SPECTRAL ANALYSIS OF ULTRASONIC WAVE BACKSCATTERED FROM A SUSPENSION OF RANDOMLY DISTRIBUTED SPHERICAL PARTICLES

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ABSTRACT — Several researches have been carried out to investigate the possibility of tissue characterization by ultrasound. The investigation can be done in either time or frequency domain. However, it has been observed that as the acoustic wave propagates through the tissues its attenuation, which is a function of frequency, depends on the tissue conditions, that is, normal or pathological. The interaction of the wave and tissue is a complex physical process and due to this reason we decided to investigate, initially, the interaction of ultrasound with a medium where control becomes possible. This work presents the theoretical formulation for the power spectrum density of a burst of sine waves backscattered from a random medium consisting of a suspension of polystyrene spheres (diameter 0.589mm, standard deviation 0.066mm) in a solution of water and sugar. The carrier frequency is 1 MHz and the pulse repetition frequency is 1500 Hz. The results obtained for different sizes of the particles are used in the case with a size distribution. Experimental results and theoretical predictions agree very well.

INTRODUCTION

There is no question that the improvements of the echo and Doppler ultrasonic imaging systems in the last three decades have made a significant contribution to ultrasonic medical diagnosis. However, progress is still being made in the techniques of tissue characterization, and it is expected that their use will continue to increase in medical diagnosis.

It is understandable that several researchers are directing their efforts to the better understanding of the mechanisms of the interaction between ultrasound and tissues. In particular, one very important interaction is scattering.

It has been observed that the frequency dependence of the attenuation of the propagating wave is a function of tissue conditions. This has motivated many studies in the frequency domain. Among them, Holasek et al. (1973) developed a system for spectral analysis of ultrasonic scattering from soft tissued in the frequency range of 1 to 25 MHz. However, instead of using tissue, they tested their system using a sponge and obtained information

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about the effects of beam spreading and nonlinearities of the acoustic signal from the results for attenuation. Sokollu et al. (1975) continued the previous work and compared the results of attenuation, as a function of frequency, for sponges with those compiled from the literature for liver homogenate. This reference mentions the utilization of the backscattered signal for the analysis. However, this presented new problems for spectral identification, mainly because of gating specific parts of the backscattered signal to determine spatial information. They found that both the shape and the duration of the gate caused a great influence in the echo spectra. Chivers and Hill (1975) described an experimental measuring system using a time-gate to select the signal backscattered from a particular volume inside soft tissues. They presented results of the frequency spectra for formalin-fixed samples of human fat, liver, and spleen in the frequency range 0.5 – 5.0 MHz. They analyzed, briefly, the limitation and advantages of frequency spectral analysis in ultrasonic diagnosis. It was mentioned, again, the influence of the duration of the selecting gate. Lizzi and Laviola (1976) used the spectral analysis of ultrasonic echoes to characterize structures of the eye and orbit, and their investigation was carried out on differential diagnosis, utilizing parameters of backscatter frequency slope, backscatter spectra, and attenuation spectra. Kuc, Schwartz and von Micsky (1976) considered that as the acoustic attenuation constant, in dB/cm, for most soft tissues is known to increase linearly with frequency in the range 0.3 to 10 MHz, then an ultrasonic pulse with a Gaussian envelope transmitted through the soft tissue would still maintain the type of envelope with its spectrum translated on frequency. They performed experiments on in vitro formalin-fixed human liver tissues, using a carrier frequency of 2 MHz. First, transmission was considered either using two transducers or only one to transmit and receive the signal reflected on a rigid plane surface located on the other side of the tissue sample. This caused the wave to travel twice inside the tissue. They obtained good results and this motivated them to analyse the signals backscattered from internal tissue structures, since in practice it becomes extremely difficult to either use direct transmission or double transmission by means of a reflector plane located on the other side of the tissue and opposite to the face of the transducer. This is because of the large attenuation of the acoustic wave as it propagates across the body. However, the results for backscattering were not as good as for transmission. It is clear that the possibility of characterizing tissue by ultrasound exists. The literature has already provided ample experimental evidence.

In this paper we present a theoretical analysis for the power spectrum density of the backscattered acoustic wave as well as experimental results. We will consider a pulsed acoustic wave with a carrier frequency of 1 MHz and 8 μsec for the duration of the burst incident on a random medium consisting of a suspension of polystyrene spheres (mean diameter = 0.589 mm, standard deviation = 0.066 mm) in a solution of water and sugar. We chose the carrier frequency of 1 MHz because the attenuation of the acoustic wave on this medium is more sensitive to frequency for values close to 1 MHz.

We consider the random nature of the backscattered wave and analyse the problem for different values of the duration of the receiving gate and different positions of the sample volume inside the random medium. We also consider the size distributions of the particles. Our results, both theoretical and experimental, refer to the case when first order multiple scattering phenomena apply and they are in very good agreement.

