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

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National Semiconductor

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 [redacted]

Requires NDA

- 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

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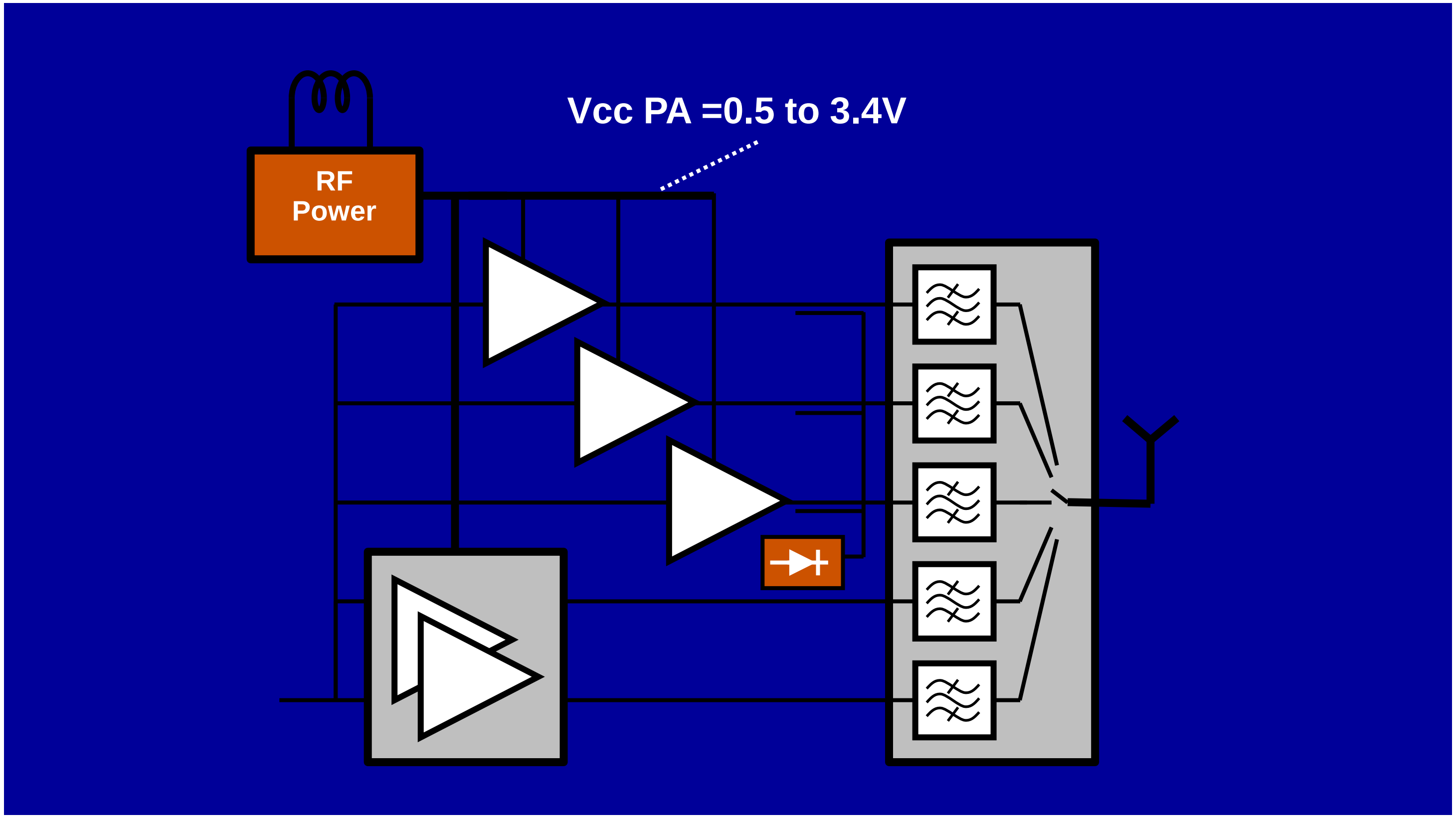
Multi-mode Multi-band RF Transmitter with variable PA Vcc supply

