IMPLEMENTATION OF A MULTIBAND FRONTEND FOR A MEDIUM RANGE BASESTATION WITHIN THE RMS PROJECT: TEST AND MEASUREMENT RESULTS

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

ABSTRACT

This contribution reports about the design and lab implementation of a Multiband Frontend (MBFE) for a 3G Medium Range Basestation, achieved in the scope of the German research project RMS (Reconfigurable Mobile Communication System), embedded in the framework program "Mobile on Chip" [1].

Last year's contribution to the SDRF TC focused on the requirements, candidate architectures and envisaged technologies for such a Multiband Frontend [2]. Now the final practical implementation and verification of the testbed is described. Test and measurement results on achieved performance related to the chosen technology are given. Even though final evaluation is not yet completely finalized, principle feasibility of the chosen approach can be demonstrated.

1. INTRODUCTION

The main target for introducing SDR technology into the basestation of a mobile radio access network (RAN) is to increase flexibility, to improve QoS of future mobile radio access networks, and last but not least, to reduce overall infrastructure costs. To make the SDR BS a reality, some major technical innovations have been required. This includes provision of multiband/wideband, low noise RF frontends.

Mid 2001 a research project on key components for reconfigurable basestations has been started within the RMS project. This activity, partly funded by the German Ministry of Research and Education (BMBF), is performed by Alcatel and Technical University of Dresden in collaboration with RMS project partners Infineon Technologies, Lucent and Nokia until end of 2004.

Alcatel's sub-project mainly targets on the concept and demonstration of a flexible multiband, multistandard RF frontend aiming in the first step at a limited number of selected frequency bands for UMTS FDD and HSDPA. It also evaluates base station architectures suitable for a reconfigurable multiband, multi-standard basestation and investigates the impact of an SDR concept on the whole mobile network environment. In order to overcome some of the problems caused by the lack of appropriate components, one of the targets was the specification of key components in cooperation with the other project partners and to do prototype manufacturing as well as evaluation of those devices.

In the second half of 2004 an appropriate MBFE demonstrator is going to be implemented, covering the frequency range from 1.7 GHz to 2.7 GHz and corresponding to the mobile standards mentioned above. The testbed, which is currently under final integration and evaluation, allows to test and verify the performance of different components within the investigated direct-conversion architecture.

2. MULTIBAND FRONTEND

This section provides only a rough overview of the overall MBFE architecture, since a more detailed discussion has already been given in [2]. A closer look is then taken at the TX- and RX-Frontend implementation as well as the power amplifier (PA).

2.1. Overall Architecture and Requirements

The frontend is the part of a basestation, which covers the radio equipment between the antenna and the base-band processing. Figure 1 gives a global overview and shows all the modules deployed in the (TRX) Multiband Frontend of a Medium Range Basestation.

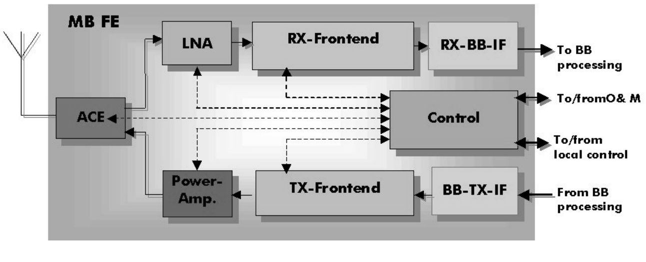

Figure 1: Overall MBFE architecture

In TX direction the serial baseband signal is de-serialized by the Baseband-TX Interface (BB-TX-IF) and handed to the TX-Frontend for filtering, digital-to-analog conversion and up-conversion to RF. In the power amplifier the RF-signal is then amplified to the defined output power level.

The Antenna Coupling Equipment (ACE) provides selection of the required bands – to and from the antenna – and the separation of corresponding TX and RX sections. In contrast to true SDR due to limitations of the analog-to-digital converters (ADC) regarding dynamic range, input power and sampling rate, the ACE is needed to suppress the own TX signal and all other out of band signals to a level that can be handled by the low noise amplifier (LNA), demodulator and converter.

In RX direction the received signal from the antenna is pre-filtered in the ACE and amplified in the LNA. The LNA has to fill the gap from the sensitivity of the demodulator and ADC down to system sensitivity level but also must be able to handle inband blockers. In the RX-Frontend the down-conversion, analog-to-digital conversion and channel filtering is performed. The interface (RX-BB-IF) afterwards serializes the signal towards base-band processing.

