Chapter 3

Methodology

In this chapter a detailed description is made on the design philosophy adopted, which led to the development of the (3,1) drive hydrophones, along with the test facilities, experimental set-up and methodology employed for validating their performance.

3.1 DESIGN PHILOSOPHY

Availability of piezofilms in different shapes and sizes opened new vistas in the vast field of transducers, particularly for underwater applications. Piezopolymers are more sensitive than quartz and far more sensitive than ceramics as a transformer of mechanical to electrical energy [17]. KYNAR piezofilm manufactured by Pennwalt Corporation is used in the present work. The basic resin
used for Kynar piezofilm is Polyvinylidene Fluoride (PVDF), which exhibits good piezoelectric properties when poled. For collecting the charges developed on its surface, the piezofilm is usually provided with metallised coatings on its surfaces. Of several metallisation available, film with tin aluminium metallisation is used in this work. First some preliminary experiments were carried out on the film to study its transduction properties.

Like all other piezoelectric materials, the PVDF is also highly anisotropic. Hence the electrical and mechanical responses differ for electrical and mechanical excitations along different directions. The mechanical output produced for a particular electrical excitation is determined by the piezoelectric strain constant $d$, and the equivalent electrical output developed for a given pressure input is defined by piezoelectric stress constant $g$.

The film’s axes or drives are identified by numerals shown in Fig. 3.1 [17].

![Fig. 3.1: Numerical Classification of Axes.](image)

$i = 1, 2, 3$ corresponds to length, breadth and thickness drive respectively. If an electric field $E$ is applied, corresponding strain in the film is defined by,
\begin{equation}
S_i = d_{3i}E
\end{equation}

$S_i$ and $d_{3i}$ are the strain developed and piezoelectric strain constant respectively in the $i^{th}$ direction. In the Eq. (3.1) the first numerical subscript is the axis of polarisation or applied electric field and the second subscript denotes the mechanical stress or strain axis.

Similarly for a stress of $X$ applied in the $i^{th}$ direction, the resultant voltage output will be,

\begin{equation}
E = g_{3i}X_i
\end{equation}

where $E$ is the resultant output voltage and $g_{3i}$ is the piezoelectric stress constant in the $i$th direction.

3.2 STRETCH DRIVE VIBRATION OF PVDF

Most conventional transducers utilise thickness or $(3,3)$ drive of vibration. In this drive, the film is made to vibrate normal to its surface and the output is taken across the film.

During the process of poling, the film is subjected to a stretching process in a particular direction, while applying a high d.c. field. This direction is termed as the stretch direction. In the stretch drive, known as $(3,1)$ drive, of vibration the film is intended to vibrate along the direction of stretching and the output is taken across its electroded surfaces.

Table 3.1 presents the piezoelectric constants and acoustic impedance of commonly used pressure transducer materials [17]. As can be inferred, the high
piezoelectric stress constant and low piezoelectric strain constant makes the film highly voltage sensitive. The product of the stress and strain constants is a measure of the figure of merit of hydrophones, which for the piezofilm is 2.5 times greater than their counterparts like ceramics.

Table 3.1: Some of the properties of the commonly used pressure transducer materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>$d_{31}$ $(10^{-12})$ C/N</th>
<th>$g_{31}$ $(10^{-3})$ Vm/N</th>
<th>$k_{31}$ % at 1 kHz</th>
<th>Acoustic Impedance $(10^6)$ kg/m$^2$·sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVDF</td>
<td>23</td>
<td>216</td>
<td>12</td>
<td>2.7</td>
</tr>
<tr>
<td>PZT</td>
<td>110</td>
<td>10</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>BaTiO$_3$</td>
<td>76</td>
<td>5</td>
<td>21</td>
<td>30</td>
</tr>
</tbody>
</table>

As the electromechanical coupling constant $k_{31}$ is comparatively low for piezopolymers, which means that the output acoustic power generated will be lesser for PVDF compared to PZT for the same electric input. Hence it is not usually recommended for projector applications. Other disadvantages of the polymeric ferroelectrics compared with ceramics include the thermal depolarisation when heated to temperatures above 100°C for long times, thus limiting the use of polymers below this temperature. Although the piezoelectric stress constant is comparatively higher for polymers, it is difficult to pole a thick piece of film, necessitating the use of multilayer stacks for high voltage outputs. Mechanical relaxation occurs when the polymers are subjected to a stress for long time, this will adversely affect the static measurements carried out with polymeric transducers.