THEORY

Let us consider an electrical signal $u_i(t)$ applied to the transducer. This generates the acoustic wave p_i incident in the random medium (Figure 1).

The espectral density $W_i(\omega)$ for $u_i(t)$ is

$$W_i(\omega) = \int_{-\infty}^{\infty} u_i(t)e^{j\omega t}\, dt \;, \tag{1}$$

with $j = \sqrt{-1}$ and $\omega = 2\pi f$ in rad/sec.

The wave p_s, backscattered by the random medium, is incident on the transducer and an electric signal $u_s(t)$ is generated and is given by (see Ishimaru (1978)).

$$u_s(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} W_i(\omega)\; H(\omega)e^{-j\omega t}\, d\omega \;, \tag{2}$$

where $H(\omega)$ is a complex random function and called the transfer function for the random medium which is assumed to be linear and time invariant.

The spatial resolution along the direction of wave propagation is obtained by gating $u_s(t)$. The duration of this gate defines the size dr of the elementary volume dV, shown in Figure 1.

Calling the gate function by $g(t)$, the received signal $v_o(t)$ due to backscattering from particles in the elementary volume dV is

$$v_o(t) = g(t)u_s(t) \tag{3}$$

This signal $v_o(t)$ is a time varying random function and its power spectrum density, $W(\omega)$, is given by

$$W(\omega) = \int_{-\infty}^{\infty} < v_o(t_1)v_o{}^*(t_2) > e^{j\omega(t_1-t_2)}dt_1dt_2 \;, \tag{4}$$

where < > represents the ensemble average and * means complex conjugate.

The gate spectral density $G(\omega)$ is

$$G(\omega) = \int_{-\infty}^{\infty} g(t)e^{j\omega t}\, dt \;, \tag{5}$$

with

$$g(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} G(\omega)\, e^{-j\omega t}\, d\omega \quad . \tag{6}$$

Substituting expressions (2), (3), and (5) into (4), we obtain

$$W(\omega) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left[\left(\frac{1}{2\pi} \int_{-\infty}^{\infty} G(\omega') e^{-j\omega' t_1} d\omega'\right) \left(\frac{1}{2\pi} \int_{-\infty}^{\infty} G^*(\omega'') e^{j\omega'' t_2} d\omega''\right) \right.$$

$$\left. \cdot \left(\frac{1}{2\pi}\right)^2 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} W_i(\omega_1) W_i^*(\omega_2) \langle H(\omega_1) H^*(\omega_2) \rangle e^{-j\omega_1 t_1 + j\omega_2 t_2} d\omega_1 d\omega_2 \right]$$

$$\cdot\ e^{j\omega(t_1 - t_2)} dt_1 dt_2 \tag{7}$$

After integration in t_1, t_2, ω'', we get

$$W(\omega) = \left(\frac{1}{2\pi}\right)^2 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} G(\omega-\omega_1) G^*(\omega-\omega_2) W_i(\omega_1) W_i^*(\omega_2) \langle H(\omega_1) H^*(\omega_2) \rangle d\omega_1 d\omega_2 \tag{8}$$

In expression (8), functions G and W_i are obtained once $u_i(t)$ and the gate function $g(t)$ are known. It remains only to determine the transfer function $H(\omega)$. This function depends on the random medium.

Using Figure 1 and assuming that first order multiple scattering is valid, then $H(\omega)$, due to backscattering from the elementary volume dV, is written as (see Ishimaru (1978))

$$H(\omega) = f_t(\hat{i},\omega) f_p(-\hat{i},\hat{i},\omega) f_r(-\hat{i},\omega) \frac{e^{j2K}}{(R+r)^2}\, \rho dV \quad , \tag{9}$$

where $f_t(\hat{i},\omega)$ is the transmitting field pattern, related to the gain function $G_T(\hat{i},\omega)$ of the transducer by

$$4\pi f_t(\hat{i},\omega) f_t^*(\hat{i},\omega) = G_T(\hat{i},\omega) \quad ; \tag{10}$$

$f_r(-\hat{i},\omega)$ is the receiving field pattern of the transducer, related to $G_T(\hat{i},\omega)$ as

$$(4\pi/\lambda^2) f_r(-\hat{i},\omega) f_r^*(-\hat{i},\omega) = G_T(\hat{i},\omega) \quad ; \tag{11}$$

with $\lambda = \frac{2\pi c}{\omega}$ and c the wave velocity;

$f_p(-\hat{i},\hat{i},\omega)$ is the backward scattering amplitude of the particle;

$$K=k(R+r) + j\,\frac{\rho\sigma_t r}{2}\;; \tag{12}$$

$$k = 2\pi/\lambda\;; \tag{13}$$

with ρ as the particle density number (number particles/unit volume) and σ_t as the total cross section of the particle.

