

# Reconfigurable RF Power Amplifiers on Silicon for Wireless Handsets

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# Reconfigurable RF Power Amplifiers on Silicon for Wireless Handsets

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# Preface

The design of power amplifiers (*PA*) for wireless applications has been a topic of great concern among the scientific community in electronics since the early 1990s. Power amplifiers dominantly determine the power efficiency and battery lifetime of modern mobile terminals. *PA* linearity is a key feature that limits the maximum allowed data rate of a radio link. The deployment of always more complex radio networks with a continuously growing throughput sharpens the specifications of power amplifiers. The market of wireless handsets (cellular phones, . . .) pushes manufacturers towards multi-standard capabilities (3G, Bluetooth, *WIFI*) and a growing level of integration. The *Bill-of-Material* and the consumed die area that are affordable are constantly reduced for cost purpose. The trade-offs that are inherent to *PA* design are therefore extremely stringent and no technical/technological solution can unanimously be regarded as a definitive contribution. To this date, the market of handset-dedicated power amplifiers is widely dominated by *III/V* technologies. However, throughout the following pages, we will try to highlight the benefits of *PA* integration on silicon. The architectures that will be proposed hereunder take advantage of silicon capabilities and strength, among others their relatively low cost and their ability to combine high power devices with low-power analog/digital control circuitry.

[Chapter 1](#) will first present the respective features of 2nd and 3rd generation cellular applications (*GSM*, *DCS*, *EDGE*, *WCDMA*. . .) and data transmission standards (*WIFI*, *WIMAX*, *LTE*). An overview of the most commonly employed *RF* power amplifier topologies will also be provided, with their advantages and drawbacks. Finally, the 0.25  $\mu\text{m}$  *BICMOS* ST Microelectronics technology will be described and compared with *III/V* processes in the prospect of *PA* development. The fundamental features of power devices will be detailed and the most appropriate technological choice prior to the *PA* design itself will be discussed.

In [Chapters 2](#) and [3](#), several novel *PA* topologies will be proposed and discussed in terms of efficiency, linearity and complexity by means of mixed system/transistor-level analyses. [Chapter 2](#) will investigate three novel switched-mode power amplifier topologies. The first non-constant-gain principle is based on the power stage bypass/extinction and applied to a silicon *HBT* demonstrator. A silicon *HBT* demonstrator that was developed in the frame of *RNRT ASTURIES* project will be

presented. The other two topologies were proposed in the frame of the European Medea+ *UPPERMOST* project and deal with the dynamic control of a fragmented reconfigurable multi-cell power stage. First, open-loop power stage control will be considered. In this topology, power detection is carried out by a specifically dedicated digital  $\Delta\Sigma$  *Built-In Current Sensor* whose behavior will be detailed. Second, a closed-loop power stage control system will be addressed and compared with the open-loop power stage control.

Lastly, [Chapter 3](#) will describe a *PA Module* that was developed in the frame of the European *FP6 MOBILIS* project. Furthermore, some mathematical developments and vector illustration will explain the theory of a continuously and dynamically power adaptive system that aims to combine linearity and efficiency even at low power levels. Moreover, frequency-dependent memory effects will be introduced in order to provide some further insight in the complex non-linear phenomenon's that may alter the behavior of power amplifiers operating at wide channel bandwidths. An illustration of memory effects will be provided in the experimental section of this chapter. A *PA module demonstrator* based on integrated silicon and passive network dice will be presented, both in a stand-alone mode and in association with the other blocks of the *MOBILIS* transceiver. The final discussion will validate the proposed efficiency/linearity improvement principle under some conditions of channel bandwidth.

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# Abbreviations

## A

<i>ACLR</i>	Adjacent Channel Leakage Ratio
<i>ADC</i>	Analogue to Digital Converter
<i>AGC</i>	Automated Gain control
<i>AM/AM</i>	(Input) Amplitude to (output) Amplitude conversion
<i>AM/PM</i>	(Input) Amplitude to (output) Phase conversion

## B

<i>BAW</i>	Bulk Acoustic Wave (resonator)
<i>BER</i>	Bit Error Rate
<i>BICS</i>	Built-In Current Sensor
<i>BOM</i>	Bill Of Material
<i>BPSK</i>	Binary Phase Shift Keying
<i>BV</i>	Breakdown Voltage
<i>BV<sub>CE</sub></i>	Collector/Emitter breakdown voltage
<i>BV<sub>CB</sub></i>	Collector/Base breakdown voltage
<i>BV<sub>DS</sub></i>	Drain/Source breakdown voltage

