Course Title: Piezoelectric Ultrasound Transducer Fundamentals - Materials, Structure, Behavior and Analysis

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Course Description: Piezoelectric ultrasound transducers are a crucial component in most ultrasound systems, with applications including biomedical imaging and therapy, nondestructive evaluation and underwater sonar. The content of this course covers topics providing a foundation of understanding about the fundamentals of ultrasound transducers and an informed appreciation of more advanced subjects in the state of the art. The course is divided into three sections. Ceramic, single crystal, polymer and foam piezoelectric materials are introduced, along with the mathematical descriptions for them and their behavior and an explanation of the physics underlying these descriptions. New materials such as ternary single crystals are compared with those in use since the 1950s. In the second section, the operating principles of transducers are described with reference to wave propagation within and external to the transducer. Electrical impedance spectroscopy is introduced as a key technique for transducer characterisation, along with ultrasound transmission and reception techniques. The different types of one-dimensional model are presented, and this leads to a description of external electrical circuitry, including the latest integrated electronic implementations. More advanced content deals with transducers containing multilayer piezoelectric structures. Experimental measurements are outlined, including a simple hands-on tutorial. The third section covers waves, fields and signals. The field of a transducer is introduced through the concept of its physical aperture, compressional and shear modes, and plane and edge waves, and reciprocity. Huygen's principle is outlined mathematically and in basic physical terms, and techniques to predict ultrasonic field characteristics are presented. More advanced work on shear waves in tissue is introduced. Electronic arrays are outlined as a direct outcome of the need to control amplitude and phase on transmission and reception. Finite element analysis is used to provide examples of transmitted fields, and more advanced topics in long range transmission and thin film devices are covered. The importance of dexterity in understanding signals in the time and frequency domains is emphasised for both transmitted and received signals, and this is illustrated with reference to time reversal techniques. An example dual-element transducer design is used as a common thread to illustrate important results throughout the course.

Paul Reynolds is a Senior Associate with Weidlinger Associates Inc (WAI), developers of the PZFlex finite element modelling package. He obtained his Ph.D. in the Finite Element Analysis of Piezocomposite Devices from the University of Strathclyde in Glasgow, Scotland, before joining WAI. Through his position as PZFlex manager, his work with both academia and industry on topics as diverse as medical imaging, medical therapeutics, SONAR, NDT, sensors and actuators has led to a broad knowledge of the modelling needs across the spectrum, and best practices to ensure efficient use of modeling resources.

Sandy Cochran is Team Leader in Medical Ultrasound and Deputy Director of the Institute for Medical Science and Technology, University of Dundee, UK. He has been working on topics in ultrasound research for almost 25 years, focusing particularly on ultrasound transducer and array design for applications in biomedical imaging and therapy, nondestructive evaluation and underwater sonar. He received his BSc, PhD and MBA degrees from the University of Strathclyde, Glasgow, Scotland in 1986, 1990 and 2001. He has worked in several different universities and with a wide range of companies, now numbering more than 25. He is an author of more than 200 papers and presentations and an inventor on several patents. His present research interests are in ultrasound transducers and arrays for applications involving imaging and intervention in the life sciences and medicine, with a bias towards miniature and microscale devices.