UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS HYDRAULIC LABORATORY

Project Report No. 322

The Use of SONAR to Measure Ice Thickness

by

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Introduction

The need frequently arises among individuals whose work must be carried out on the ice in rivers, lakes, and reservoirs for an instrument which conveniently measures ice layer thickness. Safety is possibly the most important consideration. In addition scientific studies of the processes involved in ice jam formation or of the effect of the ice layer on the ecology of the river lake or reservoir could be enhanced by an instrument that could conveniently and quickly measure ice thickness. At present ice thickness can be reliably determined by drilling a hole and measuring the thickness by some form of hook gage. This procedure requires, however, that individuals venture out on what is possibly "too thin" ice to make the measurement. For a number of thickness measurements over an area, surface drilling becomes a time consuming process.

The various forms of nondestructive measuring devices currently in use employ an echo ranging technique with electromagnetic or acoustic waves. These devices are known by a number of acronyms such as; LASER ranging, RADAR, and SONAR. Their usefulness for ice– layer thickness measurements would depend, in addition to other considerations, on the strength of the reflection from an ice water interface. The expected distance to be measured is estimated from 1 cm to 100 cm (in the Minnesota Region) from the ice surface to the ice–water interface below. The velocity of propagation of electromagnetic waves of nearly 300,000,000 m/s indicates echo ranging with electromagnetic waves would require the measurement of very small time intervals to infer distances as small as one centimeter. The time required for distance measurement using ultrasound, with a sound wave velocity of 3200 m/s in ice, would be considerably longer, typically a few hundred microseconds. While the technology exists for the measurement of the extremely short transit time of electromagnetic pulses, the cost and complexity compared to the measurement of a considerably longer time for a acoustic pulse to travel the same distance is considerably greater.

Because of the high transparency of many solids, liquids and even very turbid water to sound, various SONAR devices have been developed for navigation, submarine detection, bottom surveying and treasure location, and even fish finding. Acoustic ranging in air has been used to measure liquid level in tanks, wave height in the laboratory (Killen 1959) and automatic focusing of cameras. Possibly the most directly applicable technique employing acoustic waves in current use is flaw detection in metals (Gooberman 1968; Hueter and Bolt 1955). Since ice is a crystalline material with much internal complexity similar to metals, acoustic wave transmission and detection will be chosen as the model technology that can be adapted to this problem. This feasibility study will concentrate on the practical problems unique to natural ice as it occurs in lakes, streams, and reservoirs.

Unfortunately natural ice cover can be very inhomogeneous depending on the circumstances of formation. Bernard (1978) classifies ice cover into 12 types in three categories. Many of the differences are related to the crystal size and orientation; other differences are related to the freezing process, such as slush ice formed from a mixture of snow and water or frazil ice in flowing water. This latter group has been found to have a much greater sound attenuation than clear ice.

The principals of distance measurement by echo ranging are very well known and a great number of electronic circuits have been developed for this purpose. A feasibility study must be concerned with application practical problems. The problems which are most evident are as follows:

1. Type of transducers and ultra sound frequency to be used

2. An acoustic coupling device which will permit movement of the instrument over the ice surface.

3. The reliability of the ice water interface as a reflector of ultrasound.

4. The attenuation of sound by ice particularly with inclusion such as air bubbles. Snow cover will not be considered.

5. Identification of acoustic pulse reflections from the ice–water interface when internal reflectors are present, such as large air pockets air bubble layers, and fracture planes.

6. Data presentation and cold weather operation.

Experimental Program

The electronic system was assembled from devices and components available in the St. Anthony Falls Hydraulic Laboratory in order to remain within the funding of the research. It was convenient to procure a chest type freezer and work with small samples of ice in a temperature range of –5° F to 30° F.

It was observed that ice frequently forms on lakes with a layer of "white ice" occupying the the upper 2 or 3 inches and clear ice below. This "white ice" can be formed from snow falling on the water surface and forming a slush which then freezes as temperature falls or by the release of air which rose to the surface during freezing. Tap water would solidify in the freezer with a distribution of air bubbles or "white ice" near the upper surface. This ice layer was bonded to crystal clear ice purchased from an ice company to simulate a condition which might exist in nature. Ice blocks were also frozen from a slush mixture of ice and 33° F water which was then bonded to clear ice. The liquid layer under the ice was simulated with a 50 percent mixture of Prestone anti–freeze.

