Z Series

Adaptive Digital
Pre-Distortion (DPD)

Wi-Fi

LTE Advanced

5G

MIMO

Bluetooth

NFC

Wi-Fi

5G

IoT

5G

IoT

5G

WiGig

Bluetooth

WiGig

NFC

MIMO

Wi-Fi

5G

LTE Advanced

LITEPOINT
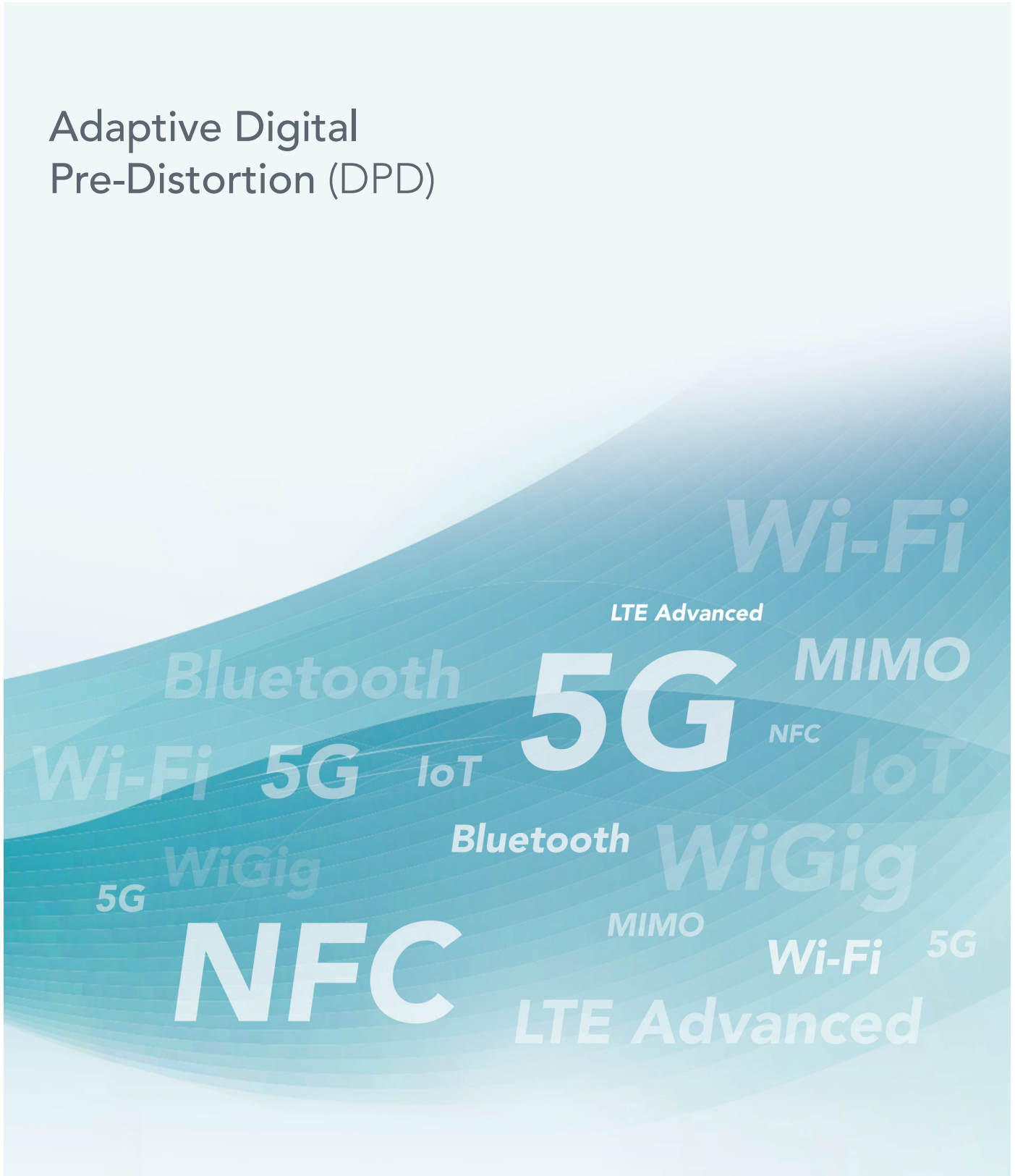
Table of Contents

Overview of Adaptive DPD

Digital Pre-Distortion (DPD) is a software tool within the zScript test executive for power amplifier (PA) and front-end module (FEM) characterization and testing. DPD measures the nonlinearity of the PA, computes an inverse operation, and creates a pre-distorted RF signal that effectively linearizes the PA. In combination with the zSeries PA/FEM DVT Set, DPD is used to quantify improvements in spectral mask and Error Vector Magnitude (EVM) that will be possible with DPD in-circuit. Adaptive DPD supports PA/FEM testing for LTE cellular devices.

