An Investigation Into Backscattered Cross Section Calibration of an Acoustic Sounder Used for Analysis of Lower Atmospheric Turbulence

by

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AN INVESTIGATION INTO BACKSCATTERED CROSS SECTION CALIBRATION OF AN ACOUSTIC SOUNDER USED FOR ANALYSIS OF LOWER ATMOSPHERIC TURBULENCE

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This thesis provides a preliminary investigation of a calibration process.
19. (continued)
Using pulsed acoustic energy backscattered from hard spheres. Supporting software calculates the desired product $E_r E_t$ based on an assumption of echosounder efficiency reciprocity. Results of the calibration process investigation indicate this assumption may be invalid. The results also indicate the software performs as intended and that the proposed calibration method possesses sufficient merit to warrant further development.

(Continued)
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by

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This thesis provides a preliminary investigation of a calibration process using pulsed acoustic energy backscattered from hard spheres. Supporting software calculates the desired product $E_rE_t$ based on an assumption of echosounder efficiency reciprocity. Results of the calibration process investigation indicate this assumption may be invalid. The results also indicate the software performs as intended and that the proposed calibration method possesses sufficient merit to warrant further development.
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I. **INTRODUCTION**

The variational effect of wind shears, convection, and temperature gradients on atmospheric density distributions characterize atmospheric turbulence. The temperature structure parameter, $C_T^2$, and the index of refraction structure parameter, $C_n^2$, quantify two density distributions that arise in acoustic and electromagnetic propagation. [Ref. 1]

The density distributions quantified by $C_n^2$ and $C_T^2$ induce phase fluctuations in propagating electromagnetic waves. The density distributions of atmospheric turbulence degrade the spatial and temporal coherences of initially coherent electromagnetic radiation. Similar, more pronounced effects occur in the propagation of acoustic waves. [Ref. 1]

A number of techniques for correcting these problems have been proposed, particularly with respect to electromagnetic propagation. These corrective techniques include the use of modular mirrors [Ref. 2], optical phase conjugation [Ref's. 2 and 3], optical and digital signal processing [Ref. 4], and simple avoidance of turbulent air masses. The appropriate timing of transmissions or suitable location of transmission and reception
facilities accomplishes avoidance [Ref's. 5 and 6]. These techniques can be applied alone or in combinations.

A knowledge of the history of the density or refractive structure along a proposed transmission path is required to effectively employ a number of these compensatory techniques. Time-averaged $C_T^2$ or $C_n^2$ profiles characterize this history [Ref's. 1 and 7].

Wroblewski and Weingartner developed and Moxey refined a high resolution, computer controlled acoustic sounder, or echosounder, system. Their computer controlled echosounder system uses a transmitted pulse of acoustic energy as a probe of atmospheric structure. The interaction of the acoustic wave packet with atmospheric turbulence is used to develop a time-averaged $C_T^2$ profile for a short spatial range [Ref's. 5, 6 and 8]. The acoustic sounder may also be used to verify certain long range optical measurements of turbulence [Ref. 6].

Development of the $C_T^2$ profile uses a $C_T^2$ expression developed from the echoonde equation summarized by Neff [Ref. 7] and the empirical acoustic backscatter cross section per unit volume expression of Tatarski [Ref. 9] [Ref's. 5 and 6]. The accuracy of the absolute values of this $C_T^2$ profile depends on the calibration of the acoustic antenna parameters.
contained in the $C_t^2$ expression. The antenna parameters of interest are $E_t$, the efficiency of conversion of electrical to acoustic power, and $E_r$, the efficiency of conversion of acoustic power to electrical power.

In this thesis acoustic energy backscattered off acoustically hard spheres was used to determine $E_r$ and $E_t$. Acoustic range equations were software implemented to perform the necessary calculations. Data and calculational results provided first order verification of the calibration process.
II THEORETICAL BACKGROUND

A. CT$^2$ REVIEW

Wroblewski and Weingartner applied the echosonde equation,

$$P_r = E_r\left[P_t E_t\right]\left[2\right]\left[\frac{CT}{2} \sigma_0(R,f)\right]\left[\frac{A}{R^2} G\right], \tag{1}$$

summarized by Neff [Ref. 7] and the acoustic backscattering cross section per unit volume expression given by Tatarski [Ref. 9] as

$$\sigma_0(R,f) = 0.0039 \frac{k^{1/3} \frac{CT^2}{T_0^2}} \tag{2}$$

to develop the volume averaged expression

$$CT^2 = \frac{1}{0.0039} \frac{1}{E_r E_t} \frac{T_0^2}{k^{1/3}} \frac{2}{CT\ AG} \frac{1}{P_r} \frac{R^2 e^{2\alpha R}}{P_t}, \tag{3}$$

where

- $P_r$ is the electrical power of the reflected signal returned to the acoustical antenna array,
- $E_r$ is the efficiency of conversion of the returned acoustic power to $P_r$,
- $P_t$ is the electrical power supplied to the acoustical array,
- $E_t$ is the efficiency of conversion of $P_t$ to acoustic power,
- $\alpha$ is the average attenuation per unit distance along the transmission path,
- $R$ is the range from the array to the target or backscattering volume,
c is the average speed of sound along the transmission path,
\( \tau \) is the length in time of the transmitted acoustic pulse,
A is the antenna's aperture area,
G is the antenna's effective aperture factor,
k is the wavenumber of the incident acoustic energy, and
\( T_0 \) is the average temperature (in degrees Kelvin) along the transmission path.

[Ref's. 5 and 6]

The conditions at the time and location of each application determine the value of the terms \( T_0, k, c, \tau, P_r, P_t, R \) and \( \alpha \) in the \( C_T^2 \) expression.

The terms A and G depend on the antenna design.

Adverse field effects such as dust, debris and vibration loosened connections cause the remaining two terms, \( E_r \) and \( E_L \), to change over the life of the system. This chapter develops the theoretical expressions supporting a determination of \( E_r \) and \( E_L \).

B. ACOUSTIC RANGE EQUATIONS AND EFFICIENCIES

In the following two sections the acoustic range equation of Neff [Ref. 7] is re-developed for targets of small area relative to the cross-section of the ensonifying field. Neff [Ref. 7], Skolnik [Ref. 10], and Probert-Jones [Ref. 11] were used for guidance.
1. One Way Range Equation and $E_{tGo}$

As defined previously, the electrical power supplied to the acoustic array is $P_t$. It is converted at an efficiency $E_t$ to an emitted acoustic power,

$$P_a = P_t E_t.$$  \hspace{1cm} (4)

$P_a$ is spread over a $4\pi$ solid angle.

A far field range $R$ is defined by the condition

$$\frac{\lambda}{2} \gg |L| - |R|$$  \hspace{1cm} (5)

for the geometry in Figure 1. $\lambda$ is the wavelength of the emitted acoustic wave.

![Figure 1: Calibration (Far Field) Geometry](image)
The acoustic intensity,

\[ I_a = \frac{P_a}{4\pi R^2}, \quad (6) \]
describes the emitted acoustic power density of an isotropic emitter at a far field range \( R \). \( I_a \) is in units of \( \text{W/m}^2 \).

If the emitted power is directional, the intensity \( I_a \) is modulated by a geometrical gain,

\[ G(\Omega) = G_0 |F(\Omega)|^2 = G_0 |F(\theta, \phi)|^2. \quad (7) \]

Note this is not the same \( G \) found in equation (1). Now,

\[ |F(0,0)|^2 = 1, \quad (8) \]

and \( G_0 \) is therefore the centerline gain of the acoustic array. [Ref. 11] The centerline direction \((0,0)\) is taken to be normal to the face of the acoustic array. The acoustic intensity \( I_a \) is now written

\[ I_a = \frac{P_a}{4\pi R^2} G(\Omega). \quad (9) \]

In a real propagating medium intensity attenuation occurs along the transmission path. The radial term \( e^{-\alpha R} \) accounts for this attenuation when the atmospheric path is assumed to be reasonably
homogeneous. The acoustic intensity is then

\[ I_a = \frac{P_a}{4\pi R^2} G(\Omega) e^{-\alpha R}. \]  \hspace{1cm} (10)

A target of cross sectional area \( A_{tgt} \) intercepts a power

\[ P_{tgt} = I_a A_{tgt}. \]  \hspace{1cm} (11)

Expanding this expression with equation (10) yields

\[ P_{tgt} = \left[ \frac{P_a}{4\pi} \right] \left[ e^{-\alpha R} G(\Omega) \right] \left[ \frac{A_{tgt}}{R^2} \right]. \]  \hspace{1cm} (12)

For a target of cross sectional area \( A_{tgt} \) with a sufficiently small solid angle \( A_{tgt} / R^2 \) little change in intensity occurs about the direction \( \Omega \). Equation (12) is now arranged as a one way range equation along the centerline direction (0,0);

\[ R = \left[ \frac{P_t E_t}{4\pi} \right]^{1/2} \left[ e^{-\alpha R} G_0 \frac{A_{tgt}}{P_{tgt}} \right]. \]  \hspace{1cm} (13)

Isolating \( E_t G_0 \) in the above expression yields

\[ E_t G_0 = \frac{4\pi R^2}{P_t} e^{\alpha R} \frac{P_{tgt}}{A_{tgt}}. \]  \hspace{1cm} (14)
Electrical power is expressed as

$$P = \frac{V_{rms}^2}{Z} = \frac{V_{ms}}{Z},$$  \hspace{1cm} (15)$$

where

- $V_{rms}$ is the empirical root mean square voltage,
- $V_{ms}$ is $V_{rms}^2$, and
- $Z$ is the electrical impedance.

$E_t G_0$ is now written

$$E_t G_0 = 4\pi R^2 \frac{Z}{(V_{ms})_t} e^{\alpha R} \frac{P_{tgt}}{A_{tgt}}. \hspace{1cm} (16)$$

The ratio $P_{tgt}/A_{tgt}$ is defined as the acoustic intensity $I_r$, received by the target. Therefore,

$$E_t G_0 = 4\pi R^2 \frac{Z}{(V_{ms})_t} e^{\alpha R} I_r. \hspace{1cm} (17)$$

2. **Two Way Range Equation and $E_r$**

For an acoustically hard target the total power reflected is $P_{tgt}$.

The power reflected from the target surface has a normalized, directional intensity distribution described by the differential scattering cross section, $\sigma$. 
The direction from the target to the array is the backscattered direction. The differential scattering cross section in the backscattered direction is called the normalized backscattered cross section, $\sigma_b$. $\sigma_b$ is defined as the power reflected toward the source per unit solid angle, normalized by the incident power density over a $4\pi$ solid angle.

The backscattered intensity from the target is

$$I_{tgt} = \frac{P_{tgt}}{4\pi R^2} \sigma_b.$$  \hfill (18)

An array of aperture area $A$ at range $R$ intercepts an attenuated, received acoustic power,

$$P_{ra} = I_{tgt} A e^{-\alpha R}.$$  \hfill (19)

Substituting equation (18) into equation (19) yields

$$P_{ra} = \frac{P_{tgt} \sigma_b}{4\pi R^2} e^{-\alpha R} A.$$  \hfill (20)

$P_{ra}$ is converted to returned electrical power, $P_r$, at a return efficiency, $E_r$;

$$P_r = P_{ra} E_r.$$  \hfill (21)
Since electrical power is expressed as
\[ P = \frac{V_{rms}^2}{Z} = \frac{V_{ms}^2}{Z} \]  \hspace{1cm} (15)

electrical power representing the returned acoustic signal from a target placed along an emitter's direction \((0,0)\) is written as
\[ \frac{(V_{ms})_r}{Z_r} = \frac{(V_{ms})_l}{Z_l} \left[ \frac{E_t G_o}{4\pi} e^{-\alpha R} \frac{A_{tgt}}{R^2} \right] \left[ \frac{E_r \sigma_b}{4\pi} e^{-\alpha R} \frac{A}{R^2} \right] \]  \hspace{1cm} (22)

For a passive, linear acoustic array circuit the concept of impedance reciprocity is invoked [Ref. 12] to yield a two way range equation for scattering from a small target;
\[ R = \left[ \frac{(V_{ms})_l}{(V_{ms})_r} E_t E_r \frac{G_o \sigma_b}{(4\pi)^2} e^{-2\alpha R} \frac{A}{A_{tgt}} \right]^\frac{1}{2} \]  \hspace{1cm} (23)

This is written to isolate \(E_r\):
\[ E_r = \frac{(V_{ms})_r}{(V_{ms})_l} \frac{(4\pi R^2)^2}{E_t G_o} \frac{e^{2\alpha R}}{A A_{tgt}} \frac{1}{\sigma_b} \]  \hspace{1cm} (24)

A part of the return signal's power is unwanted noise.

Subtracting noise power from the returned acoustic power yields
\[ E_r = \frac{(V_{ms})_r - (V_{ms})_n}{(V_{ms})_l} \frac{(4\pi R^2)^2}{E_t G_o} \frac{e^{2\alpha R}}{A A_{tgt}} \frac{1}{\sigma_b} \]  \hspace{1cm} (25)
As return voltages are quite small they are analyzed after electrical amplification. Calling the electrical amplification a gain $G_e$ allows introduction of the final modification to $E_r$: 

$$E_r = \frac{(V_{ms})_r - (V_{ms})_0}{(V_{ms})_t} \frac{(4\pi R^2)^2}{G_o^2} \frac{e^{2\alpha R}}{A A_{tgt}} \frac{1}{\sigma_b}. \quad (26)$$

C. ATTENUATION AND RANGE DETERMINATION

Employing equations (17) and (26) in the calibration process requires calculating the attenuation $\alpha$ and the range $R$ from the array to the target.

1. Attenuation

The calculated attenuation $\alpha$ for an atmospheric propagation path is assumed to be the combined result of molecular and classical absorption in the atmosphere. The classical absorption $\alpha_{cl}$ is attributed to heat conduction and viscous effects while the larger molecular absorption $\alpha_{mol}$ is attributed to the excitation of internal energy modes of atmospheric gases by the propagating sound energy. [Ref. 7]

Information from Neff [Ref. 7], Businger [Ref. 13], Neiburger [Ref. 14], and Fuller [Ref. 15] is applied to make a reasonable determination of $\alpha$. The determination is made using the average measured temperature
T_c in degrees Celsius along the propagation path, the measured atmospheric pressure P in millibars, and the measured relative humidity Rh in percent.

The molecular attenuation coefficient, \( \alpha_{\text{mol}} \), is expressed by the empirical relationship

\[
\alpha_{\text{mol}} = \frac{\alpha_{\text{max}}}{304.8} \left[ (0.18 f_{\text{ratio}})^2 + \frac{2(f_{\text{ratio}})^2}{1 + f_{\text{ratio}}^2} \right]^\frac{1}{2}.
\] (27)

\( \alpha_{\text{mol}} \) is in units of \([-\text{dB/m}]\).

Now,

\[
\alpha_{\text{max}} = 0.0078 f_m (T*)^{-2.5} e^{7.77(1-1/T*)} \] (28)

is the maximum absorption at

\[
f_m = \frac{(10 + 6600 (100 \frac{e}{P}) + 44,400 (100 \frac{e}{P})^2) P^*}{(T*)^{0.8}}.
\] (29)

\( f_m \) is in units of \([\text{Hz}]\).

Also,

\[
\frac{e}{P} = \frac{E_s \text{Rh}}{P - E_s(1 + \text{Rh})} \] (30)

is the mole ratio of water vapor in the atmosphere. The water vapor pressure \( e \) is expressed in millibars.
expresses the saturation vapor pressure $E_s$. $T_0$ is the average absolute temperature along the transmission path, as defined in Section A.

$$T^* = \frac{(1.8 T_c + 492)}{519}, \quad (32)$$

and

$$P^* = \frac{P}{1014}. \quad (33)$$

Finally,

$$f_{\text{ratio}} = \frac{f}{f_m}, \quad (34)$$

where $f$ is the operating frequency of the echosounder in [Hz]. [Ref's. 7, 13, 14 and 15]

The classical attenuation coefficient, $\alpha_{cl}$, is approximated by

$$\alpha_{cl} = 1.74 \times 10^{-10} (f)^2. \quad (35)$$

$\alpha_{cl}$ is in units of [-dB/m]. [Ref. 7]

For a total attenuation

$$\alpha_T = \alpha_{cl} + \alpha_{mol} \quad (36)$$

and the relationship
\[- \alpha_t R = 10 \log e^{-\alpha R} \]  \hspace{1cm} (37)

The average attenuation per meter is finally written as

\[ \alpha = \frac{\alpha_{cl} + \alpha_{mol}}{10} \ln 10 \]  \hspace{1cm} (38)

Equation (37) is derived from unit definitions and equation one of Neff [Ref. 7].

2. Range

The coordinate system for the backscattered cross section determination uses the center of the target spheres as the coordinate system origin. Therefore, the radius \( a \) of a target sphere and the time of return \( t_r \) of an acoustic signal from the acoustic echosounder are used to determine the range \( R \) from the target to the echosounder;

\[ R = \frac{c t_r}{2} + a . \]  \hspace{1cm} (39)

\( c \) is the average speed of sound along the transmission path, and

\[ t_r = t_{\text{receive}} - t_{\text{transmit}} . \]  \hspace{1cm} (40)

For the range of temperatures expected in normal echosounder operation the speed of sound in meter per seconds in dry air is

\[ c_{\text{dry}} = 20.05 \sqrt{T_0} . \]  \hspace{1cm} (41)
For moist air $c$ becomes

$$c = c_{\text{moist}} = c_{\text{dry}} (1 + 0.14 e/P), \quad (42)$$

where $e/P$ is defined in equation (30). [Ref. 1]

D. BACKSCATTERED CROSS SECTION DETERMINATION

Employing equations (17) and (26) in the calibration process also requires calculating $\sigma_b$, the backscattered cross section. Recall from Paragraph B.2 that the backscattered cross section is the differential scattering cross section in the direction of the energy source.

1. Initial Conditions and Assumptions

In determining the differential scattering cross section $\sigma$ it is assumed the incident wave state is unchanged after scattering. That is, for a stationary, acoustically hard target it is assumed

$$k = k_{\text{incident}} = k_{\text{scattered}}, \quad (43)$$

and that incident $k$ has good definition, i.e. the incident wave can be considered monochromatic [Ref. 16].

Selection of acoustically hard spheres as targets further simplifies the determination of the differential scattering cross section solution. This target selection sets the boundary condition at the target
surface as the Neumann boundary condition

\[ \frac{\partial \mathbf{V}}{\partial n} = 0. \tag{44} \]

\( \mathbf{V} \) is the velocity potential defined by the acoustic propagation velocity \( c \) as

\[ c = \nabla \mathbf{V}. \tag{45} \]

\( n \) lies along the direction normal to the target surface. Also,

\[ p = -\rho_0 \frac{\partial \mathbf{V}}{\partial t} \tag{46} \]

for the pressure \( p \) and rest density \( \rho_0 \) of the propagating medium. [Ref. 16].

![Figure 2: Incident Wave and Target Description](image)

The target sphere is aligned along the centroid of the main acoustic lobe of the acoustic array echosounder, that is, along the direction \((0,0)\), normal to the face of the array. The target sphere is
selected to be sufficiently small with respect to incident beam
dimensions so that an essentially uniform intensity is intercepted by
the sphere [Ref. 17]. Since the target intercepts a very small proportion
of the centroid of the transmitted sounding lobe no accommodation for
sounding lobe geometry over the target's angular area is made.
Acoustic gain is simply taken as \( G_0 \).

Target placement is also at a far field range. This allows
spherical incident waves to be treated as planar incident waves and
places the target outside the range associated with the ring time of the
echosounder [Ref. 8]. Placement of the target is also close enough to
the array to support an assumption of transmission medium homogeneity
along the transmission path.