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



Technology & Market Trends

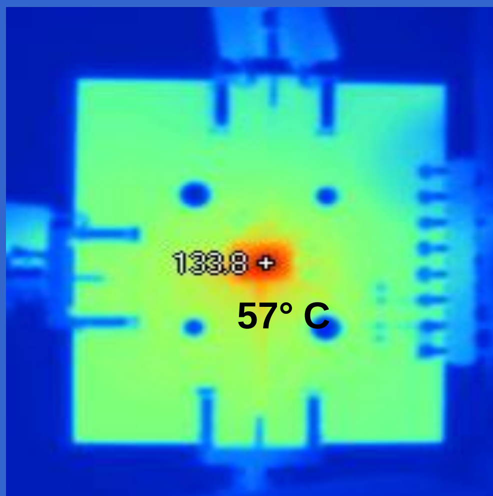
Highly Integrated System Platforms

Transmitter PA Efficiency Improvements

Smartphone Power Gap

Standards Evolution

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



PA ONLY

$V_{BATT} = 4.2V$
$V_{CC} = 4.2V$
$RF_{OUT} = 26dBm$

Temp = 57 C

PA with DCDC

$V_{BATT} = 4.2V$
$V_{CC} = 3.4V$
$RF_{OUT} = 26dBm$

Temp = 44.7 C

Reduced Thermal Emissions of PA by > 20%

Transmitter PA Efficiency Improvements

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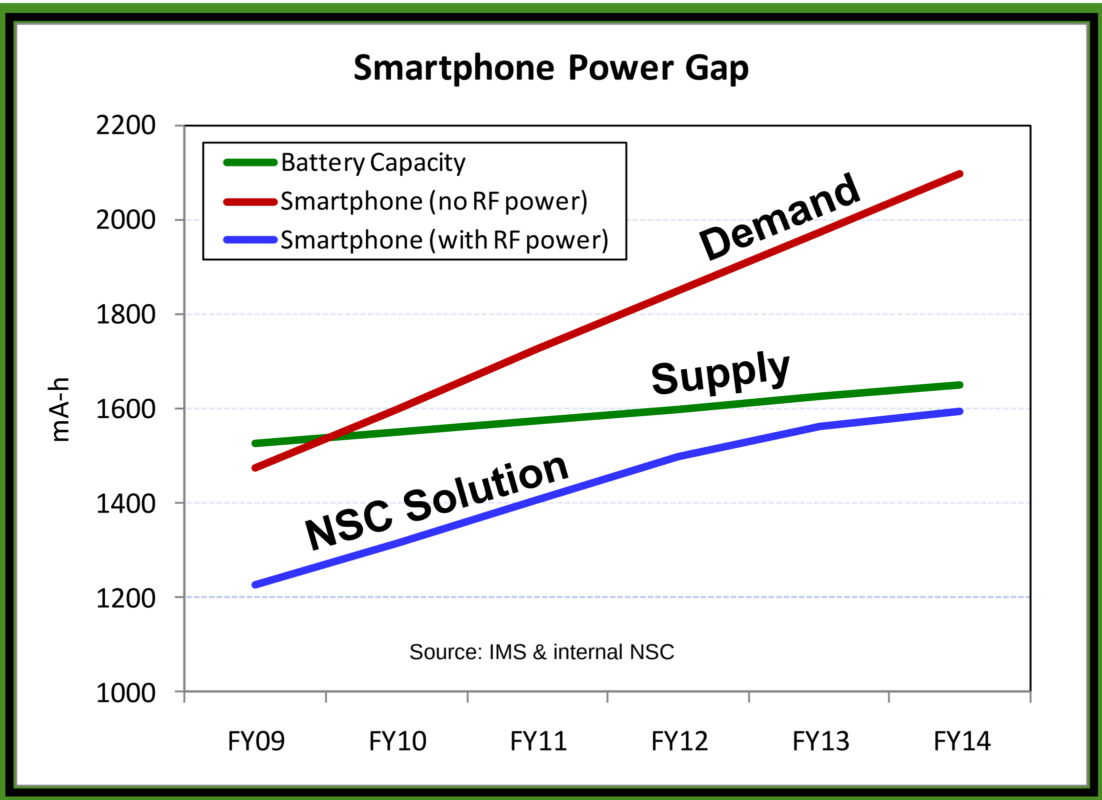
Smartphone Power Gap

Enabling longer charge cycle, smaller form factor



Highly Integrated System Platforms

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Standards Evolution

Handset Transmit Power Profile Normalized Cumulative Distributions

Constant growth in data consumption and use of BW drives need to improve PA system eff

Highly Integrated System Platforms

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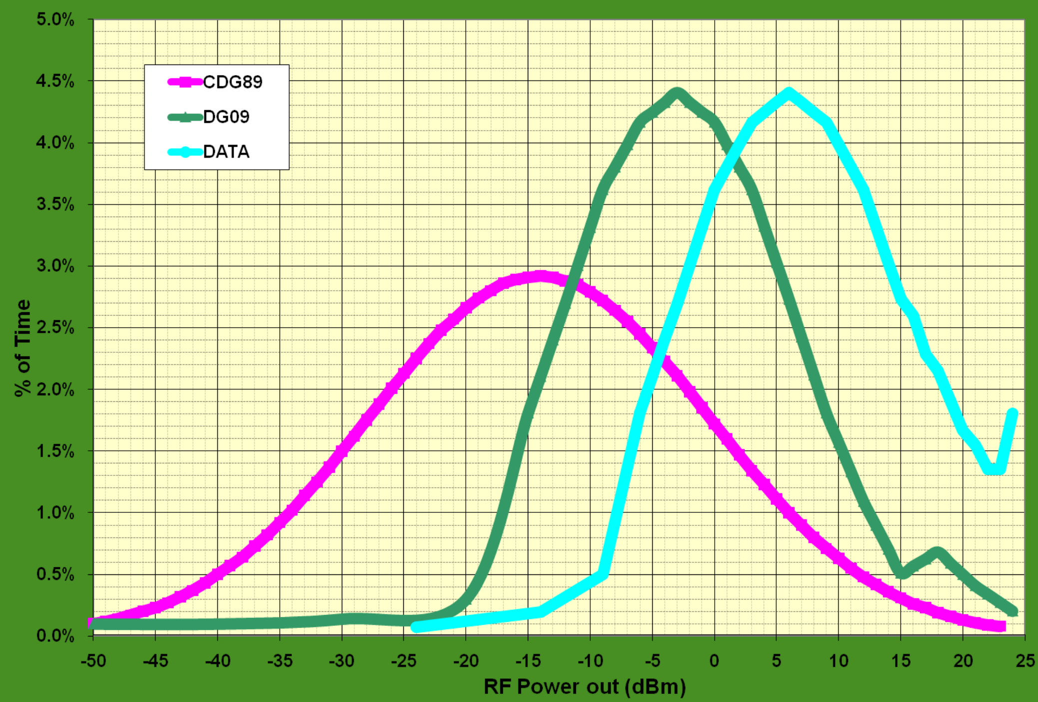
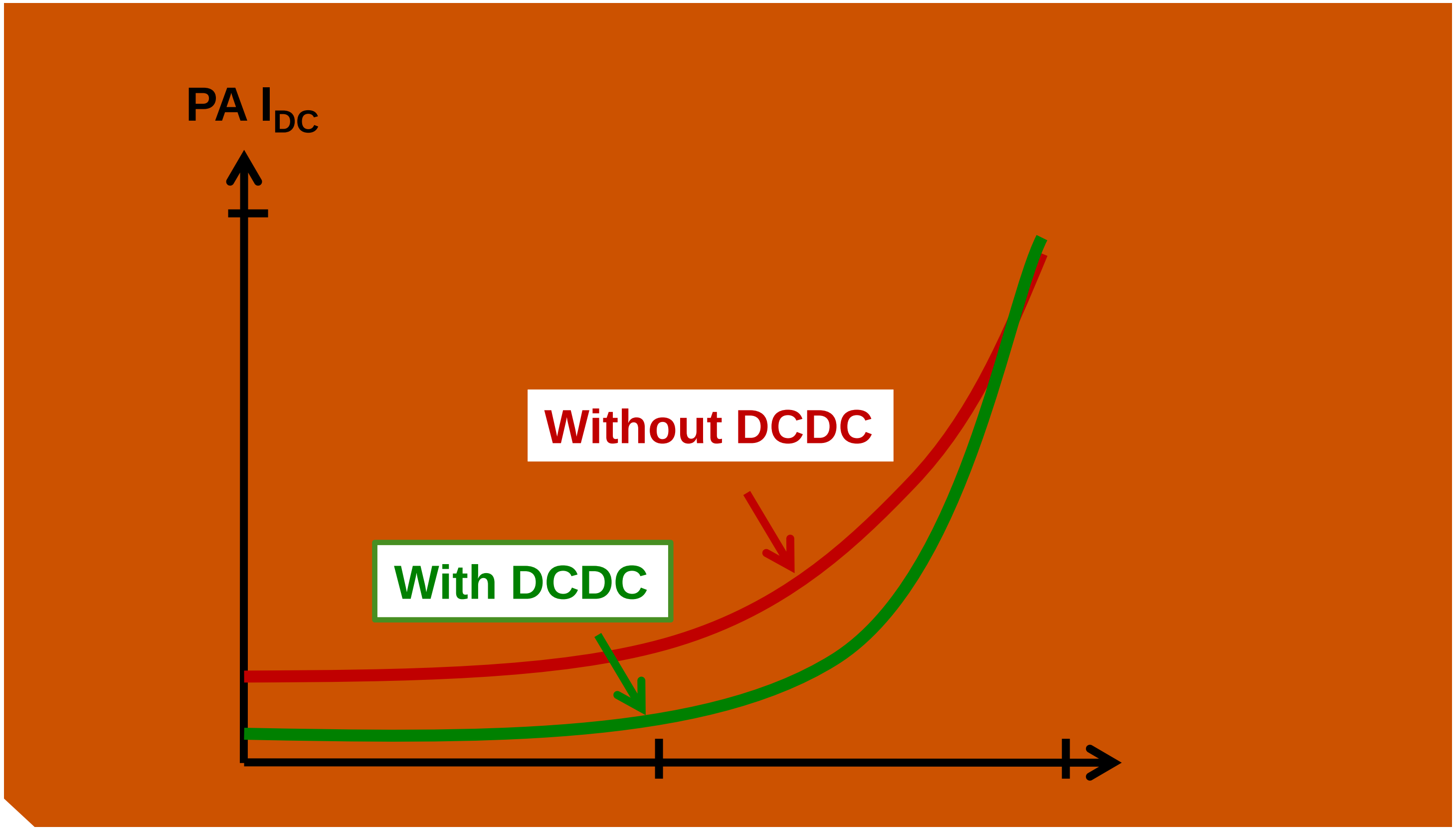


