A FLEXIBLE MULTIBAND FRONTEND FOR SOFTWARE RADIOS USING HIGH IF AND ACTIVE INTERFERENCE CANCELLATION

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ABSTRACT

A flexible analog frontend for multiband mobile communications equipment is presented. The circumvention of tight RF band filtering as applied in current single-band designs is fundamental to attain this goal. A successful application of wideband RF filtering, covering all frequency bands of interest, combined with a high intermediate frequency stage and active interferer cancellation is demonstrated. The high intermediate frequency following the RF stage allows for respectively image and sideband rejection. Direct feedthrough of the TX signal into the RX path is suppressed by active cancellation. A demonstrator capable to operate within an RF range from 800 to 2200 MHz with variable channel bandwidths up to 5 MHz has been realized and measurement results are presented and discussed.

I. INTRODUCTION

Mobile communication is evolving in a rapid manner yielding a numerous quantity of existing wireless standards and protocols, particularly in the U.S. In Europe the widespread deployment of GSM has mitigated interoperability problems, but there is significant interest in using multistandard equipment for seamless migration to 3rd generation systems like UMTS. The introduction of flexible multistandard technologies provides considerable benefits for subscribers, mobile network operators, handset and base station manufacturers [1].

The concept of software radio enables the development of flexible multistandard – multiservice radio systems, reconfigurable and adaptable by software. Initially the ideal software radio concept refers to an architecture with the entire signal processing performed in the digital domain and analog-to-digital (A/D) and digital-to-analog (D/A) conversion assumed outright at the antenna (Fig. 1). For wireless communication systems at 2 GHz and above this seems not to be realizable in the near future. However, recent advances in digital transceiver design, incorporating digital down-converters (DDC) and digital up-converters (DUC) in combination with suitable A/D and D/A data converters shift the digital signal processing edge to the IF [2]. Nevertheless, there will always remain some essential analog signal processing, at least anti-aliasing filtering.

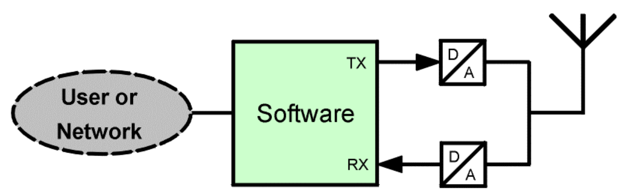

Fig. 1. Ideal software radio architecture

The aim of this work is the development of a truly flexible analog frontend for software radio applications, capable to handle all important wireless communication standards, i.e., it has to cope with a wide range of radio interfaces including different RF bands and channel bandwidths. This means that tight RF band- or duplex-filtering becomes impossible, since the filter would have to be tuned to various bands of interest. Alternatively a switched filter bank may be employed, but for real flexible systems this approach can quickly become unwieldy.

II. A CONCEPT FOR A FLEXIBLE MULTIBAND FRONTEND

Today's most important mobile communications standards are situated within an RF range from 800 up to 2200 MHz and channel bandwidths up to 5 MHz are used. Since it is not possible to design an appropriate RF filter, tunable over the desired RF frequency range, RF band filtering as applied in usual single band transceivers has to be avoided when designing a truly flexible multiband frontend. Thus, we use a new approach applying a bandpass RF filter covering the hole desired RF range, i.e., supplying a passband from 800 to 2200 MHz. Obviously some problems occur, the solutions of which will be discussed in the following sections.

A. Suppression of Images and Spurious Emissions

Down-conversion of a desired RF signal to an intermediate frequency f_{IF} or to baseband (BB) is generally performed by mixing it with a local oscillator (LO) signal (including harmonics at nf_{LO}). Any interferers or noise existing within the RF signal at frequencies equal to $nf_{LO} \pm f_{IF}$ will be converted to the same IF or BB frequency and thus be added to the desired signal. Usually these so-called images are rejected by tight RF band filtering in front of the first mixer in the RX path.

