An Integrated Wideband-IF-Receiver Architecture for Mobile Terminals

Raik Richter, H.-J. Jentschel

Dresden University of Technology, Dresden, D-01062, Germany

Abstract — **A wideband-IF receiver architecture is described for use in mobile terminals capable of receiving multiple standards like GSM, UMTS, DECT, etc. The architecture uses a single down-conversion and digitizes the wanted signal at high intermediate frequencies. The wideband nature of the architecture ensures a great adaptability to various mobile standards. It denotes a step into the direction of a fully reconfigurable software radio due to the shift of the ADC to higher frequencies. The paper is focused on the realization of the analog part of the receiver.**

I. INTRODUCTION

For the present state of the art in digital mobile communications the availability of different standards is typical, whereas each standard is characterized in particular by its specific frequency band, bandwidth and principle of access and method of modulation. Therefore the utilization of specific transceivers for every standard seems to be necessary.

From the user's point of view it is preferable to use only one receiver for all standards. This is because of costs and general convenience. This vision is called multi-standard reception and in this case the device is a multi-mode receiver.

A simple concept for the realization of a multi-mode receiver consists in the parallel utilization of several separate specific receivers. Each of these receivers corresponds to a special standard (Fig. 1).

Clearly due to different reasons (costs, power consumption, performance, size, etc.) this concept is not optimal. Therefore possible improvements have to include a remarkable reduction of hardware-effort.

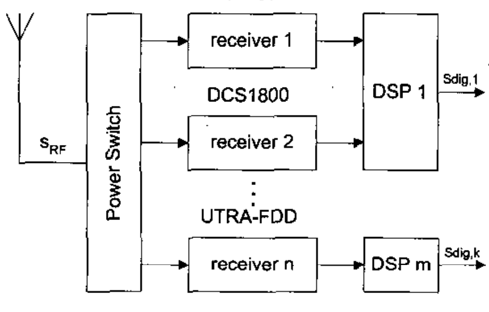

Fig. 1 Simple Multi-mode receiver

Basically this is possible by joining the different single standard receivers into one receiver that is able to operate in all the frequency bands defined by the different standards. Referring to GSM, GPS, DCS 1800, PCS 1900 and UTRA-FDD as standards of interest it follows that the receiver has to operate in a frequency range from 0.88GHz up to 2.17GHz, corresponding to a wideband-receiver behavior.

Besides of this aspect there are additional challenges. Processing different standards by a single reconfigurable receiver is most suitable when software based programmability and extensive Digital Signal Processing (DSP) are applied. Therefore, sampling the received signal as near as possible to the antenna is desirable. Because of technological restrictions it is clear that direct sampling of the received antenna signal s_{RF} is not feasible. Therefore, the frequency band of s_{RF} must be down-converted down to a value suitable for sampling. Thus, the choice of an intermediate frequency (IF) and the definition of a proper architecture is the first challenge in the design of modern wideband-receivers.

Well known architectures in this context are Zero-IF and Low-IF with an IF in the base-band range [1]-[3]. Taking into consideration the intrinsic disadvantages of these architectures, like dynamic DC-offset, RF-leakage, image rejection, they will be disregarded in the following considerations.

The subsequent investigations are focused basically on architectures with at least one frequency down-conversion of s_{RF} to get an IF-signal with frequency f_{IF}. In general the architecture of such a receiver can be divided into an analog and a digital section (Fig. 2). While the second and

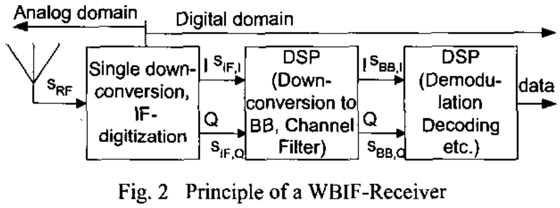

Fig. 2 Principle of a WBIF-Receiver

0-7803-7695-1/03/$17.00 © 2003 IEEE

third stage of the receiver illustrated in Fig. 2 realize purely digital signal processing the first stage includes the analog RF front-end and performs the transformation of the analog s_{RF} into the digital s_{IF}. Besides sampling the basic signal operations of this stage are selection, mixing and amplification. These operations must be carried out considering wideband demands on the one hand and restriction due to the integrated implementation on the other hand. This concerns tolerances of the circuit components causing non exact parameters of filters, mixers and amplifiers.

