First Integrated Bipolar RF PA Family for Cordless Telephones

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Abstract

A 400-600mW 900MHz-2.5GHz RF power amplifier family for ISM/DECT/WLL applications is presented. All PAs are balanced and realized using standard 26GHz bipolar technology which eases system integration for future products. They include additional functions, such as power ramping, antenne switch driver, supply and temperature compensation, not realized in common GaAs technologies.All amplifiers operate between 3 and 4.5V and are mounted in a TSSOP10 package.

Keywords: RF Power Amplifier, Balanced Amplifier, DECT, ISM, Silicon Bipolar IC-Technology; Modeling

1. Introduction

Due to the introduction of the DECT standard (Digital Enhanced Cordless Telephone) in Europe the market for cordless telephones has changed dramatically, from older analogue CT1 designs to new digital telephones. For the world market, especially in the US, similar standards have been defined, using the ISM band (Industrial Scientific Medical). Now related products also enter the market, not only pure telephones, but also WLL applications. The transition to the new technology is of course more related to the CMOS base band chip set, but also in the RF part the level of integration is much higher than few years ago. However up to now the power amplifier was realised in a still very discrete way. The main design constraint here is to achieve about 27dBm of output power P_{out} in the frequency band from 1880 to 1900MHz (DECT, 24dBm are required at the antenna, but there is some loss due to antenna switch and bandpass filter, for ISM up to 1W at the antenna is possible) with a high power added efficiency PAE. The high PAE is needed to achieve a large talk time for a given battery charge. This has often been achieved by using either discrete bipolar transistors (disadvantage: high component count) or integrated GaAs MMICs on the basis of MESFETs (disadvantage: need for an additional negative supply and an external high-current supply switch). The task of building a transceiver and the RX front-end using a standard bipolar technology is already solved by many companies [e.g. 1], but it seems to be more critical for PA´s. Package parasitics, substrate coupling and breakdown voltage, but also limited design methods (figure 1 and table 2) and the need for a high PAE are the main reasons [2-5]. In spite of these problems there are good reasons to use a standard Silicon technology. Inherent Si IC advantages are small size, very low costs, high volume availability, but many other features may be implemented by designers to further reduce costs and component count, e.g. integrated power ramping, power selection, extra outputs for driving the PIN diode antenna switch or even the LNA and the switch itself. Another design goal for the PA family was to achieve good RF performance in a wide range of temperature and supply voltage even in the presence of production tolerances.

2. Realization

All integrated PAs were build using the same 26GHz B6HF technology also used for standard RF IC´s. The balanced topology was choosen due to the lack of good RF packages. With a balanced PA a linear gain of about 30-40dB, a PAE of 35-45% and 45dB forward isolation was achieved for a two-stage design in a standard TSSOP10 package (see table 1). A similar single-ended design will need either on-chip vias (expensive), flip-chip (maybe a future option, but testing and application are critical) or a three-stage amplifier (stability problems [6]). If you want to integrate more functionality the balanced configuration has also the advantage of lower substrate and package noise, e.g. one redesign was needed due to substrate coupling from the RF stages to the bandgap circuitry and due to a long logic line crossing sensitive chip areas influenced by the RF output. Also biasing via current mirrors becomes much easier because there is a virtual ground, so the influence of the RF stages to the biasing circuitry is further reduced. In the balanced PAs we use symmetrical coils with center tap for the interstage match to decrease size and to increase quality factor and resonance frequency [7]. An IC technology gives also the advantage to implement precision analog building blocks e.g. to control the bias currents of the RF stages. This is important because a well-controlled output power is a primary demand for any RF PA. To minimize component tolerances and to adjust the output power a single external resistor is used in conjunction with the internal bandgap for biasing the RF stages. The Widlar bandgap was modified with an additional resistor to achieve a certain temperature coefficient to compensate the negative TC of the two RF stages (due to reduction of transconductance and transition frequency vs temperature). Another major influence is the supply voltage. Normally there is a strong increase in P_{out} for an increasing supply voltage V_{CC}. Inspite of a varying V_{CC} (due to tolerances or battery discharge) system designers need a constant output power. Therefore the internal biasing circuitry was modified to give a approximately constant output power by reducing the bias currents at higher supply voltages. Ten pins are not too much for an IC design, but there are still some free pins which allows more functionality and to decrease the total system component count. To simplify the application all ICs include the power ramping (adjustable with an external capacitor), a logic controlled output power selection (e.g. between 27 and 19dBm) and a driver pin for an PIN diode antenna switch (figure 2).