A possibility to handle this problem, circumventing tight RF band filtering, would be the use of image-reject architectures [3]. Therewith an image rejection of 30 to 35 dB can be provided. As this may not fulfill the requirements for some cases, another approach has been considered. It is related to the receiver's frequency plan. The goal is to enable image rejection by the RF band filter with a passband from 800 up to 2200 MHz. Choosing the IF within the range of 800 to 2200 MHz is not allowed to avoid direct feedthrough of unfiltered RF interferers situated at IF. With respect to requirements for spurious emissions the LO signal is not allowed to occur in this range either. Thus, the IF cannot be fixed within the range below 800 MHz, because either the image or the LO frequency would be located within the passband of the RF filter. Ultimately, the IF can only be located at frequencies above $f_{RF,max} = 2200$ MHz. Simple considerations show that high side injection is needed ($f_{LO} = f_{IF} + f_{RF}$) in the case of $f_{RF,max} < f_{IF} < 2f_{RF,max}$, otherwise ($f_{IF} > 2f_{RF,max}$) low side injection ($f_{LO} = f_{IF} - f_{RF}$) is also feasible. The final receiver architecture we realized in the demonstrator is shown in Fig. 2.

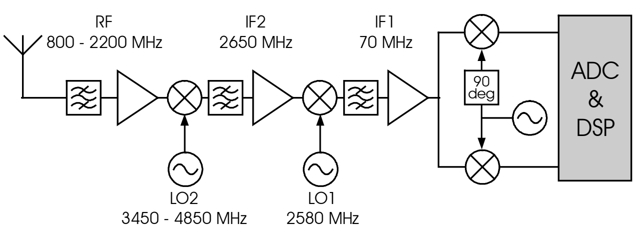

Fig. 2. Analog RX frontend implying a high IF stage subsequent to the RF

The first IF has been fixed at 2650 MHz. Main channel selection is performed at the second IF at 70 MHz. For a multistandard application with different channel bandwidths the bandwidth of this analog channel filters has to be chosen as the widest of the desired channel bandwidths which is 5 MHz in our considerations. Further channel selection has to be performed in the digital domain.

The issues treated for the receiver in this section are quite similar to those of the transmitter. Thus, the frequency plan and filtering scheme of the receiver have also been applied for the TX path of the demonstrator.

B. Handling of Undesired Interferers

One of the strongest interferers that has to be considered is the direct feedthrough of the TX signal into the RX path. This is particularly important for systems capable to transmit and receive at the same time such as UMTS and GSM-evolutions like GPRS and EDGE. Since it is not possible to overcome this feedthrough applying the described transceiver architecture based on wideband RF filtering, its suppression by means of active cancellation is proposed. The difference between the maximum transmit output power and the receive blocking requirements of the mobile communications standards under consideration yields a requirement for the suppression of about 50 dB. Another approach to evaluate the required TX/RX isolation has been used in [4]. Depending on the receiver's frontend analog components input intercept point $IIP3$ the required isolation is about 60 dB for $IIP3 = +30$ dBm and about 50 dB if $IIP3 = +40$ dBm. It has to be taken into account that only the TX signal part reflected at the antenna couples to the RX input. Referring to Fig. 3 the return loss of the used (broadband) antenna is better than -7 dB in every case. Together with an additional attenuation of at least 3 dB caused by the antenna coupling network this leads to the needed additional suppression of about 40 dB.

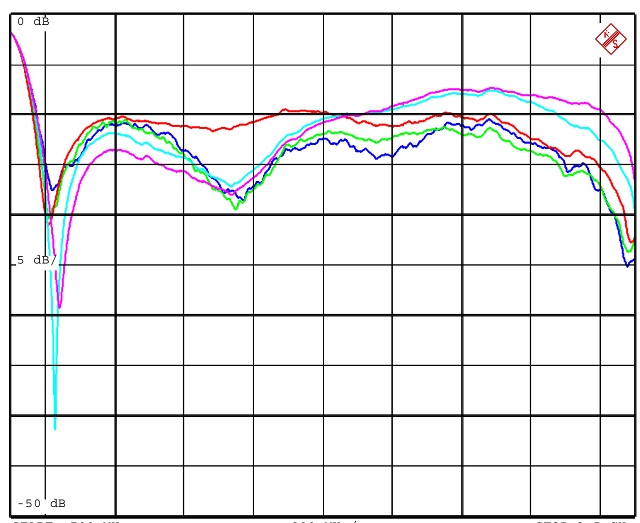

Fig. 3. Measured return loss $|S_{11}|$ of the used wideband antenna for different environmental conditions

The successful implementation of active cancellation needs accurate estimation of the negative replica of the signal to suppress. To attain a suppression of 40 dB the relative errors in amplitude (α) and phase (φ) have to be better than $\Delta\alpha/\alpha < 0{,}01$ and $\Delta\varphi/\varphi < 0{,}0032$.

