High-Intensity Focused Ultrasound Phased Arrays: Recent Developments in Transrectal Transducers and Driving Electronics Design

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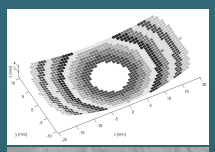
Abstract

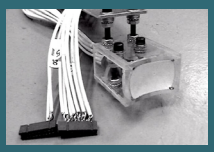
This work presents the design and characterization of 4 specific transrectal HIFU phased array transducers of various element counts and operating frequencies for the non-invasive treatment of prostate diseases, and a general-purpose HIFU phased array driving electronics design capable of controlling up to 1024 channels. Four different HIFU phased arrays have been simulated during the last 3 years to investigate optimum array geometries, high-power transducer materials (piezoelectric and/or piezocomposite), interconnect structures, and excitation methods. The developed electronics were used to test 3 of the 4 arrays that have actually been implemented, and were used for electronic focusing of the HIFU beam in real time from 25 mm to 45 mm from the face of the array. The characteristics of these arrays and the results of these investigations is presented. The implementation details of the driving electronics are also shown. Efforts are currently underway to finalize the design of the HIFU array of choice and to integrate it into the commercial Sonablate®500 system for clinical evaluation.

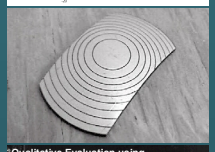
Transrectal HIFU Phased Arrays - Overview

Parameter	2.0 MHz Annular	2.8 MHz Annular	4.0 MHz Annular	4.0 MHz Cylindrical
Geometry	Spherical	Spherical	Spherical	Cylindrical
Aperture	40x22 mm	35x22 mm	50x22 mm	80x22 mm
Radius of Curvature	45 mm	35 mm	45 mm	35 mm
Num. of Elements	9 Rings	17 Rings	20 Rings	413 Channels
Operating Freq.	2.04 MHz	2.77 MHz	4.34 MHz	4.0 MHz
Material	N3B (Keramos)	High-Power (Imasonic)	K270 Composite (Keramos)	K270 Composite (Keramos)
Imaging	Center Single 10 mm element	Center Single 10 mm Element	Center Single 10 mm Element	Imaging Array
TAP (normalized per cm² of array surface)	>5.5 W/cm²	>5.5 W/cm²	>10 W/cm² (bulk material)	>10 W/cm² estimated
Efficiency	70%	39%	51%	>50% estimated
Bandwidth	116 kHz (6%)	1.45 MHz (52%)	450 kHz (10%)	>20% estimated
Element Impedance	140Ω +/- 20Ω -47° +/- 6°	155Ω +/- 20Ω -60° +/- 7°	58Ω to 108Ω -23° to -53°	~1.5kΩ estimated
Cross-Coupling	Up to 50%	Up to 5%	Up to 5%	<5% estimated
Acoustic Matching	None	Unknown	None	None
Backing	Air	Unknown	Air	Air

2.0 MHz Annular Array (9 Rings) - Details



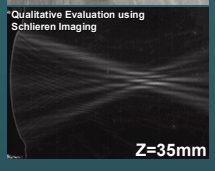


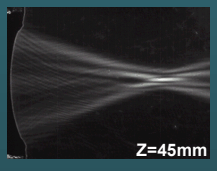


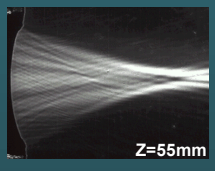
Goals:

(i) to develop laser etching techniques to define arbitrary electrode shapes, and

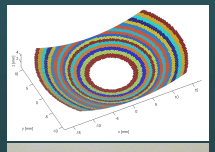
(ii) to provide a medium-frequency HIFU phased array transducer to test the 1st generation of HIFU phased array driving electronics.







