Instantaneous in-band radio frequency interference suppression using non-linear folders

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A front-end adaptive folder with a filter is presented to instantaneously push jammers to higher frequencies while preserving the integrity of small signals of interest. A programmable filter is utilised to further suppress folded jammers for achieving a widely scalable dynamic range over a large frequency range. To achieve maximum programmability with a minimal increase of power and area, combinatorial intrinsic device characteristics are exploited to tune folding points for rapid adaptation to a changing electromagnetic environment.

Introduction: The growth of wireless devices increases the need for spectrum sharing among multiple users. For multi-user communication networks in spectrum-congested environments, unintentional or malicious interference significantly degrades the performance of radios. In-band interference cannot be removed with filters because the jammers are in the same frequency band. State-of-the-art communication systems, such as cognitive radios and software-defined radios, utilise machine learning or signal processing algorithms to classify different user signals and identify available channels to increase spectrum sharing efficiency. However, the system may suffer huge latency because such high-order analysis requires a long processing time to discriminate desired signals and interference [1]. Moreover, in order to acquire small RF signals and large interference for digital signal processing, the RF front-end needs to achieve a large dynamic range over a wide frequency range [2], which is power hungry for wideband applications. An alternative approach to relax the dynamic range requirement is to insert a cancellation path at the RF/analogue front-end [3]. After the signal components of interest are discriminated from the interference with spectrum analysis, interference cancellation can be performed with an auxiliary path. However, replicated signals in the auxiliary path may not match the frequently-changing interference patterns, so the cancellation may not work well for unknown and frequency-varying interference. To suppress interference near the input of radios to avoid saturation and distortion, a folding structure with filtering is presented to attenuate in-band interference directly at the RF front-end. Hence, the presented RF interference suppression approach can rapidly react to malicious jammers and mitigate unintentional interference at the RF front-end to relax the dynamic range requirement for improving the feasibility of low-power digital radio systems.

Circuit architecture: To instantaneously mitigate in-band jammers, a RF front-end consisting of a programmable folder and a filter is presented in Fig. 1 to rapidly adapt to the changing spectrum. In order to quickly react to strong in-band jammers, input components from different signal levels are folded into a smaller range, instinctually changing signal frequencies according to their initial amplitudes. For example, Fig. 2 shows received signals (in blue) that are jammed by a high-power jammer (in red). Undesired large-amplitude jammers are moved to higher frequencies that are outside of the band of interest. Therefore, the following filter can be used to filter out folded jammers. In this way, the folded jammer will not saturate the receiver so that it can be processed with low-power small-dynamic-range circuits. The first folding point can be configured to adapt to the amplitude of desired signals. Hence, the folder can preserve the integrity of small signals of interest.

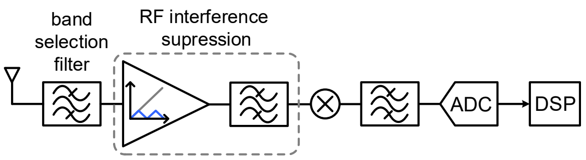

Fig. 1 *Proposed folding structure to rapidly fold and remove in-band RF interference of known and unknown characteristics*

The topology of the folding circuit is a parallel arrangement of differential pairs with identical current sources, as shown in Fig. 3. The inputs of differential pairs in the folding amplifiers are connected to the input signal and the threshold voltages that are set to adapt to desired signals. Owing to the cross-coupling structure in the input differential pairs, about half the tail current sources contribute currents that flow through the loading Z_{L1}, and the other half contributes to the other side (loading Z_{L2}). According to the voltage difference between input signals and threshold levels, the bias current is switched between Z_{L1} and Z_{L2}. The input range can thus be divided into multiple regions with a smaller signal range. The initial amplitude determines which region the folded signal will fall into. Hence, the input–output characteristic of the proposed folding structure can be parameterised by the number of piecewise linear segments or folds (M). When the amplitude of the jammer is folded by M times, its output frequency becomes M times. The folder number can be programmed according to performance objectives and the following filter can be configured to filter out the folded jammer at $M{\cdot}f_J$. N-path filters [4] can be utilised to filter out the folded RF interference because of the high-quality factor and the flexibility for widely tunable frequencies. The presented RF folding structure achieves a scalable and adaptive dynamic range, which significantly improves the energy efficiency and design complexity of the RF front-end.

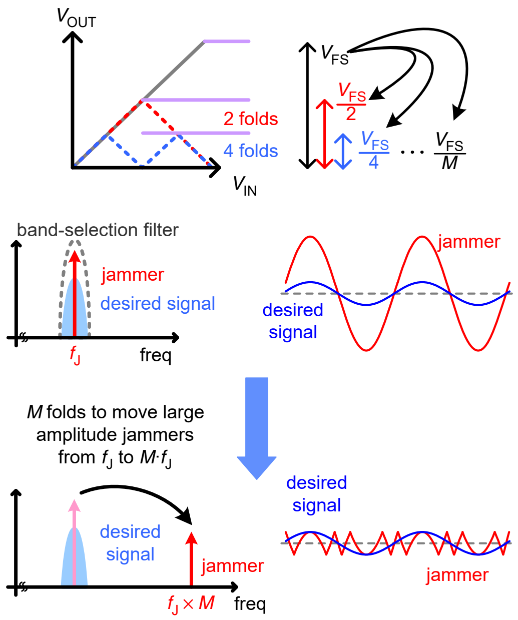

Fig. 2 *Received signals with a high-power jammer that is moved to higher frequency*