3. Summary and Outlook

The PAs presented show a state-of-the-art RF performance, comparative with actual GaAs MESFET MMIC designs only outperformed by some HEMT designs. Recently there is a trend to further reduce the supply voltage down to 2.4V (two NiCd cells). Some GaAs MMICs are known which are already able to operate down to 2V, so future low-voltage Si PAs are under development using 70GHz-SiGe B7HF technology. A further outlock is the integration of the front-end switch [8] - maybe with the complete transceiver - to realize more compact RF systems. But for now this will be focussed on more low-end applications like Bluetooth or remote controls. Improved design tools (e.g. with large signal optimization) and simulation models (espacially for substrate, package and transistor breakdown) are needed to make the design flow faster and more accurate.

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[2] E.O. Johnson, ”Physical Limitations on Frequency and Power Parameters of Transistors”, *RCA Review*, Vol. 26, June 1965

[3] J.R. Long, M.A. Copeland, ”The Modeling, Chracterization, and Design of Monolythic Inductors for Silicon RF IC´s”, *IEEE Journal of Solid-State Circuits*, Vol. 32, No. 3, March 1997, p. 357ff

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[6] S.L. Wong, ”A 1W 830MHz Monolythic BiCMOS Power Amplifier”, *ISSCC*, 1996, p. 52-53

[7] W.B. Kuhn, ”Center-tapped Spiral Inductors for Monolithic Bandpass Filters”, *IEEE Electronic Letters*, February 1995, p. 131-132

[8] R.H. Caverly, ”Linear and Nonlinear Characteristics of the Silicon CMOS Monolythic 50Ω Microwave and RF Control Element”, *IEEE Journal Solid-State Circuits*, Vol. 34, No. 1, January 1999, p. 124-126

Table 1 : Measured data from the PA family (V_{CC}=3,6V, T=25°C, see also figure 3)

	Output Power P_{out}	Efficiency PAE	Gain G
ISM900	27.5dBm	47%	38dB
DECT	27dBm	41%	33dB
ISM2400	26dBm	35%	30dB

Common data :

- 3...4.5V supply voltage
- Integrated power down, power ramping and power selection
- 4mA output for driving the antenna PIN diode switch
- Simple interface to the driver in PMB4420/PMB5420/PMB5611/PMB5614
- Low tolerances due to external reference resistor for biasing
- Integrated temperature compensation: TC(P_{out})=-1.5dB/100K
- Integrated adjustable supply voltage compensation: ΔP_{out}=±0,3dB for V_{CC}=3...4.5V
- TSSOP10 heatslug package (15mm²), internal interstage matching
- 45dB forward isolation in power down