The electronic circuits usually supply a high frequency electrical pulse of a few cycles to a piezoelectric transducer. This pulse is repeated a few hundred times a second (Gooberman 1968) The electrical pulse causes the piezoelectric transducer to emit a pulse of sound at the same high frequency which is returned to the transducer as an echo. A high gain amplifier is connected to the same or identical transducer to amplify the echo pulse. Specialized circuits measure the time between the transmitted sound pulse and the return echo. Electrical circuits to produce the necessary signals were assembled from general laboratory equipment consisting of a Wavetek oscillator controlled by a gating oscillator. Pulse amplitude, pulse length, frequency, and repetition rate could be varied over a great range. A Phillips–Fluke analog digital oscilloscope served as receiver and for time interval measurement. The gating oscillator was assembled from a low frequency oscillator and a tone burst generator as shown in fig. 1. The electrical output at the various locations are also shown in Fig. 2.

The transducers were constructed around a barium titanate disk 19 mm in diameter and approximately 1.8 mm thick as shown in fig. 2. There is no reason for the excessive length of the plastic barrel other than convenience in handling. These transducers have a resonant frequency of 0.82 MHz. When the transducers are coupled to a flat ice surface they should be expected to have a radiation pattern similar to a piston source in a infinite baffle as shown in Fig. 3 (Kinsler & Fry 1950). The use of a transducer with a narrow beam pattern allows more sound energy to be directed in the preferred direction with a saving in total energy of operation.

It is not usually possible to place two solid surfaces in sufficiently close contact and achieve efficient acoustic energy transfer of sound from one to the other without the use of a liquid coupling layer. For the measurements of velocity, attenuation, and reflection, a layer of Dow–Corning silicone vacuum grease served very well.

Results and Discussion

The acoustic frequency, transducer size, transmitter energy, and acoustic attenuation in the ice are all directly or indirectly related. It would be desirable to vary all until an optimum condition was reached; however, size, weight, and portability impose some arbitrary choices. It was decided to use a transducer constructed with barium titanate disks 1.9 cm in diameter which were available at SAFHL. The frequency of 830 KHz was initially chosen to correspond to the thickness resonant frequency of the BaTio disks. As work progressed it was found that this was a fortuitous choice. The theoretical radiation pattern for these has been given in fig. 3. It can be seen that the width of the main lobe of the radiation pattern is approximately ± 18 °F.

The sound velocity and attenuation was measured by placing the transmitting and receiving transducer on opposite sides of the ice slabs at a number different thicknesses. The transmitted and received signals could be observed on a digital oscilloscope. It was possible to measure the time between pulses and the voltage amplitude by positioning the cursers on similar points on the pulses.

The combined delay in both the transducer and the silicone grease coupling averaged 5.1 microseconds. This was measured as above by placing very thin slabs of ice between the two transducers and noting the time delay corresponding to the various thicknesses (1 and 2 cm). The delay time in the transducers could be found by assuming that the velocity of propagation of the sound was the same in both cases.

The measured velocity of sound from a number of samples is 3700 meters per second. This is higher than the value of 3200 m/s (Kinsler & Fry 1950). No explanation for this difference is presently available. A frequency of 0.83 MHz. produces a wavelength in the ice of .44 cm. The beam width of the transducer is determined by the ratio of the radius of the transmitting crystal and the wavelength of the sound in the media.

The pressure attenuation as measured by two identical transducers placed on opposite sides of ice slabs of various thickness (1 to 30 cm), gave an attenuation (alpha) of approximately 0.09 cm^{-1} for crystal clear ice.

$$P_1 = P_0 \, e^{-\alpha(x_1 - x_0)}$$

where P_1 = pressure at distance x_1
P_0 = Pressure at distance x_0

Slabs of ice frozen from a mixture of snow and 33° F water gave a very high attenuation of approximately 0.35 to 0.7 cm^{-1}. The measured acoustic velocity was found to be between 3800 and 4000 meters per sec. Efforts to measure thickness by means of echoes reflected from a snow ice antifreeze interface was unsuccessful because of the high attenuation given above and the low reflection at the granular interface.

From the measured velocity, a reflection and transmission coefficient can be estimated, which would predict that an acoustic pressure wave of approximately 1/3 magnitude of the incident would be reflected. This could be verified from measurements. When the reflecting surface was very irregular, as is the case for ice frozen from slush, very little reflection occurs.

