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A Triple-frequency transducer and its Multi-frequency Image Fusion Method

Zhangjian Li
[1]*University of Science and Technology of China;* [2]*Suzhou Suzhou Institute of Biomedical Engineering and Technology, Chinese Academy of Sciences*
Suzhou, China
lizj@sibet.ac.cn

Weiwei Shao
Suzhou Institute of Biomedical Engineering and Technology, Chinese Academy of Sciences
Suzhou, China
shaowei@sibet.ac.cn

Zhile Han
Suzhou Institute of Biomedical Engineering and Technology, Chinese Academy of Sciences
Suzhou, China
hanzl@sibet.ac.cn

Pengbo Liu
Suzhou Institute of Biomedical Engineering and Technology, Chinese Academy of Sciences
Suzhou, China
liupb@sibet.ac.cn

Chen Yang
[1]*University of Science and Technology of China;* [2]*Suzhou Institute of Biomedical Engineering and Technology, Chinese Academy of Sciences*
Suzhou, China
yangc@sibet.ac.cn

Xinle Zhu
Suzhou Institute of Biomedical Engineering and Technology, Chinese Academy of Sciences
Suzhou, China
zhuxl@sibet.ac.cn

Jiabing Lv
Suzhou Institute of Biomedical Engineering and Technology, Chinese Academy of Sciences
Suzhou, China
lvjb@sibet.ac.cn

Yaoyao Cui
Suzhou Institute of Biomedical Engineering and Technology, Chinese Academy of Sciences
Suzhou, China
cuiyy@sibet.ac.cn

***Abstract*—It is difficult to acquire images with high resolution and deep imaging depth in the same ultrasonic image. This contradiction limits the performance of ultrasonic imaging system. Multi-frequency transducers may be a choice. By using image fusion technology, ultrasonic images corresponding to different frequencies can be fused to obtain higher quality images. In this work, an ultrasound transducer which can work at three frequencies synchronously is presented. Frequency domain models are built to assist its design and related experimental devices are fabricated. The triple-frequency transducer is with outer diameter less than 1.5mm. Pulse-echo results indicates that all its elements' waveform and bandwidth are suitable for ultrasonic imaging. A synchronously imaging is carried out on a multi-layer phantom, fusion algorithm is realized through MATLAB code. The results indicates the triple-frequency transducer can image the deeper targets with reasonable image quality.**

Keywords—Triple-frequency Transducer, FEM Method, Image Fusion Method

I. Introduction

Ultrasonic transducer is the key component of ultrasonic imaging system. Its central frequency determines the resolution of ultrasonic images. The higher the frequency, the easier it is to obtain high-quality images. However, the increasing of frequency often leads to the decrease of detection depth, which limits the imaging range of transducers and is unfavorable to clinical use[1]. At present, conventional ultrasonic transducer has operating frequency range from 2 to 20 MHz, generally works at a single frequency. If operator wants to alter the working frequency to obtain suitable depth, he or she must employ another probe. This becomes inconvenience in clinic use, especially in interventional ultrasound (such as intravascular ultrasound), the changing of probe can greatly increase the patient's pain. This contradiction between resolution and imaging depth limits the performance of ultrasonic imaging system. It is an urgent problem remained to be solved.

Multi-frequency ultrasonic transducers can work at different central frequencies and switch flexibly. When working at low frequencies, they can obtain large detection depth and obtain coarse information in a large scale. When detailed pathological information is need in a specific region, transducer can be switched to high-frequency condition. Combined with image fusion technology, ultrasonic images working at different frequencies can be fused to obtain high-quality images[2].

In recent years, multi-frequency transducer had been applied in many fields. Gessner et al adopt a dual frequency transducer to obtain high resolution of the blood vessels (10 MHz) and stimulate the cell (resonance frequency 1-5 MHz) simultaneously. High contrast ultrasound images were successfully obtained in vitro and vivo experiment[3]. Lukacs et al proposed a transducer for micro bubble control and real-time high-frequency imaging, its low frequency working frequency is 2 MHz and high frequency can reach 30 MHz, focusing depth over 12 mm, animal experiments achieved more than 12 dB signal enhancement compared to the commercial device[4]. Jianguo Ma et al successfully developed a dual-frequency transducer with working frequency 5MHz and 30MHz and applied it in the vascular vulnerable plaques diagnosis[5]; the dual-frequency transducer was also applied in microbubble contrast imaging in further research[6].