The whole operation of the MBFE is managed by the control module. All parameters and settings in the MBFE for initialization, calibration, compensation or reconfiguration are supervised from here.

The requirements for the MBFE are mainly derived from the requirements for a Medium Range Basestation (MRBS) for UMTS FDD according to the 3GPP specifications [3].

For the current application an output power in the range of 2 – 6.5 W has been selected. Addressing the medium range power class, allows the introduction of a new power transistor technology with wideband capabilities, which will become mature for higher power classes only step by step.

The different frequency bands to be covered by the current multiband approach are listed in Table 1. The frequency range addresses the already defined Bands I, III and IV [3] plus the Extension Band, the segmentation of which is still under discussion [4], [10]. Band I is the original UMTS band, while Band III is nowadays used for GSM1800.

Operating Band	RX Frequency	TX Frequency
I	1920 – 1980 MHz	2110 – 2170 MHz
III	1710 – 1785 MHz	1805 – 1880 MHz
IV	1710 – 1755 MHz	2110 – 2155 MHz
Ext. Band	2500 – 2570 MHz	2620 – 2690 MHz

Table 1: Selected frequency bands for MBFE implementation

2.2. Tx- and Rx-Frontend

Direct-conversion architectures are used in both, the RX- and TX-Frontend (see Figure 2 and Figure 3). This concept minimizes the number of analog parts in the Frontends and is thus highly flexible in terms of multiband capability and extendibility to multistandard applications [6].

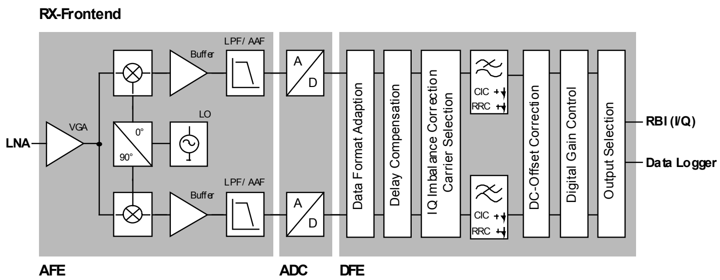

Figure 2: Implementation of RX-Frontend

Samples for a highly linear and wideband capable IQ-demodulator and IQ-modulator devices – used in the analog parts of the RX- and TX-Frontend – have been specified and developed in the RMS project. Inevitable imperfections of these analog devices can be compensated in the digital part of the Frontends [9].

While in the TX-Frontend the phase correction is done with a type of complex modulator inside the Digital Frontend (DFE), the gain imbalance compensation can either be provided by the DFE or by the output stages of the implemented digital-to-analog converter (DAC). The DC-offset effects can also be compensated either in the digital or analog domain, resulting in an improved suppression of the local oscillator (LO) in the RF spectrum.

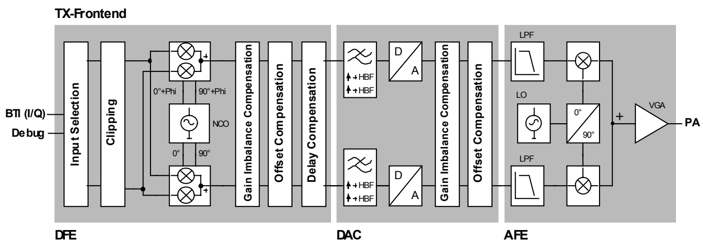

Figure 3: Implementation of TX-Frontend

With the implementation in Figure 3, the TX-Frontend can be (re-)configured for two different ways of operation: zero-IF mode or low-IF mode.

