Application Report

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GC5325 Envelope Tracking

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ABSTRACT

This application note discusses setup and performance information for the GC5325 Transmit Solution device operating in conjunction with a Nujira High Accuracy Tracking (HAT) Voltage Modulator in an Envelope Tracking and DPD application.

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1 Introduction

Modern wireless communications demand higher data through-puts which are typically achieved by employing QAM or OFDM based technologies with high modulation rates resulting in signals with high Peak-to-Average Ratios (PAR). These high PAR signals require the signal to be decreased significantly from the peak power level of the PA resulting in poor efficiency. There are several techniques to improve the efficiency of the PA such as Crest Factor Reduction (CFR), Digital Pre-Distortion (DPD) Linearization and Envelope Tracking (ET).

CFR can be applied to reduce the PAR of the signal allowing operation closer to the peak level of the PA, resulting in improved efficiency. Care must be taken with the implementation of CFR to ensure that in band Error Vector Magnitude (EVM) and spurious requirements are satisfied.

Closed-loop DPD can be used to compensate for distortion caused by non-linearities resulting from operating near the compression point of the PA improving the Adjacent Channel Power (ACP) and in band EVM of the transmitted signal. This allows the PA to be driven harder, closer to the peak power level, resulting in greater PA efficiency.

Envelope Tracking is a technique that requires the supply voltage of the final PA stage to be modulated dynamically with the envelope of the input signal. This would make the PA operate closer to the peak level at all times and dramatically improve the efficiency of the PA. Although implementation difficulties (accuracy, bandwidth, noise) have made this method impractical in the past, recent improvements in power supply modulation, and the introduction of the High Accuracy Tracking (HAT) supply voltage modulator from Nujira have allowed practical realization of this technique.

Traditional Fixed PA Supply Voltage has significant amount of power loss as heat. Envelope Tracking techniques modulate the supply Voltage to track the envelope of the signal to reduce the amount of power dissipated as heat.

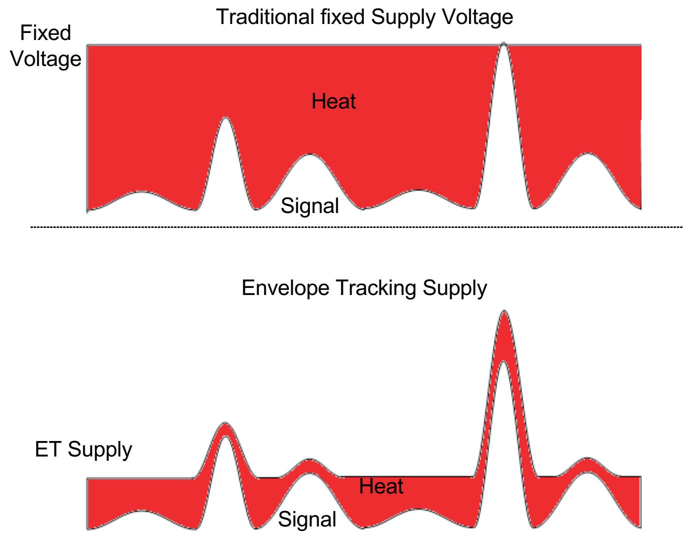

Figure 1. Traditional Supply vs Envelope Tracking Supply

2 Implementation

The system was implemented using the GC5325 SEK DPD demonstration solution from Texas Instruments and Nujira HAT voltage supply modulator.

