Linearization of power amplifier

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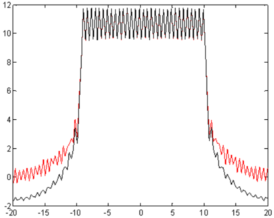
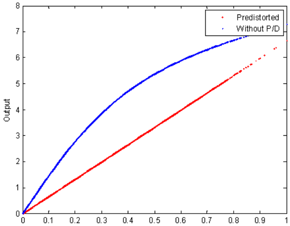
Linearity vs. Power Efficiency

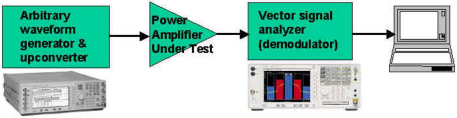
Power efficiency ⇒ *Battery lifetime*, *Thermal management*

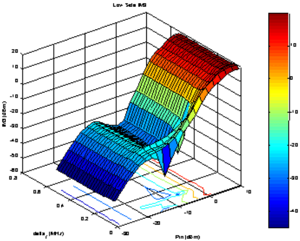
Linearity ⇒ **Sophisticated Modulation Techniques** ⇒ *Spectral efficiency*





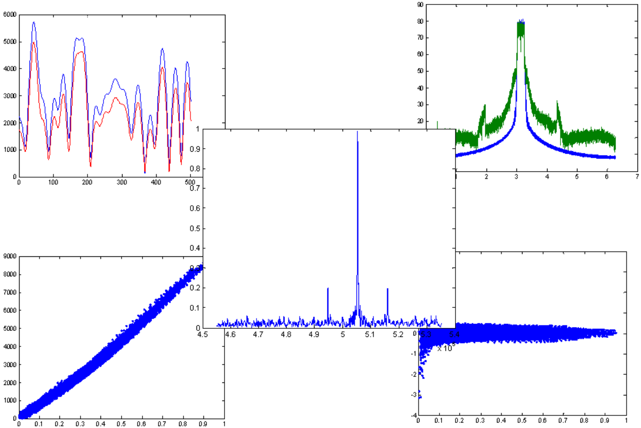
Measure real PA





Measure real PA - synchronization

Automatic phase synchronization of two signals



Volterra series

$$y(t) = k_0 + \sum_{n=1}^{\infty} \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} k_n(t_1, t_2, \cdots, t_n) x(t - t_2) \cdots x(t - t_n) dt_1 d_{t2} \cdots dt_n, \qquad (1)$$

where k_n is called the Volterra series kernel and can be regarded as a higher-order impulse response of the system.

Polynomial series with memory

$$y(t) = \sum_{k=1}^{K} \sum_{q=0}^{Q} a_{kq} \, x(t-q) |x(t-q)|^{k-1}. \qquad (2)$$

Despite the simplicity of the definition the stability and condition when performing the inversion of the generating matrix, the method is not very stable due the ill-conditioned matrix.

Orthogonal polynomial series with memory

To increase the stability of matrix, when performing Moore-Penrose pseudo-inverse, orthogonal polynomials can be used.

$$a_i = 2^{1-i} \binom{i}{\frac{i-1}{2}} \widetilde{a}_i, \tag{3}$$

$$y(t) = \sum_{k=1}^{K} \sum_{q=0}^{Q} a_{kq}\, x(t-q)|x(t-q)|^{k-1}. \tag{4}$$

Dynamic Deviation Reduction (DDR)

$$y(t) = \sum_{k=0}^{\frac{K-1}{2}} \sum_{i=1}^{Q} g_{2k+1,1}(i)\, |x(n-i)|^{2k} x(n-i) + \sum_{k=1}^{\frac{K-1}{2}} \sum_{i=1}^{Q} g_{2k+1,2}(i)\, |x(n-i)|^{2(k-1)} x^{*}(n-i). \quad (5)$$

