A Dynamically Adaptive, Power Management IC for WCDMA RF Power Amplifiers in Standard CMOS Process

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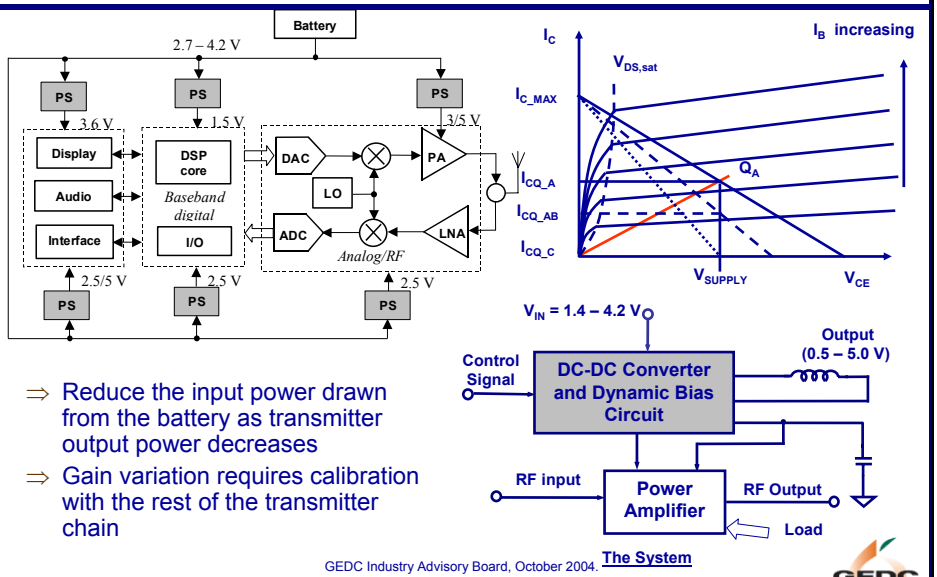
GEDC

Abstract

- Energy-efficient, linear RF power amplifiers are *critical* and *paramount* to achieve *longer battery life* in state-of-the-art wireless handsets.
- In the proposed system, the energy-efficiency of a WCDMA RF PA is improved by dynamically adjusting the supply voltage and current as a function of its transmitted power.
- Key Features of the Power Management IC
  - Low voltage ⇒ Single cell operation (*Li-ion/NiCd/NiMH*)
  - Integrated ⇒ Except filter inductor, capacitor and compensation
  - High efficiency ⇒ Buck, Buck-boost, and Boost mode operation
  - Low quiescent power ⇒ PFM Mode at light load for better standby performance
  - Integrated dynamic gate(base) bias circuit
- 1.96 GHz, 3.84 MHz HPSK Modulation WCDMA RF PA
  - 25 dBm maximum output power
  - Less than –35 dBc/-58 dBc adjacent/alternate channel leakage ratio (ACLR)
  - Less than 10 % rms error vector magnitude (EVM)
  - More than ***seven times average efficiency improvement*** over fixed-supply class-AB PA

GEDC

High Efficiency WCDMA RF PA

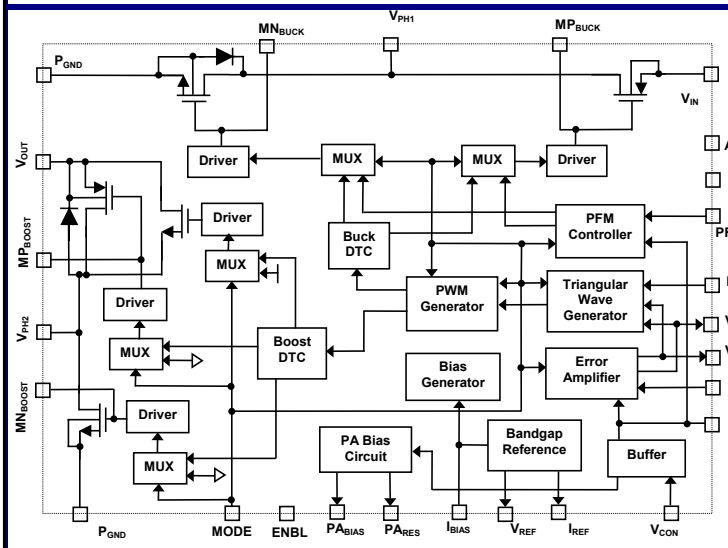


⇒ Reduce the input power drawn from the battery as transmitter output power decreases