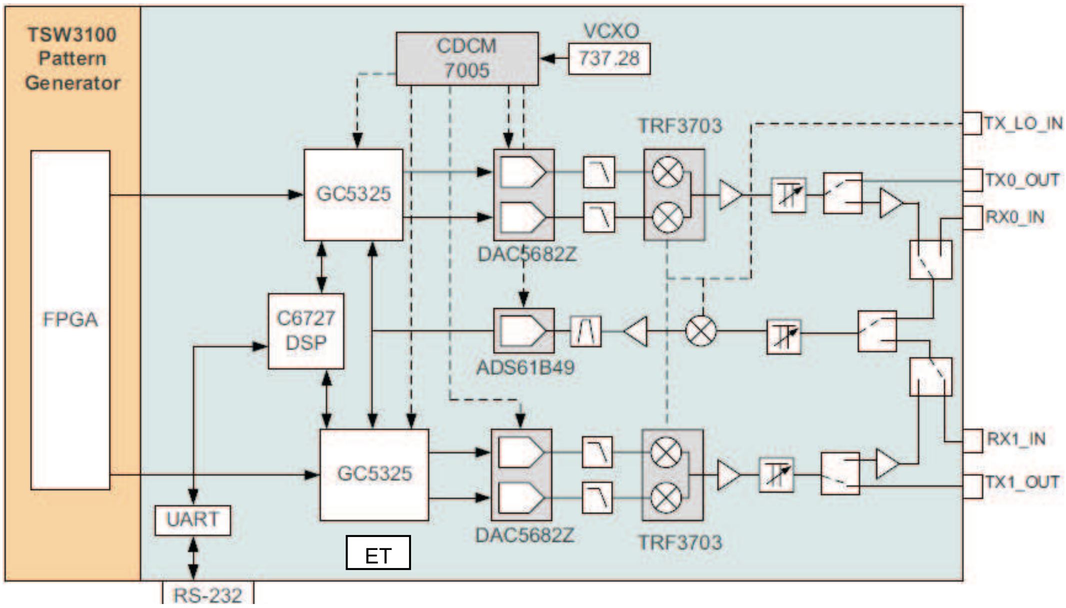

Figure 2. GC5325SEK Block Diagram

The GC5325SEK demonstration platform provides all the necessary elements to implement a real DPD and linearization system including a standards compliant baseband signal generator (TSW3100), the GC5325 IC which performs CFR+DPD+ET signal generation, entire analog baseband to RF TX signal chain, entire RF to analog feedback signal chain, a TMS320C6727B-250™ floating point DSP to implement the adaptive DPD algorithm, and full Graphical User Interface (GUI) to control the system.

2.1 Envelope Tracking Function

The ET function is available in the GC5322 and GC5325. This function is comprised of 4 functional blocks: Delay, Fractional Delay Adjust, Envelope Magnitude calculation, and a Look-Up Table for voltage shaping.

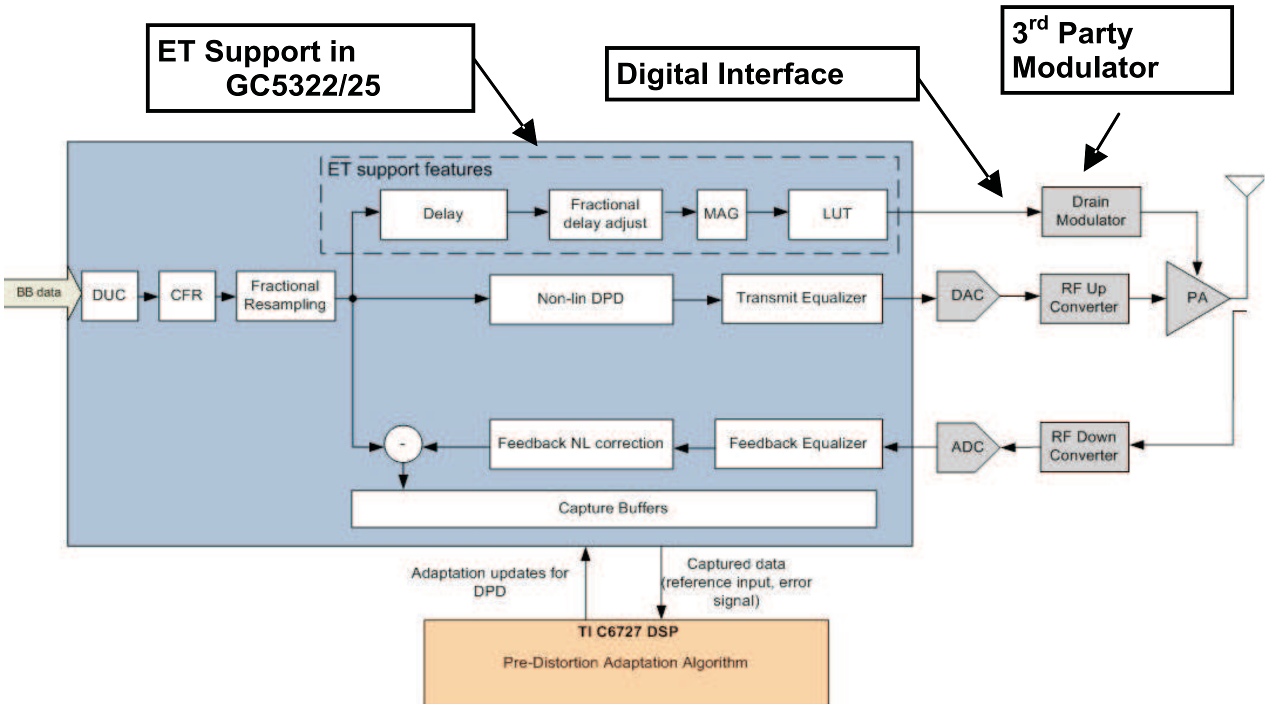

Figure 3. Envelope Tracking Functional Block Diagram. DUC Block Not Supported in GC5325