Finally, the potential describing the target falls off faster than
\( 1/r \). The describing potential for an acoustically hard sphere with
radius \( a \) is

\[
V(r) = \begin{cases} 
\infty & r < a \\
0 & r \geq a 
\end{cases}
\]  

Thus, for \( r > a \) \( V(r) \) falls off faster than \( 1/r \).
Note that with the exception of the specific surface boundary condition for acoustic waves the above conditions and assumptions closely correspond to those for plane electromagnetic waves incident on a perfectly conducting sphere, and for perfectly elastic nuclear scattering in a center of mass coordinate system. [Ref's. 16, 18, 19 and 20]

2. The Incident Wave

The asymptotic form of an incident plane wave approaching a scattering target but beyond the influence of the target's potential $V(r)$ is the undisturbed, or free, plane wave. In the spherical polar coordinates $(r,\theta,\phi)$ illustrated in Figure 3 a free, monochromatic plane wave of unit amplitude propagating in the direction $\Omega_o$ given by $(\theta_o,\phi_o)$ is

$$f(r,t) = e^{ikr[\cos(\theta_o)\cos(\theta) + \sin(\theta_o)\cos(\theta - \phi_o)]} e^{-i\omega t}.$$  \hspace{1cm} (48)

[Ref. 16]

![Spherical Polar Coordinates](image)

Figure 3: Spherical Polar Coordinates
For a wave of unit amplitude incident along the z axis, $Q_0 = 0$

and the free wave $f(r,t)$ is presented as

$$f(r,t) = e^{ikr \cos(\theta)} e^{-i \omega t} = e^{ikz} e^{-i \omega t}.$$  \hspace{1cm} (49)

Note this is a solution with axial symmetry for the free wave equation [Ref. 18].

The wave equation describing the behavior of the undisturbed or free monochromatic wave $f(r,t)$ is

$$\left( \nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} \right) f(r,t) = 0.$$  \hspace{1cm} (50)

$c$ is the speed of propagation of the free wave. If the wave function $f(r,t)$ has a simple harmonic time dependence, i.e.,

$$f(r,t) = e^{-i \omega t} f(r),$$  \hspace{1cm} (51)

then for a wave number

$$k = \frac{\omega}{c} = \frac{2\pi}{\lambda}$$  \hspace{1cm} (52)

the free wave equation becomes the Helmholtz equation

$$[\nabla^2 + k^2] f(r,t) = 0$$  \hspace{1cm} (53)

[Ref. 21].
The stationary solution \( f(r) \) of the free wave equation can be written as the product

\[
 f(r) = f_1(q_1)f_2(q_2)f_3(q_3) \quad (54)
\]

for orthogonal curvilinear coordinates \( q_1, q_2, q_3 \) [Ref. 16]. Recall an undisturbed plane wave has a cylindrical symmetry about the axis of propagation [Ref. 22]. Using the spherical polar coordinates

\[
 q_1 = r, \quad q_2 = \theta, \quad q_3 = \phi, \quad (55)
\]

the stationary solution describing an undisturbed plane wave propagating along the \( z \) axis is

\[
 f(r) = f_1(r)f_2(\theta) \quad (56)
\]

Substituting \( f(r) \) into the free wave equation expressed in spherical coordinates and separating the coordinate dependencies yields the separated free wave equation,

\[
 (kr)^2 + \frac{1}{f_1} \frac{d}{dr} \left[ r^2 \frac{d}{dr} f_1 \right] = -\frac{1}{f_2 \sin \theta} \frac{d}{d\theta} (\sin \theta \frac{d}{d\theta} f_2). \quad (57)
\]

Using a separation constant of \( l(l+1) \) the equation for the angular dependency of the free wave becomes

\[
 \frac{1}{f_2 \sin \theta} \frac{d}{d\theta} (\sin \theta \frac{d}{d\theta} f_2) + l(l+1) = 0. \quad (58)
\]
Letting

\[ \cos(\alpha) = x \quad (59) \]

in the angular equation yields

\[ [(1 - x^2) \frac{d^2}{dx^2} - 2x \frac{d}{dx} + 1(1 + 1)] f_2 = 0 \quad (60) \]

The previous equation is known as the Legendre differential equation [Ref. 21]. The most useful solutions to the Legendre differential equation are the Legendre polynomials, designated by \( P_l(x) \). They can be generated by the recursion relationships

\[ P_0(x) = 1, \quad (61a) \]

\[ P_1(x) = x \quad (61b) \]

and

\[ P_l(x) = [2 - 1/l] x P_{l-1}(x) - [1 - 1/l] P_{l-2}(x) \quad (61c) \]

[Ref. 21]. Therefore,

\[ f_{2,1}(\alpha) = P_1(\cos \alpha) \quad (62) \]

From equation (57), the equation describing the radial dependency of the free wave is

\[ \left\{ \frac{d^2}{dr^2} + \frac{2}{r} \frac{d}{dr} + \left[ k^2 - \frac{1(1+1)}{r^2} \right] \right\} f_1 = 0 \quad (63) \]
Changing scale to the variable \( s = kr \) yields the differential equation

\[
\left\{ \frac{d^2}{ds^2} + \frac{2}{s} \frac{d}{ds} + \left[ 1 - \frac{1}{s^2} \right] \right\} f_1 = 0
\]  

(64)

[Ref. 17].

This differential equation has the spherical Bessel function \( j_i(s) \) with amplitude \( A_i \) as a solution;

\[
f_{1,i}(s) = A_i j_i(s)
\]

(65)

[Ref. 18].

The stationary solution of the free wave equation in spherical coordinates is now written as the partial wave

\[
f_i(r) = P_i(\cos \theta) \left[ A_i j_i(kr) \right].
\]

(66)

The most general form of this free wave equation solution is a Fourier-Bessel series,

\[
f(r, \theta) = \sum_{i=0}^{\infty} A_i j_i(kr) P_i(\cos \theta)
\]

(67)

[Ref's. 17 and 21].

A plane, free wave of unit amplitude propagating in the direction \( \theta_0 = 0 \) is then

\[
e^{ikz} = \sum_{i=0}^{\infty} A_i j_i(kr) P_i(\cos \theta).
\]

(68)
The norm of the Legendre polynomials, the asymptotic expression

\[ j_1(kr) \sim \frac{\sin(kr - \frac{\pi}{2})}{kr} \]  

(69)

and the process detailed in Elton [Ref. 18] are used to determine \( A_1 \);

\[ A_1 = i^1 [21 + 1] . \]  

(70)

Therefore,

\[ e^{ikz} = \sum_{l=0}^{\infty} i^l [21 + 1] j_l(kr) P_l(\cos \theta) \]  

(71)

[Ref's. 18 and 21].

3. Detection Conditions and Assumptions

As the dimensions of the incident acoustic wave packet are greater than the size of the target it is expected that a portion of the incident wave packet continues to propagate past the target. The total or disturbed wave description is then a superposition of the incident and scattered wave descriptions. [Ref. 17]

The acoustic array serves as both transmitter and receiver, or detector. This keeps the detector outside the path of continued propagation of the incident wave packet. [Ref. 17] Therefore, only the scattered wave description is of interest in the calibration of the array.
The placement of the target at a far field range simultaneously places the detector in the region of asymptotic behavior of the scattered wave.

4. The Disturbed Wave

Once an incident wave described by the velocity potential $V(r)$ enters the region of influence of a scattering target's spherical potential $V(r)$ the wave equation becomes the disturbed wave equation

$$\left\{ \nabla^2 + [k^2 - V(r)] \right\} V(r) = 0 \quad (72)$$

[Ref. 17]. Comparison of the form of the disturbed wave equation to the free wave equation gives an expectation of a solution of the form

$$V(r) = V_1(r) V_2(\theta) \quad (73)$$

Substituting $V(r)$ into the disturbed wave equation and separating variables yields

$$-\frac{1}{V_2 \sin \theta} \frac{d}{d\theta} \left( \sin \theta \frac{d}{d\theta} \right) V_2 = r^2 [k^2 - V(r)] + \frac{1}{V_1} \frac{d}{dr} r^2 \frac{d}{dr} V_1 \quad (74)$$

The angular equation for the disturbed wave is identical in form to the angular equation for the free wave and independent of the Neumann boundary condition $\partial V/\partial r = 0$. Therefore,

$$V_{2,1}(\theta) = P_1(\cos \theta) \quad (75)$$
Using the previous substitution of \( s = kr \) yields the now modified Bessel equation as the radial equation for the disturbed wave:

\[
\left\{ \frac{d^2}{ds^2} + \frac{2}{s} \frac{d}{ds} + \left[ 1 - \frac{1(1+1)}{s^2} V(r) \right] \right\} \psi_1 = 0. \quad (76)
\]

Following the solution development in Elton [Ref. 18] and applying the Neumann boundary condition at \( r = a \) leads to a solution

\[
\nu_{1,1}(r) = i^1 [21 + 1] \left[ j_1(kr) - a_1 \ h_1^{(1)}(kr) \right]. \quad (77)
\]

The relationship

\[
a_1' = i e^{-i\delta_1} \sin \delta_1 = \frac{j_1'(ka)}{h_1^{(1)}(ka)} \quad (78)
\]

is defined from Morse [Ref. 17] and Bowman [Ref. 16]. Additionally,

- the \( j_1(kr) \) are the spherical Bessel functions of the first kind, argument \( kr \), and order 1,
- \( h_1^{(1)}(kr) \) are the Hankel functions of argument \( kr \) and order 1,
- the \( \delta_1 \) are the phase shifts of the usual partial wave description for spherical scattering solutions [Ref's. 17 and 20],
- the \( j_1'(ka) \) are the first derivatives of the \( j_1(kr) \), taken with respect to the argument \( kr \) and evaluated at \( r = a \),
- \( h_1^{(1)}(ka) = j_1'(ka) + i \ y_1'(ka) \), and
- \( \gamma_1'(ka) \) are the first derivatives of the \( y_1(kr) \), the spherical Bessel functions of the second kind with argument \( kr \) and order 1, taken with respect to the argument \( kr \) and evaluated at \( r = a \).
The general series solution for the total disturbed wave \( \nu(r) \) is then
\[
\nu(r) = \sum_{l=0}^{\infty} i^l [2l + 1] P_l(\cos \theta) \left[ j_l(kr) - a_l^1 h_l^{(1)}(kr) \right].
\] 
(80)

5. The Scattered Wave and Its Amplitude

The general asymptotic form for a disturbed wave \( \nu(r, \theta) \)
resulting from a plane wave \( \nu_1(r, \theta) \) incident along \( \theta_0 = 0 \) and scattered by
a spherical potential \( V(r) \) is
\[
\nu(r, \theta) = e^{i k z} + s(\theta) e^{i k r}/r.
\]
(81)

[Ref. 18]. This description of the asymptotic disturbed wave is a
superposition of the incident plane wave \( e^{i k z} \) and a spherical, scattered
wave \( s(\theta) e^{i k r}/r \). The term \( s(\theta) \) is called the scattering amplitude
[Ref's. 18, 19 and 22].

Now, recalling the series equivalence for the plane wave incident
along \( \theta_0 \) in equation (71), and comparing the general series solution for
the disturbed wave in equation (80) to its asymptotic form in equation
(81) gives
\[
s(\theta)e^{i k r}/r = -\sum_{l=0}^{\infty} i^l [2l + 1] P_l(\cos \theta) a_l^1 h_l^{(1)}(kr).
\]
(82)
This is a series expression for the scattered wave. Therefore,

\[
s(\Omega) = \frac{\sqrt{4\pi}}{k} \sum_{l=0}^{\infty} [2l + 1] P_l(\cos \theta) a_l^* \quad \text{(83)}
\]

[Ref's. 16 and 18].

6. The Backscattered Cross Section

The scattering amplitude \( s(\Omega) \) is related to the differential scattering cross section \( \sigma(\Omega) = \sigma_{\text{tgt}} \) by

\[
\sigma(\Omega) = |s(\Omega)|^2 \quad \text{(84)}
\]

[Ref's. 18, 19 and 22].

Applying the series expression for the scattering amplitude in equation (83) to the previous equation yields

\[
\sigma_{\text{tgt}} = \sigma(\Omega) = \frac{4\pi}{k^2} \sum_{l=0}^{\infty} [2l + 1] a_l^* P_l(\cos \theta)^2. \quad \text{(85)}
\]

For the backscattered direction \( \theta = \pi \) this gives a backscattered cross section of

\[
\sigma_b \sigma_{\text{tgt}} = \sigma_B = \frac{4\pi}{k^2} \sum_{l=0}^{\infty} [2l + 1] |a_l^*|^2. \quad \text{(86a)}
\]

[Ref's. 16 and 17]. For the spherical target \( A_{\text{tgt}} = \pi a^2 \), so

\[
\sigma_b = \frac{4}{(ka)^2} \sum_{l=0}^{\infty} [2l + 1] |a_l^*|^2. \quad \text{(86b)}
\]
It should be noted a plane wave of unit amplitude incident from
the positive z direction and backscattered along \( \theta = 0 \) would introduce a
factor of \((-1)^l\) into the previous sum [Ref. 16].

E. SPHERICAL BESSEL FUNCTIONS AND THEIR DERIVATIVES

Implementation of the previous equation necessitates calculation of
the \( a_l' \). The recursion relations

\[
j_0'(ka) = \frac{[-j_0(ka) + \cos(ka)]}{ka}, \quad (87a)
\]

\[
j_1'(ka) = \left\{-[1 + \frac{1}{2}j_1(ka)]/ka \right\} + j_{l-1}(ka), \quad (87b)
\]

\[
y_0'(ka) = \frac{[-y_0(ka) + \sin(ka)]}{ka} \quad (87c)
\]

and

\[
y_1'(ka) = \left\{-[1 + \frac{1}{2}y_1(ka)]/ka \right\} + y_{l-1}(ka) \quad (87d)
\]

determine the \( j_l'(ka) \) and \( y_l'(ka) \) needed for the calculation of \( a_l' \) in
equation (78) [Ref's. 21 and 23].

Determination of the regular and irregular spherical Bessel functions
at \( r = a \) supports the use of the recursion relations in equations (87). As
\( ka \) is real the irregular spherical Bessel functions are stable enough to use
the recursion relations
\[ y_0(ka) = -\frac{\cos(ka)}{ka}, \tag{88a} \]

\[ y_1(ka) = \frac{y_0(ka) - \sin(ka)}{ka} \tag{88b} \]

and

\[ y_1(ka) = \left\{ (21 - 1)\frac{y_{1-1}(ka)}{ka} \right\} - y_{1-2}(ka) \tag{88c} \]

in their determination [Ref's. 23 and 24].

Because the size of the argument of the regular spherical Bessel functions may be very small the method of negative continued fractions is appropriate to the fast and accurate determination of a converging solution to these functions [Ref. 24]. The regular spherical Bessel function reciprocals are therefore determined by the negative continued fraction calculation

\[ \frac{1}{j_1(ka)} = \frac{1}{j_0(ka)} \frac{1}{[-][b_{1,1}] [b_{1,2}, b_{1,1}] \ldots [b_{1,1}] [b_{1,2}, b_{1,1}] \ldots} \tag{89} \]

Now,

\[ b_{1,m} = \frac{2(1 + m - 1)}{ka} \tag{90} \]
and

\[-[\{b_{1,m}, \ldots, b_{1,2}, b_{1,1}\} = b_{1,m} - \frac{1}{b_{1,m-1}} - \cdots - \frac{1}{b_{1,2}} - \frac{1}{b_{1,1}}\]

\[= b_{1,m} - \frac{1}{b_{1,m-1} - 1} \frac{1}{b_{1,m-2} - 1} \frac{1}{b_{1,m-3} - 1} \cdots \frac{1}{b_{1,2} - \frac{1}{b_{1,1}}} \quad (91)\]

[Ref. 25].

While the regular spherical Bessel function reciprocal calculation of equation (89) would appear to involve an infinite number of terms, the calculation can in fact be terminated when the \(m^{th}\) numerator term equals the \(m^{th}\) denominator term to the desired precision for the spherical Bessel function's solution. [Ref's. 24 and 25]
III. CALIBRATION PROCESS AND SOFTWARE

Small quantities of data were collected in the anechoic chamber at the Naval Postgraduate School. This data aided first order verification of the calibration process and its supporting software. A brief description of the anechoic chamber is provided in Appendix A.

The calibration process and data development occurred in two stages. The first stage used equation (26) and two way propagation path measurements to determine \( c_b E_r E_l G_0 \). The second stage determined \( E_l G_0 \) using equation (17) and one way propagation path measurements.

\( E_r \) was then determined from \( c_b E_r E_l G_0, E_l G_0 \) and the calculated \( c_b \) of equation (66b).

Because reciprocity was assumed for \( E_r \) and \( E_l \)

\[ E_r E_l = E_r^2 \]  \hspace{1cm} (92)

provided the desired calibration information.

Supporting software was written to perform calculations required for calibration. The next section describes the development of this software.
A. CALIBRATION SOFTWARE DEVELOPMENT

Calibration software was written in BASIC. It was used with a
BASIC 4.0 compiler on a Hewlett Packard 310 computer. Computer
performance was enhanced by an Infotek floating point processor.

Notation in the programs sometimes differs from that in the thesis
text as a result of H.P. keyboard limitations. Variable definitions are
located at the beginning of subprograms or modules. These definitions
are provided throughout a program as an aid in determining program to text
variable equivalence.

The main effort of software development was calculation of
backscattered cross sections. This was done with equation (86b).
Information available for summation loop verification was differential
scattering cross section information. Differential scattering section
software was developed first.

1. Differential Scattering Cross Section Software Development

   The differential scattering cross sections $\sigma$ were calculated
using equation (85) and equation (78).

   To support equation (78) employment the subprograms
calculating the values of the Legendre polynomials and the values of the
regular and irregular spherical Bessel functions were developed first. Each subprogram was developed and tested separately in test programs. Each test program was designed to provide a tabular output for verification against values found in Abramowitz and Stegun [Ref. 23].

The Legendre values were calculated using equations (61). The irregular spherical Bessel functions were calculated using equations (88). The regular spherical Bessel functions were calculated using equations (89), (90) and (91).

Following verification these subprograms were assembled with subprograms calculating the derivatives of the regular and irregular spherical Bessel functions, the normalized differential scattering cross section $\sigma$, the scattering modulus of Bowman [Ref. 16], and with three graphics subprograms. This assembly created the differential scattering cross section program found in Appendix B.

The values of the regular and irregular spherical Bessel function derivatives at $r=a$ were calculated using equations (87).

Differential scattering cross sections were calculated using equation (85). The number of orders $l$ required for the summation calculation in equation (85) was determined by generating tabular outputs.
and determining the number of orders required for numerical stability to occur to 12 decimal places. This stability process was based on the concept of the phase shift $\delta_i$ of each outgoing partial scattered wave becoming progressively smaller with increasing $I$ until $a_i'$ (equation (78)) became negligible for the precision desired [Ref's. 18, 19, 20 and 22].

Tabular outputs covered a $ka$ value range of one to thirty at varying scattering angles, including $\theta = \pi$. This $ka$ value range selection was based on the expected maximum target size to be encountered during actual echosounder employment.

Twenty-one orders greater than the integer value of the argument $ka$ were determined to be required for equation (85)'s summation. The number of orders required was greater than the usually cited relationship

$$ka \approx \sqrt{1(1 + 1)}$$

(93)
gives. It should be noted that the precision criteria of $\sigma$ was greater than that normally encountered. [Ref's. 18, 19, 20 and 22]

The graphics subprograms of the differential scattering cross section program provided outputs for comparisons to Figure 80 in
Morse [Ref. 17] and Figure 10.10 of Bowman [Ref. 16]. These comparisons were used to verify the functioning and output of the differential scattering cross section program.

