Short Course on October 7, 2012

Title: **Nonlinear Effects in Acoustic Wave Piezoelectric Devices**

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Course Description

Most precision acoustic wave devices share many common features such as piezoelectric materials, smaller sizes, driven by alternating voltage, and stringent requirements on frequency stability and other parameters. Consequently, device design and analysis have to be done with the consideration of propagation of high frequency waves in finite piezoelectric structures with complications due to ubiquitous nonlinear bias fields from thermal, stress, electric, acceleration, and/or chemical fields that cause performance variations in different environments. Since the devices are employed as elements of frequency standards and detection, their frequency performances have to be maintained by precision designs, manufacturing, and operations. This poses a great challenge in the analysis and design using only linear models of piezoelectricity. Hence good nonlinear models and their analyses are needed. The nonlinear models with coupled mechanical and electric fields are promising because our research work on the nonlinear behavior of quartz crystal resonators, a typical bulk acoustic wave (BAW) device, has been successful in extracting their electrical circuit parameters and in identifying the major factors impacting their precision frequency performances.

The course will focus on the development of nonlinear piezoelectric equations for acoustic wave piezoelectric devices. Nonlinear material properties of the piezoelectric materials and nonlinear description of deformation have to be taken into account. The nonlinear governing equations are derived and presented. The linear and nonlinear material constants for common piezoelectric materials are discussed and presented. The nonlinear behavior of quartz resonators such as their frequency-temperature behavior, drive level dependency, intermodulation in trapped energy resonators, nonlinear resonance including the Duffing effect will be studied and presented. The analysis requires very high accuracy numerical methods available in MATLAB and finite element software. A systematic analytical procedure must be established for the nonlinear analysis of acoustic wave devices. The nonlinear models will yield nonlinear electrical parameters for the Butterworth Van Dyke resonator. The analytical foundation based on nonlinear theory of piezoelectricity and approximation, and solution procedures have been validated in BAW device analysis and are equally applicable to SAW and other devices. The nonlinear models are difficult to solve analytically and numerically, hence efforts in simplifying and approximating the nonlinear governing equations should be made. Simplified models of nonlinear acoustic waves are derived and presented. Some examples of the simplified models, their solution methods and results are presented.

Yook-Kong Yong received a B.S. degree in civil engineering (1979) from Lafayette College, and M.A. (1981) and Ph.D.(1984) degrees in structures/mechanics from Princeton University. Dr. Yong is a registered Professional Engineer in New Jersey. He serves as an associate editor for the journal *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*. He is a member of the IEEE and ASCE societies. At the IEEE Society, he served as the chair of Technical Program Committee for the IEEE Ultrasonics Symposium 201, as a member of the Technical Program Committee for the IEEE Ultrasonics Symposia, and IEEE Frequency Control Symposia in the years 1989 to present. He has served as a University Senator and a member of the New Brunswick Faculty Council. He belongs to the Chi Epsilon Civil Engineering and Tau Beta Pi Honor societies. He is the recipient of the Carrol Phillips Bassett Civil Engineering Prize from Lafayette College. His research interests are in the numerical modeling of bulk acoustic wave and surface acoustic wave piezoelectric resonators and filters; their frequency-temperature behavior, acceleration sensitivity, noise characteristics and thermal stress behavior. He has also practiced as a consultant in the industry.

Ji Wang received his B.S. degree in structural engineering in 1983 from Gansu University of Technology (currently Lanzhou University of Technology). From 1983 to 1988, he was a structural engineer at the 11th Institute of Project Planning and Research in Xi'an, Shaanxi, China. From 1988 to 1990, he was a visiting scientist at Argonne National Laboratory working on structural analysis. From 1990 to 1995, he was a graduate student at Princeton University studying high-frequency vibrations of piezoelectric plates. He received his M.S. and Ph.D. degrees in civil engineering from Princeton in 1993 and 1996, respectively. He was employed by Epson Palo Alto Laboratory from 1995 to 1999, NetFront Communications from 1999 to 2001, and SaRonix from 2001 to 2002. Since 2002, he has been a Qian River Fellow Professor at Ningbo University, Ningbo, China and the founding director of the Piezoelectric Device Laboratory. He has been associated with the IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society through symposium Technical Program Committees and is the Funding Chair of the Committee on Electromagnetic Devices within the Chinese Society of Theoretical and Applied Mechanics. His research has been on physical acoustic waves in piezoelectric resonators and computational methods. He has working relationships with major acoustic wave device producers worldwide and has been participating in industrial activities extensively.

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