2.1.1 ET Delay + Fractional Delay Block

Accurate time alignment between the ET voltage supply waveform and the PA input signal is critical – any time mis-alignment between the ET modulated supply waveform and the PA input signal can result in memory effects that may be impossible to linearize. The Integer Delay and Fractional delay are used by the system to time align the HAT modulator output with the input signal at he the PA. The Integer Delay is set to account for delay differences between the HAT modulator and the DPD path plus the analog transmit signal chain in steps of nTs where Ts is the ET sampling time – typically the sampling frequency is 122.88Msps. The fractional delay is used to perform further time alignment within fractions of the ET sample time.

2.1.2 Envelope Magnitude Calculation

The amplitude of the envelope is computed as the unsigned polar magnitude of the IQ signal and is representative of the input signal amplitude across the full range of signal powers. The envelope calculation is performed after the CFR block at the Fractional Resampler output just before the non-Linear DPD block.

For proper tracking purposes, the envelope reference signal requires a minimum bandwidth from 2.5–3x the modulation rate. This would require a sample rate of 6x the modulation rate. For a typical ET sample rate of 122.88Msps a signal BW of 20MHz can be accommodated.

2.1.3 Envelope Look-Up Table and Shaping Function

A suitable shaping function is required to bias the PA device within a valid operating range and to improve linearization characteristics. This shaping function must be updated prior to starting the modulator and DPD. The ET look-up table within the GC5325 is capable of storing 2^{16} samples of 16 bits wide. The Nujira modulator requires 14 bits and is connected to the 14 MSBs of the GC5325 ET port.

The ET connector on the GC5325SEK is the ERNI 054596 and is identical to the connector on the Nujira HAT modulator. A cable with the mating connectors ERNI 024403 is required to connect the GC5325SEK to the Nujira HAT Modulator.

The connector pinout is included in Table 1 for reference.

Table 1. ET Connector Pinout(1)

PIN	NAME	DIR	TYPE	PIN	NAME	DIR	TYPE
1	Addr Sel 0	I	LVCMOS	26	DGND	–	–
2	DGND	–	–	27	IN_p5	I	LVDS
3	Addr Sel 1	I	LVCMOS	28	IN_n5	I	LVDS
4	I2C SCL	I/OD	I2C	29	IN_p6	I	LVDS
5	TDDPowerSave	O	LVCMOS	30	IN_n6	I	LVDS
6	I2C SDA	I/OD	I2C	31	DGND	–	–
7	nHostInt	O	OD	32	DGND	–	–
8	DGND	–	–	33	IN_p7	I	LVDS
9	DGND	–	–	34	IN_n7	I	LVDS
10	DGND	–	–	35	IN_p8	I	LVDS
11	DCLKINp	I	LVDS	36	IN_n8	I	LVDS
12	DCLKINn	I	LVDS	37	DGND	–	–
13	DGND	–	–	38	DGND	–	–
14	DGND	–	–	39	IN_p9	I	LVDS
15	IN_p0	I	LVDS	40	IN_n9	I	LVDS
16	IN_n0	I	LVDS	41	IN_p10	I	LVDS
17	IN_p1	I	LVDS	42	IN_n10	I	LVDS
18	IN_n1	I	LVDS	43	IN_p11	I	LVDS
19	IN_p2	I	LVDS	44	IN_n11	I	LVDS
20	IN_n2	I	LVDS	45	IN_p12	I	LVDS
21	IN_p3	I	LVDS	46	IN_n12	I	LVDS
22	IN_n3	I	LVDS	47	IN_p13	I	LVDS
23	IN_p4	I	LVDS	48	IN_n13	I	LVDS
24	IN_n4	I	LVDS	49	nResetOut	O	OD
25	DGND	–	–	50	nResetIn	I	LVCMOS

(1) I = Output, O = Output, OD = Open Drain

2.1.4 HAT Modulator Control

The HAT modulator is controlled by an I^{2}C™ interface implemented within a MATLAB GUI. An Aardvark USB/I2C adapter is used to translate the Matlab commands to the necessary I^{2}C control signals required by the HAT modulator. This module connects directly onto a header on the GC5325SEK. These signals are then routed along with the envelope samples on the ERNI connector that provides the ET connection to the HAT modulator.