EXPERIMENTAL SYSTEM

Figure 2 shows a block diagram describing the experimental setup. The transducer and chamber were immersed in a water tank. We transmitted a burst of sine waves with a carrier frequency of 1 MHz and a pulse width of 8 μsec. The receiving gate was delayed by T_d to permit the investigation of the spectral density related to a sample volume located inside the chamber. Different positions for the sample volume are analyzed.

A pulse repetition frequency of 1500 Hz was used and by adjusting the spectrum analyzer to make one scanning from 900 kHz to 1050 kHz during 0.3 sec, with a resolution bandwidth of 1 kHz, three backscattered pulses were allowed to contribute for every 1 kHz interval in the 150 kHz bandwidth we analyzed.

We could not use the ideal case of allowing only one backscattered pulse to contribute to a 1 kHz interval because this would compromise the convergence of the power spectrum density to its average. The number of three pulses with a resolution of 1 kHz was our best choise.

After every scanning, the spectral density was sent to the microcomputer, and each component in the frequency was squared. The average for the power spectral density was calculated after 100 spectral densities were transmitted to the microcomputer.

Details about the random medium can be found in Machado, Sigelmann and Ishimaru (1983). We used ρ as 84 cm^{-3} which insures that first order multiple scattering is valid, as shown in this reference.

APPROXIMATIONS TO THEORETICAL EXPRESSIONS

Now we will make use of our experimental setup and substitute some values into expression (8) such that simplifications for $W(\omega)$ become possible. The applied signal $u_i(t)$, to generate a burst of sine waves, is

$$u_i(t) = \mathrm{Re}\ \{[U(t+T_i/2) - U(t-T_i/2)]e^{-j\omega_o t}\} \quad , \tag{14}$$

where $U(t) = 1$ for $t \geqslant 0$ and 0 for $t < 0$,

$\omega_o = 2\pi f_o$ and f_o is the carrier frequency (1 MHz) ,

T_i = the width for the transmitted pulse (8 µsec) .

From expressions (1) and (14), we obtain $W_i(\omega)$

$$W_i(\omega) = T_i \frac{\sin[(\omega-\omega_o)T_i/2]}{(\omega-\omega_o)T_i/2} . \tag{15}$$

The gate used to select the sample region and called g(t) is

$$g(t) = U(t+T_g/2-T_d) - U(t-T_g/2-T_d) \quad , \tag{16}$$

where T_g is the duration of the gate and T_d is the delay.

From expressions (5) and (16), we obtain $G(\omega)$

$$G(\omega) = T_g \frac{\sin(\omega T_g/2)}{\omega T_g/2} e^{j\omega T_d} \tag{17}$$

For T_g, we used values of 10, 20, and 30 µsec.

For the final expression of the power spectrum density, we will use expression (9) and the geometrical configuration of transducers and chamber to determine the correlation function of $H(\omega)$. We consider that the particles are uncorrelated with each other. Therefore, this gives

$$\langle H(\omega_1)H^*(\omega_2)\rangle = \int_V f_t(\hat{i},\omega_1)f_1^*(\hat{i},\omega_2)f_p(-\hat{i},\hat{i},\omega_1)f_p^*(-\hat{i},\hat{i},\omega_2)$$

$$\cdot\ f_r(-\hat{i},\omega_1)f_r^*(-\hat{i},\omega_2)\ \frac{e^{j2(K_1-K_2^*)}}{(R+r)^4}\ \rho dV \quad , \tag{18}$$

where V is the volume inside the chamber defined by the acoustic beam,

$$K_i = \omega_i(R+r)/c + j\ \frac{\rho r}{2}\ \sigma_t(\omega_i) \quad , \tag{19}$$

with $i = 1$ or 2

We measured the radiation pattern for the transducer in terms of $f_t(\hat{i},\omega)f_r(-\hat{i},\omega)$ and this product turned out to have a phase angle almost independent on the frequency and an amplitude $A(\omega)$ which is presented in Figure 3. Laterally, the radiation pattern presented a Gaussian type function. This permits us to write

$$f_t(\hat{i},\omega)f_r(-\hat{i},\omega) = BA(\omega)e^{-(2\theta/\theta_b)^2 \ln(2)} , \tag{20}$$

where B is a constant of proportionality and θ_b is the half-power beam angle.