The graphics subprograms used to generate Figure 4 provide linear polar plots of the differential scattering cross section $\sigma(\Omega)$ normalized by the cross sectional area $A_{\text{tgt}}$ of the target sphere. These linear polar plots show the normalized differential scattering cross section of acoustically hard spheres ensonified by plane acoustic waves incident from the left, i.e. from $\theta = \pi$.

The first view of each sheet in Figure 4 shows the entire normalized differential scattering cross section pattern, including the forward lobe, or "shadow zone", along $\theta = 0$. The second view of each sheet is a magnified plot showing the scattering detail at a scale comparable to the normalized backscattered cross section value. Note the two views are identical on Sheet 1. The need for magnification with increasing $ka$ becomes apparent on subsequent sheets.
Figure 4, Sheet 1 of 3: Differential Scattering Cross Section Program Output for Comparison to Figure 80 of Morse [Ref. 17].

C = 343 M/S.
F = 5000 Hz.
A = .0109180290561 M.
K*A = 1.
NORMALIZED BCKSCTR = .680073464081
Figure 4, Sheet 2 of 3: Differential Scattering Cross Section Program Output for Comparison to Figure 80 of Morse [Ref. 17].
Figure 4, Sheet 3 of 3: Differential Scattering Cross Section Program Output for Comparison to Figure 80 of Morse [Ref. 17].
Figure 4 was used for comparison to Figure 80 of Morse [Ref. 17]. The radial scale of Morse was not graduated so verification consisted of a check for the correct number and approximate angular location of minimums and maximums in the differential scattering cross section patterns.

The graphics subprograms used to generate Figure 5 provide semi-logarithmic plots of the scattering modulus \( S \) of Bowman [Ref. 16].

\[
S = k \frac{s(\theta)}{\sqrt{4\pi}}
\]  

(94)

is the scattering modulus \( S \) of Bowman [Ref. 16]. \( s(\theta) \) is the scattering amplitude \( s(\Omega) \), as defined by equation (83), with a factor of \((-1)^l\) introduced into the sum, that is,

\[
s(\theta) = \frac{\sqrt{4\pi}}{k} \sum_{l=0}^{\infty} (-1)^l (2l + 1) P_l(\cos \theta) \alpha_l^0.
\]

(95)

\( s(\Omega) \) is normally used to calculate \( \sigma(\Omega) \), per equation (84). The scattering modulus \( S \) of Bowman [Ref. 16] could also be used to calculate \( \sigma(\Omega) \). Note the introduction of \((-1)^l\) into the summation corresponds to the case of an acoustically hard sphere ensonified by a plane acoustic wave incident from \( \theta = 0 \).
Comparison of Figure 5 to Figure 10.10 of Bowman [Ref. 16] shows a match in both $\theta$ and $\phi$. This graphical match verifies the functioning and output of the differential scattering cross section program of Appendix B.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{Figure 5, Sheet 1 of 3: Differential Scattering Cross Section Program Output for Comparison to Figure 10.10 of Bowman [Ref. 16].}
\end{figure}
Figure 5, Sheet 2 of 3: Differential Scattering Cross Section
Program Output for Comparison to Figure 10.10 of Bowman [Ref. 16].
Figure 5, Sheet 3 of 3: Differential Scattering Cross Section
Program Output for Comparison to Figure 10.10 of Bowman [Ref. 16].

C = 343 M/S.
F = 5000 HZ.
A = .109180290961 M.
K*A = 10.
NORMALIZED BCKSCTR = .957615718739
2. **Backscattered Cross Section Software Development**

The differential scattering cross section program of Appendix B was modified to yield the backscattered cross section program of Appendix C. With the modification the normalized differential scattering cross section is calculated for the backscattered direction only. Equation (86b) is used for this calculation.

Additionally, the graphics subprograms of the differential scattering cross section program were replaced by one graphics subprogram. The new graphics subprogram was designed to provide a rectangular graph of the normalized backscattered cross section, $\sigma_b$. $\sigma_b$ is plotted as a function of $ka$ for a specifiable range of values of $ka$.

Figure 6 was generated by the backscattered cross section program. It was used for comparison to Figure 10.11 of Bowman [Ref. 16]. This comparison served as a verification of the calculated, normalized backscattered cross section values. Note the $ka$ axis is labeled $K^A$.

Figure 7 was generated to verify the normalized backscattered cross section profile was approaching a value of one as $ka$ left the Mie scattering regime and entered the "geometric optics" region. Note the $ka$ axis is labeled $K^A$. 

44
Figure 6: Backscattered Cross Section Program Output for Verification of Calculated Normalized Backscattered Cross Section Values by Comparison to Figure 10.11 of Bowman [Ref. 16].
Figure 7: Backscattered Cross Section Program Output for Verification of the Normalized Backscattered Cross Section Asymptotic Behavior with Increasing $ka$. 
3. **Acoustic Array Efficiency Software Development**

The acoustic array efficiency program in Appendix D determined \( E_r E_t \). In general, each major section of Chapter II of this thesis and each set of analyzed data is represented by a subprogram of the acoustic array efficiency program.

The acoustic array efficiency program of Appendix D includes the non-graphics subprograms present in the backscattered cross section program of Appendix C. It also includes subprograms designed to furnish stored data, calculate attenuation and range using equations (27) through (42), and use developed information to calculate \( E_t G_0 \) with equation (17).

Equation (86b) was used to calculate \( \sigma_b \).

The appropriate subprogram and main program calculational results were then used in equation (26) to determine \( E_r \). \( E_r \) was used in equation (92) to determine \( E_r E_t \).

**B. DATA ACQUISITION AND SUPPORTING EQUIPMENT**

Data collected 28 November and 30 November provided information needed for calculation of \( \sigma_b E_r E_l G_0 \). Data collected 7 December allowed calculation of \( E_l G_0 \) and the calculation of \( E_r \)'s.

Collected data is presented in Appendix E.

1. **Two Way Propagation Path Measurements**

Two way propagation path data were collected 28 and 30 November. Measurements were used to calculate the product \( \sigma_b E_r E_l G_0 \).

Figure 8 provides a connection schematic for the data acquisition equipment.

![Figure 8: Data Acquisition Equipment Set-up](image)
Four target spheres were available and measured for size. They included one hollow aluminum sphere (sphere number one) and three solid aluminum and brass spheres. Table (1) lists the data and the calculated values of $A_{tgt} = \pi a^2$, $k_a$, and $\sigma_b$. $\sigma_b$ was calculated from equation (86b).

Table 1: Target Sphere Dimensional Data and Normalized Backscattered Cross Section Calculational Results for Frequency of 5000 [Hz].

<table>
<thead>
<tr>
<th>Target No.</th>
<th>Sphere Diameter [m]</th>
<th>Sphere Radius [m]</th>
<th>$A_{tgt}$ [m$^2$]</th>
<th>$k_a$</th>
<th>$\sigma_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.2546 ± .0006</td>
<td>.1273</td>
<td>.05091</td>
<td>11.62</td>
<td>.9142</td>
</tr>
<tr>
<td>2</td>
<td>.1013 ± .0001</td>
<td>.05065</td>
<td>.008060</td>
<td>4.619</td>
<td>1.000</td>
</tr>
<tr>
<td>3</td>
<td>.07634 ± .00003</td>
<td>.03817</td>
<td>.004577</td>
<td>3.479</td>
<td>1.051</td>
</tr>
<tr>
<td>4</td>
<td>.06240 ± .00008</td>
<td>.03120</td>
<td>.003058</td>
<td>2.843</td>
<td>.6836</td>
</tr>
</tbody>
</table>

Figure 9 shows the target spheres' theoretical normalized backscattered cross section distribution plotted on a graph generated by the backscattered cross section program of Appendix C.
The target spheres were suspended in turn in the anechoic chamber. Placement was made using the criteria in Section D.1 of Chapter II. The range $R$ from the array to a target was determined to be 5.30 [m].

Temperature $T_c$ and relative humidity $R_h$ along the propagation path were determined with a Weathermeasure Temperature and Relative
Humidity Meter. $T_c$ was usually about 21 [°C] with a relative humidity of approximately 50%. Atmospheric pressure $P$ was read from a barogram supplied by the Naval Postgraduate School meteorological station. Specific $T_c$, Rh, and $P$ data are furnished in Appendix E.

The unshrouded, close packed, hexagonal acoustic array of Moxcey [Ref. 8] was used to ensonify each target.

$$A = N_s \pi r_s^2$$ (96)

determined the aperture area $A$ of the array. $N_s = 19$ was the number of speakers in the array and $r_s = .0381$ [m] was the average speaker horn radius [Ref. 8].

Moxcey [Ref. 8] determined the half width of the array's main lobe to be 12°. The angular half widths of targets two, three and four were all less than 5% of the main lobe's half width. Target one's angular half width was 11.5% of the main lobe's half width.

A sinusoidal input from a Hewlett Packard 3314 A function generator drove the array via a pre-amplifier. Signal input from the HP3314A function generator to the pre-amplifier was set for 20 cycles at 5000 [Hz]. The voltage input to the pre-amplifier's power amplifier
terminal (see Figure 8) was 3.5 [V] for spheres two, three and four and 3.0 [V] for sphere one.

Twenty cycles is considerably less than the number of cycles expected in actual echosounder application. It was necessary to keep the pulse packet this small because the anechoic chamber's corner was only about 1.5 [m] from the target mounting location. Voltage input for sphere one was reduced to 3.0 [V] to avoid clipping of its greater return signal voltage.

Actual transmission voltage inputs $V_t$ to the array from the pre-amplifier were measured with a Nicolet 3091 oscilloscope at the pre-amplifier's array terminal. The array was disconnected from the pre-amplifier for $V_t$ measurements. $V_t$ values are provided in Appendix E. They are also stored in the Trans30 and Trans35 subprograms of the acoustic array efficiency program in Appendix D.

The Nicolet oscilloscope was connected to a Hewlett Packard 7090 A measurement plotting system. This connection provided a hard copy plot of voltage vs. time traces.

The returned signal was amplified and filtered.

Pre-amplifier gain $G_e$ was determined as 11,094 by Moxcey [Ref. 8].
Filtering was done with a Wavetek Brickwall filter model 753 A to remove the low frequency normal modes of oscillation of the speaker drivers from the return signal. Filtering was accomplished at 0 [dB] gain and 5000 [Hz] for both low and high pass settings.

The processed return signal voltages $V_r$ were displayed and measured on the Nicolet 3091 oscilloscope. $V_r$ measurements were made at the Out 2 terminal of the Wavetek Brickwall filter (see Figure 8). They were taken at 10 [$\mu$S] intervals for two full cycles along the asymptotic region of the return signal trace.

The Nicolet 3091 oscilloscope was connected to the Hewlett Packard 7090 A measurement plotting system. Figure 10 shows the Hewlett Packard plotter's traces for target sphere two's return signal voltages as printed and subsequently labeled. The figure is representative of the oscilloscope traces for each target return. Data for all targets are provided in Appendix E.

The time of return $t_r$ was determined as the time difference between the first positive maxima of the transmitted pulse packet and the first positive maxima of the target's return pulse packet.
Figure 10, Sheet 1 of 2: Target Sphere
Two's 5000 [Hz] Return Signal Trace

Figure 10, Sheet 2 of 2: Target Sphere Two's
5000 [Hz] Return Signal Trace, Scaled Down
For Oscilloscope Measurement.
Noise voltage $V_n$ measurements were made with the same measuring equipment setup used for $V_r$ measurements. The target spheres were removed. $V_n$ measurements were taken at a time of return $t_r$ comparable to the time of measurement of $V_r$.

$V_n$ measurements were actually made on occasions well separated chronologically from the $V_r$ measurements. Therefore, they were proportionally corrected in line 2530 of the acoustic array efficiency program. The corrections account for the slight variations in input voltages and propagation path attenuations that occurred between the two measurement occasions.

Figure 11 shows a representative noise trace. Data from the noise measurements is presented in Appendix E and stored in the Noise30 and Noise35 subprograms of the acoustic array efficiency program in Appendix D.

Unless otherwise specified above the remaining data from the two way propagation path measurements are stored in the subprograms titled Sphere1, Sphere2, Sphere3 and Sphere4. All remaining data are also presented in Appendix E.
2. One Way Propagation Path Measurements

One way propagation path data were collected 7 December. Measurements were used to calculate $E_{tG_o}$ with equation (17).

Data from the one way propagation path measurements are provided in Appendix E. Data are also stored in the Gain30 and Gain35 subprograms of the acoustic array efficiency program of Appendix D.
For one way path measurements, i.e. for the determination of $E_t G_0$, an Ivie Electronics Inc. IE 30 A Audio Analyzer (Serial #805 A 426) was used to measure received target intensity $I_r$ in [dB]. Intensity measurements were referenced to $10^{-12} \text{W/m}^2$. The acoustic signal supplied for this measurement was a continuous wave at 5000 [Hz]. Measurements were taken at the suspension site of the calibrating targets.

A Fluke 8060 A True RMS Multimeter was used to measure the root-mean-square voltage ($V_{rms}$) supplied to the acoustic array at its input. ($V_{rms}$) was squared to determine ($V_{ms}$).

The Weathermeasure temperature and relative humidity meter was unavailable for $E_t G_0$ data collection. Hygrothermographs from the Naval Postgraduate School's meteorological station were used to estimate the anechoic chamber's relative humidity $R_h$ and temperature $T_c$ on 7 December. Estimates were based on comparisons to the hygrothermographs and measured $R_h$ and $T_c$ of 28 and 30 November.
C. RESULTS

Data analysis was performed with the aid of the acoustic array efficiency program of Appendix D. Data used in calculations is furnished in Appendix E.

The product $\sigma_b E_r E_t G_o$ was generated from two way propagation path data and application of equation (26). The average of calculated $\sigma_b$'s compared to the average of the experimental product $\sigma_b E_r E_t G_o$ gives a normalizing product $E_r E_t G_o$. The experimental product $\sigma_b E_r E_t G_o$ and the normalizing product $E_r E_t G_o$ are used to calculate experimental $\sigma_b$'s.

These results are supplied in Table 2.

Table 2: Target Sphere Experimental, Normalized Backscattered Cross Section Calculational Results.

<table>
<thead>
<tr>
<th>Target No.</th>
<th>$ka$ [m$^2$]</th>
<th>Calc'd $\sigma_b$</th>
<th>$\sigma_b E_r E_t G_o$</th>
<th>$E_r E_t G_o$</th>
<th>Exp'l $\sigma_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.62</td>
<td>.9142</td>
<td>55.90</td>
<td></td>
<td>.947</td>
</tr>
<tr>
<td>2</td>
<td>4.619</td>
<td>1.000</td>
<td>59.88</td>
<td></td>
<td>1.01</td>
</tr>
<tr>
<td>3</td>
<td>3.479</td>
<td>1.051</td>
<td>61.62</td>
<td></td>
<td>1.04</td>
</tr>
<tr>
<td>4</td>
<td>2.843</td>
<td>.6836</td>
<td>37.98</td>
<td></td>
<td>.644</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td>.912</td>
<td>53.85</td>
<td>59.0</td>
<td></td>
</tr>
</tbody>
</table>
The experimental $\sigma_b$ are plotted on a graph generated by the backscattered cross section program of Appendix C. This plot is Figure 12. It is similar to Figure 9 and gives $\sigma_b$ as a function of $ka$. Note $ka$ is labeled $K\times A$.

Figure 12: Target Spheres' Experimental, Normalized Backscattered Cross Section Distribution Compared to a Calculated Backscattered Cross Section Distribution Curve Generated by the Backscattered Cross Section Program of Appendix C.
As ka increases the experimental $\sigma_b$ distribution rises from just below the calculated $\sigma_b$ curve to just above it.

$E_G$ was determined using one way propagation path data and equation (17). $E_G$, or $E_t$, was assumed to be the same for spheres two, three, and four because the supply voltage and target locations were the same. The angular half widths of target spheres two, three and four were between 4.6% and 2.8% of the echosounder's main lobe's half width.

Table 3: Acoustic Array Product $E_G$

<table>
<thead>
<tr>
<th>Target No.</th>
<th>HP3314A Func'n Gen'r</th>
<th>Supply Volt. [V]</th>
<th>$E_G$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.0</td>
<td>94.70</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>95.11</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
<td>95.11</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3.5</td>
<td>95.11</td>
<td></td>
</tr>
</tbody>
</table>

Calculated $\sigma_b$, $E_G$, and two way propagation path data were used in equation (26) to determine $E_r$. $\sigma_b$ values were calculated from the target.
spheres' measured diameters, 2a. $A_{tgt}$ was calculated as $\pi a^2$. Calculation results are furnished in Table 4.

Table 4: $E_r$ and $E_t E_r$. $E_r$ Determined From Two Way Propagation Path Data and Equation (26). $E_t E_r$ Determined From Assumption of Efficiency Reciprocity.

<table>
<thead>
<tr>
<th>Target No.</th>
<th>$A_{tgt}$ [m$^2$]</th>
<th>Calc'd $\sigma_b$</th>
<th>$\sigma_b A_{tgt}$ [m$^2$]</th>
<th>$E_r$</th>
<th>$E_t E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.05091</td>
<td>0.9142</td>
<td>0.04654</td>
<td>0.6456</td>
<td>0.4169</td>
</tr>
<tr>
<td>2</td>
<td>0.008060</td>
<td>1.000</td>
<td>0.008060</td>
<td>0.6296</td>
<td>0.3964</td>
</tr>
<tr>
<td>3</td>
<td>0.004577</td>
<td>1.051</td>
<td>0.004810</td>
<td>0.6167</td>
<td>0.3803</td>
</tr>
<tr>
<td>4</td>
<td>0.003058</td>
<td>0.6836</td>
<td>0.002090</td>
<td>0.5841</td>
<td>0.3411</td>
</tr>
</tbody>
</table>

The $E_r$'s determined for Moxcey's unshrouded hexagonal array are in the range of .58 to .65. This is above the value range of 0.5 ± 0.1 determined by Weingartner for his square acoustic array [Ref. 6].

Table 4 results were used to construct Figures 13 and 14. Figure 13 gives $E_r$ as a function of the calculated, normalized backscattered cross section, $\sigma_b$. Figure 14 gives $E_r$ as a function of the apparent target size, $\sigma_b A_{tgt}$. 
Figure 13: Acoustical to Electrical Power Conversion Efficiencies, $E_r$, as a Function of the Normalized Backscattered Cross Sections, $\sigma_b$, Calculated from Measured Sphere Sizes.

Figure 14: Acoustical to Electrical Power Conversion Efficiencies, $E_r$, as a Function of the Apparent Target Sizes, $\sigma_b A_{tgt}$.
Recalling equation (20),

\[ P_{tgt} = \left[ \frac{P_e}{4\pi} \right] \left[ e^{-\alpha R} G(\Omega) \right] \left[ \frac{A_{tgt}}{R^2} \right], \quad (20) \]

and equation (12),

\[ P_{ra} = \frac{P_{tgt}}{4\pi R^2} \sigma_b e^{-\alpha R} A_{tgt}, \quad (12) \]

serves as a reminder that the received acoustic power, \( P_{ra} \), depends on the apparent target size, \( \sigma_b A_{tgt} \).

Figure 14's trend and the dependency of \( P_{ra} \) on \( \sigma_b A_{tgt} \) were used as suggestions for the construction of Figure 15. Figure 15 is a plot of \( E_r \).