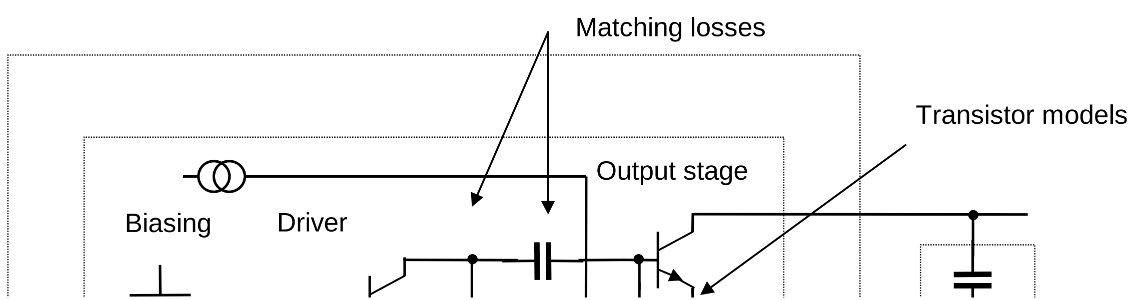

Figure 1: Balanced PAs and parasitics

Table 2 : Parasitics in an integrated RF power amplifier

Part	**Influence**	**Comments**
Transistor models	May have a large influence, especially on interstage matching !	Gummel-Poon may be sufficient, but not in all cases. High current/low voltage region is critical!
Capacitances to substrate	Often a low influence (not for transistor or MOS-C capacitances)	This is different to low power/high impedance designs.
Series resistors	Medium influence. Look also at the MOS capacitances	Reduces gain
Series inductances	Large influence ! Not only as feedback in BJT emitters stages	Changes frequency response
On-chip coils	Medium influence. A Q of 5..7 is realistic. You have to include the connecting lines to the coil	Modeling is not too difficult, but Q is limited for typical Si technologies
Package model	Strong influence due to series inductances	Difficult to model above 2GHz, strong influence on grounding
Substrate model	Medium influence on bias and RF performance	Difficult to model, important for mixed mode designs