The volume dV can be written as

$$dV \cong 2\pi(R+r)^2\theta d\theta dr \tag{21}$$

Then substituting expressions (20) and (21) into (18), we have

$$\langle H(\omega_1)H^*(\omega_2)\rangle = BB^*F(\theta_b)f_p(-\hat{i},\hat{i},\omega_1)f_p^*(-\hat{i},\hat{i},\omega_2)A(\omega_1)A(\omega_2)e^{\frac{j2}{c}(\omega_1-\omega_2)R}$$

$$\cdot\ \rho\int_0^L \frac{e^{\frac{j2}{c}(\omega_1-\omega_2)r}\ e^{-\rho r(\sigma_t(\omega_1)+\sigma_t(\omega_2))}}{(R+r)^2}\, dr , \tag{22}$$

$$\text{with } F(\theta_b) = 2\pi\int_0^{\pi/2} e^{-8(\theta/\theta_b)^2 \ln(2)}\ \theta d\theta . \tag{23}$$

Now we rewrite expression (8) as

$$W(\omega) = \left(\frac{1}{2\pi}\right)^2 BB^*F(\theta_b)\rho\int_0^L \frac{1}{(R+r)^2}\left[\int_{-\infty}^{\infty} F_1(\omega,r)d\omega_1 \int_{-\infty}^{\infty} F_2(\omega,r)d\omega_2\right]dr , \tag{24}$$

where
$$F_1(\omega,r) = T_g\,\frac{\sin[(\omega-\omega_1)T_g/2]\,e^{j\omega T_d}}{(\omega-\omega_1)T_g/2}\; T_i\,\frac{\sin[(\omega_1-\omega_o)T_i/2]}{(\omega_1-\omega_o)T_i/2}$$

$$\cdot\ f_p(-\hat{i},\hat{i},\omega_1)A(\omega_1)e^{-\rho r\sigma_t(\omega_1)}\,e^{\frac{j2}{c}\,\omega_1(R+r-cT_d/2)} , \tag{25}$$

and $F_2(\omega,r) = F_1^*(\omega,r)\big|_{\omega_1=\omega_2}$ (26)

We can simplify expression (24) by noting that both $F_1(\omega,r)$ and $F_2(\omega,r)$ have a complex exponential term which is a function of R+r and cT_d.

When R+r differs from $cT_d/2$ function $F_1(F_2)$ is oscillationg around the axis for $\omega_1(\omega_2)$ and it does not contribute significantly to the integral in $\omega_1(\omega_2)$. The main contribution comes when R+r = $cT_d/2$.

Using this to simplify expression (24), we obtain

$$W(\omega) = \left(\frac{1}{2\pi}\right)^2 BB^*F(\theta_b)\,\frac{4}{(cT_d)^2}\,\rho\int_{-\infty}^{\infty} F_1(\omega)d\omega_1\left[\int_{-\infty}^{\infty} F_1(\omega)d\omega_1\right]^*, \tag{27}$$

where now

$$F_1(\omega) = \frac{T_g\,\sin\left[(\omega-\omega_1)T_g/2\right]}{(\omega-\omega_1)T_g/2}\,e^{j\omega T_d}\,\frac{T_i\,\sin\left[(\omega_1-\omega_0)T_i/2\right]}{(\omega_1-\omega_0)T_i/2}$$

$$\cdot\, f_p(-\hat{i},\hat{i},\omega_1)A(\omega_1)e^{-\rho(cT_d/2-R)\sigma_t(\omega_1)} \tag{28}$$

Expressions (27) and (28) are the simplifications obtained to calculate to power spectrum density $W(\omega)$.

To calculate $W(\omega)$, we developed a Fortran program called SPECRG (TAMP, DIA(I), SIZEP(I), DENS3, DENSP, LAMBS,LAMB, MIU, OMEGA1, OMEGA2, OMEGAO, TSW, RGW, RGD, DIST, LENG, RHO) where TAMP = $A(\omega)$, DIA(I) = ith diameter in the distribution of the size of the spheres, SIZEP(I) = probability density for ith diameter, DENS3 (DENSP) = density of solution (particle), LAMBS (LAMB) = inverse of the compressibility modulus of solution (particle), MIU = shear modulus of the particle, OMEGA1 (OMEGA2) = lowest (highest) angular frequency in the bandwith of $W(\omega)$, OMEGAO = ω_o, TSW = T_i, RGW = T_g,RGD = T_d, DIST = R, LENG = L, RHO = ρ.

RESULTS

The range 0.9 to 1.050 MHz of the power spectrum density $W(\omega)$ is the most interesting one. In this frequency band the total cross section σ_t changes very rapidly. As shown in Figure 4, in this range σ_t and consequently the attenuation, in dB, depends on the 13^{th} power of the frequency.

Figures 5, 6, and 7 show the experimental and theoretical results for $W(\omega)$ normalized to the power spectrum density $W_o(\omega)$ due to backscattering from the sample volume SV located inside the chamber at 1.5 cm from its front face. In each of these figures, the results refer to two different delays in the receiving gate which defined sample volumes located at 3 and 6 cm distant from the front face.

For the results presented in Figure 5, the receiving gate had a width, T_g, of 10 μsec and for the results in Figure 6 and 7, the width was 20 and 30 μsec, respectively.

We considered the size distribution of the particles to calculate $W(\omega)$ and in Figure 8, we present $W(\omega)/W_o(\omega)$ for different sizes, using T_g as 20 μsec and two different delays which defined sample volumes at 3 and 6 cm distant from the front face.

