DESIGN CONSIDERATIONS OF CMOS RF CIRCUITS FOR SAW-BASED SENSORS

Victor Miranda da Silva, Edval J. P. Santos
victorms@ieee.org
edval@ee.ufpe.br

Laboratory for Devices and Nanoestructures/DES
Universidade Federal de Pernambuco - UFPE
Caixa Postal 7800 CEP: 50711-970 Recife-PE

Abstract:

This article describes a research proposal for the development of CMOS RF circuits for SAW-based sensor applications. Surface Acoustic Wave, SAW, can be excited electrically in piezoelectric materials, and can be used to build sensors as the surface wave is sensitive to the environment. One possible technique is to use the SAW-based sensor as the feedback of an RF amplifier to build an oscillator. This research is part of the work towards the master degree.

1 Introduction

Some sensors require circuit which operate in the RF range. One such sensor is the Surface Acoustic Wave based sensor technology [WOL01]. SAW-based sensor has been used with success in many applications, such as: artificial nose, biomedical sensor, juice classification, automobile stability, etc.. Surface waves can be excited electrically in piezoelectric materials, and can be used to build sensors as the surface acoustic wave is sensitive to the environment. One possible technique is to use the SAW-based sensor as the feedback of an RF amplifier. The amplifier will oscillate if the Nyquist criterion is satisfied.

We present a research proposal for the development of CMOS RF circuits for SAW-based sensor applications. CMOS is the standard process for today VLSI digital circuits, and it is well known for its low-power and low-cost characteristics. Besides, CMOS has the advantage of decades of development, which has produced a large and reliable library of digital circuitry. As we will need both analog and digital circuits on the same substrate, CMOS was elected the process of choice.

This article is divided in five parts. The first part is this introduction. The second part describes the block diagram of a smart sensor. In the third part we present some of the available topologies for CMOS RF circuits. Next, we discuss some aspects of the master thesis research proposal. Finally, the conclusions.

2 Block Diagram of the Smart Sensor

As mentioned in the Introduction, we can build an oscillator using the SAW sensor as the delay line. The frequency of the oscillator will change as the physical or chemical quantity changes. Frequency measurements are easier to make. After calibration, the oscillator frequency change is a direct measurement of the property of interest. The basic oscillator is presented in Fig. 1.

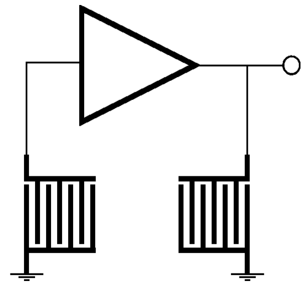


FIGURE 1 - Block diagram of the SAW-based oscillator.

Another alternative is presented in Fig. 2 [WOL 01].

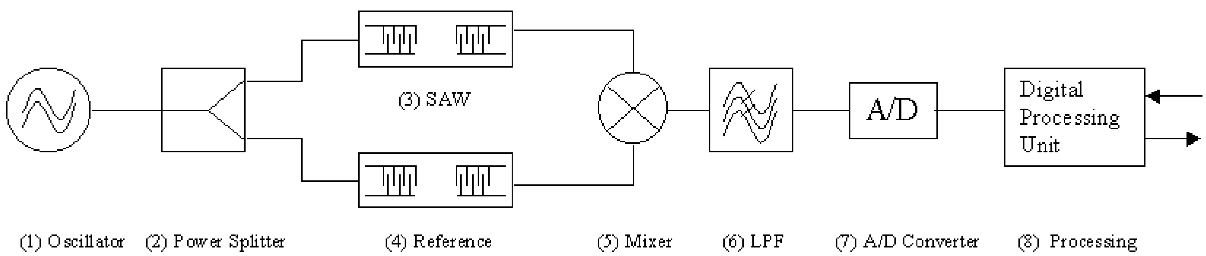


FIGURE 2 - Block diagram of the Smart Sensor.

The block diagram consists of an oscillator (1) and two SAW delay lines. One of the delay lines (4) is used as the reference. The other (3) is exposed to the environment. The two delay lines outputs are the inputs of the mixer (5). After passing through a low pass filter (6), the double frequency component is rejected. The amplitude of the low frequency signal is proportional to the difference of phase of the signal that passed through the reference and SAW delay lines paths. Then, the low frequency signal can be easily converted by an analog to digital converter (7) and processed by the digital circuit (8). The Digital-Processing unit can interact with the user or be communications unit for sensor network applications.

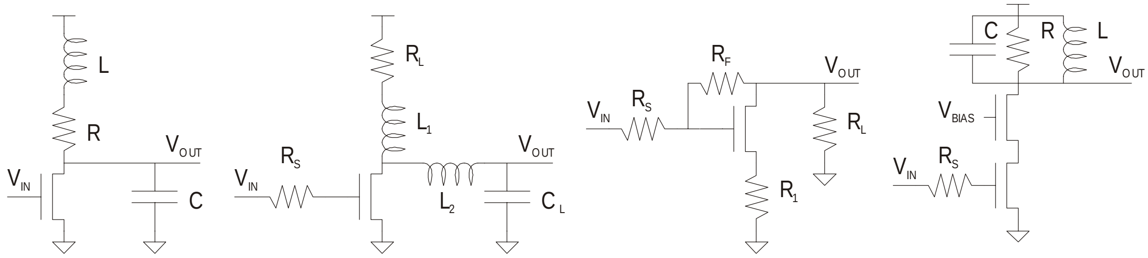
As the center frequency of the SAW sensor is in the RF range, we need RF amplifier, oscillator, and mixer circuits.

