MULTIBAND FRONTEND FOR A MEDIUM RANGE BASESTATION

Wolfgang Koenig, Siegfried Walter, Ulrich Weiss, Dirk Wiegner
(Alcatel R&I, Stuttgart, Germany, wolfgang.koenig@alcatel.de)

ABSTRACT

Existing and upcoming mobile communication systems are characterised by coexisting different standards using different frequency ranges, serving different markets. Mobile radio providers addressing these different markets and standards, therefore need a wide range of basestation (BTS) variants.
A reconfigurable BTS covering several standards and bands promises a solution to reduce the number or required versions. This paper addresses architecture aspects of a homogenous multiband RF frontend for a BTS. Alternative concepts are discussed, where reconfigurability concerning frequency band, air interface standard or modulation type is playing a special role. Considering characteristics of existing and upcoming tuneable/programmable radio components it is outlined, how reconfiguration mechanisms and compensation techniques can be applied.
In a 3G transmitter the power amplifier has to fulfil strong requirements. Starting from these technical requirements, characteristics and limits of candidate technologies are elaborated. Investigations on broadband power amplifiers, based on wide band-gap technologies are reported.
Design considerations are supplemented by first lab results of a real multiband demonstrator system.

1. INTRODUCTION

A mobile radio basestation that flexibly adapts to different frequency bands and air interface standards by a pure change in SW is a very encouraging vision. However commercial viability of an SDR basestation for public mobile communication systems will only be given when required technologies become mature and cost competitive. A smooth transition from dedicated systems to more and more flexible i.e. reconfigurable systems by introducing reconfigurable elements/modules (without substantially affecting the system costs) seems to be a reasonable way towards a Software Defined Radio.
This contribution concentrates on the architecture of a reconfigurable Multiband Frontend (MBFE) for a Medium Range Basestation (MRBS) which is a good starting point for such a transition. It targets on a frequency band from 1.7 –2.7 GHz, applicable for 3rd Generation Mobile Radio Systems and especially covers the medium power range.

With the 'classical' SDR solution analogue to digital conversion is performed for the full target band and all signal processing is controlled and performed digitally. This limits the total bandwidth that can be handled today with conventional A/D -D/A technology to about 30 MHz [3]. Therefore an approach with digital reconfigurability of some analog RF components, enabled for operation in different (predefined) frequency bands, has been chosen.
Even though flexibility of such a reconfigurable device is limited compared to the ultimate target of a fully Software Defined Radio, this brings significant advantages.
For the manufacturer it reduces the number of required product variants, decreasing overall developments costs and required time to market for new products. For high power applications full field reconfigurability might be limited, e.g. requiring exchange of the antenna duplexer, but commissioning of generic modules at the factory might still introduce some benefits.
For the operator it opens the possibility for a dynamic BTS reconfigurability in the field introducing more flexibility for network planning and management. Additional frequency bands could be easily introduced in existing sites/equipment. Such new frequency bands will emerge with the smooth migration from 2G to 3G networks, introduction of new frequency bands for 3G usage as well as with the densification of networks introducing hierachical layered networks. Multiband capability is also a prerequisite for implementation of emerging concepts on dynamic spectrum sharing/allocation, targeting on a more efficient use of this limited resource.

2. MULTIBAND FRONTEND

2.1. Overall Architecture and Requirements

Figure 1 gives a global overview and shows all the modules deployed in the (TRX) Multiband Frontend of a (Medium Range) Basestation. Most of those modules are described in the following subsection (2.2.). Since the main focus will be put on TX- and RX-Frontends as well as on the power amplifier, these modules are described in separate sections (3. resp. 4.) in more detail.
The basic requirements for the MBFE can be derived from the 3GPP standard [1]. In TX direction the most critical requirements are the Adjacent Channel Leakage Ratio

(ACLR), the error vector magnitude (EVM) and the peak code domain error (PCDE).

