

## **Sensing, Sampling, Quantization, and Information Theory – A Practical Approach**

*By Marco Tartagni and Alessandro Piovaccari, Alma Mater Studiorum–Università of Bologna*

At the base of any sensing, or measurement in general, lies the concept of resolution, which determines the intrinsic limits of any acquisition process. This concept, originally defined in terms of DC measurements, would be better defined for signals that are intrinsically stochastic. Through a stochastic definition of resolution based on information theory, it is possible to introduce design frameworks that allow to optimize the full acquisition chain from the sensing element, through signal conditioning, all the way to the sampling and quantization (analog/digital conversion).

This tutorial will start with an intuitive review of the fundamental theoretical and practical concept of sensing, sampling, quantization, and information theory, followed by a description of the afore mentioned optimization process as well as application examples of design and optimization of acquisition chains. It will be shown how is it possible, by changing targets, to obtain different designs optimized in terms of sensitivity, cost and power consumption. Finally, it will be shown how these concepts can provide approximate solutions that can be used in the design and modeling of building blocks like signal quantizers and delta-sigma converters, avoiding the use of hard mathematical concepts like special functions, and providing a more intuitive view. More examples will be provided, including the determine of the gain of a quantizer in a delta-sigma loop and the use of dynamic element-matching.

## Short bios

**Marco Tartagni** obtained his M.S. in EE and a Ph.D. in EECS from the University of Bologna, Italy. In 1992, he joined the EE Department at Caltech in Pasadena, CA, initially as a visiting student and later in 1994 as a research fellow. During his time there, he focused on various aspects of analog VLSI for image processing.

Since 1995, he has been a faculty member in the EE Department at the University of Bologna, where he currently holds the position of Full Professor. From 1996 to 2001, he was a team leader in the collaborative laboratory between STMicroelectronics and the University of Bologna. His work during this period involved the development of intelligent CMOS sensors, including CMOS cameras and the world's first prototype of a silicon-based fingerprint capacitive sensor. He is currently focusing his research on sensor design theory and Machine Learning assisted spectral sensing.

Marco Tartagni is a co-recipient of the IEEE Van Vessel Outstanding Paper Award, which he received at the 2004 ISSCC Conference. He has also taken on the role of European coordinator for the FP6 Receptronics project in the field of Nanoelectronics. Furthermore, he has served on the scientific committees of the IEEE Custom Integrated Circuit Conference (CICC) from 2017 to 2021 and the IEEE International Electron Device Meeting (IEDM) since 2023.

**Alessandro Piovaccari** is an Adjunct Professor and Visiting Fellow at the University of Bologna. He is the VP of Conferences for the IEEE Solid-State Circuits Society, a board member CTO Council of the Global Semiconductor Alliance, the Center for Leadership Education at the Johns-Hopkins University, and UTeach at the University of Texas at Austin. He is also an advisor for the Berkeley Skydeck and Silicon Catalyst startup incubators, and part of the technical advisory board of several semiconductor startups. He has more than 25 years of technical and management experience in the semiconductor industry, including CTO and SVP of Engineering at Silicon Labs. He co-architected and led the development of many wireless and IoT SoC integrated circuits, which have surpassed the 4 billion devices shipments. Most notably, the first worldwide single-chip TV tuner IC, still used by nine of the world's top-ten TV makers, and 80 percent market share. He has been a long-time contributor for the IEEE Custom Integrated Circuits Conference, covering the role of TPC Chair in 2015 and being part of the Steering Committee from 2015 to 2022.

Alessandro received his PhD and Laurea degrees in EECS from the University of Bologna and a Post-Grad certificate (summa cum laude) in EECS from the Johns-Hopkins University. He is a Senior Member of IEEE and Lifetime Fellow at Silicon Labs. He received an IEEE SSCS award in leadership for organizing the first virtual solid-state conference. He holds 32 US patents, including a Patent of the Year award.