The choice of f_{IF} is affected by several conditions. It is demanded that the bandwidth of the IF-signal should cover the whole frequency band of at least one standard. On the other hand with regard to subsequent sampling, f_{IF} should not be chosen to high. Since the signal will be sampled at f_{IF}, the required value of f_{IF} is determined by the Nyquist bandwidth to maintain a faultless sampling. Following the DCS 1800 specification the minimal Nyquist bandwidth is 75MHz.

Although the IF-signal coves the bandwidth of a whole standard, only one channel of the standard has to be processed by the receiver in a specific case. In respect of sampling that means that a narrow band-pass signal needs to be treated. Therefore a sub-sampling technique could be utilized. To ensure suitable conditions for the DSP in the base-band we apply sampling in the 2nd Nyquist zone (Fig. 3).

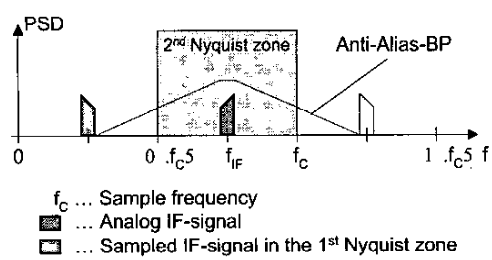

Fig. 3 Sampling in the 2nd Nyquist zone

In the following the aspect of image rejection in heterodyne architectures is reviewed in the context of an application as wideband IF receiver.

II. Classical Heterodyne Architecture

A simple RF front-end based on a classical heterodyne architecture is illustrated in Fig. 4. In contrast to homodyne architectures signal power at the image frequency imposes a serve problem that must be dealt with explicitely. Since the image signal power may be much higher than the power of the desired signal the RF front-end must provide very high image rejection to maintain a reasonable SNR at its output.

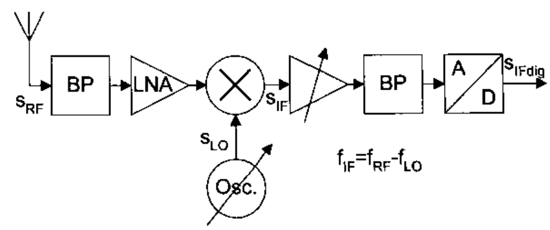

Fig. 4 Classical heterodyne RF front-end

In the case of a classical heterodyne receiver with a real IF-signal s_{IF} (non quadrature heterodyne receiver), the rejection of the image signal is carried out completely by filtering using a RF-BP-filter immediately after the antenna (Fig.4). The advantage of this architecture is the simplicity. However, at present it is not possible to realize a RF-BP to meet the wideband specifications of image rejection [4].

One solution to this problem is using heterodyne receivers with quadrature down conversion. The basic characteristic of this type of receiver is the utilization of complex signals. From this follows the general ability of rejecting the image signal and a great potential for an integrated realization [5], [6].

III. Single-IF Double Quadrature Receiver

The single-IF double quadrature architecture proposed in this paper is a suitable concept for the realization of an integrated wideband receiver. The use of a single analog intermediate frequency results in a simple design with a high operational reliability of the analog part of the receiver.

The frequency bands of the different standards are down-converted to an invariant IF. The main advantage of a fixed IF is the simplification of the analog LO-oscillator