In this research, we propose a triple-frequency transducer, it can work on 12 MHz, 20MHz, and 30MHz synchronously. When working, the transducer can work on the three frequencies at the same time and fused image will be gained, the fused image will be of high imaging resolution and large imaging depth. To realize this triple-frequency transducer, related FEM models are built to analyses the crosstalk between different working frequencies, its generated sound field is simulated to optimize the construction design. Based on the theoretical analysis, a triple-frequency transducer is fabricated. And a multi-layer phantom is employed to verify its imaging feasibility. Related fusion algorithm is realized through MATLAB code.

II. Methods

A. Transducer Design (Heading 2)

Fig.1. displays the triple-frequency transducer's construction, it is formed by three parts: base support, transducer elements, isolation filler. The base support is working as the basic framework of the transducer, it can support the transducer elements and help the cable connect to the probe, it is also working as the damping material to improve the echo performance. Transducer elements are the core of the transducer, there are three working elements, they can work at 12MHz, 20MHz and 30MHz respectively, all the elements have the same sandwich structures. Isolation filler is the filler between elements, it is made from high attenuation material and can reduce the cross-talk between elements. The whole transducer has an outer diameter 1.5mm, length 3.5mm, the size of working element is 3.0mm length and 0.9mm width, their thickness are less than 0.3mm.

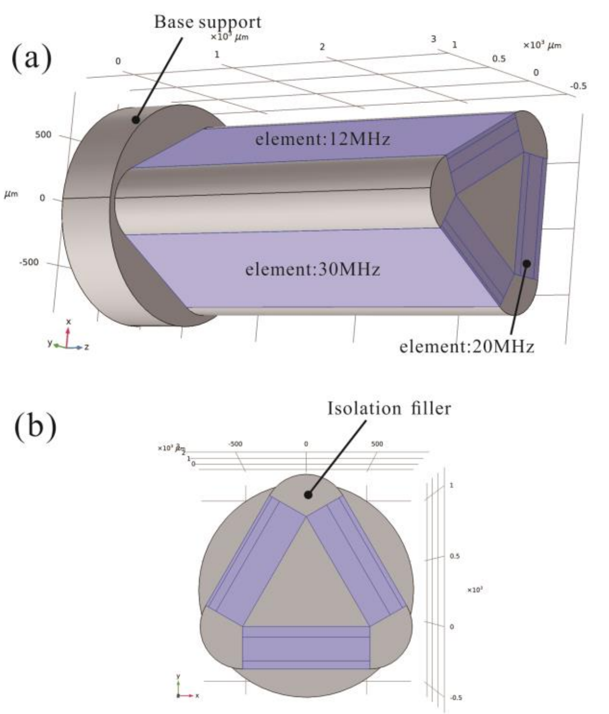

Fig. 1. The triple-frequency transducer's construction

B. Simulation Analysis

To evaluate the transducer's performance and optimize the design, FEM models are built using COMSOL Multiphysics® (v.5.4. COMSOL AB, Stockholm, Sweden. 2018) for parametrical analysis. The FEM models apply piezoelectric module and acoustic module to simulate the acoustic pressure distribution in frequency domain. The FEM model is meshed using free triangular method except the water area, the maximum element size is set as 10μm. The area of water is mapped as quadrilateral, its maximum size of element is set as 10μm. The frequency-domain results are in Fig.2.