The following calculations indicates the voltage output of the piezofilm for
vibrations in both (3,3) and (3,1) directions. If a piezofilm of length $l$, width $w$ and thickness $t$ is subjected to a compressive stress of $T$ Newton per square metres, then the voltage generated for,

$$V_{3} = g_{33} T t$$  \hspace{1cm} (3.3)$$

and for (3,1) drive;

$$V_{I} = g_{31} F/w$$  \hspace{1cm} (3.4)$$

Where $F$ is the force acting over the film and $g_{33}$ and $g_{31}$ are the corresponding voltage constants. The output voltages computed for (3,1) and (3,3) drives for a given stress input of $100 \text{ N/m}^2$ are shown in Table 3.2.

<table>
<thead>
<tr>
<th>Film Dimensions $l \times w \times t$</th>
<th>Voltage computed in (3,1) drive</th>
<th>Voltage computed in (3,3) drive</th>
<th>The ratio of computed stress developed in the (3,1) drive to that in the (3,3) drive.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 cm x 1 cm x 28 $\mu$m</td>
<td>1.08 V</td>
<td>0.95 mV</td>
<td>1785</td>
</tr>
<tr>
<td>4 cm x 2 cm x 28 $\mu$m</td>
<td>0.86 V</td>
<td>0.95 mV</td>
<td>1428</td>
</tr>
<tr>
<td>3 cm x 3 cm x 28 $\mu$m</td>
<td>0.65 V</td>
<td>0.95 mV</td>
<td>1071</td>
</tr>
</tbody>
</table>

Vast escalation in the voltage generated for (3,1) drive compared to that in (3,3) drive can be explained as due to the concentration of the given force input to a much smaller cross-sectional area of the film, which results in larger stress and a substantial increase in the output. This is the foremost and basic principle adopted for the development of hydrophones.

### 3.3 TERMINAL ELECTRODES

Polarised piezopolymers are usually available with metallised surfaces and
with a marking of its stretch direction on the surface. According to the procedural requirements, the film can be cut in any shape as shown Fig. 3.2(a).

As the polymer has low melting point, it is not possible to solder the terminal electrodes directly to the film surface, as is done in the case of ceramics. Different techniques were therefore attempted. The first method adopted was to solder the cable leads to two very thin sheets of copper and these membranes of copper were then attached to the film surface with a conducting adhesive cement. This method was found to be unsatisfactory as it was not hard and sufficient to withstand the twisting as well as the weight of the cable. A better and more reliable technique used in the major part of the present work for lead attachment is shown in Fig. 3.2(b). It consists of two copper clads, which are etched and cut as shown. The leads of the output cable are soldered to the projected portion of these etched pieces. And they are attached to a 'L' shaped broad aluminium frame as shown, using nuts and bolts. The film is inserted in between these electrodes and is tightened properly using nuts and bolts. This arrangement ensures the electrodes always to be in contact with the film surface irrespective of the cable strains. Proper and careful etching of the copper clads is required so as to avoid contact between the two metal surfaces of the electrodes. This assembly is connected to the tail end of the film to lessen its interference in the vibration of the film.

3.4 METHODOLOGY

Before going into the design details of the hydrophones, a description is made on the methodology adopted for the calibration of the test hydrophones,
Fig 3.2(a) : A PVDF sheet with markings of stretch direction

Fig 3.2(b) : Terminal electrodes used for extracting the film output.
which involves evaluation of the most significant electroacoustic parameter, the
response (sensitivity) of the hydrophone, relating the generated voltage at its
output to the incident acoustic pressure, as a function of frequency.

The basic and widely used standard electroacoustic response is the free field
voltage sensitivity, which is a measure of the voltage across the terminals of the
hydrophone for a plane wave of unit acoustic pressure. It is also known as the open
circuit response and is normally expressed as number of decibels relative to 1 volt
produced by an acoustic pressure of 1 micro pascal, and is usually denoted as dB
re: 1V/μPa.

3.5 DECIBELS

The most suitable and widely used reference unit in underwater acoustic
measurements is the decibel system, which gives a convenient measure of the ratio
in comparison with a reference one. The reason for adopting this system is that
generally in acoustic phenomena the range of the signal amplitude variations are
extremely high and it is possible to accommodate these fluctuations conveniently
with a logarithmic scale. In areas of acoustics and communication engineering, the
interest is generally in signal ratios rather than its absolute values.