When transmitting an acoustic wave from one solid to another, a liquid or semi–liquid is required between the surfaces to provide a molecular bond between the surface irregularities. Silicon vacuum grease worked very well for this purpose in the laboratory phase of the development. It was obvious that grease would have to be applied to the transducers for each measurement with the field instrument. An alternative coupling means was needed. A plastic cup partly filled with a 50 percent Prestone was found to work almost as well as the silicon grease, with the added advantage that the transducers could be turned through a small angle to receive the maximum echo. The bottom of the cup was fitted with a 3 mil plastic sheet cut from a freezer bag. A much lighter plastic would contact an irregular surface more effectively but was judged to be too fragile. The angle adjustment of the transducers frequently made it possible to distinguish echoes reflected from the lower surface of the ice and those from internal flaws. An added complication was the added delay time for the sound pulse to propagate through the coupling liquid. If the transducer position is made variable, then a suitable correction for the change in delay time will have to be made. It would be expected that the choice of a liquid with an acoustic impedance value that is the geometric mean impedance between the Barium titanate crystal would result in an improved transmission between the ice and transducer (Kinsler & Fry 1950). In the laboratory only the hydrostatic pressure of a 1/2 inch of liquid forced the plastic diaphragm on the coupling unit into contact with the ice. The contact could be much improved by increasing the pressure until limited by the berating strength of the plastic film.

Conclusion

It was found that the thickness of a layer of ice could be measured from the time required for an ultrasound pulse to propagate through a layer of ice and return as an echo from the ice liquid interface. The greatest difficulty arose from ice frozen from a slush from a mixture of snow and cold water. This was due to the high attenuation of the sound in passing through the "slush ice." The sound velocity in the sample was found to be little different from clear ice and little reflection occurred at the "slush ice," clear ice interface. The observation that little reflection was observed at the slush–ice clear–ice interface implies good transmission of sound between the two regions. Since this region of slush–ice or "white ice" does not give a strong reflection of the sound wave, it should be possible to observe an echo from the ice–water surface below.

Information on the structure of the water–ice interface with regard to the reflection was not attainable. If flat regions exist slightly larger than the beam diameter at the intercept of the beam with the lower surface, then the directional pattern of the transducer will be preserved in the reflection and a very strong echo will be received. If the water–ice interface is very irregular with many small surfaces (with a linear dimension approximately equal to one wavelength), then the sound will be scattered and only a very small fraction will be reflected toward the receiver. Possibly only a field test will demonstrate the most common condition of the water–ice interface.

Fig. 4 gives the measuring system constructed from general laboratory equipment. This system could be moved to the field for measurement of ice cover thickness on a typical lake. The only reason this was not done within the grant was the unavailability of ice cover during the execution period of the grant.

Fig. 5 illustrates proposed design of a field instrument. It is expected that the electronics, with the exception of batteries, will occupy only a few cubic inches. The transducers can be mounted on a small sled which can be pushed a considerable distance ahead of an operator or, if very thin ice is to be surveyed, the sled can be moved over the ice by remote control.

