Power Management Design Challenges and Techniques for Power Amplifiers in 2G/3G/4G Multimode Handsets

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National Semiconductor’s Innovation in RF SMPS for Handsets

• Creator of first DCDC for RF PA in 2004
• Shipped in significant volumes since 2005
• Continuous innovator
  – First GSM support
  – First Boost support
  – First

• Estimate: RF DCDC has saved 2 Mega Watts of Power over the last 5 years
• DCDC for RF PA will ship in all 3G and 4G handsets by 2012

Requires NDA

Multi-mode Multi-band RF Transmitter with variable PA Vcc supply

- Typical smartphone includes 2 to 5 3GPP bands plus
- Quad band GSM/EDGE
Technology & Market Trends

Highly Integrated System Platforms

Transmitter PA Efficiency Improvements

Smartphone Power Gap

Standards Evolution

Buck DCDC + PA Reduces Worst Case Thermal of Highly Integrated Phones

Reduced Thermal Emissions of PA by > 20%

PA ONLY

\[ V_{\text{BATT}} = 4.2\text{V} \]
\[ V_{\text{CC}} = 4.2\text{V} \]
\[ RF_{\text{OUT}} = 26\text{dBm} \]

Temp = 57°C

PA with DCDC

\[ V_{\text{BATT}} = 4.2\text{V} \]
\[ V_{\text{CC}} = 3.4\text{V} \]
\[ RF_{\text{OUT}} = 26\text{dBm} \]

Temp = 44.7°C

Smartphone Power Gap

Enabling longer charge cycle, smaller form factor

Source: IMS & internal NSC

Constant growth in data consumption and use of BW drives need to improve PA system efficiency.
DCDC + PA Transmitter Efficiency Improvements

Highly Integrated System Platforms

Smartphone Power Gap

Technology Trends

DCDC dynamically adjusts PA supply voltage to optimize efficiency during lower power RF Tx

**DCDC + PA Transmitter Efficiency Improvements**

3GPP Band 1
LTE 5MHz QPSK, Freq = 1977.5MHz, Vbatt = 3.7V

**Advantage With DCDC**

**Highly Integrated System Platforms**

**Smartphone Power Gap**

**Technology Trends**
Standards Evolution

From “NICE TO HAVE” in 2/2.5G to “MUST HAVE” in 3G

Global Growth of UMTS/HSPA

Source: Informa Telecoms & Media, WCIS, Dec 2008 Forecast
# RF Power Management Evolution in Mobile Devices

## RF Performance Constraints
- Transmit Spectral Mask
- Voltage Switching Transients
- Low Supply Noise

## Talk Time Improvement
- PA + DCDC Architecture Improvement
- Light Load Efficiency Enhancement
- Low Voltage Battery support

## Solution Size Reduction
- Multi-mode PA support
- Smaller Switch Inductor
- Integrated Inductor
Increased RF Performance

- High current capability (up to 2.5A)
- High efficiency (up to 96%)
  - At Heavy and Light Loads
- Performance requirements for the DCDC converter extend into the PA requirements.
  - Detailed understanding of the RF performance is mandatory
  - Rx Band Noise
  - EVM, ACLR, PvT
Transmit Spectral Mask
Adjacent Channel Leakage Ratio

- Pout ACLR1 Linearity meets ACLR spec with 6 dB margin
- Higher data rate uplink possible (16QAM) at Vbatt = 3.4V

- Pout degraded and ACLR1 Linearity does not meet -40 dBc
- Lower data rate uplink (QPSK) at Vbat = 3.2V
Transient Performance

• **Wcdma Inner Loop Power Control**
  - During active transmission in wcdma or HSPA the UE will ratchet the Tx output power up or down
  - Window < +/- 25 usec for transitioning between two successive power levels

• **GSM Power Ramp**
  - Power vs. Time template requires tight output regulation
  - For DCDC with fast transient response, it is beneficial to adjust the PA Vcc on a slot-by-slot basis

![GSM Multi-Slot Timing Diagram]

