Multi Component Carrier, Sub-Band DPD and GnuRadio Implementation

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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 uplink
- ***Need efficient way to linearize for this scenario***

Power Spectral Density

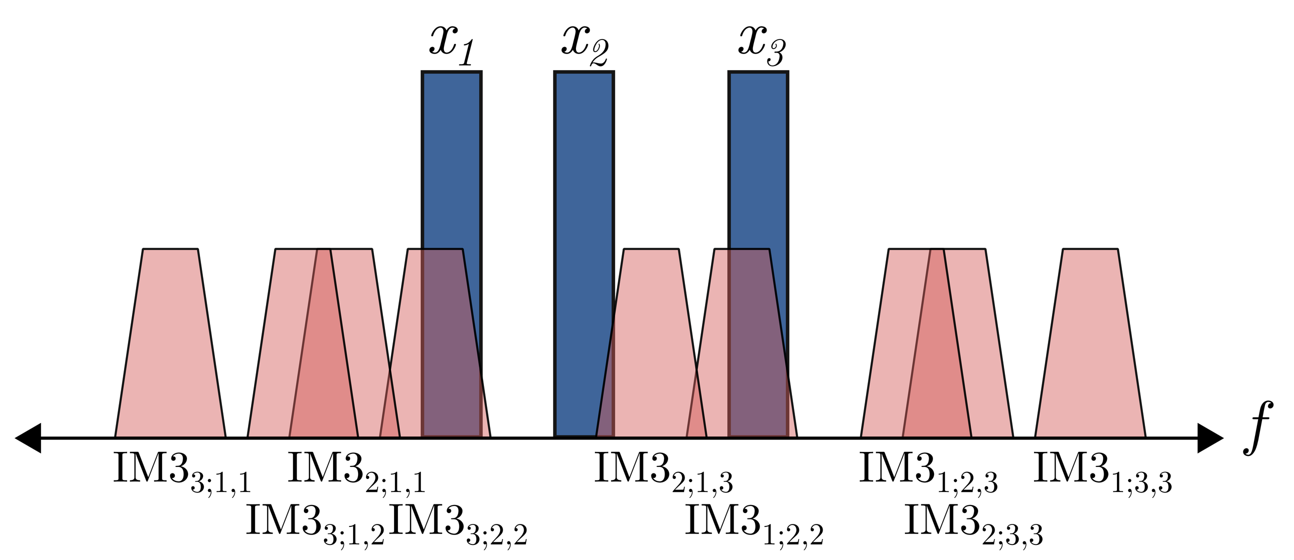


Fig. 1: Intermodulations when broadcasting more than 2 carriers.

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 Hamerstein baseband PA model
  - Third order, memoryless

