RF Pre-Distortion for Linearizing Power Amplifiers

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Company Background
What do we do? And why?

**What:** Adaptive pre-distortion to linearize RF power amplifiers
- RF Power Amplifier Linearizer (RFPAL)
- Reduce distortion to increase PA efficiency and useable output power
- Lower system cost & reduce design time
- Target cellular wireless and microwave

**How**
- Single-chip programmable, high-performance, analog signal processing platform; lower power consumption and much lower cost (vs. DPD)
- Compute & Adapt in the digital domain, Apply in the analog/RF domain
- Programmability of digital; the simplicity, cost, size and power of analog

**Why**
- **Higher PAR Waveforms:** the move to more complex modulation schemes, multi-carrier systems, time-slotted waveforms, etc. increase signal variability (peak-to-average ratio)
- **New Devices & Systems:** A variety of PA architectures and transistor technologies put increasing demands on linearity & efficiency
- **Cost:** Push to lower CAPEX and OPEX
  - Electric bills is a non-trivial component of expenses
  - Current digital solutions are expensive, large, and power-hungry, and require integration from BB to PA.
Company Timeline

2001

Company Founded

Focus for 1st 6 years: Optical & Wireline Markets

2007

Shifted focus to Wireless Infrastructure

2009

Add Microwave P2P (up to 60 MHz signal BW) & Broadcast segments

2010

SC1887 in production
Cellular (W)CDMA market

2011

SC1889 in production
(Low-Cost SC1869) Cellular 4G
Time-slotted waveforms
Improved performance

2012

SC1894
Expanded frequency range (168 MHz – 4.2 GHz)
Performance improvements
Monitoring/control funcs.

2013

SC2200 for MIMO Systems
Technology & Product
Power Amplifiers & the Need to Linearize

- **PA output power (dBm) vs. input power (dBm)**
- **Efficiency (%) and Inter Modulation Product (dBc) vs. output power (dBm)**
Predistortion Principle

No predistortion

With predistortion

5-10 x BW expansion
Digital Pre-Distortion (DPD)

**Benefits**
- Programmable, customizable for particular application, control

**Challenges**
- High power consumption, high frequency reconstruction filter, wide band up-mixer, challenging clock generation to achieve converters SNR, lack of modularity, cost…
RFPAL (RF PA Linearization)

Benefits:

- Lower power digital processor, easy reconstruction filter, relaxed up-mixer requirements, low power, low cost, easy to use; feedback path fully integrated; DAC only need transmit at 1x signal bandwidth

Challenges

- Potentially ... degree of control for end user
RFPAL in Microwave Backhaul Designs

Easy to linearize split-mount or integrated backhaul systems

128QAM, 28 MHz BW
Before correction

After correction

RMS EVM=4.6%
RMS EVM=2.8%
RFPAL System Architecture

- **RFOUT**
- **RFIN**
- **RFFB**
- **RF SIGNAL PROCESSOR**
  - QPS
  - Envelope
  - **ANALOG Correction Processor**
- **DIGITAL LOGIC**
  - Down-Convert & Sample
  - Generate Spectrum
  - Power Analysis
- **μP**
  - Initialize
  - Calibrate
  - Adapt & Track
- **EEPROM**
- **CLK**
- **SPI**
RFPAL Signal Path

Moves application of signal processing from digital to analog domain
Analog Volterra Series

\[ V_{IN}(t) = r^2(t) \]

\[ V_{OUT}(t) = \sum_{p=1}^{4} \sum_{m=1}^{5} c_{2m} r^{2m}(t - \tau_p) \]

Delay 1 = \( \tau_1 \)
Delay 2 = \( \tau_2 \)
Delay 3 = \( \tau_3 \)
Delay 4 = \( \tau_4 \)

DAC's

Coefficient

Scintera
Cost Function

\[ C(w) = \log_2 \left[ f_1(P_{1L}, P_{1U}) + f_2(P_{2L}, P_{2U}) \right] \]

\[ w_{opt} = \min_w C(w) \]

Use a Stochastic gradient search algorithm to optimize
Cost Surface & Adaptation

Cost Surface
(artist’s rendition)

Semiconductors for Wireless Communications
Extensible Approach

- **Basic idea**: linearize by extracting parts of the error spectrum
  - No need to down-convert the entire signal

![Signal](image)

