

P2G-1

**STRESS FIELD DESIGN IN VIBRO-ACOUSTOGRAPHY  
BEAM FORMING**

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**Background:** Vibro-acoustography is an elasticity imaging method that images the acoustic response of a material to a *localized harmonic* excitation generated by ultrasound radiation force [Fatemi and Greenleaf, Science 280:82-85, 1998]. Proper beam forming for the stress field (radiation force) of the probing ultrasound is very important because it determines the resolution of the imaging system. Ideally, the stress field should be confined to a small 3D region.

**Approach:** Three beam forming geometries are studied: AM, confocal, and x-focal. Low frequency oscillatory radiation force (e.g., 10 kHz) can be obtained by amplitude modulating a single ultrasound beam sinusoidally (AM), or by interfering two beams of slightly different frequencies. For instance, the confocal transducer is a two-element spherically focused annular array and the x-focal has two transducers whose beam axes cross at their foci at an angle. The amplitude of radiation force on a unit point target is calculated from the ultrasound energy density averaged over a short period of time. This force has an oscillatory component whose magnitude is proportional to the product of the pressure field amplitudes of the two beams. The profiles of radiation stress amplitude for a point target on the focal plane and on the beam axis are derived for all three geometries. These profiles represent the point-spread-function of the system.

**Methods:** The theory is validated by experiments using a small sphere target (radius = 200  $\mu\text{m}$ ) glued on a thin membrane. A laser vibrometer is used to measure the velocity profiles of the sphere, which are proportional to the radiation stress exerted on the target, as the transducer is scanned over the focal plane and the beam axis. **Results:** The experimental velocity profiles for all three beam forming geometries agree well with the corresponding theoretical results.

**Conclusion:** The theoretical models for the three beam forming methods are validated by direct measurements. The results can serve as guidance for transducer design for vibro-acoustography. The theory and experimental technique may be useful in designing linear array transducers for vibro-acoustography.

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## TIME-DOMAIN PRESSURE OF A SPHERICALLY CURVED WEDGE TRANSDUCER

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Many applications in both imaging and high-intensity focused (HIFU) ultrasound utilize transducers with a spherical curvature. In some cases, the transducers have sections cut out of them to insert a diagnostic probe, or their electrodes are modified to create an array. Frequently, the resulting electrode geometry consists of combinations of annular rings and wedges where a wedge is formed by making a cut in the spherical cap parallel to its diameter when viewed along the axial direction. For example, a spherically curved HIFU transducer with a rectangular hole cut out of it may be thought of as an annular ring combined with four wedges. In this paper, we present a technique to calculate the time-domain pressure of a wedge transducer using the spatial impulse response (SIR) method. Analytic expressions were derived to find the SIR at any point P in the sound field. Convolution of the SIR at P with the time derivative of the surface velocity of the transducer yields the time-domain pressure waveform at P. The form of the analytic expressions for the SIR vary over fixed time intervals related to the geometry of the wedge and to the location of P.

The results of the SIR model for the wedge were compared to experimental hydrophone measurements of a wedge transducer operated at 4.7 MHz having a geometric focus of 9 cm and an outer diameter of 8 cm. Experimental results were also acquired for a more complex transducer geometry consisting of two geometrically opposed wedges. The sound field for this transducer shows an interesting pattern consisting of a strong main lobe and side lobes that decrease in amplitude in the cross-wedge direction. For both transducer configurations, the experimental and theoretical  $\#3$ -dB beamwidths differed by  $10 \pm 5\%$ . The utility of the wedge SIR model is that it can be used in a modular fashion with well-known spherical cap SIR models to expedite beam computations of novel transducer designs such as the combination HIFU/diagnostic transducer mentioned above.

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## P2G-3

### **DESIGN AND EVALUATION OF A BROADBAND MULTI-CHANNEL ULTRASOUND DRIVING SYSTEM FOR THERAPEUTIC PHASED ARRAYS**

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Therapeutic ultrasound phased arrays show great promise in applications where precise beam steering and controlled power deposition are needed. In addition, cavitation and mechanical effects, which are fast becoming essential elements of ultrasound therapy, could be better controlled with multi-frequency phased array systems. High power broadband piezocomposite transducers are now available for therapy, but large scale (100+ channels) driving systems still need to be developed. In this study, we design, construct, and evaluate a multi-channel broadband phased array driving system capable of powering large scale phased arrays. The design investigated is a multi-channel arbitrary waveform amplifier capable of delivering 1-2 watts of electric power per element. In this system, a PC is used to load the desired 40-MHz sampled waveform for each channel into individual channel memories. During the output phase, each channel's waveform is D/A converted then amplified and filtered with op-amp circuits. The output is then matched to the transducer elements. The timing of all the D/A converters are centrally controlled, so relative waveform timing, including phase delays, can be precisely programmed for each channel. For reasons of scalability, cost and bandwidth, the design proved to be ideal for multi-frequency large scale arrays. A 50-channel system based on this design was constructed and used to power a 1-2 MHz piezocomposite phased array transducer. Ultrasound beam plots of multi-frequency exposures were performed and compared to theoretical models showing good agreement. This system is capable of providing 1-2 watts of power up in the DC - 3 MHz range and 1/2 watt at frequencies greater than 5 MHz. In addition, the circuitry for 50 channels fit on 23 cm x 40 cm printed circuit board, leading the way for a low-cost tabletop system capable of sophisticated beam steering and frequency control for focus ultrasound therapy.

