

VELOCITY AND ATTENUATION COEFFICIENT MEASUREMENT TECHNIQUES
USING THE INTERFEROMETRIC MODE OF A 100 MHZ SCANNING LASER
ACOUSTIC MICROSCOPE

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Abstract

An interferogram is produced when the Scanning Laser Acoustic Microscope (SLAM, Sonomicroscope 100[®], Sonoscan Inc., Bensenville Illinois U.S.A.) is operating in its interferometric mode. The interferogram contains the phase and amplitude information of the wavefield, which has penetrated through the specimen of known thickness. The interferogram is visualized on a monitor as equal phase wavefronts and digitized with an A/D converter. The individual raster lines of the interferogram appear as sinusoids. If there has been a localized change in the specimen velocity the phase of the adjacent lines would have been shifted relative to each other in that area. The amplitude of the sinusoids along the specimen is an indication of the acoustic pressure from which the relative changes can be evaluated for the localized attenuation coefficient.

The bending of the equal phase wavefronts carries the information of the relative ultrasonic velocity variations along the specimen. When the specimen is immersed into saline, in which the ultrasonic velocity is known, these relative values can be transformed into absolute ones based on Snell's Law. The accuracy of the technique is better than 0.3%. The application of this procedure is illustrated with an image of the two dimensional velocity distribution in a wounded dog skin. The areas of hair follicle, wound, surrounding skin and saline are clearly to be separated. The pixel size is 64*64 squaremicrometers and the whole image contains 1410 pixels.

The attenuation coefficient can also be determined from the same interferogram data. The amplitudes of the equal wavelength sinusoids are measured as a function of position and specimen thickness. The attenuation coefficient is calculated as the slope of the insertion loss versus thickness curve. The linearity of the insertion loss measurement has been verified using precision electrical attenuators to decrease the basic illumination on the imaging area. The linear range showed up to be from 0 to 15 dB and the accuracy is better than 0.5 dB. The technique has been applied with fatty rat liver specimens and the results are in agreement with an other technique, which utilizes the amplitude mode of the SLAM. However, the pixel size has decreased by a factor of 22 and it is now about 64 micrometers both vertically and horizontally.

1 Introduction

The 100 MHz SLAM is a very powerful tool in tissue characterization [1-6] because two ultrasonic propagation properties of soft tissues can be measured on the microscopic scale i.e. the velocity and attenuation coefficient [2,7-9]. 100 MHz corresponds to a wavelength of about 15 μm in soft tissues and the measurement information from an area of 3 mm horizontally by 2 mm vertically is digitized into 1514 and 482 data points, respectively. This way the pixel size is about 2 μm horizontally and 4 μm vertically. The specimen thicknesses vary from tens to hundreds of micrometers.

2 The interferometric mode of the SLAM

The SLAM can produce two acoustical and one optical image (see Fig. 1 (a), (b) and (c), respectively). The optical image is used for proper placement and orientation of the specimen. The utilization of one of the acoustical modes, namely the amplitude mode, has been reported in an earlier paper [9] and in this paper the use of the interferometric mode for both the velocity and attenuation coefficient determinations is reported.

Figure 1(a) is a photograph of an interferogram shown on the monitor of the SLAM. Two different kinds of information are included in the interferogram i.e. the bending of the equal phase wavefronts carries the information for the determination of the velocity properties and the variation in the amplitude of the equal wavelength sinusoids is due to different attenuation properties in the imaging area. In the next paragraphs the velocity measurement technique is explained briefly because it has already been reported in detail [8]. The main emphasis is on the attenuation coefficient determination from the same interferogram data.



Figure 1: (a) Interferogram, (b), acoustic image, (c) optical image and (d) two dimensional velocity distribution image of 75 μm section of dog skin which contains a 12 day old incisional wound. The pixel size is 64 μm x 64 μm and the light and dark areas correspond to high and low velocity values, respectively, [8].

3 Velocity measurement

The shifting of the equal phase wavefronts is due to different velocity properties in the objects. The tissue specimen is in the middle of the image and it is surrounded with saline. The velocity can be calculated using Eq. (1) [2,7,8].

$$C_x = (C_o / \sin \theta_o) \sin \left\{ \arctan \left[(1 / \tan \theta_o) - (N \lambda_o / T \sin \theta_o) \right]^{-1} \right\} \quad (1)$$

where C_o is the velocity in saline (1507 m/s), θ_o is the angle from the normal of the acoustic beam in the reference medium (about 11 degrees in saline), N is the normalized fringe shift, T is the specimen thickness and λ_o is the wavelength in saline. The only unknown parameter in Eq. (1) is the normalized fringe shift N and it can be determined using spatial domain calculations [2,7] or in spatial frequency domain [8]. For the latter, N is given by [8].

$$N = \frac{\phi_2(\xi_o) - \phi_1(\xi_o)}{2\pi} \quad (2)$$

which is based on the so called origin shift theorem i.e. when a sinusoid is shifted relative to its original position, the information for determining the shift can be found in the phase information of the frequency spectrum. In this case the frequency component $-\xi_o$ corresponds to the parameter $1/\text{wavelength}$. $\phi_2(\xi_o)$, $\phi_1(\xi_o)$ are the phases for the specimen and saline, respectively.

4 Attenuation coefficient measurement

The amplitude variations of the sinusoids can be used to determine, as a function of specimen position, the localized attenuation coefficient. Using Fourier-transformation and Parseval's relationship, the insertion loss due to the specimen of certain thickness can be measured.

