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A TONE-BURST RANGING SYSTEM FOR PARALLEL-LINE SOUNDING

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OTTAWA

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ABSTRACT

To improve the efficiency of hydrographic surveying operations on inland and coastal waters it is desirable to employ a parent vessel in the centre, with up to six side vessels running courses parallel to the parent vessel at distances depending on the survey scale. A simple equipment is described which allows the side vessels to maintain their stations with respect to the parent vessel by measuring the difference in the time of arrival between a radio signal and a sound pulse transmitted simultaneously from the parent vessel at regular intervals. The indicating unit also provides a permanent record so that if a side vessel should err from its course, appropriate corrections can be made when the depth soundings are plotted.

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A TONE-BURST RANGING SYSTEM FOR PARALLEL-LINE SOUNDING

- W. Wyslouzil -

INTRODUCTION

The equipment to be described was developed at the request of the Department of Energy, Mines and Resources in an attempt to improve the efficiency of their hydrographic surveying operations on inland and coastal waters. Their plan is to have a parent vessel in the centre with up to six side vessels running courses parallel to the parent vessel and stationing themselves upon it. The separation of the vessels along the beam line depends upon the survey scale, but generally, on a 1:20,000 scale the separation would be 0.2 inches on the plot or approximately 300 feet.

The parent vessel would be equipped with sophisticated and expensive positioning devices. The problem was to develop some simple and relatively inexpensive equipment to indicate to the helmsman of a side vessel his distance from the parent vessel with an accuracy of ±17 feet.

The most straightforward approach appeared to be a system utilizing the velocity of sound in air. A short, high-intensity tone burst and a radio signal are transmitted from the parent vessel simultaneously at regular intervals. On the side vessel the time lag between the arrival of the radio and sound signals is measured with an instrument quite similar to a recording depth sounder, the main difference being that the sweeping arm is held in a certain starting position until it is released upon arrival of the radio pulse. The sound signal is picked up with a microphone, and amplified to produce a mark on the recording chart. The tone-burst transmitter on the parent vessel is provided with a push-button marked FIX which can be used to generate pulses of longer-than-normal duration, resulting in a longer mark on the side vessel's indicator. This feature may be useful in synchronizing the whole surveying operation.

The radio link is established with commercially available walkie-talkies. Over-all accuracy of the system depends primarily on a knowledge of the velocity of sound in air under given conditions of wind and temperature. Since these parameters are easily determined, corrections can be made without difficulty. Advantages of this system are its intrinsic simplicity, extreme ease of installation, and potentially low cost.

GENERAL DESCRIPTION

Transmitting Equipment

Equipment installed on the parent vessel consists of the tone-burst transmitter, comprising the modulator unit and loudspeaker, as well as the radio transmitter (See Plate I).

a) Modulator

In the modulator a low-level signal of required frequency, pulse width, and repetition rate is generated by gating the output from a continuously operating oscillator. The signal is then amplified and fed to the loudspeaker. The modulator chassis also contains a dc-to-dc converter to generate the required modulator supply voltages from a 12-V storage battery with a current drain of 250 mA. The modulator is contained in a case measuring 4 × 6 × 8 inches, and weighs $4\frac{1}{2}$ lb. Operating controls are a power ON-OFF switch and the FIX push-button whose function is explained in the introduction.

b) Loudspeaker

The loudspeaker is a standard 8-inch exponential horn with a 30-W driver unit, mounted on a telescoping stand for convenient installation. Where side vessels are stationed on both sides of the parent vessel two loudspeakers would of course be required.

c) Radio Transmitter

To generate the synchronizing radio signal a commercially available walkie-talkie can be utilized in the transmit mode, mounted in the general vicinity of the loudspeaker. The walkie-talkie microphone will then pick up the sound signal, thereby generating an appropriate radio signal.