3 CMOS RF Circuits Topologies

RF circuit design is much more involving than at lower frequencies, especially because of the extreme care to avoid parasitics and impedance matching. In integrated circuits, one can add the poor or limited electrical characteristics of the passive elements available. For example, in tuned amplifier and LC oscillators, high Q inductors are needed. Unfortunately, inductors larger than 10nH consume significant die area and have low Q (typically below 10) and low self-resonant frequency [LEE 98]. Another key design point is to improve the high-frequency performance constraint imposed by the parasitic capacitances and inductances.

It will be important in the early stage of the design process to study in detail several topologies of circuits. From this study we will understand limitations and differences of the circuits together with implementation considerations.

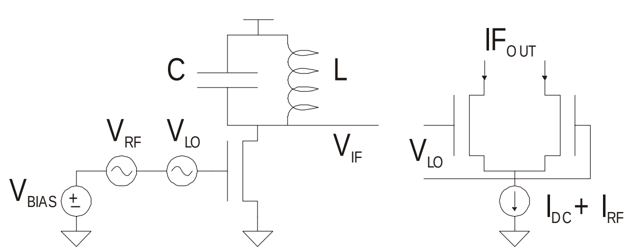
In Fig. 3 are shown some amplifier topologies for high-frequency amplifier design [LEE 98]. The first one (Fig. 3a) is a shunt-peaked amplifier. This amplifier is a standard common-source configuration, with the addition of the inductance that provides bandwidth enhancement. Shunt peaking is a form of bandwidth enhancement in which a one-port network is connected between the amplifier proper and the capacitive load. If a series inductor is used to perform this separation, the overall result is a combination of shunt and series peaking (Fig. 3b). An alternative approach is to use negative feedback and a particularly useful example is the shunt-series amplifier shown in Fig. 3c. Where it is not necessary to provide gain over a large frequency range we can use tuned amplifiers. Additionally, we can use the cascoding technique with tuned amplifiers. Cascoding works removing the coupling between input and output ports, and eliminates the Miller effect. An example of cascode amplifier with single tuned load is shown in Fig. 3d.



(a) (b) (c) (d)

FIGURE 3 – Amplifier topologies.

Mixer circuits can be implemented as a multiplier or using the amplifier nonlinearity [LEE 98]. In both cases, one gets a multiplication operation. The mixer multiplies both input signals generating a signal with frequency equal to the difference of the two input frequencies. The first example (Fig. 4a) uses the MOSFET as the nonlinear device. The signal multiplication can be performed in the current domain. A mixer employing this technique is sketched in Fig. 4b.



(a) (b)

FIGURE 4 – Mixer topologies.

Finally, we must analyze some classical oscillator configurations, such as Colpitts, Sony, Hartley, Clapp, etc..

4 Research Proposal

The focus of this research is the implementation of an 100MHz RF amplifier in a standard CMOS process. The circuit topologies need to be carefully studied in terms of its characteristics and limitations. One has to have the application in mind to identify the necessary optimization in the circuits. For example, in [ROF 95] their communication system employs an FSK modulation technique (meaning constant envelope signal) and the power amplifier linearity could be disregarded. In this way, the power amplifier module designed for that system was optimized for high efficiency and low cost rather than high linearity and high power.

It will be necessary to examine the constraints imposed by CMOS process in the circuit performance and choose the optimum CMOS process. Laying out the circuit requires special attention and careful considerations, especially because of distributed resistance-capacitance of the interconnecting wires and junction capacitances of the diffusion areas. Last but not the least, we will need to learn characterization techniques and fundamentals of RF printed-circuit board layout design.

We summarize here some subjects to master in the CMOS RF field:

- Basics of RF circuits topologies
- Design techniques
- CAD tools
- PC board design and chip testing

5 Conclusion

We presented in this article a research proposal for development of CMOS RF circuits for SAW-based sensors applications. We have pointed out the necessity of starting the study of basic building blocks to examine their performance and select the best topology for the application. We also listed several points that we will be taken into account in the design and implementation stages.

6 References

[WOL 01] Wolff, Ulrich; Dickert, Franz L.; Fischerauer, Gerhard K.; et al. "SAW Sensors for Harsh Environments." ***IEEE Sensors Journal***, vol. 1, n. 1, June 2001, p 4-13.

[LEE 98] LEE, Thomas H. ***The Design of CMOS Radio-Frequency Integrated Circuits***. London: Cambridge University Press, 1998.

[ROF 95] Rofougaran, Maryam. "A 900 MHz RF Power Amplifier in 1 um CMOS for a Spread-Spectrum Communication Transceiver." M.Sc. Thesis. Los Angeles: University of California, 1995.