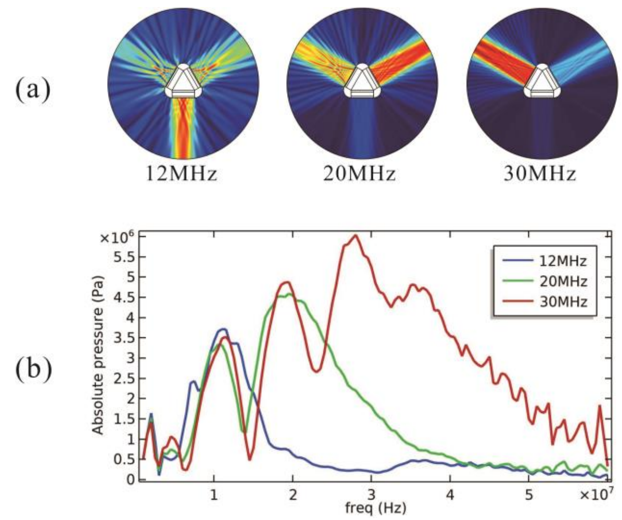

Fig. 2. The simulation results in frequency domain

(a) are the sound field distribution at different frequency. We can notice that all the three elements can obvious transmit sound wave at 12MHz and the 12MHz-element has the strongest strength, but the difference in intensity is modest. When working at 20MHz, the strongest element becomes the 20MHz-element, followed by the 30MHz-element, the 12MHz-element is the weakest. When working at 30MHz, the situation is similar, the strongest part is 30MHz element and 12MHz element is weakest. (b) shows the absolute acoustic pressure each element emission at different frequency, it provides more detail information about the transmitted sound field. All the three curves have similar acoustic pressure near 12MHz; when near 20MHz, the 12MHz-element emission intensity decrease rapidly while the others elements nearly the same; when the frequency increase to near 30MHz, the emission intensity of 20 MHz-element also decrease rapidly and 12MHz-element remains low. Besides, by observing the emission sound field, we can discover that only if the element works on its own corresponding working frequency can the element have a well emission sound field, a well emission sound field is beneficial to the image quality. This suggest that it is indispensable to isolate the interference from the 12MHz-element and 20MHz-element. So the isolation filler will play a key role to reduce the crosstalk. Base on the simulation conclusions and suggestions, a triple-frequency transducer is fabricated through sophisticated procedures including precision grinding, sputtering, layer bonding, precision slicing, perfusion molding and electrode cable bonding etc

III. Results and Discusison

A. Transducer Pulse-echo Evaluation

Through Pulse-echo method, we can know the transducer elements' center frequency, sensitivity, pulse width, pulse bandwidth etc. The triple-frequency transducer is immersed in a water tank, its emission wave can be reflected by a acrylic hard plate and received by the transducer itself, its position is adjusted to help the pulse sound wave incident the reflector surface vertically through the position adjustment system. The transducer is actuated by a pulse generator/receiver system (DPR500, Imaginant Inc. NY, USA), the received signal is displayed and stored in a digital oscilloscope (DPO5034, Tektronix, USA). The water is deionized and de-aerated before the experiment and its temperature is maintained at 25℃.

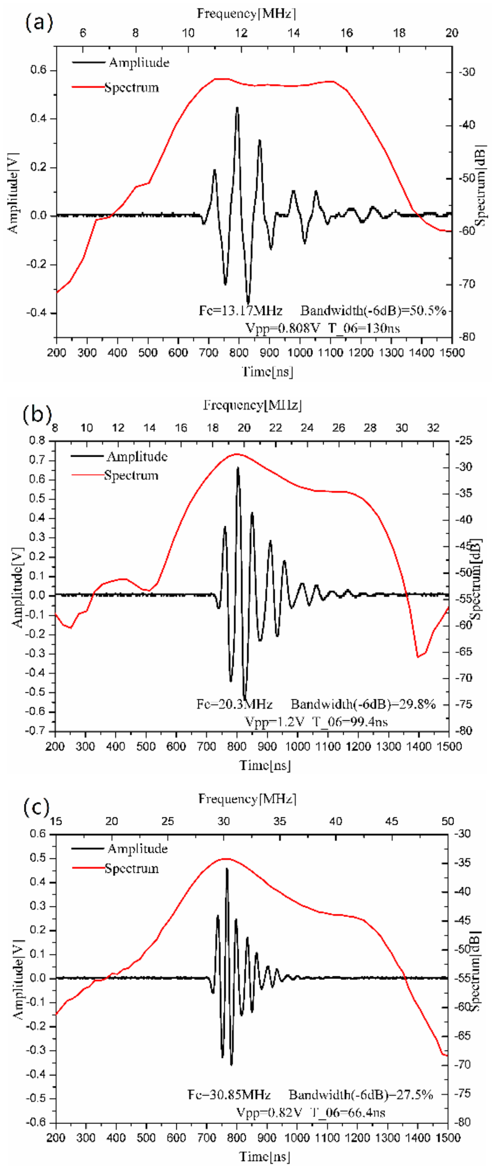

Fig. 3. The transducer elements pulse-echo results. (a)(b)(c) are the 12MHz, 20MHz, 30MHz echo result respectively.

