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

Georgia Tech Analog Consortium Presentation

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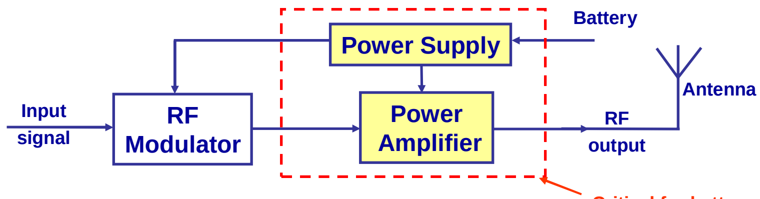
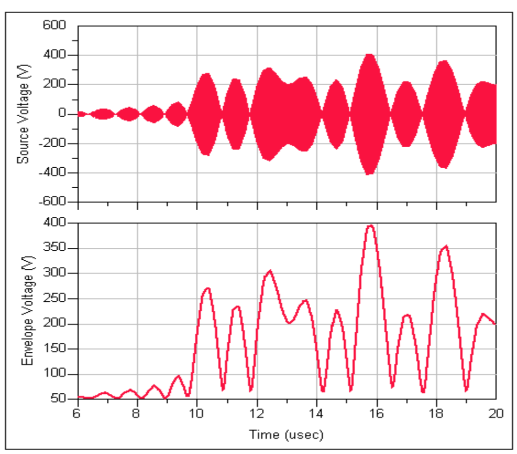
Introduction



- **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**

Introduction

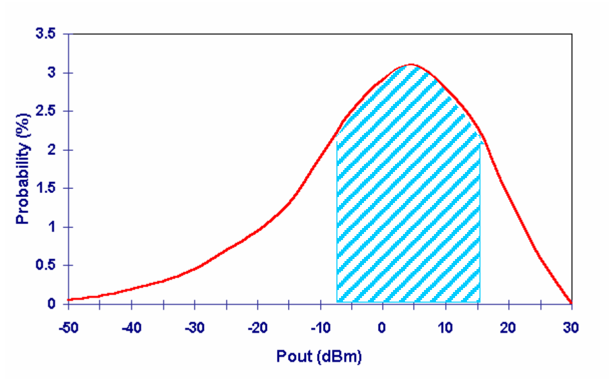


CDMA Reverse link time domain signal
P_{in}= 0 dBm (1mW)

- **Large peak to average ratio**
  - → **PA designed for peak power will be inefficient at the valleys**
  - → **Intuitively, goal should be to maintain high efficiency throughout**
  - ⇒ **Control the operation of the PA by following the envelope for all power levels**

Power Amplifier Loading Profile

CDMA IS-95



Peak usage is at about 5 dBm = 3.16 mW

$\Rightarrow$ **Optimize in the vicinity of the peak**

$\Rightarrow$ **PA must be efficient across wide loading conditions**

$\Rightarrow$ **Efficiency and linearity trade-off!**

Power Amplifier Efficiency - Overview

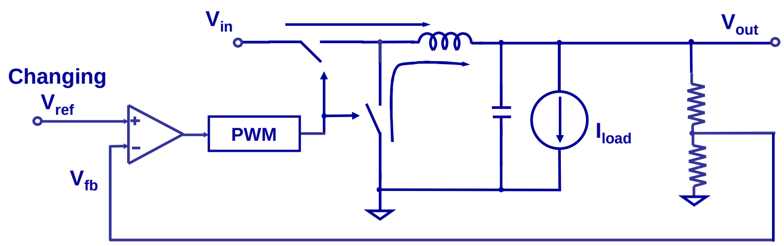
Non-switching PAs

- **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 $\Rightarrow$ Requires efficiency enhancement schemes**

Switching PAs

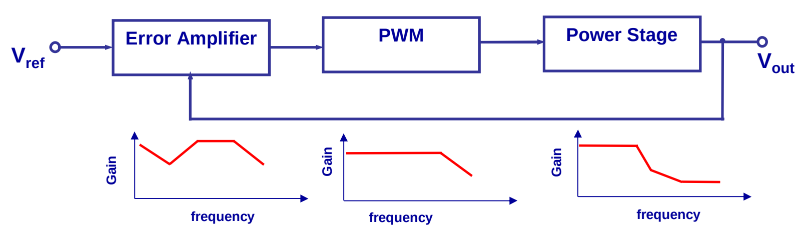
- **Class D, E, and F**
- **Mitigate the efficiency degradation by operating the output device as a switch**
- **Reduced voltage current overlap, more efficient**
- **Efficient but nonlinear $\Rightarrow$ Needs a linearization scheme**