Receiving Equipment

Each side vessel carries a microphone, a receiver-indicator, a 60-cycle inverter, and a radio receiver (See Plate II).

a) Microphone Assembly

To enhance the noise rejection characteristics of the equipment, the microphone is placed in a simple rectangular horn, 18 inches in length and with a mouth area of 10 by 10 inches. This provides an effective 3-db beamwidth of 30° with a gain of 14 db. The microphone assembly is installed above deck and directed towards the parent vessel.

b) Receiver Indicator

The microphone output is fed to the receiver, a tuned amplifier with a centre frequency of 2 kHz and a bandwidth of 200 Hz. The signal is then further amplified to a level capable of producing a mark on conductive recording paper.

To translate the time lag between received radio and sound signals into a distance indication a light arm $2\frac{1}{2}$ inches in length is driven through a slip clutch with a synchronous motor. The clutch is driven at exactly 60 rpm. The arm is initially held in a certain starting position by means of a small pin. When the radio signal is received an electromagnet momentarily retracts the pin, allowing the arm to rotate through one revolution. A fine wire extending perpendicularly from the end of the arm sweeps across conductive recording paper whose effective width of 3 inches represents a distance of 200 feet. If the sound pulse arrives while the arm sweeps across the paper a mark is burned on the chart. The electromagnet and pin assembly is mounted on a plastic disk which also serves as a cursor and can be rotated to change the starting position of the arm and hence the range of the display so that the centre line of the recording can represent any distance from 200 to 900 feet. The paper is transported across a metal backing plate by a conventional driven-capstan system powered by a small synchronous clock motor. The paper speed is 0.6 inch per minute, just fast enough so that consecutive marks are distinguishable. The indicator and receiver are contained in a case 15 inches wide, 8 inches deep, and 10 inches high with a total weight of $20\frac{1}{2}$ lb. Operating controls mounted on the front panel are RECEIVER GAIN and RANGE.

c) Inverter

The indicator unit may be powered directly from the line but normally an inverter is used which generates an alternating voltage of 115 V at 60 Hz ± 1% from a 12-V dc supply at a current drain of 1 ampere. The inverter is housed in a standard Hammond case measuring 4 × 8 × 8 inches and weighs 10 pounds. A power ON-OFF switch is located on the inverter.

d) Radio Receiver

Again a commercially available walkie-talkie can be utilized by taking the output at the speaker and feeding it to the indicator unit.

DESCRIPTION OF CIRCUITRY

Tone-Burst Transmitter

a) Oscillator, Gating, and Preamplifier (Fig. 1)

A low-level 2-kHz signal is generated by a Colpitts oscillator (Q_1). The oscillator output is fed to a preamplifier (Q_6 and Q_7) through a 180-kΩ resistor. Gating is accomplished with transistor Q_5 as follows. Q_5 is normally in saturation so that the signal is bypassed to ground through a 0.22 μF capacitor. To generate the tone burst, Q_5 is turned off for a length of time corresponding to the required pulse width. This is accomplished by connecting the base of Q_5 to the collector of Q_2, which is normally off and comprises one side of a monostable multivibrator (Q_2 and Q_3). When the multivibrator is triggered, Q_2 turns on, thereby turning off Q_5 and the oscillator output is applied to the preamplifier.