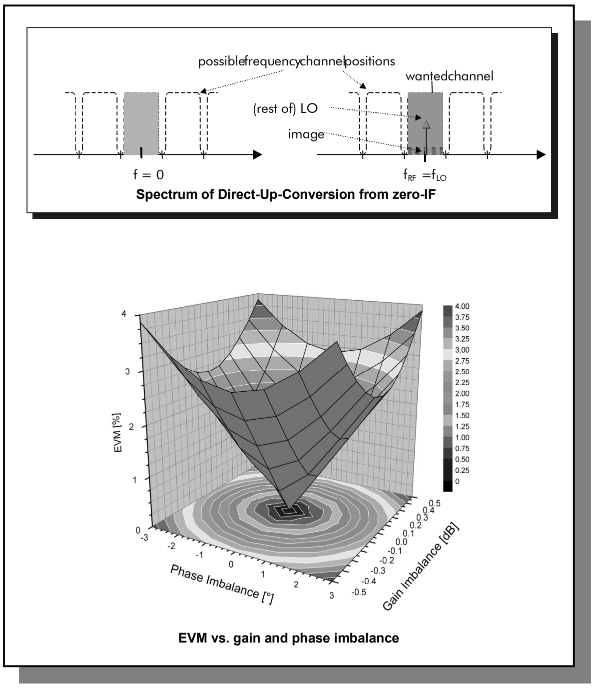

Figure 4: TX operation in zero-IF mode

In zero-IF mode (Figure 4), the phase and gain imbalances directly influence the EVM. But the simulation results show that for the available highly precise IQ-modulator devices these influences do not cause an EVM of more than 2%. So there is no compensation required for this.

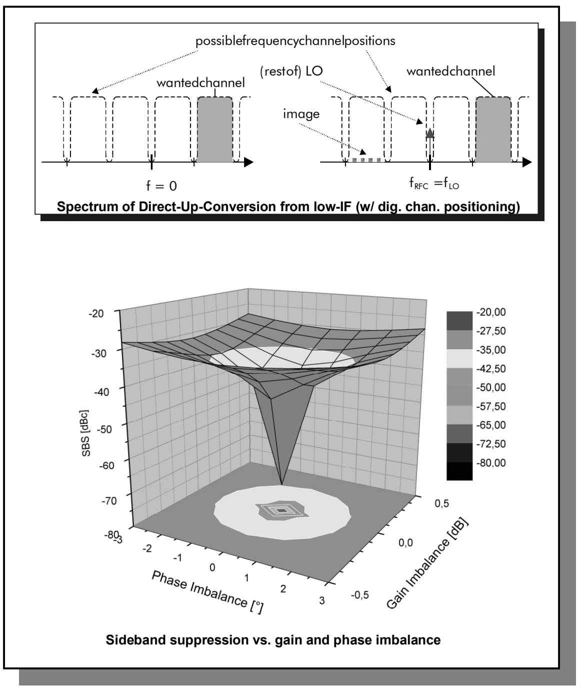

Figure 5: TX operation in low-IF mode

When operated in low-IF mode (Figure 5), the wanted channel is placed digitally at a low IF (single-sideband approach). In this case the image falls into the used band and therefore has to be suppressed carefully.

As shown in Figure 5, this sideband suppression is very sensitive to gain and phase imbalances. Also the LO has to be suppressed in this case to hold the spectrum emission mask. A compensation necessarily has to be done here for all, the gain and phase imbalances and the DC-offsets.

2.3. Power Amplifier

The overall architecture of the power amplifier (PA) is given in Figure 6. At the input a variable digital attenuator can control the overall gain. The preamp is realized with broadband gain blocks. The driver, presently realized in GaAs, and the main amplifier (GaN) are controlled via gate voltage and drain current by an Amp Control Interface connected to the Control unit. A coupler with monitor output for feedback allows output power measurement and the circulator together with the power detector is used to detect antenna reflection and improve VSWR. All the functions in the PA and also the power sequencing are managed digitally by the Control unit.

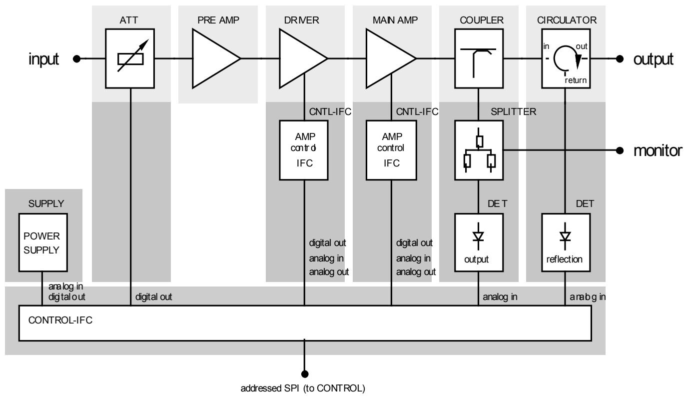

Figure 6: Power amplifier design

Especially the last stage in this module is the most critical relating to gain, efficiency and wide-band capability. Also – because of the high crest factor in UMTS signals (> 11 dB) – the linearity is an important issue for fulfilling the ACLR requirements.