DCDC + PA Transmitter Efficiency Improvements



Highly Integrated System Platforms

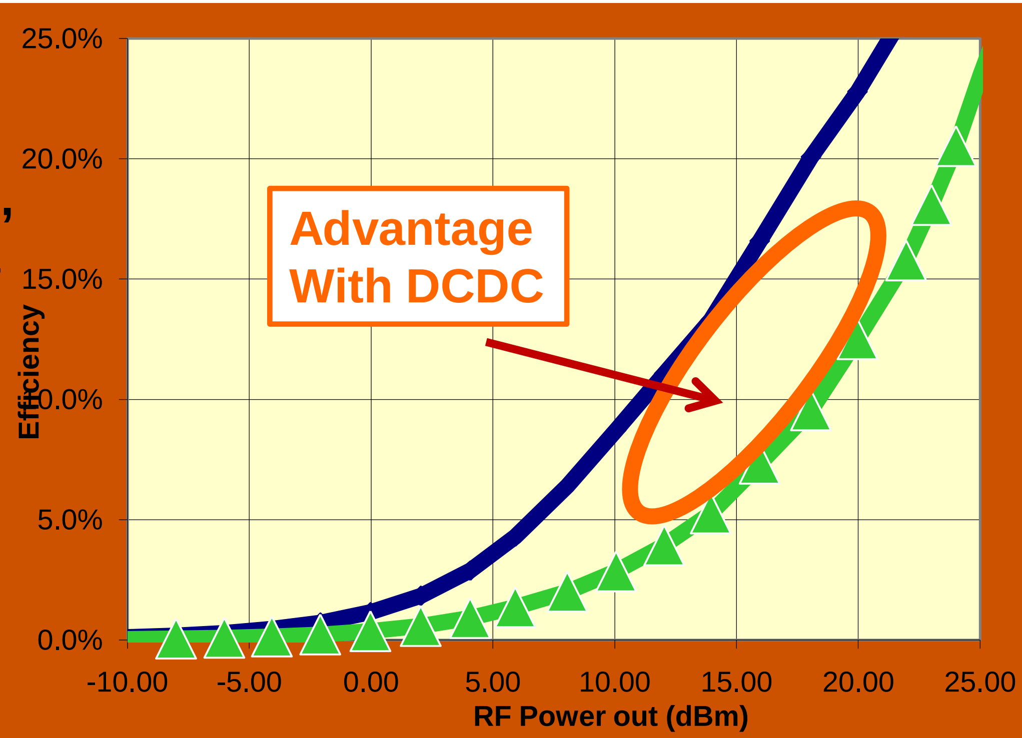
Smartphone Power Gap

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



Highly Integrated System Platforms

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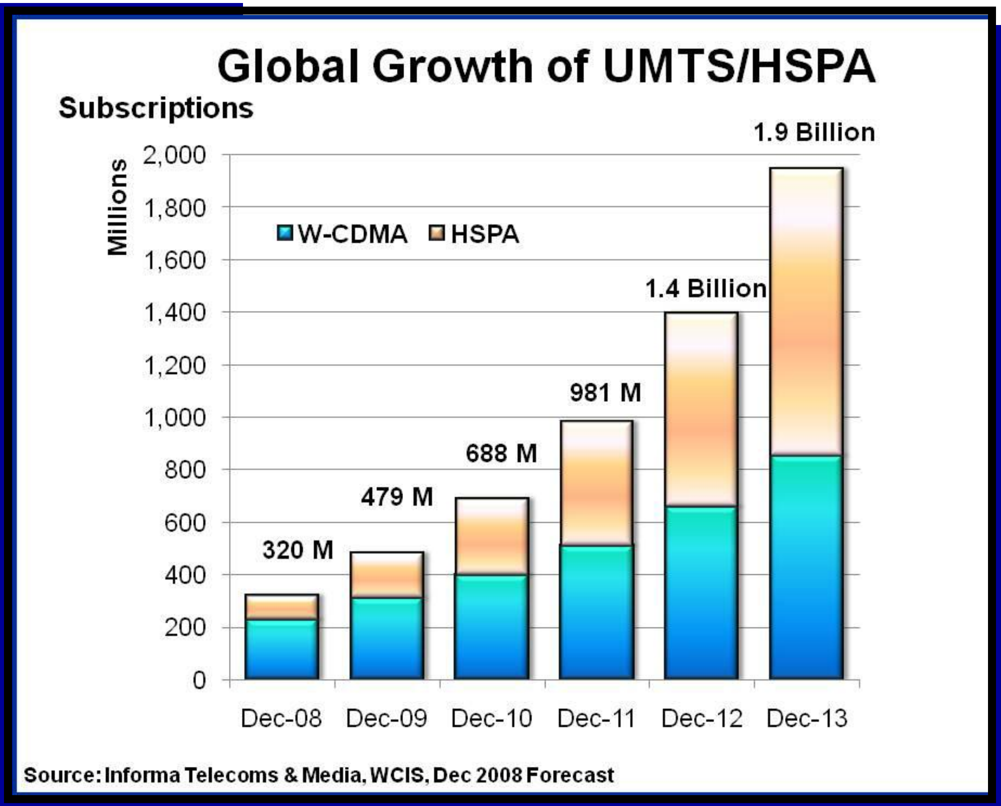
From "NICE TO HAVE" in 2/2.5G
to "MUST HAVE" in 3G