The basic principle of the insertion loss measurement technique [9] is used also here. The recordings of the insertion loss values are done in respect to the same basic illumination. A least squares fit is done for determining the slope of the insertion loss versus thickness curve, which yields the attenuation coefficient.

5 Results

The linearity of this technique was determined using calibrated electrical attenuators. The basic illumination at a point in the imaging area was decreased by adding known amounts of electrical attenuation between the driver and the ultrasonic transducer. The results are given in Table I. The decreasing of the amplitude was recorded on logarithmic scale as insertion loss values. Then the computer printed insertion loss values versus electrical attenuation values were fitted to a straight line with a least squares fit algorithm. As a parameter here was used the pixel size i.e. the number of data points included in the vertical direction. The number of data points in the horizontal direction was 32 data points because an FFT-algorithm was utilized in the Fourier-transformations. The results show a linear range in the insertion loss measurements from 0 dB to 15 dB. The correlation coefficients show that even with a pixel size containing 16 sinusoids (rows 241 to 256) the technique is working. The pixel size in this case is about 64 μm both horizontally and vertically.

TABLE I
 Verification of the attenuation coefficient measurement technique using precision electrical attenuators. The insertion loss values given by this technique were compared to the electrical attenuation values of 0, 3, 6, 9, 12 and 15 dB with a least squares fit algorithm. The slope and correlation coefficients are listed as a function of pixel size which was fixed horizontally to 32 data points (approximately one wavelength) and varied vertically from the whole 2 mm to 64 μm in a stepwise manner.

Range of the rows Included in the analysis [index]	Least squares fit	
	Slope [dB/dB]	Correlation coefficient
1-482		
1-120	1.18	1.0000
121-240	0.98	0.9989
241-360	1.21	0.9985
361-480	1.27	0.9984
225-240	1.26	0.9989
241-256	1.31	0.9993
	1.24	0.9976

Figure 2 gives the results of the analysis of a normal rat liver specimen for one particular thickness of 920 μm . Curves I and II are the velocity and insertion loss profiles along the specimen in the vertical direction, respectively. The cusp seen in both of the curves includes the data points of the rat liver which is surrounded by saline. The average velocity in the liver specimen is 1560 m/s. When the profile of the insertion loss curve is combined with the profiles of other 3 thicknesses (370 μm , 550 μm and 740 μm) then the attenuation coefficient can be calculated and the least squares analysis yields a value of 13.5 dB/mm. Another technique which utilizes the amplitude mode of the SLAM [9] yielded an attenuation coefficient value of 12.7 dB/mm. The difference between these two techniques is 6%. One reason for the difference is the fact that the measurement data is obtained from different sizes of specimen areas. The pixel size has decreased with a factor of 22 and it is now about 64 μm both vertically and horizontally.

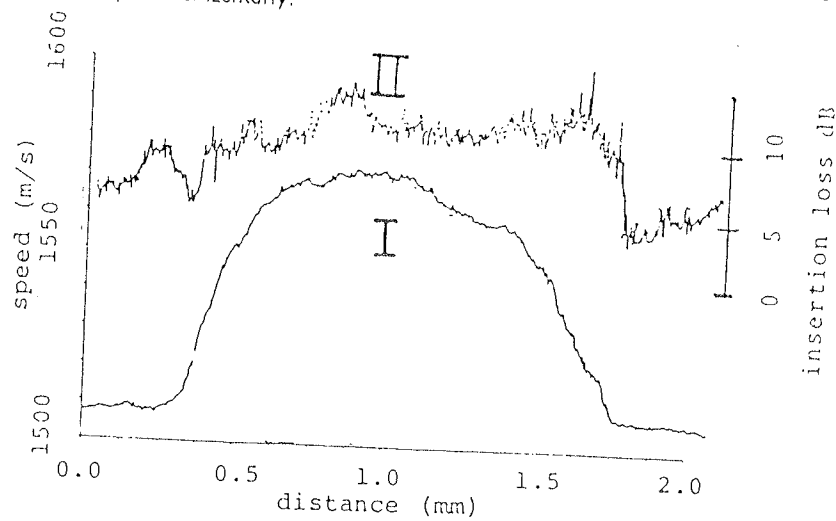


Figure 2: Velocity and insertion loss profiles along the imaging area, which contains a rat liver specimen of thickness of 920 μm and it is surrounded with saline.

The velocity measurement technique has been extended to produce two dimensional images of the velocity distribution on the imaging area. Figure 1(d) shows an image of this kind. The light and dark areas correspond to high and low velocity values on linear scale from 1500 m/s to 1650 m/s, respectively. The "hot spot" on the lower left hand corner corresponds to a hair follicle and the velocity value there is about 1650 m/s. The dark area corresponds to the surrounding saline. The medium light and dark areas are the visualization of the areas of skin (1590 m/s) and wound (1540 m/s), respectively. This kind of image enables the study of different kinds of tissues in the same specimen in microscopic detail.

6 Summary

Techniques for measuring both the velocity and attenuation properties of a specimen using the Interferometric mode of the SLAM have been presented. The velocity measurement technique has been reported in detail elsewhere [8] and the main topic of this paper was to report a measurement technique for the attenuation coefficient, which has previously been determined using the amplitude mode of the SLAM [9]. Both techniques reported here have been verified using biological specimens and the results are in agreement with the results of another technique.

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