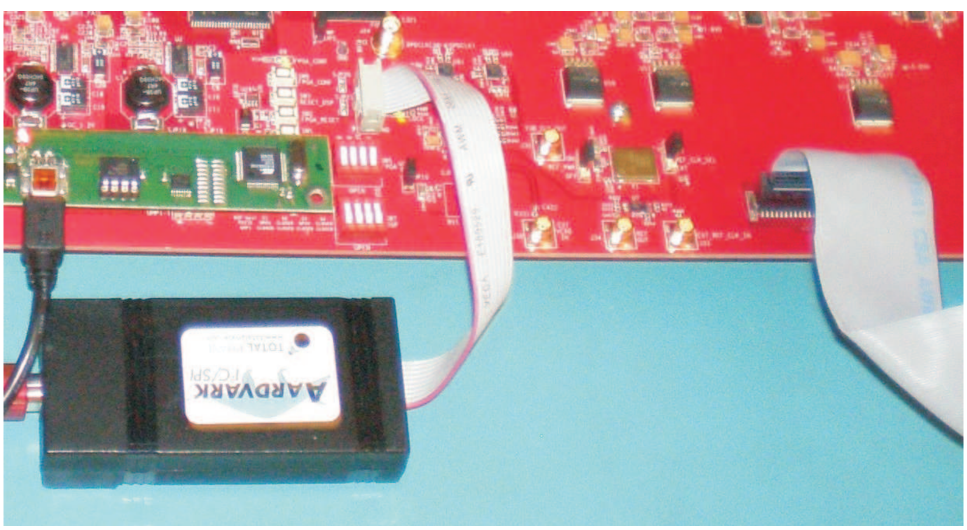

Figure 4. I2C Connection Using Aardvark USB/I2C Adapter

Once a connection is established with the HAT modulator, the GUI can be used to start and stop the modulator as well as capture the real time samples of the envelope shaping function from the ET port.

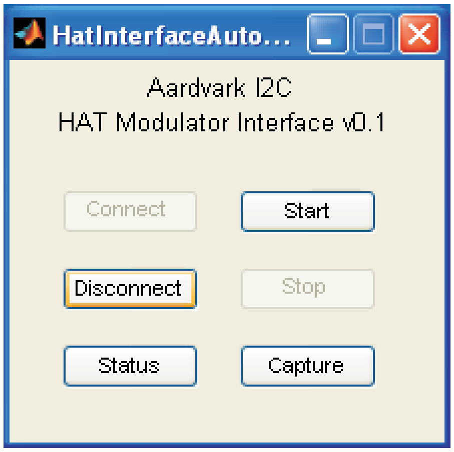

Figure 5. MATLAB GUI I2C Interface for HAT Modulator

2.2 System Operation

The Envelope Tracking system setup is similar to the standard DPD setup: the TSW3100 is used to provide baseband signals; the GC5325 performs CFR and DPD. With the addition of ET, the GC5325 also generates the envelope signal and the Nujira HAT modulator drives the envelope modulated supply voltage for the high power RF PA.