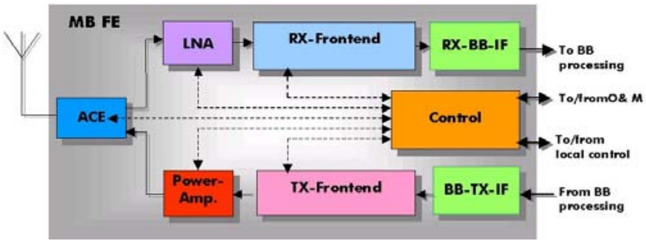
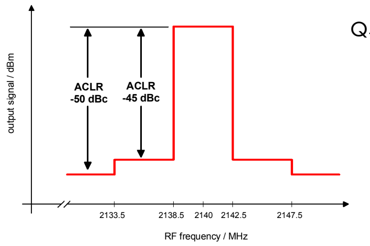


Figure 1: Overall MBFE architecture

The values to be achieved for the ACLR are shown in figure 2. The EVM, based on the definition in figure 3, must be < 17.5 % for W-CDMA signals and the PCDE < -33 dB.



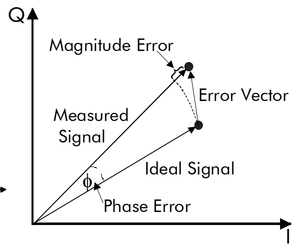


Figure 2: ACLR Spectrum Mask

Figure 3: EVM Definition

According to table 1 the output power of a MRBS lies in the range of 0.25 – 6.3 W. Derived from this for the current application a power range between 2 –6.5 W is selected.

Table 1: Basestation Classes and related output power

BS Class	Output Power
Wide Area BS	No upper limit
Medium Range BS	$\leq$ + 38 dBm
Local Area BS	$\leq$ + 24 dBm

In RX direction the requirements are defined with the help of a Bit Error Rate (BER), which has to be derived together with an accompanying base band processing part. E.g. for an incoming signal at a Reference Sensitivity level of –111 dBm, a BER $< 10^{-3}$ has to be achieved for a measurement channel running at a data rate of 12.2 kbps. The same BER is required for an incoming signal at –105 dBm, when there is a blocking interfering W-CDMA signal with –35 dBm at a minimum offset of 10 MHz.
The different frequency bands to be covered by the current multiband approach are listed in table 2. Band I is the original UMTS band, while Band III is nowadays used for GSM1800. The usage of the Extension Band is still under discussion at IMT, but at least parts of it may be used for UMTS FDD in future.

Table 2: Selected frequency bands for MBFE

Operating Band	RX Frequency	TX Frequency
Band I	1920 – 1980 MHz	2110 – 2170 MHz
Band III	1710 – 1785 MHz	1805 – 1880 MHz
Ext. Band	2500 – 2690 MHz	2500 – 2690 MHz

2.2. Submodules and according requirements

The antenna coupling equipment (ACE) provides selection of the required bands and the separation of according TX and RX sections. A special tri-band diplexer has been specified which - under the proposition of the medium power class requirement - can be realised by bringing new materials into use (ceramic dual/triple mode monoblock filters), which lead to low size and hence lower cost.
For the low noise amplifier (LNA) module a high dynamic range (high IP1, IP3) is required. A compromise has to be found between wide band matching and high amplification. A high gain positively influences the NF of the whole receive chain, but counteracts the broadband input matching. A compromise could be either a band-preselection by switching between different matching networks or the implementation of a multiple stage LNA with lower gain but wide bandwidth in each stage.
The whole operation of the MBFE is managed by the control module. All parameters in the MBFE which have to be loaded, changed, adjusted during initialisation, calibration or reconfiguration procedures are supervised from here. The module can communicate commands and status responds by two interfaces: Via a directly connected local steering terminal and via a connection to the Operation and Maintenance (O&M) control section of the BTS. Also the operating SW may be downloaded from either line.
Rx-and Tx-Frontends are connected to the baseband (BB) processing part of the BTS through appropriate interface modules, which serialize/deserialize the symbols into/from a high speed bit stream. Hence it is possible to operate the MBFE not only in a compact µ-BTS system but also as remote frontend connected to a BTS host via electrical or optical connections.