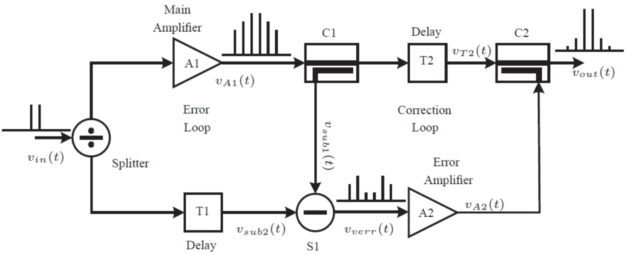
For second-order the model is rewritten as

$$\begin{aligned} y(t) = & \sum_{k=0}^{\frac{K-1}{2}} \sum_{i=1}^{Q} g_{2k+1,1}(i)\, |x(n-i)|^{2k} x(n-i) \\ & + \sum_{k=1}^{\frac{K-1}{2}} \sum_{i=1}^{Q} g_{2k+1,2}(i)\, |x(n-i)|^{2(k-1)} x^{2}(n) x^{*}(n-i) \\ & + \sum_{k=1}^{\frac{K-1}{2}} \sum_{i_1=1}^{Q} \sum_{i_2=1}^{Q} g_{2k+1,3}(i_1, i_2) |x(n-i)|^{2(k-1)}\, x^{*}(n) x(n-i_1) x(n-i_2) \\ & + \sum_{k=1}^{\frac{K-1}{2}} \sum_{i_1=1}^{Q} \sum_{i_2=1}^{Q} g_{2k+1,4}(i_1, i_2) |x(n-i)|^{2(k-1)}\, x(n) x^{*}(n-i_1) x(n-i_2) \\ & + \sum_{k=1}^{\frac{K-1}{2}} \sum_{i_1=1}^{Q} \sum_{i_2=1}^{Q} g_{2k+1,5}(i_1, i_2) |x(n-i)|^{2(k-2)}\, x^{3}(n) x^{*}(n-i_1) x^{*}(n-i_2). \end{aligned} \quad (6)$$

And then simplified

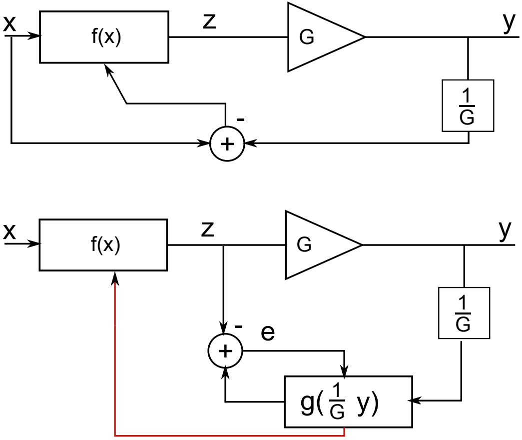
$$\begin{aligned} y(t) = & \sum_{k=0}^{\frac{K-1}{2}} \sum_{i=0}^{Q} g_{2k+1,1}(i)\, |x(n)|^{2k} x(n-i) \\ & + \sum_{k=1}^{\frac{K-1}{2}} \sum_{i=1}^{Q} g_{2k+1,2}(i)\, |x(n)|^{2(k-1)} x^{2}(n) x^{*}(n-i) \\ & + \sum_{k=1}^{\frac{K-1}{2}} \sum_{i=1}^{Q} g_{2k+1,3}(i) |x(n)|^{2(k-1)}\, x(n) |x(n-i)|^{2} \\ & + \sum_{k=1}^{\frac{K-1}{2}} \sum_{i=1}^{Q} g_{2k+1,4}(i) |x(n)|^{2(k-1)}\, x^{*}(n) x^{2}(n-i). \end{aligned} \quad (7)$$

Feedforward techniques



- Matching delay lines, amplifier gains not trivial.
- Susceptible to drift and ageing.
- Low-loss delay lines, summations critical.

