CMUTs: Theory, Technology, and Applications

B. T. Khuri-Yakub, O. Oralkan, and M. Kupnik
E. L. Ginzton Laboratory
Stanford University, Stanford CA 94305-4088

This course provides basic knowledge and understanding of capacitive micromachined ultrasonic transducers (CMUTs) and their applications.

After a short background discussion of previous implementations of capacitive ultrasonic transducers, we will provide all the information necessary for the successful design of a CMUT: The simple parallel plate capacitor transducer and its electrical equivalent circuit model will be explained in detail, including the derivation of all essential design equations, and the theoretical device performance limits. This is followed by developing an approximate analytical model which better represents the realizable membrane of a CMUT. A motivation for a more sophisticated finite element model is given, and the key techniques of finite element analysis based CMUT designs are explained and demonstrated using brief examples. Next, we compare and contrast CMUTs that are designed for airborne and immersion applications. Only for immersed operation the periodic structure of a CMUT array needs to be considered to minimize parasitic cross-talk effects. Two acoustic cross-talk modelling techniques will be discussed for that purpose.

Then, the two main CMUT fabrication techniques, *i.e.* sacrificial release and direct wafer bonding, are explained and compared to each other. Next, we discuss device characterization which will cover electrical, mechanical and ultrasonic measurements: optical interferometer, electrical input impedance, output pressure, receive sensitivity, impulse response and dynamic range. As part of the electrical characterization we will discuss the design and implementation of low noise front end electronics and the need for their integration in the vicinity of the CMUT.

Besides an overview of several CMUT applications, we conclude the course by giving two detailed design examples, one for an airborne device for chemical/biological sensing applications and one for medical imaging applications.

Butrus (Pierre) T. Khuri-Yakub is a Professor of Electrical Engineering at Stanford University. He received the BS degree in 1970, the MS degree in 1972, and the Ph.D. degree in 1975, all in electrical engineering. He has been a Professor of Electrical Engineering at Stanford University since 1982. His current research interests include medical ultrasound imaging and therapy, micromachined ultrasonic transducers, smart bio-fluidic channels, ultrasonic fluid ejectors, and ultrasonic nondestructive evaluation, imaging and microscopy. He has authored over 500 publications and has been principal inventor or co-inventor of 76 US and International issued patents. He was awarded the Medal of the City of Bordeaux in 1983 for his contributions to Nondestructive Evaluation, the Distinguished Advisor Award of the School of Engineering at Stanford University in 1987, the Distinguished Lecturer Award of the IEEE UFFC society in 1999, a Stanford University Outstanding Inventor Award in 2004, and a Distinguished Alumnus Award of the School of Engineering of the American University of Beirut in 2005.

Ömer Oralkan received his B.S. degree from Bilkent University, Ankara, Turkey, in 1995, his M.S. degree from Clemson University, Clemson, SC, in 1997, and his Ph.D. degree from Stanford University, Stanford, CA, in 2004, all in electrical engineering. He joined the research staff at the E. L. Ginzton Laboratory of Stanford University in 2004 as an Engineering Research Associate. He was promoted to the rank of Senior Research Engineer in 2007. His past and present research interests include analog and digital circuit design, semiconductor device physics and fabrication, micromachined sensors and actuators, and medical imaging. His current research focuses on the design and implementation of integrated systems for catheter-based medical imaging applications, photoacoustic imaging, and chemical and biological sensor arrays. Dr. Oralkan has authored and co-authored over 100 publications and received the 2002 Outstanding Paper Award of the IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society. He is a member of the IEEE.

Mario Kupnik is a research associate of electrical engineering at Stanford University. He received his Diplom Ingenieur degree in electronics engineering from Graz University of Technology, Austria in 2000. After working as an Analog Design Engineer for Infineon Technologies AG, he received his Ph. D. in physical measurement techniques at the University of Leoben, Austria in 2004, and then completed a two-year PostDoc at the Khuri-Yakub Ultrasonics Group, Stanford University in February 2007. Mario Kupnik has more than five years teaching experience in the field of electrical engineering, two of these years at the graduate level. His present research interests include the design, modeling, fabrication, and application of micromachined sensors and actuators, with a main focus on capacitive micromachined ultrasonic transducers mainly for air-coupled applications. Examples are transit-time gas flowmeters for hot and pulsating gases, ultrasonic nondestructive evaluation using noncontact ultrasound, nonlinear acoustics, and bio/chemical gas sensing applications (electronic nose). He holds several patents relating to analog front-end circuits for contactless smart card systems, ultrasonic transit-time gas flowmeters, and CMUT fabrication techniques. He serves as a technical program committee member of the IEEE Ultrasonics Symposium.