⇒ Gain variation requires calibration with the rest of the transmitter chain

The System

Block Diagram of the Chip



⇒ Integrated Power FETS

⇒ Dual-mode, noninverting buck-boost converter for high efficiency over wide loading conditions

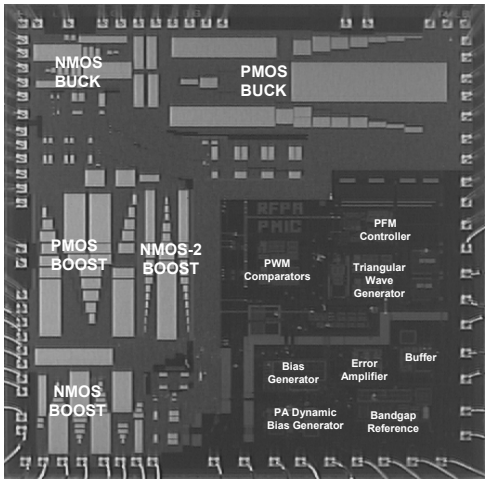
⇒ Voltage-mode PWM controller at high PA output power

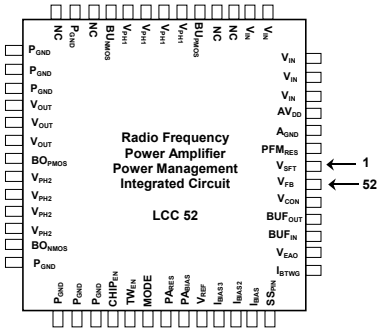
⇒ PFM controller at light loading conditions