Basically there are two different concepts of designs for the main amplifier. The multiband concept which splits the whole bandwidth in part bands, with tunable or switchable elements doing a reconfigurable matching. The other concept is the real broadband approach with only one fixed matching, which is simpler to implement, but has higher requirements for the transistors in the amplifier. This concept is the preferred one.

High power in a broadband application needs high operating voltage. This favors wide band-gap materials with high breakdown voltage. On the other hand low parasitics – needed for broadband matching – need low transistor size. The combination of high electron mobility, high thermal conductivity (for high gain at low transistor size) and wide band-gap (for high breakdown voltage), today is best fulfilled by GaN as transistor material [8]. Simulations results with present transistor parameters show that the target for a Medium Range Basestation can be reached.

3. TEST & MEASUREMENT RESULTS

Due to the fact that the integration of the MBFE is not yet completely finished, the results shown here are still on a sub-system or module level.

3.1. IQ-Modulator

The wideband capability of the IQ-modulator device regarding linearity and intermodulations has already been shown in [2] with an ACLR measurement over the whole frequency range from 1600 to 2800 MHz.

Figure 7 shows the improved ACLR and EVM – measured at a today's IQ-modulator device – vs. the complete multiband frequency range.

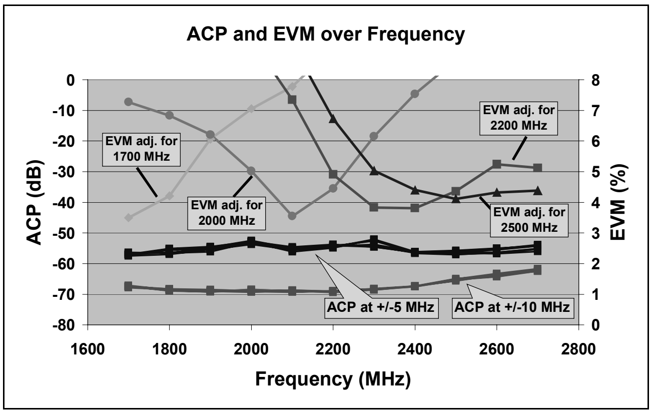

Figure 7: ACP and EVM at IQ-modulator output

The ACLR requirements in [3], i.e. 45 dB for ACLR5 and 50 dB for ACLR10 are reached with a margin of 7 dB resp. 12 dB.

While the ACLR is nearly ideal constant vs. the frequency, the EVM shows a significant frequency dependency, which is related to the LO-suppression. When the level of the LO feed-through is coming close to the level of the flat roof of the CDMA signal, the influence on the EVM is no longer negligible. But with the help of the DC-offset compensation mechanism, the LO can be suppressed per frequency by >50 dB. In this case an EVM <4.5% is achievable. Figure 7 contains a set of EVM curves, optimized for 1.7 GHz, 2.0 GHz, 2.2 GHz and 2.5 GHz.

3.2. Compensation of Imperfections in the TX-Frontend

The effects of the compensation mechanism for gain imbalance, phase imbalance and DC-offset in low-IF mode operation are shown in Figure 8 and Figure 9. Without compensation the spectrum emission mask is violated dramatically by the LO line and also by the image of the wanted channel.

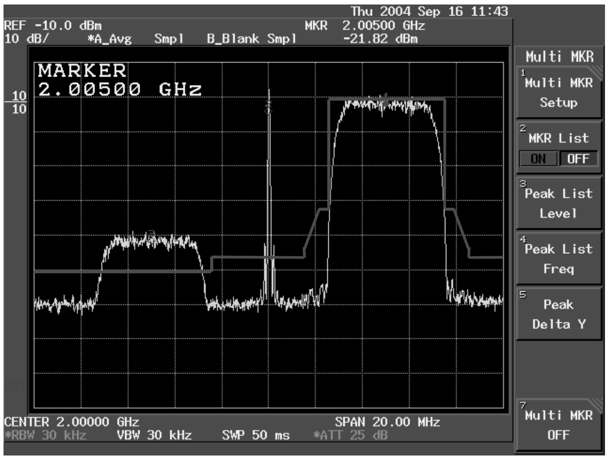

Figure 8: Output of TX-Frontend in low-IF mode – uncompensated

By using the compensation mechanisms in the DFE and DAC, the DC offsets in the analog branches of the IQ-modulator can be adjusted to suppress the LO line by more than 50 dB so that it falls below the mask. Adjusting the gain and phase imbalances leads to an improvement of approx. 15 dB in side-band suppression.