![Figure 15: Acoustical to Electrical Power Conversion Efficiencies, \( E_r \) as a Function of the Received Acoustic Powers, \( P_{ra} \)](image-url)
versus $P_{ra}$. $P_{ra}$ was calculated using the definition (from equation (21))

$$P_{ra} = \frac{P_r}{E_r} \quad (97)$$

and the relationship (from equation (15))

$$P_r = \frac{(V_{ms})_r}{Z} \quad (98)$$

Note Figure 15's trend is for $E_r$ to increase with an increase in $P_{ra}$ for the range of target sizes investigated.
IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The larger magnitudes of $E_r$ determined for Moxcey's hexagonal array suggest it may be more efficient than Weingartner's square array. However, the drivers for each array are identical.

The 0.08 to 0.15 differences in efficiencies are more likely the result of the difference in calibration methods. Weingartner's measurements [Ref. 6] used steady state, continuous waves. The use of steady state, continuous waves allows the development of standing waves. This calibration investigation used pulsed waves. The use of pulsed waves did not provide sufficient time for standing waves to completely develop in the backscattered energy. [Ref. 26] This calibration method should provide more accurate efficiency values since it more nearly approximates the echosounder system's actual field operating configuration.

Additionally, steel braid and nylon lines were used to suspend the target spheres. These supports probably reflected enough acoustic energy to have a small influence on results. Other fixtures in the anechoic...
chamber, such as support clamps and lights, may have also contributed small amounts of reflected energy to the returned signal.

Calibration of the computer controlled echosounder required determination of the product $E_r E_t$. The calibration process assumed $E_r = E_t$. The calibration results in Tables 3 and 4 for spheres two, three, and four indicate $E_r$ varied with constant $E_t G_0$, or constant $E_t$. Such a variation negates the assumption of reciprocity for $E_r$ and $E_t$.

Figure 15 suggests the acoustic array's efficiency $E_r$ increased in response to an increase in $P_{ra}$ and $(V_{rms})_r$.

The acoustic gain for spheres two, three and four was probably not constant, as assumed. However, $G_0$ is the maximum for $G(O)$, and $E_r$ is inversely proportional to $G_0$, per equation (26). An averaging process accounting for the slight differences in gain encountered by spheres two, three and four would have increased the data points spread observed in Figures 14 and 15.

Additionally, the pre-amplifier's gain may not have been constant for the range of received voltage values encountered. This would have introduced either an apparent increase in $E_r$ or dampened an increase in $E_r$. 

66
with an increase in $(V_{rms})_r$. Such a gain variation could have effectively
negated the assumption of efficiency reciprocity. However, this
pre-amplifier is approximately 0.1% linear for less than 10 [V] peak
[Ref. 26]. Received voltages in this investigation were all less than 10 [V].

B. RECOMMENDATIONS

Because efficiency reciprocity is now in question it is necessary to
determine $G_0$ by calculation or measurement. Such a determination would
allow the desired calibration quantity $E_rE_t$ to be written as

$$E_rE_t = E_r \frac{E_tG_0}{G_0} \quad (99)$$

One method of calculating $G_0$ would involve integrating the acoustic
array's calculated or measured intensity pattern (see Moxcey [Ref. 8]) for
determination of an equivalent isotropic emitter. To determine $G_0$ the
centroid intensity of the array's emitted intensity pattern would be
compared to that of the equivalent isotropic emitter. This would be
repeated for each transmission power level of interest.
Calculation of $G_0$ would allow a determination of $E_t$ using $E_tG_0$. Such a determination of $E_t$ would allow a reciprocity comparison to $E_r$ and support a more accurate evaluation of $E_rE_t$.

The accuracy of $E_r$ and $E_tG_0$ could be further refined as follows.

Use a calibrating site that allows the use of a pulse train closer in length to actual field use.

Make target return and noise voltages and site intensity measurements as chronologically close as possible.

Measure the barometric pressure in the propagation path directly along with the relative humidity and temperature.

The received and transmitted electrical powers for $E_r$ and the transmitted electrical power for $E_tG_0$ were all measured at the pre-amplifier end of the pre-amplifier/array transmission line. This included transmission line power losses due to impedance as efficiency decreases. The present calibration process includes the transmission line impedance as part of the array impedance.

The amount this impedance power loss actually affects $E_r$ could be evaluated by determining the impedances seen in each direction at the pre-amplifier end of the pre-amplifier/array transmission line.
pre-amplifier's array terminal. This would be an opportune time to verify the validity of transmission line impedance reciprocity.

Use the Nicolet oscilloscope to record a triggered readout from a calibrated microphone suspended at the target site at 45° to the centroid's axis. This would allow $E_L G_0$ to be determined for a pulse packet rather than for a continuous wave. Coupled with a proper calibrating site selection this technique should minimize interference problems such as anechoic chamber corner reflections.

A larger number of apparent target sizes spanning the desired range of apparent target sizes should be used to redetermine $E_r$ for Moxcey's array. The $E_r$ distribution should be examined for a smooth and asymptotic behavior. Comparative $E_r$ values for Moxcey's array could be determined using the method outlined by Weingartner [Ref. 6].

Weingartner's square array's $E_r$ could also be determined with this thesis' calibration process and compared to Weingartner's $E_r$ value [Ref. 6].

The refined $E_r$ curve in the now calibrated echosounder system should be used to develop an absolute $C_T^2$ plot of an air mass. An established method such as a tower mounted vertical array of thermocouples would be
used simultaneously to generate a comparative absolute $C_T^2$ plot of the same air mass.

C. SUMMARY

Realizing the potential of the computer controlled echosounder for analyzing lower atmospheric turbulence required a calibration of the echosounder. This thesis described theory and software for performing calculations crucial to a backscattered cross section calibration of the echosounder. The backscattered cross section calibration was evaluated in this thesis.

$E_r$'s values indicate the evaluated calibration process requires some refinement. They also indicate the calibration method possesses sufficient merit to warrant further development and that the software performs as intended.
APPENDIX A

ANECHOIC CHAMBER DESCRIPTION

The anechoic chamber is located in room 019 of building 232 at the Naval Postgraduate School. Acoustic research on sound sources, sound receivers and sound scatterers may be conducted in the chamber with a minimum of interference from wall reflection and external noise.

Wall reflection is minimized by 102 centimeter deep wedges made of P.F. 612 fiberglass. The wedges are attached to the walls, ceiling and floor of the chamber. Approximately 142 cubic meters of fiberglass is used to absorb 99% of incident sound energy for frequencies greater than 100 Hertz. External noise isolation is accomplished by separating the chamber's inner concrete block sides from the outer 12 inch concrete walls with a two inch thick lining of fiberglass and cork.

A usable region of approximately 8.2 meters by 4.3 meters by 3.4 meters is available. This region is floored by a grid of 225 wire cables, with each cable placed in a tension of 150 to 200 pounds per square inch. *

*This Appendix was compiled from the description posted by the entrance to the anechoic chamber instrumentation and control room.
Examples of the output of this program are Figures 4 and 5, located in

Chapter III.

REAL C SPEED OF SOUND.
REAL Freq FREQUENCY OF THE EMITTER.
REAL A RADIUS OF THE SPHERE.
REAL L ORDER OF THE FUNCTION CALCULATED IN A SUBROUTINE. IT IS USED AS A LOOP INDEX AND TO DESIGNATE THE ARRAY ELEMENT FOR THE FUNCTION OF CORRESPONDING ORDER.
REAL Lmax MAX. SIGNIFICANT ORDER OF THE SUM DETERMINING THE DIFFERENTIAL SCATTERING CROSS SECTION (DSCS) AND SCATTERING MODULUS (SM).
REAL K THE WAVE NUMBER, 2•PI•FREQ/C.
REAL Ka K•A, THE ARGUMENT OF THE REGULAR AND IRREGULAR SPHERICAL BESSEL FUNCTIONS AND THEIR DERIVATIVES.
REAL J(S1)          ! ARRAY FOR THE REGULAR SPHERICAL
BESSEL FUNCTIONS (RSB) OF
ARGUMENT KA AND ORDER 0 THROUGH
LMAX.

REAL Dj(S1)         ! ARRAY FOR THE DERIVATIVES OF THE
RSB (THE DRSB).

REAL Y(S1)          ! ARRAY FOR THE IRREGULAR SPHERICAL
BESSEL FUNCTIONS (ISB) OF
ARGUMENT KA AND ORDER 0 THROUGH
LMAX.

REAL Dy(S1)         ! ARRAY FOR THE DERIVATIVES OF THE
ISB (THE DISB).

REAL P(51)          ! ARRAY FOR THE LEGENDRE
POLYNOMIALS OF ARGUMENT COS(PHI).

REAL Sm(360)        ! THE ARRAY REPRESENTING THE
SCATTERING MODULUS (SM).

REAL Ds(360)        ! THE ARRAY REPRESENTING THE
DIFFERENTIAL SCATTERING CROSS
SECTION NORMALIZED BY THE CROSS
SECTIONAL AREA OF THE SPHERE
(DSCS).

NOTE DS(PHI)=4*SM(PHI)^2/KA^2.

+++ NOTE +++
THE ARRAY DIMENSIONS (30+21) NEED
TO BE INCREASED TO ACCOMODATE
KA>30.

+++++ MAIN PROGRAM ++++++++++++++++++++++++++++++++

CALL Init(C,Freq,A,Lmax,Ka)    ! INPUT AND CALCULATE REQUIRED
PARAMETERS.

CALL Difscrt(Lmax,ka,uji(*),j(*),Dy(*),y(*),P(*),Sm(*),Ds(*))
! CALCULATE THE SM(*) AND DS(*)..

CALL Outpt(C,Freq,A,Ka,Sm(*),Ds(*)) ! OUTPUT THE SM(*) AND/OR DS(*).

+++ ++++++++++++++++++++++++++++++++
910 !++++ MAIN PROGRAM CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++!
920 !
930 PRINTER IS 1
940 PRINT
950 PRINT "END" ! ADVISES THE USER OF THE MAIN
960 PRINT ! PROGRAM'S CONCLUSION.
970 END
980 !
990 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
1000 !
1010 !$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
1020 !
SUB Init(C,Freq,A,Lmax,Ka)
REM THIS MODULE REQUESTS THE APPROPRIATE INPUT VARIABLES TO DETERMINE C, FREQ, A, LMAX, AND KA.
REM
REM ++++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++++++++++++

REAL Temp % AMBIENT AIR TEMPERATURE IN DEG C.
REAL Circ % CIRCUMFERENCE OF THE TGT. SPHERE.
REAL Diam % DIAMETER OF THE TARGET SPHERE.

+++ REQUESTING AND CALCULATING SYSTEM PARAMETERS ++++++++++++++++++++++

PRINT "DO YOU DESIRE TO INPUT" 
PRINT "(1) THE SPEED OF THE SOUND, " 
PRINT "(2) THE AMBIENT AIR TEMPERATURE?"
INPUT Choice
END While WHILE Choice<>1 AND Choice<>2

IF Choice=1 THEN 
PRINT "PLEASE ENTER C IN M/S."
INPUT C
END IF

IF Choice=2 THEN 
PRINT "PLEASE ENTER TEMP IN DEGREES CELSIUS."
INPUT Temp
Temp=Temp+273.
C=20.05*SQRT(Temp)
END IF

+++ DETERMINING FREQ ++++

PRINT "PLEASE ENTER THE ECHOSOUNDER FREQUENCY IN HZ."
INPUT Freq

75
Choice = 0

*** DETERMINING KA ***

WHILE Choice <> 1 AND Choice <> 2 AND Choice <> 3

PRINT "DO YOU DESIRE TO INPUT "
PRINT "(1) THE SPHERICAL BESSEL ARGUMENT K*A,"
PRINT "(2) THE SPHERE'S CIRCUMFERENCE,"
PRINT "(3) THE SPHERE'S DIAMETER?"
PRINT
INPUT Choice
END WHILE

IF Choice = 1 THEN
DIRECTLY ENTER KA,
PRINT "PLEASE ENTER K*A."
INPUT Ka
END IF

IF Choice = 2 THEN
CALCULATE KA FROM THE TARGET CIRCUMFERENCE,
PRINT "PLEASE ENTER THE TARGET CIRCUMFERENCE IN CM."
INPUT Circ
Ka = Circ * (10^2) * Freq / C
END IF

IF Choice = 3 THEN
OR CALCULATE KA FROM THE TARGET DIAMETER.
PRINT "PLEASE ENTER THE TARGET DIAMETER."
PRINT "DIAMETER IN CM."
INPUT Diam
Ka = Diam * (10^2) * PI * Freq / C
END IF

K = 2 * PI * Freq / C
A = Ka / K
Lmax = INT(Ka + 21)
MAX. SUMMATION ORDER CALCULATED.

+++++++++++++ MODULE CONCLUSION ++++++++++++++++++++
SUBEND
SUB Disct(Lmax,Ka,Oj(*),J(*),Y(*),P(*),Sm(*),Ds(*))
REM THIS MODULE CALCULATES THE ARRAYS SM(*) AND DS(*) REPRESENTING THE
REM SCATTERING MODULUS AND THE DIFFERENTIAL SCATTERING CROSS SECTION
REM NORMALIZED BY THE CROSS SECTIONAL AREA OF THE SPHERE, RESPECTIVELY.
REM
+++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS +++
REAL Fac FACTOR COMMON TO RSM AND ISM.
REAL Rsm THE REAL COMPONENT OF THE
REAL Sm SCATTERING MODULUS, SM.
REAL I5m THE IMAGINARY COMPONENT OF THE
REAL Fact THE (POLAR) ANGLE OFF THE AXIS
REAL Phi OF PROPAGATION OF THE INCIDENT
OF THE AXIS
PLANES, WITH ORIGIN AT THE
SPHERE CENTER. COS(Phi) IS THE
ARGUMENT OF THE LEGENDRE
POLYNOMIALS P(*) OF ORDER 0
THROUGH LMAX.

+++
CALL Drsb(Lmax,Ka,Oj(*),J(*)) CALCULATE THE DERIVATIVES OF THE
CALL D5b(Lmax,Ka,Oy(*),Y(*)) CALCULATE THE DERIVATIVES OF THE
FOR Phi=0 TO 360
CALL Leg(Lmax,Ka,Phi,P(*)) CALCULATE THE ARRAY P(*).
Rsm=0 CALCULATING THE REAL AND IMAGINARY
I5m=0 COMPONENTS OF THE SM.
FOR L=0 TO Lmax
Fac=(Dj(L)*(2*L+1)*P(L))/(Dj(L)*Dj(L)+Dy(L)*Oy(L))
Rsm=Rsm+Fac*Dy(L)
I5m=I5m+Fac*Dj(L)
NEXT L
2620 Fact=Rsm*Rsm+Ism*Ism
2630
2640 Sm(Phi)=SQR(Fact)  
2650 CALCULATING THE ARRAY REPRESENTING  
2660 THE SM(Phi).  
2670 Ds(Phi)=4*(Fact)/(Ka*Ka)  
2680 CALCULATING THE ARRAY REPRESENTING  
2690 THE DIFFERENTIAL SCATTERING CROSS 
2700 SECTION NORMALIZED BY THE CROSS 
2710 SECTIONAL AREA OF THE SPHERE. 
2720 NEXT Phi 
2730 
2740 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
2750!
2760 !++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++++++
2770!
2780 SUBEND
2790 
2800 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
2810!
2820 !$$$$$$SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS$$
2830!
SUB Orsb(Lmax,Ka,Dj(*),J(*))
REM THIS MODULE CALCULATES THE DERIVATIVES OF THE REGULAR SPHERICAL
REM BESSEL FUNCTIONS (DRSB) OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX.
REM THE CALCULATION OF THE DERIVATIVE INVOLVES THE RSB'S OF THE SAME
REM AND PREVIOUS ORDER.
REM
CALL Rsb(Lmax,Ka,J(*))  \CALCULATE THE RSB VALUES J(*).
RAD
DJ(0)=(-J(0)+COS(Ka))/Ka  \CALCULATE THE INITIAL DRSB DJ(0).
FOR L=1 TO Lmax  \CALCULATE THE REMAINING DRSB.
DJ(L)=(-((L+1)/Ka)*J(L)+J(L-1)
NEXT L

CALL Rsh(Lmax,Ka,J(*))  \CALCULATE THE RSB VALUES J(*).
DJ(0)=(-J(0)+COS(Ka))/Ka  \CALCULATE THE INITIAL DRSB DJ(0).
FOR L=1 TO Lmax  \CALCULATE THE REMAINING DRSB.
DJ(L)=(-((L+1)/Ka)*J(L)+J(L-1)
NEXT L

SUBEND

++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++
SUB Rsb(Lmax,Ka,J(*))
REM THIS MODULE CALCULATES THE REGULAR SPHERICAL BESSEL FUNCTIONS
REM (RSB) OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX. THE
REM CALCULATION USES THE CONTINUED FRACTION APPROACH.

REAL RI  ! THE EVOLVING RATIO OF J(0)/J(L).
REAL Numr  ! THE EVOLVING NUMERATOR FACTOR USED
            ! IN CALCULATION OF RL.
REAL Denr  ! THE EVOLVING DENOMINATOR FACTOR
            ! USED IN CALCULATION OF RL.
REAL Scexp  ! EVOLVING SCALING EXPONENT FOR VERY
            ! LARGE OR VERY SMALL VALUES OF RL.
REAL Nflag  ! 0 FLAG FOR NUMR.
REAL Dflag  ! 0 FLAG FOR DENR.
REAL Bnm  ! EVOLVING TERM USED IN THE
            ! CALCULATION OF NUMR AND DENR.
REAL Binc  ! INCREMENT USED IN THE EVOLUTION
            ! OF BNM.

RAD  ! ANGLE UNITS FOR CALC'NS.

J(0)=(SIN(Ka))/Ka  ! *** CALCULATE THE INITIAL ***
            ! *** RSB, J(0). ***

FOR L=1 TO Lmax  ! *** CALCULATING THE RATIO ***
    RI=1.0  ! INITIALIZING RL.
    Numr=0.  ! INITIALIZING NUMR.
    Denr=0.  ! INITIALIZING DENR.
    Scexp=0.  ! INITIALIZING SCEXP.
    Nflag=0.  ! INITIALIZING NFLAG.
    Dflag=0.  ! INITIALIZING DFLAG.
    Bnm=1.0/Ka  ! INITIALIZING BNM.
    Binc=2.0/Ka  ! CALCULATE BINC.