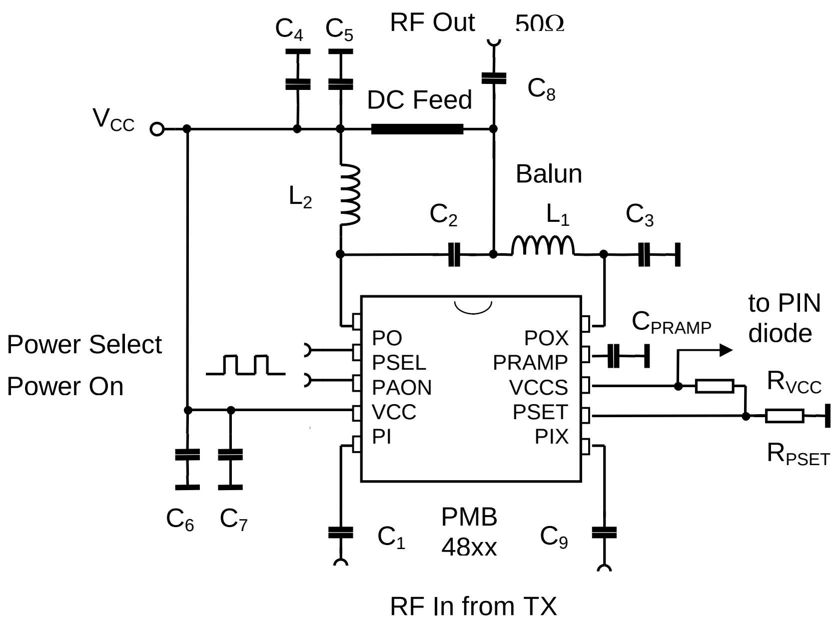

Figure 2: Application of the DECT/ISM PAs PMB48xx

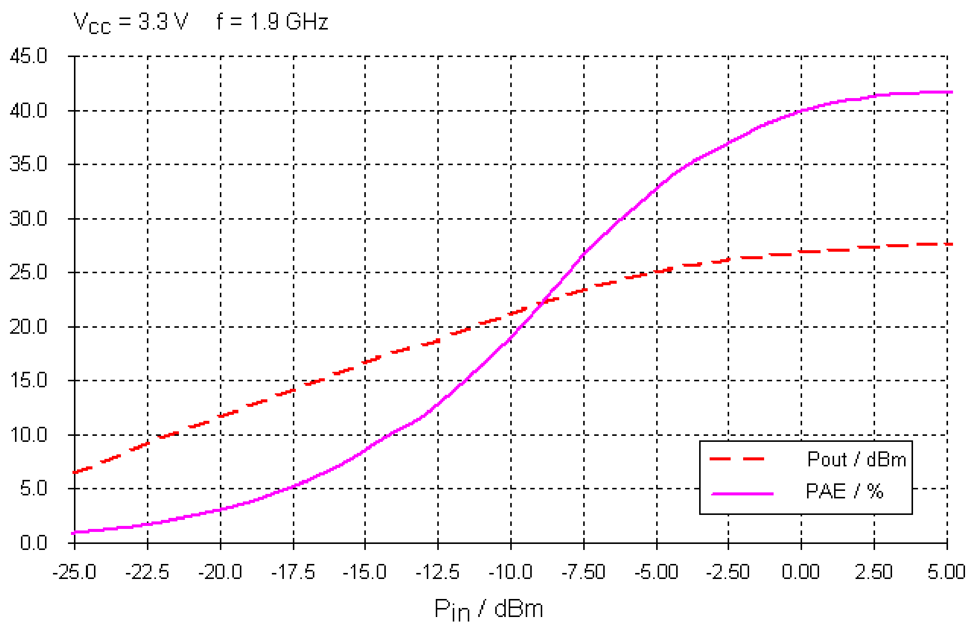

Figure 3: Output Power P_{out} and Efficiency PAE versus Input Power P_{in} (DECT-PA)

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16.3.1999

Dear Mr. Grünbacher,

as a ESSCIRC (21.-23.9. in Duisburg) proceeding manuscript I will send you both the paper and a disk with the PDF file.

Best regards

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DECT/ISM Market

Level of Integration

GaAs MESFET vs. Si Bipolar

Realization

Circuits

Performance

Modeling

Outlook

SiGe

Problems with Cellular PA´s

DECT/ISM Market

DECT is a standard for cordless telephones :
European digital standard, but now world wide
1900MHz
250mW antenna power (24dBm)
TDMA operation
GFSK modulation

In ISM bands (900MHz or 2450MHz) similar operation possible using frequency hopping technique.

Level of PA Integration

- Few years ago : discrete BJT 3-stage designs
- Now GaAs MESFET or Si BJT MMIC´s
- Trend to integrate more functions like LNA, Power-Ramping, PIN diode driver, etc.

DECT/ISM Market

GaAs MESFET vs. Si Bipolar

DECT/ISM-PA Design-Goals :

P_{out} = 26..27dBm (to compensate losses and additional margin)

P_{in} = 0..3dBm (typical driver amplifiers)

V_{CC} = 2...5V (depending on system design!)

PAE >35% (to reduce current consumption)

Price as low as possible!