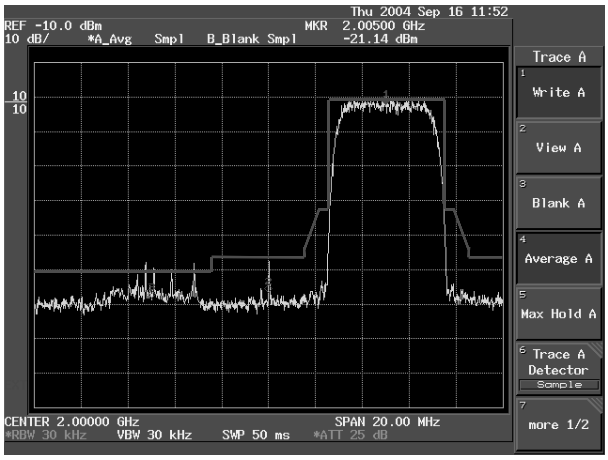

Figure 9: Output of TX-Frontend in low-IF mode – compensated

3.3. IQ-Demodulator and Reference Sensitivity

Considering the measured noise figure of an IQ-demodulator together with the LNA and antenna filters, an overall noise figure of less than 4.5 dB can be achieved for the receiver at the antenna connector. This leads to a reference sensitivity (BER of 10^{-3} in the 12.2 kBit/s uplink DPDCH) of less than -122 dBm between 1.7 and 2.7 GHz (Figure 10).
For a MRBS the reference sensitivity level is specified with –111 dBm. So there is a margin of >10dB.

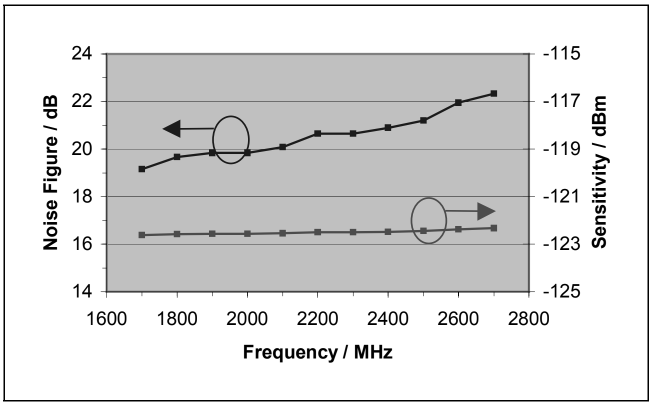

Figure 10: Measured noise figure of IQ-demodulator and derived reference sensitivity level of receiver

3.4. PA Preamplifier

Figure 11 shows the gain of the preamplifier/driver chain of the PA for a W-CDMA signal with 11 dB crest. A gain of about 32 dB is achieved in the complete frequency range from 1700 to 2700 MHz.

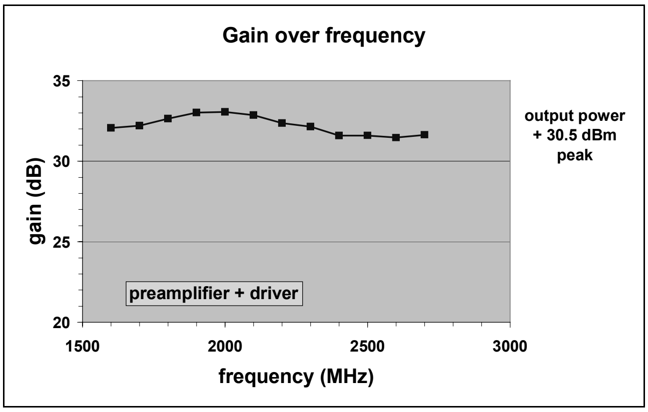

Figure 11: Gain of preamplifier and driver

Figure 12 shows that the chain can deliver an output power of 30.5 dBm peak and 20.5 dBm average for 50 dB ACLR at 5 MHz. The EVM is less than 2% and the PCDE is below –55 dB, i.e. both values are far below the specified limits. So the maximum output power is only limited by IM3 of the driver stage, causing the ACLR for 5 MHz.