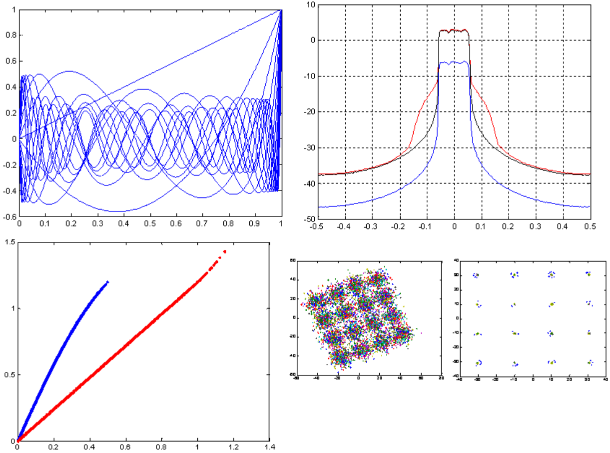
Feedback adaptation of predistortion



Results for different methods I

Orthogonal Polynomial

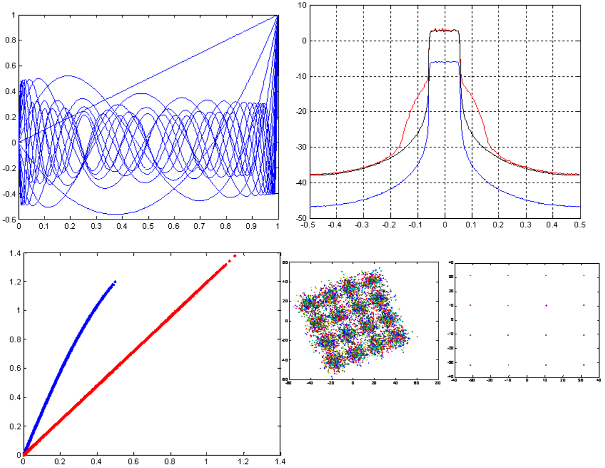
Polynomial level = 7, OFDM (64 carriers, 2400 Data bits, 16QAM), Saleh PA



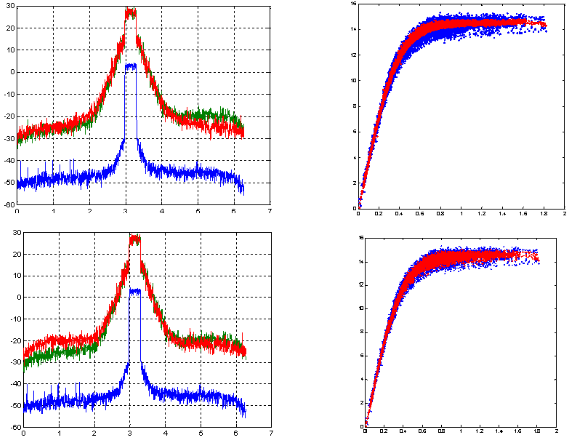
Results for different methods II

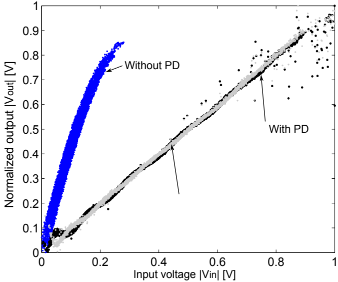
Orthogonal Polynomial

Polynomial level = 15, OFDM (64 carriers, 2400 Data bits, 16QAM), Saleh PA

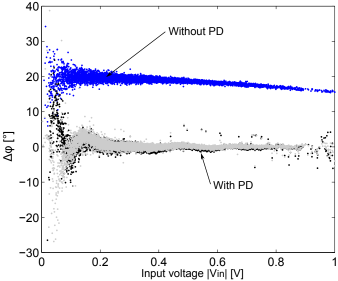


DDR second-order (real data class AB PA working at 1.455 GHz, Motorola MRFC1818 GaAs MESFET)



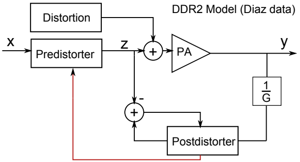


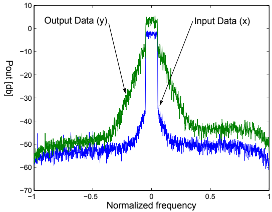
Without PD
With PD
Normalized output |Vout| [V]
Input voltage |Vin| [V]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1



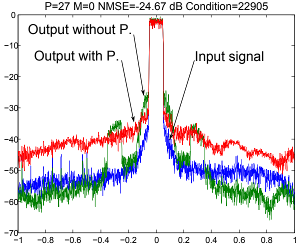
Without PD
With PD
Δφ [°]
Input voltage |Vin| [V]
40
30
20
10
0
−10
−20
−30
0
0.2
0.4
0.6
0.8
1