CONCLUSION

In this work, we developed the formulation to calculate the power spectrum density for an acoustic wave backscattered from a random medium. The first order multiple scattering theory and the experimental data agree very well.

In the literature, many authors normalized their results with respect to the signal resultant from the reflection of the acoustic wave from a perfect reflector. We normalized with respect to the signal backscattered from a volume inside the medium as close to the transducer as possible. With this normalization, we eliminated the backscattering effects of the random medium; and therefore, the results reflect the attenuation characteristics of the wave propagating in the random medium. We point out that no significant differences were observed in our results for distinct values of the width of the receiving gate. Although σ_t changes with the 13th power of frequency, the results for the attenuation do not show the same type of dependence.

The random medium discussed in this paper is quite different from biological tissues. Nevertheless, because this random medium has controllable particle shape, particle size, particle concentration, length of random medium propagated by the wave, etc., it is simpler to model. However, even for this random medium which is simple when compared to biological tissue, many difficult problems arose. But we were able to explain, successfully, the mechanism of interaction between the acoustic wave and the random medium.

As a next step, the investigation must proceed with more realistic models for biological tissues, and the results should be explained in terms of scattering theories. These steps should progress up to the point that a biological tissue becomes used as a random medium. In this case, after understanding the scattering mechanism by this random medium, then tissue characterization by ultrasound will be possible.

ACKNOWLEDGEMENT

We appreciate the support from CNPq-Brazil, the Army Research Office, and the Office of Naval Research - U.S.A.

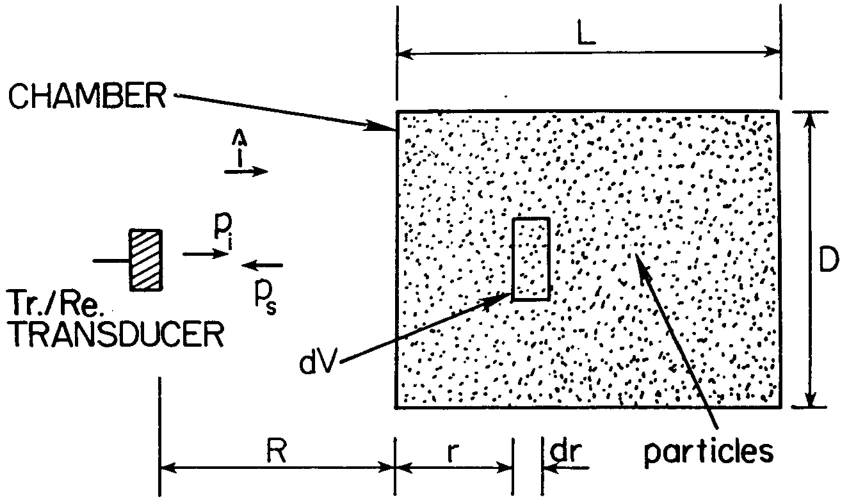

Figure 1. Geometry for the spectral analysis of ultrasonic waves backscattered by elementary volume dV of random medium. L = 15 cm, D = 9 cm, R = 13.5 cm. Incident wave is p_i, backscattered wave is p_s. The unit vector $\hat{i}$ is in the direction of p_i.

