PhD research activity – Final report

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Research topic: Advanced CMOS IC Design Techniques for Optimizing the Baseband Analog Front-End of Mobile Phones

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Summary

Nowadays, the desire to always be connectable by a communication device is larger than ever, thus growing the needs for the development of circuits that will make the dream of this Global Village a reality. Mobility, while remaining reachable at all the time, is possible with the use of wireless communications that have the common characteristic of having a limited power source in the battery. This pushes to improve the circuit techniques to increase the portable electronic device autonomy. A higher autonomy makes a product more usable, lighter (because a smaller battery is necessary), and much more appealing to the consumer. Systems with a higher functionality, higher capacity and a slick design are only possible if power consumption is reduced to a minimum. Furthermore, new products are developed on a regular basis. As a consequence, system integrators and everyone working in such a competitive environment see their time-to-market as a small window of opportunity. All design steps until the product reaches the shop shelves have to be optimized. Usually, the first steps in the engineering development require a large percentage of this time, which has to be minimized to keep costs low.

The presented work has been developed in cooperation between the R&D department of ST-Ericsson Switzerland and the University of Rome “Sapienza”. It covers the modeling, analysis, design, optimization and IC characterization of two different analog and mixed-signal sections of today’s baseband front-end of mobile phones: the audio subsystem and the power management unit (PMU). The final goal is to optimize the two sub-sections in terms of efficiency, performance and area reduction, pushing the overall integration and costs to a leading edge level.

In the first part, concerning the audio subsystem, the following topics have been addressed:

- The design of a class-AB/D audio power amplifier in standard 65nm CMOS technology for direct battery hook-up. Circuit techniques are used to overcome the voltage limitations of standard MOS transistors for operation at voltage levels of 2.5V-4.8V. Both amplifiers can drive more than 650mW into an 8Ω load with distortion levels of 1\% and 5\% for class-D and class-AB, respectively, all from a 3.6V power supply. The achieved power-supply-rejection ratios (PSRR) are 72dB and 84dB, respectively. The stereo implementation of both amplifiers together is smaller than 0.5mm\textsuperscript{2}.
The design of a fully integrated solution for a single speaker mobile application. It makes use of a capacitor-free low-dropout regulator (LDO) which shares the pass device with the output audio power stage, allowing high quality performances for both hands-free and receiver modes and high power for hands-free. The system is capable of delivering 1W in hands-free operation, and 80mW in receive with 118dB of PSRR and 0.06% of THD. The whole design has been implemented using TSMC 45nm CMOS technology.

A novel topology for a micro-machined acoustic speaker suitable for cellular phones. The membrane is composed of two materials, both of them with different functions: a silicon moving part acting as a rigid piston and a polymer annulus acting only as suspension. The high ratio between Young moduli and masses of membrane and suspension leads to a simpler design of the mass-spring-damper system. This new topology can be obtained thanks to a new micromachining technology that leads to a higher adhesion between polymer and silicon. Simulations presenting the main micro-loudspeaker parameters (e.g. SPL, frequency response) are presented in detail as well as in the principal technological steps.

In the second part, for the PMU section, several topics are presented as well:

A fully independent ground referenced power management unit (GRPMU) for headset audio, made up of two linear regulators and a regulated charge pump providing symmetrical power supply for the headset audio amplifier. It aims to reduce the cost of the external components as well as to improve the integration level. It has been implemented in standard CMOS 65nm technology. Details on the architecture and the final measurement on silicon are presented. As improvement for the GRPMU system, an innovative inverting charge pump on a series-parallel architecture is presented as well. Implemented in 40nm CMOS technology, all the details of the architecture and the final measurement on silicon are shown, highlighting great performance in terms of efficiency and THD when applied as negative power supply for high quality earphone audio amplifiers.

An ultra-low power, integrated coulomb counter gas gauging system which is able to consume only 40µA during sleep mode with good accuracy; it is implemented in 45nm CMOS technology.

A 1.2A DCDC boost converter with integrated NMOS switch for delivering higher audio power, compatible with low voltage battery standard, showing about 80% efficiency, implemented in 45nm CMOS technology.

All the circuit design work has been designed, simulated and measured in the R&D department of ST-Ericsson Switzerland, using edge CMOS technology and packaged in ST-Microelectronics in Crolles (France). In the case of the microspeaker design, the sample has been manufactured in the Electronic Engineering Department of the University of Rome “Sapienza” with the help of Prof. Balucani.
Research overview and contributions

For each application, complexity and performance must be carefully weighed against power consumption. Even though the desire is to integrate as much as possible, one must remember that this might not always lead to a more power efficient circuit. Each one of the available technological options, when properly combined, offer not only the desired increased battery autonomy but also a lower cost. The research work that is now completed has contributed, amongst others, the following results:

- An high quality, fully integrated and totally flexible audio solution in terms of a 700mWrms class AB/D amplifier together with a ground referenced power management unit which are today integrated in millions of phones in the market;
- A fully integrated solution for low end market phones which require the usage of a single speaker solution;
- A novel inverting charge pump for future and more efficient ground referenced audio solutions;
- A high power DCDC boost converter with integrated switch for providing more than 1Wrms audio power for the hands-free melodies.

The analysis, simulation, optimization and measurement of audio and power management circuits in CMOS have been discussed in this thesis. Several steps towards extreme integration have been shown, highlighting what can still be further investigated. It was shown that it is possible to achieve high power, high voltage design in leading edge CMOS technologies without any change in the process flow and several high voltage design tricks have been presented.

Possibilities for future work

Future research can continue, either incrementally from the point where the presented study has left off or by pursuing one of the following suggestions. High performances can be obtained in a relatively inexpensive technology like CMOS, but the main advantages arise from the possibility of integrating a full system on a chip. Nevertheless, the fact should be stressed that the most difficult thing in any design like the ones presented in this work is measuring. Without measurement results this type of work is unfinished, even though this is sometimes a disregarded issue. Advancements can come both from integration, where the final product design is eased, and by increasing the performance of a single block. Several issues can be addressed and different research paths can be followed, of which the following seem interesting to dedicate more time to:

- Single speaker application has not been implemented yet on silicon and this can be the first thing to be tried for use in the future, following the guidelines showed in this work and then having the chance of measuring concrete results;
- First important steps towards a possible integration of a micro-speaker as MEMS device has been presented. This work can continue further with a CMOS technology allowing MEMS device integration, which today is not available within ST-Ericsson;
- The DCDC boost converter can undergo a further integration, through diode on silicon for example.
List of publications


• F. Neri, W. Groeneweg, M. Balucani, “Power Management Unit for a Ground Referenced Audio Amplifier for Mobile Phones in 65nm CMOS”, IEEE Melecon 2010 conference, Malta


• F.Neri, F.di Fazio, M.Balucani, R.Crescenzi, “A Novel Topology for a Micromachined Loudspeaker”, ECTC 2011 conference, Florida (USA)

• S.Perticaroli, F.Neri, F.Palma, M.Balucani, “4.55GHz phase and quadrature pulsed bias VCO in 40nm CMOS technology”, Ph.D. Research in Microelectronics and Electronics (PRIME), 2011 7th Conference on, 3-7 July 2011