3.6 MEASUREMENT TECHNIQUES

The different methods [121-125] available to find the free field voltage
sensitivity of the hydrophones, can be broadly divided into two groups as Primary
and Secondary methods. The primary method is confined to the basic measurements
like voltage, current, electrical and acoustical impedance, length, mass etc. of the transducer along with its operating frequency.

In the secondary method, the response of the transducer under test is compared with a reference transducer, which has already been calibrated using primary method. Even though the secondary methods in no way can compete with the primary calibration techniques, they are still convenient and popular as it requires fewer measurements and provides fewer sources of error than do primary methods. So for routine calibrations the secondary methods are increasingly popular. The measurement accuracy and reliability of the secondary methods can be improved by averaging the results obtained with two or more standard reference hydrophones.

Some of the widely used calibration techniques are given below [126],

- Comparison Method
- Reciprocity Method
- Two Projector Null Method
- Impedance Method
- Static Method
- Impulse Method
- Radiation Pressure Method

Of these, comparison method and reciprocity method are extensively used for the calibration of hydrophones.

In most of the measurement techniques, one of the pre-requisite is that the
medium should be homogenous and infinite. Reflecting boundaries, temperature gradients, gas bubbles, marine life etc., contribute adversely to the free field conditions.

3.6.1 Reciprocity method

Reciprocity method of calibration is a primary method and hence a reference standard transducer is not necessary, but it needs a series of measurements on several transducers. This method is based on electroacoustics reciprocity, equivalent to the electrical reciprocity for bilateral networks. One of the requirements of this method is the need for a reciprocal transducer. The peculiarity of a reciprocal transducer is that, its receiving sensitivity to the transmitting response will be a constant, termed as the reciprocity parameter. This parameter is largely influenced by the acoustic medium, the frequency of operation and the boundary conditions, but it is free from the design parameters of the hydrophone. Most of the piezoelectric and piezoceramic transducers are reciprocal at normal signal levels.

3.6.2 Comparison method

This is the most simple, reliable and straightforward method for calibration of hydrophones. This secondary method mainly consist of subjecting the unknown hydrophone and a previously calibrated reference hydrophone to the same free field pressure, and then comparing the output electrical voltages of the two. This method is also known as substitution method, as the test hydrophone is substituted for a standard hydrophone in the given measurement conditions.
In the comparison method the characteristics of the projector are irrelevant. The only requirement is that the pressure field should be homogenous throughout the medium surrounding the hydrophone. For this the test and the reference hydrophones are kept at considerable distances from the projector. If the standard reference hydrophone is not omnidirectional, it must be kept with the acoustic axis pointed towards the projector.

If the open circuit output voltage of the standard hydrophone is $V_s$ and that of the unknown hydrophone for the same pressure is $V_t$, then the sensitivity of the test hydrophone can be calculated as follows [127].

$$M_t = M_s \frac{V_t}{V_s} \quad (3.5)$$

in decibels,

$$20 \log M_t = 20 \log M_s + 20 \log V_t - 20 \log V_s \quad (3.6)$$

i.e.,

$$S_t = S_s + 20 \log \frac{V_t}{V_s} \quad (3.7)$$

where $M_t$ and $M_s$ are the sensitivities of the test and standard hydrophones respectively, and $S_t$ and $S_s$ are their decibel equivalents.

The apparent factors which may jeopardise the reliability of the calibrations using this method include, the inability to measure the voltage under the true open circuit conditions, instability of the standard, absence of the true free field and insufficient signal to noise ratio.

Due to its lucid and faithful nature, comparison method is used throughout this work for validating the performance of the hydrophones.
3.7 CALIBRATION OF HYDROPHONES

The evaluation of the response of the hydrophones fall in the general category of free field, far field measurements. The ideal free field conditions assumed theoretically are difficult to accomplish practically. A true free field which is a uniform boundless medium, is one of the requirements for the standard measurements, is beyond the bounds of possibility. Yet another criteria for evaluation is that the measurement should be done in far field, and can be fulfilled to a certain extent by keeping sufficient separation between the projector and the hydrophone. A suitable means for measuring input current or voltage and open circuit voltage, is also having some influence on the measurements. Finally, the values of the parameters like distance between the projector and hydrophone, water density and frequency are also playing a role in determining the trustworthiness of the measurements.