## C

<i>CCDF</i>	Complementary Cumulative Distribution Function
<i>CDMA</i>	Code Division Multiple Access
<i>CHE</i>	Channel Hot-Electron injection
<i>CMFB</i>	Common-Mode Feed-Back
<i>COB</i>	Chip on Board
<i>CW</i>	Continuous-Wave

## D

<i>DAC</i>	Digital to Analogue Converter
<i>DACH</i>	Drain Avalanche Hot Carrier injection

<i>DCS</i>	Digital Communication System
<i>DPCCCH</i>	Dedicated Physical Control Channel
<i>DPDCH</i>	Dedicated Physical Data Channel
<i>DSP</i>	Digital Signal Processing
<i>DUT</i>	Device Under Test

**E**

<i>EDGE</i>	Enhanced Data rates for <i>GSM</i> Evolution
<i>EER</i>	Envelope Elimination and Restoration
<i>ET</i>	Envelope Tracking
<i>EVM</i>	Error Vector Magnitude

**F**

<i>FBI</i>	Feed-Back Information
<i>FCC</i>	Federal Communications Commission (USA)
<i>FDD</i>	Frequency Division Duplex

**G**

<i>GBW</i>	Gain×Bandwidth product
<i>GMSK</i>	Gaussian Minimum-Shift Keying
<i>GPRS</i>	General Packet Radio Service
<i>GSM</i>	Global System for Mobile communications

**H**

<i>HEMT</i>	High Electron Mobility Transistor
<i>HBT</i>	Hetero-junction Bipolar Transistor
<i>HICUM</i>	High Current transistor Model
<i>HPSK</i>	Hybrid Phase Shift Keying
<i>HS-DPDCH</i>	High-Speed Dedicated Physical Data Channel
<i>HSUPA</i>	High-Speed Uplink Packet Access

**I**

<i>IF</i>	Intermediate Frequency
<i>IMD<sub>3</sub></i>	3rd order Inter-Modulation Distortion
<i>IPD</i>	Integrated Passive Device
<i>ISI</i>	Inter-Symbol Interference

**L**

<i>LDD</i>	Lateral Lightly Doping
<i>LDMOS</i>	Laterally Doped MOSFET
<i>LINC</i>	Linear amplification with Non-linear Components
<i>LNA</i>	Low Noise Amplifier
<i>LO</i>	Local Oscillator
<i>LOCOS</i>	LOCAl Oxidation of Silicon

**N**

<i>NF</i>	Noise Figure
<i>nodeB</i>	Base Station
<i>NTF</i>	Noise Transfer Function

**O**

<i>OCP<sub>1</sub></i>	1 dB Output Compression Point
<i>OED</i>	Oxidation Enhanced Diffusion
<i>OFDM</i>	Orthogonal Frequency Division Multiplexing
<i>OIP<sub>3</sub></i>	3rd order Output-referred Intercept Point
<i>OSR</i>	Over-Sampling Ratio

**P**

<i>PA</i>	Power Amplifier
<i>PAE</i>	Power Added Efficiency
<i>PAPR</i>	Peak-to-Average Ratio
<i>PCB</i>	Printed Circuit Board
<i>PLL</i>	Phase-Lock Loop
<i>PSK</i>	Phase-Shift Keying
<i>PWM</i>	Pulse Width Modulation

**Q**

<i>QAM</i>	Quadrature Amplitude Modulation
<i>QOS</i>	Quality of Service
<i>QPSK</i>	Quadrature Phase Shift Keying

**R**

<i>RNRT</i>	Réseau National de Recherche en Télécommunication (French National Research Network in Telecommunication)
<i>RRC</i>	Root Raised Cosine

*RSSI* Received Signal Strength Indicator  
*RX* Reception path

## **S**

*SIP* System in Package  
*SNR* Signal-to-Noise Ratio  
*SNDR* Signal-to-Noise/distortion Ratio  
*SOI* Substrate on Isolator  
*STF* Signal Transfer Function  
*STI* Shallow Trench Isolation

## **T**

*TDD* Time Division Duplex  
*TDMA* Time Division Multiple Access  
*TFCI* Transport Format Channel Information  
*TPC* Transport Power Control  
*TQFP* Thin Quad Flat Pack  
*TX* Transmission path

## **U**

*UE* User Equipment

## **V**

*VCO* Voltage-Controlled Oscillator  
*VGA* Variable-Gain Amplifier  
*VSWR* Voltage Standing-Wave Ratio

## **W**

*WCDMA* Wide-band Code Division Multiple Access  
*WIMAX* Worldwide Interoperability for Microwave Access  
*WLAN* Wireless Local Area Network