3. TX- AND RX-FRONTENDS

3.1. Architecture discussion

An important role plays the selection of the architectures for RX- and TX-modules itself. When comparing homodyne and heterodyne concepts, the heterodyne ones (Single-IF-/ Double-IF-conversion) suffer from the multiple stages and the according analog bandfilters which have to remove the images produced in each stage by the mixing process. These filters have to be variable in the context of multi-standard

operation. Consequently this would lead to a set of selectable parallel filters required for each stage.
Main obstacles of homodyne architecture types (Zero-IF- / Direct-Up/Down conversion concept) on the other hand are the sensitivity on local oscillator (LO) pulling in transmit direction, selfmixing of LO leakage signal and hence producing DC offset, and varying DC offset caused by second order distortion of the IQ-mixers in receive direction. An extensive discussion of these items can be found in [2].

3.2. Selection of favourable architecture

Taking those two major concept groups and extraordinary (five-port, polar modulation) architecture types and applying selection criteria like extendability (e.g. for multicarrier operation), availability of components, number of components (power consumption, size), costs of components, reconfigurability (relating to different standards) and multiband capability, then the final choice for the Rx-frontend is a Zero-IF-concept (figure 4).

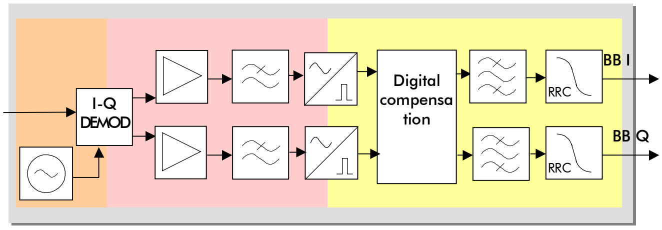


Figure 4: Architecture RX-Frontend

The selection of this concept is substantially influenced by the parallel specification and development of a highly linear wideband demodulator in the RMS project (see conclusion). LO selfmixing is avoided by usage of a programmable LO running on double frequency and accordingly divided by prescalers in the demodulator. Therefor a configurable LO concept has been developed in addition, which can cover the required frequency range of 3.4 – 5.4 GHz in appropriate frequency segments.

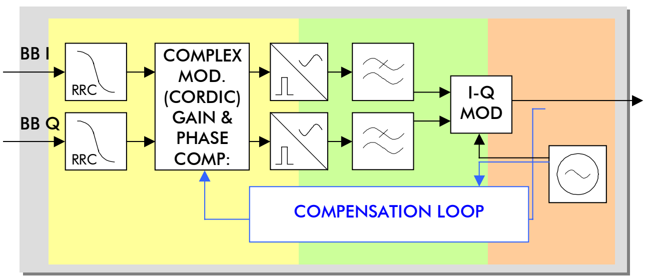


Figure 5: Architecture TX-Frontend

The selected architecture for the TX-Frontend is a zero-IF-concept with optional reconfiguration into a single-sideband-solution, where channels are placed digitally at a low IF (figure 5). The LO pulling problem is avoided by doubling the LO frequency corresponding to the RX-case. Consequences of imbalances relating to gain and phase are reduced by usage of a highly accurate I/Q modulator also specified and developed in the RMS project.

3.3 Imperfections and compensation

The selected architecture for the TX-Frontend has to deal mainly with three types of imperfections:

- Phase imbalance. The 90° phase shift between the I and Q branch in the analogue IQ-modulator differs slightly over the wide frequency range.
- Gain imbalance. The gain in the analogue I and Q branches from D/A converter to I and Q mixing stages can vary due to device inaccuracies.
- DC offset. Offsets in the analogue I and Q branches can be originated at the D/A output stage and in the IQ-modulator.

In a zero-IF direct-up-conversion architecture the phase and gain imbalances directly influence the EVM. Simulation results of this effect are shown in figure 6.