RF Noise

- **Wideband noise**
  - Stringent noise requirements for 3GPP Rx frequency bands as well as GPS
  - Switching frequency ripple must be extremely low at higher harmonic frequencies

- **RFIC operating voltage is dropping from 2.5V to < 1.8V**
  - Critical components pulled from RFIC into RF PMU
    - DCDC for PA
    - LDO’s
    - DCDC for RFIC
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Transmitter Efficiency Improvements

- **Transmitter Needs**
  - Power amplifier efficiency is optimized for max $P_{OUT}$
  - Majority of time $P_{OUT}$ is lower $\rightarrow$ PA is at poor efficiency

- **Variable Supply**
  - Optimize supply voltage based on $P_{OUT}$
  - Improve PA efficiency at lower powers

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<table>
<thead>
<tr>
<th>Fixed Supply</th>
<th>Adaptive Supply</th>
<th>High Speed Tracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Savings (Past)</td>
<td>40% Savings with DCDC</td>
<td>More Power Savings?</td>
</tr>
</tbody>
</table>
Envelope Tracking System Architecture

- Components: Chipset, **ET Modulator** and PA
  - Significant enhancement of PA efficiency with high-PAR signals and medium to high TX power levels
  - Supporting all modulation methods up to full LTE

- Open-loop vs. Closed loop solution
  - Less modifications to firmware
  - More cost effective, less processing

**Envelope Tracking Modulator**

- **High performance analog circuitry**
  - **Wide bandwidth requirements**
  - **Fast transitions between peaks and valleys**

![LTE PA Icc vs. Time](image-url)
Handset spends a lot of time at lower power levels

- Low Voltage, Low Current
- Traditional DCDC performance drops off at light loads
Wider Battery Operating Range

• Buck-Boost
  – Increases usable region of battery
  – No MPR Backoff required
  – Larger coverage area
  – Higher Data Rates

Extended RF spec compliant region of operation with Boost-Buck DCDC
## RF Power Management Evolution in Mobile Devices

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|---------------------------|-------------------------------------------------|
| Talk Time Improvement     | • PA + DCDC Architecture Improvement  
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• Low Voltage Battery support |
| Solution Size Reduction   | • Multi-mode PA support  
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RF Front End Integration

Biasing Blocks
- RFIC/LNA Supply
- Adaptive Bias Controller
- PA Driver Bias
- PA Ramp/Envelope
- PA Bias Controller
- PA Output Bias
- DCDC
- Boost
- SUPA

Filters
- SAWs
- LPFs
- Tx/Rx Duplexers

Power Amp Modules
- Output Matching Networks

Sensors
- Power Detect
- Temp Sensor
- VSWR Det
- Alarm

TRX Path Control
- N:1
- Antenna Tuning Element

ANT

Solution Size Reduction

Multi-mode PA Support

Traditional Front-End

Converged Front-End

Controlling SMPS for PA Module

- Multiple options to consider
  - Interface type (Analog or Digital).
  - Controller type (RFIC or BBIC).
  - Single-chain or multi-chain PA Modules.
  - Multi-slot power ramping for GSM/EDGE.
Reducing Switch Inductor Size

- Smaller inductor value reduces filtering of switching noise
- Higher switching frequency trades off efficiency due to AC switching losses

• DCDC on Ferrite
  - Parasitic inductance on all pins
    - Especially critical on power and grounds
  - Max height constrained to ≤ 1.0 mm
    - DC resistance increases
Conclusions/Challenges

- New Multi-mode Multi-band handsets are demanding higher and higher levels of performance
- Variable RF PA supply is required for next generation of slim trim and high data rate smartphones
- Maintaining RF noise performance with DCDC for PA is not trivial
National’s RF Front End Benefits

- **Increased Usage Time**: >25%
- **Decreased Thermal Emissions**: >20%
- **Small Solution Size**: <10mm²
- **Reduced BOM Cost**: >5%
- **Increased Coverage Area**: >10%

National Semiconductor

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