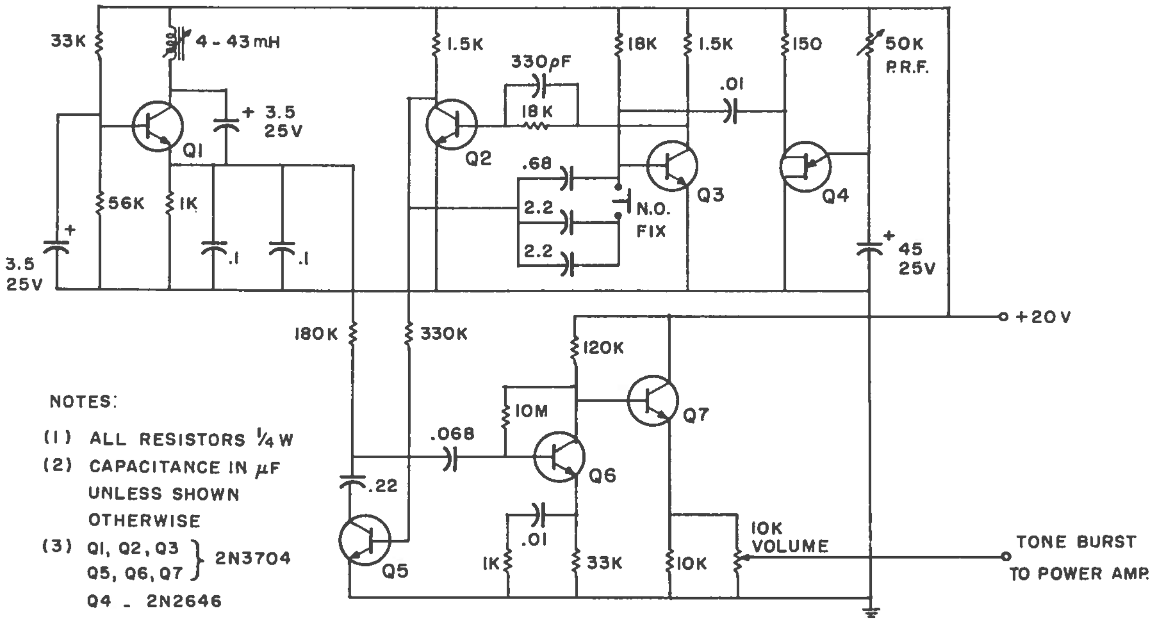


Fig. 1 Circuit diagram of tone-burst transmitter oscillator, gating, and preamplifier

Pulse width is determined by the amount of capacitance between the collector of Q_2 and the base of Q_3. By depressing the FIX push-button, more capacitance is connected, resulting in a wider pulse. To trigger the multivibrator at regular intervals, negative-going trigger pulses are generated at base 2 of unijunction transistor Q_4 which operates as a relaxation oscillator. Repetition rate is adjusted with a 50-kΩ potentiometer by controlling the charging rate of the emitter timing capacitor.

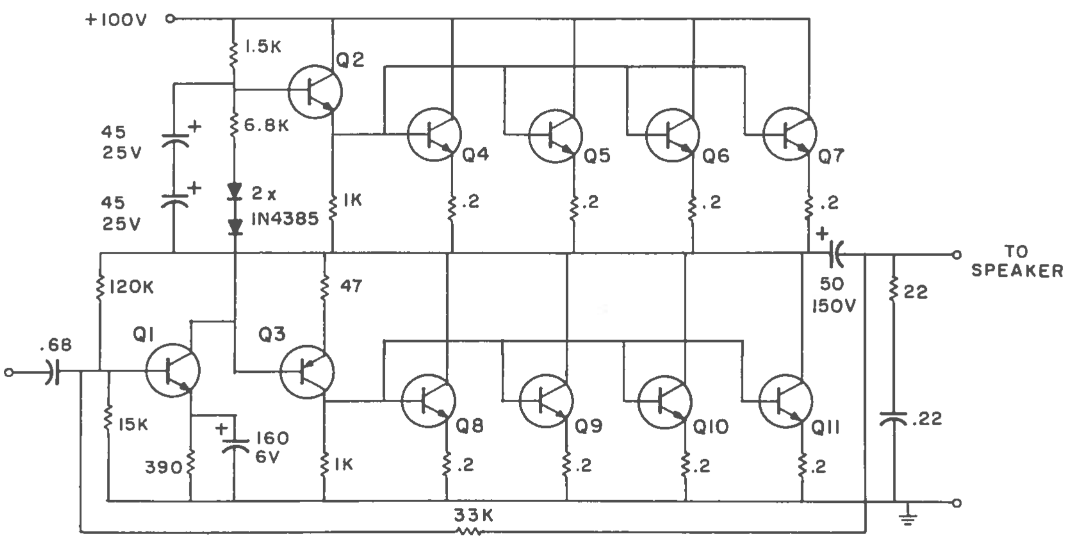
The preamplifier has one stage of amplification (Q_6) and an emitter follower output stage Q_7 to drive the power amplifier. A 10-kΩ potentiometer in the emitter of Q_7 serves as a volume control.