Features and Specifications

Adaptive DPD is targeted towards cellular PA testing with upgraded testing capabilities:

- Adaptive learning step optimizes DPD engine for each specific PA architecture
- Multi-carrier testing with signal bandwidth up to 100 MHz
- Improves Adjacent Channel Leakage (power) Ratio (ACLR)
- Improves EVM
- Superior performance compared to standard GMP/LUT based DPD
- Crest Factor Reduction (CFR) algorithm achieves "close-to-minimum" EVM for target Peak-to-Average-Ratio (PAR)

Requirements

Figure 1 shows a block diagram of a typical test setup for PA testing with DPD using equipment from LitePoint. The typical equipment list includes:

- Vector Signal Generator (VSG), such as z8751
- Vector Signal Analyzer (VSA), such as z8651
- PXI/PXIe chassis and host computer
- Cables, directional coupler(s) and attenuator(s)
- Optional Power Meters
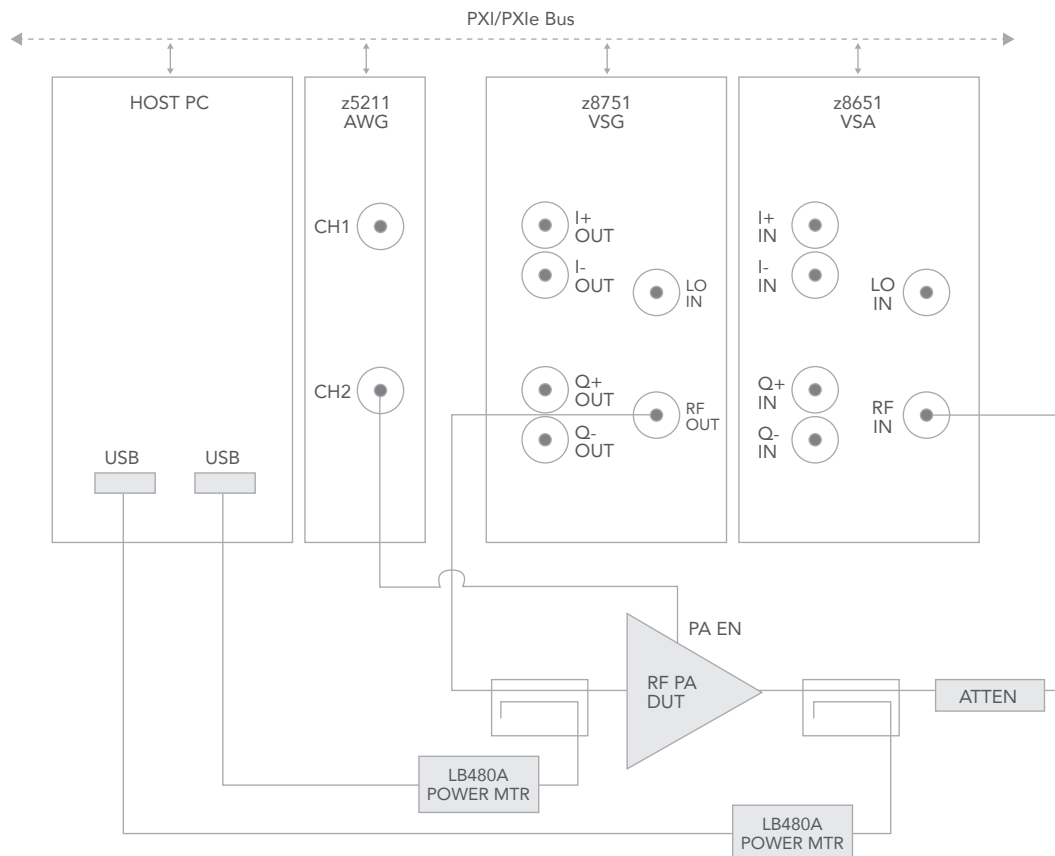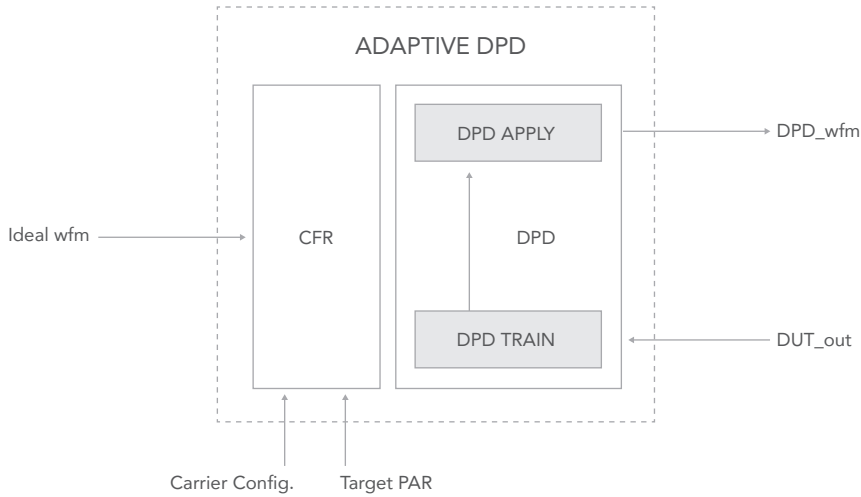- Optional Arbitrary Waveform Generator (AWG)