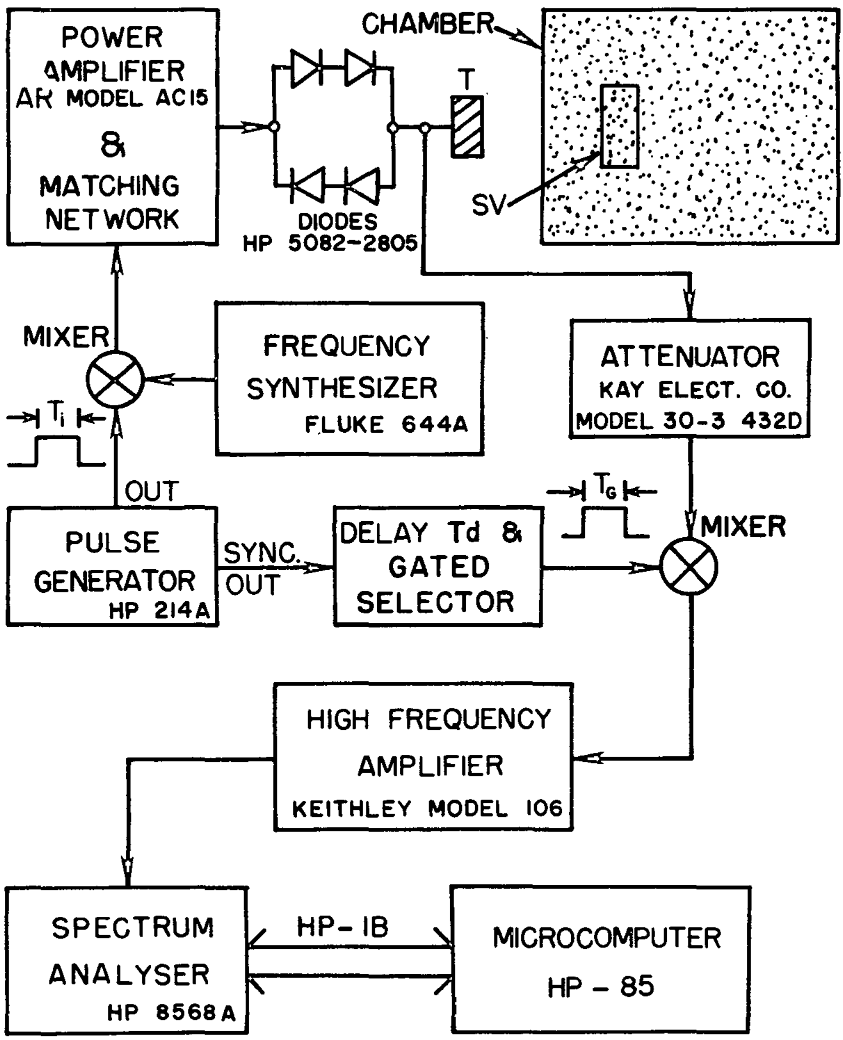

Figure 2. Block diagram of the system to measure the power spectrum density. The distance between sample volume SV and transducer T is defined by T_d

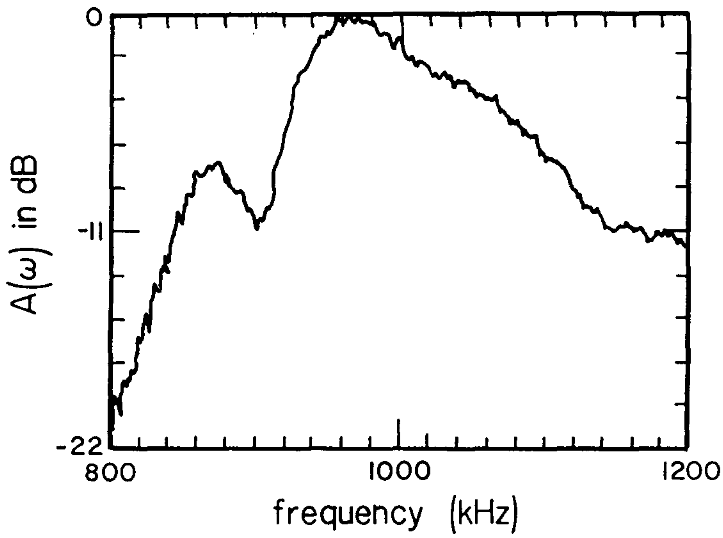

Figure 3. Amplitude A(ω) of the radiation pattern of the transducer as a function of frequency in kHz.

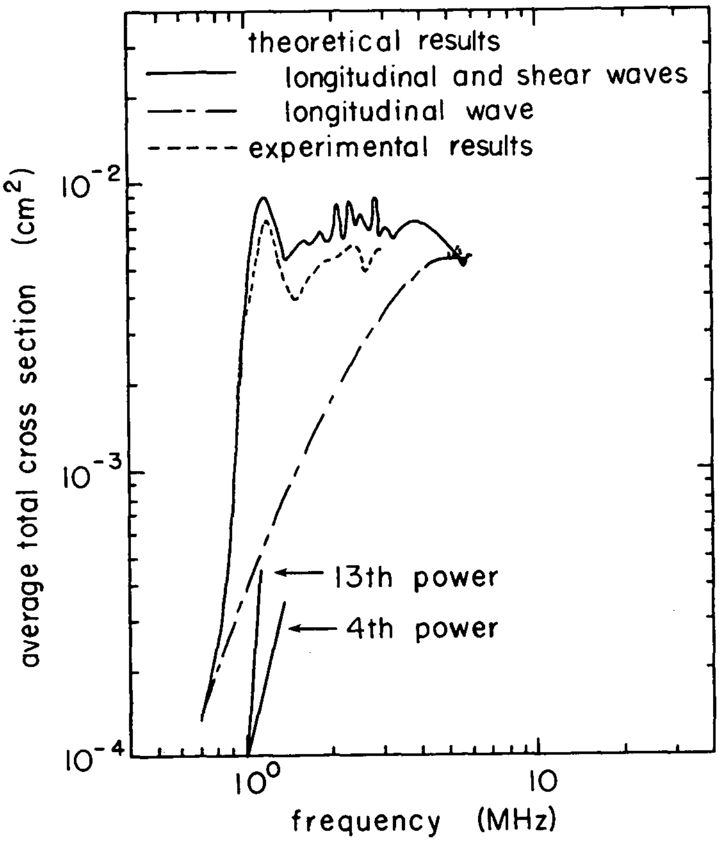

Figure 4 — Average total cross section σ_t as a function of frequency. The theoretical results for σ_t are presented in two ways, one considering only longitudinal wave inside the particles and the other considering both longitudinal and shear waves inside the particles. The later consideration, used throughout this paper, is necessary to explain the dependence of σ_t to the 13th power of frequency and for the good agreement between theoretical and experimental results when the frequency is about 0.9 MHz or $ka \approx 1$ ($k = 2\pi/\lambda$, a = radius of the particle).

