Digitally Enhanced Software-Defined Radio Receiver
Robust to Out-of-Band Interference

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Abstract*—A software-defined radio (SDR) receiver with improved robustness to out-of-band interference (OBI) is presented. Two main challenges are identified for an OBI-robust SDR receiver: out-of-band nonlinearity and harmonic mixing. Voltage gain at RF is avoided, and instead realized at baseband in combination with low-pass filtering to mitigate blockers and improve out-of-band IIP3. Two alternative "iterative" harmonic-rejection(HR) techniques are presented to achieve high HR robust to mismatch: a) an analog two-stage polyphase HR concept, which enhances the HR to more than 60 dB; b) a digital adaptive interference cancelling (AIC) technique, which can suppress one dominating harmonic by at least 80 dB. An accurate multiphase clock generator is presented for a mismatch-robust HR. A proof-of-concept receiver is implemented in 65 nm CMOS. Measurements show 34 dB gain, 4 dB NF, and □_ _ dBm in-band IIP3 while the out-of-band IIP3 is □__ dBm without fine tuning. The measured RF bandwidth is up to 6 GHz and the 8-phase LO works up to 0.9 GHz (master clock up to 7.2 GHz). At 0.8 GHz LO, the analog two-stage polyphase HR achieves a second to sixth order __ dB over 40 chips, while the digital AIC technique achieves __ dB for the dominating harmonic. The total power consumption is 50 mA from a 1.2 V supply. ***Index Terms*—Adaptive interference cancellation, adaptive signal processing, baseband processing, blocker, blocker filtering, CMOS, cross-correlation, digitally assisted, digitally enhanced, harmonic mixing, harmonic rejection, interference mitigation, linearity, LMS, low-noise amplifier (LNA), low-noise transconductance amplifier (LNTA), mismatch, multiphase, multiphase clock, nonlinearity, out-of-band interference, passive mixer, polyphase, receiver, robust receiver, SAW-less, software radio (SWR), software- defined radio (SDR), switching mixer, wideband receiver.**

I. Introduction

SOFTWARE-DEFINED RADIO (SDR) concepts have recently drawn considerable academic interest and increasinglyalso industrial interest. Limiting our discussion to RF transceivers, most work focuses on integrating the functionality of multiple dedicated narrowband radios into one radio, which is reconfigurable by software [1], [2]. This is hoped to bring cost and size reductions while supporting an ever increasing set of communication standards in a single device. The SDR concepts might also allow field upgradable radios to accommodate emerging standards and become an enabler for cognitive radio applications, to improve the efficiency of utilizing the scarce spectrum resources.

To support the reception of different radio standards, a wideband radio receiver seems an obvious solution. Some wideband receivers have been reported, e.g., for wideband TV receivers [3], [4] , ultra-wideband receivers [5], [6], and SDR applications [1], [2]. However, *wideband receivers are not only wideband to desired signals but also wideband to undesired interference.* Traditional wireless standards use dedicated radio bands, so that in-band interference (IBI) can be distinguished from out-ofband interference (OBI). For a SDR aiming at covering arbitrary frequencies, the definition of IBI and OBI may become fuzzy. Still, we will use the terms IBI and OBI in this paper as: 1) current SDR receivers often aim at covering multiple traditional radio standards which have clear band definitions; 2) even if this is not the case, e.g., for cognitive radio, a SDR still aims at implementing selectivity, i.e., receive a signal for which baseband bandwidth is much smaller than . In the latter case OBI can be interpreted as "out-of-baseband interference".

For popular mobile communication applications, the IBI can be as strong as to dBm while the OBI can be as strong as to 0 dBm [7]. An RF band-selection filter is often employed to suppress OBI to below the IBI level, requiring high quality factor and sharp roll-off. These filters are difficult to integrate on-chip and are often dedicated to one specific band. In a SDR receiver, the dedicated RF filter is undesired owing to its poor flexibility. State-of-the-art multi-band receivers [8], [9] use multiple dedicated RF filters in parallel, which increases size and cost for every band that is added.

This paper aims at improving the robustness of a radio receiver to OBI in order to relax the requirement on RF filters, exploiting fully integrated analog and digitally enhanced mixed-signal techniques. At least two mechanisms generate in-band distortion due to OBI: 1) nonlinearity related mixing of strong OBI via, e.g., intermodulation or cross-modulation; 2) harmonic mixing of interferers with LO harmonics due to hard-switching mixers and/or the use of digital LO waveforms. We will explain these two mechanisms briefly below as well as review the state-ofthe-art solutions for these problems.