Figure 1. Test equipment block diagram for PA testing
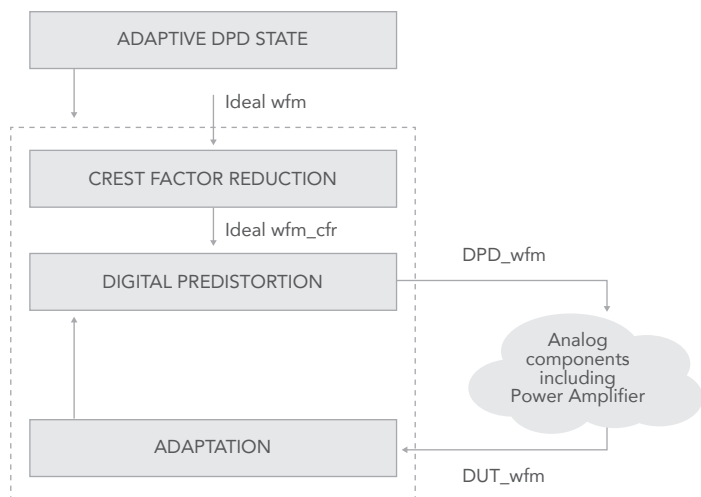
Adaptive DPD: Block Diagram

Adaptive DPD has three main building blocks:

1. Crest Factor Reduction (CFR): Lowers Peak-to-Average Ratio (PAR) of the signal while maintaining spectral properties intact
2. DPD Apply: Applies pre-distortion to the reference waveform
3. DPD Train: Updates DPD Engine coefficients based on feedback from the PA output.
   Updated coefficients are computed using a robust adaptation engine

```
                    ADAPTIVE DPD
    ┌─────────────────────────────────────┐
    │   ┌───────┐      ┌──────────────┐    │
    │   │       │      │  DPD APPLY    │───┼──→ DPD_wfm
    │   │       │      └──────────────┘    │
Ideal wfm ─┼──→│  CFR  │          DPD          │
    │   │       │      ┌──────────────┐    │
    │   │       │      │  DPD TRAIN    │←──┼──  DUT_out
    │   └───────┘      └──────────────┘    │
    └──────▲──────────▲────────────────────┘
           │          │
     Carrier Config.  Target PAR
```

Adaptive DPD: High Level Flowchart

A high-level usage scenario for the blocks in Adaptive DPD.

```
┌───────────────────────────┐
│   ADAPTIVE DPD STATE      │
└───────────────────────────┘
        │          │ Ideal wfm
        ▼          ▼
┌───────────────────────────┐
│  CREST FACTOR REDUCTION   │
└───────────────────────────┘
                   │ Ideal wfm_cfr
                   ▼
┌───────────────────────────┐          DPD_wfm
│  DIGITAL PREDISTORTION    │─────────────────→ ╭─────────╮
└───────────────────────────┘                  │ Analog   │
        ▲                                        │ components│
        │                                        │ including │
┌───────────────────────────┐                  │ Power     │
│       ADAPTATION          │←─────────────────│ Amplifier │
└───────────────────────────┘      DUT_wfm     ╰─────────╯
```