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

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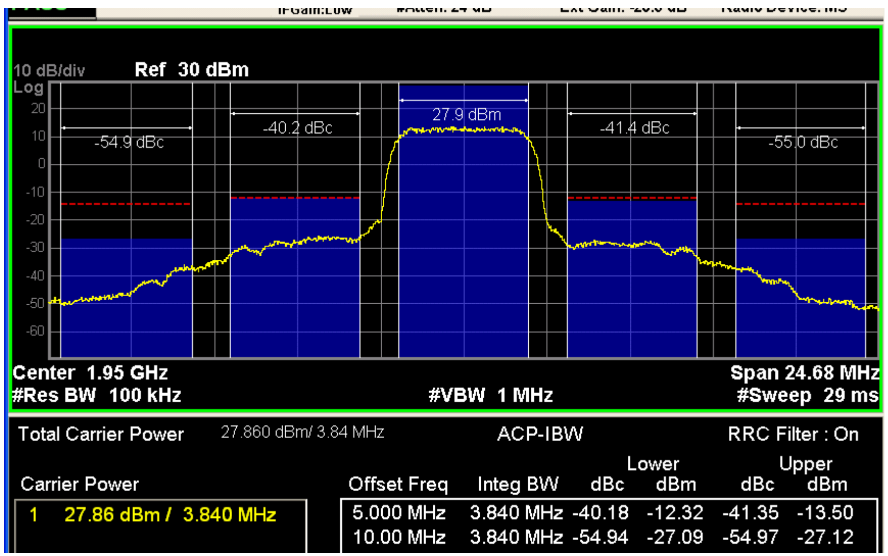
Increased RF Performance

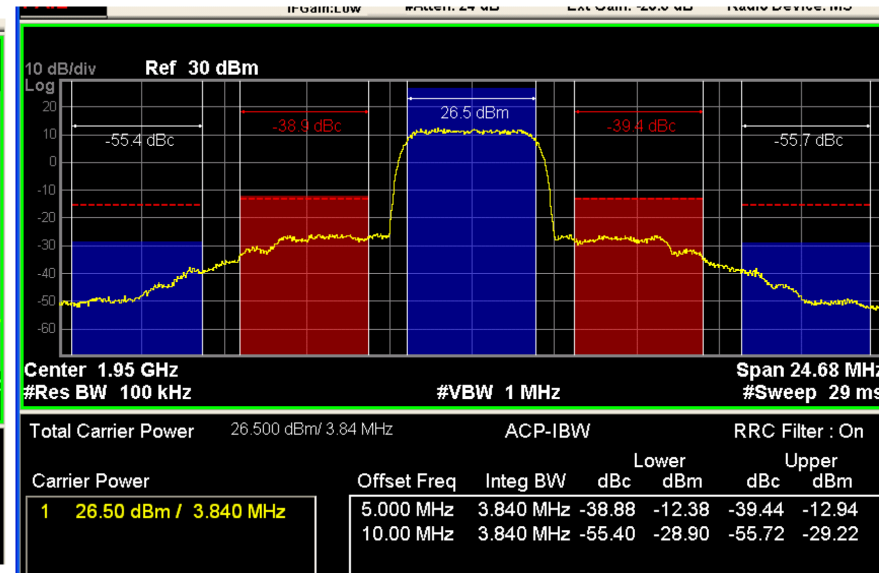
RF Spectral Constraints

- **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

RF Spectral Constraints





- **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**

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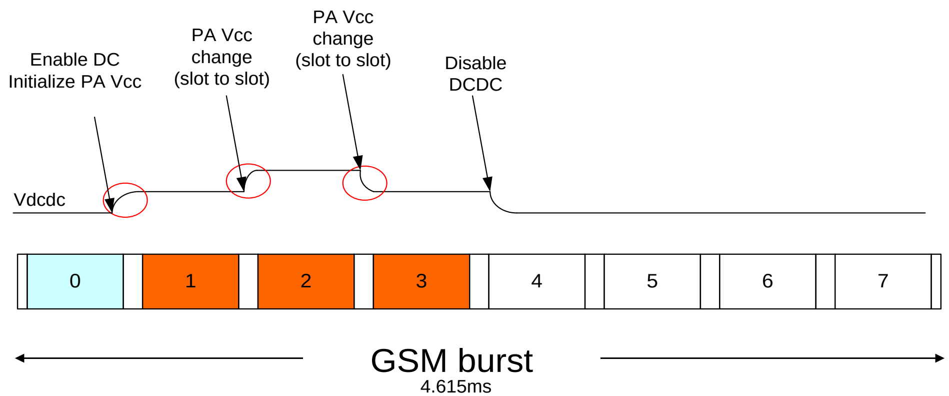
Transient Performance

RF Spectral Constraints

- **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

RF Noise

RF Spectral Constraints

- 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

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

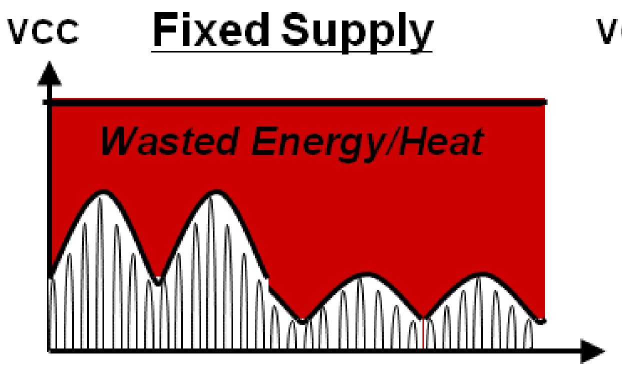
- Multi-mode PA support
- Smaller Switch Inductor
- Integrated Inductor

Transmitter Efficiency Improvements

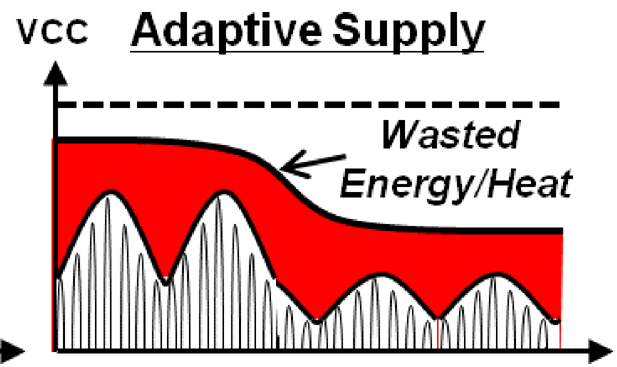
- **Transmitter Needs**
  - **Power amplifier efficiency is optimized for max P_{OUT}**
  - **Majority of time P_{OUT} is lower → PA is at poor efficiency**