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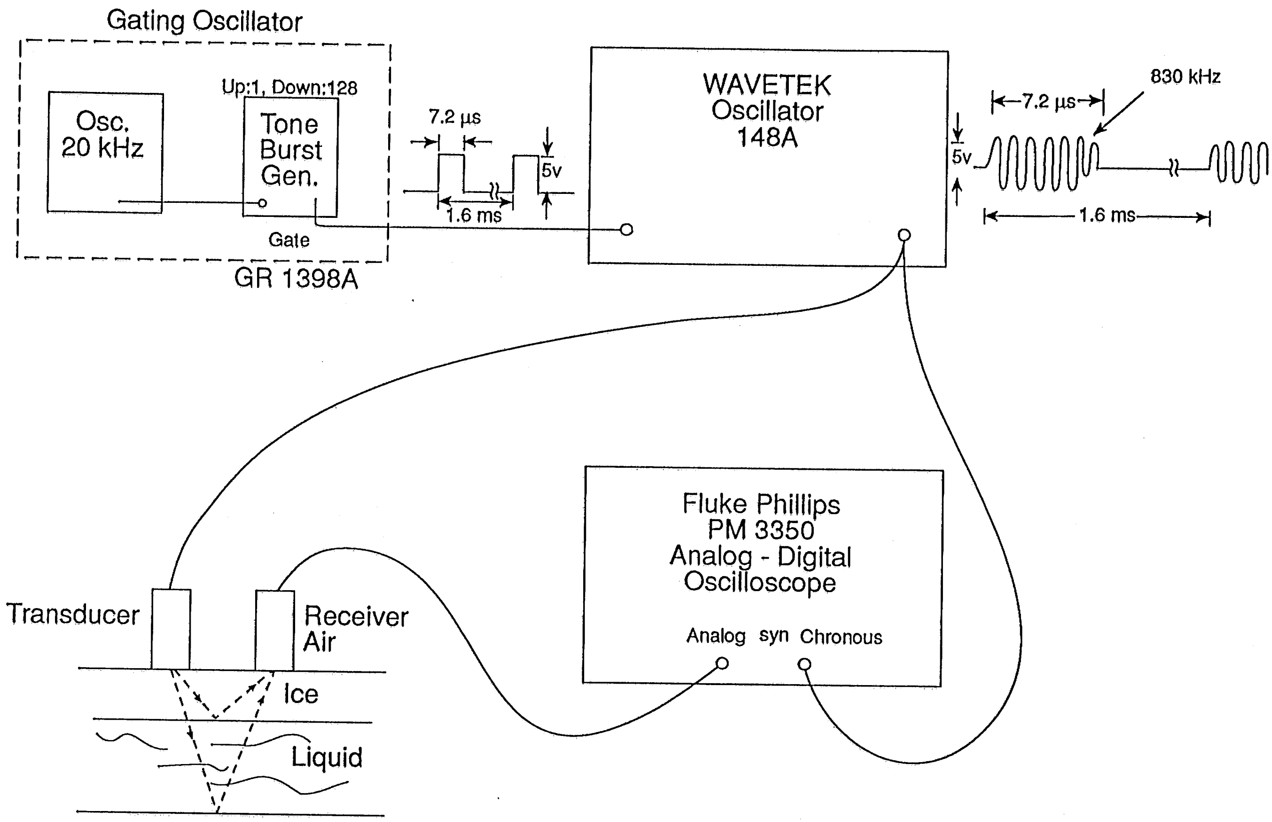


Figure 1. Laboratory pulse measuring system.

