE-Advanced CA Scenario

- Three, 20MHz CCs, scenario CA 41C-41A
- Bandpass filter around passband on the RF Frontend
- Only one spurious region is in violation of the emission limits

• Result

- Rapid convergence of coefficients
- Suppression below the emission limit in the spurious region

DPD Coefficient Learning

• LMS Adaptive Training

$$\alpha_{i,j,k}(n+1) = \alpha_{i,j,k}(n) - \mu \frac{x_i^*(n) x_j(n) x_k(n) e_{i,j,k}^*(n)}{\|x_i^*(n) x_j(n) x_k(n)\|} \quad (6)$$

- Decorrelates the error signal, e , with basis functions from Equation 3 to learn the DPD coefficients, α .
- Rate is controlled by LMS parameter μ .
- Learning is resilient to temperature changes, PA Gain changes, and changes in signal characteristics.

GNURadio Simulator

Future Work

- Main carrier linearization
- Hardware testing on the USRP with external PAs

Can change carrier magnitude and placement, PA model, and DPD application dynamically.