3710 FOR Ordcnt=1 TO L
3720 Bnm=Bnm+Binc
3730 IF Nflag=0 THEN
3740 Numr=Bnm-Numr
3750 IF Numr<>0 THEN
3760 Rl=Rl*Numr
3770 Numr=1.0/Numr
3780 IF ABS(Rl)>10^250 THEN CALL Scale(Rl,Scexp)
3790 ELSE
3800 Nflag=1
3810 END IF
3820 ELSE
3830 END IF
3840 Nflag=0
3850 END IF
3860 NEXT Ordcnt
3870 Bnm=Bnm+Binc
3880 IF Nflag=0 THEN
3890 Numr=Bnm-Numr
3900 IF Numr<>0 THEN
3910 Rl=Rl*Numr
3920 Numr=1.0/Numr
3930 IF ABS(Rl)>10^250 THEN CALL Scale(Rl,Scexp)
3940 ELSE
3950 Nflag=1
3960 END IF
3970 ELSE
3980 END IF
3990 Nflag=0
4000END IF
4010 IF Dflag<>0 THEN
4020 Denr=Bnm-Denr
4030 IF Denr<>0 THEN
4040 Rl=Rl/Denr
4050 Denr=1.0/Denr
4060 IF ABS(Rl)>10^250 THEN CALL Scale(Rl,Scexp)
4070 ELSE
4080 Dflag=1
4090 END IF
4100 ELSE
4110 Dflag=0
4120 END IF
4130 END WHILE
\texttt{4250 \texttt{J(L)}=\texttt{J(0)}/(\texttt{R1*10^('Scexp'))}} \quad | \quad \texttt{*** \texttt{J(L)} DETERMINED. ***}
\texttt{4270}
\texttt{4280 \texttt{NEXT L}}
\texttt{4290}
\texttt{4300}
\texttt{4310 \texttt{+++++++++++++++++++++++++++++++++++++++++++++++++++++++}}
\texttt{4320 !}
\texttt{4330 \texttt{++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++}}
\texttt{4340 !}
\texttt{4350 \texttt{SUBEND}}
\texttt{4360}
\texttt{4370 \texttt{+++++++++++++++++++++++++++++++++++++++++++++++++++++++}}
\texttt{4380 !}
\texttt{4390 \texttt{$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$}}
\texttt{4400 !}
4410 !!!
4420 !$$SS$$$$$$S$$$$$$$S$$$$$$S$$$$$$$S$$$$$$S$$$$$$S$$$$$$S$$$$$$S$$$$$$S
4430 SUB Scale(Rl,Scexp)
4440 REM ++++++++++++++++++++++++++++++++++++++++
4450 REM THIS MODULE SCALES RL TO MAINTAIN NUMERICAL ACCURACY IN THE
4460 REM ONGOING CALCULATION OF RL.
4470 REM ++++++++++++++++++++++++++++++++++++++++
4480 
4490 !++++ SCALING RL ++++++++++++++++++++++++++++++++++++++++
4500 
4510 IF RI>10^250 THEN
4520 RI=RI*10^-250
4530 Scexp=Scexp+250
4540 END IF
4550 IF RI<10^-250 THEN
4560 RI=RI*10^250
4570 Scexp=Scexp-250
4580 END IF
4590 SUBEND
4600 
4610 
4620 !+++++++++++++++++++++++++++++++++++++++
4630 
4640 !++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++
4650 
4660 
4670 
4680 !+++++++++++++++++++++++++++++++++++++++
4690 
4700 !$$S$$$$$$S$$$$$$S$$$$$$S$$$$$$S$$$$$$S$$$$$$S$$$$$$S$$$$$$S$$$$$$S$$
4710 !
SUB Disb(Lmax,Ka,Dy(*),Y(*))
REM !+++++ METHODS OF THE IRRREGULAR SPHERICAL BESSEL FUNCTIONS OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX. THE CALCULATION OF THE DERIVATIVE USES THE ISB'S OF THE SAME ORDER.
REM !+++++ SUB Disb(Lmax,Ka,Dy(*),Y(*))
REM !+++++ METHODS OF THE IRRREGULAR SPHERICAL BESSEL FUNCTIONS OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX. THE CALCULATION OF THE DERIVATIVE USES THE ISB'S OF THE SAME ORDER.

CALL Isb(Lmax,Ka,Y(*)) ! CALCULATE THE ISB VALUES.
RAD ! ANGLE UNITS FOR CALC'NS.
Dy(0)=(-Y(0)+SIN(Ka))/Ka ! THE INITIAL ISB DERIVATIVE.
FOR L=1 TO Lmax ! THE REMAINING ISB DERIVATIVES.
Dy(L)=-(L+1)/Ka)*Y(L)+Y(L-1)
NEXT L

FUNCTION SUBEND
REM THIS MODULE CALCULATES THE IRREGULAR SPHERICAL BESSEL FUNCTIONS
REM OF ARGUMENT KA AND ORDER L THROUGH LMAX. THE CALCULATION IS
REM ACCOMPLISHED BY FORWARD RECURSION.

REM CALCULATING THE ISB

! INITIAL ISB'S CALCULATED.

! REMAINING ISB'S CALC'D.

! MODULE CONCLUSION
SUB Leg(Lmax,Ka,Phi,P(*))
REM THIS MODULE CALCULATES THE LEGENDRE POLYNOMIALS OF ARGUMENT COS(Phi) AND ORDERS 0 THROUGH LMAX. CALCULATION IS ACCOMPLISHED BY FORWARD RECURSION.
REM
!++++ CALCULATING THE LEGENDRE POLYNOMIALS

! DEG
! ANGLE UNITS FOR CALC'NS.
! X=COS(Phi)
! ARGUMENT OF THE LEG. POL'S.
! P(0)=1
! INITIAL LEG. POL'S. CALC'D.
! FOR L=2 TO Lmax
! REMAINING LEG. POL'S. CALC'D.
! P(L)=(2-(I/L))*X*P(L-I)-((I)/L)*P(L-2)
NEXT L
! 
! !++++ MODULE CONCLUSION

SUBEND
SUB Outpt(C,Freq,A,Ka,Sm(*),Ds(*))

REM THIS MODULE CONTROLS THE OUTPUT OF THE CALCULATED DSCS AND SM IN

REM GRAPHICAL PRESENTATIONS.

REM

+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

REM THIS MODULE CONTROLS THE OUTPUT OF THE CALCULATED DSCS AND SM IN

REM GRAPHICAL PRESENTATIONS.

REM

+++++++++++++++++++++++++++++++++++++++++++.+++++++++++++++++++++++

+++

MODULE VARIABLE DECLARATIONS AND DEFINITIONS +++++++++++++++++++++

REAL Desire INTERACTIVE LOOP CONTROL.
REAL Rpt POLARPLT SCALING CONTROL; A
REAL Repetition INDEX.

+-----

DETERMINING THE DESIRED OUTPUT ++++++++++++++++++++++

Desire=0

WHILE Desire<>1 AND Desire<>2 AND Desire<>3

PRINT "DO YOU DESIRE"
PRINT " (1) A PLOT OF THE DSCS," 
PRINT " (2) A PLOT OF THE SM," 
PRINT " OR (3) BOTH?"

INPUT Desire

END WHILE

WHILE Desire<4

IF Desire=1 OR Desire=3 THEN

FOR Rpt=1 TO 2

CALL Polarplt(Ds(*),Rpt) PLOTTING THE DSCS.

PRINT NEXT Rpt

END IF

IF Desire=2 THEN

CALL Recplt(Sm(*)) PLOTTING THE SM.

PRINT

END IF

IF Desire=1 OR Desire=2 THEN

PRINT...

PRINT "C =";C;"M/S."
PRINT "F =";Freq;"HZ."
PRINT "A =";A;"M."
PRINT "K*A =";K*a;"1.
PRINT ",NORMALIZED ";
PRINT "BCKSCTR = "*Ds(180)
PRINT CHR$(12) PRINTER FORM FEED.

IF Desire=1 OR Desire=2 THEN Desire=4

IF Desire=3 THEN Desire=2

END WHILE

87
6200 |+++++++++++++++++++++++++++++++++++++++
6210 |+++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++
6220 |
6230 |+++++ SUBEND ++++++++++++++++++++++++++++++++++++++++
6240 |
6250 |
6260 |
6270 |+++++++++++++++++++++++++++++++++++++++
6280 |
6290 |$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
6300 |
SUB Polarplt(Ds(*),Rpt)
REM
REM THIS MODULE MAPS THE CALCULATED, NORMALIZED DSCS ARRAY Ds(*) ON
REM LINEAR POLAR PLOTS. THE FIRST PLOT INCLUDES THE ENTIRE DSCS,
REM WHILE THE SECOND PLOT SHOWS THE SCATTERING DETAIL AROUND THE
REM NORMALIZED RANGE. PLOT SELECTION IS GOVERNED BY A REPETITION
REM INDEX, Rpt, AND IS CONTROLLED IN THE CALLING MODULE (OUTPT).
REM
REAL Xgumax
REAL Ygumax
REAL Gumax
REAL Dtmx
REAL Endpt
REAL Ring
REAL Tick

!++++ INITIALIZING THE PLOTTER
GINIT PLOTTER IS CRT,"INTERNAL"
GRAPHICS ON
GCLEAR

!+++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS
REAL Xgumax THE MAXIMUM ABSCISSA VALUE IN
REAL Ygumax THE MAXIMUM ORDINATE VALUE IN
REAL Gumax THE MINIMUM OF XGUMAX AND YGUMAX;
REAL Dtmx THE MAX. VALUE OF THE ARRAY Ds(*).
REAL Endpt THE MAX. RADIAL SCALE VALUE IN
REAL Ring GRID RING SPACING IN USER UNITS.
REAL Tick RADIAL AXIS TICK MARK SPACINGS IN

!+++++ INITIALIZING THE PLOTTER
GINIT PLOTTER IS CRT,"INTERNAL"
GRAPHICS ON
GCLEAR
GRAPH CONSTRUCTION AND LABELLING

\[ X_{\text{gumax}} = 100 \times \max(1, \text{RATIO}) \]
\[ Y_{\text{gumax}} = 100 \times \max(1, 1/\text{RATIO}) \]
\[ \text{Gumax} = \min(X_{\text{gumax}}, Y_{\text{gumax}}) \]

**LABELLING MAJOR RADIALS**

\[ \text{VIEWPORT 5, Gumax-5,5, Gumax-5} \]
\[ \text{VIEWPORT 5, Gumax-5,5, Gumax-5} \]

**SCALING THE GRAPH TO USER UNITS.**

**DEFINES THE TOTAL PLOTTING AREA IN GRAPH UNITS.**

**DETERMINING MAX. RADIUS VALUE**

**MAJOR RADIALS CONSTRUCTION**

**RANGE RING CONSTRUCTION**
7300 FOR Angle=30 TO 150 STEP 30
7310 IF Angle<>90 THEN
7320 PLOT Endpt*COS(Angle), Endpt*SIN(Angle), -2
7330 DRAW Endpt*COS(180+Angle), Endpt*SIN(180+Angle)
7340 END IF
7350 NEXT Angle
7360 PENUP
7370
7380
7390
7400 |+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
7410 |
7420 |++++ PLOTTING THE CALCULATED DISCS ++++++++++++++++++++++++++++++++++++++++++++++
7430 |
7440 LINE TYPE 1
7450 DEG
7460 FOR I=0 TO 360
7470 PLOT Ds(I)*COS(I), Ds(I)*SIN(I) ! IN POLAR FORMAT.
7480 NEXT I
7490 |
7500 |+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
7510 |
7520 |++++ PRINTING THE PLOT +++++++++++++++++++++++++++++++++++++++++++++++++++++++++
7530 |
7540 DUMP GRAPHICS #701
7550 |
7560 |+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
7570 |
7580 |++++ MODULE CONCLUSION +++++++++++++++++++++++++++++++++++++++++++++++++++++++++
7590 |
7600 GRAPHICS OFF
7610 SUBEND
7620 |
7630 |+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
7640 |
7650 |$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
7660 |
SUB Recplt(Sm(*))
REM THIS MODULE MAPS THE CALCULATED SCATTERING MODULUS ARRAY SM(*) ON
REM A SEMI-LOG PLOT.
REM
+++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++++++++

REAL Xgumax
! THE MAXIMUM ABSCISSA VALUE IN GRAPHICS DISPLAY UNITS.
REAL Ygumax
! THE MAXIMUM ORDEINATE VALUE IN GRAPHICS DISPLAY UNITS.
REAL Dtnx
! THE MAX. VALUE OF THE ARRAY SM(*).
REAL Dtnn
! THE MIN. VALUE OF THE ARRAY SM(*).
REAL Mxy
! THE MAX. ORDEINATE SCALE VALUE IN USER DEFINED UNITS.
REAL Mny
! THE MIN. ORDEINATE SCALE VALUE IN USER DEFINED UNITS.

+++++ INITIALIZING THE PLOTTER ++++++++++++++++++++++
GINIT
PLOTTER IS CRT,"INTERNAL"
GRAPHICS ON
GCLEAR

Xgumax=100*MAX(1,RATIO)
Ygumax=100*MAX(1,1/RATIO)
CSIZE 4
MOVE Xgumax/2,0
LABEL "PHI (DEGREES)"

** LABELLING THE ABSCISSA AXIS **
DEG I

LABELLING THE ORDINATE AXIS.

** GRAPH CONSTRUCTION **

** ORDINATE USER UNITS **

** DETERMINED. **

VIEWPORT IS.Xgumax-5,10.Ygumax-5

DEFINES THE TOTAL PLOTTING AREA

IN GRAPH UNITS.

** ORGANIZE Y USER UNITS **

** DETERMINED. **

Mxy=INT(LGT(Otmx))+1

** PLOTS THE AXES. **

Mny=INT(LGT(Otn))

ANISOTROPICALLY SCALES THE GRAPH

TO USER UNITS.

** LOGARITHMIC GRID LINES I.A.W. **

** THE VERTICAL SCALE. **

** PLOTS THE HORIZONTAL **

** I.A.W. THE HORIZONTAL SCALE. **

** PLOTS THE VERTICAL GRID LINES **

** I.A.W. THE HORIZONTAL SCALE. **

** LABELLING THE ABSCISSA SCALE **

** LABELLING THE ORDINATE SCALE **

POWER OF 10 LABELS.

HALF THE NEXT POWER OF 10 LABELS.
8720 CLIP ON
8730
8740
8750
8760 ++++++++++++++++++++++++++++++++++++++++++++++++++++++
8770
8780 +++ PLOTTING THE CALCULATED SCATTERING MODULUS ++++++++++++++++++++++++
8790
8800 LINE TYPE 1
8810 FOR I=0 TO 180
8820 PLOT I,LGT(SM(I+180))
8830 NEXT I
8840 USE SM(I) IN PLACE OF SM(I+180)
8850 FOR A PLANE WAVE INCIDENT FROM THE
8860 LEFT (180 DEG'S).
8870
8880 ++++++++++++++++++++++++++++++++++++++++++++++++++++++
8890
8900 PRINTING THE PLOT ++++++++++++++++++++++++
8910
8920
8930
8940 ++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++
8950
8960 GRAPHICS OFF
8970 SUBEND
8980
8990 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++
9000
9010 $$$$$$$$$$$$$$$$$$$$$$$$$$$$$ $$$$$$$ $$$$$$$
APPENDIX C

BACKSCATTERED CROSS SECTION PROGRAM

Examples of the output of this program are Figures 6 and 7, located in Chapter III.

10 !$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
20 !
30 REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
40 REM ACOUSTICALLY HARD SPHERE BACKSCATTERING OF PLANE ACOUSTIC WAVES
50 REM
60 REM THIS PROGRAM CALCULATES AND GRAPHS THE NORMALIZED, BACKSCATTERED
70 REM CROSS SECTION FOR ACOUSTICALLY HARD SPHERES OF A SELECTED RANGE
80 REM OF DIAMETERS ENSONIFIED BY AN INCIDENT PLANE WAVE.
90 REM
100 REM
110 REM
120 REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
130 !
140 !+++ MAIN PROGRAM VARIABLE DECLARATION AND DEFINITION ++++++++++++++++
150 |
160 |
170 REAL Nb5(301) ! THE ARRAY REPRESENTING THE
180 | NORMALIZED, BACKSCATTERED CROSS
190 | SECTION (NBCS).
200 |
210 REAL K ! THE WAVE NUMBER, 2*PI*FREQ/C.
220 |
230 REAL A ! RADIUS OF THE SPHERE.
240 |
250 REAL Ka ! K*A, THE ARGUMENT OF THE REGULAR
260 | AND IRREGULAR SPHERICAL BESSEL
270 | FUNCTIONS AND THEIR DERIVATIVES.
280 |
290 REAL Kamin ! INTEGER OF THE MIN. VALUE OF KA.
300 |
310 REAL Kamax ! INTEGER OF THE MAX. VALUE OF KA.
320 |
330 REAL Stp ! KA INCREMENT.
340 |
350 |
360 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
370 !
380 !+++++ MAIN PROGRAM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++
390 |
400 CALL Bckscir(Nbs(*),Kamin,Kamax,Stp) ! CALCULATE THE NBS(*).
410 |
420 CALL Recplt(Nbs(*),Kamin,Kamax,Stp) ! OUTPUT THE NBS(*).
430 |
440 |+++++++++++++++++++++++++++++++++++++++++++++++++++++++
450 |
460 !+++++ MAIN PROGRAM CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++++++++++
470 |
480 PRINTER IS 701
490 PRINT CHR$(12)
500 END
510 |
520 |+++++++++++++++++++++++++++++++++++++++++++++++++++++++
530 |
540 |$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$ $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
550 |
SUB Bcksctr(Nbs(*),Kamin,Kamax,Stp)
REM THIS MODULE CALCULATES THE ARRAY NBS(*) REPRESENTING THE
REM BACKSCATTERED CROSS SECTION NORMALIZED BY THE CROSS SECTIONAL AREA
REM OF THE SPHERE.
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

REM THIS MODULE CALCULATES THE ARRAY NBS(*) REPRESENTING THE
REM BACKSCATTERED CROSS SECTION NORMALIZED BY THE CROSS SECTIONAL AREA
REM OF THE SPHERE.
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

**** MODULE VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++++++++

REAL L
ORDER OF THE FUNCTION CALCULATED
IN A SUBROUTINE. IT IS USED
AS A LOOP INDEX AND TO DESIGNATE
THE ARRAY ELEMENT FOR THE FUNCTION
OF CORRESPONDING ORDER.

REAL Lmax
MAX. SIGNIFICANT ORDER OF THE SUM
DETERMINING THE DIFFERENTIAL
SCATTERING CROSS SECTION (DSCS)
AND SCATTERING MODULUS (SM).

REAL J(S1)
ARRAY FOR THE REGULAR SPHERICAL
BESSEL FUNCTIONS (RSB) OF
ARGUMENT KA AND ORDER 0 THROUGH
LMAX.

REAL Dj(S1)
ARRAY FOR THE DERIVATIVES OF THE
RSB (THE DRSB).

REAL Y(S1)
ARRAY FOR THE IRREGULAR SPHERICAL
BESSEL FUNCTIONS (ISB) OF
ARGUMENT KA AND ORDER 0 THROUGH
LMAX.

REAL Dy(S1)
ARRAY FOR THE DERIVATIVES OF THE
ISB (THE DISB).

REAL P(S1)
ARRAY FOR THE LEGENDRE
POLYNOMIALS OF ARGUMENT -1.

REAL Rsm
THE REAL COMPONENT OF THE
SCATTERING MODULUS.

REAL Ism
THE IMAGINARY COMPONENT OF THE
SCATTERING MODULUS.

REAL Fac
FACTOR COMMON TO RSM AND ISM.

**** NOTE ****
THE ARRAY DIMENSIONS (30+21) NEED
TO BE INCREASED TO ACCOMODATE
KAMAX>30.
CALCULATING THE NBCS ARRAY

**PRINTEP IS**

**INPUT** Kamin, Kamax

**DETERMINE DESIRED RANGE OF KA VALUES.**

Kamin = INT(Kamin)
Kamax = INT(Kamax)
Stp = .1

**FOR** Ka = Kamin + Stp TO Kamax **STEP** Stp

Lmax = INT(Ka + 21)

**CALL** Drsb(Lmax, Ka, Dj(*), J(*))
CALCULATE THE DRSB OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX.

**CALL** Disb(Lmax, Ka, Dy(*), Y(*))
CALCULATE THE DISB OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX.

**CALL** LegI80(Lmax, Ka, P(*))
CALCULATE P(*) OF ARGUMENT -1 AND ORDERS 0 THROUGH LMAX.

Rsm = 0
Ism = 0
CALCULATING THE REAL AND IMAGINARY COMPONENTS OF THE SCATTERING

**FOR** L = 0 TO Lmax

Fac = (Dj(L) * (2 * L + 1) * P(L)) / ((Dj(L) * Dj(L)) + (Dy(L) * Dy(L)))
Rsm = Rsm + (Fac * Dy(L))
Ism = Ism + (Fac * Dj(L))

**NEXT** L

**CALCULATING THE ARRAY REPRESENTING THE NBCS.**

Nbs((Ka - Kamin) / Stp) = 4 * (Rsm * Rsm + Ism * Ism) / (Ka * Ka)

**NEXT** Ka

**SUBEND**
SUB Drsb(Lmax,Ka,Dj(*),J(*))

REM THIS MODULE CALCULATES THE DERIVATIVES OF THE REGULAR SPHERICAL

REM BESSEL FUNCTIONS (DRSB) OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX.