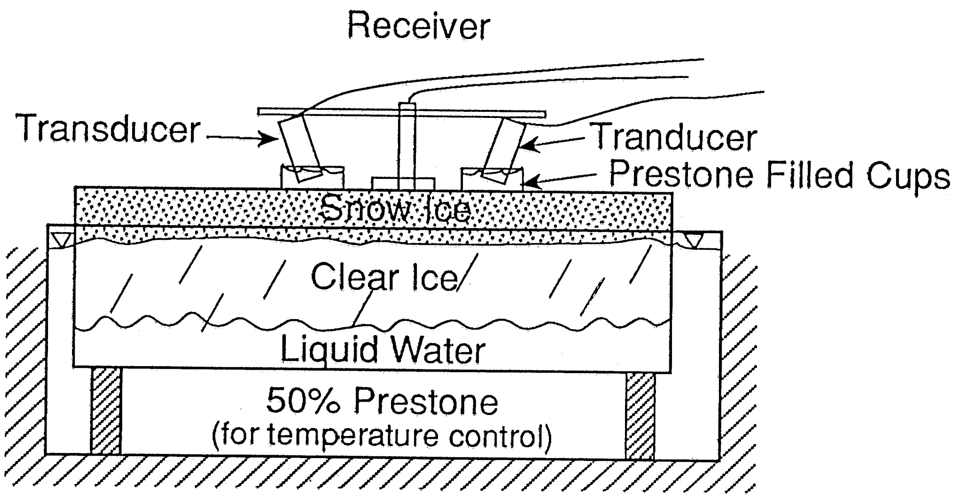


Figure 2. Transducers

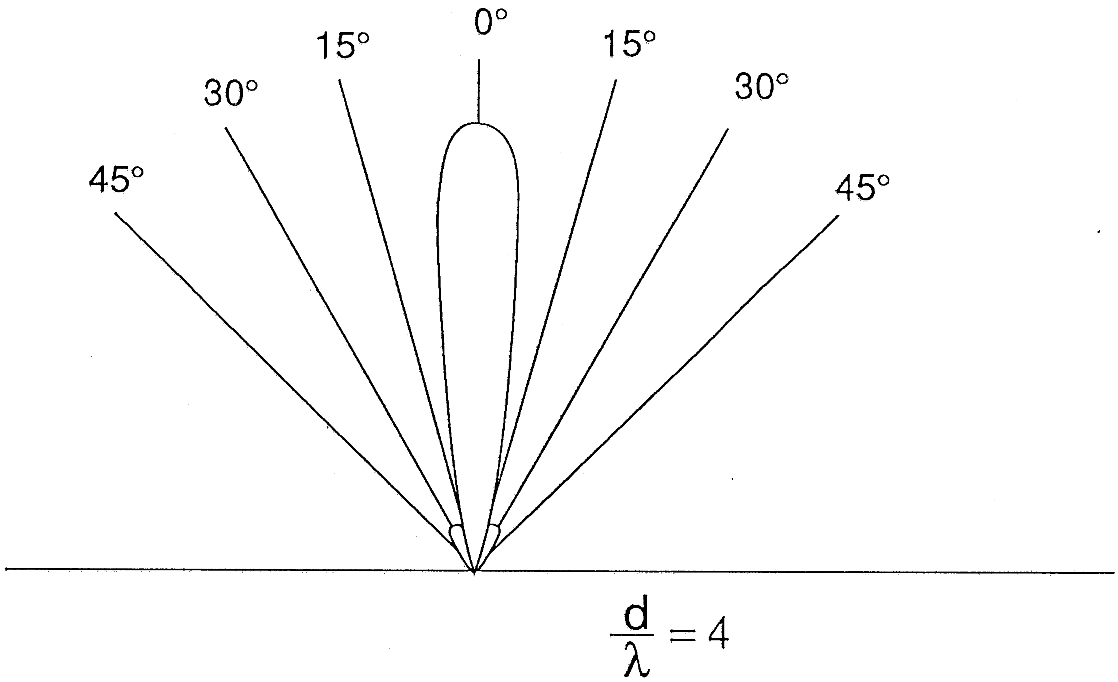


Figure 3. Theoretical transducer radiation pattern

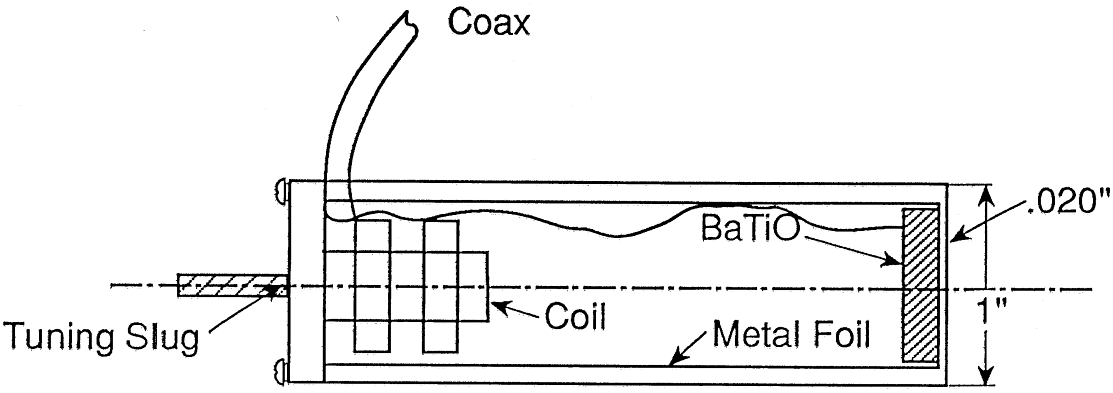


Figure 4. Laboratory test system

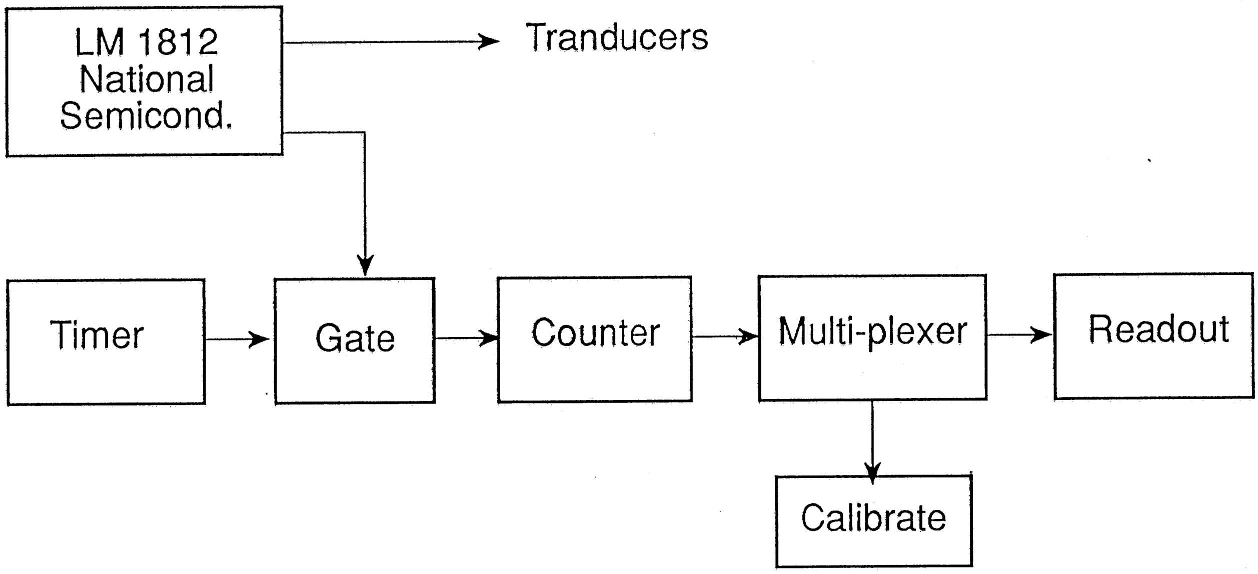


Figure 5a. Proposed instrument circuit

MARCH 1975

LM1812 ultrasonic transceiver

general description

The LM1812 is a special monolithic IC which consists of a 12W ultrasonic transmitter circuit, which uses novel circuitry to eliminate costly alignment adjustments, a selective receiver which uses only one external LC network, impulse noise rejection circuitry, a 10W display driver, and a keyed modulator.

The system operates from a 12V battery, drives power into a transducer, receives an echo and drives a display lamp.

A single LC network is time shared between the receiver and the transmitter to reduce external parts, to eliminate alignment labor and to guarantee that the received signal is always of the proper frequency.

Application areas include both sonar (distance measuring in water) and "sonic" radar (or "Sodar"—distance measuring in air) where a liquid level must be detected without actual immersion of a sensor or the presence of an object must be detected as in collision avoidance or an intrusion or burglar alarm system. As a sonar system, the presence of partially submerged objects can be detected, such as marine life, or the depth of a body of water can be determined (as for keel clearance or depth indicators). In addition, data transmission is possible for remote control applications such as in model submarines or hydroacoustic communication links.

