Efficiency Enhancement of CDMA Power Amplifiers in Mobile Handsets Using Dynamic Supplies

Georgia Tech Analog Consortium Presentation

Biranchinath Sahu

Advisor: Prof. Gabriel A. Rincón-Mora

Analog Integrated Circuits Laboratory
School of Electrical and Computer Engineering
Georgia Institute of Technology
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Introduction

- **Power Amplifier (PA)**
  - Increases the power level of the RF signal
  - Consumes majority of power
- **CDMA and WCDMA use non-constant envelope modulation scheme**
  - Linear amplifier is used to minimize distortion and spectral re-growth
  - PA is operated at reduced power (back-off) to meet linearity
  - At back-off, efficiency degrades
- **Power Supply**
  - Supplies power to the PA, must be efficient

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CDMA Reverse link time domain signal

\[ P_{\text{in}} = 0 \text{ dBm (1mW)} \]
Power Amplifier Loading Profile

CDMA IS-95

Peak usage is at about 5 dBm = 3.16 mW
⇒ Optimize in the vicinity of the peak
⇒ PA must be efficient across wide loading conditions
⇒ Efficiency and linearity trade-off!

Power Amplifier Efficiency - Overview

Non-switching PAs
- Class A, AB, B, and C
- Output transistor behaves as a current source and output voltage is sinusoidal, or partially sinusoidal
- Loss is due to voltage and current overlap in the output transistor
- Linear but inefficient ⇒ Requires efficiency enhancement schemes

Switching PAs
- Class D, E, and F
- Mitigate the efficiency degradation by operating the output device as a switch
- Reduced voltage current overlap, more efficient
- Efficient but nonlinear ⇒ Needs a linearization scheme
- **Efficiency Insight**
  - Conduction loss – varies with load current
  - Switching loss – constant with load current, but varies with switching frequency
  - Light load efficiency is dictated by switching losses
- **Key to high efficiency**
  - Lower switching frequency ⇒ Lower switching losses
  - Variable switching frequency ⇒ Variable noise spectrum

- **Bandwidth (BW) is dependant on**
  - Power stage’s pole(s) and zero(s)
  - Error amplifier’s pole(s) and zero(s)
  - PWM circuit’s BW
  - Usually, the loop BW is one-tenth of the switching frequency, but it can be increased to one-fifth of the switching frequency
  - For increased loop BW, higher switching frequency ⇒ higher loss
Linearizing Non-linear PA

Kahn Envelope Elimination and Restoration (EER)

- DC-DC Converter Limitations
  - Bandwidth requirement
    - Converter closed loop BW has to be 4 times the baseband signal BW to meet the IMD requirements

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Baseband BW</th>
<th>Converter BW</th>
<th>Switching frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDMA IS-95</td>
<td>1.25 MHz</td>
<td>5 MHz</td>
<td>25 MHz</td>
</tr>
<tr>
<td>WCDMA</td>
<td>3.84 MHz</td>
<td>15.36 MHz</td>
<td>76.8 MHz</td>
</tr>
</tbody>
</table>

- Other Limitations
  - Delay mismatch between envelope signal and RF signal must be within 20 ns
  - Envelope detection and restoration of low power signals (-70 dBm)
  - Linearity of envelope detector
  - Limiter phase corruption
  - At present, this technique has been shown for 30 kHz baseband bandwidth applications only (NADC standard)

Envelope Follower

- Converter BW requirement, linearity of detector, delay mismatch limitations apply to this topology as well.

Power Tracking Power Amplifier

- Unlike envelope follower, the DC-DC converter only responds to the peak of the envelope, which is representative of the input power.
  - Converter BW need not be very high, lower switching frequency
  - Higher light load efficiency
  - Higher average efficiency
  - No delay line requirement
  - Power is lost in the valleys of the envelope
    - Possible improvements: Use Doherty PA
Using Doherty Configuration

- Main amplifier (normally class-B) supplies power during the majority of the envelope
- Auxiliary amplifier supplies power only during peak power requirements (class-C operation)
- Proper phasing of the two outputs is necessary
  ⇒ High efficiency across wide envelope range
  ⇒ Dynamic supply and bias for the amplifiers during power back-off


Comparative Evaluation

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>EER</td>
<td>Theoretically maximum efficiency can be obtained</td>
<td>- Large converter BW, higher switching frequency, inefficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Linearity of detector, phase distortion of limiter, delay mismatch</td>
</tr>
<tr>
<td>Envelope follower</td>
<td>Potentially efficiency is close to the peak PA efficiency</td>
<td>- Large converter BW, higher switching frequency, inefficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Linearity of detector, delay mismatch</td>
</tr>
<tr>
<td>Power Tracking</td>
<td>-DC-DC converter need not be fast, lower</td>
<td>- Peak efficiency may not be great (but,</td>
</tr>
<tr>
<td></td>
<td>switching frequency, efficient at light load</td>
<td>average efficiency is what matters for battery life)</td>
</tr>
<tr>
<td></td>
<td>- Simplest scheme</td>
<td></td>
</tr>
<tr>
<td>Power Tracking</td>
<td>-DC-DC converter need not be fast, lower</td>
<td>- Higher complexity</td>
</tr>
<tr>
<td>+Doherty</td>
<td>switching frequency, efficient at light load</td>
<td>- Power divider and combiner needs to be micro strip lines (on-chip components are lossy)</td>
</tr>
<tr>
<td></td>
<td>- High peak load efficiency as well</td>
<td></td>
</tr>
</tbody>
</table>

Summary

- Requirements for power amplifiers for the next generation CDMA/WCDMA mobile handsets
  - High efficiency across wide loading conditions
  - Linear to meet the ACPR requirements
- EER and Envelope follower are not suitable for CDMA handsets because of the high BW requirement of the DC-DC converter
  - High BW requires high switching frequency ⇒ Inefficient
- Power tracking dynamically adaptive supply scheme is the “best candidate” for improving efficiency of CDMA handsets
- Power amplifier using Doherty configuration with dynamic supply can further improve the efficiency
- Goal: System-on-chip integrated solution of the dynamically adaptive power supply and the PA

The End!