⇒ Integrated bandgap reference

⇒ Integrated power amplifier dynamic bias circuit

Die Plot and Pin Diagram





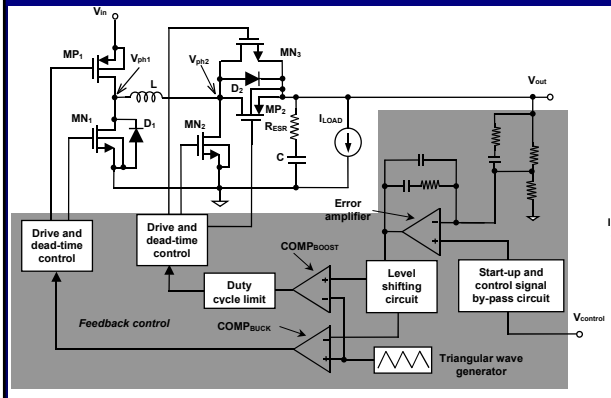
Only external components

⇒ **Power Inductor, output capacitor**

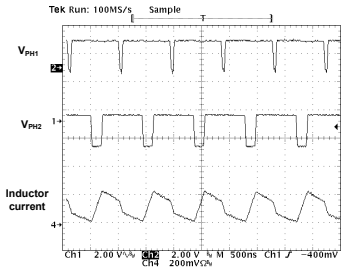
⇒ **Frequency compensation network**

⇒ **Input bulk capacitor**

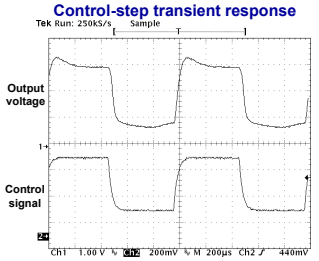
Buck-Boost Converter – PWM Mode



Intermediate buck-boost mode operation



Control-step transient response



Key features of the converter in PWM Mode

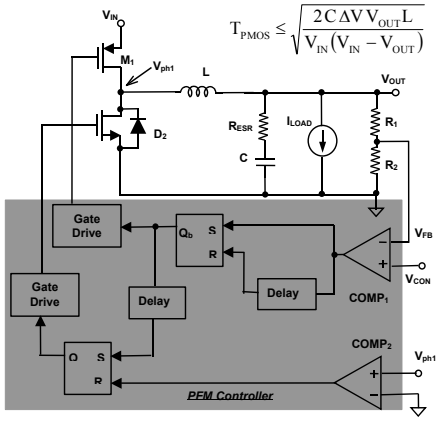
⇒ **Input supply range of 1.4 – 4.2 V**

⇒ **Output voltage 0.5 – 5 V with maximum load of 0.3 A**

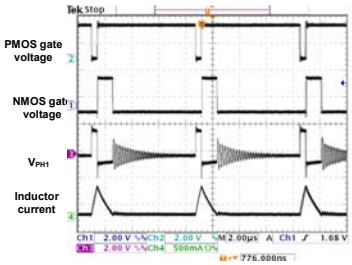
⇒ **Peak efficiency of 90 %**

⇒ **Worst-case peak-to-peak ripple of 90 mV**

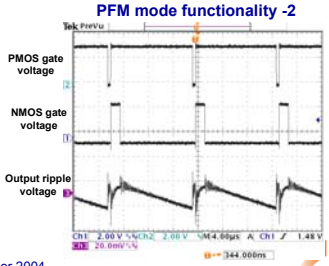
Buck-Boost Converter – PFM Mode



PFM mode functionality -1



PFM mode functionality -2

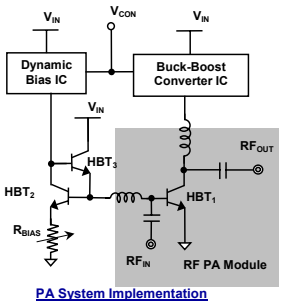


Key features of the converter in PFM Mode

⇒ **Adaptive on-time keeps peak-to-peak ripple voltage less than 25 mV over 1.4 – 4.2 V supply**

⇒ **Efficiency of 80 % at light load: 0.5 V with 50 mA load**

PA System – Experimental Results

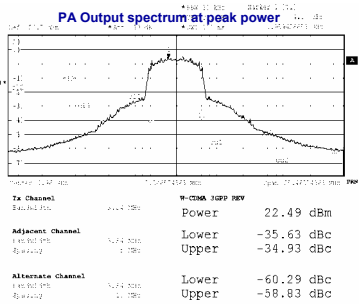


PA System Implementation

⇒ **Collector current in the PA stage is adjusted by varying R_{BIAS}**

⇒ **HBT_1 and HBT_2 can be easily implemented in an IC as current mirror**

PA Output spectrum at peak power



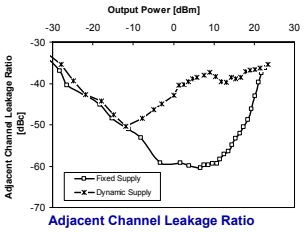
⇒ **Peak output power of 25 dBm**

⇒ **Class-AB operation at high output power**

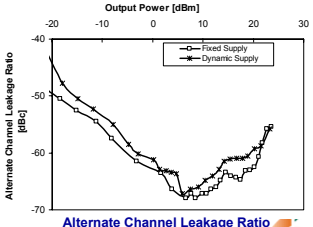
⇒ **ACLR 1 < -35 dBc throughout the output power range**