REM THE CALCULATION OF THE DERIVATIVE INVOLVES THE RSB'S OF THE SAME

REM AND PREVIOUS ORDER.

REM +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

I++++ CALCULATING THE DERIVATIVES OF THE RSB +++++++++++++++++++++++++++++

CALL Rsb(Lmax,Ka,J(*)) I CALCULATE THE RSB VALUES J(*).

RAD I ANGLE UNITS FOR DRSB CALC'NS.

Dj(0)=(-J(0)+COS(Ka))/Ka I CALCULATE THE INITIAL DRSB DJ(0).

FOR L=1 TO Lmax I CALCULATE THE REMAINING DRSB.

Dj(L)=-(L+1)/Ka)*J(L)+J(L-1)

NEXT L

NEXT L

++++ MODULE CONCLUSION +++++++++++++++++++++++++++++++++++++++++++++++++++

SUBEND

+++++MODULE CONCLUSION +++++++++++++++++++++++++++++++++++++++++++++++++++

END
REM THIS MODULE CALCULATES THE REGULAR SPHERICAL BESSEL FUNCTIONS
REM (RSB) OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX. THE
REM CALCULATION USES THE CONTINUED FRACTION APPROACH.

!+++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++

REAL RI THE EVOLVING RATIO OF J(0)/J(L).
REAL Numr THE EVOLVING NUMERATOR FACTOR USED IN CALCULATION OF RL.
REAL Denr THE EVOLVING DENOMINATOR FACTOR USED IN CALCULATION OF RL.
REAL Scexp EVOLVING SCALING EXPONENT FOR VERY LARGE OR VERY SMALL VALUES OF RL.
REAL Nflag 0 FLAG FOR NUMR.
REAL Oflag 0 FLAG FOR DENR.
REAL Bnm EVOLVING TERM USED IN THE CALCULATION OF NUMR AND DENR.
REAL Binc INCREMENT USED IN THE EVOLUTION OF BNM.

!+++++ CALCULATING THE RSB ++++++++++++++++

RAD ANGLE UNITS FOR CALC'NS.

*** CALCULATE THE INITIAL ***
J(0)=(SIN(Ka))/Ka

*** CALCULATING THE RATIO ***
FOR L=1 TO Lmax
RI=1.0 INITIALIZING RL.
Numr=0. INITIALIZING NUMR.
Denr=0. INITIALIZING DENR.
Scexp=0. INITIALIZING SCEXP.
Nflag=0. INITIALIZING NFLAG.
Oflag=0. INITIALIZING OFLAG.
Bnm=1.0/Ka INITIALIZING BNM.
P := 2.0/Ka CALCULATE BINC.
FOR Ordent=1 TO L
    Bnmm=Bnnm+Binc
    IF Nflag=0 THEN
        Numr=Bnnm-Numr
        IF Numr<>0 THEN
            RI=RI+Numr
            Numr=1.0/Numr
            IF ABS(RI)>10^250 THEN CALL Scale(RI,Scexp)
        END IF
    END IF
    ELSE
        Nflag=1
    END IF
ELSE
    IF Nflag=0 THEN
        Numr=Bnnm-Numr
        IF Numr<>0 THEN
            RI=RI+Numr
            Numr=1.0/Numr
            IF ABS(RI)>10^250 THEN CALL Scale(RI,Scexp)
        END IF
    END IF
ELSE
    Nflag=1
END IF
NEXT Ordent
WHILE Numr<>Denr OR Nflag=1 OR Dflag=1
    Bnmm=Bnnm+Binc
    IF Nflag=0 THEN
        Numr=Bnnm-Numr
        IF Numr<>0 THEN
            RI=RI+Numr
            Numr=1.0/Numr
            IF ABS(RI)>10^250 THEN CALL Scale(RI,Scexp)
        END IF
    END IF
    ELSE
        Nflag=1
    END IF
ELSE
    IF Dflag=0 THEN
        Denr=Bnnm-Denr
        IF Denr<>0 THEN
            RI=RI+Denr
            Denr=1.0/Denr
            IF ABS(RI)>10^250 THEN CALL Scale(RI,Scexp)
        END IF
    END IF
    ELSE
        Dflag=1
    END IF
ELSE
    IF Dflag=0 THEN
        Denr=Bnnm-Denr
        IF Denr<>0 THEN
            RI=RI+Denr
            Denr=1.0/Denr
            IF ABS(RI)>10^250 THEN CALL Scale(RI,Scexp)
        END IF
    END IF
    ELSE
        Dflag=1
    END IF
END WHILE
2950  \( J(L) = J(0)/(R_{10}^{10^6}(Sc_{\text{exp}})) \)  
\[
J(L) \text{ DETERMINED.} 
\]
2990 NEXT L
3000 !
3010 !
3020 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
3030 !
3040 !++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++
3050 !
3060 SUBEND
3070 !
3080 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
3090 !
SUB Scale(RI,Scexp)
REM   ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
REM   THIS MODULE SCALES RL TO MAINTAIN NUMERICAL ACCURACY IN THE
REM   ONGOING CALCULATION OF RL.
REM   ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
REM SCALING RL ++++++++++++++++++++++++++++++++++++++++++++++++++++++

IF RI>10^250 THEN
   RI=RI*10^-250
   Scexp=Scexp+250
END IF

IF RI<10^-250 THEN
   RI=RI*10^250
   Scexp=Scexp-250
END IF

REM MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++++++++
SUBEND
SUB Disb(Lmax,Ka,Dy(0),Y(*))
REM THIS MODULE CALCULATES THE DERIVATIVES OF THE IRREGULAR SPHERICAL BESSEL FUNCTIONS OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX. THE CALCULATION OF THE DERIVATIVE USES THE ISB’S OF THE SAME AND PREVIOUS ORDER.
REM CALCULATING THE DERIVATIVES OF THE ISB
CALL Isb(Lmax,Ka,Y(*)) CALL CALCULATE THE ISB VALUES.
RAD ANGLE UNITS FOR CALC’NS.
Dy(0)=(-Y(0)+SIN(Ka))/Ka THE INITIAL ISB DERIVATIVE.
FOR L=1 TO Lmax THE REMAINING ISB DERIVATIVES.
Dy(L)=-(L+1)/Ka)*Y(L)+Y(L-1) NEXT L
!++++ MODULE CONCLUSION
SUBEND
!++++ CALCULATING THE DERIVATIVES OF THE ISB ++++++
CALL Isb(Lmax,Ka,Y(*)) CALL CALCULATE THE ISB VALUES.
RAD ANGLE UNITS FOR CALC’NS.
Dy(0)=(-Y(0)+SIN(Ka))/Ka THE INITIAL ISB DERIVATIVE.
FOR L=1 TO Lmax THE REMAINING ISB DERIVATIVES.
Dy(L)=-(L+1)/Ka)*Y(L)+Y(L-1) NEXT L
!++++ MODULE CONCLUSION
SUBEND
! ISB(Lmax,Ka,Y(*))
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
REM THIS MODULE CALCULATES THE IRREGULAR SPHERICAL BESSEL FUNCTIONS
REM OF ARGUMENT KA AND ORDER L THROUGH LMAX. ".." CALCULATION IS
REM ACCOMPLISHED BY FORWARD RECURSION.
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CALCULATING THE ISB +++++++++++++++++++++++++++++++++++
!
RAD! ANGLE UNITS FOR CALC'NS.
Y(0)=-COS(Ka)/Ka
Y(1)=(Y(0)-SIN(Ka))/Ka
FOR L=2 TO Lmax! REMAINING ISB'S CALC'D.
Y(L)=((2*L-1)/Ka)*Y(L-1)-Y(L-2)
NEXT L
!
MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++
SUBEND
!
REMARK ! ISB(Lmax,Ka,Y(*))
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ REM THIS MODULE CALCULATES THE IRREGULAR SPHERICAL BESSEL FUNCTIONS REM OF ARGUMENT KA AND ORDER L THROUGH LMAX. ".." CALCULATION IS REM ACCOMPLISHED BY FORWARD RECURSION.
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ REM ISB'S ARE CALC'ED.
RAD! ANGLE UNITS FOR CALC'NS.
Y(0)=-COS(Ka)/Ka! INITIAL ISB CALC'ED.
Y(1)=(Y(0)-SIN(Ka))/Ka
FOR L=2 TO Lmax! REMAINING ISB'S CALC'D.
Y(L)=((2*L-1)/Ka)*Y(L-1)-Y(L-2)
NEXT L
!
END
SUB LegI90(Lmax,Ka,P(*))

REM THIS MODULE CALCULATES THE LEGENDRE POLYNOMIALS OF ARGUMENT -1 AND
ORDER 0 THROUGH LMAX. CALCULATION IS ACCOMPLISHED BY FORWARD
RECURSION.

SUBEND

!++++ CALCULATING THE LEGENDRE POLYNOMIALS ++++++++++++++++++++++++

X=-1  ! ARGUMENT OF THE LEG. POL'S.
P(0)=1  ! INITIAL LEG. POL'S. CALC'D.
P(1)=X

FOR L=2 TO Lmax  ! REMAINING LEG. POL'S. CALC'D.
P(L)=(2-(I/L))*X*P(L-I)-(I-(I/L))*P(L-2)

NEXT L

!++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++

$\text{SUB LegI90(Lmax,Ka,P(*))}$
SUB Recplt(Nb5(*),Kamin,Kamax,Stp)
REM THIS MODULE MAPS THE CALCULATED SCATTERING MODULUS ARRAY SM(*) ON
REM A SEMI-LOG PLOT.
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS +++++++++++++++++++++++++
REAL Xgumax \ THE MAXIMUM ABSISSA VALUE IN
\ GRAPHICS DISPLAY UNITS.
REAL Ygumax \ THE MAXIMUM ORDI NATE VALUE IN
\ GRAPHICS DISPLAY UNITS.

INITIALIZING THE PLOTTER ++++++++++++++++++++++++++++++++++++++++
GINIT
PLOTTER IS CRT,"INTERNAL"
GRAPHICS ON
GCLEAR

INITIALIZING THE PLOTTER ++++++++++++++++++++++++++++++++++++++++

GRAPH CONSTRUCTION AND LABELLING ++++++++++++++++++++++++++++++++++++++
Xgumax=100*MAX(1,RATIO)
Ygumax=100*MAX(1,1/RATIO)
CSIZE 4
LINE TYPE 1
LORG 4
MOVE Xgumax/2,0
LABEL "K*A"

DEG

LABEL "NORM'D BCKSCTR GROSS SEC'N"
LDIR 0

VIEWPORT 10,Xgumax-5,10,Ygumax-5
DEFINES THE TOTAL PLOTTING AREA IN GRAPH UNITS.
WINDOW Kamin,Kamax,0,1.2
LINE TYPE 4
GRID Stp*10,.1,Kamin,0,61,10,.2

107
4890 CLIP OFF
4900 CSIZE 3
4910 LINE TYPE 1
4920
4930 LORG 6
4940 FOR I=Kamin TO Kamax STEP Stp*20
4950 MOVE I,0
4960 LABEL I
4970 NEXT I
4980
5000 LORG 8
5010 FOR I=0 TO I STEP .5
5020 MOVE Kamin,I
5030 LABEL I
5040 NEXT I
5050 CLIP ON
5060
5080 !
5090 |+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5100 |
5110 !++++ PLOTTING THE CALCULATED NBCS ++++++++++++++++++++++++++++++++++++++++
5120 |
5130 FOR I=Kamin+Stp TO Kamax STEP Stp
5140 PLOT I,Nbs((I-Kamin)/Stp)
5150 NEXT I
5160 |
5170 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5180 |
5190 !++++ PRINTING THE PLOT ++++++++++++++++++++++++++++++++++++++++++++++++++++
5200 |
5210 DUMP GRAPHICS 3701
5220 |
5230 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5240 |
5250 !++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++4
5260 |
5270 GRAPHICS OFF
5280 SUBEND
5290 |
5300 !__________________________________________________________________________
5310 |
5320 !__________________________________________________________________________
APPENDIX D

ACOUSTIC ARRAY EFFICIENCY PROGRAM

This program was used to analyze data and determine the calibration product $E_p E_t$. The output of this program was also used to construct Figures 13, 14, and 15.

The power supply mentioned in the Gain30 and Gain35 subprograms was the HP3314A function generator. All data contained in the data subprograms are repeated in Appendix E. Data units are available in Appendix E with their respective data.

```plaintext
10 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
20 !
30 REM +--------------------------------------------------------------------------------------------+
40 REM ACOUSTIC ARRAY EFFICIENCY
50 REM
60 REM THIS PROGRAM CALCULATES THE EFFICIENCY AND CENTERLINE GAIN OF
70 REM AN ACOUSTIC ARRAY BASED ON THE RETURN FROM AN ACOUSTICALLY HARD
80 REM SPHERE OF DIAMETER D ENSONIFIED BY AN INCIDENT PLANE WAVE OF
90 REM FREQUENCY F.
100 REM
110 REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++
120 !
130 !++++ VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++++++++
160 !
170 !
180 REAL Vmsr ! MEAN SQUARE VOLTAGE RECEIVED FROM
190 ! THE TARGET SPHERE AND MEASURED
200 ! AFTER PRE-AMPLIFICATION.
210 !
220 REAL Vmsn ! MEAN SQUARE VOLTAGE RECEIVED IN
230 ! THE ABSENCE OF A TARGET AND
240 ! MEASURED AFTER PRE-AMP.
250 !
```
REAL Vmst
MEAN SQUARE VOLTAGE TRANSMITTED.

REAL R
THE RANGE FROM THE PLANE OF THE
ARRAY SPEAKER DIAPHRAGMS TO THE
CENTER OF THE TARGET SPHERE AND TO
THE SPECTRUM ANALYZER MICROPHONE.

REAL Et
THE EFFICIENCY OF CONVERSION
FROM TRANSMITTED ELECTRICAL POWER
TO TRANSMITTED ACOUSTICAL POWER.

REAL Go
THE CENTERLINE GAIN OF THE ACOUSTIC
ARRAY.

REAL Elgo
ET*GO

REAL A1
THE ATTENUATION COEFFICIENT,
"ALPHA".

REAL C, Cmoist
THE SPEED OF SOUND IN HUMID AIR.

REAL Efreq
THE SELECTED FREQUENCY OF THE
ACOUSTIC ARRAY.

REAL K
THE WAVE NUMBER, 2*PI*EFREQ/C.

REAL A
THE RADIUS OF THE TARGET SPHERE.

REAL Ka
K*A, THE ARGUMENT OF THE REGULAR
AND IRREGULAR SPHERICAL BESSEL
FUNCTIONS AND THEIR DERIVATIVES.

REAL Aa
THE APERTURE AREA OF THE ARRAY.

REAL Gpre
THE PRE-AMP'S ELECTRICAL GAIN.

REAL Nbs
THE VARIABLE REPRESENTING THE
NORMALIZED, BACKSCATTERED CROSS
SECTION (NBCS).

REAL Atgt
CROSS SECTIONAL AREA OF THE
TARGET SPHERE.

REAL Sesph
SURFACE AREA OF AN IMAGINARY
SPHERE CENTERED ON THE ARRAY
AND HAVING A RADIUS EQUAL TO
THE RANGE TO THE CENTER OF THE
TARGET SPHERE.

REAL Prat
THE RATIO OF RECEIVED TARGET
ELECTRICAL POWER TO THE
TRANSMITTED ELECTRICAL POWER.
REAL Er

THE EFFICIENCY OF CONVERSION
FROM RECEIVED ACOUSTICAL POWER
TO RECEIVED ELECTRICAL POWER.

!++++ MAIN PROGRAM ++++++++++++++++++++++++++++++++++++++++++++++++++++++

CALL Init(Vmsr,Vmsn,Vmst,R,Etgo,At,Aa,Gpre)

INPUT AND CALCULATE REQUIRED
PARAMETERS.

CALL Bcksctr(Ka,Nbs)

CALCULATE THE NBCS.

PRINT "NBS=";Nbs

PRINT "ATGT=";Atgt

Sasph=4*PI*R*R

Prat=(Vmsr-Vmsn)/(Gpre*Gpre*Vmst)

Er=(Prat)*(Sasph*Sasph/Etgo)*(EXP(2#At*R)/(Aa*Atgt))/Nb5

PRINT "Er=";Er

PRINT "EtGo=";Etgo

PRINT "Go=";Etgo/Er

PRINT "EtEr=";Er*Er

PRINT CHRS(12)

PRINTER IS 1

PRINT "AT "END" ADVISES THE USER OF THE MAIN

PRINT PROGRAM'S CONCLUSION.

END

$SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS$
SUB Init(Vmsr, Vmsn, Vmit, R.Etgo, At, A, Ka, Aa, Gpre)
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
REM THIS MODULE DETERMINES THE VALUES OF THE PARAMETERS REQUIRED FOR
REM THE CALCULATION OF Er.
REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++.++++++++++
!
+++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++++++}

REAL Ch                   ! A CONTROL VARIABLE USED FOR
REAL Vr(60)               ! CONTROLLING SELECTION OF THE
REAL J, Jt, Jn, Jtn      ! CORRECT GAIN DATA SETS.
REAL Tc                   ! ONE AND A LOOP CONTROL VARIABLE.
REAL Patm                 ! THE AMBIENT TEMPERATURE IN DEG. C.
REAL Rh                   ! THE ATMOSPHERIC PRESSURE MEASURED
REAL Tgttm                ! IN MILLIBARS.
REAL Dia                  ! THE MEASURED DIAMETER OF THE
REAL Nuspkr               ! TARGET SPHERE.
REAL Diaspkr              ! THE NUMBER OF SPEAKERS IN THE
REAL Vt(60)               ! ARRAY.
REAL Noise(60)            ! THE AVERAGE DIAMETER OF AN ARRAY
REAL Tnoise(60)           ! SPEAKER.
REAL Noise(60)            ! THE ARRAY REPRESENTING THE
REAL Tcn                  ! MEASURED TRANSMISSION VOLTAGES.
REAL Rhn                  ! THE ARRAY REPRESENTING THE
REAL Rh                   ! MEASURED NOISE RETURN VOLTAGES.
REAL Tcn                  ! Tc FOR NOISE DETERMINATION.
REAL Rhn                  ! Rh FOR NOISE DETERMINATION.
REAL Patmn  ! Patm FOR NOISE DETERMINATION.
REAL Efrcnn  ! Efrcnn=Efrcn.
REAL Cn    ! C FOR NOISE DETERMINATION.
REAL Athn  ! Athn FOR NOISE DETERMINATION.
REAL Vmstn  ! Vmst FOR NOISE DETERMINATION.
REAL Rspkr  ! THE AVERAGE RADIUS OF AN ARRAY SPEAKER.