Crest Factor Reduction

The Crest Factor Reduction algorithm lowers the Peak-to-Average-Ratio (PAR) of the input signal causing a minimal damage to the signal while maintaining the frequency domain properties intact. The algorithm supports both contiguous and non-contiguous carrier aggregation scenarios. Crest Factor Reduction, included with Adaptive DPD, is implemented via a proprietary "Clipping and Filtering" algorithm which achieves close-to-minimum EVM for target PAR. Figure 2 shows the signal at various stages of the algorithm. Figure 3 exhibits EVM vs PAR for a 40 MHz LTE signal constructed with 2x20 MHz LTE signals.
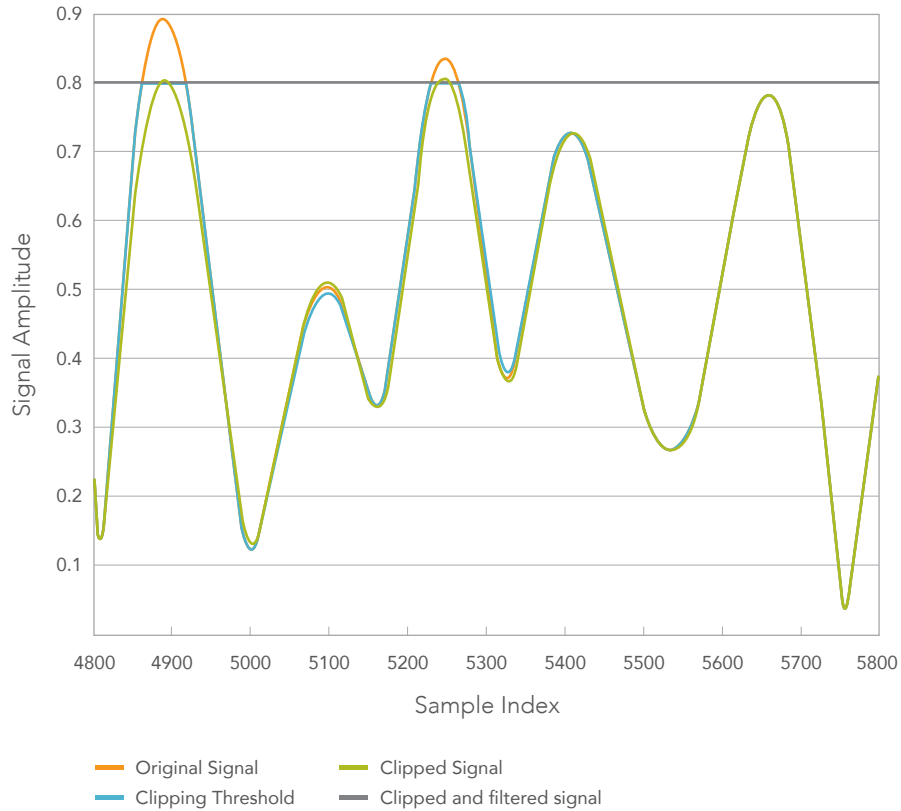