The following facilities available with CUSAT / NPOL were used for the calibration of hydrophones,

1. Underwater Transducer Evaluation Facility (UTEF)
2. Acoustic Test Facility (ATF)
3. Underwater Acoustic Research Facility (UARF)

3.7.1 Underwater Transducer Evaluation Facility (UTEF)

This test facility forms a part of the Ocean Electronics Lab of Department of Electronics of the Cochin University of Science & Technology. UTEF is mainly devoted for the evaluation of hydrophones in water and air. The test tank of this
set-up is of 600 cm x 355 cm x 215 cm, with a capacity of 15,000 gallons of water. This rectangularly shaped tank is having two moving platforms, which can be slide through the rails provided at the top of the tank. The platform I has three dimensional movement and is usually used for fixing the projector. The platform II is fitted with a B&K 3922 turn table, which can be remotely controlled using B&K 2307 level recorder. Usually hydrophone is fixed in a rod, and the rod is inserted into the turn table. Normally the platform II is fixed at one end of the tank and the platform I is adjusted for the desired distance. As the size of the tank is small, it is very difficult to take low frequency measurements free from the wall reflections. A moderately instrumented control room with the necessary set-ups will facilitate measurements in water and air using comparison method.

This tank was used for some preliminary calibration of hydrophones. Air calibrations of the hydrophones were carried out in the air measurement laboratory of UTEF.

3.7.2 Acoustic Test Facility (ATF)

This is a sophisticated test facility of Naval Physical Oceanographic Laboratory (NPOL), for the evaluation of various transducer parameters. This facility comprises of a test tank with slanted walls of size 1225 cm x 765 cm on top and 1070 cm x 610 cm at bottom, with a uniform depth of 610 cm, with a capacity of 4,80,000 litres of water and is designed for measurements above 4 kHz. It also consists of two moving platforms, each with a three dimensional movement, and can be remotely controlled from Instrumentation cabin near the tank. Both the
platforms are equipped with turn tables. A transfer crane with a capacity of 3 tons, separately installed above the tank, facilitates immersion of large projectors and transducer arrays.

The instrumentation available as part of the facility includes an infrastructure for measuring various characteristics of hydrophones and projectors. The data acquisition for most of the measurements is through a computer.

Performance characteristics of certain sets of hydrophones were carried out in this tank. For getting a clear picture of the resonance frequency, signal-to-noise ratio etc. of the hydrophones, some preliminary measurements were carried out here, before meticulously calibrating them. The directivity pattern of the hydrophones was also taken in using this facility.

Even though the preliminary measurements were carried out in the above two facilities, increasing degree of accuracy is achieved by calibrating the test hydrophones in the Lake Facility of NPOL, which satisfies the free-field and far-field conditions up to certain limits.

3.7.3 Underwater Acoustic Research Facility (UARF)

All the final calibrations of the hydrophones were carried out at UARF, Kulamavu near Idukki. This Lake Facility of NPOL forms a part of the vast Idukki hydroelectric reservoir, having a total stretch of around 30 km. UARF mainly consists of two huge platforms - *M.V. Kolumban* and *F.P. Kuravan*. *M.V. Kolumban* is a barge of length 19 m and breadth 8 m, and is driven with two
powerful engines, for propulsion. The barge comprises of an engine room, an instrument room along with a vast free deck space. Along the length of the barge the hydrophone and the projector can be suitably positioned. The barge can be anchored anywhere in the lake, depending on the water depth requirements.

*F.P. Kuravan*, a floating platform, is made up of small floats, over which a deck of 15.6 m x 10.8 m is fabricated. As the platform does not have any propulsion mechanism, it has to be towed for navigating in the lake. A 5 ton capacity mobile crane and a manually rotating turn table (capacity 2 tons) are some of the facilities available on the deck. An on board UPS serves for an uninterrupted and regulated power supply for the instruments. Besides this, a well equipped instrumentation cabin also forms part of the floating platform. There is a central well for positioning large transducer arrays in water without affecting the hydrodynamics of the platform. There is also a longitudinal channel for positioning hydrophones at different ranges from the projector.

Depending on the technical requirements and the logistic support available, either the floating platform or the barge, or both were used for the measurements on different sets of hydrophones. A watercraft *M.V. Jalaprayog*, which also forms a part of the facility was used for ferrying various instruments from shore to the platforms and back.

### 3.8 Experimental Set-up

The hydrophones under test were evaluated in water using the Comparison method. Fig. 3.3 shows the experimental set-up used for the measurements. Even
Fig 3.3: Experimental set up for measuring the frequency response of the hydrophones in water.
though while carrying out measurements in different facilities described above, some additional instruments like extra preamplifiers, filters etc. were used, in accordance with the field requirements, the basic experimental set-up remained the same. It broadly consists of a signal generator, gating system, a power amplifier and of course a projector in the transmitting side, a conditioning amplifier and a source for measuring the output signal (usually a C.R.O) along with the standard and test hydrophone constitute the receiving part.