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

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

- **IM3 Spurious Signals and Their Locations**

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

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

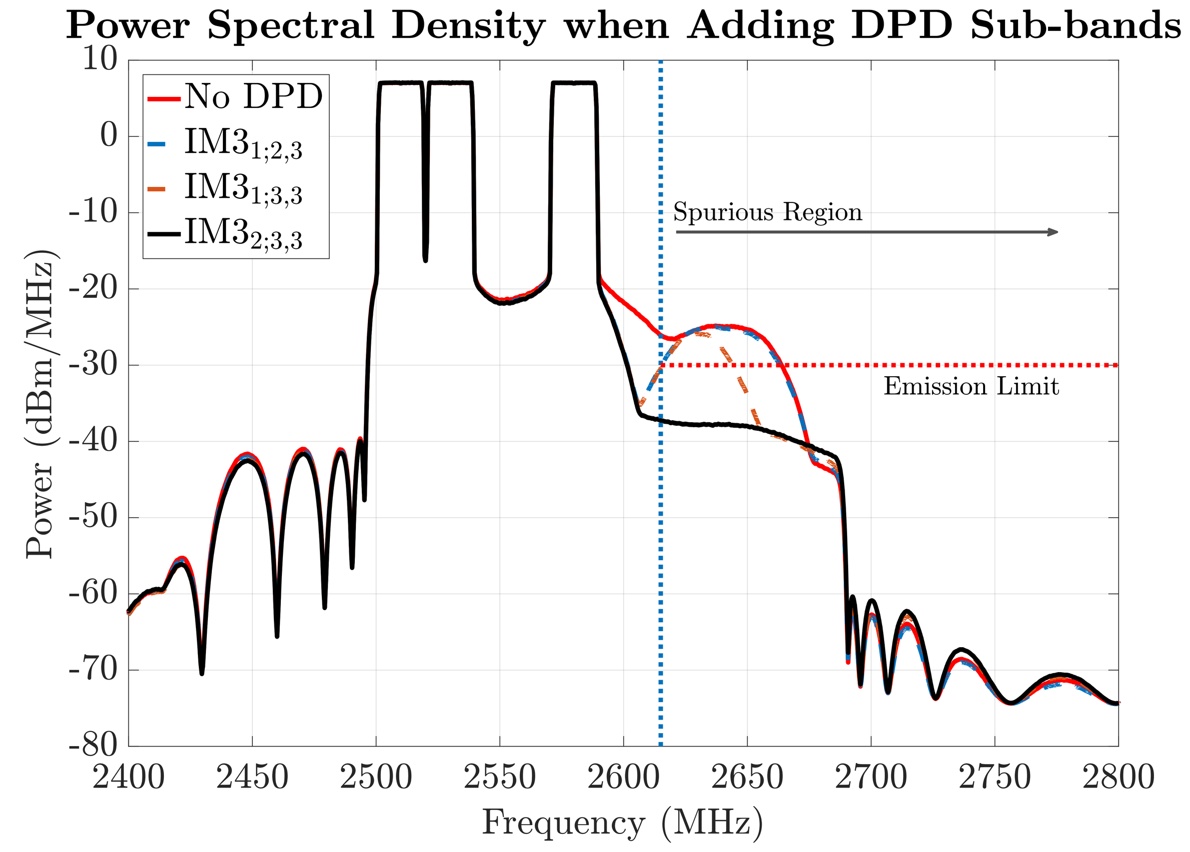
- **DPD Processing**