+++++ DETERMINING SYSTEM PARAMETERS ++++++++------------------------------------------

PRINT "WHICH TARGET DATA SET ";
PRINT "DO YOU WISH ANALYZED?"
PRINT "TARGET NO. "; Sphere
PRINT
IF Sphere=1 THEN
   Ch=3.0
   CALL Gaino(Ch,Elgo)
   CALL Sphere1(Vt(*),Jc,Patm,Rh,Tgttm,Dia,Efreq,Nuspkr,Diaspkr,Gpre)
   CALL Trans30(Jt,Vt(*))
   CALL Noise30(Jn,Jtn,Noise(*),Tnoise(*),Tcn,Rhn,Patmn,Efreq)
   END IF

IF Sphere=2 THEN
   Ch=3.5
   CALL Gaino(Ch,Elgo)
   CALL Sphere2(Vt(*),Jc,Patm,Rh,Tgttm,Dia,Efreq,Nuspkr,Diaspkr,Gpre)
   CALL Trans35(Jt,Vt(*))
   CALL Noise35(Jn,Jtn,Noise(*),Tnoise(*),Tcn,Rhn,Patmn,Efreq)
   END IF

IF Sphere=3 THEN
   Ch=3.5
   CALL Gaino(Ch,Elgo)
   CALL Sphere3(Vt(*),Jc,Patm,Rh,Tgttm,Dia,Efreq,Nuspkr,Diaspkr,Gpre)
   CALL Trans35(Jt,Vt(*))
   CALL Noise35(Jn,Jtn,Noise(*),Tnoise(*),Tcn,Rhn,Patmn,Efreq)
   END IF

++++

113
IF Sphere=4 THEN
  Ch=3.5
  CALL Geino(Ch,Etgo)
  CALL Sphere4(Vr(*),J,Tc,Patm,Rh,Tgttm,Dia,Efreq,Nuspkr,Diaspkr,Gpre)
  CALL Trans35(Jt,Vt(*))
  CALL Noise35(Jn,Jtn,Noise(*),Tnoise(*),Tcn,Rhn,Patmn,Efreqn)
END IF

CALL Voltsms(Vr(*),J,Vmsr)
PRINT "VMSR";Umsr
CALL Atten(Tcn,Rhn,Patmn,Cn,Atn,Efreqn)
CALL Voltsms(Tnoise(*),Jtn,Vmstn)
CALL Voltsms(Noise(*),Jn,Vmsn)
CALL Voltsms(Vt(*),Jt,Vmst)
PRINT "VMST";Vmst

A=Dia/2
PRINT "A=";A
CALL Range(Tgttm,A,Tc,Rh,Patm,C,At,Efreq,R)
PRINT "C=";C
PRINT "AT=";At
PRINT "ATTEN=";EXP(At*R)
PRINT "R=";R
Vmsn=Vmsn*EXP(2*R*(Atn-At))*Vmst/Vmstn
PRINT "VMSN=";Vmsn
Ka=2*PI*Efreq*A/C
PRINT "KA=";Ka
Rspkr=Diaspkr/2
Aa=Nuspkr*PI*Rspkr*Rspkr
PRINT "AA=";Aa

MODULE CONCLUSION
SUBEND
SUB Gain(Ch,Etgo)

REM *************************************************************
REM THIS MODULE DETERMINES THE VALUE OF EtGo.
REM *************************************************************

!++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++++++

REAL Vrms
REAL Ir
REAL Za

!++++ DETERMINATION OF EtGo ++++++++++++++++++++++++++++++

IF Ch=3.0 THEN CALL Gain30(Vrms,Tc,Rh,Patm,Ir,Efreq,Za)
IF Ch=3.5 THEN CALL Gain35(Vrms,Tc,Rh,Patm,Ir,Efreq,Za)

CALL Atten(Tc,Rh,Patm,C,Efreq) CALCULATING AT.
Pt=Vrms*Vrms/Za
Etgo=Ir*4*PI*R*EXP(At*R)/Pt CALCULATING EtGo.

!++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++
SUB Voltsms(Volt(*),J,Vms)
REM THIS MODULE DETERMINES THE MEAN SQUARE VALUE OF THE INPUT VOLTAGE ARRAY.
REM
+++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS +++++++++++++++++++++

REAL Volt(*)
REAL Volts THE SUM OF VOLT(*)'S ELEMENTS.
REAL Vavg THE AVERAGE VALUE OF VOLT(*).
REAL V THE DIFFERENCE BETWEEN VOLT(I) AND Vavg.
REAL Vms THE MEAN SQUARE VALUE OF VOLT(*).

+++ DETERMINATION OF VMS ++++++++++++++++++++++++++++++++++++++++++++

Volts=0 FOR I=0 TO J Volts=Volts+Volt(I) NEXT I
Vavg=Volts/(J+1) FOR I=0 TO J U=Volt(I)-Vavg Vms=(U*U)+Vms NEXT I
Vms=Vms/(J+1)

+++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++

SUB END

+++ END OF MODULE +++++++++++++++++++++++++++++++++++

      jjj
SUB Range(Tgttm, A, Tc, Rh, Patm, C, At, Efreq, R)
REM THIS MODULE DETERMINES THE AVERAGE PATH ATTENUATION AND THE RANGE
REM BETWEEN THE ARRAY AND THE TARGET CENTER.
REM
++++ DETERMINATION OF R AND AT +++++++++++++++++++++++++++++++++++++++++++++++

Tgttm=Tgttm/1000
CALL Attten(Tc, Rh, Patm, C, At, Efreq) ! AT AND C DETERMINED.
R=Tgttm*C/2+A ! R DETERMINED.

++++ MODULE CONCLUSION +++++++++++++++++++++++++++++++++++++++++++++++++++++++
SUBEND
SUB Attenu(Tc,Rh,Patm,Cmoist,At,Efreq)
REM THIS MODULE CALCULATES THE ATTENUATION USING RELATIVE HUMIDITY
REM IN PERCENT, ATMOSPHERIC PRESSURE IN MILLIBARS, AND TEMPERATURE
REM IN DEGREES CENTIGRADE.
REM
!++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++++++!
REAL Tk THE AMBIENT TEMPERATURE IN DEG. K.
REAL Es THE SATURATION VAPOR PRESSURE.
REAL Pratio THE RATIO OF WATER PRESSURE IN MILLIBARS TO ATMOSPHERIC PRESSURE IN MILLIBARS.
REAL Cdry THE SPEED OF SOUND IN DRY AIR.
REAL H THE SPEED OF SOUND IN WET AIR.
REAL Past P ASTERISK.
REAL Tast T ASTERISK.
REAL Fm MAX. FREQ.
REAL Amax MAX EXPECTED ATTENUATION.
REAL Fra Max EXPECTED ATTENUATION COMPONENTS.
REAL F2 FRAT*FRAT
REAL Acl,Amol ATTENUATION EXPONENT COMPONENTS.
4340  !++++ CALCULATING THE ATTENUATION ++++++++++++++++++++++++++++++++++++++++
4350  
4360  
4370  Tk=Tc+273.15  ! CONVERSION OF TEMP IN CELSIUS TO TEMP IN KELVIN.
4380  
4390  
4400  Rh=Rh/100  ! CONVERSION OF RH IN PCT. TO PRATIO.
4410  Es=10^((9.4-2353/Tk))  !
4420  Pratio=Es*Rh/(Patm-Es*(1+Rh))  !
4430  
4440  Cdry=20.05*SQR(Tk)  ! CALCULATION OF THE SPEED OF SOUND.
4450  Cmoist=Cdry*(1+.14*Pratio)  
4460  
4470  H=Pratio*100  
4480  Past=Patm/1014  
4490  Tast=(1.8*Tc+492)/519  
4500  Fm=(10+6600*H+44400*H*H)*Past/(Tast^2)  
4510  
4520  Amax=.0078*Fm*(Tast^(-2.5))*EXP(7.77*(1-1/Tast))  
4530  
4540  Frat=Efreq/Fm  
4550  F2=Frat*Frat  
4560  
4570  Amol=Ampx*SQR(.18*.18+F2+(2*F2/(1+F2))^.2)/304.8  
4580  Acl=1.74*10^-10*(-1)*Efreq*Efreq  
4590  At=(Amol+Acl)*LOG10(10)/10  
4600  
4610  
4620  !++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
4630  
4640  !++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++
4650  
4660  SUBEND  
4670  
4680  !++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
4690  
4700  !SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
SUB Bcksclrl(Ka,Nbs)
REM THIS MODULE CALCULATES THE BACKSCATTERED CROSS SECTION NORMALIZED
REM BY THE CROSS SECTIONAL AREA OF THE SPHERE.
REM
!+++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS +++++++++

REAL L  ! ORDER OF THE FUNCTION CALCULATED
         ! IN A SUBROUTINE. IT IS USED
         ! AS A LOOP INDEX AND TO DESIGNATE
         ! THE ARRAY ELEMENT FOR THE FUNCTION
         ! OF CORRESPONDING ORDER.

REAL Lmax  ! MAX. SIGNIFICANT ORDER OF THE SUM
         ! DETERMINING THE NORMALIZED
         ! BACKSCATTERING CROSS SECTION
         ! (NBCS).

REAL J(51)  ! ARRAY FOR THE REGULAR SPHERICAL
            ! BESSEL FUNCTIONS (RSB) OF
            ! ARGUMENT KA AND ORDER 0 THROUGH
            ! LMAX.

REAL Dj(51)  ! ARRAY FOR THE DERIVATIVES OF THE
             ! RSB (THE DRSB).

REAL Y(51)  ! ARRAY FOR THE IRREGULAR SPHERICAL
             ! BESSEL FUNCTIONS (ISB) OF
             ! ARGUMENT KA AND ORDER 0 THROUGH
             ! LMAX.

REAL P(51)  ! ARRAY FOR THE LEGENDRE
            ! POLYNOMIALS OF ARGUMENT COS(180).

REAL Fac  ! FACTOR COMMON TO RSM AND ISM.

REAL Rsm  ! THE REAL COMPONENT OF THE
         ! SCATTERING MODULUS, SM.

REAL Ism  ! THE IMAGINARY COMPONENT OF THE
         ! SM.
5210 ! ++++ NOTE ++++
5220 ! THE ARRAY DIMENSIONS (30+21) NEED
5230 ! TO BE INCREASED TO ACCOMODATE
5240 ! KA>30.
5250 !
5260 !
5270 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5280 !
5290 !+++ CALCULATING THE NBCS ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5300 !
5310 Lmax=INT(Ka+21)
5320 !
5330 CALL Drsb(Lmax,Ka,Dj(*),J(*)) ! CALCULATE THE DERIVATIVES OF THE
5340 ! REGULAR SPHERICAL BESSEL FUNCTIONS
5350 ! OF ORDER 0 THROUGH LMAX.
5360 CALL Disb(Lmax,Ka,Dy(*),Y(*)) ! CALCULATE THE DERIVATIVES OF THE
5370 ! IRREGULAR SPHERICAL BESSEL FUNC'NS
5380 ! OF ORDER 0 THROUGH LMAX.
5390 !
5400 CALL Legl80(Lmax,Ka,P(*)) ! CALCULATE THE ARRAY P(*).
5410 !
5420 Rsm=0
5430 Ism=0
5440 FOR L=0 TO Lmax
5450 Fac=(Dj(L)*(2*L+1)*P(L))/(Dj(L)*Dj(L)+Dy(L)*Dy(L))
5460 Rsm=Rsm+(Fac*Dy(L))
5470 Ism=Ism+(Fac*Dj(L))
5480 NEXT L
5490 !
5500 Nbs=4*(Rsm*Rsm+Ism*Ism)/(Ka*Ka) ! CALCULATING THE NBCS.
5510 !
5520 !
5530 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5540 !
5550 !+++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5560 !
5570 SUBEND
5580 !
5590 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
5600 !
5610 !$S$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
5630 !
5640 !$SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
REM THIS MODULE CALCULATES THE REGULAR SPHERICAL BESSEL FUNCTIONS
REM (RSB) OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX. THE CALCULATION USES THE CONTINUED FRACTION APPROACH.

!+++++ MODULE VARIABLE DECLARATIONS AND DEFINITIONS ++++++++++++++++++++++++++++++

REAL R1
! THE EVOLVING RATIO OF J(0)/J(L).
REAL Numr
! THE EVOLVING NUMERATOR FACTOR USED IN CALCULATION OF RL.
REAL Denr
! THE EVOLVING DENOMINATOR FACTOR USED IN CALCULATION OF RL.
REAL Scexp
! EVOLVING SCALING EXPONENT FOR VERY LARGE OR VERY SMALL VALUES OF RL.
REAL Nflag
! 0 FLAG FOR NUMR.
REAL Dflag
! 0 FLAG FOR DENR.
REAL Bnm
! EVOLVING TERM USED IN THE CALCULATION OF NUMR AND DENR.
REAL Binc
! INCREMENT USED IN THE EVOLUTION OF BNM.

!++++ CALCULATING THE RSB ++++++++++++++++++++++++++++++

RAD
! ANGLE UNITS FOR CALC'NS.

** CALCULATE THE INITIAL **
J(0)=(SIN(Ka))/Ka
** RSB, J(0). **
*** CALCULATING THE RATIO ***

FOR L=1 TO Lmax

RI=1.0

Numr=0.

Denr=0.

Sexp=0.

Nflag=0.

Dflag=0.

Bnm=1.0/Ka

Binc=2.0/Ka

/* CALCULATE THE L "NAKED" */

FOR Ordct=1 TO L

Bnm=Bnm+Binc

IF Nflag=0 THEN

Numr=Numr

IF Numr<>0 THEN

RI=RI+Numr

Numr=1.0/Numr

ELSE

ABS(RI)>10^-250 THEN CALL Scale(RI,Sexp)

ELSE

Nflag=1

END IF

END ELSE

END IF

NEXT Ordct

WHILE Numr<>Denr OR Nflag=1 OR Dflag=1

Bnm=Bnm+Binc

IF Nflag=0 THEN

Numr=Numr

IF Numr<>0 THEN

RI=RI+Numr

Numr=1.0/Numr

ELSE

ABS(RI)>10^-250 THEN CALL Scale(RI,Sexp)

ELSE

Nflag=1

END IF

END ELSE

END IF

Denr=Denr-Denr

IF Denr<>0 THEN

RI=RI/Denr

Denr=1.0/Denr

ELSE

IF Oflag=0 THEN

CHECK DENR=0 FLAG NOT SET;

END ELSE

END IF

END IF

END ELSE

END IF

END WHILE

/* NUMR FACTORS OF J(0)/J(L), */

INCREMENT BNM.

/* AND DENR TERMS OF J(0)/J(L), */

NOTE WHEN NUMR=DENR THEN

/* RL=J(0)/J(L). */

END ELSE

/* CHECK SCALING OF UPDATED RL. */

END IF

END IF

END ELSE

DEFERRED FOR ONE INCREMENT OF BNM.

/* CHECK NUMR=0 FLAG NOT SET; */

INCREMENT BNM.

/* UPDATE NUMR IF NUMR<>0. */

/* UPDATE RL IF UPDATED NUMR<>0. */

/* PREPARE NUMR FOR NEXT EVOLUTION. */

/* CHECK SCALING OF UPDATED RL. */

/* CALCULATE THE REMAINING NUMR AND DENR TERMS OF J(0)/J(L). */

/* WHEN NUMR=DENR THEN */

/* RL=J(0)/J(L). */

/* IF NFLAG<>0 THE PREVIOUS STEPS ARE */

DEFERRED FOR ONE INCREMENT OF BNM.

/* IF NFLAG<>0 THE PREVIOUS STEPS ARE */

DEFERRED FOR ONE INCREMENT OF BNM.

/* UPDATE DENR IF DENR<>0. */

/* UPDATE RL IF UPDATED DENR<>0. */

/* PREPARE DENR FOR NEXT EVOLUTION. */
IF ABS(R1)>10^-250 THEN CALL Scale(R1,Scexp)
ELSE
  Dflag=1
END IF
ELSE
  IF DFLAG<>0 THEN CALL Scale(R1,Scexp)
  ELSE
    Dflag=0
  END IF
END WHILE

J(L)=J(0)/(R1*10^(Scexp))
*** J(L) DETERMINED. ***

NEXT L

!+++++++++++++++++++++++++++++++++++++++++++++++
!+++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++
!SUBEND

!+++++++++++++++++++++++++++++++++++++
7200 !
7210 !SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
SUB Isb(Lmax, Ka, Dy(*), Y(*))

REM THIS MODULE CALCULATES THE DERIVATIVES OF THE IRREGULAR SPHERICAL BESSEL FUNCTIONS OF ARGUMENT KA AND ORDERS 0 THROUGH LMAX. THE CALCULATION OF THE DERIVATIVE USES THE ISB'S OF THE SAME AND PREVIOUS ORDER.

CALL Isb(Lmax, Ka, Y(*)) ! CALCULATE THE ISB VALUES.

RAD ! ANGLE UNITS FOR CALC'NS.

Dy(0)=(-Y(0)+SIN(Ka))/Ka ! THE INITIAL ISB DERIVATIVE.

FOR L=1 TO Lmax ! THE REMAINING ISB DERIVATIVES.

Dy(L)=-(L+1)/Ka*Y(L)+Y(L-1)

NEXT L

SUBEND

END
SUB Isb(Lmax,Ka,Y(*))
REM THIS MODULE CALCULATES THE IRREGULAR SPHERICAL BESSEL FUNCTIONS
REM OF ARGUMENT KA AND ORDER L THROUGH LMAX. THE CALCULATION IS
REM ACCOMPLISHED BY FORWARD RECURSION.
REM
REM CALCULATING THE ISB
REM
RAD
Y(0)=-COS(Ka)/Ka
Y(1)=(Y(0)-SIN(Ka))/Ka
FOR L=2 TO Lmax
Y(L)=((2*L-I)/Ka)*Y(L-1)-Y(L-2)
NEXT L

SUBEND

END
SUB Leg0(Lmax,Ka,P(*))
REM THIS MODULE CALCULATES THE LEGENDRE POLYNOMIALS OF ARGUMENT -1 AND
REM ORDER 0 THROUGH LMAX. CALCULATION IS ACCOMPLISHED BY FORWARD
REM RECURSION.