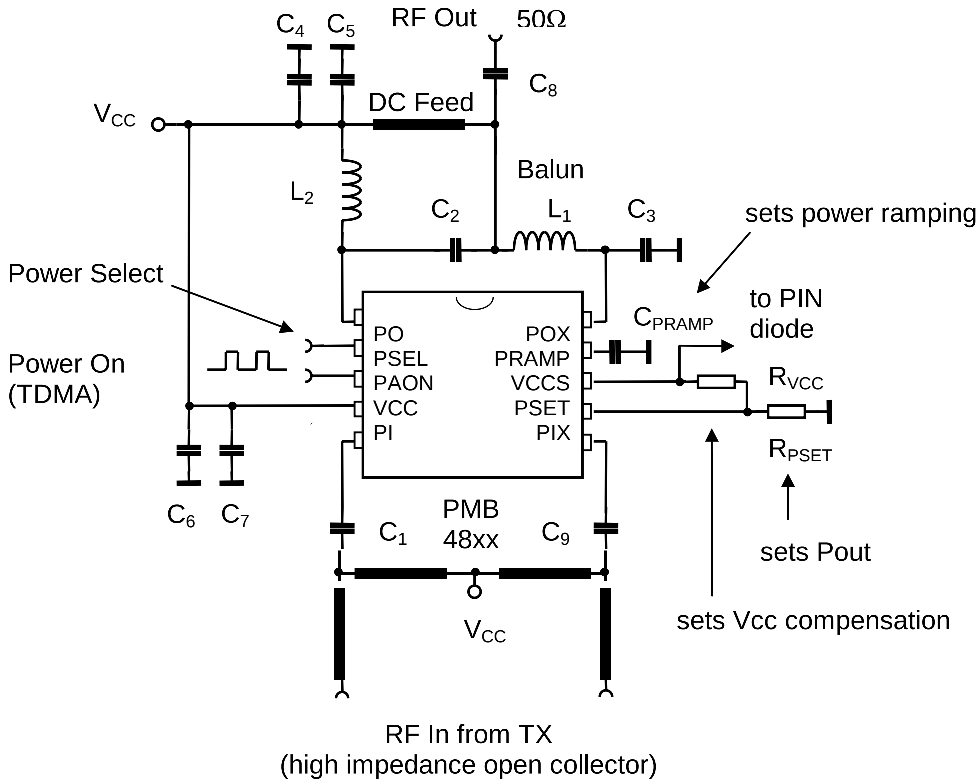
Few external elements

GaAs MESFET good for RF performance, but need for a drain switch and negative gate voltage. Some GaAs PA´s operate at V_{GS}=0, but then there is no control of output power, i.e. maybe large tolerances and the driver must do the TDMA power ramping characteristic.

Realization

Circuits

Application :



B6HF 26GHz

Technology

Why balanced?

TX signal path is very often balanced => no PA input balun

Less ground noise => possibility for a higher level of integration

But output balun is a bit more complicated then a simple matching network

Realization

Performance

V_{CC}=3,6V, T=25°C, P_{in}=2-3dBm :

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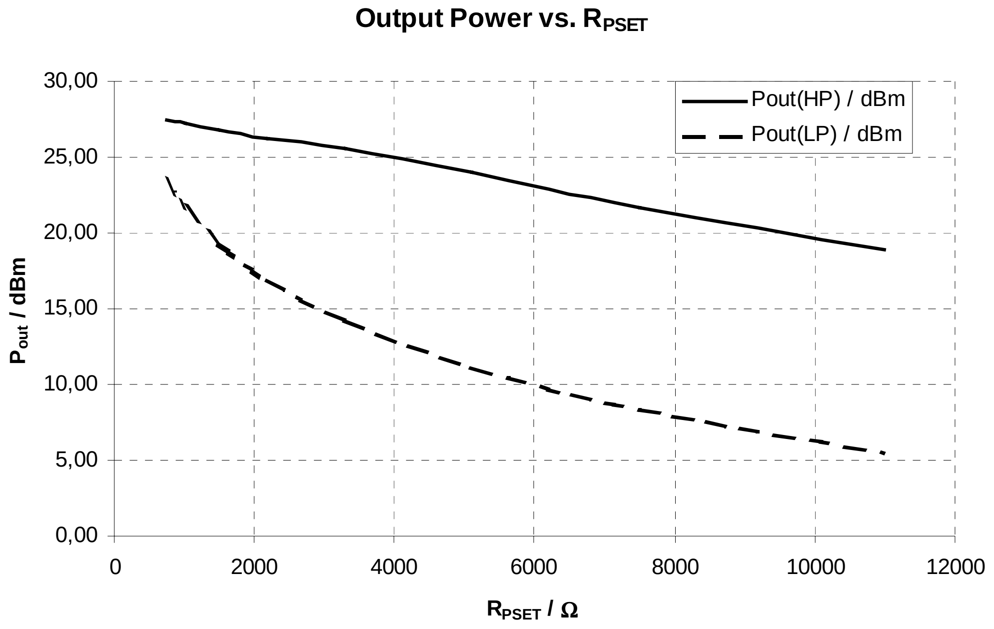