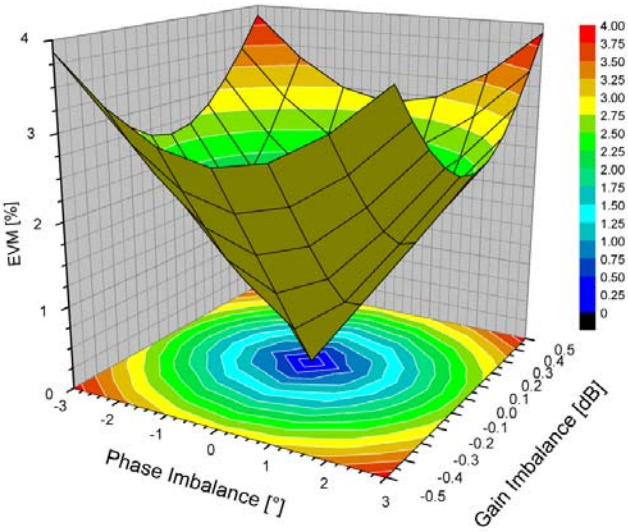


Figure 6: EVM over phase and gain imbalance in an analogue IQ-modulator

Figure 7 depicts the simulated influence of a DC-offset onto the appearance of an LO signal at the output of the IQ-modulator. In the ideal case the LO is totally suppressed.
As proved by according simulation results, phase and gain imbalances in the I and Q paths of the transmit chain can be pre-compensated in the digital signal processing part. This leads to a significant improvement of the EVM in the zero-IF-case and a drastic reduction of image in the SSB-case.

While the phase correction is done with a type of complex modulator inside the Digital Frontend (DFE), the gain compensation can also be provided by the output stages of some D/A converters.

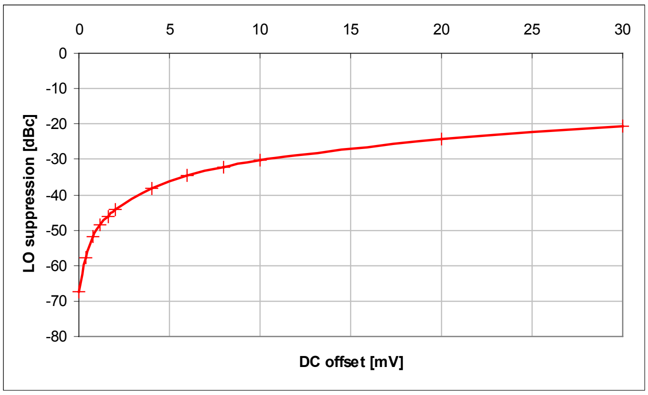


Figure 7: LO level at the output of an IQ-modulator over DC offset

The DC-offset effects can be compensated either in the digital or analogue domain, resulting in an improved LO suppression. Special D/A converters offer the possibility to use integrated offset adjustments.

Although the compensation mechanisms themselves are available, the determination method for the optimum values still has to be identified. There are two principal possibilities: dynamic compensation with a feedback loop or collection and storage of compensation values from a calibration environment during fabrication. While one-time storage of calibration values in the factory saves the effort and cost of the compensation loop, dynamic compensation may become necessary because of temperature and/or aging effects, which require a real-time-compensation.

4. MULTIBAND POWER AMPLIFIER

One important module in the MBFE regarding functionality and manufacturing as well as operating costs is the power amplifier (PA) [5]. Especially the last stage in this module is the most critical relating to gain, efficiency and wide-band capability and therefore this issue is addressed in the following.

4.1. System and Technology Requirements

For a medium range BTS a power amplifier is required which delivers an average output power of 2 – 6.5 W. The MBFE PA has in addition to cover a bandwidth of 1000 MHz at minimum matching effort and at low cost.