Figure 2. Signal at various stages of Crest Factor Reduction (CFR) Algorithm
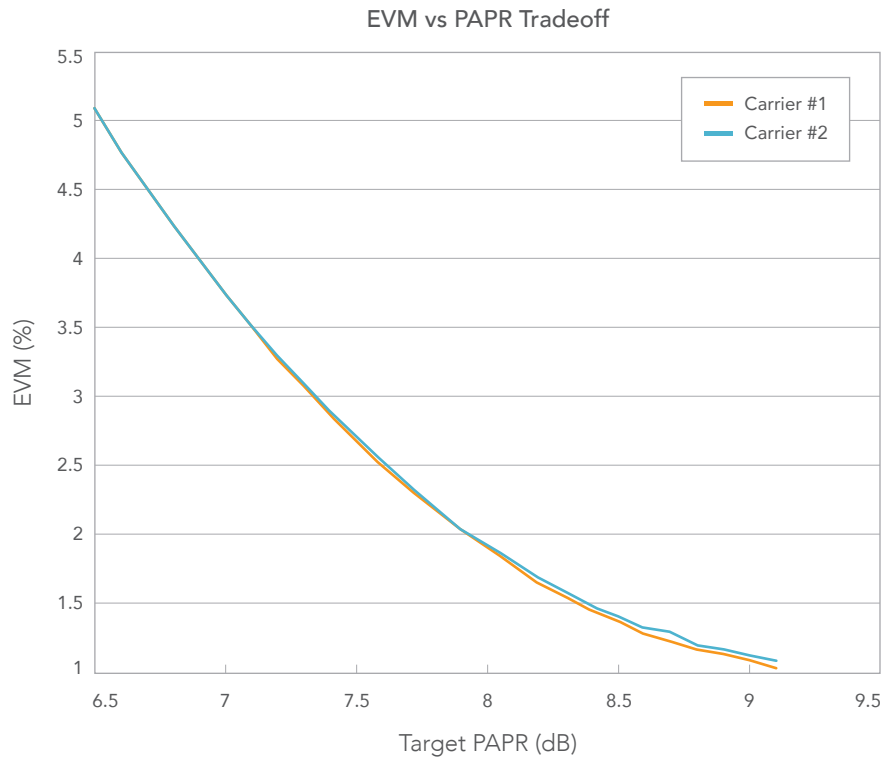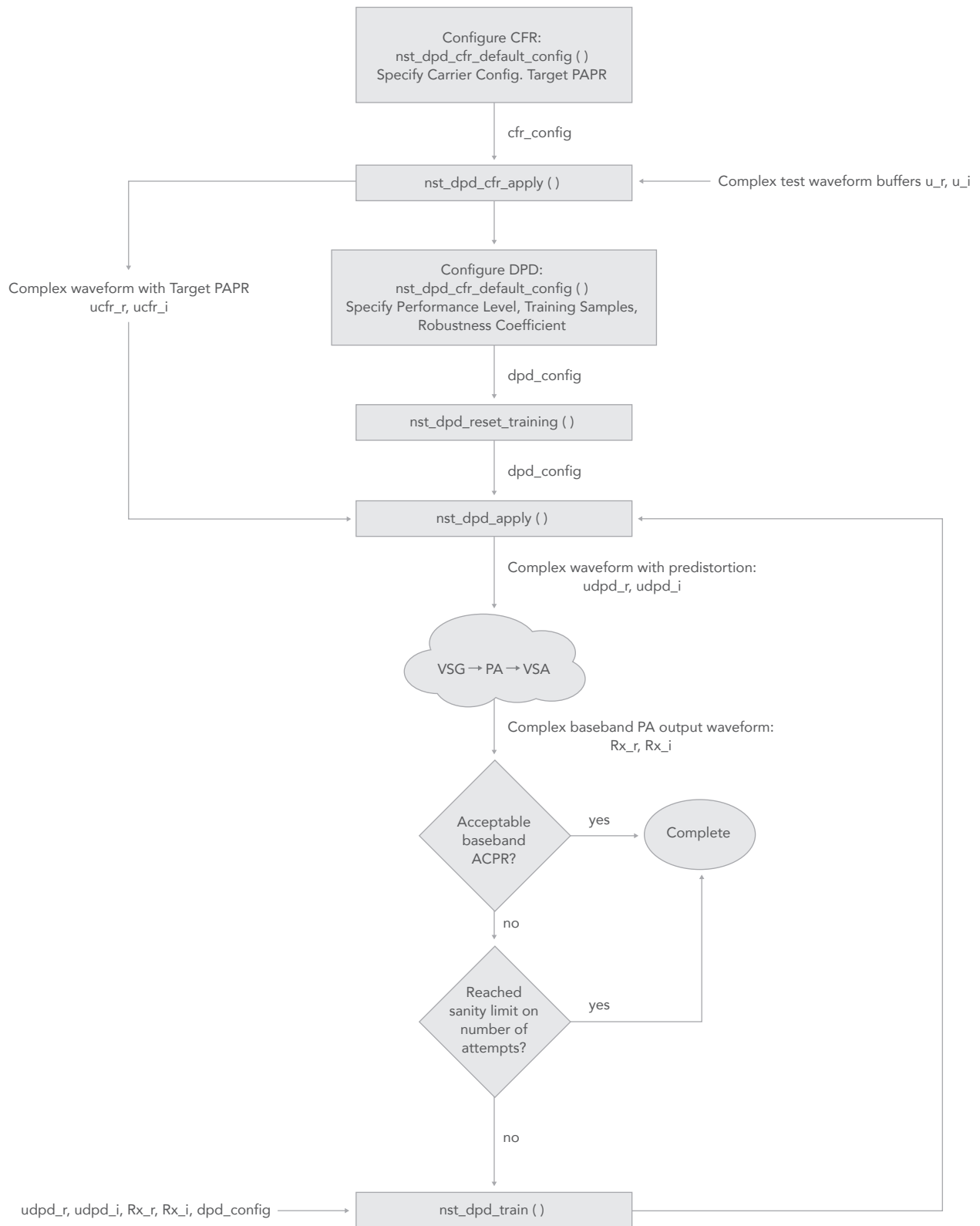
EVM vs PAPR Tradeoff