The sinusoidal signals from the signal generator are gated using gating system. These gated signals are amplified and fed to the projector. These transmitted acoustic signals received by the unknown hydrophone are amplified using conditioning amplifier and fed to a C.R.O for measuring the voltage levels. This is repeated for the desired frequency range. The experiment is repeated for the test hydrophone also. After compensating for extra gain provided either for the test or the standard hydrophone, the voltage outputs of both are compared and by knowing the sensitivity of the standard hydrophone, the sensitivity of the test hydrophone is computed using comparison method.

According to the availability of infrastructure in different measurement facilities, a variety signal generators and power amplifiers were used, but these instruments hardly had any influence in the final results. For all the measurements the conditioning preamplifier B&K 2650 was used at the receiving side so as to condition the input to the C.R.O. Gated signals were used for all measurements to distinguish the reflected echoes from the direct signals. This was done by triggering the C.R.O for every gated output, so that by adjusting the time base the
direct signal can be extracted. The pulse width and repetition rate were also suitably minimised so as to avoid the superposition and time stretching of the direct signal from the reflected ones.

Different projectors and standard hydrophones were employed during the various phases of measurements. These include, underwater speakers UW-15 and UW-60 of Gearing & Watson, ITC TR 25, and MASA J-11 as the projectors and B&K 8100, B&K 8104 (both with a receiving sensitivity of -205.5 dB re 1V/ \( \mu \)Pa in water) and ITC 1042 (with a sensitivity of -202 dB re 1V/ \( \mu \)Pa in water) as the reference hydrophones.

For convenience, measurements on both the standard as well as test hydrophone were carried out together, by immersing them in water side by side and measuring their outputs simultaneously. It was assumed that the distance between them is sufficient to keep them as independent transducers. They were immersed to a depth of around 5-10 meters and the distance between them and projector was maintained in the range of 6-10 meters. The pulse width of the transmitted signals were kept in the range of 1-10 msec.

3.9 AIR CALIBRATION

If the acoustic impedance of the transducer is very high, so that the radiation impedance is negligibly small, and if the dimensions of the transducer are small enough so as to neglect the diffraction effect, then its receiving response will be same in air and water. Most of the conventional acoustical calibration methods can be used to calibrate the hydrophones in air.
Some of the test hydrophones were calibrated in air also so as to ascertain their response in air. The experimental set-up for air measurements is shown in Fig. 3.4. The only difference between the set-ups in air and water is the transmitter, which is a loud speaker in air. All the air calibrations were carried out at UTEF. Either B&k 8100 or B&K 8104 was used as the reference hydrophones and comparison method was used for the calculating the sensitivity of the test hydrophone. As the velocity of sound in air is only one fourth that in water, it is possible to reduce the distance between the transmitter and receivers considerably.

3.10 DIRECTIVITY PATTERN

Directivity pattern of a transducer is its response as a function of transmitted or received sound waves in a specified plane at a given frequency. The pattern provides an idea on the variation of sensitivity of the transducer with direction. It is also a free field far field parameter, used for computing the efficiency of energy conversion of the transducer. If the transducer is reciprocal, then its receiving and transmitting pattern will be similar. For convenience it is usually traced in polar charts.

The set-up shown in Fig. 3.5 can be used for plotting the directivity pattern of a hydrophone [126]. The test hydrophone is fixed to a turn table using a metal rod. The experimental set-up for comparison method can be used here, except that the output from the conditioning amplifier is fed to a level recorder. Keeping the projector fixed, it is energised for a particular frequency and the turn table accommodating the hydrophone is rotated remotely using level recorder B&K 2307.
Fig 3.4: Experimental set up for measuring the frequency response of the hydrophone in air.
Fig. 3.5: Field set-up for plotting the directional response of the hydrophone.
For a full rotation of $360^\circ$ of the hydrophone, variation in its output are drawn on a polar chart of the level recorder. This gives the directivity pattern of the hydrophone for that particular frequency. The directivity pattern of the standard can also be drawn so as to compare it with that of the test hydrophone. As the directivity pattern is a function of frequency, the experiment can be repeated for different frequencies. The directivity patterns were measured at ATF.