b) <u>Power Amplifier</u> (See Fig. 2)

The low-level signal from the preamplifier is further amplified by Q_1. Q_2 and Q_3 are drivers for the output stage. To minimize the saturation resistance of the output stage, two sets of 4 transistors are connected in parallel as shown. A 33-kΩ resistor provides negative feedback to stabilize the amplifier.

c) <u>Dc-to-dc Converter</u> (See Fig. 3)

To generate the voltages necessary for the operation of the tone-burst transmitter, the 12-V supply is alternately connected to the two primary windings of the transformer, generating a square-wave output at a frequency of about 16 kHz. Both the high- and low-voltage outputs are rectified and filtered.



NOTES: (1) ALL RESISTORS ½ W
(2) ALL CAPACITANCE IN μF
(3) QI, Q2 _ 2N3767 Q3 _ 2N3741 Q4 to QII _ MJE340

Fig. 2 Circuit diagram of tone-burst transmitter power amplifier

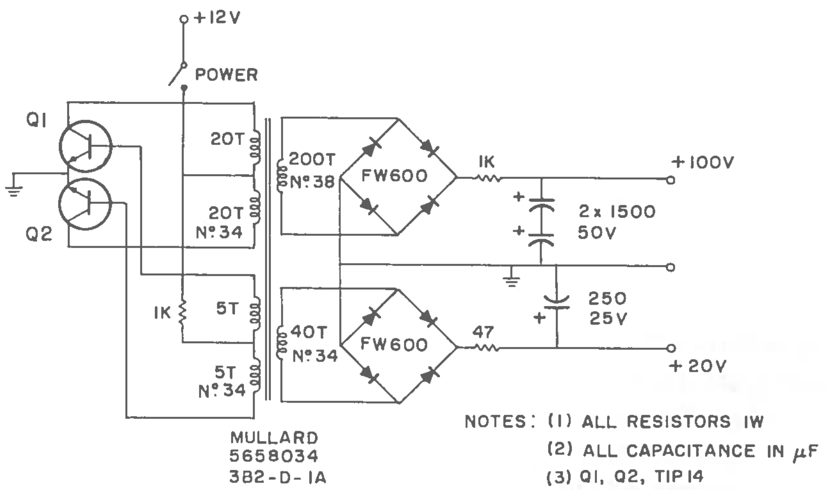


Fig. 3 Circuit diagram of tone-burst transmitter dc-to-dc converter

Indicator

a) Receiver (See Fig. 4)

The microphone output is fed to emitter follower Q_1 to reduce loading on the high-impedance crystal microphone. The signal is then amplified in a two-stage narrow band amplifier. Receiver gain control is achieved by changing the bias on the first amplifier stage by means of the 10-kΩ potentiometer as shown. Q_4 provides further amplification. Q_5 is an emitter-follower buffer stage biased at cut-off, so that the positive-going portion of the signal is amplified. The output is coupled directly to the base of Q_6.

A high voltage signal capable of marking recording paper is generated at the output by means of a step-up transformer.