Figure 3. EVM vs PAR tradeoff for a 40 MHz LTE signal constructed with 2x20 MHz LTE signals

Adaptive DPD Configuration Options

The main options that the user sets to configure Adaptive DPD are:
- DPD performance level (0 through 3, increasing performance with number)
- Target peak to average power ratio (PAR) for CFR algorithm
- Number of samples used for training. Typically, 20,000 samples are sufficient to reach good performance. Generally, DPD performance improves with an increasing number of training samples. The user is encouraged to increase/decrease the number to see impact on performance and execution time.
- Robustness coefficient: this is typically set to 0.001. The recommended range of robustness coefficient is between 0.0000001 and 1. The default value is sufficient for most of the testing scenarios, but some corner cases may require the user to increase the robustness coefficient. An increase in robustness may come at the price of performance. Typically for signal bandwidths of 60 MHz and above, set robustness coefficient to 0.1; and for signal bandwidths below 60 MHz, set robustness coefficient to 0.001.

User Level Block Diagram and Calling Sequence

```
                        ┌─────────────────────────────────┐
                        │         Configure CFR:          │
                        │   nst_dpd_cfr_default_config ( ) │
                        │  Specify Carrier Config. Target PAPR │
                        └─────────────────────────────────┘
                                      │
                                      │ cfr_config
                                      ▼
                        ┌─────────────────────────────────┐
         ┌──────────────│       nst_dpd_cfr_apply ( )      │◄──── Complex test waveform buffers u_r, u_i
         │              └─────────────────────────────────┘
         │                            │
         │                            ▼
         │              ┌─────────────────────────────────┐
         │              │         Configure DPD:          │
         │              │   nst_dpd_cfr_default_config ( ) │
         │              │ Specify Performance Level, Training Samples, │
         │              │       Robustness Coefficient    │
         │              └─────────────────────────────────┘
         │                            │
 Complex waveform with Target PAPR    │ dpd_config
       ucfr_r, ucfr_i                 ▼
         │              ┌─────────────────────────────────┐
         │              │     nst_dpd_reset_training ( )   │
         │              └─────────────────────────────────┘
         │                            │
         │                            │ dpd_config
         │                            ▼
         │              ┌─────────────────────────────────┐
         └─────────────►│         nst_dpd_apply ( )        │◄──────────────┐
                        └─────────────────────────────────┘               │
                                      │                                     │
                                      │ Complex waveform with predistortion: │
                                      │        udpd_r, udpd_i                │
                                      ▼                                      │
                              ☁ VSG → PA → VSA                               │
                                      │                                      │
                                      │ Complex baseband PA output waveform:  │
                                      │            Rx_r, Rx_i                 │
                                      ▼                                      │
                              ◇ Acceptable ─── yes ───► ( Complete )         │
                                 baseband                    ▲               │
                                  ACPR?                      │               │
                                      │                      │               │
                                      │ no                   │               │
                                      ▼                      │               │
                              ◇ Reached ──── yes ────────────┘               │
                                 sanity limit on                             │
                                 number of                                   │
                                 attempts?                                   │
                                      │                                      │
                                      │ no                                   │
                                      ▼                                      │
  udpd_r, udpd_i, Rx_r, Rx_i, dpd_config ──────► nst_dpd_train ( ) ──────────┘
```

Example Code

Please consult the example code to get started with using the DLL. The following code initializes the hardware and assumes a unity gain from the VSG to VSA. Connect the LitePoint Equipment in transceiver loopback mode to ensure the following code is working properly.