The pulse-echo results are displayed in Fig.3. The results indicates the echoes have center frequencies 13.17MHz, 20.3MHz, 30.85MHz, all the elements are working near on their own design frequency. All the echoes have high sensitivities, the 20MHz element has the highest amplitude about 1.2V, the 20MHz and 30MHz elements are over 0.8V,almost the same; such sensitivities are helpful to ensure the SNR of the signal. The higher the working frequency is, the shorter the echo is; their -6dB pulse width are 130ns, 99.4ns, 66.4ns. The 12MHz element echo has wider spectrum bandwidth about 50.5% while the 20MHz and 30MHz echoes are 29.8%, 27.5%, which is narrower and consistent with the theoretical design. Generally speaking, the waveforms of elements show no distortion and their trailing wave is reasonable, such waveforms are suitable for ultrasound imaging.

B. *Synchronously Imaging*

In this part, a phantom is employed to test the synchronously imaging. This phantom is home-made and made up with PDMS(Dow Corning Corporation Midland, Michigan, USA). The phantom is of multi-layer structure, the boundary between layers can reflect the sound wave. Wires are buried inside the phantom at different position. The synchronously imaging is carried out immerse in the water.

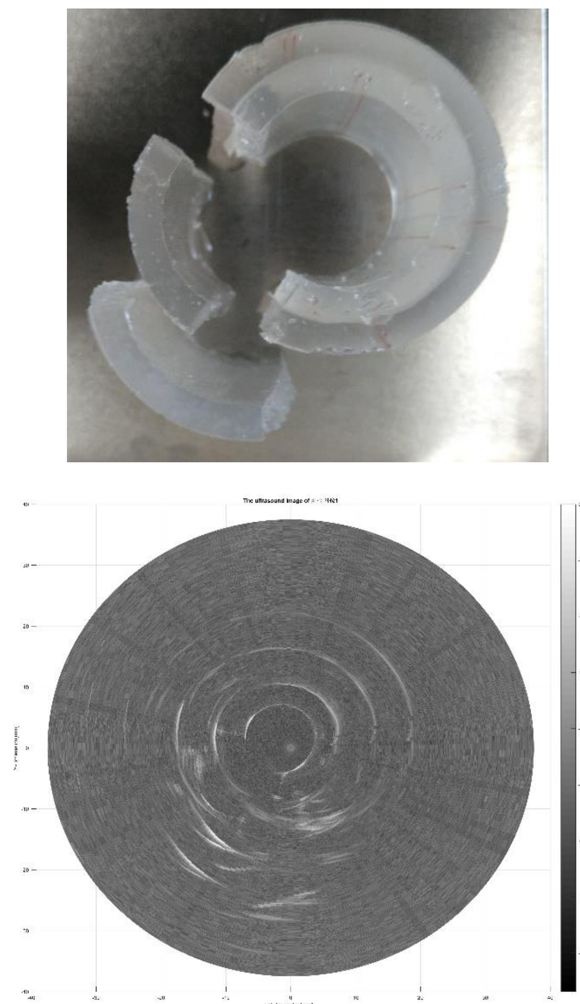

Fig. 4. The multi-layer phantom and its fused image

The transducer is actuated by the same pulse generator/receiver system (DPR500, Imaginant Inc. NY, USA), the received signal is stored in the digital oscilloscope (DPO5034, Tektronix, USA). The water is deionized and de-aerated before the experiment and its temperature is maintained at 25℃. The image is obtained by the radical scan of transducer, each image is constructed by 360 lines, and the transducer is rotated by a revolving unit. After the scanned data collection, the image will be shown through B-mode via MATLAB algorithm. Fusion algorithm is also realized through MATLAB code.

Fig.4. is the final fused ultrasound image. This image is of great contrast level and phantom's multi-layer structure can be clearly seen. The results indicates the triple-frequency transducer can image the deeper targets with reasonable image quality, and verify that this triple-frequency transducer can alleviate the contradiction between resolution and depth.

IV. Conclusion

In this work, a triple-frequency transducer is presented, its elements have center frequencies 13.17MHz, 20.3MHz and 30.85MHz. Frequency domain FEM simulation results indicates its 12MHz element are the main source of crosstalk and the isolation filler is indispensable. Pulse-echo results shows that its elements have high sensitivity and narrow pulse width, their waveforms of elements display no distortion and their trailing wave is reasonable, which are suitable for ultrasonic imaging. Synchronously imaging is performed via the MATLAB fusion algorithm, the final fused ultrasound image is of great contrast level and phantom's multi-layer structure can be clearly seen. All the results above indicate the feasibility of triple-frequency transducer in solving the contradiction between resolution and depth.

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