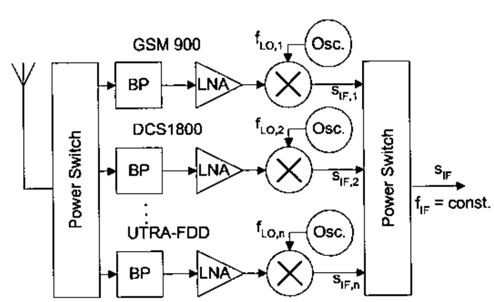

Fig. 5 Down-conversion stage with fixed IF frequency

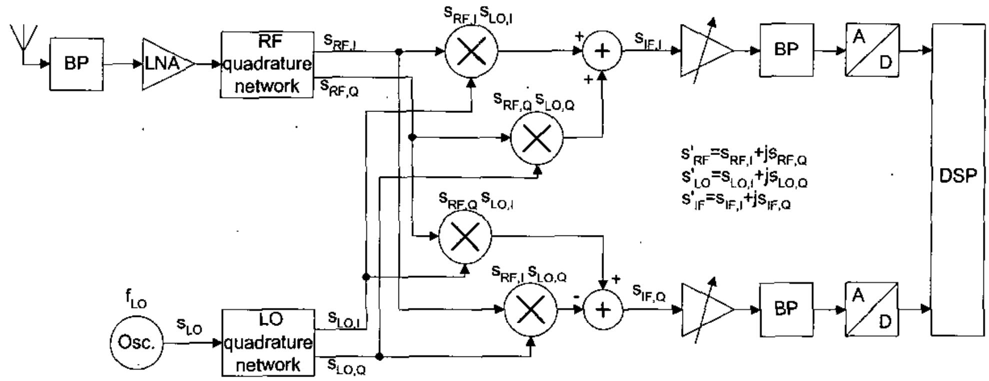

Fig. 6 Single-IF double quadrature receiver

needed for the single down-conversion. The LO-oscillator is only a simple one-frequency oscillator which can be integrated much easier than a tunable LO-oscillator which must realize the channel selection. The general architecture of the single down-conversion stage for usage in a multi-standard receiver is illustrated in Fig. 5.

The received IF-signal is characterized by a wideband signal with variable bandwidth according to the received mobile standard. Therefore the IF band-pass filter, which has the function of anti-aliasing and a partial channel filtering, needs also a variable bandwidth. Due to the required high IF the integrated realization of such a filter is one problem of this architecture.

The selection of the desired channel in the IF band is realized by the ADC itself. We favor two different mechanisms for the realization of this function:

- Tunable clock-frequency of a BP-$\Sigma\Delta$ADC
- Variable conversion characteristic of a BP-ADC (tunable filter coefficients of the ADC)

The problem of image rejection is solved using quadrature RF- and LO-signals (Fig. 6). These signals are provided by quadrature networks. Due to the wideband nature of the signals the quadrature networks are preferably realized as passive polyphase filters [7], [8]. Compared with a single quadrature receiver architecture (only the LO-signal is a quadrature signal) now a certain value of image rejection can be obtained with greater phase- and magnitude-errors in the quadrature networks. The image rejection ratio IRR_{DQ} can be described by the following expression:

$$IRR_{DQ} = IRR_{RFQN} + IRR_{LOQN} = 10\lg\left[\frac{(1+\Delta A_{RF})^2 + 2(1+\Delta A_{RF})\cos(\Delta\phi_{RF}) + 1}{(1+\Delta A_{RF})^2 - 2(1+\Delta A_{RF})\cos(\Delta\phi_{RF}) + 1} \cdot \frac{(1+\Delta A_{LO})^2 + 2(1+\Delta A_{LO})\cos(\Delta\phi_{LO}) + 1}{(1+\Delta A_{LO})^2 - 2(1+\Delta A_{LO})\cos(\Delta\phi_{LO}) + 1}\right] \quad (1)$$

ΔA ... magnitude error, $\Delta\phi$ ... phase error

Fig. 7 shows the dependency of the IRR_{DQ} on $\Delta A=\Delta A_{RF}=\Delta A_{LO}=0.01$ and $\Delta\phi_{RF/LO}$. For instance, the image rejection is 40dB for a phase error of 1° and a magnitude error of 0.1% in a single quadrature receiver. To get the same value of image rejection in a double quadrature architecture the phase errors $\Delta\phi_{RF}$ and $\Delta\phi_{LO}$ must be lower then 10° and the magnitude errors $\Delta A=\Delta A_{RF}=\Delta A_{LO}$ must be lower then 1% (see Fig. 7).

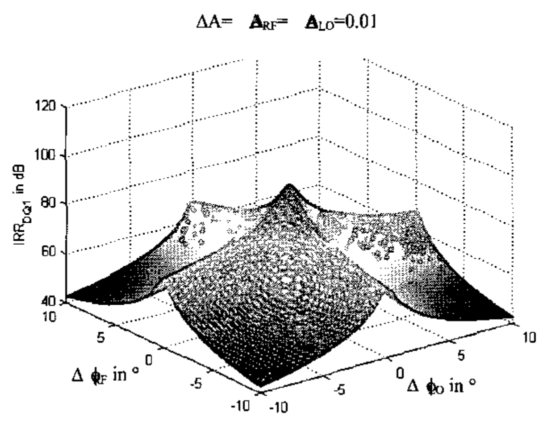

Fig. 7 IRR as a function of phase- and magnitude errors in a double quadrature receiver

