Project Title:	**Design of integrated RF front-ends with an increased robustness to parasitic signal feedthrough**
Project Number	**IMURA0756**

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Research Academy Themes:

Highlight which of the Academy's Theme(s) this project will address?
(Feel free to nominate more than one. For more information, see www.iitbmonash.org)

1. Advanced computational engineering, simulation and manufacture
2. Infrastructure Engineering
3. Clean Energy
4. Water
5. <mark>Nanotechnology</mark>
6. Biotechnology and Stem Cell Research
7. Humanities and Social Sciences

The research problem

Since the introduction of the superheterodyne receiver, patented in 1917 by Edwin Armstrong, electronic mixers are used in a multitude of electronic applications requiring one or more frequency translations. Also identified as multipliers because of their operation, mixers multiply two signals with different frequencies in the time domain, hereby resulting in output signals lying at the fundamental as well as at the sum and difference frequencies. Because of this multiplication, any circuit exhibiting a second order nonlinearity and through which two or more arbitrary signal frequencies are routed, generates sum and difference frequencies: often undesirable (since this

causes signals to spread in adjacent channels), this property is identified as cross modulation. Consequently, mixers based on a nonlinear operation are therefore usually avoided because they tend to generate spurious components that are difficult to filter. However, since active devices are inherently nonlinear, it is important to realize that every signal coupling parasitically in a transistor circuit may cause cross modulation because of the transistor's intrinsic nonlinearity: for this reason, any feedthrough from the RF signal or from the local oscillator to the mixer or other subcircuits is highly undesirable and should be avoided.

Mixers are nowadays usually designed as active multipliers: in particular, mixers in superheterodyne radio receivers multiply the local oscillator (LO) signal with the radio frequency (RF) signal that has been received by the antenna, generating a sum or difference component lying at the chosen intermediate frequency (IF), hereby allowing the demodulation to occur at the latter frequency. In direct conversion receivers (also called zero-IF receivers), the precision of the LO signal is even more crucial since any deviation of the LO frequency from the RF carrier frequency results in large demodulation errors as well as a considerable DC and low frequency offset that can cause disturbances or even worse, pull the receiver front end out of its operating region. To summarize, the precision of the receiver is highly dependent on the accuracy of the generated oscillator signal (phase noise), as well as on the various mixer design parameters (like linearity, noise figure, matching and isolation).

[1] T. Lee, "The design of CMOS radio-frequency integrated circuits", Cambridge University Press, 2nd edition, 2004.
[2] J. Rogers and C. Plett, "Radio frequency integrated circuit design", Artech House Publishers, 2nd edition, 2010.

Project aims

Because the LO signal power is usually much larger than the RF signal power, any LO signal coupling to the demodulation stage might disrupt the correct operation of the demodulator by causing cross modulation, or even by forcing the circuit out of its correct operating region. Equally harmful, the large LO signal might leak to the antenna, where it can radiate, disturb and interfere with neighbouring receivers. As can be appreciated in above explanation, LO feedthrough of any kind is highly undesirable, and should therefore be minimized at all costs. RF feedthrough is a considerable problem as well, since it causes frequency components located at the RF carrier frequency to appear at the output of the mixer. Active balanced mixer topologies cancel either LO either RF feedthrough, depending on how LO and RF signals are connected to the circuit. Double balanced mixers, also called Gilbert mixers, theoretically cancel LO and RF feedthrough: unfortunately, owing to nonidealities and to mismatches, a finite amount of feedthrough is still present. Feedthrough between the LO and the RF ports is equally harmful as it introduces reradiation through the front end or through the antenna, as explained above. It should be noted that the latter problem is even worse for direct conversion receivers, where the RF carrier and LO frequencies are the same: any LO leaking to the front end or to the antenna will self-mix with the original LO signal, hereby potentially generating very high DC levels, forcing the analogue front-end out of its operating region.

Very often, mixers and frequency synthesizers are studied and designed separately, and eventually placed together on a chip. Basic layout precautions (symmetry, shielding, guard rings close to sensitive transistors, separate supply lines and bondpads, use of buried layers, on chip decoupling …) as well as design techniques (fully differential designs, improvement of matching, use of cascode and shielding devices, …) mitigate the effect of parasitic coupling and feedthrough: however, although previously listed precautions are highly recommended, they may not be sufficient to guarantee a faultless operation. The specific aim of this project is to design and develop voltage controlled oscillators (VCO's) and mixer combinations for WiFi and WiMAX systems which present an inherent high degree of immunity against LO and RF feedthrough. By studying and identifying the potential interference problems appearing by the interaction between both the mixer and the frequency synthesizer building blocks, parasitic coupling paths between the LO, RF and IF ports will be identified and quantized. Once these coupling mechanisms are fully understood and described mathematically, new topologies will be put forward, and corresponding design rules will be derived and refined.

Expected outcomes

The expected outcomes from this project are threefold: *Highli*

- *Firstly, mixer – local oscillator circuit topologies for WiFi and WiMAX systems with a high isolation against RF and LO feedthrough will be studied and developed. These topologies will be verified with simulations, and two test chips will be designed corroborating the theoretical simulations with actual measurements during the course of this Ph. D. project.*

- *Secondly, the student participating in this research project will be required to publish his or her circuits in highly ranked journals and conferences, in order to disseminate and share with the international academic community the achieved results of this project. Moreover, in case suitable inventive ideas come out of this project, joint patents will be applied for.*

- *Thirdly, a set of general mathematical properties and design guidelines for achieving a high LO and RF isolation will be derived from the achieved findings. These design guidelines will prove to be very valuable when comparing various existing mixer and frequency synthesizer topologies for WiFI and WiMAX, and categorizing their susceptibility to LO and RF feedthrough.*

How will the project address the Goals of the above Themes?

This project proposal is situated in the domain of micro and nanotechnology, and will explore ways to improve the basic limitations in existing mixer and frequency synthetisation topologies for WiFi and WiMAX systems owing to LO and RF feedthrough. The approach that will be followed in this project is to identify the existing major parasitic paths in mixer and local oscillator topologies, and to subsequently develop design topologies that possess an innate immunity against LO and RF feedthrough by mitigating, cancelling or circumventing the existing parasitic paths. This knowledge will contribute in designing robust integrated transceiver architectures.

Capabilities and Degrees Required

Candidates should have a MEng or BEng, and have taken CMOS and VLSI design courses. Experience with EDA design tools like Cadence or Tanner is a definite bonus. Candidates should be assertive, problem solvers, passionate about analogue and mixed-signal IC design and willing to work independently.

Potential Collaborators

TBD

Please provide a few key words relating to this project to make it easier for the students to apply.

Radio frequency integrated circuit design, mixed-signal integrated circuit design, CMOS.