Talk Time Improvement

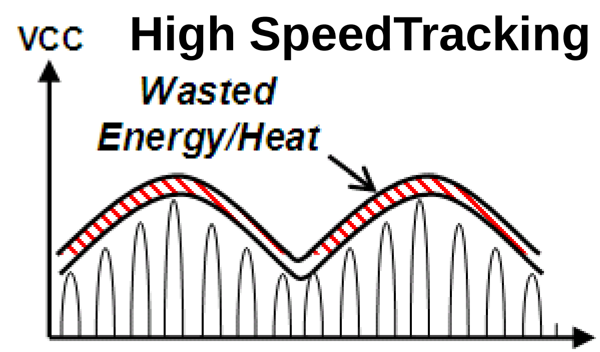
- **Variable Supply**
  - **Optimize supply voltage based on P_{OUT}**
  - **Improve PA efficiency at lower powers**



No Savings (Past)



40% Savings with DCDC

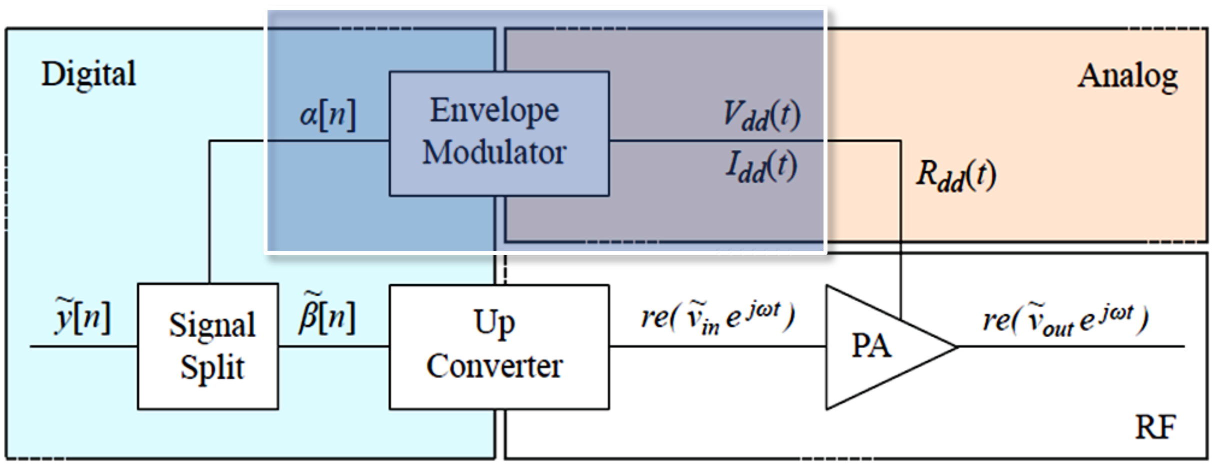


More Power Savings?