A source of influence that has to considered is the strong dependence of the antenna return loss $|S_{11}|$ on frequency up to 1dB/MHz (Fig. 3). Since the antenna reflection S_{11} directly affects the TX/RX feedthrough signal arriving at the LNA, these variations in the frequency response of the feedthrough cannot be balanced within the small error restrictions defined by any analog cancellation network. Especially for broadband systems like UMTS with channel bandwidths of up to 5 MHz this is impossible. This results in the active cancellation architecture proposed in [5]. Here, the needed inverse signal is computed accurately over the desired frequency range, i.e., the TX channel bandwidth, in the baseband and then transformed up to RF via an auxiliary transmitter AX as shown in Fig. 4. There it is superimposed with the receiver's input signal including the TX/RX feedthrough to be suppressed.

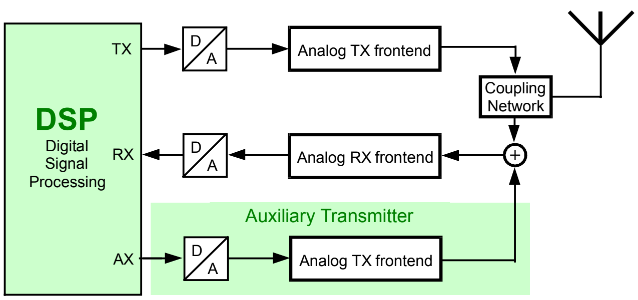

Fig. 4. Concept of active cancellation of the TX/RX feedthrough applying an auxiliary transmitter

At a first glance the proposed technique may look quite costly with respect to chip area and power efficiency. But on the one hand it represents a fundamental approach for the design of real flexible multiband frontends and on the other hand the power consumption of the auxiliary transmitter AX only needs to be at most 10 dB below the TX power (-7 dB antenna return loss, -3 dB antenna coupling network).

III. Measurement Results

The performance of the proposed concept has been tested at various RF bands within the specified RF range from 800 to 2200 MHz. Different test signals (CW, GMSK and W-CDMA) have been used. The measurement results treated in the following show the case of a typical UMTS uplink transmit signal at a center frequency of 1960 MHz. The UMTS transmit signal was synthesized by using root-raised cosine filtered (roll-off factor $\alpha = 0.22$) Gaussian noise as an approximation for the worst case of a multicode signal.

A. Spurious Emissions

The output RF spectrum measured at the antenna port (up to a frequency of 7 GHz) is shown in Fig. 5. The transmit signal as specified above is indicated by Marker 1.

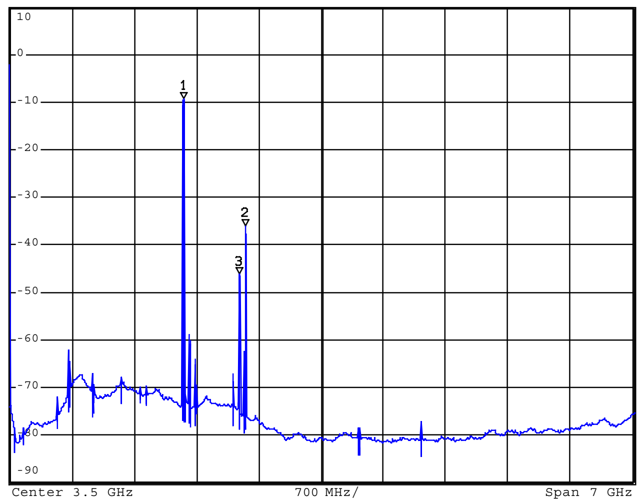

Fig. 5. Spurious emissions measured at the antenna connector for a typical UMTS signal at a center frequency of 1960 MHz

The requirements of spurious emissions as defined in [6] are fulfilled except at the frequencies of 2650 MHz and 2580 MHz. These spurious signals are the feedthrough of the IF2 and the LO1 (referred to Fig. 2) which are not suppressed sufficiently because of the low rejection supplied by the wideband RF filter (10 dB at 2.6 GHz; upper cut-off frequency at 2.4 GHz). The spurious at 2580 MHz is also caused by insufficient rejection supplied by the channel filter at the IF2 stage (8 dB insertion loss at center frequency, 26 dB rejection at 2.58 GHz). These drawbacks can be overcome by fixing IF2 at a higher frequency or/and implementing an RF filter supplying higher edge steepness and thus higher suppression out of the desired frequency range. Furthermore, the rejection of the LO1 feedthrough by the bandpass filter at IF2 could be improved by selecting a higher IF1.