2.8 MHz Annular Array (17 Rings) - Details

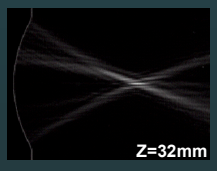


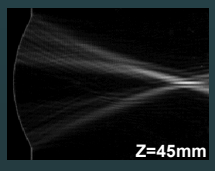
Goals:

(i) to investigate the use of piezocomposite materials for HIFU phased arrays,

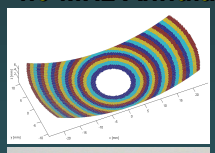
(ii) to experimentally verify the focusing ability of annular arrays over the region of interest: z=20 mm to z=45 mm, and

(iii) to quantify electrical and acoustic element cross-coupling characteristics and compare them with element cross-coupling characteristics of PZT materials.





4.0 MHz Annular Array (20 Rings) - Details

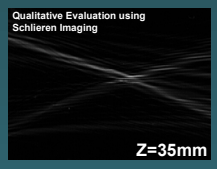


Goals:

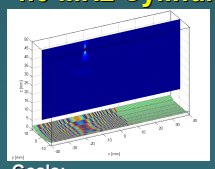
(i) to develop piezocomposite forming techniques to define curved HIFU phased arrays,

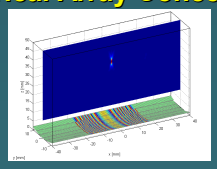
(ii) to experimentally verify the focusing ability of annular arrays at clinically proven excitation frequencies, and

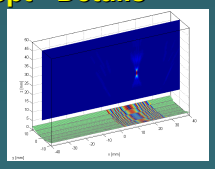
(iii) to investigate the suitability of alternate piezocomposite materials for HIFU phased array construction.



4.0 MHz Cylindrical Array Concept - Details



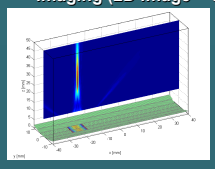


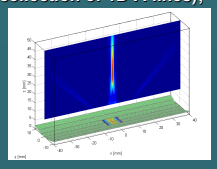


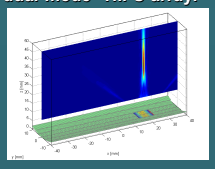
Goals:

(i) to replace linear mechanical transducer motion with variable-size sub-aperture electronic scanning (effective 1.5D HIFU array), and

(ii) to replace mechanical imaging system with electronically-controlled imaging (2D image = collection of 1D A-lines); "dual-mode" HIFU array.



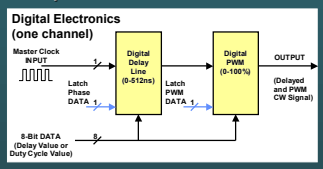


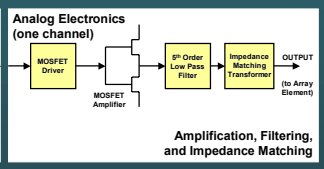


Driving Electronics

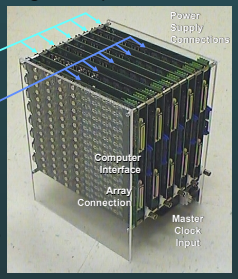
Goal: to develop general purpose HIFU phased array driving electronics.

- Small Footprint Digital/Analog Board Pair (25x25x4 cm).
- 64 Channels/Board, Stackable/Scalable up to 1024 Channels Total.
- 2 ns Phase Resolution (8 bit Control, Digital Delay Line).
- 7-bit Amplitude Resolution (Digital PWM).
- 1-5 MHz Operating Frequency (Programmable).
- CW Operation, Programmable On/Off Time.
- Individual Impedance Matching and Filtering/Channel.
- Capable of driving Elements up to 2 kΩ Impedance.
- Single Digital Computer Interface (over Nat. Inst. Digital I/O Board).
- Input Power: 5 V (4 A), 9 V (2 A), 0-75 V (6.5 A) per Board Pair.
- Both Low-Power (<2.5 W/Channel) and High-Power (<15 W/Channel) Implementations.





Picture of 20-Channel High-Power HIFU Phased Array Driving Electronics, consisting of a single digital board (20/64 channels populated) and a single high-power analog board (20/32 channels populated).



Picture of 320-Channel Low-Power HIFU Phased Array Driving Electronics, consisting of 5 digital boards (fully populated) and 5 low-power analog boards (fully populated).

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