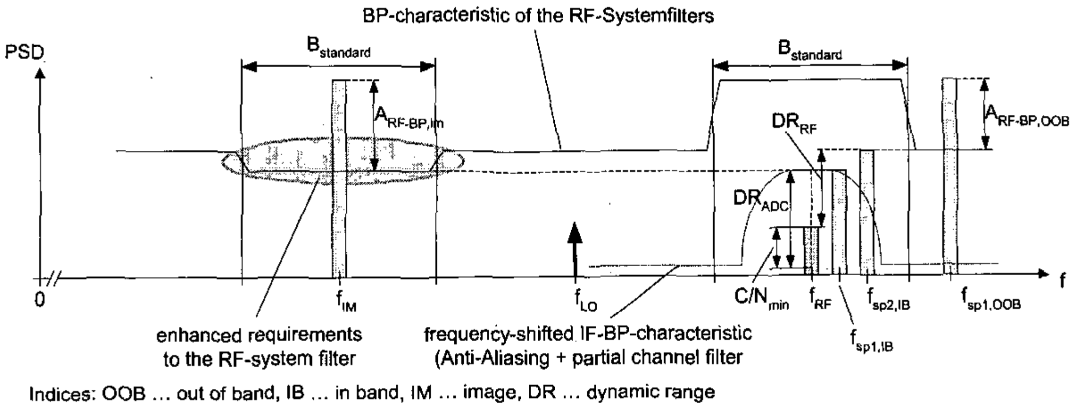

Fig. 8 Image rejection requirements of the RF-BP in the quadrature receiver

This behavior is an important advantage in respect of a fully integrated solution. Thus, it is not necessary to compensate possible phase- and magnitude errors in the receiver chain to improve the image rejection.

Due to the excellent image rejection of the architecture the requirements of the RF-system filter (RF-BP) with respect to the suppression of image signals are also relaxed. Fig. 8 shows that the minimal attenuation is determined by the greatest spurious signal at the input of the ADC. This is only a small additional requirement compared to the remaining parts of the frequency band.

IV. Conclusion

Next generation broadband wireless communication devices require a re-configurable multi-standard receiver. A wideband receiver architecture suitable for a fully integration has been presented. It's considered an alternative to the Zero-IF architectures widely employed today. Due to the shift of the ADC to higher frequencies the proposed heterodyne receiver architecture is a step into the direction of fully reconfigurable software radio. The work is currently in progress to demonstrate its capability in practice.

Acknowledgement

This research was supported by Siemens AG Munich, Information and Communication Mobile, Mobile Phones.

References

[1] Jacques C. Rudell, Paul R. Gray "A 1.9GHz Wide-Band IF Double Conversion CMOS Receiver for Cordless Telephone Applications", *IEEE JSSC*, Vol. 32, No. 12, Dec. 1997

[2] A. A. Abidi, "Direct-Conversion Radio Transceivers for Digital communications", *IEEE JSSC*, Vol. 30, No. 12, Dec. 1995

[3] B. Minnis, P. Moore, "A Re-Configurable receiver Architecture for 3G Mobiles", *2002 IEEE Radio Frequency Integrated Circuits Symposium*, vol. MO4A-2, pp. 187-190, June 2002

[4] S. Mirabbasi, K. Martin, "Classical and Modern Receiver Architectures", *IEEE Communication Magazine*, Nov. 2000

[5] H. R. Karimi, B. Friedrichs, "Wideband Digital Receivers For Multi-Standard Software Radios", http://cienciafisica.com/publicaciones01/circuitos_hf/disenohf047.PDF

[6] R. Richter, „Integrierte Wideband IF-Empfänger", *Interner Technischer Bericht*, TU Dresden, Dez. 2002

[7] F. Behbahani, Y. Kishigami, J. Leete, A. A. Abidi, "CMOS Mixers and Polyphase Filters for Large Image Rejection", *IEEE JSSC*, Vol. 36, No. 6, June 2001

[8] S. H. Galal, H. F. Ragaie, M. S. Tawfik, "RC Sequence Asymmetric Polyphase Networks for RF Integrated Tranceivers", *IEEE Transactions on Circuits and Systems – II: Analog and Digital Signal Processing*, vol. 47, No. 1, Jan. 2000