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

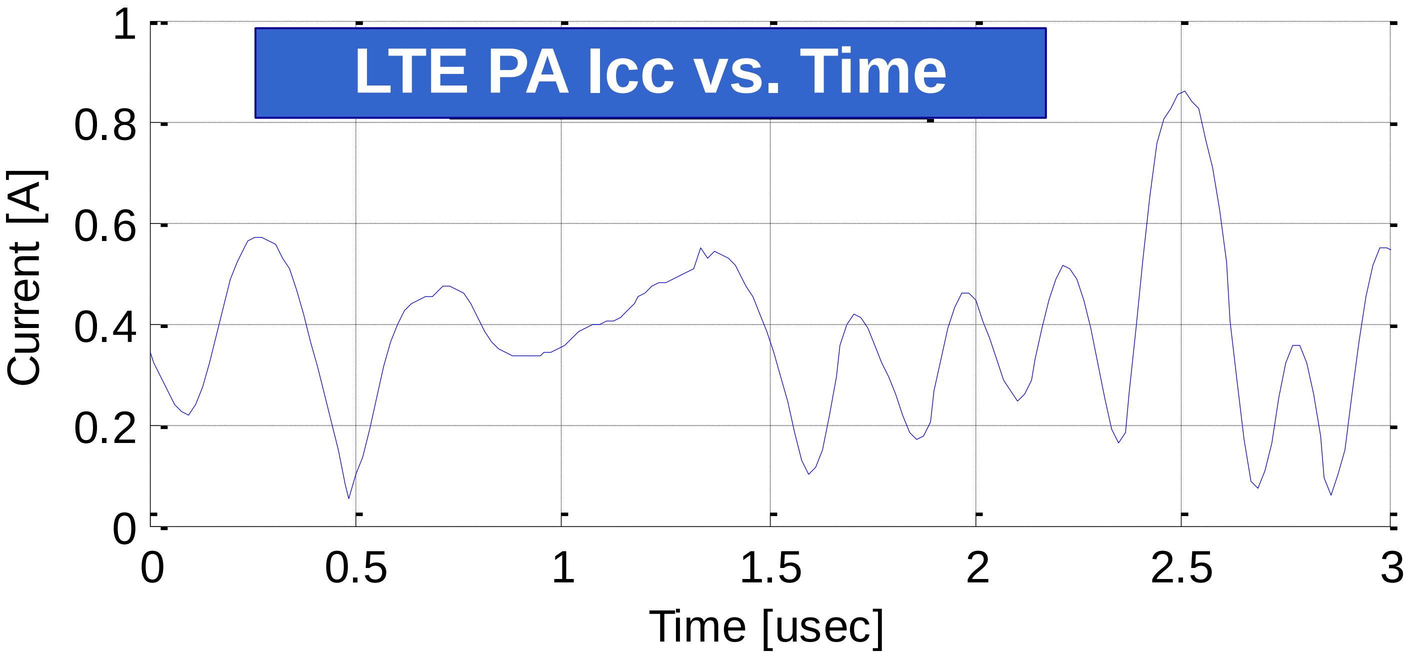
Talk Time Improvement



Envelope Tracking Modulator

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

Talk Time Improvement

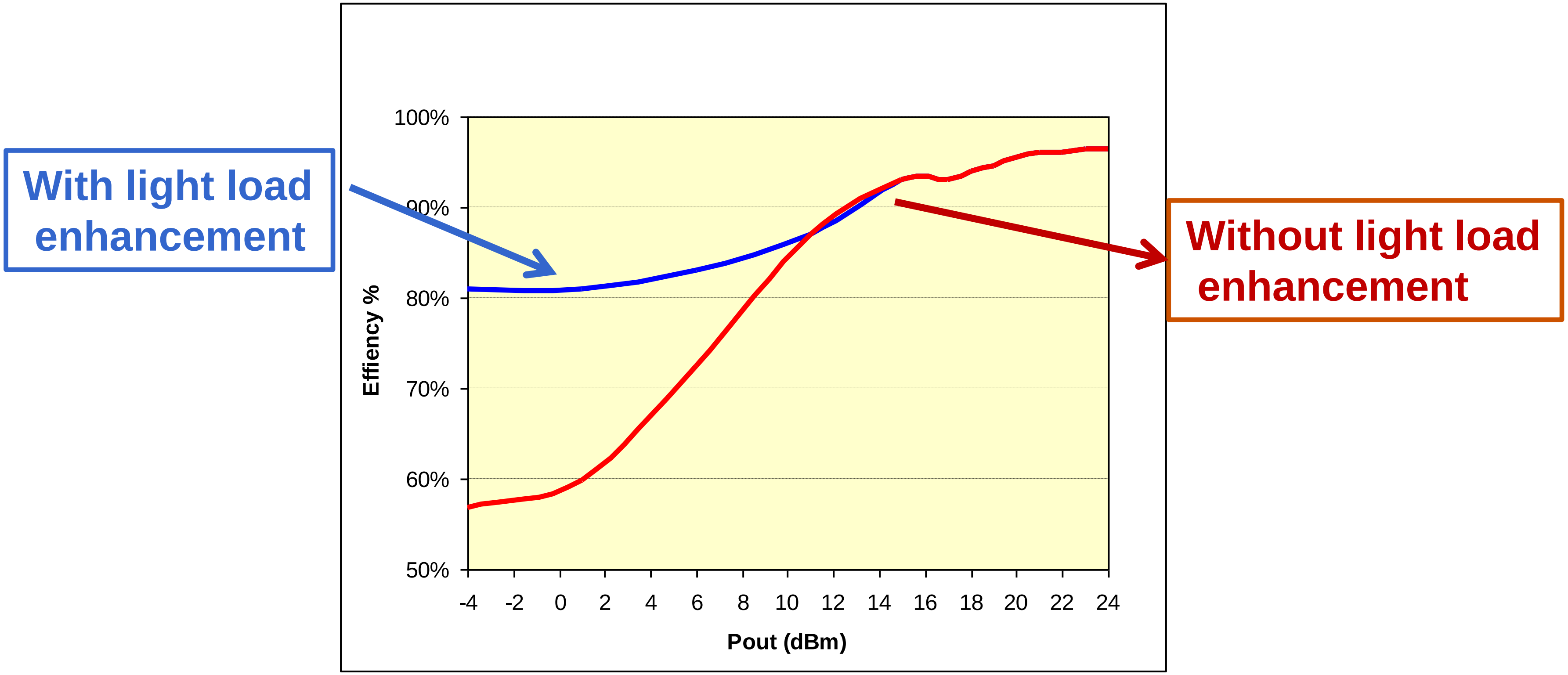


Light Load Performance Enhancement

Handset spends a lot of time at lower power levels

- Low Voltage, Low Current
- Traditional DCDC performance drops off at light loads