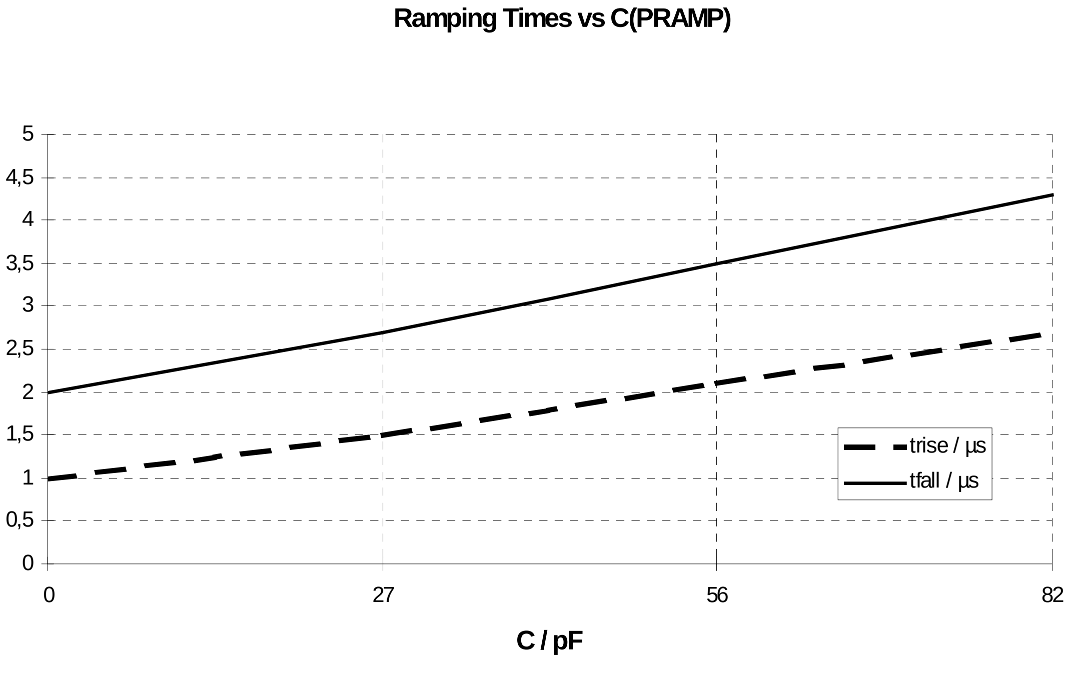

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