B. Cancellation of the TX/RX-Feedthrough

The principal feasibility of the proposed concept for active cancellation to handle the undesired TX/RX-feedthrough is demonstrated in Fig. 6. The TX signal measured at the antenna port is indicated by Marker 1. The feedthrough of this signal to the input of the RX path, measured at the input of the LNA, is indicated by Marker 2. The third trace indicated by Marker 3 represents this feedthrough suppressed by about 37 dB (within the desired bandwidth) utilizing active cancellation. This adds up to a total suppression of more than 60 dB which satisfies the requirements on suppression outlined above. It is supposed that the performance can be further improved by adaptive real-time calculation of the cancellation signal [5].

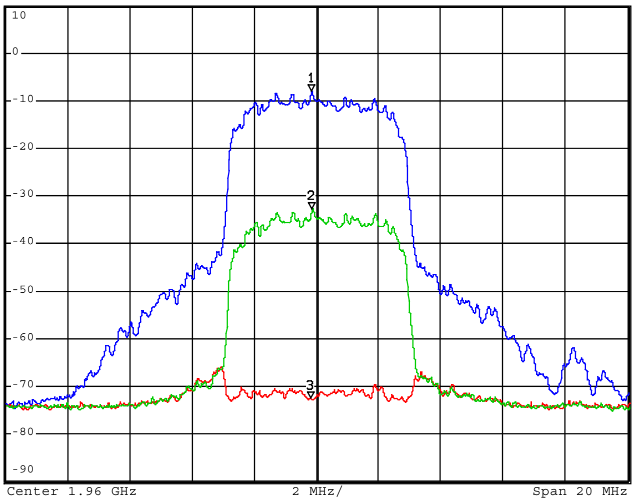

Fig. 6. Suppression of the TX/RX-feedthrough by means of active cancellation with auxiliary transmitter

Power measurements of the transmit signal at the antenna port have been performed. The channel power is about 10 dBm, adjacent channel leakage power ratio ACLR is about 28 dB at 5 MHz offset and more than 55 dB at 10 MHz offset from the carrier. Thus, the requirement for ACLR at 5 MHz offset as defined in [6] is not satisfied but only small improvements are necessary to fulfill the UMTS specifications. Furthermore, it has to be considered that the ACLR was measured with RRC filtered Gaussian noise which has a much higher crest factor than the QPSK test signal for ACLR measurement specified in [6].

IV. Conclusion

Because of simple adaptability to different standards the concept of the software radio seems to be the ideal architecture for multistandard terminals. Its realization includes the development of a flexible (i.e., not only switchable) multiband analog frontend. The concept and successful implementation of such a frontend, capable of operating in the RF frequency range from 800 up to 2200 MHz for radio channel bandwidths up to 5 MHz has been presented. Sources that limit the performance have been identified, both at the component level and the system level. Current work is focused on numerical simulation to evaluate crucial effects, especially interferers captured at the antenna are important to be dealt with.

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References

[1] W. H. W. Tuttlebee, "Software-Defined Radio: Facets of a Developing Technology," *IEEE Personal Communications*, vol. 6, no. 2, pp. 38-44, April 1999.

[2] D. Efstathiou, Z. Zvonar, "Enabling Components for Multi-Standard Software Radio Base Stations," *Wireless Personal Communication*, vol. 13, no. 1, pp. 145-166, 2000.

[3] B. Razavi, "Challenges in Portable RF Transceiver Design," *IEEE Circuits and Devices*, vol. 12, no. 5, pp. 12-25, Sept. 1996.

[4] P. B. Kenington, "Emerging Technologies for Software Radio," *Electronics & Communication Engineering Journal*, vol. 11, no. 2, pp. 69-83, April 1999.

[5] W. Schacherbauer, T. Ostertag, C. C. W. Ruppel, A. Springer, R. Weigel, "An Interference Cancellation Technique for the Use in Multiband Software Radio Frontend Design," *Proc. 30th European Microwave Conference*, Oct. 2000, Paris, France, pp. 341- 344

[6] 3rd Generation Partnership Project Technical Specification (3GPP TS 25.101/V3.4.0), *UE Radio Transmission and Reception (FDD)*, Oct. 2000