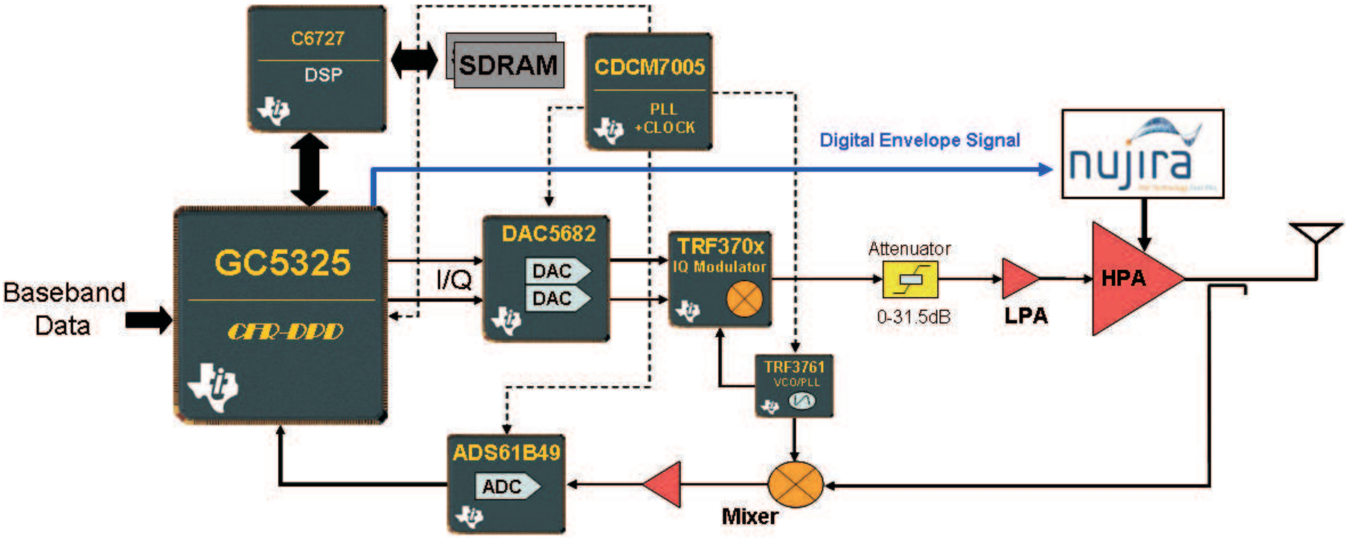

Figure 6. ET System Block Diagram

The baseband envelope modulated supply voltage for the RF PA tracks the signal level as shown below. Traditionally with fixed voltage supplies, smaller signals operate in a less efficient manner, with any excess voltage above the signal level being dissipated as heat. In a high PAR signal, this makes the fixed voltage system inefficient, typically with over 65% of the power being dissipated as heat (This device under test has about 32% efficiency at 45dBm output). With ET, the PA voltage mostly tracks the signal envelope. For practical reasons, the lowest voltage of the modulator is not 0, and as such does not track the signal as closely for the smaller signals. However, even in this low signal level case, significantly less power is lost as heat since the supply voltage is lower.

2.2.1 GC5325 GUI and ET Setup

The GC5325SEK system should be set up for standard DPD as described in the GC5325SEK Users Guide (SLWU063). This section is extended to include the setup for ET.

Once the default DPD setup has been completed and the system has been verified with a DPD cycle using the internal loopback path, the DPD Control and ET Control buttons are accessible.

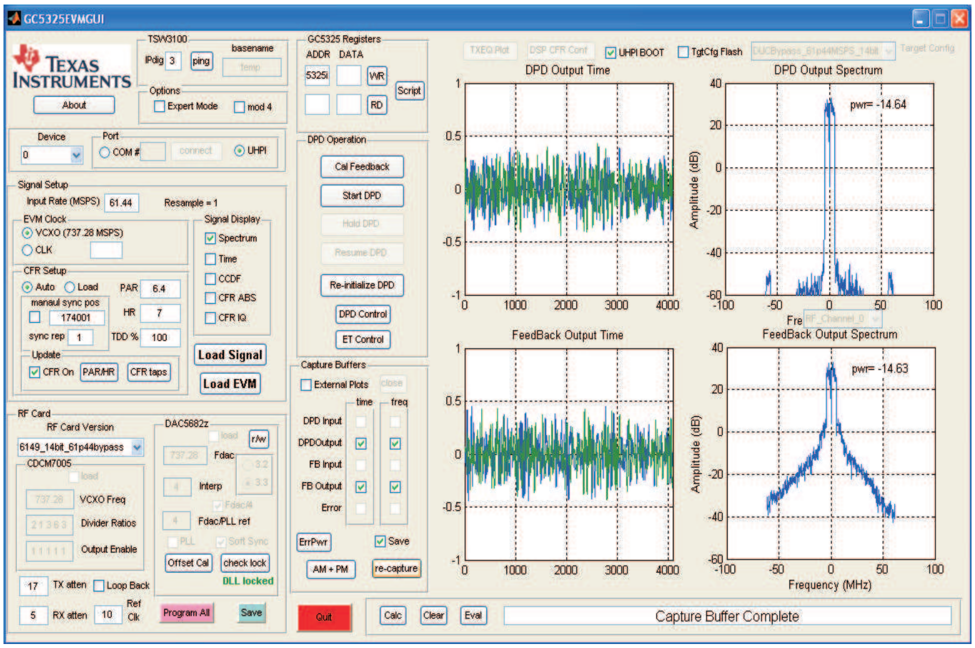

Figure 7. GC5325SEK GUI

The ET Panel allows various shaping functions to be loaded into the Look-Up Table. Currently the Nujira shaping functions are included in the ET Control GUI panel; however, a feature is available to load in custom defined shaping waveforms. The overall delay of the envelope signal also needs to be set. The GUI calculates and sets the whole and fractional sample delays. This delay is different between various HAT modulators and lineups and needs to be adjusted accordingly. Monitoring the PA output signal along with the PA voltage supply tap and a frame sync using a high speed oscilloscope provides a mechanism to determine the correct delay. As shown in Figure 8, the supply voltage tracks the PA output once the correct delay is determined.