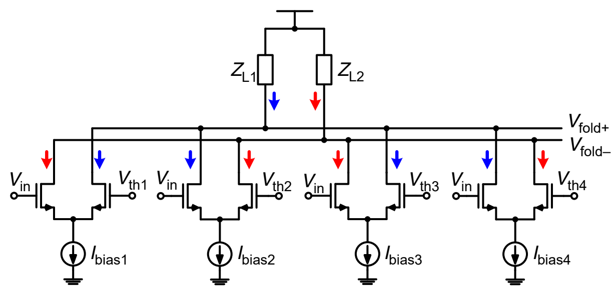

Fig. 3 *RF folder that divides input range into multiple regions with smaller signal range*

Adaption of folding points: To achieve maximum programmability while consuming a minimal area and power, combinatorial redundancy is deployed in tuning elements, including threshold voltages of the RF folders because large combinations of the intrinsic transconductance can achieve widely selectable offset voltages. Exploitation of the combinatorial randomness of process mismatch can provide high-resolution tuning steps in both voltage domain and time domain for high-speed operations [5]. The selectable elements are shown in Fig. 4 are chosen and combined to programme the folding points of each differential pair in the folding circuit in Fig. 3. Hence, input differential pairs of the RF folders with different combinations can quickly adapt to the desired signals in changing environments.

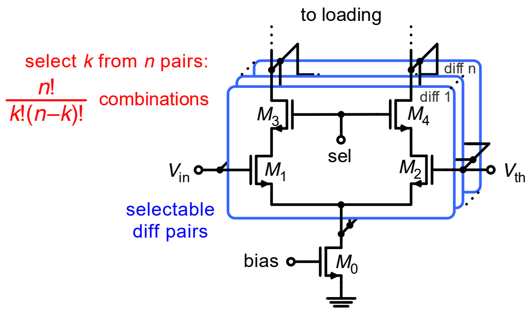

Fig. 4 *Combinatorial redundancy that is utilised in the differential pairs of the RF folders*

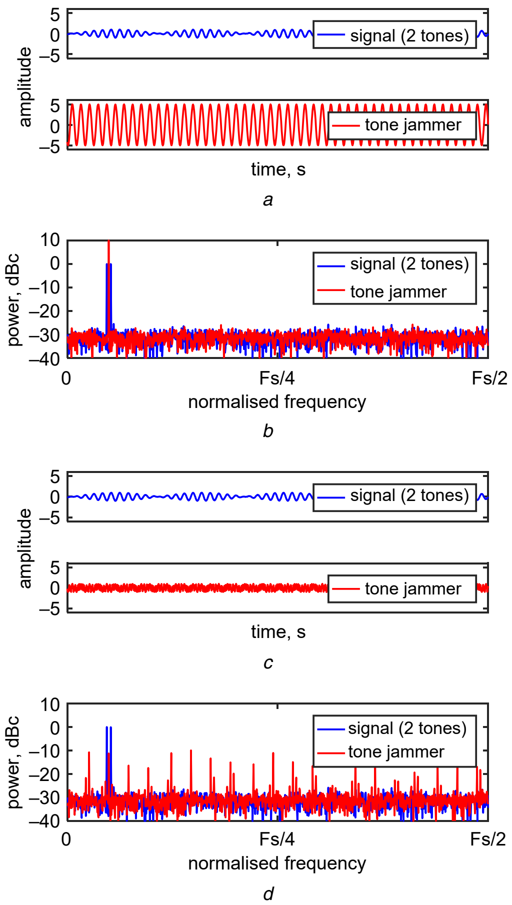

Fig. 5 *Simulation results of proposed RF folding structure*

a Received signals that are corrupted by tone jammers
b Spectrum of corrupted signals
c Folded in-band tone jammer while the integrity of desired signal is preserved
d Spectrum of four-segment folder that shows suppression of in-band strong interference

Simulation results: Simulation results of four folds are shown in Fig. 5. Fig. 5*a* depicts an example of the received complex signals in a multiple-user communication network: received signals (in blue) are corrupted by tone jammers (in red). Fig. 5*b* shows spectrum of received signals corrupted by strong in-band tone jammers. Fig 5*c* illustrates that folding attenuates in-band tone jammers while preserving the integrity of the desired signal. Fig. 5*d* presents the simulation result of an example four-segment folder that shows in-band strong tone jammer suppression in the spectrum. The in-band interference is efficiently mitigated and moved to high frequencies after the RF folder while the desired two-tone signals remain in the same strength. Higher in-band interference suppression is expected to achieve with more folds. The simulation results show the ability of the presented folded front-end for in-band interference suppression, where the tone jammer is moved outside of signal band through folding and filtering.

Conclusions: A front-end adaptive folder with a filter is presented to instantaneously push jammers to higher frequencies while preserving the integrity of small signals of interest. Combinatorial randomness is deployed as tuning elements to change threshold voltages of RF folders to achieve maximum programmability with a minimal increase of area and power. By suppressing the interference near the input of radios, the presented architecture can efficiently avoid saturation and distortion at RF front-end.

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One or more of the Figures in this Letter are available in colour online.

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