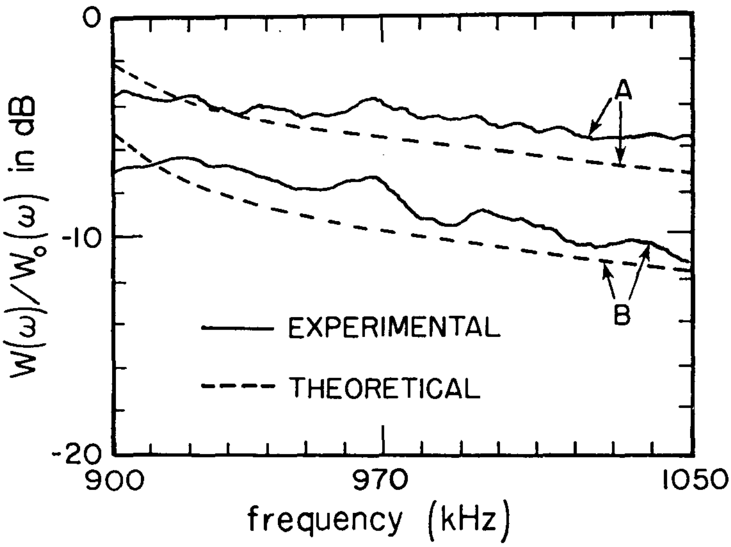

Figure 5. Power spectrum density $W(\omega)$ normalized to the power spectrum density $W_o(\omega)$ due to backscattering from the sample volume SV inside the chamber and distant 1.5 cm from its front face. Curves A and B are the results for SV distant 3 and 6 cm, respectively, from the front face, as a function of frequency in kHz. The value of T_g was 10 μsec.

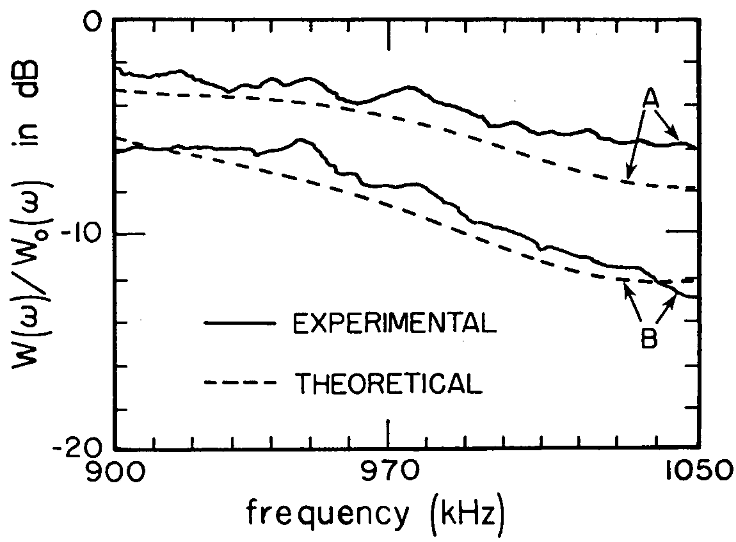

Figure 6. Same as in Figure 5, except T_g was 20 μsec.

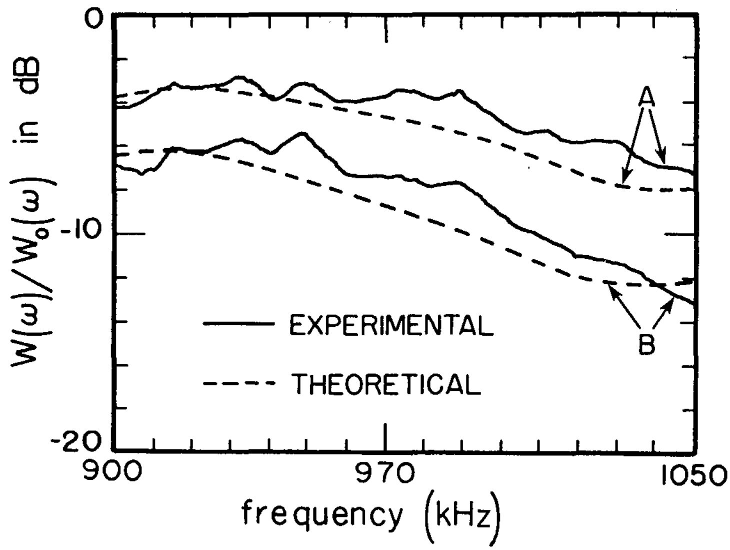

Figure 7. Same as in Figure 5, except T_g was 30 μsec.