Because of the high crest factor in UMTS signals (> 11 dB), the linearity is an important issue for fulfilling the ACLR requirements. While efficiency is decreased significantly by using a high back-off in order to improve the linearity, an acceptable trade-off between linearity and efficiency has to be found by choosing an appropriate operating mode of the amplifier. Another way to improve the efficiency is the use of peak to average reduction mechanisms (clipping) and linearisation techniques. Also the choice of the transistor technology affects the efficiency.

Additional commercial requirements are reduced operating costs, reduced development time/costs and reduced maintenance costs.

The above discussed amplifier system requirements can be mapped onto transistor technology requirements.

In order to achieve a broadband capability of the amplifier, low input and output capacities as well as an impedance level near 50 Ω are required, both benefited by a high power per unit width.

A high power per unit width is also essential for high output power, which can either be achieved by high current or by high operating voltage. But only a high operating voltage – benefited by a high breakdown voltage of the technology – leads to smaller devices and therefore reduced capacities and losses.

High linearity of a transistor is favoured by low memory effects, good thermal conductivity of substrate, a suitable transistor topology (e.g. HEMT topology) and also small capacitance variations as a function of DC and RF signal levels.

A high operating voltage as well as small devices and reduced circuit complexity are technology parameters which affect the efficiency.

For the commercial requirements, a low cost technology, simple amplifier circuits and a high reliability of the technology are the supporting factors.

4.2. Power Amplifier Concepts

In order to cover the required bands a multiband and a broadband approach can be distinguished.

In the multiband concept the whole band is split into part-bands and only one part-band is active at one time. An enabling condition for such a multiband amplifier is the availability of suitable switchable or tuneable elements like MEMS-devices (micro electro-mechanical systems) in order to adjust the adaptive matching networks to the intended band. Benefits of this concept are the use of relatively cheap technologies like LDMOS and an optimal matching for each frequency band. But the adaptability of the matching networks also leads to problems like more complex matching circuits, reduced reliability and necessity of a matching control.

In opposition to the multiband concept, the broadband amplifier approach covers all intended frequency bands by single fixed matching networks, without the need for any adaptive elements. So the broadband amplifier concept

means simpler matching circuits, no additional matching control and therefore higher reliability compared to the multiband amplifier.
A drawback is the trade-off between bandwidth and output power, which means on technology level a trade-off between impedance level and transistor size. An enabling condition for this concept is the availability of a suited broadband semiconductor technology.

4.3. Technology Comparison

For an example of a 10 W amplifier, important parameters of the most promising technologies are shown in table 3, basing on realistic data from literature.

Table 3: Comparison of technologies for realisation of a 10 W amplifier (green: benefits for broadband amplifiers)

	LDMOS	GaAs-HEMT	GaN-HEMT	SiC-MESFET
Size	10 W @ 1 W/mm: 10 mm	10 W @ 1 W/mm: 10 mm	10 W @ 5 W/mm: 2 mm	10 W @ 2 W/mm 5 mm
Bias V_{DC}	30 V	10 V	30 V	30 V
Capacitance C_{out}	10 pF	2 pF	0.4 pF	4 pF
R_{opt}	45 Ω	5 Ω	45 Ω	45 Ω
Z_{out}	2 Ω	5 Ω	40 Ω	10 Ω
Output Bandwidth	400 MHz	> 15 GHz	8 GHz	900 MHz
Thermal Conductivity of Substrate	1.5 W/(Kcm)	0.5 W/(Kcm)	4.9 W/(Kcm) (SiC)	4.9 W/(Kcm)
Costs	relative low	high	high	high
Linearity	heavily depending on operation mode			
Power Added Efficiency	heavily depending on operation mode			

While in case of LDMOS or GaAs-HEMT, a device with 10 mm gate length is necessary, for a GaN-HEMT only 2 mm are sufficient for the same output power.
This reduction of necessary transistor size leads also to reduced capacitances. Especially for GaN-HEMTs this results in an output impedance, which is close to 50 Ω.
In case of GaN-HEMTs, different substrates can be used. With SiC as substrate material, the thermal conductivity of GaN-HEMTs as well as of SiC-MESFETs is superior compared to GaAs or Si.
A wide band-gap of the material results in a high breakdown voltage, leading to high possible bias voltages. While the value for LDMOS in table 3 is already close to the limit of this technology, for GaN higher values can be expected in future.
In literature so called figures of merit [6] are applied to characterise a technology. As shown in table 4, both Baliga's figure of merit and Johnson's figure of merit indicate that GaN is by far the superior material compared to the remaining three technologies.