**Multi-band Signals**

- **Wideband Signal**
  - Signal @ 1.8 GHz
  - Signal @ 2.1 GHz

![Error Spectra](image)
# Product Line Summary

<table>
<thead>
<tr>
<th></th>
<th>SC1887</th>
<th>SC1869</th>
<th>SC1889</th>
<th>SC1894</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency of operation</strong></td>
<td>698 - 2800MHz</td>
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<td>168 - 4200MHz</td>
</tr>
<tr>
<td><strong>Max. signal BW</strong></td>
<td>1.2 - 40/60MHz</td>
<td>1.2 - 20MHz</td>
<td>1.2 - 60MHz</td>
<td>25 kHz - 60MHz</td>
</tr>
<tr>
<td><strong>Waveforms</strong></td>
<td>CDMA &amp; WCDMA</td>
<td>Same as SC1889</td>
<td>CDMA, WCDMA, LTE, TD-LTE, WiMAX, HSDPA</td>
<td>Same as SC1889</td>
</tr>
<tr>
<td><strong>PAs</strong></td>
<td>Class A/AB &amp; Doherty</td>
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<td>Class A/AB &amp; Doherty</td>
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</tr>
<tr>
<td><strong>PA output power</strong></td>
<td>Up to 50 W</td>
<td>Up to 10W</td>
<td>5 W - 60W</td>
<td>Up to 60W</td>
</tr>
<tr>
<td><strong>Added features (paid for add-ons)</strong></td>
<td>RFFB RMS power detector</td>
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<td>RFIN &amp; RFFB RMS power detector, gate bias control, temp. &amp; spectral monitoring</td>
<td></td>
</tr>
</tbody>
</table>

**SC2200 (MIMO) ... 2H 2013**
Representative Results
Macro: 30W LTE 20 MHz Using Freescale MRF8S2100 Doherty

**Graphs:**
- **Left Graph:**
  - Graph title: \( \text{SN460 hw3.1 PAM121 25° LTE20M1\%100#8.21 2140.0 MHz 11/01/24 11:01:27 U} \)
  - X-axis: Frequency Offset from Carrier Center, MHz
  - Y-axis: PA Output Power, dBm / 30 kHz
  - Data points:
    - \( \text{BO}=0.5 \)
    - \( \text{P}_{\text{out}} = 45.0 \text{ dBm} \)
    - \( \text{P}_{\text{out}} = 44.6 \text{ dBm} \)

- **Right Graph:**
  - Graph title: \( \text{BO=0.5 SN460 hw3.1 PAM121 25° LTE20M1\%100#8.21 2140.0 MHz 11/01/24 11:01:27 U} \)
  - X-axis: Frequency Offset from Carrier Center, MHz
  - Y-axis: ACLR, dBc
  - Data points:
    - ACLR1L-0: -31.6 dBc
    - ACLR1L-1: -51.3 dBc
    - ACLR1U-0: -31.0 dBc
    - ACLR1U-1: -50.6 dBc
    - ACLR2L-0: -49.7 dBc
    - ACLR2L-1: -56.6 dBc
    - ACLR2U-0: -50.6 dBc
    - ACLR2U-1: -56.6 dBc

**Equation:**
\[ \text{PAR} = 8.2 \text{ dB, Amplifier } P_{3\text{dB}} = 53.9 \text{ dBm, } \eta_{\text{drain}} = 39\% \]
LTE with low traffic loading: E-TM2.0

Blue – Uncorrected
Yellow – 100% Loaded
Magenta – Partial Loaded Signal Shown at Right

LTE20M1-1#14.34.mat, dwell = 20 μs, duty factor = 0.00 dB
peak across 20 us
12 kHz LPF

Resource Blocks (Frequency)
Slot (Time)

Amplitude

Semiconductors for Wireless Communications
Scintera®
2.5W (@ Antenna) Asymmetric Doherty Line-up

![Diagram of a semiconductor circuit with RF Xcvr, SC1894, DVR, PA, and 28V connections.]

**10MHz LTE 7.5 PAR**

- **PSD-1** and **PSD-0**
- **ACLR2L-0** = -44.5 dBc
- **ACLR1L-0** = -29.2 dBc
- **ACLR2L-1** = -58.1 dBc
- **ACLR1L-1** = -51.4 dBc
- **ACLR1U-0** = -29.3 dBc
- **ACLR2U-0** = -43.9 dBc
- **ACLR1U-1** = -60.7 dBc
- **ACLR2U-1** = -57.7 dBc

**Power-added efficiency**: 45% PAE
2x1W (@ Antenna) Reference Product Line-up

Dual Xcvr

* Triquint PA requires special match for 33dBm.

20MHz 4xWCDMA 7.8dB PAR

PA Output Power, dBm / 30 kHz

Power-added efficiency, %
Summary

- **Technology**: Programmable analog signal processing platform is ideally suited to address a wide range of markets & applications
  - Initial focus on RF PA linearization

- **Markets**: Target markets expanding
  - Broadcast, Microwave backhaul, Public Safety, White space

- **Advantages**: Differentiated solution addressing customer issues
  - Low power consumption, low cost, small form factor and high performance
  - Rfin/Rfout, simple design and integration of RFPAL enables fast time to market
  - Supports a wide variety of
    - Waveforms & modulations (2G/3G/4G, broadcast, microwave, …)
    - Range of transmit powers (0.5W-60W)
    - Infrastructure (macro base stations, repeaters, small cells, …)
    - Technologies (LDMOS, GaN, GaAs, etc.)
    - Architectures (class A, A/B, Symmetric & Asymmetric Doherty,...)