3.11 ADDITIONAL PRE-AMPLIFIERS

Usually the hydrophones are equipped with built-in preamplifiers, which facilitate them to enhance the signal-to-noise ratio as well as to reduce the effective output impedance, which will cater the signal with a low impedance path. Usually signal output from the transducer are comparatively feeble and cables are used to carry this signal to the nearest instrument, probably a conditioning amplifier. Therefore the properties of the signal cable has much influence on the fate of the resultant output available at the conditioning amplifier. For normal measurements in water at least 25 m of cable is required for the proper positioning of the hydrophone. So the impedance of the cable as well as its cable noise will dwindle the signal-to-noise ratio [128]. This problem can be solved to a certain extent with the help of low capacitance cables. As this type of cables were not available in the open market, ordinary two core shielded cables were used with either of the following two types of preamplifiers.

1. AMP 4001
2. AMP 4002
AMP 4001 is a buffer amplifier where as AMP 4002 is a differential amplifier.

3.11.1 AMP 4001

This is a buffer amplifier [129], which is normally connected very near to the hydrophone. A buffer is an amplifier with unity gain, and is having a high input impedance and low output impedance. Hence by using this amplifier the signal path can be changed from a high impedance to a low impedance one, thereby reducing the damping of the signal due to high cable capacitance. As the output impedance of the hydrophone is usually very high a MOSFET op-amp CA 3140 is used. The circuit diagram of the amplifier is as shown in Fig. 3.6. It was wired in a PCB with input and output connections, and was moulded for making it water proof. For simultaneously taking the output signal from the preamplifier and to provide it with a proper d.c. power, a four core shielded cable was used.

3.11.2 AMP 4002

With the help of AMP 4001, the damping of the signal due to the cable capacitance was considerably reduced, still the cable noise used to creep in to the signal dwindling the signal-to-noise ratio. For eliminating this noise, the buffer amplifier was replaced with a differential amplifier AMP 4002.

The function of a differential amplifier [130] is to amplify the difference of the two input signals. Normally the differential amplifier will have high input impedance and high CMRR. It finds applications where a small signal voltage and
Fig. 3.6: Circuit diagram of AMP 4001.

Fig. 3.7: Circuit diagram of AMP 4002.
large common mode inputs are available. For an ideal differential amplifier the output $V_o$ is given by,

$$V_o = A(V_1 - V_2)$$ (3.8)

Where $A$ is the gain of the differential amplifier, and $V_1$ and $V_2$ are the difference inputs. Thus if the signal is common to both inputs, then output will be zero. However this is not completely true as the output not only depends on the difference inputs, but on the average of the two also, known as the common mode signal.

As the cable noise and other related noises are common to both the inputs, the noise level can be considerably reduced with this amplifier. The circuit of the differential amplifier (AMP 4002) is shown in Fig. 3.7. It is having two stages, the first one being a differential amplifier and the second a voltage amplifier. MOSFET op-amp CA 3140 was used here also. The overall gain $A$ of the amplifier can be calculated using the following equation.

$$A = \left(1 + \frac{2R_3}{R_g}\right) \left(\frac{R_2}{R_1}\right)$$ (3.9)

Here $R_1 = 1\,\text{K}\Omega$, $R_2 = 10\,\text{K}\Omega$, $R_3 = 4.7\,\text{K}\Omega$ and $R_g = 4.7\,\text{K}\Omega$ were considered and hence the gain was set at 30 (29.7 dB). This gain was properly compensated in the calculations of hydrophone sensitivity. All capacitors were of 0.1μF, used for filtering high frequency noise. The amplifier was suitably enclosed for making it water-tight. A regulated D.C power supply of +12, 0, -12 was provided to the amplifier using positive and negative voltage regulators LM 7812 and LM 7912.
respectively.

3.12 IMPEDANCE ANALYZER HP 4192 A

This is a fully automatic, high performance test instrument capable of measuring wide range of impedance parameters as well as gain, phase and group delay. Measurement range varies from 5 Hz to 13 MHz with a resolution of 1 mHz and oscillation level of 5 mv to 1.1 V r.m.s. Eleven impedance parameters can be measured using this instrument, including the absolute values of impedance and capacitance, which are useful parameters in the transducer design. The instrument can be remotely controlled through a built in HP-IB interface.

The impedance as well as the capacitance of the different transducers were measured using impedance analyzer. For the measurements the analyzer was interfaced with a computer through a GP-IB card. Measurements were taken and the data were stored in the computer using a software in BASIC.