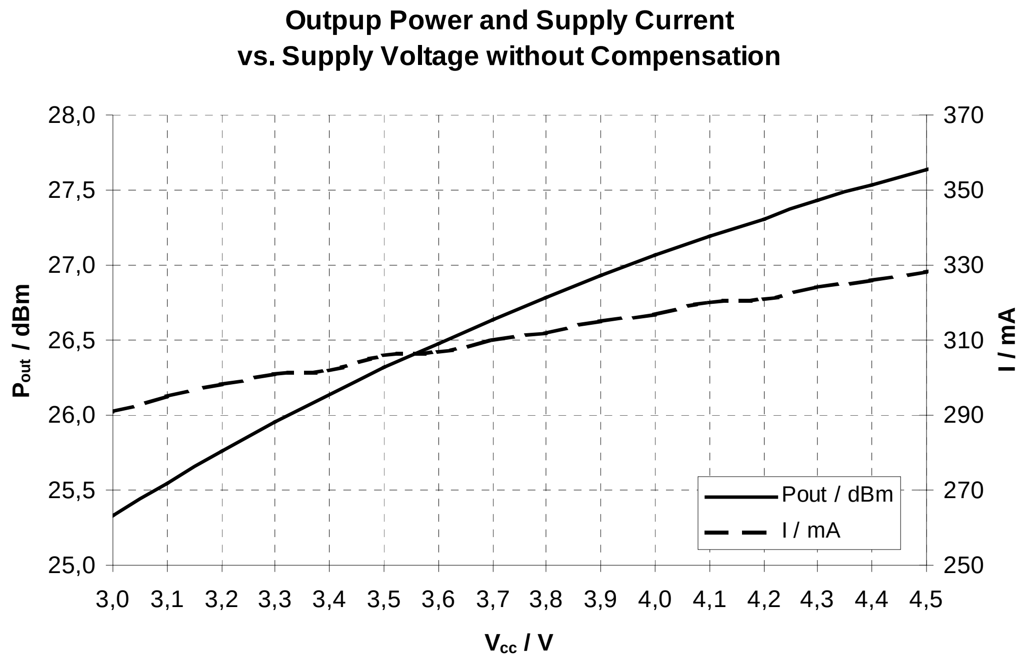
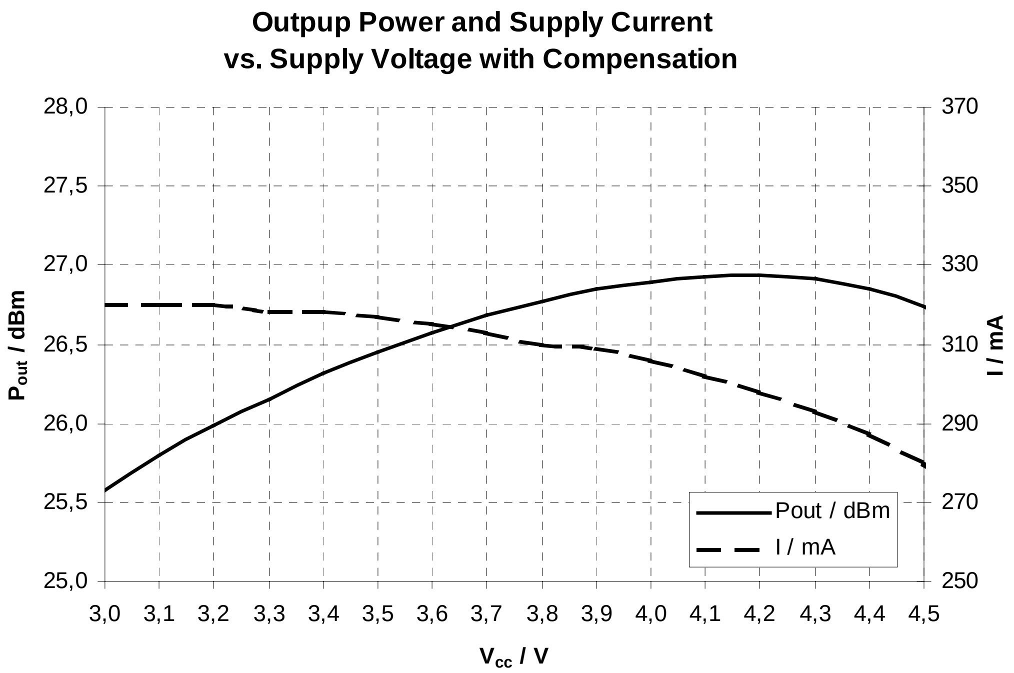
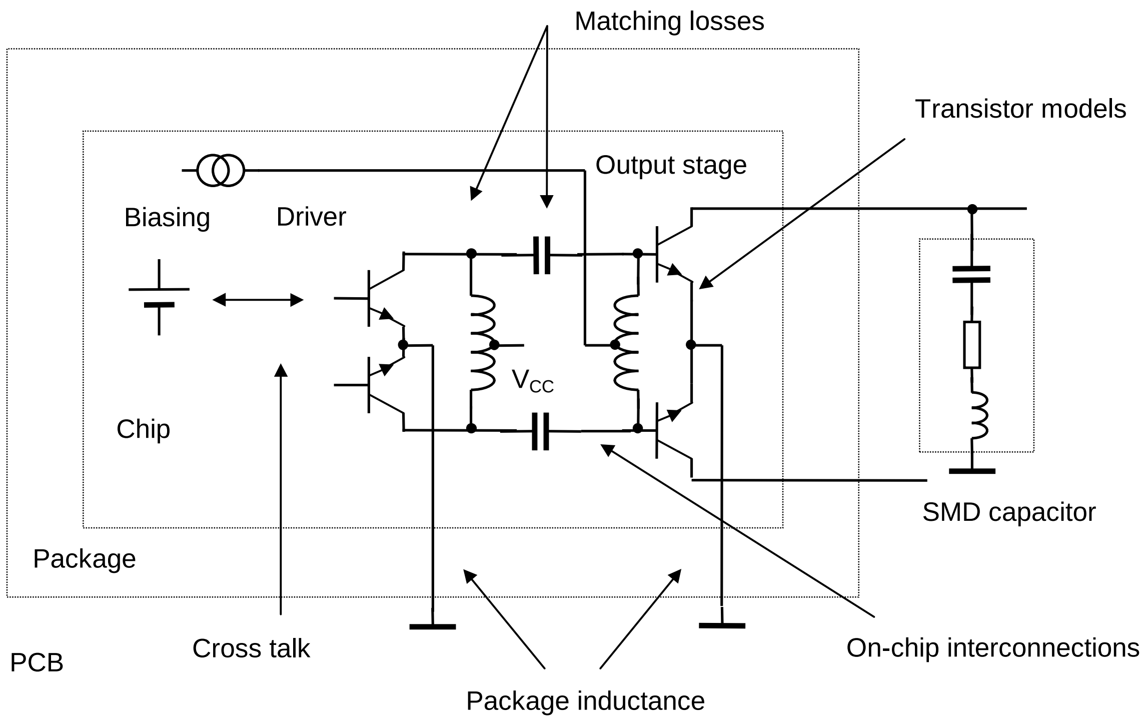




