Novel RF/Microwave Circuits And Systems for Lab on-Chip/on-Board Chemical Sensors

Recent research focuses on expanding the use of RF/Microwave circuits and systems to include multi-disciplinary applications. One example is the detection of the dielectric properties of chemicals and bio-chemicals at microwave frequencies, which is useful for pharmaceutical applications, food and drug safety, medical diagnosis and material characterization. Dielectric spectroscopy is also quite relevant to detect the frequency dispersive characteristics of materials over a wide frequency range for more accurate detection. In this dissertation, on-chip and on-board solutions for microwave chemical sensing are proposed.

An example of an on-chip dielectric detection technique for chemical sensing is presented. An on-chip sensing capacitor, whose capacitance changes when exposed to material under test (MUT), is a part of an LC voltage-controlled oscillator (VCO). The VCO is embedded inside a frequency synthesizer to convert the change in the free runing frequency of the VCO into a change of its input voltage. The system is implemented using 90 nm CMOS technology and the permittivities of MUTs are evaluated using a unique detection procedure in the 7-9 GHz frequency range with an accuracy of 3.7% in an area of 2.5 x 2.5 mm2 with a power consumption of 16.5 mW. The system is also used for binary mixture detection with a fractional volume accuracy of 1 - 2%.

An on-board miniaturized dielectric spectroscopy system for permittivity detection is also presented. The sensor is based on the detection of the phase difference between the input and output signals of cascaded broadband True-Time-Delay (TTD) cells. The sensing capacitor exposed to MUTs is a part of the TTD cell. The change of the permittivity results in a change of the phase of the microwave signal passing through the TTD cell. The system is fabricated on Rogers Duroid substrates with a total area of 8 x 7.2 cm2. The permittivities of MUTs are detected in the 1-8 GHz frequency range with a detection accuracy of 2%. Also, the sensor is used to extract the fractional volumes of mixtures with accuracy down to 1%.

Additionally, multi-band and multi-standard communication systems motivate the trend to develop broadband front-ends covering all the standards for low cost and reduced chip area. Broadband amplifiers are key building blocks in wideband front-ends. A broadband resistive feedback low-noise amplifier (LNA) is presented using a composite cross-coupled CMOS pair for a higher gain and reduced noise figure. The LNA is implemented using 90 nm CMOS technology consuming 18 mW in an area of 0.06 mm2. The LNA shows a gain of 21 dB in the 2-2300 MHz frequency range, a minimum noise figure of 1.4 dB with an IIP3 of -1.5 dBm. Also, a four-stage distributed amplifier is presented providing bandwidth extension with 1-dB flat gain response up to 16 GHz. The flat extended bandwidth is provided using coupled inductors in the gate line with series peaking inductors in the cascode gain stages. The amplifier is fabricated using 180 nm CMOS technology in an area of 1.19 mm2 achieving a power gain of 10 dB, return losses better than 16 dB, noise figure of 3.6-4.9 dB and IIP3 of 0 dBm with 21 mW power consumption.

All the implemented circuits and systems in this dissertation are validated, demonstrated and published in several IEEE Journals and Conferences.