Adaptive system - with distortion





Normalized mean square error for modeling the PA is -33 dB.



$$ACPR_L = -33.6789[dB]$$
$$ACPR_R = -33.8989[dB]$$
$$Distortion(t) = 0.01\ x(t)\ sin(0.3\ \pi\ t)$$

Available predistortion boards on the market

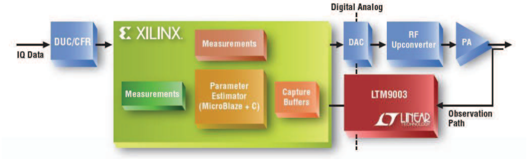
LTM9003

Bandwidth: Claim 60MHz, but in the notes there is written **20 MHz – with Spartan-6**

Multiple Memory Correction Models

Bandpass filter 184MHz Center, 125MHz Bandwidth

Pinmax=1591mW



Available predistortion boards on the market

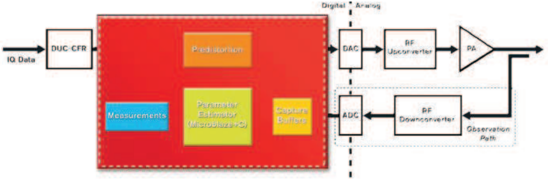
XILINX

DPD v2.0

Bandwidth: 15MHz+ Virtex-4 FPGA, 20MHz+ Virtex-5 (but up to 20MHz+)

Memory and reactive models

Pinmax=1200mW



Scintera

SC1889

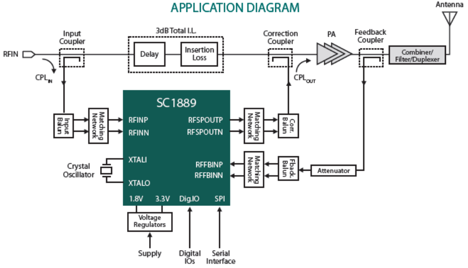
Bandwidth of Input signal: up to 60MHz
Operational BW: 698-2800MHz

Pinmax=450mW

Memory models

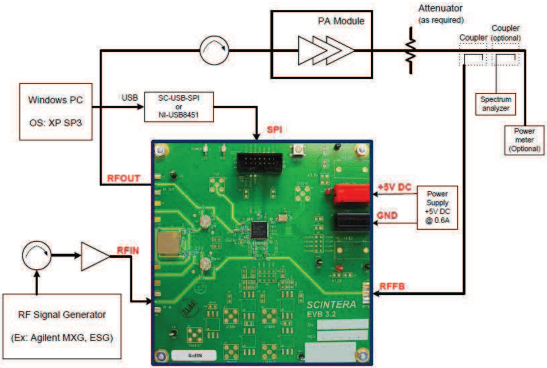
DEVELOPMENT TOOLS	
PRODUCT	DESCRIPTION
P/N: SC1889-EVK900	Evaluation Kit: 698 MHz – 960 MHz
P/N: SC1889-EVK1500	Evaluation Kit: 1400 MHz - 1800 MHz
P/N: SC1889-EVK1900	Evaluation Kit: 1800 MHz – 2200 MHz
P/N: SC1889-EVK2200	Evaluation Kit: 2100 MHz – 2800 MHz
P/N: SC-USB-SPI	SPI-USB Interface/Controller

APPLICATION DIAGRAM



Available predistortion boards on the market

SC1889-EVK



Available predistortion boards on the market

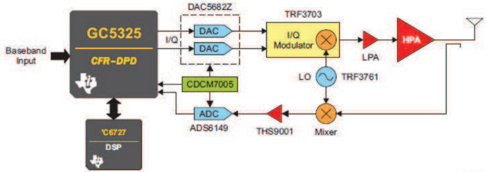
TEXAS INSTRUMENTS

GC5325

Up to 20-MHz Combined Signal Bandwidth

DPD: Memory Compensation

Transmit- and Feedback-Channel Equalizers



Available predistortion boards on the market

GC5325EVM

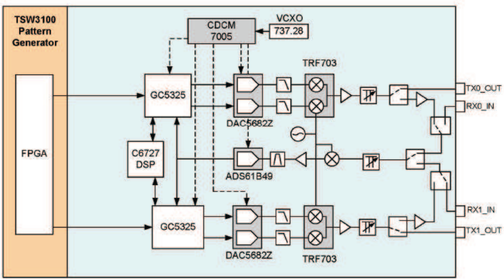
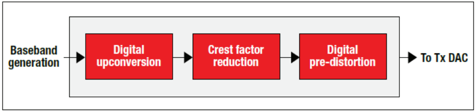