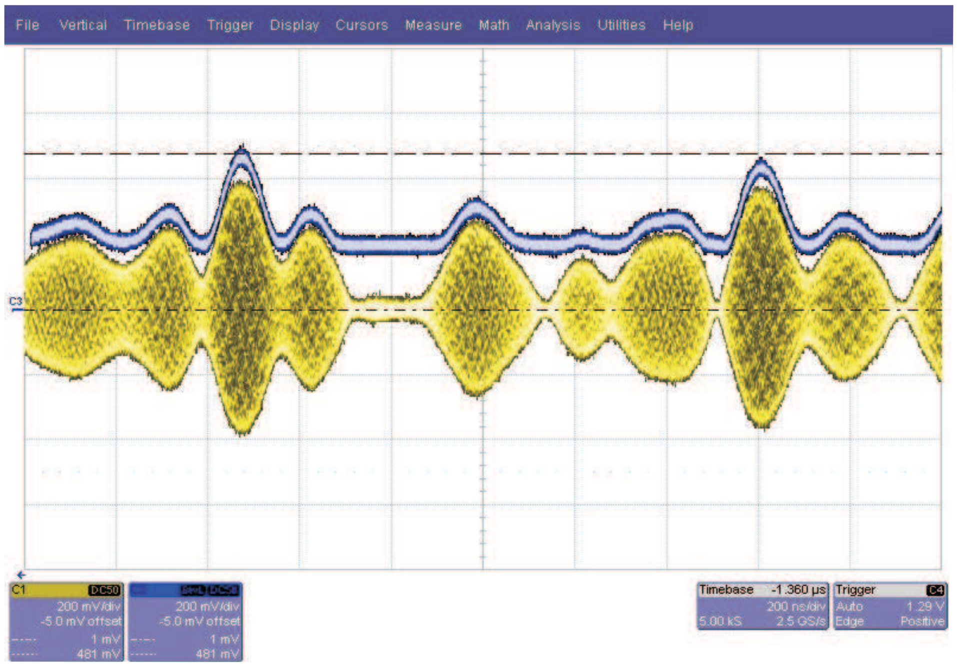

Figure 8. HAT Modulator Voltage Output (purple) Tracks the Envelope of the PA Signal (Yellow)

The DPD Long feature can be used to enable more cross terms in the DPD algorithm. This typically improves the DPD performance a couple of dB, but increase iteration time. Increasing the DPD polynomial order improves correction of higher order IM products that fall inband, at a further expense of increased iteration time.