Table 4: Figures of merit characterising high power/high frequency technologies

Material	Si	GaAs	GaN	SiC	based on
Baliga's Fig. of Merit	1	9.6	24.6	3.1	diel. const., electron mobility and critical field
Johnson's Fig. of Merit	1	3.5	80	60	breakdown voltage and electron sat. velocity

4.5. GaN-Amplifier Sample

A first GaN on Sapphire amplifier chip has been realised in collaboration with University of Stuttgart, as shown in figure 8.

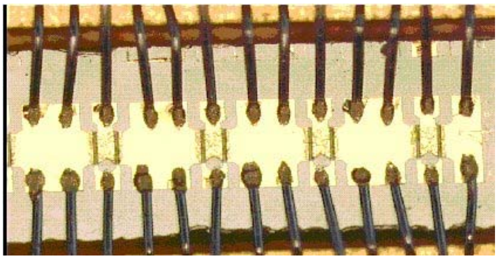


Figure 8: Amplifier chip with transistors with two gate fingers in parallel.

The output power goal of this amplifier chip is about 1 W. Using measured parameters of the chip, an amplifier stage including input- (two section λ/4-transformer) and output-matching (λ/4-transformer) has been designed as shown in figure 9.

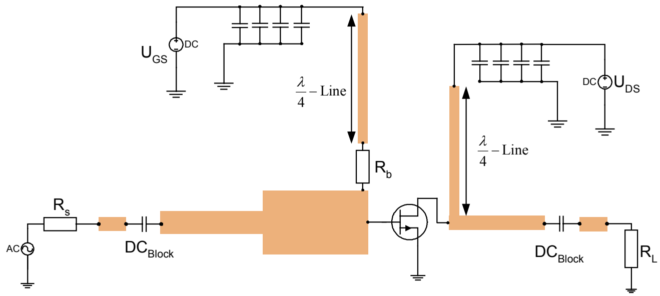


Figure 9: GaN power amplifier stage design

Figure 10 shows a first simulation result regarding the bandwidth of the unpacked amplifier chip inside the power amplifier design of figure 9.

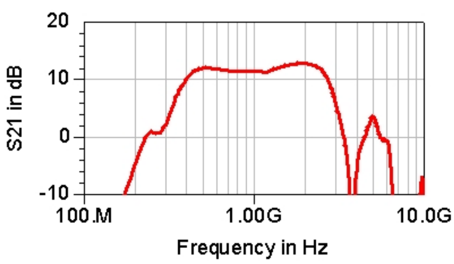


Figure 10: Bandwidth simulation of matched amplifier chip

Currently the chip has been packaged in a standard LDMOS package and work towards power amplifier assembly is ongoing.

5. DEMONSTRATOR

While the final MBFE will be evaluated in an environment comprising terminal emulator(s), network emulator and a living Node B, for first measurements a part of the transmit chain has been set up for initial measurements (figure 11) in order to evaluate the D/A-converters and the I-Q modulator and to attempt some compensation.

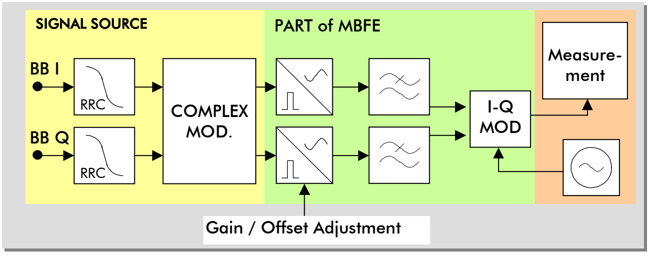


Figure 11: TX demonstration setup

The first measurements on ACLR according to 3GPP specifications are shown in figure 12.