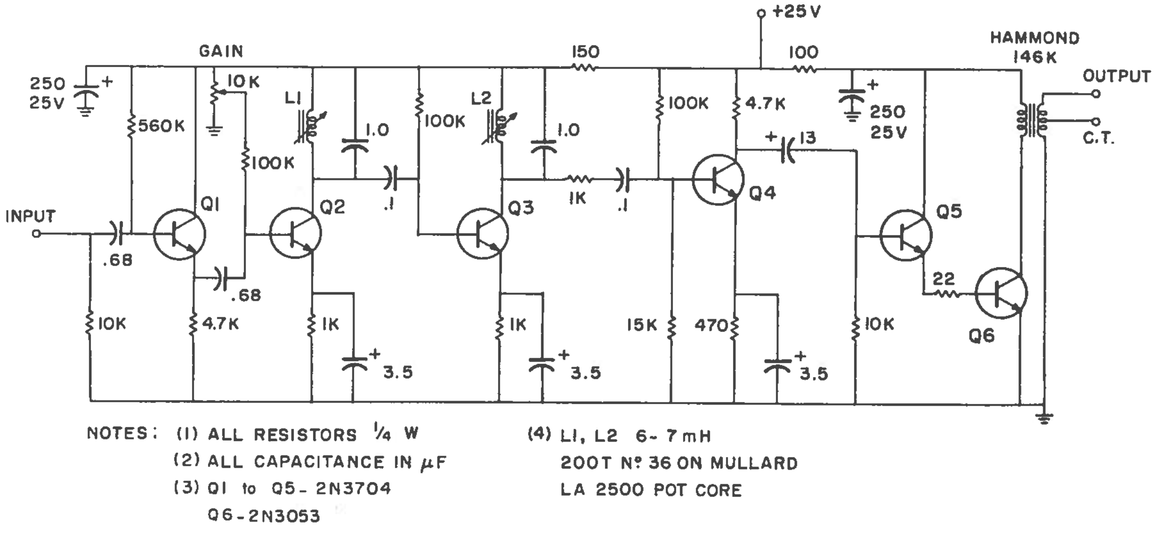


Fig. 4 Circuit diagram of indicator receiver

b) Release Solenoid Driver (See Fig. 5)

Signal is taken directly from the speaker of the walkie-talkie providing the receiving end of the radio link. A single-stage amplifier (Q_1) tuned to 2 kHz serves to reject unwanted signals, Q_2 is biased at cut-off and hence amplifies only the positive-going portion of the signal. The 2.0-μF capacitor across the emitter resistor bypasses the 2 kHz component of the signal to ground and retains the signal envelope which is used to trigger the SCR. Three 500-μF capacitors are charged to approximately 75 V through the 3.3-kΩ resistor. When the SCR is triggered on, these capacitors suddenly discharge through the electromagnet retracting the pin on the display unit. The 3.3-kΩ charging resistor then limits the current through the SCR to less than its holding current so that the SCR turns itself off, allowing the capacitors to charge up again.

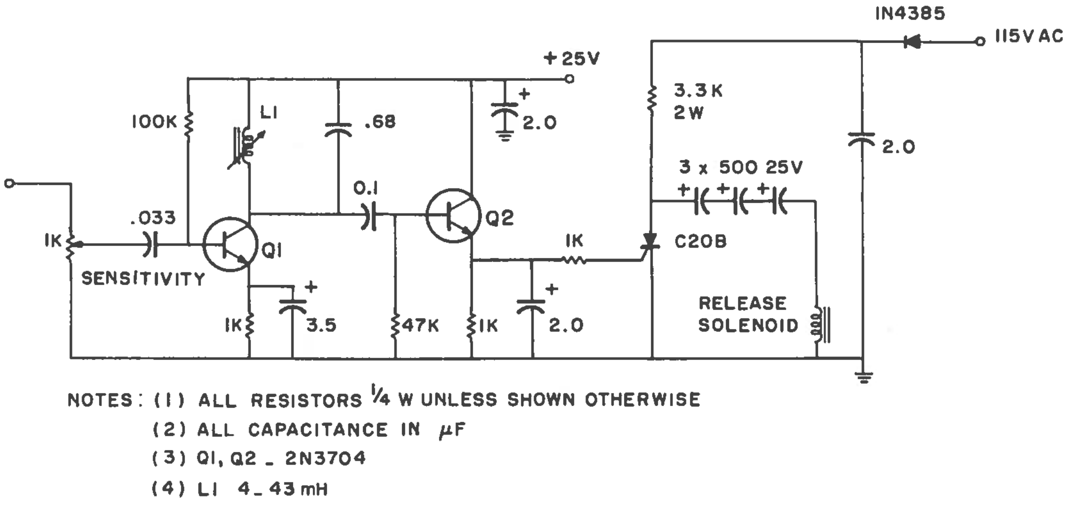


Fig. 5 Circuit diagram of indicator release solenoid driver

c) Indicator Power Supply (See Fig. 6)

Two small filament transformers are connected to simulate a 115V/25V transformer. The low-voltage output is simply rectified and filtered as shown.