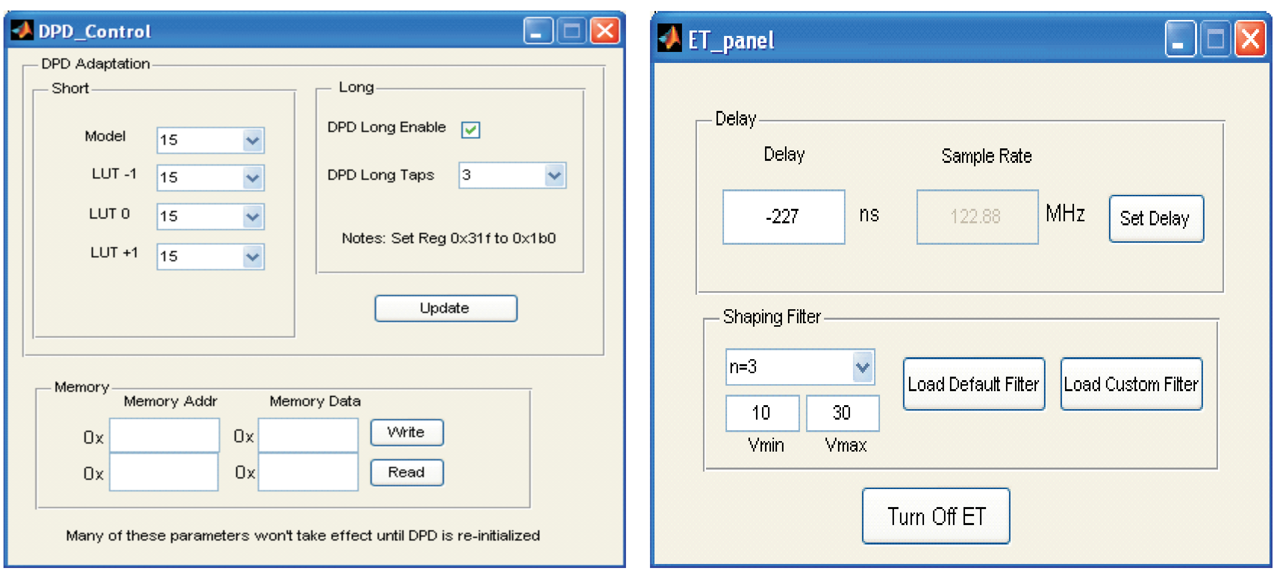

Figure 9. DPD Control and ET Panel Control

The HAT modulator is controlled by the I^2C MATLAB GUI. Once the shaping function has been loaded into the ET Look-Up table, the HAT modulator can be started. This enables the supply voltage of the PA. The TX signal level should be kept low while the ET delay is adjusted to align the PA output and the ET envelope. Once the envelope is aligned, the amplitude may be increased until the desired PA output power is achieved at which point DPD may then be engaged (Calibrate Feedback, Start DPD).

3 Results

The GC5325 was loaded using a 2 carrier TM1 WCDMA signal with CFR ON to generate a 6.5dB PAR output signal. The ET signal was enabled to drive the HAT modulator and the supply voltage output was connected to a Class AB PA amplifier.

With DPD enabled (Long/cross terms enabled also), the system is able to achieve over 20dB of correction for the ACP spec at an output power of 47dBm (50W). The efficiency in this case is calculated to be about **50%** for both 2 carrier and 4 carrier TM1 UMTS signals.

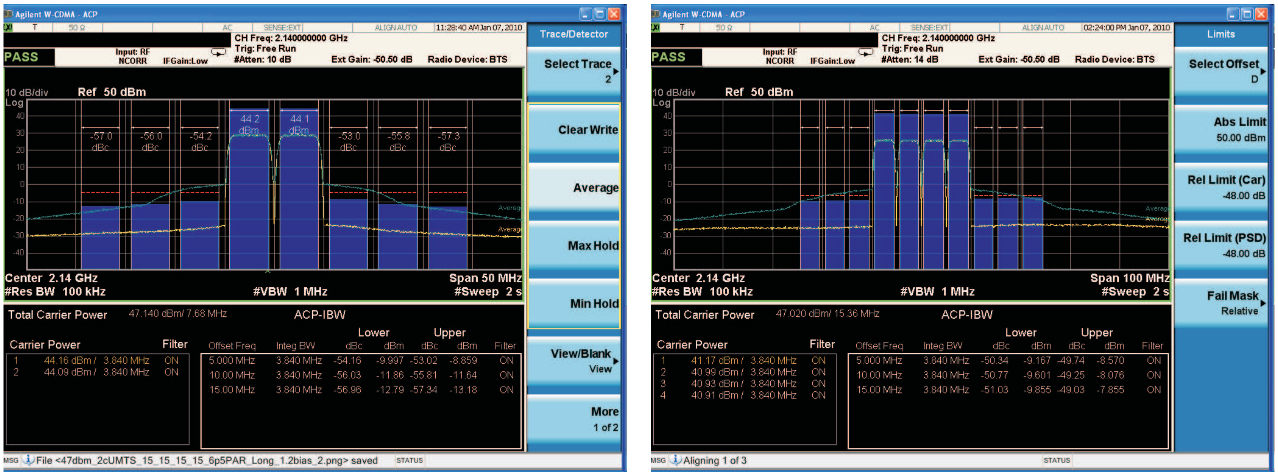

Figure 10. 2 Carrier TMI WCDMA, 6.5-dB PAR and 4-Carrier 6.6-dB PAR ET+DPD Results