DLL usage via zScript®

Provided in example_adaptive_DPD.csv

DLL usage via C++

Provided in example_adaptive_DPD.cpp

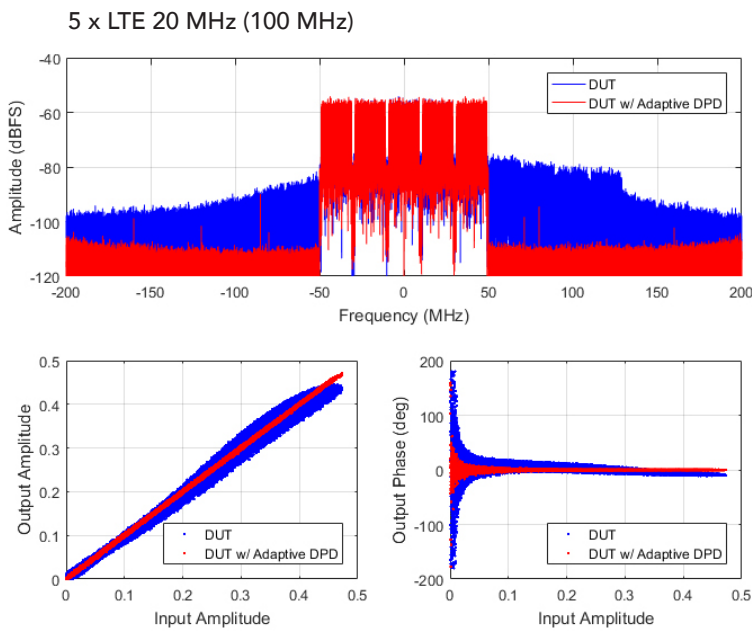### DLL usage via Matlab®

Provided in example_adaptive_DPD.m

5 x LTE 20 MHz (100 MHz)

Figure 4. Sample plot generated by Matlab® example code with a PA in the loop for a 100 MHz LTE signal with a 90 W power amplifier. Blue curves are without DPD while red curves are with Adaptive DPDsignals

2 x LTE 5 MHz (60 MHz)
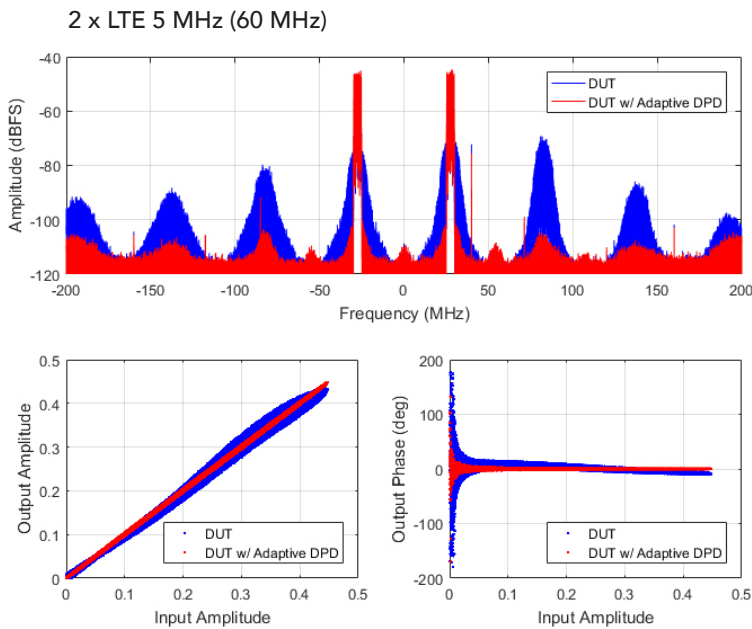
Figure 5. Sample plot generated by Matlab® example code with a PA in the loop for a 60 MHz LTE signal with a 90 W power amplifier. Blue curves are without DPD while red curves are with Adaptive DPDsignals

General DPD Usage Guidelines and Best Practices

Noise Floor Correction via Time Domain Averaging

If noise floor of the signal chain is limiting the DPD performance, Noise Floor Correction is recommended. This can be accomplished by reading in multiple periods of the test waveform from the VSA, and then averaging them in the baseband time-domain. The resulting waveform will have a lowered noise floor.