Realization

Modeling : A Balanced PA and it´s parasitics



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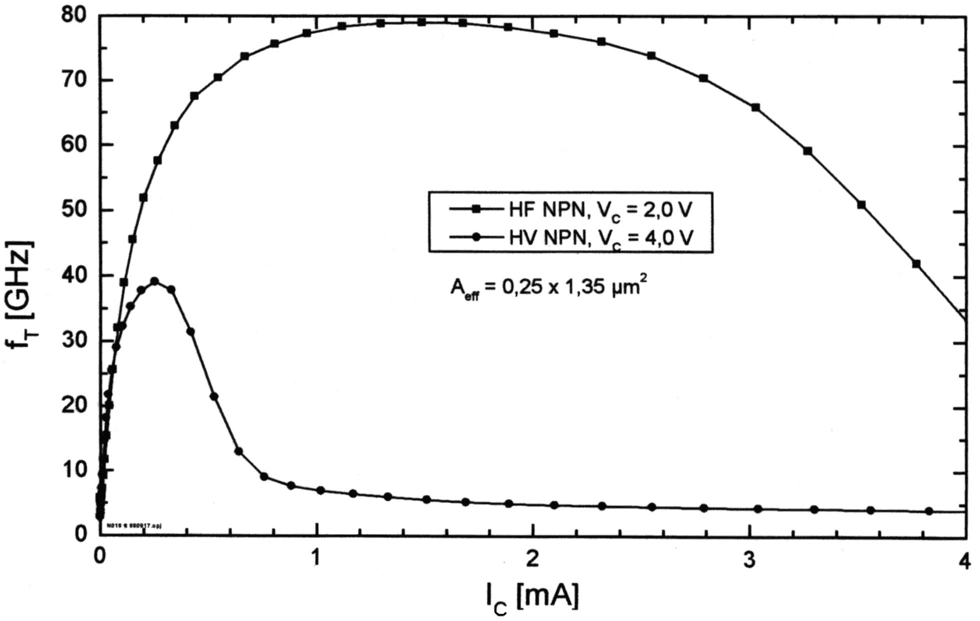
Outlook

SiGe

SiGe IC technologies have typical f_T, f_{max} >50GHz, but V_{CEO} = 2.5..3.5V



f_T for a high frequency npn-Transistor and for a high voltage type (no SIC)

Modifications needed for V_{CC}>3V

But two-cell operation possible without DCDC converter!

Outlook

Problems with Cellular PA´s

PA should directly operate from LiOn battery voltage

In linear theory the peak-to-peak voltage swing at the collector is

$V_{pp} = 2 \cdot (V_{CC} - V_{sat})$

But for high efficiency the swing is larger, for Class E e.g.

$V_{pp} = 3.56 \cdot (V_{CC} - V_{sat})$

So even in normal operation for V_{CC}=3.6V and V_{sat}=0.1V V_{CEmax} is around 12.5V. When charging the batterie or in the presence of mismatch or in failure mode the peak transistor voltage can be much higher. The PA must withstand these voltages and should not generate additional distortions.

Need for

$V_{CEO} > V_{Bat,max}$ (around 6V)
$V_{CER} > 3.5 V_{Bat,max}$ (around 21V)

But changing technology for higher breakdown voltage will result in lower gain.