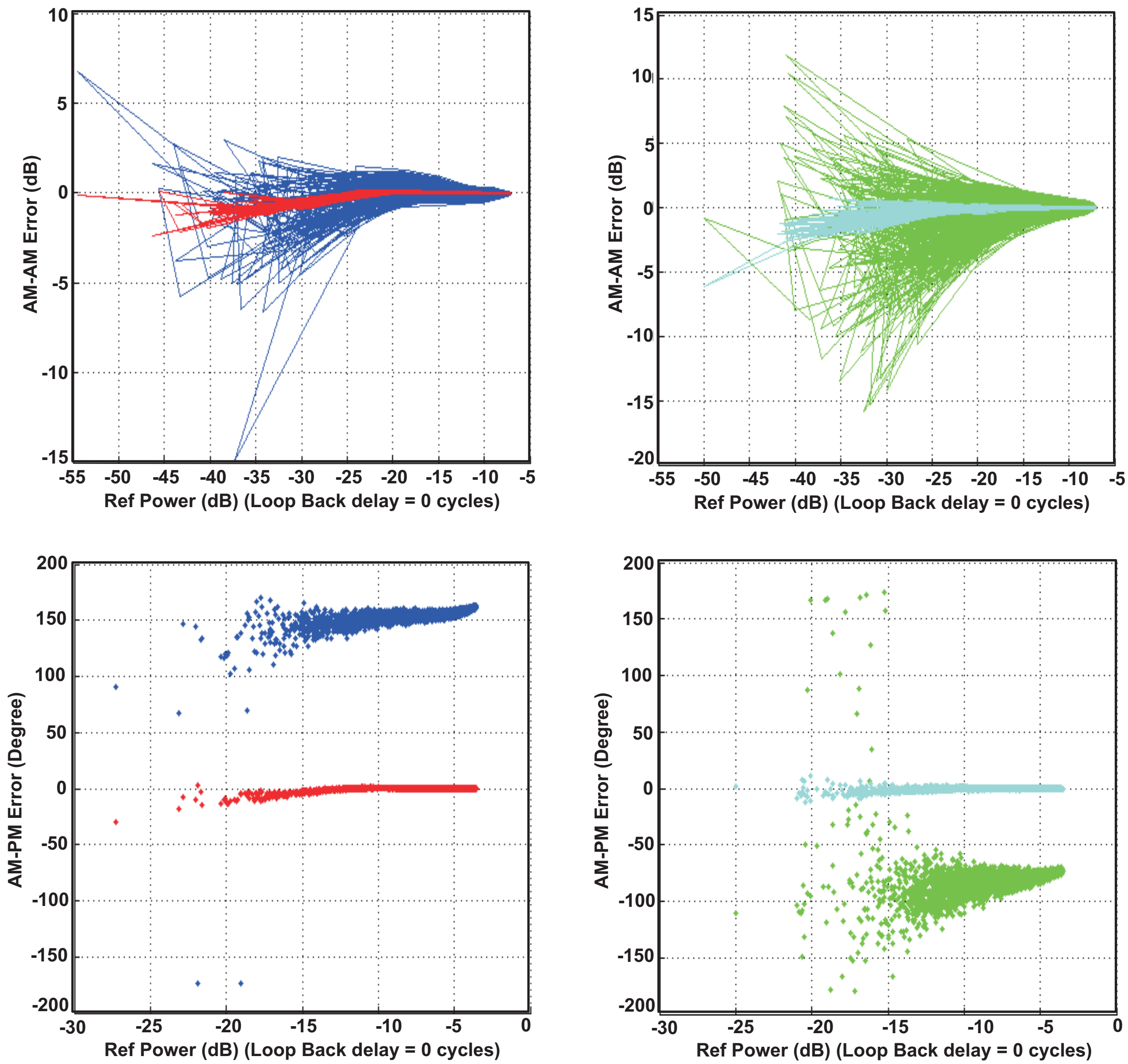

Figure 11. AM-AM Plot and AM-PM Plot Showing ET Pre-DPD (Blue 2 Carrier TM1, Green 4 Carrier TM1) and ET Post-DPD (Red 2 Carrier TM1, Teal 4 Carrier TM1).

The AM-AM plot shows the normalized amplitude variation at the PA output over the range of the signal amplitudes at the PA input. The X axis is the range of the input amplitudes, and the Y axis is the variation in amplitude at the PA output. This gives an indication of the amplitude response of the PA at a particular operating point. For a PA that is linear, the amplitude variations are close to 0 dB across all input amplitude ranges since the normalized PA output tracks the PA input. As the PA starts to operate near saturation, the PA output response shows both compression and expansion effects which are reflected in the AM-AM plot. The larger amplitude variations at the smaller signal levels are due to the normalization of small errors to smaller signal amplitudes.

The AM-PM plot is similar to the AM-AM plot. However, the AM-PM plot shows the phase variation of the output signal relative to the phase of the input signal over the range of input signal levels. This plot shows the phase response of the PA at a particular operating point. When the PA is operating in a linear region, the phase response is linear and shows near 0 degrees of variation. As the PA operates near saturation, the phase difference changes.

In both cases, the AM-AM and AM-PM plots help the user understand the PA amplitude and phase response before and after linearization.

4 Summary

Many of the implementation challenges involving Envelope Tracking have been addressed by using the GC5325 DPD system with signal envelope output coupled with the high performance Nujira HAT supply voltage modulator. Significant gains in device efficiency are achievable by modulating the supply voltage of the transistor to ensure that the PA is constantly operating near saturation. The GC5325 DPD system can then be employed to provide linearization of the PA. It is expected that with next generation transistor devices, using Envelope Tracking and DPD, PA efficiencies will approach 60% while still meeting standard requirements for linearity.

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