## P2G-4

### **ULTRASOUND ARRAY TRANSDUCER TESTING AND CHARACTERIZATION**

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Ultrasound array transducers are normally characterized in both time and frequency domain. Parameters like sensitivity, center frequency and bandwidth are commonly used to describe transducer performance though the test set up may have a significant influence on their values. Because of that, the comparison

of different probes based on quantitative data is often difficult and inaccurate. This work presents an approach to transducer testing that reduces the effect of the test set up on the output variables. In addition, a new set of parameters has been introduced to provide a better description of how the transducer works as an array once it is driven by the ultrasound system. The method is based on the deconvolution between the echo and the transmitting pulse. The result of the deconvolution process is an approximation of the transducer transfer function because it does not account for the electrical impedance of both pulser and transducer. Two different types of time-of-flight (tof) corrections are then performed; the first correction aligns all the individual echoes to account for any inter-element tof variation, the second one corrects only for tof variations due to the misalignment between the transducer and the target. The waveforms that result from the first type of correction are then averaged in the time domain to form the Average Transducer Pulse from which all the average values are calculated in both frequency and time domain. The waveforms that result from the second type of correction are used to calculate the Running Average Pulses. This is intended to simulate the way that array transducers are actually driven by the ultrasound system and the element span depends on the number of elements used to form a single image line. At the end, both individual element values and running average values are presented as variations with respect to the Average Waveform, This provides a complete description of how the transducer performs.

## P2G-5

### **SPECKLE REDUCTION OF ECHOGRAPHIC IMAGE USING HIGHER ORDER HARMONIC COMPONENTS**

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In order to reduce speckle noise appearing in ultrasonic echographic images, we have devised a method of retrieving harmonic components contained in echo signals from inside a body, forming images for every harmonic of higher order, and averaging them, and are now studying effectiveness of the method. In this paper, we prototyped a probe in which separated transmission and reception transducers are positioned in the form of a concentric circle. By using this probe, we studied effectiveness of the devised method. The prototyped probe was such designed that transmit transducer with the center frequency of 2MHz is made of PZT and receive transducer with the center frequency of 15MHz is made of PVDF, so that harmonics of higher order can be measured with good S/N ratio. As a result, we could measure up to ninth order harmonic component. We also demonstrated that the speckle could be effectively reduced with higher resolution through summation of complex valued harmonic images generated from respective harmonic components up to ninth order harmonic component.

## P2G-6

### **A METHOD FOR IMPROVED TRANSDUCER PERFORMANCE FROM 20 MHZ TO 100 MHZ CONSIDERING THE EFFECTS OF OUTPUT IMPEDANCE OF A HIGH FREQUENCY PULSER**

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This paper describes a method for improving transducer performance by considering the effects of output impedance of a high frequency pulser. A major assumption made by most transducer engineers is that the output impedance of the pulse drive waveform is below  $50 \Omega$  across the entire frequency spectrum. However, this is not the case and the output impedance has a reactive component that considerably effects transducer center frequency and bandwidth. The output impedance of several high frequency pulsers are measured across their operating frequency spectrum. The output impedance is then modeled as a parallel RLC surrogate circuit. The surrogate circuit is then implemented into a time domain PSpice simulation model including pulse drive shape, receiver, and transducer Mason model using a lossy transmission line. Using the simulation, the transducer performance with the RLC circuit model of (reactive) pulser output impedance is compared to that of just a resistor model of (real) pulser output impedance. Results show that the transducer performance is not optimum with the reactive output impedance. In order to correct this phenomenon an auto-transformer is used to step down the reactive output impedance below  $50 \Omega$  across the frequency spectrum. This method shows improved results of transducer performance. Since the simulation showed adequate results the output impedance was measured again using an auto-transformer. The pulse echo response of a 80 MHz LiNO<sub>3</sub> transducer was measured with and without an auto-transformer attached to the pulser. Improved transducer performance is shown when using an auto-transformer attached to the pulser in the laboratory.

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## P2G-7

### **A NEW CONFIGURATION OF TRANSDUCER TO SYSTEM INTERFACE**

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Signal to noise ratio (SNR) is one of the most important parameters in ultrasound imaging systems, it determines the image quality of the systems, such as penetration of B mode, sensitivity of CD flow and etc. Noise contribution of

an ultrasound system could be from (1) transducer and its interface to system; (2) signal preprocessing path; (3) signal post-processing path. In this paper, a new transducer to system interface is developed to suppress the noise from the transducer and its interface to system.

Several features unique to the transducer to system interface that could help suppress the noise from the transducer and its interface to the system (1) differential input is adopted in the front end amplifiers; (2) a GORE IMAGIN<sup>®</sup> probe cable is recruited in the interface. With differential input configuration, the cable impedance matches the system receiving impedance of 120 ohms; (3) a transformer between the cable and system front end is deployed to couple the signal; (4) there are MUX boards in the interface to switch between transducer elements; (5) the common signal reference ground is the transducer ground; (6) T/R switches are actual switches instead of diodes. (7) The lower dielectric constant of the cable makes the effective length of the cable shorter.

Within the transducer and its interface to system, the potential noise sources are (1) the thermal noise from the transducer, cable and MUX; (2) crosstalk among channels; (3) common mode noise. To maximize the SNR of the transducer and its interface to system, the transducer is tuned to match the impedance of the system, the results of different tuning schemes for a 3.5MHz curved linear array are presented in this paper. The sensitivity, bandwidth can be both improved via tuning. A theoretical model is constructed to model the crosstalk among the adjacent channels, experiments have been conducted to validate the model, the effect of the length of the cable is also studied in this paper. Finally, the differential input configuration of the front end amplifier greatly suppresses common mode noise when the two input lines are balanced. The noise level of the transducer and its interface to system is quantitatively studied in this paper.

**Session: P2H**

**TRANSDUCER MODELING**  
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**P2H-1**

**ANALYSIS OF SPURIOUS RESONANCES IN SINGLE  
AND MULTI-ELEMENT PIEZOCOMPOSITE  
ULTRASONIC TRANSDUCERS**

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