Dynamic DC-DC Conversion



- 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

Dynamic DC-DC Conversion

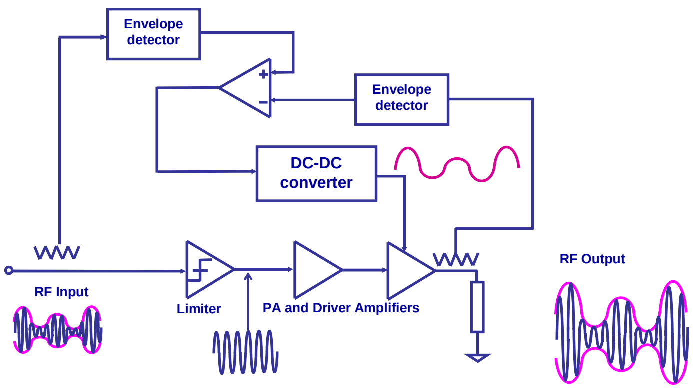


- Bandwidth (BW) is dependant on
  - Power stage's pole(s) and zero(s)
  - Error amplifier's pole(s) and zero(s)
  - PWM circuit's BW
- Usually, the loop BW is one-tenth of the switching frequency, but it can be increased to one-fifth of the switching frequency
- For increased loop BW, higher switching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

  ⇒ higher loss

Linearizing Non-linear PA

Kahn Envelope Elimination and Restoration (EER)



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Linearizing Non-linear PA

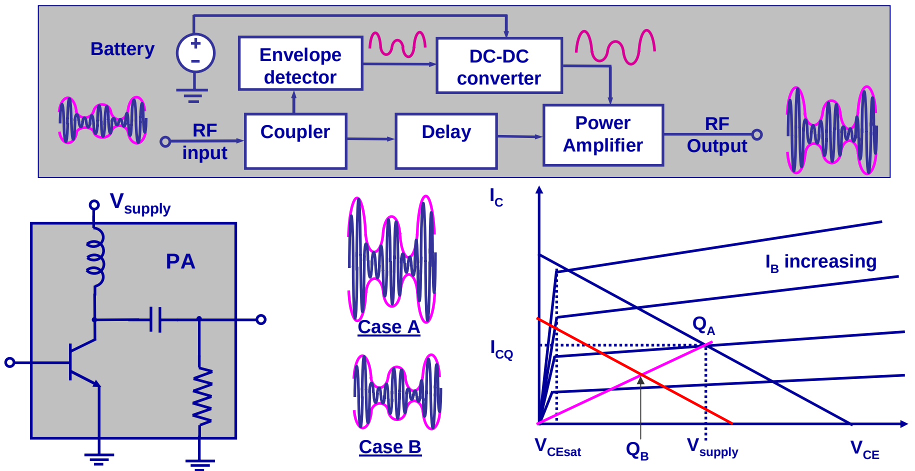
- DC-DC Converter Limitations
  - Bandwidth requirement
    - Converter closed loop BW has to be 4 times the baseband signal BW to meet the IMD requirements*

Scheme	Baseband BW	Converter BW	Switching frequency
CDMA IS-95	1.25 MHz	5 MHz	25 MHz
WCDMA	3.84 MHz	15.36 MHz	76.8 MHz

- 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)

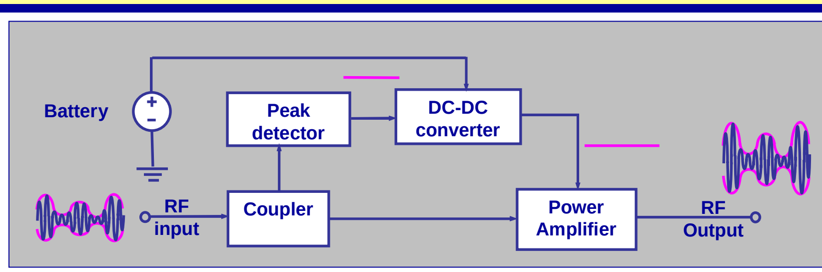
*F.H. Raab, "Intermodulation in Kahn-Technique Transmitters", *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, no. 12, pp. 2273-2278, December 1996.

Envelope Follower



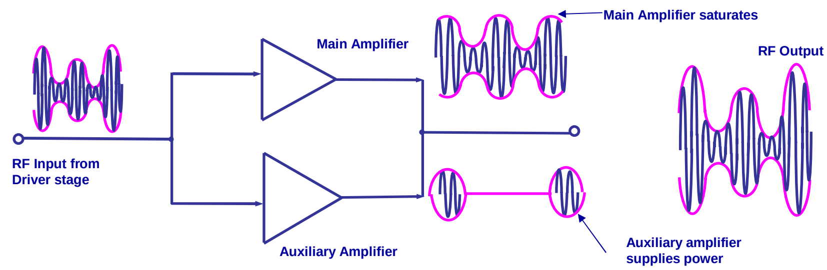
- Converter BW requirement, linearity of detector, delay mismatch limitations apply to this topology as well

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

*W.H. Doherty, "A new high efficiency power amplifier for modulated waves",*Proceedings of the Radio Engineers*, vol. 24, no. 9, pp.1163-1182, September 1936.

Comparative Evaluation

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

*A. Shirvani, D.K. Su, and B.A. Wooley, "A CMOS RF power amplifier with parallel amplification for efficient power control", *IEEE Journal of Solid-State Circuits*, vol. 37, no. 6, pp. 684-693, June 2002.

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 !