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

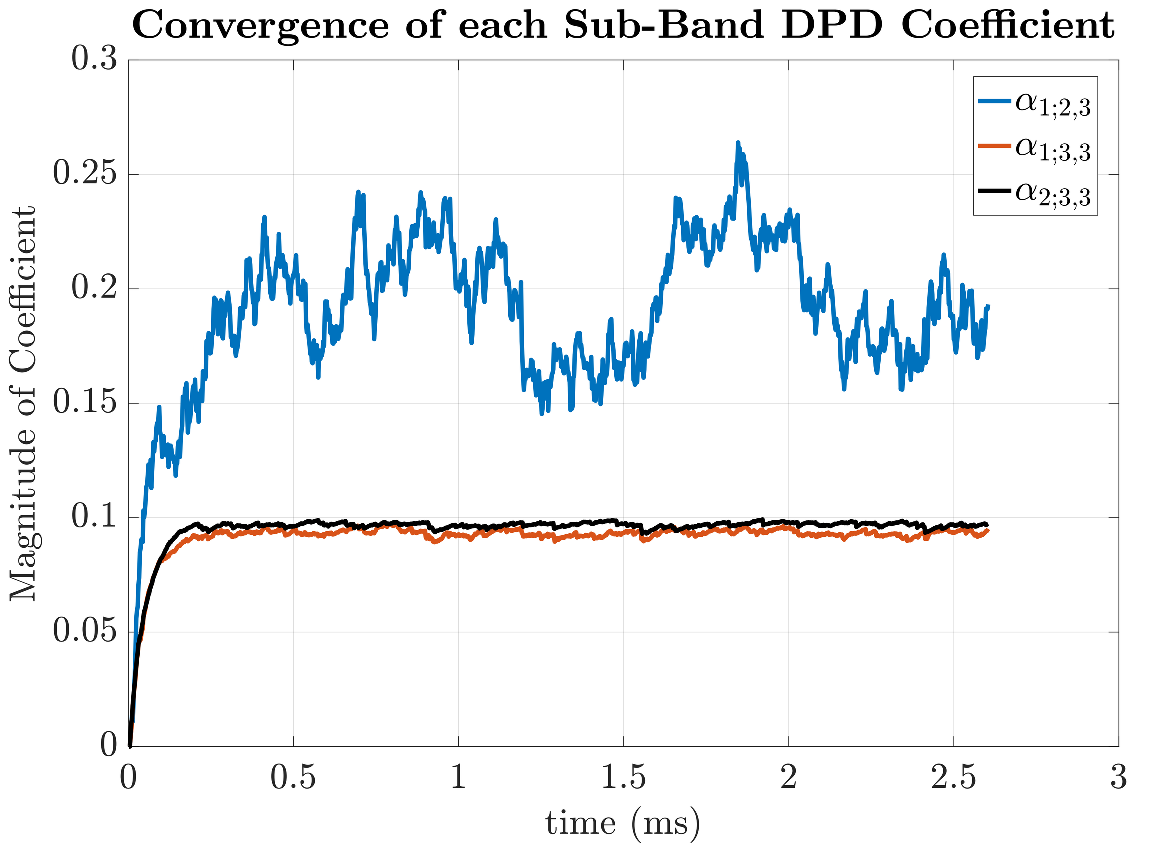
MATLAB Simulation

- **LTE-Advanced CA Scenario**
  - Three, 20MHz CCs, scenario CA 41C-41A
  - Bandpass filter around passpand 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

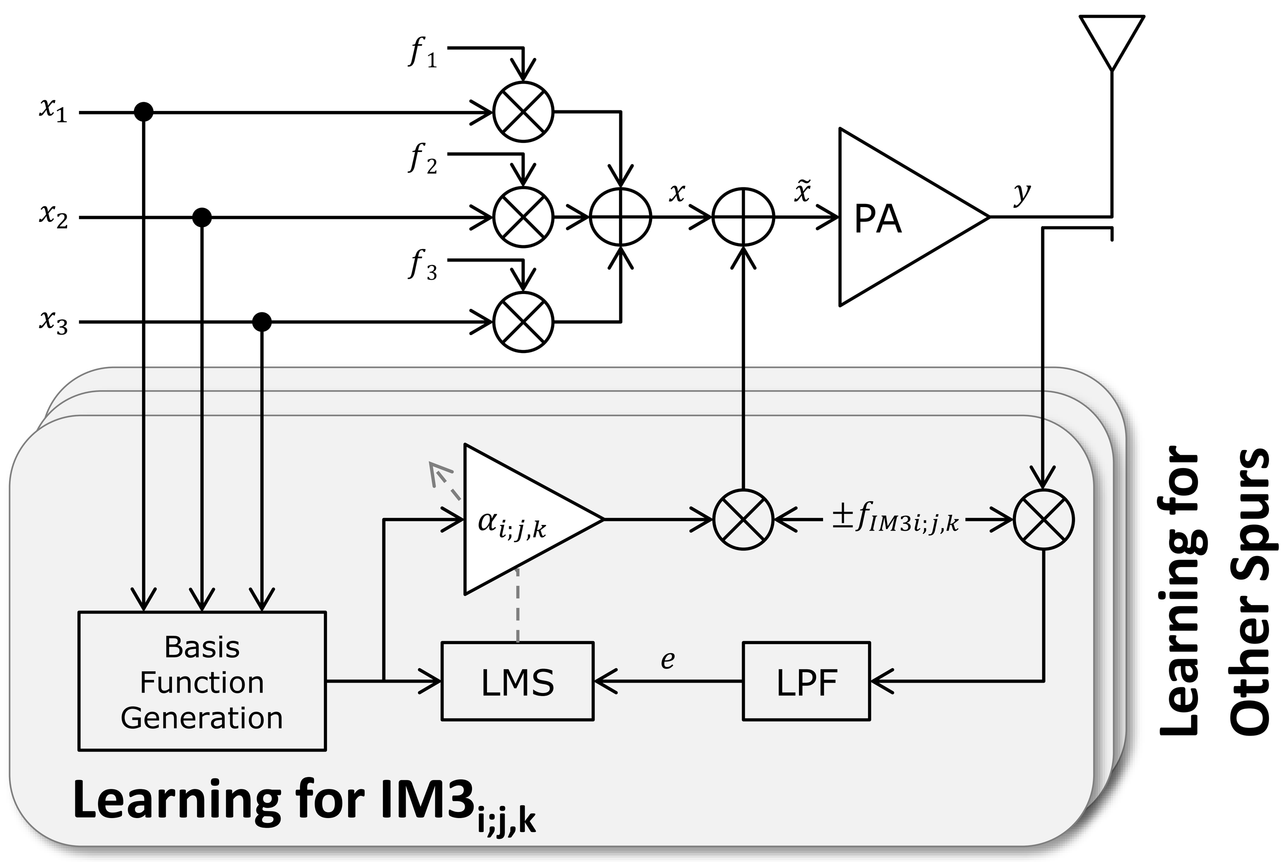
Power Spectral Density when Adding DPD Sub-bands