⇒ **ACLR 2 < -58 dBc**

⇒ **Degradation at lower power due to noise floor of the spectrum analyzer**

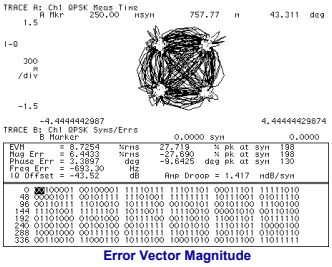


Adjacent Channel Leakage Ratio



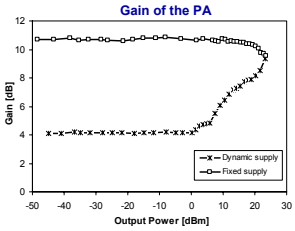
Alternate Channel Leakage Ratio

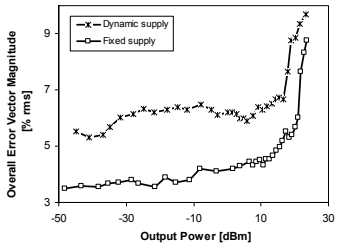
PA System – Experimental Results



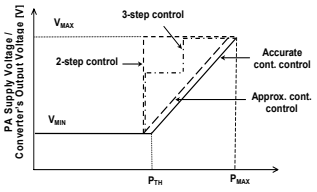
Error Vector Magnitude

- ⇒ Error vector magnitude less than 10 % throughout the output power range
- ⇒ EVM degradation with dynamic supply and bias current is due to output ripple voltage of the power supply





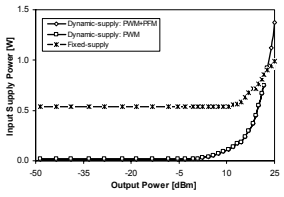
- ⇒ Gain variation from 4-dB to 10-dB with bias current adjustment
- ⇒ Open-loop look-up table based calibration with automatic gain control circuit to achieve the transmitter's output power dynamic range
- ⇒ Alternate: finite step control instead of continuous control

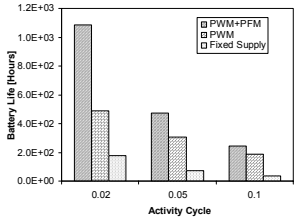


Battery Life Improvement

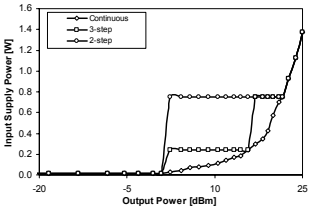
Battery life is dependant on the average efficiency over the period for which the PA is operational and standby power consumption of the system when the PA is in sleep mode.

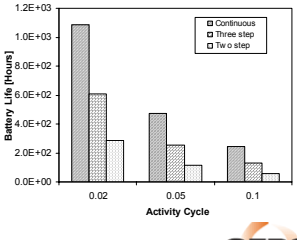
Activity Cycle = Active Mode / (Active Mode + Standby Mode)





- ⇒ If the PA remains operational all the time, there is no advantage of using dual-mode control
- ⇒ However, most portable applications remain in standby mode, and therefore lower quiescent current is desirable along with high efficiency over loading range
- ⇒ Efficiency in continuous 1-dB control in almost twice compared to 3-step control
- ⇒ Trade-off: complexity of calibration circuit and efficiency improvement





Summary

- **This work experimentally demonstrates the feasibility and potential battery life improvement in PA driven application using a power-tracking dynamically-adaptive supply voltage and bias current control scheme**
  - Nominal voltage and current at peak PA output power
  - Reduced supply and current as PA output power decreases
  - Power change (1dB in 666 μsec) is slower than envelope (3.84 MHz)
    - Low bandwidth power supply ⇒ High efficiency
- **High efficiency buck-boost power supply IC with**
  - Dual-Mode operation (PWM+PFM)
  - Minimum input supply of 1.4 with nominal V_{TP} = 0.95 V, V_{TN} = 0.75 V
  - Adaptive on-time control for accurate peak-to-peak ripple – critical for PA

Conclusion: Design, Implementation, and experimental validation of a novel, integrated buck-boost supply and dynamic biasing circuit for high efficiency, WCDMA RF PAs in a standard CMOS process