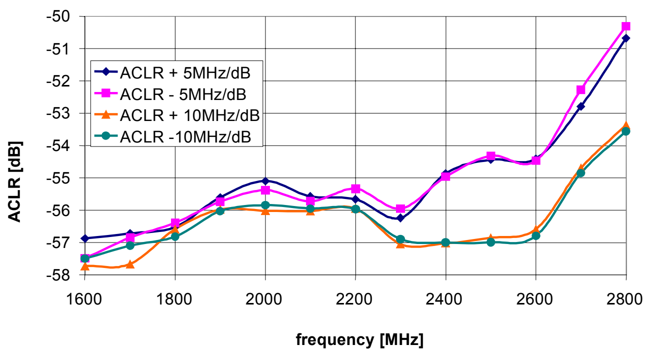


Figure 12: ACLR measurement results

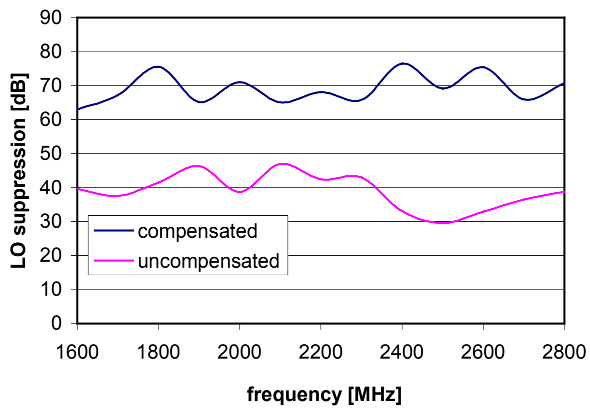


Figure 13: Compensation results concerning LO suppression

While the results cover the specification limits of the emission mask shown in figure 2, for the upper frequency range a better margin should be reached by some changes in chip or even board design only.

For the LO suppression an amendment of up to 40 dB may be reached by appropriate DC-offset compensation (figure 13). This is especially important for the SSB operation variant and for multi-carrier applications.

6. CONCLUSION

This paper reports about the research on a RF Multiband Frontend that is performed within a German Research project called Reconfigurable Mobile Systems (RMS), partly funded by the German Ministry of Research and Education (BMBF), in collaboration with RMS project partners Infineon, Lucent and Nokia. The main target of this collaboration is to accelerate the deployment of components suited to serve the requirements of future mobile communication systems. In the Alcatel part of this project the concept for a multiband frontend targeting on a medium range basestation is worked out and shall be practically verified by means of a testbed currently under implementation [4]. Intermediate results point on technical feasibility respecting cost considerations enabling practical conversion into future products. The concept is designed in a way that will allow smooth integration with future releases of Alcatel Evolium Node B.

7. REFERENCES

[1] [3GPP TS 25.104 V6.1.0] 3rd Generation Partnership Project: "*Technical Specification Group Radio Access Networks: UTRA (BS) FDD; Radio Transmission and Reception.*"

[2] WWRF Working Group 3 "Reconfigurable SDR Equipment and Supporting Networks, Reference Models and Architectures" -White Paper-, V.2, p. 23 ff., 2000.

[3] W. Koenig, S. Walter "Following the Software-Defined-Radio-Idea in the design concept of base-stations: possibilities and limitations", *Annales des télécommunications*, n° 7-8, pp. 613-625, Paris, 2002.

[4] W. Koenig, S. Walter, "Architecture of a Multiband Frontend for a Medium Range Basestation", European Microwave Week, Munich, 2003

[5] I. Dettmann, D. Wiegner, "Power Amplifier for Reconfigurable Mobile Systems", European Microwave Week, Munich, 2003

[6] U. K. Mishra, P. Parikh, Y. Wu, "AlGaN/GaN HEMTs – An Overview of Device Operation and Applications", *Proceedings of the IEEE* Vol. 90, No. 6, June 2002