CMOS RF AMPLIFIER FOR SAW-BASED INTEGRATED SMART SENSOR

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Abstract— **SAW-based sensors have high insertion loss, around $-10\,\text{dB}$ to $-30\,\text{dB}$, and typically are designed to operate within the $100-500\,\text{MHz}$ range. These specifications represent key issues when designing a CMOS RF amplifier to use with these sensors. We have designed and implemented an integrated amplifier with $+20\,\text{dB}$ gain and tuned to $250\,\text{MHz}$ in $0.6\,\mu$m CMOS technology from AMS. We have also realized a discrete version with the *BF961* MOSFET.**

Keywords— **amplifier, SAW, RF**

1. INTRODUCTION

There is a special interest in Surface Acoustic Wave (SAW) based sensors, because they present high sensitivity and low-power consumption, making them good candidates for portable smart sensor implementation. One possible detection technique is to build an oscillator with an SAW sensor feedbacking an RF amplifier (fig. 1). Thus, the oscillator frequency change is a function of the desired quantity. This work deals specifically with the development of a CMOS RF amplifier to use with this class of sensors. The $100 - 500\,\text{MHz}$ range is a key issue on this design, because to get the desired frequency performance in the RF range, it is common to use inductors. Unfortunately, taking into account current technology, the inductance values for integrated inductors are inadequate. However, using careful design and layout considerations, we have designed and implemented an integrated amplifier with $+20\,\text{dB}$ gain and tuned to $250\,\text{MHz}$. The design is carried out in $0.6\,\mu$m CMOS technology from Austria Mikro Systeme (AMS). We have also realized a discrete version with the *BF961* MOSFET. Both amplifiers can be used, together with an SAW resonator, to build an oscillator for gas detection. This paper is divided in five sections, this introduction is the first, next the integrated amplifier is described. Third, the discrete version is presented. Next, the results and analysis are presented. Finally, the conclusions.

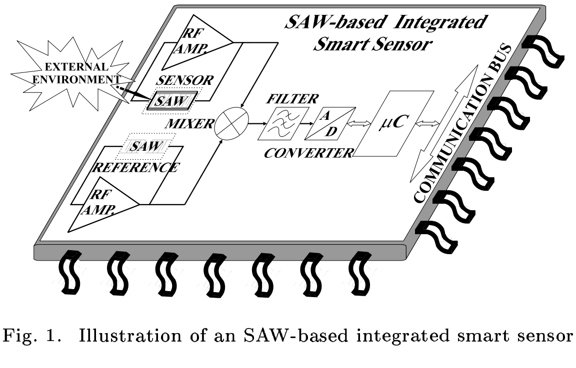

Fig. 1. Illustration of an SAW-based integrated smart sensor

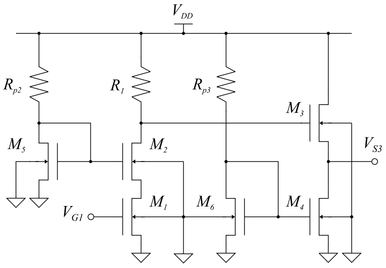

Fig. 2. Schematic diagram of the integrated amplifier

2. INTEGRATED AMPLIFIER

The integrated amplifier specifications were derived from a commercial SAW resonator. The amplifier open loop gain must take into account [1]: insertion loss of the SAW device ($\sim 10\,\text{dB}$), gain margin to ensure a quick and reliable oscillation startup ($\sim 6\,\text{dB}$), and additional mismatching and loss ($\sim 4\,\text{dB}$). As a result, the amplifier open loop gain must be greater than $20\,\text{dB}$ at $250\,\text{MHz}$. The reflection coefficient has been established as less than $-10\,\text{dB}$, in compliance with Rofougaran [2]. We have chosen the input/output impedance of the amplifier equal to $50\,\Omega$ because it is the characteristic impedance of measurement equipment, and the power supply voltage as $5\,\text{V}$.

However, the amplifier has also to be designed in order to satisfy the requirements of an oscillator for SAW sensors. The resolution and lower detection limit of the sensor depend strongly from the oscillator frequency stability.