REM ++ Calculating the Legendre Polynomials ++++++++++++++++++++++++

X=-1 ! ARGUMENT OF THE LEG. POL'S.
P(0)=1 ! INITIAL LEG. POL'S. CALC'D.
P(1)=X
FOR L=2 TO Lmax ! REMAINING LEG. POL'S. CALC'D.
P(L)=2-(1/L)*X*P(L-1)-(1-(1/L))*P(L-2)
NEX L

++++ Module Conclusion ++++++++++++++++++++++++ 

SUBEND
SUB Gain30(Urms, Tc, Rh, R, Patm, Ir, Efreq, Za)
REM THIS MODULE CONTAINS THE DATA USED FOR DETERMINATION OF 3.0V INPUT FROM THE POWER SUPPLY.
REM
!++++ LOADING DATA ++++++++++++++++++++++++++++++++++++++++++++++++++++++++
!
!
RESTORE 630
READ Urms, Tc, Rh, R, Patm, Ir, Efreq, Za
630: DATA .426, 21.0, 50.0, 5.3, 1021.5, 2.951E-3, 5000, 15.8
!
!++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++++++++++
!
SUBEND
!
8680 !
8690 !+++++++++++++++++++++++++++++==================================
8700 SUB Gain3S(Vrms,Tc,Rh,R,Patm,Ir,Efreq,Za)
8710 REM +++++++++++++++++++++++++++++++++++++++++++++++++++++++++
8720 REM THIS MODULE CONTAINS THE DATA USED FOR DETERMINATION OF E16o WITH
8730 REM 3.5V INPUT FROM THE POWER SUPPLY.
8740 REM +++++++++++++++++++++++++++++++++++++++++++++++++++++++++
8750 !
8760 !++++ LOADING DATA ++++++++++++++++++++++++++++++++++++++++++++++++++
8770 !
8780 !
8790 RESTORE 635
8800 READ Vrms,Tc,Rh,R,Patm,Ir,Efreq,Za
8810 635: DATA .523,21.0,50.0,5.30,1021.5,4.467E-3,5000,15.8
8820 !
8830 !
8840 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++
8850 !
8860 !++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++
8870 !
8880 SUBEND
8890 !
8900 !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++
8910 !
8920 !+++++++++++++++++++++++++++++==================================
8930 !
SUB SphereJ(Dt(*),J,Tc,Patm,Rh,Tgltm,Dia,Efreq,Nuspkr,Diaspkr,Gpre)

REM ++++++++++++++++++++++++++++++++++++++++++++++++++
REM THIS MODULE CONTAINS THE DATA USED FOR DETERMINATION OF Er WITH
REM TARGET NO. 1 EMPLOYED.
REM ++++++++++++++++++++++++++++++++++++++++++++++++++

!++++ LOADING DATA ++++++++++++++++++++++++++++++++++++++++++++++++++

! $=39

READ Tc,Patm,Rh,Tgltm,Dia,Efreq,Nuspkr,Diaspkr,Gpre
READ Dt(I)
NEXT I
READ Tc,Patm,Rh,Tgltm,Dia,Efreq,Nuspkr,Diaspkr,Gpre
READ Dt(I)
NEXT I

!++++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++++

SUBEND
SUB Sphere2(Dt(*), J, Tc, Ptm, Rh, Tgttm, Dia, Efreq, Nuspkr, Diaspkr, Gpre)
REM +---------------------------------------------------------------------+
REM THIS MODULE CONTAINS THE DATA USED FOR DETERMINATION OF Er WITH
REM TARGET NO. 2 EMPLOYED.
REM +---------------------------------------------------------------------+
REM !++++ LOADING DATA +---------------------------------------------------------------------+
REM
J=39
RESTORE S2
FOR I=0 TO J
READ Dt(I)
NEXT I
READ Tc, Patm, Rh, Tgttm, Dia, Efreq, Nuspkr, Diaspkr, Gpre
S2: DATA 4.72, 4.66, 4.16, 3.23, 2.01, .560, -.940, -2.35, -3.52, -4.36
DATA -4.77, -4.70, -4.18, -3.25, -1.99, -.560, .960, 2.34, 3.51, 4.34
DATA 4.74, 4.66, 4.13, 3.19, 1.95, .500, -1.00, -2.40, -3.57, -4.38
DATA -4.78, -4.68, -4.15, -3.20, -1.92, -.480, 1.02, 2.39, 3.54, 4.34
DATA 21.0, 100.9, 4.49, 8.30, 55.1, 1013, 5000, 19, .0762, .11094
SUBEND

!++++ MODULE CONCLUSION +---------------------------------------------------------------------+

SUBEND
REM THIS MODULE CONTAINS THE DATA USED FOR DETERMINATION OF Er WITH

REM TARGET NO. 3 EMPLOYED.

REM++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++.+

J=39
RESTORE S3
FOR I=0 TO J
READ Dt(I)
NEXT I
READ Tc,Patm,Rh,Tgttm,Dia,Efreq,Nuspkr,Diaspkr,Gpre
S3: DATA 3.61,3.40,2.86,2.04,1.01,-.120,-1.25,-2.25,-3.04,-3.54
DATA -3.68,-3.46,-2.91,-2.07,-1.04,.110,1.25,2.24,3.00,3.48
DATA 3.63,3.39,2.84,2.02,.970,-1.30,-2.31,-3.08,-3.56
DATA -3.69,-3.46,-2.69,-2.04,-.990,.160,1.29,2.26,3.05,3.50
DATA 21.3,1009.6,49.8,30.59,.07634,5000,19,.0762,11094
READ tia
SUBEND

9900 !
9910 !
9920 !
9930 !
9940 !
9950 !
SUB Sphere4(Dt(*), J, Tc, Patm, Rh, Tgttm, Dia, Efreq, Nu5pkr, Diaspkr, Gpre)

REM THIS MODULE CONTAINS THE DATA USED FOR DETERMINATION OF Er WITH
TARGET NO. 4 EMPLOYED.

REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

LOADING DATA ++++++++++++++++++++++++++++++++++++++++++++++++++++++

J = 33
RESTORE S4
FOR I = 0 TO J
READ Dt(I)
NEXT I
READ Tc, Patm, Rh, Tgttm, Dia, Efreq, Nu5pkr, Diaspkr, Gpre
S4: DATA 2.28, 2.10, 1.68, 1.01, 1.03, -1.64, -2.07, -2.31
DATA -2.34, -2.12, -1.71, -1.12, -4.40, -3.20, 1.02, 1.62, 2.06, 2.28
DATA 2.29, 2.10, 1.68, 1.09, 4.40, -3.40, -1.04, -1.66, -2.10, -2.32
DATA -2.35, -2.12, -1.70, -1.11, -4.00, 3.40, 1.04, 1.64, 2.06, 2.28
DATA 21.4, 1009.9, 49.6, 30.64, 0.06240, 5000, 19, 0.0762, 11094
DATA 1.4, 1009.9, 49.6, 30.64, 0.06240, 5000, 19, 0.0762, 11094

REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

I

REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

SUBEND

REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

I
REM THIS MODULE CONTAINS DATA USED IN DETERMINATION OF Er WITH
REM 3.0V APPLIED.

REM +++++++++++++++++++++++++++++++.+.+.+++++++++++++++++++++++++++++++++

REM THIS MODULE CONTAINS DATA USED IN DETERMINATION OF Er WITH
REM 3.0V APPLIED.

REM +++++++++++++++++++++++++++++++.+.+.+++++++++++++++++++++++++++++++++

I=39
RESTORE T30
FOR I=0 TO J
READ Dt(I)
NEXT I
T30: DATA .690,.680,.590,.440,.320,.160,-.020,-.230,-.410,-.550
DATA -.610,-.610,-.520,-.360,-.240,-.080,.110,.320,.490,.630
DATA .690,.680,.590,.430,.320,.150,-.040,-.240,-.420,-.560
DATA -.620,.660,-.510,-.380,-.240,-.070,.120,.330,.500,.640
10500 !
10510 !
10520 !+++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++}
10530 !
10540 !+++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++}
10550 !
10560 SUBEND
10570 !
10580 !+++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++}
10590 !
10600 !+++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++}
10610 !
REM THIS MODULE CONTAINS DATA USED IN DETERMINATION OF Er WITH
REM 3.5V APPLIED.
REM

LOADING DATA

J=39
RESTORE T35
FOR I=0 TO J
READ Dt(I)
NEXT I
T35: DATA .830,.770,.640,.490,.290,.080,-.180,-.400,-.610,-.730
DATA -.770,-.720,-.580,-.430,-.240,-.020,.240,.460,.660,.780
DATA .830,.770,.630,.470,.290,.060,-.190,-.420,-.600,-.720
DATA -.770,-.710,-.570,-.420,-.230,-.010,.240,.480,.670,.790

MODULE CONCLUSION

SUBEND
I

REM THIS MODULE CONTAINS DATA USED IN DETERMINATION OF Er WITH 3.0V APPLIED.
REM
LOADING DATA

!++++

FOR I=0 TO J
READ Dt(I)
NEXT I

Jt=39
RESTORE Tn30
FOR I=0 TO Jt
READ Tdt(I)
NEXT I

READ Tcn,Rhn,Patmn,Efreqn
N30: DATA 0,0,-.02,-.03,-.04,-.06,-.08,-.1,-.11,-.12
DATA -.12,-.11,-.08,-.07,-.05,-.04,-.01,0,0
DATA 0,0,-.02,-.03,-.05,-.07,-.08,-.1,-.11,-.12
DATA -.12,-.12,-.11,-.08,-.07,-.04,-.03,-.02,0,0
DATA .01,0,0,-.03,-.04,-.07,-.09,-.11,-.12,-.12
DATA -.12,-.12,-.11,-.08,-.07,-.04,-.03,0,0,01
DATA .69,.68,.59,.44,.32,.16,.02,.23,.41,.55
DATA -.61,.61,.52,.36,.24,.08,.11,.32,.49,.63
DATA .69,.68,.59,.43,.32,.15,.04,.24,.42,.56
DATA -.62,-.6,-.51,-.38,-.24,-.07,.12,.33,.5,.64
DATA 20.8,51.7,1016.7,10000
DATA .69,.68,.59,.44,.32,.16,.02,.23,.41,.55
DATA -.61,.61,.52,.36,.24,.08,.11,.32,.49,.63
DATA .69,.68,.59,.43,.32,.15,.04,.24,.42,.56
DATA -.62,-.6,-.51,-.38,-.24,-.07,.12,.33,.5,.64
DATA 20.8,51.7,1016.7,5000
!+++++ MODULE CONCLUSION

SUBEND

1130
1131
1132
1133
1134
1135
1136
1137
1138
11390 !
11400 !$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
11410 SUB Noise35(J,Jt,Dt(*),Tdt(*),Tcn,Rhn,Patmn,Efreqn)
11420 REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
11430 REM THIS MODULE CONTAINS DATA USED IN DETERMINATION OF Er WITH
11440 REM 3.5V APPLIED.
11450 REM ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
11460 !
11470 !++++ LOADING DATA ++++++++++++++++++++++++++++++++++++++++++++++++++++++
11480 !
11490 !
11500 J=39
11510 RESTORE N35
11520 FOR I=0 TO J
11530 READ Dt(I)
11540 NEXT I
11550 Jt=39
11560 RESTORE Tn35
11570 FOR I=0 TO Jt
11580 READ Tdt(I)
11590 NEXT I
11600 READ Tcn,Rhn,Patmn,Efreqn
11610 N35: DATA -.06,-.08,-.08,-.08,-.06,-.04,-.02,0,.02
11620 DATA -.05,-.06,.06,.06,.04,.03,.02,0-.03,-.05
11630 DATA -.07,-.08,-.09,-.08,-.08,-.06,-.04,-.02,.01,.03
11640 DATA -.04,.07,.05,.05,.04,.01,-.01,-.04,-.06
11650 Tn35: DATA .74,.83,.82,.72,.53,.38,.18,-.06,-.31,-.53
11660 DATA -.68,-.77,-.75,-.64,-.46,-.3,-.14,.4,.6
11670 DATA -.75,.83,.81,.7,.536,.16,-.08,-.33,-.54
11680 DATA -.69,-.76,-.74,-.63,-.46,-.28,-.08,.16,.41,.62
11690 DATA 21.3,51.3,1016.6,5000
11700 !
11710 !
11720 !+++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++++
11730 !
11740 !++++ MODULE CONCLUSION ++++++++++++++++++++++++++++++++++++++++++++++++++
11750 !
11760 SUBEND
11770 !
11780 !+++++ LOADING DATA ++++++++++++++++++++++++++++++++++++++++++++++++++++++
11790 !
11800 !$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
11810 !
APPENDIX F

ACOUSTIC ARRAY CALIBRATION DATA

This appendix contains data used to determine the calibration product $E_r E_L$. Data units are contained in square brackets.

For listings of the same type of data the units and uncertainty are explicitly given for the first datum. Remaining data in the listing have the same units and uncertainty as the first datum.

1. TWO WAY PROPAGATION PATH DATA

Pre-amplifier gain $G_p$ and array impedance $Z$ were previously determined by Moxcey. $G_p$ was determined to be 11,094. $Z$ was determined to be 15.8 [Ω]. [Ref. 8]

The remaining data are presented in the following tables.

$V_{\text{supply}}$ is the voltage supplied by the HP3314A function generator to the pre-amplifier (see Figure 8).
Table 5a: Two Way Propagation Path Data for Sphere One, Collected 30 November 1987; Run #2: Data Re-measured Because First Run $V_r$ (with 3.5 [V] Supply) Was Clipped.

Diameter $= 2a = .2546 \pm 0.0006$ [m]
$T_c = 20.2 \pm 0.1$ [$^\circ C$]
Rh $= 52.8 \pm 0.1$ [%]
P $= 1016.8 \pm 0.2$ [mb]
No. pulses $= 20$
$V_{\text{supply}} = 3.0$ [V]
t$_r = 30.31$ [mS] - 400 [$\mu S$] = 29.91 $\pm$ 0.1 [mS]

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Table 5b: Two Way Propagation Path Data for Sphere One Continued, Collected 30 November 1987; Run #2: Data Re-measured Because First Run $V_r$ (with 3.5 [V] Supply) Was Clipped.

<table>
<thead>
<tr>
<th>$t$</th>
<th>$V_r$</th>
<th>$t$</th>
<th>$V_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.68 ±0.01 [mS]</td>
<td>9.54 ± 0.03 [V]</td>
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<td>9.60</td>
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</table>
Table 6a: Two Way Propagation Path Data for Sphere Two, Collected 28 November 1987.

Diameter = \(2a = 10.13 \pm 0.01 \text{ [cm]}\)

\(T_c = 21.0 \pm 0.1 \text{ [° c]}\)

\(R_h = 49.8 \pm 0.1 \text{ [%]}\)

\(P = 1009.4 \pm 0.2 \text{ [mb]}\)

No. pulses = 20

\(V_{\text{supply}} = 3.5 \text{ [V]}\)

\(t_r = 30.95 \text{ [mS]} - 400 \text{ [μS]} = 30.55 \pm 0.1 \text{ [mS]}\)

<table>
<thead>
<tr>
<th>(t)</th>
<th>(V_t)</th>
<th>(t)</th>
<th>(V_t)</th>
</tr>
</thead>
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<tr>
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<td>830 (\pm 5) [mV]</td>
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<td>830</td>
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Table 6b: Two Way Propagation Path Data for Sphere Two Continued, Collected 28 November 1987.

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<th>V_r</th>
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<td>-1.92</td>
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<td>-0.480</td>
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<td>1.02</td>
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<td>4.34</td>
<td>34.52</td>
<td>4.34</td>
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</table>
Table 7: Two Way Propagation Path Data for Sphere Three, Collected 28 November 1987.

Diameter = 2a = 7.634 ± 0.003 [cm]  
Tc = 21.3 ± 0.1 [° C]  
Rh = 49.8 ± 0.1 [%]  
P = 1009.6 ± 0.2 [mb]  
No. pulses = 20  
V_supply = 3.5 [V]  
t_r = 30.99 [mS] - 400 [μS] = 30.59 ± 0.1 [mS]

V_t data is the same as sphere two's (see Table 6a).

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<th>t</th>
<th>V_r</th>
</tr>
</thead>
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<td>34.19</td>
<td>3.39</td>
</tr>
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<td>2.86</td>
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<td>2.84</td>
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<td>2.04</td>
<td>34.21</td>
<td>2.02</td>
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<td>-3.46</td>
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<td>-2.89</td>
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<tr>
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<td>-2.07</td>
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<td>-2.04</td>
</tr>
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<td>1.29</td>
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<td>2.24</td>
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</table>
Table 8: Two Way Propagation Path Data for Sphere Four, Collected 28 November 1987.

Diameter = 2a = 6.240 ± 0.008 [cm]  
T_c = 21.4 ± 0.1 [° c]  
Rh = 49.6 ± 0.1 [%]  
P = 1009.9 ± 0.2 [mb]  
No. pulses = 20  
V_supply = 3.5 [V]  
t_r = 31.04 [mS] - 400 [μS] = 30.64 ± 0.1 [mS]

V_l data is the same as sphere two’s (see Table 6a).

<table>
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<th>t</th>
<th>V_r</th>
<th>t</th>
<th>V_r</th>
</tr>
</thead>
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<td>34.03</td>
<td>2.29</td>
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<tr>
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</table>
Table 9: Noise Data for 3.0 [V] Supply Voltage;

\[ T_c = 20.8 \pm 0.1 \, ^\circ\text{C} \quad \text{Rh} = 51.7 \pm 0.1 \, \% \quad P = 1016.7 \pm 0.2 \, [\text{mb}] \]

\[ V_{\text{supply}} = 3.0 \, [\text{V}] \quad \text{No. pulses} = 20 \]

\[ V_t \] data is the same as sphere one's (see Table 5a).

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<th>( V_n )</th>
<th>t</th>
<th>( V_n )</th>
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Table 10a: Noise Data for 3.5 [V] Supply Voltage; Collected 30 November 1987.

\[ T_c = 21.3 \pm 0.1 \, ^\circ \text{C} \]
\[ R_h = 51.3 \pm 0.1 \, \% \]
\[ P = 1016.6 \pm 0.2 \, \text{mb} \]
No. pulses = 20
\[ V_{\text{supply}} = 3.5 \, \text{[V]} \]

<table>
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<tr>
<th>t</th>
<th>( t \pm 0.01 , \text{[mS]} )</th>
<th>( V_t \pm 5 , \text{[mV]} )</th>
<th>t</th>
<th>( V_t )</th>
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<td>740 \pm 5 , \text{[mV]}</td>
<td>2.44</td>
<td>750</td>
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<tr>
<td>2.25</td>
<td>830</td>
<td>2.45</td>
<td>830</td>
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<td>2.26</td>
<td>820</td>
<td>2.46</td>
<td>810</td>
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<tr>
<td>2.27</td>
<td>720</td>
<td>2.47</td>
<td>700</td>
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<td>530</td>
<td>2.48</td>
<td>500</td>
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<td>2.49</td>
<td>360</td>
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<td>180</td>
<td>2.50</td>
<td>160</td>
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<tr>
<td>2.31</td>
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<td>2.51</td>
<td>- 80</td>
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<tr>
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<td>2.52</td>
<td>-330</td>
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<td>2.53</td>
<td>-540</td>
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<td>-280</td>
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<td>2.42</td>
<td>400</td>
<td>2.62</td>
<td>410</td>
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<tr>
<td>2.43</td>
<td>600</td>
<td>2.63</td>
<td>620</td>
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Table 10b: Noise Data for 3.5 [V] Supply Voltage Continued; Collected 30 November 1987.

<table>
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<th>$V_n$</th>
<th>t</th>
<th>$V_n$</th>
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</thead>
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<tr>
<td>33.80 ±0.01 [mS]</td>
<td>60 ± 5 [mV]</td>
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<td>33.81</td>
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<td>34.19</td>
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2. ONE WAY PROPAGATION PATH DATA

One way propagation path data are presented in the following tables. 

T_c and Rh are estimated. The estimates were based on hygrothermographic comparisons and 28 and 30 November data.

Table 11: One Way Propagation Path Data for 3.0 [V], 5000 [Hz] Continuous Wave Supply from the HP3314A Function Generator; Collected 7 December 1987.

\[(V_{rms})_t = 0.246 \pm 0.001 \, [V]\]
\[T_c \approx 21.0 \, [^\circ \text{C}]\]
\[Rh \approx 50.0 \, [%]\]
\[P = 1021.5 \pm 0.2 \, [\text{mb}]\]
\[R = 5.30 \, [\text{m}] \text{ (calculated from two way propagation path data for spheres two, three and four)}\]

\[l_r \text{ (referenced to } 10^{-12} \, [\text{W/m}^2])\]
94.7 ± 0.1 [dB]
94.5
94.7
95.0
94.8
95.1
94.2
Table 12: One Way Propagation Path Data for 3.5 [V], 5000 [Hz] Continuous Wave Supply from the HP3314A Function Generator; Collected 7 December 1987.

\[(V_{rms})_t = 0.523 \pm 0.001 \text{[V]}\]
\[T_c \approx 21.0 \text{[°c]}\]
\[Rh \approx 50.0 \text{[%]}\]
\[P = 1021.5 \pm 0.2 \text{[mb]}\]
\[R = 5.30 \text{[m]} \text{ (calculated from two way propagation path data for spheres two, three and four)}\]

\[I_r \text{ (referenced to } 10^{-12} \text{[W/m}^2\text{])}\]
\[97.4 \pm 0.1 \text{[dB]}\]
96.4
95.1
97.0
96.2
97.1
96.4
95.4
96.3
97.4
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