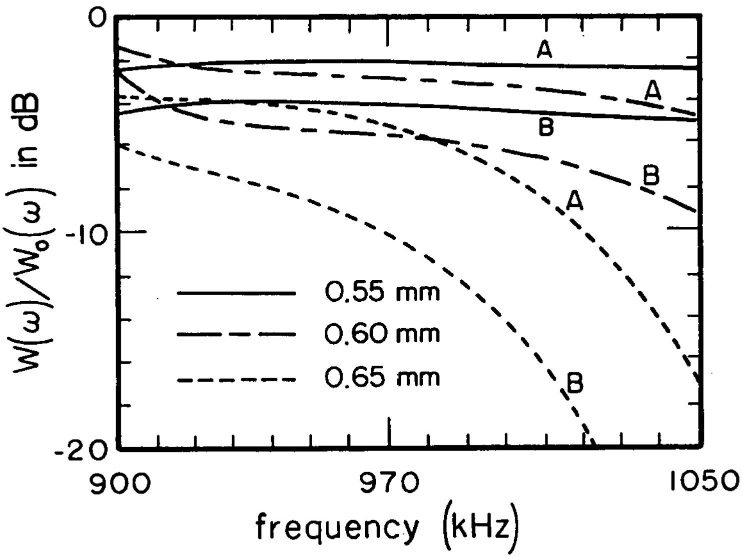

Figure 8. Theoretical results for $W(\omega)/W_0(\omega)$, as a function of frequency in kHz, for particles with diameters of 0.55 mm, 0.60 mm, and 0.65 mm. Curves A and B are the results for the sample volume SV distant 3 and 6 cm, repectively, from the front face of the chamber. The value of T_g was 20 μsec.

REFERENCES

1. CHIVERS, R.C. and HILL, C.R. (1975), "A spectral approach to ultrasonic scattering from human tissue: methods, objectives and backscattering measurements", Phys. Med. Biol., vol. 20, no. 5, pp 799-815.
2. HOLASEK, E., JENNINGS, W.D., SOKOLLU, A. and PURNELL, E.W. (1973), "Recognition of tissue patterns by ultrasonic spectroscopy", IEEE Ultrasonics Symposium Proc., pp. 73-76.
3. ISHIMARU, A. (1978), "Wave propagation and scattering in random media", Academic Press, New York, Vol. I and II.
4. KUC, R., SCHWARTZ, M. and von MICSKY, L. (1976), "Parametric estimation of the acoustic attenuation coefficient slope for soft tissue", IEEE Ultrasonics Symposium Proc., pp 44-47.
5. LIZZI, F.L. and LAVIOLA, M.A. (1976), "Tissue signature characterization utilizing frequency domain analysis", IEEE Ultrasonics Symposium Proc., pp. 714-719.
6. MACHADO, J.C., SIGELMANN, R.A., and ISHUMARU, A. (1983), "Acoustic wave propagation in randomly distributed spherical particles", J. Acoust. Soc. Am. 74(5), pp. 1529-1534.
7. SOKOLLU, A., PURNELL, E.W., HOLASEK, E. and JENNINGS, W.D. (1975), "Methods of tissue identification by ultrasonic spectra", National Bureau of Standards Special Publication 453, Proc. Seminar on Ultrasonic Tissue Characterization, pp. 97-107.

ANÁLISE ESPECTRAL DA ONDA ULTRASSONICA RETROESPALHADA POR UMA SUSPENSÃO DE PARTÍCULAS ESFÉRICAS DISTRIBUIDAS ALEATORIAMENTE

RESUMO -- Inúmeras pesquisas foram realizadas para investigar a possibilidade da caracterização de tecidos humanos por ultra-som. A investigação pode ser realizada tanto no domínio do tempo como no da frequência. Porém, se observa que a atenuação da onda acústica que se propaga através dos tecidos, a qual é função da frequência, depende das condições do tecido, sejam elas normais ou patológicas. A interação da onda com tecido é um processo físico bastante complexo e por esta razão decidimos investigar, inicialmente, a interação da onda com um meio mais simples e possível de se controlar.

Este trabalho apresenta uma formulação teórica para o cálculo da densidade espectral de potência de uma salva de ondas acústicas senoidais retroespalhadas por uma distribuição aleatória de esferas de poliestireno (diâmetro 0,589 mm e desvio padrão 0,066 mm) suspensas numa solução de água e açúcar. A frequencia da portadora do sinal transmitido é de 1 MHz e a frequencia de repetição do pulso é de 1500 Hz. Os resultados obtidos para diferentes tamanhos das partículas são usados no caso em que existe uma distribuição de tamanhos das partículas. Os resultados experimentais e previsões teóricas coincidem satisfatoriamente.