Following Vellekoop et al. [3], the short-term stability, if an automatic gain control is used to keep the oscillator output voltage $v_0(t)$ at a constant amplitude, is defined as:

$$\text{Stability} = \frac{1}{\omega_0}\left[\overline{(\Delta\omega)^2}\right]^{1/2} = \frac{A}{\omega_0\tau}\left[\frac{S_n}{2T\overline{v_0^2(t)}}\right]^{1/2}. \tag{1}$$

From equation (1) we found that in order to increase short-term stability, we must reduce spectral density of noise of the amplifier (S_n). The other parameters are fixed by design constraints. Therefore, we have chosen for this design, an unilateral cascode amplifier [4]. The schematic diagram of the integrated amplifier is shown on fig. 2. Transistors M_1 and M_2 make the cascode common source gain stage with passive load, R_1, and the output stage is a source follower amplifier, M_3. The remaining components make the bias network.

The IC layout was drawn using ICStation© tool from Mentor Graphics Co. The “CACTUS” IC layout,

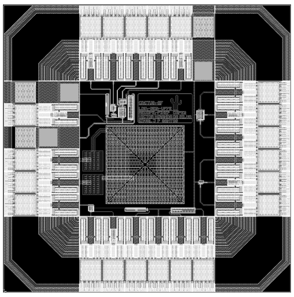

Fig. 3. Layout of the CACTUS IC

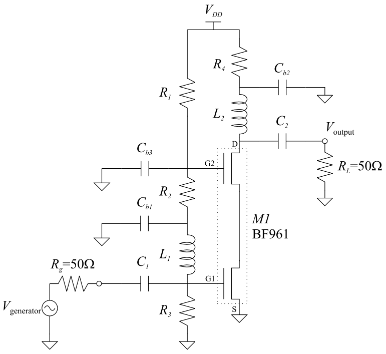

Fig. 4. Schematic diagram of the discrete amplifier

as we named the chip, is presented in fig. 3. It contains the integrated amplifier plus testing devices.

3. DISCRETE AMPLIFIER

As a complementary test, we have implemented a discrete version (fig. 4) of the amplifier, using the *BF961* transistor.

4. RESULTS AND DISCUSSION

4.1. Integrated Amplifier

After proper matching input and output ports of the amplifier, the simulated transmission (S_{21}) and reflection (S_{11}) coefficients in the $100-400$ MHz range were obtained for both schematic and layout, as presented in fig. 5. The results indicate that the simulated gain, S_{21}, satisfy the design specifications. Although, only a reflection coefficient around or less than -10 dB is considered adequate. Therefore, only the schematic simulated result meets this requirement. Comparing input impedances of both schematic and layout simulation results, we note that real part of $Z_{\text{input}}^{\text{layout}}$ has a very low value, $0.76\,\Omega$, which results in poor matching when compared to $50\,\Omega$. We have tried some matching configurations, such as an inductive source degeneration [4], but all with any major improvement. The chip is ready and we expect to receive it soon to confirm the results obtained. Then, we can proceed with the appropriate impedance matching.

4.2. Discrete Amplifier

The open loop frequency response of the discrete amplifier (fig. 4) has been measured with the M140001

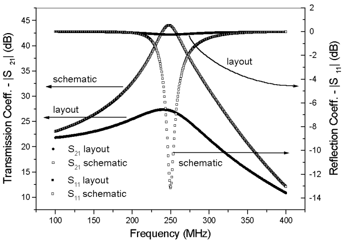

Fig. 5. Simulated frequency response of the integrated amplifier

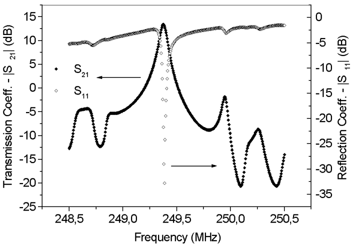

Fig. 6. Measured frequency response of the discrete amplifier with M140001 resonator

SAW resonator connected at its output.

5. CONCLUSIONS

We have presented the design of MOS RF amplifiers for SAW-based sensors. We have designed and implemented two amplifiers versions, one discrete and the other integrated. We have verified that the layout simulated reflection coefficient result is insufficient. Although, the critical issue is to obtain enough gain at desired frequency. The integrated circuit has been fabricated using $0.6\,\mu$m CMOS process from AMS. The discrete version of the amplifier circuit has been tested with a commercial SAW resonator and the results obtained are adequate.

6. ACKNOWLEDGMENTS

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