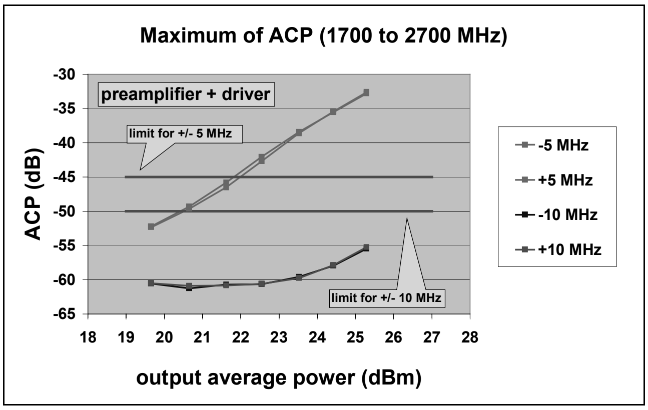

Figure 12: ACP at driver output

3.5. PA GaN Amplifier Stages

Figure 13 shows the small signal response of a GaN transistor amplifier which handles the addressed frequency bands. The output power of this amplifier is 34 dBm peak what is yet below our target.

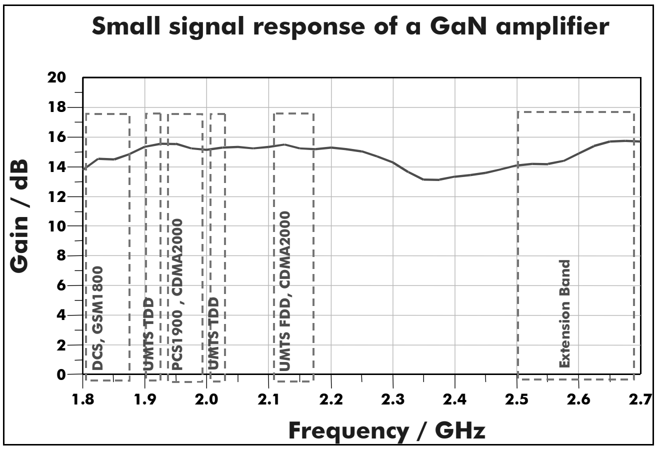

Figure 13: Measured small signal response of a GaN main amplifier stage

Present new amplifier designs which handle both, frequency and power, are under work. Lab samples of power amplifiers with a bandwidth of 200 MHz, meeting the linearity requirements for output power levels up to 38 dBm average and 48 dBm peak are available from external sources.

4. FUTURE DIRECTIONS

The deployment of the MBFE in an SDR multi-standard BS needs to be complemented by a flexible baseband (BB) processing part and the establishment of a configuration management entity. Both entities are targeted by work performed in the EU funded E^2R project, where Alcatel is participating [7]. The main modules of the physical layer architecture concept developed there are the Configuration Control Module (CCM), the operational software environment (OSE) and a module which comprises the so-called configuration execution modules (CEM). This module consists of the MBFE, the programmable/re-configurable processing elements (e.g. DSPs, FPGAs) and a set of communication elements (shared busses, switches, cross-connects etc.). By means of the latter elements the processing devices are connected to functional modules guaranteeing the data and control flow requirements of the actual required system functionality. Depending on the 'intelligence' of the CEMs the configuration is performed by supply of program code, bitstream or just parameter setting through an according control & measurement plane under control of the CCM. An appropriate RTOS performing on a general purpose processor platform builds the basis of the required OSE where the CCM executes as one special task.

Scenarios like loading different air interface standards to the platform, run standards in parallel, allowing bug fixing and algorithm enhancement as well as shifting resources and thus performance from one standard to the other are obviously not limited to the physical layer itself. Therefore another logical entity is present, a Reconfiguration Manger (RM). It shall have control over the UE's and BS's CCMs on one hand and on the network entities on the other hand and thus guarantee the required End-to-End reconfiguration process.

5. CONCLUSION

By using the direct-conversion principle – due to analog imperfections – it is necessary to implement adequate compensation mechanisms, which are very effective. It has been shown that an architecture based on direct-conversion is really multiband capable. The selected concept has been proven in TX direction for zero-IF and low-IF operation.

Multiband/wideband components today are available regarding modulators, demodulators and also amplifiers.

For the last stage of the power amplifier GaN is getting a suitable technology. It is able to handle the required bandwidth and power, but not yet both at the same time.

Since there are no widely tunable duplexer filters available today, the full field re-configurability of a multiband frontend is partly restricted. It requires parallel implementation of respective antenna filters or the frontend has to be commissioned for the targeted frequency band.

The way to an ultimate Software Radio (without antenna filters) is still a long one. But the approach described above – which is feasible today – comes already very close in terms of re-configuration, compensation and flexibility.

6. REFERENCES

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