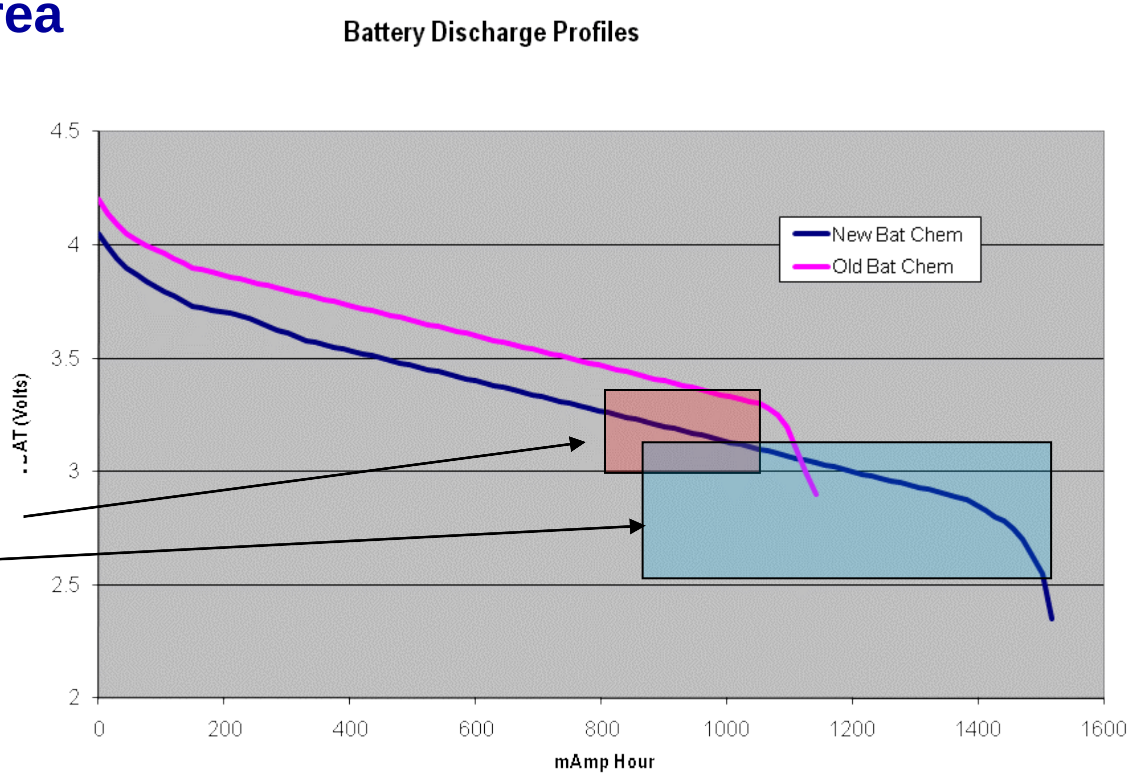
Talk Time Improvement



Wider Battery Operating Range

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

Talk Time Improvement



Extended RF spec compliant region of operation with Boost-Buck DCDC

RF Power Management Evolution in Mobile Devices

RF Performance Constraints	• Transmit Spectral Mask • Voltage Switching Transients • Low Supply Noise
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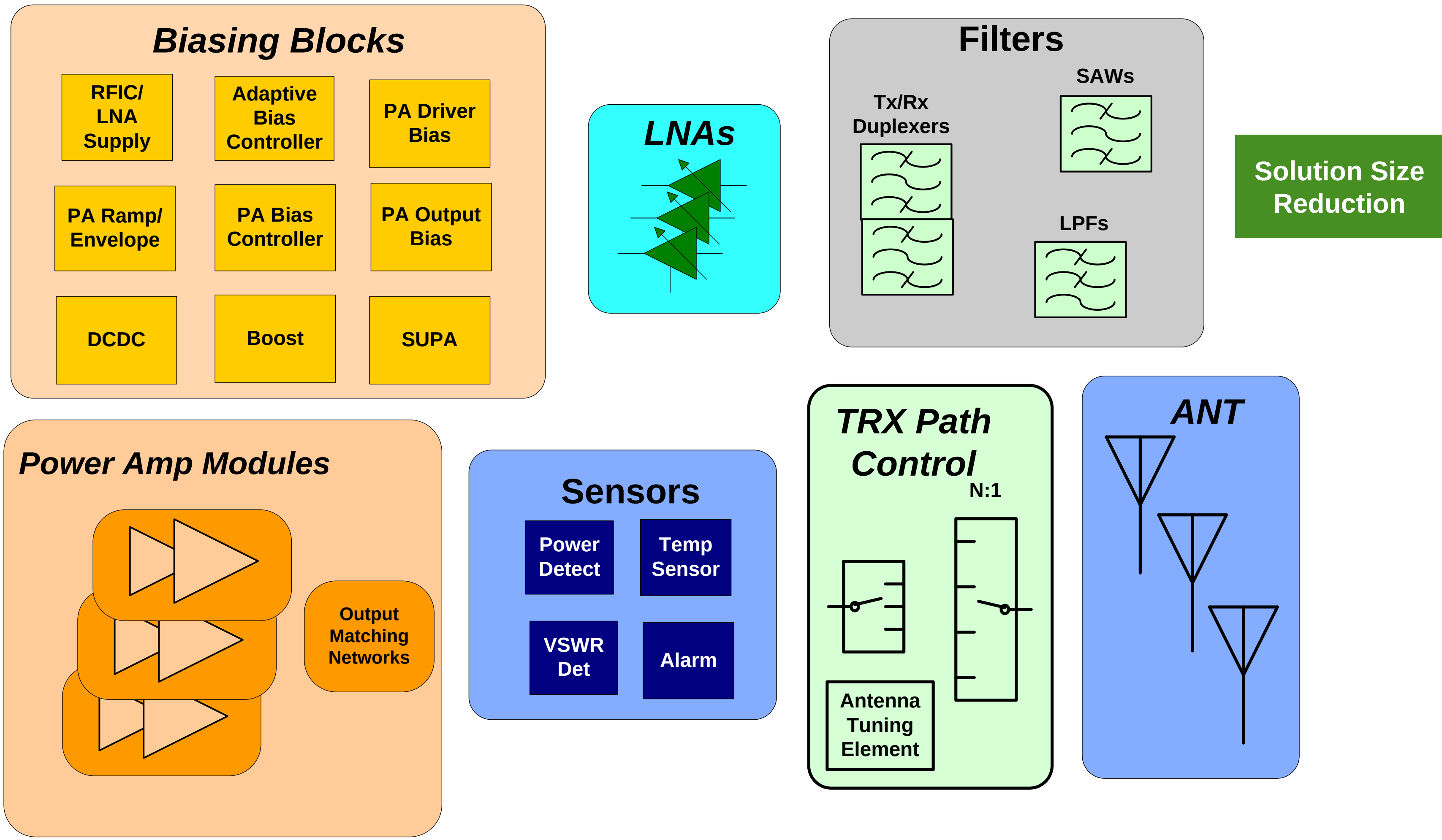
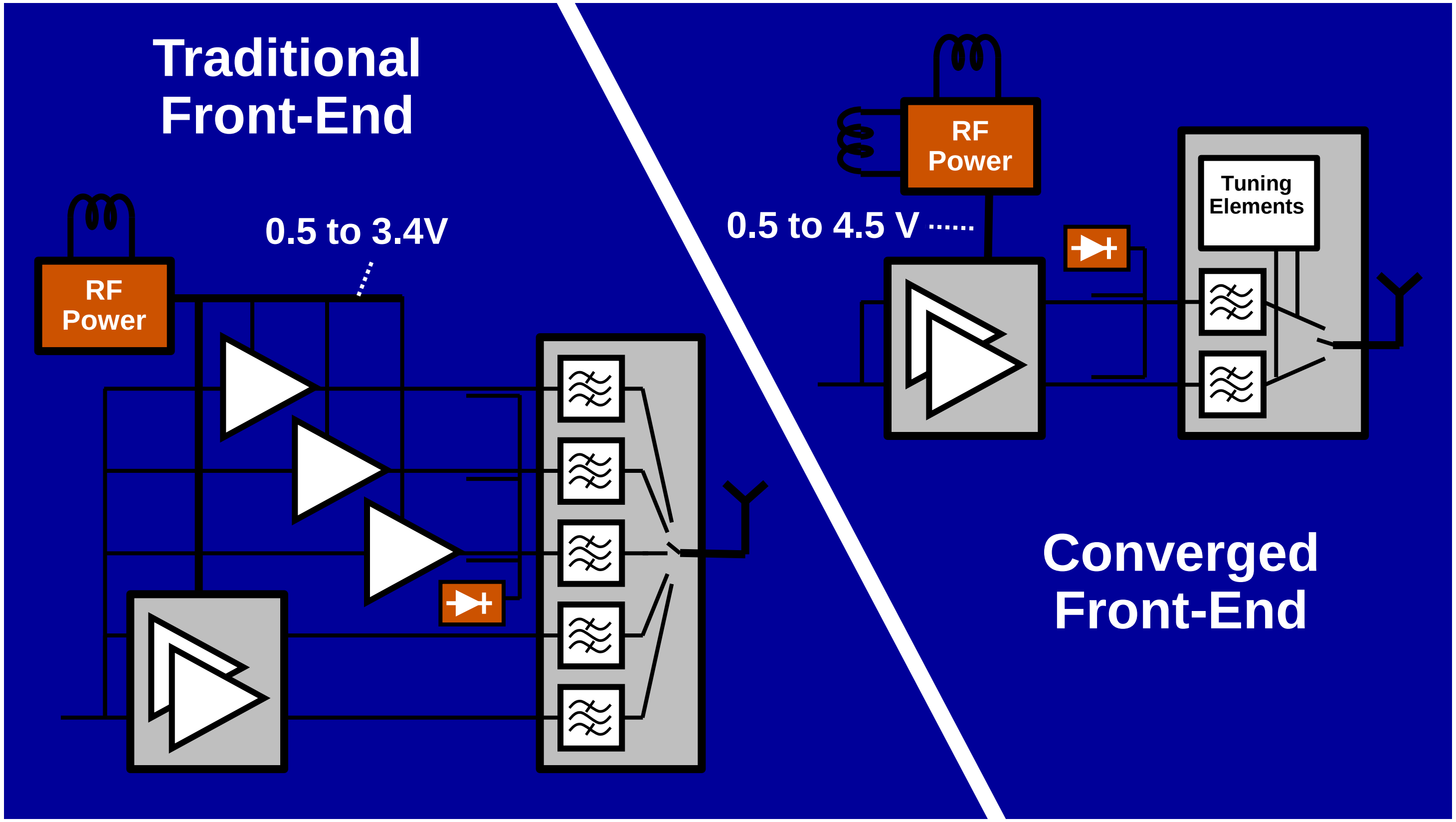
Solution Size Reduction	• **Multi-mode PA support** • **Smaller Switch Inductor** • **Integrated Inductor**