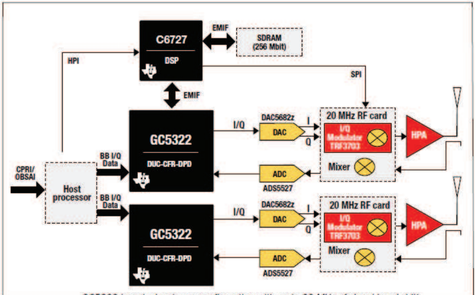
Figure 1. GC5325EVM Block Diagram

Texas Instruments

GC5322



Up to 40-MHz Signal Bandwidth



GC5322 in a dual-antenna configuration with up to 20 MHz of signal bandwidth

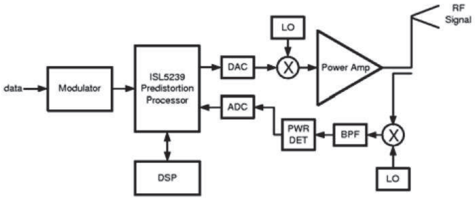
Available predistortion boards on the market

intersil

ISL5239

Up to 20-MHz Combined Signal Bandwidth

Memory effects compensation



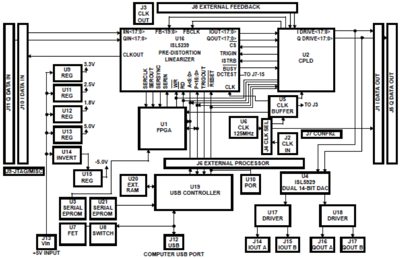
intersil

ISL5239EVAL1

Up to 20-MHz Combined Signal Bandwidth

Memory effects compensation

Matlab utility programs have been developed and are available to aid in characterizing the Power Amplifier (PA) and to facilitate programming the device Look-Up Table(s).

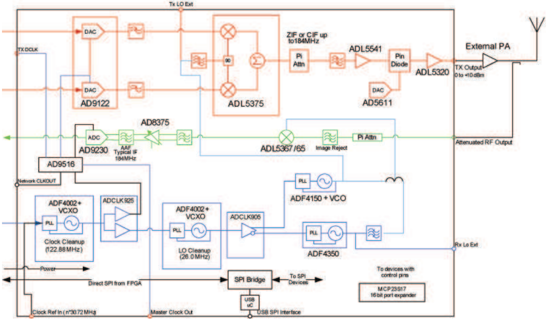


ANALOG DEVICES

AD-MSDPD-EVB

Signal Bandwidth 122.88MHz ??

FPGA or DSP with implemented algorithm need to be connected



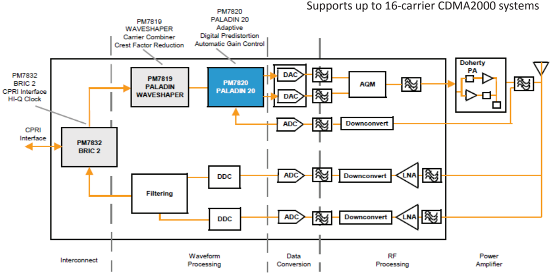
PMC-SIERRA

First industrial solution

PM7800 PALADIN 10
PM7815 PALADIN 15
PM7815 PALADIN 20

Signal Bandwidth 10MHz - PM7800
Signal Bandwidth 15MHz - PM7815
Signal Bandwidth 20MHz - PM7820
Memory ????

Supports macro BTS, micro BTS, and RRH architectures
Supports up to 4-carrier WCDMA systems
Supports up to 16-carrier CDMA2000 systems



Thank you for your attention.

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