Convergence of each Sub-Band DPD Coefficient



DPD Coefficient Learning

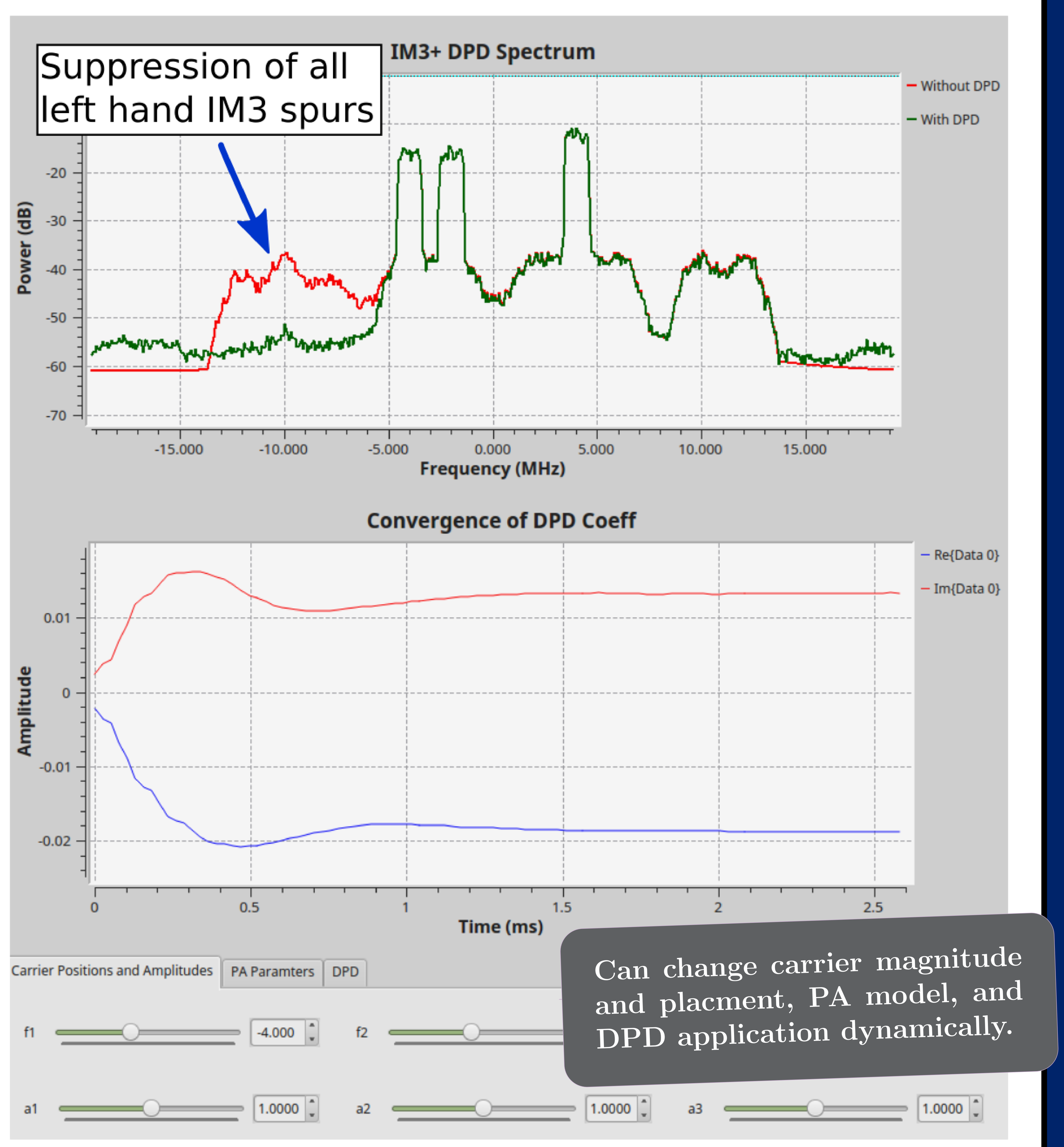


- **LMS Adaptive Training**

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

- 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**