High Frequency Thick Film Ultrasonic Transducers Used for Estimation of Flow-Mediated Vasodilation of the Radial Artery

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***Abstract* - Preceding atherosclerosis is an endothelial dysfunction. Therefore there is a growing interest in the application of non-invasive clinical tools to assess endothelial function. Commercially available ultrasound machines can measure flow-mediated vasodilatation of the brachial artery using maximum 10-12 MHz linear probes. The higher the probe frequency, the better the axial resolution. Recently, a new technology of piezoelectric transducers based on PZT thick film technology has been developed in Meggitt (Denmark) as a response to a call for devices working at higher frequencies. The thick films exhibited at least 30% bandwidth broadening comparing to the standard PZ 27 transducers, resulting in an increase in match filtering encoding output by a factor of 1.4-1.5 and finally resulting in a signal to noise gain of the same order. The introduction of a high frequency 25-30 MHz ultrasound scanner to measure radial artery diameter after reactive hyperemia opens a new window for more precise imaging of endothelial function.**

***Keywords-thick film transducers, atherosclerosis, flow mediated vasodilation*.**

I. INTRODUCTION

High frequency (HF) ultrasonography is gaining increased interest in skin, eye and small animals imaging. However, an excessive attenuation of ultrasound at HF limits the range of the available frequencies, considering the permissible peak pressure of the probing beam. Our motivation was to develop the dedicated wobbler scan head with the transducer exhibiting wide-bandwidth behavior and enabling transmission of wide-band encoded probing pulses with peak pressure not exceeding the acceptable levels.

The issue of maximizing penetration depth with concurrent retaining or enhancement of image resolution constitutes one of the time invariant challenges in ultrasound imaging. Concerns about potential and undesirable side effects set limits on the possibility of overcoming the frequency dependent attenuation effects by increasing peak acoustic amplitudes of the waves probing the tissue. To overcome this limitation, a pulse compression technique employing 16 bit Complementary Golay Code (CGS) was implemented at 25-35 MHz. In comparison with the other, earlier proposed, coded excitation schemes, such as chirp, pseudo-random chirp and Barker codes, the CGS allows virtually side lobe free operation, [1, 2]. Section II describes the influence of the transducer bandwidth on the overall gain of the compressed ultrasonic echoes. Section III describes the method and the preliminary results of measurements of the radial artery diameter. The conclusions close the article.

II. WIDE BAND THICK FILM PROBE

The bandwidth of a Golay coded sequence often exceeds fractional bandwidth of the available imaging transducer. It results in final gain of the compressed echo signal for different spectral widths of CGS. For example, in the case of 80% fractional transducer bandwidth, the peak-to-peak amplitude in compressed signal decreases to 90%. For 60% and 50% fractional bandwidth the compressed signals decrease to 57% and 50%, respectively. Also, with the narrowing of the transducer bandwidth the pulse width elongates. In the case of 80% fractional transducer bandwidth, the full width at half maximum (FWHM) in compressed signal is equal to 37ns. Following transducer bandwidth decreasing leads to FWHM widening and for 60% and 50% fractional transducer bandwidth, the FWHM in compressed signal is equal to 61.4ns and 63.5ns, respectively. Assuming speed of sound in tissue equals to 1540 m/s the corresponding spatial FWHM would be equal to 57 μm, 94.5 μm and 97.8 μm respectively [1]. The bandwidth of the used transducer is shown in Fig.1.

The proper material for wide band thick film flat and concave transducers was developed by Insensor® - Meggitt (Copenhagen, Denmark). The technology based on screen or pad printing process offers not only flexibility of defining the thickness (i.e., resonant frequency) of the transducers through printing the specified number of film layers, but also the option of readily selecting the shape of the

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transducer and semi assembling of the final device since the film can be deposited on the appropriate substrate, e.g., of porous ceramic with well defined acoustic properties acting as backing for the transducer. The printing process offers possibility to deposit the piezoceramic film on a focusing substrate. The piezoceramic film will follow the curvature of the backing forming an active layer of well defined and uniform thickness. The top and bottom electrodes are deposited as a part of the printing process and provided with leads for electrical connections.

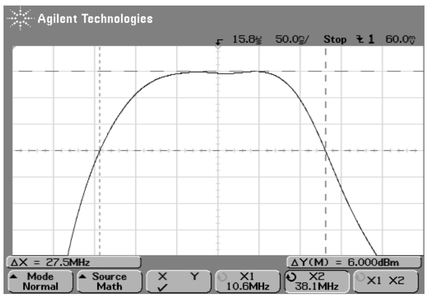

Figure 1. FFT spectrum of the ultrasonic echoes for the thick film transducer; central frequency close to 27 MHz, bandwidth= 27.5 MHz.

Piezoceramic thick films have relatively low acoustic impedance of approx. 18 MRayls and the acoustic properties of the substrate/backing material have been optimized to match it.

III. Methods and Results

Compression of the received coded sequences effectively resulted in very short, one wavelength long, probing pulses and allowed for very precise measurements of internal diameter of the radial artery. In 1994, Celermajer et al [3] described the technique to test the endothelium and smooth muscle dependent dilation capability by producing the reactive hyperemia in brachial artery. In 2002, Corretti et al [4] published the initial guidelines for the ultrasonic assessment of flow-mediated vasodilatation (FMD) of the brachial artery. Since then numerous reports on the technique were published [e.g., 5, 6]. In general enthusiastic, however due to the limited axial resolution of the commercial US scanners working in 10 MHz frequency range, the precision of the diameter measurements was not better than 0.2 mm. resulting in considerable ambiguity in final estimation of artery diameter dilation. That is why we have decided to modify the technique increasing the scanning frequency up to about 30 MHz and tracking the dilation of the radial artery instead of brachial one.

FMD of radial artery was examined in total 12 healthy young volunteers (25-35 years) men. The longitudinal scan of the radial artery of 36 year old volunteer is shown in Fig.2. In vivo and in vitro examinations were performed using a high frequency ultrasound scanner uScan developed at IPPT PAN. The device operates with a single element mechanically wobbling thick film transducer at the frequency 25-35 MHz.

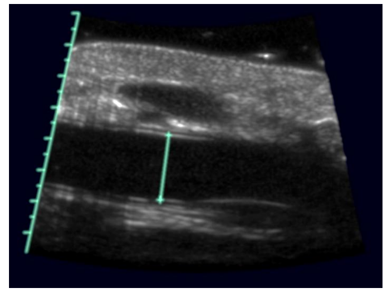

Figure 2. Longitudinal scan of the radial artery, systolic diameter= 2 mm

The Radial Artery Reactive Response (RARR) was induced by a five minute artery ischemia through the inflated tourniquet on the arm or forearm. Restoration of blood flow in the artery is strongly promoting the release of nitric oxide NO. The measured initial internal radial artery diameter was in range of 1.59-2.25 mm; the maximum diameter 2.01-2.60 mm was observed 40-60 seconds after tourniquet deflation.

. IV. Conclusions

In the pilot study, the model of the brachial artery ultrasound demonstrated that using HF scanning ultrasound allowed to precisely register an increase in the diameter dimension of the radial artery ultrasound model already by 5%. RARR in healthy volunteers, using a transient ischemic calling stimulation has shown changes from 30 to 40 %, while in the four volunteers after cardiac incidents, these changes did not exceed 10 %.

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