Design for MOSIS Educational Program (Research)

Project Title:
"Electrical characterization of a 2.4 GHz Low Noise Amplifier through temperature measurements"

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Electrical characterization of a 2.4 GHz Low Noise Amplifier through temperature measurements

Project description:

A 2.4GHz Low Noise Amplifier has been design in TSMC025 technology in order to be electrically characterized by thermal measurements, for what a thermal sensor has been integrated together with the LNA.

A recent new technique has been presented, which proposes the electrical characterization of high frequency analog circuits by low frequency thermal (non invasive) measurements [Altet06][Mateo06]. It has been proved theoretically and by means of simulations, and the present project proposal is aimed to prove it experimentally.

The LNA that has been designed is a single input, single ended LNA, with inductive source degeneration and inductive matching network at the input, with an inductive choke inductor as load. All inductors are on-chip inductors. The LNA works at 2.4GHz as central frequency and the simulated voltage gain obtained is 17 dB, with a noise figure of 5 dB and 2.7 mw of power consumption.

The thermal sensor designed is a differential temperature sensor. It uses npn2 bipolar transistor in the input differential pair in order to sense temperature. To calibrate the sensor different heat sources (resistors) have been also integrated.

The objective of the project is to obtain the gain, central frequency and bandwidth of the LNA through thermal measurements by using the previously mentioned temperature sensor. The experimental results will be correlated through thermal measurements carried out by using laser reflectometer setup and a Michaelson interferometer [Altet02].

Fabrication process

The circuits has been implemented in the TSMC 0.25 micron mixed-signal technology (1P5M+SILICIDE 2.5V/3.3V). The technology code for this process is CR025 (CM025).

Packaging requirements

No packaging will be required: from previous experiences in RF design Chip on Board measurements are preferred (better control of input and output parasitics), and it allows at the same time external silicon surface temperature measurement (see Test and Characterization Plans).

Estimated project size (length and width)

The total estimated area of the design is 2 mm^2. The total estimated length and width are 1.41mm and 1.41mm respectively. These data include the 20 pads required (the design is core limited).

Simulation plans

First, the circuit level simulation of the temperature sensor is carried out by using Cadence and HSPICE environment in order to find the proper transistor dimensions to get the greatest temperature sensitivity suitable for thermal testing in RF applications. Therefore, the static and dynamic electrical responses of the sensor, as well as its performance as thermal sensor have been analyzed.

Also, the circuit level simulation is carried out by using SpectreRF in the Analog Design Environment from Cadence (version 5.033) in order to estimate the common parameters which are important in the design verification of Low Noise Amplifiers. Various analyses to determine the compromise among gain, noise, power, linearity, stability and matching performances are completed into the test-bench where the single-ended LNA is placed. An appropriate modeling of the parasitic capacitance and bondwire effects are taken into account. The expected behavior of the temperature increase on each transistor of the LNA, due to its operation, and the viability of the proposed technique we want to prove, have been carried out by using Dynamic Link between ADS and Cadence. S-parameters and Harmonic Balance analysis have been performed for this purpose.

Also, both circuits, thermal sensor and Low Noise Amplifier, are simulated with normal and corners manufacturing process variations in order to verify the performance under these process conditions. The layout of the circuits is done by using Virtuoso Layout Editor from Cadence.

Test and characterization plans

The goal of the measurements are: first, to characterize the built-in temperature sensor; second, to extract the electrical characteristics of the LNA by using classical approaches (using Network and Spectrum Analyzer connected to the input and output of the LNA); third, to obtain its electrical characteristics (specifically, central frequency and bandwidth) by measuring temperature close to the LNA by means of the integrated differential temperature sensor; and fourth, to correlate the electrical and the thermal measurements obtained. The final goal is then to demonstrate that electrical characteristics of RF amplifiers can be obtained by measuring temperature. In addition to the specific objectives of the project, we also characterize the thermal coupling through silicon substrate of the TSMC 0.25 microns technology used.

Specifically:
- Characterization of the built-in differential temperature sensor: Temperature gradients will be generated by using integrated resistors as heat sources. We will perform DC characterization and AC characterization activating the heat source with a periodic voltage source and measuring the sensor's output with a lock-in amplifier. These are similar measurements to what is reported in [Altet02].
- Electrical characterization of the 2.4 GHz LNA: the following figures of merit will be extracted: S parameters in the ISM band, voltage gain, bandwidth, current consumption and linearity.
- Following the procedure established in [Altet06][Mateo06], extraction of the bandwidth and the central frequency of the amplifier by measuring temperature using the built-in differential temperature sensor.

- Following the procedure established in [Altet06][Mateo06], extraction of the bandwidth and the central frequency of the amplifier by measuring temperature using off-chip temperature measuring systems: Laser interferometry and a laser reflectometer set-up [Altet02]. Using off-chip temperature sensors allows detecting the effect of noise coupling in the measurements performed with the built-in temperature sensor.
- Correlation of the thermal and electrical measurements and the simulation.

[Altet02] J. Altet, S. Dilhaire, S. Volz, J.-M. Rampnoux, A. Rubio, S. Grauby, L. David Patino-Lopez, W. Claeys, and J.-B. Saulnier, "Four different approaches for the measurement of IC surface temperature: application to thermal testing", *Microelectronics Journal*, vol. 33, no. 9, September 2002, pp 689-696.

[Altet06] J. Altet, D. Mateo, J. L. González, E. Aldrete-Vidrio, "Observation of High-Frequency Analog/RF Electrical Circuit Characteristics by on-Chip Thermal Measurements", *IEEE International Symposium on Circuits and Systems* (ISCAS 2006), Island of Kos, Greece. *To be published*.

[Mateo06] D. Mateo, J. Altet, E. Aldrete-Vidrio, J. L. González, "Frequency Characterization of a 2.4 GHz CMOS LNA by Thermal Measurements", *IEEE RFIC Symposium 2006*, San Francisco, CA. *To be published*.