RF Front End Integration



Multi-mode PA Support

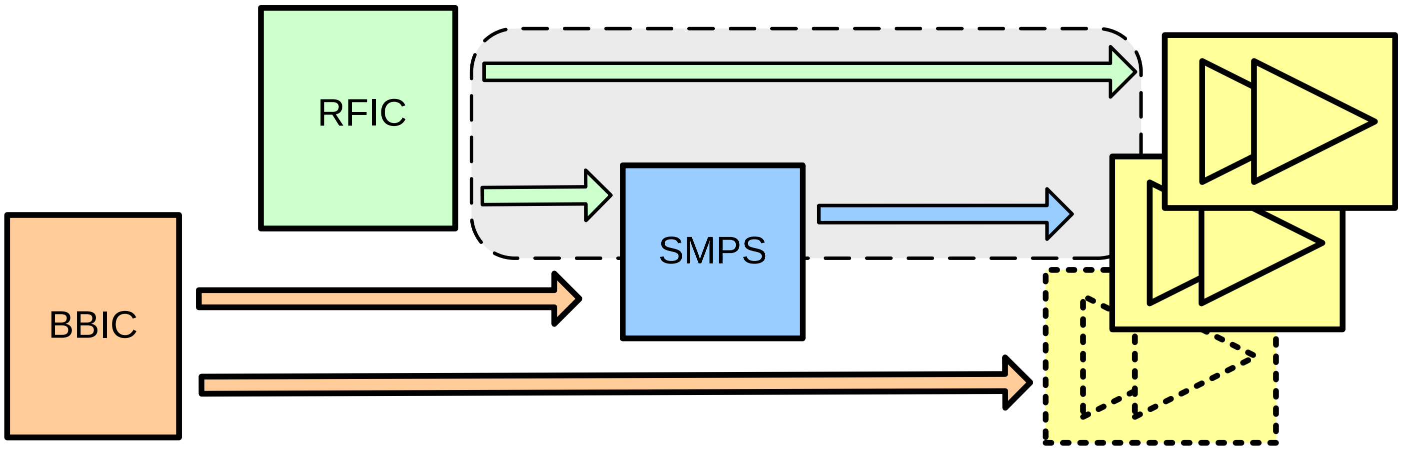


Solution Size Reduction

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.**

Solution Size Reduction

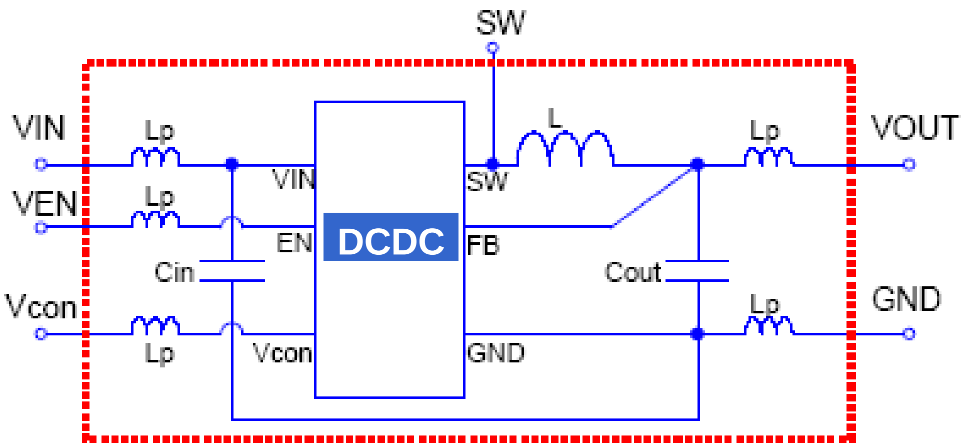


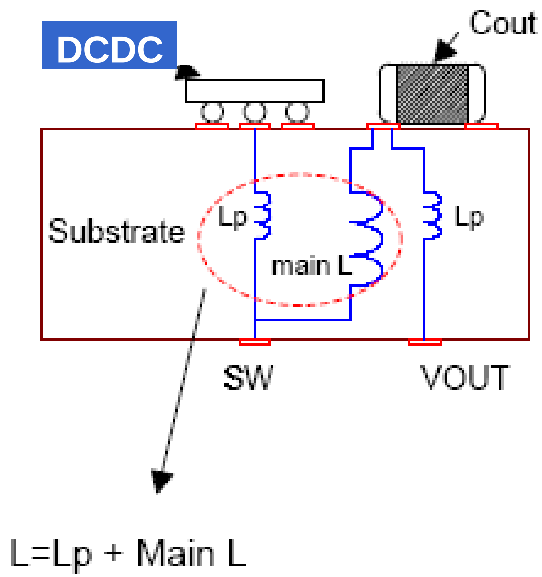
Reducing Switch Inductor Size

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

Solution Size Reduction

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





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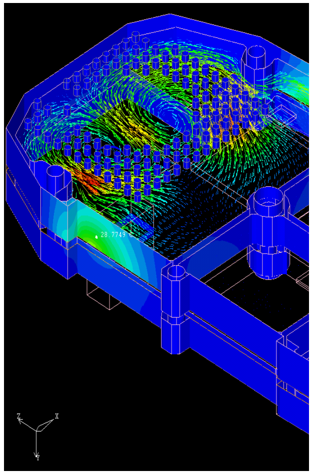
Conclusions/Challenges

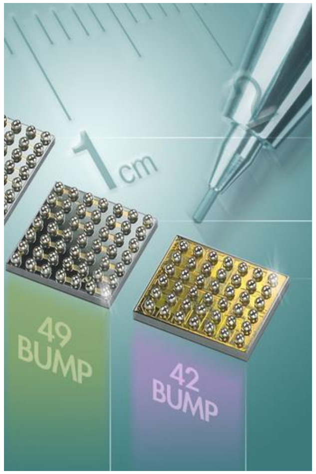
- **New Multi-mode Multi-band handsets are demanding higher and higher levels of performance**
- **Variable RF PA supply is required for next generation of slim trim and high data rate smartphones**
- **Maintaining RF noise performance with DCDC for PA is not trivial**

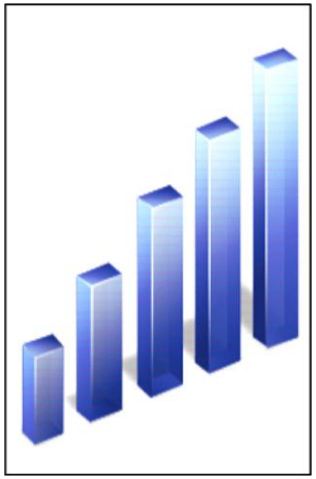
National's RF Front End Benefits

Measurable Benefits

Increased Usage Time	Decreased Thermal Emissions	Small Solution Size	Reduced BOM Cost	Increased Coverage Area
>25%	>20%	<10mm^2	>5%	>10%







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