Convergence Time

Adaptive DPD may take multiple iterations to converge to good performance. Typical factors impacting the number of iteration to converge include:

- Number of training samples: a larger number of training samples results into fewer number of iterations to converge
- DPD performance level: a higher level DPD may take more iterations to converge compared to lower level DPD

Choosing the Number of DPD Training Iterations

Training the Adaptive DPD is an iterative process - each time the DPD is trained, its effectiveness as a linearizer as measured, for example, by ACPR at the PA output improves. The user controls the number of training iterations and can choose to favor best performance (more iterations) or shortest runtime (fewer iterations). Typically the DPD performance converges after ~5 iterations.

Choosing the Baseband Signal Level

Baseband signal level (expressed as dB in reference to Full Scale or dBFS) must be chosen carefully. A large baseband amplitude, say close to 0 dBFS, may warrant a high SNR but will not leave any headroom for DPD expansion. Conversely, a very small baseband amplitude, say -30 dBFS will result into a lower SNR. The recommended range of baseband amplitude is between -10 to -6 dBFS.

Impact of LO Leakage and Image on DPD Performance

DPD performance in terms of ACLR and EVM may degrade in the presence of strong LO leakage or strong image. This is because the nonlinear interaction of the LO leakage and image with the test signal may create undesired frequency components. DPD best practices recommends that the user ensure that transmitter is operating with calibrated LO leakage and IQ mismatch. The following steps must be taken to ensure that LO leakage and image are not causing DPD performance degradation:

1. Apply a signal with offset frequency in baseband
2. Observe the level of image and LO leakage in reference to power in the test signal
3. Calibrate the signal chain for LO leakage and IQ mismatch.
   It is recommended that the image and LO leakage levels are below -50 dBc
4. Run DPD.

Impact of Signal Chain on DPD Performance

A poorly designed signal chain can severely limit the performance of a DPD. The factors that may contribute towards a poor signal chain are:

- Components with a high noise figure. It is recommended to select components that lead to the highest overall SNR for the signal chain.
- Components with a large VSWR will cause standing waves to be created due to imperfect matching
- A component that is heavily compressed
- Ground bouncing may degrade performance. To eliminate this, make sure that the reference plane of all the power supplies are tied together
- EM fields interference could also lead to poor DPD performance. If the PA is radiating and putting out more than 10 W, it is recommended to shield the PA from the rest of the chain.

Tips on designing a signal chain optimized for DPD

1. Ensure that noise from any given component is not limiting the performance
2. Ensure that no component is compressed beyond its rated power
3. Connect pads or isolators between ports that may have poor impedance matching
4. Isolate the power amplification stages by connecting attenuator pads or isolators
5. Signal chain loop gain should be close to 0 dB. For example, if the gain introduced by the amplifier stage is 40 dB, the PA output should be attenuated by 40 dB before connecting it to the VSA

FAQ

What kind of power amplifiers does Adaptive DPD compensate nonlinearity for?

- Semiconductor type: GaN, Si, GaAs
- Device type: HEMT, HBT, LDMOS
- Circuit type: Doherty, Class AB

What is a typical operating range of a power level?

- $P_{ouT} = P_{SAT} - PAR$; where P_{SAT} is defined as 3 dB compression point of power level over the entire operating bandwidth, and PAR is peak-to-average ratio
- Although there's no limit to PA's output power, adaptive DPD has has been verified on PA with output power up to 100 W (50 dBm)

What is a typical power efficiency of power amplifiers used?

- Up to 60%

What is a typical ACLR achieved by Adaptive DPD?

Typically, between -50 dBc to -65 dBc. Achievable performance depends on the signal chain design in addition to following factors

1. PA topologies and devices
2. Bandwidth of PA
3. Operating power level in relation to $P_{SAT} - PAR$
4. Instantaneous bandwidth in relation to compensation bandwidth
5. DPD Level used. A higher DPD level yields higher performance
6. Baseline transceiver performance
7. Quality of image and LO leakage correction

Adaptive DPD uses following 3rd party libraries. Respective license information is included.

LAPACK/BLAS License:

KissFFT License:

RESTRICTED RIGHTS LEGEND

DISCLAIMER

TRADEMARKS

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