unique characteristics

- RF transmitter design prevents "mode-hopping" of transducer
- Operates with interchangeable transducers without realignment
- Only one tuned circuit is used
- No additional transistors are needed
- A zero reference output, which "appears" the same as a normal return, is generated to coincide with the Tx. pulse
- Impulse noise is rejected
- Can be used with various displays

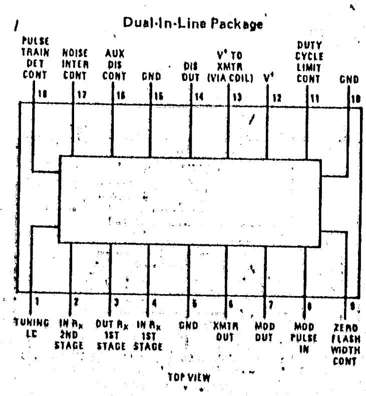
advantages

- Reduces assembly labor content
- Allows transducer replacement in the field without a factory return
- Allows multiple transducers to be used with the same electronics
- Provides for more consistent system performance in production

features

- Has special access pins (7 and 16) which allow adding an audible alarm feature to indicate an echo within a presettable maximum depth (or range)
- Does not require any heat sinking of the IC package
- Uses a built-in monostable multivibrator, with the capacitor on the chip, to pulse drive the transmitter for high efficiency and to minimize transducer interaction
- Has special circuitry to limit the maximum ON time of the display driver
- Can operate with a neon, a LED display device, a digital readout or a CRT

connection diagram



Circle DATA UPDATE No. 482

Figure 5b. Manufacturer's specification for the LM1812