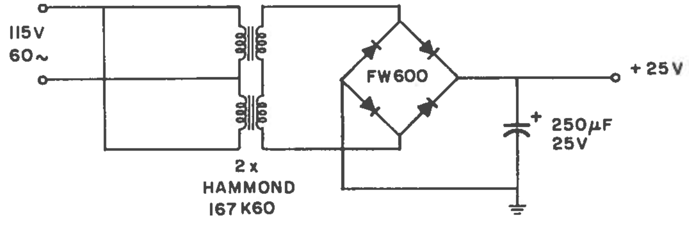
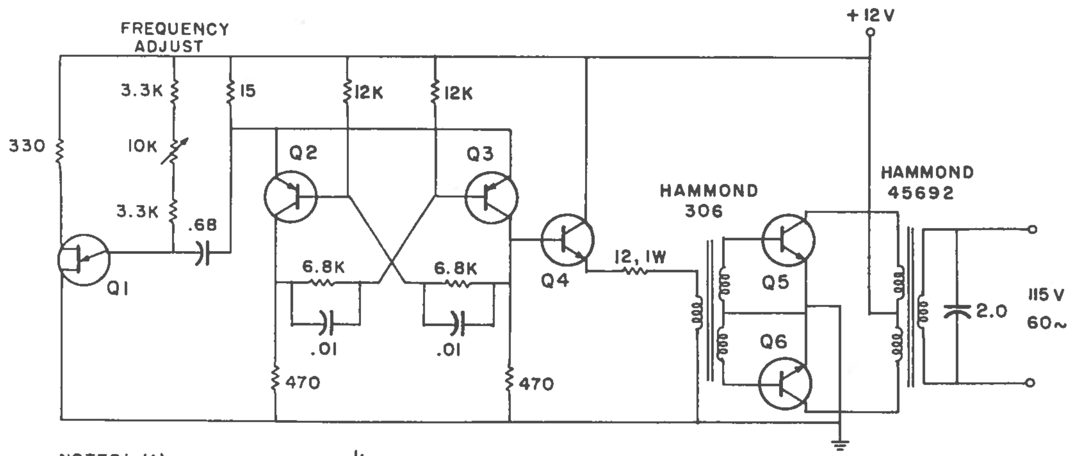


Fig. 6 Circuit diagram of indicator power supply

d) 60-Cycle Inverter (See Fig. 7)

A unijunction transistor relaxation oscillator Q_1 is used to control the frequency of the inverter. The oscillator frequency is set to exactly 120 Hz by means of the 10-kΩ potentiometer, and whenever the transistor fires, a negative-going pulse is generated across the 15-ohm resistor. These pulses in turn trigger the bistable multivibrator Q_2 Q_3 generating a 60-Hz square wave at the collector of Q_3. Q_4 is an emitter-follower buffer stage to apply the 60-Hz square wave to the primary of the driving transformer. The driving voltages applied to Q_5 and Q_6 are 180° out of phase so that the output transistors are turned on alternately, connecting first one side and then the other side of the output transformer primary winding to the 12-V dc supply. The resulting output is a square wave of required amplitude at 60 Hz.



NOTES: (1) ALL RESISTORS ¼W UNLESS SHOWN OTHERWISE
(2) ALL CAPACITANCE IN μF
(3) Q1 - 2N2646 Q2, Q3 - 2N3703 Q4, Q5, Q6 - 2N3054

Fig. 7 Circuit diagram of 60-cycle inverter

ACKNOWLEDGMENT

The author is indebted to Mr. S.K. Keays for building the prototype equipment.

APPENDIX I

SOME FUNDAMENTAL CONSIDERATIONS

Choice of Frequency and Pulse Width

The choice of frequency and pulse width is governed by consideration of ambient noise, attenuation, and range resolution. Figure 8, the frequency spectrum of on-board noise on a typical survey launch, shows that a very high

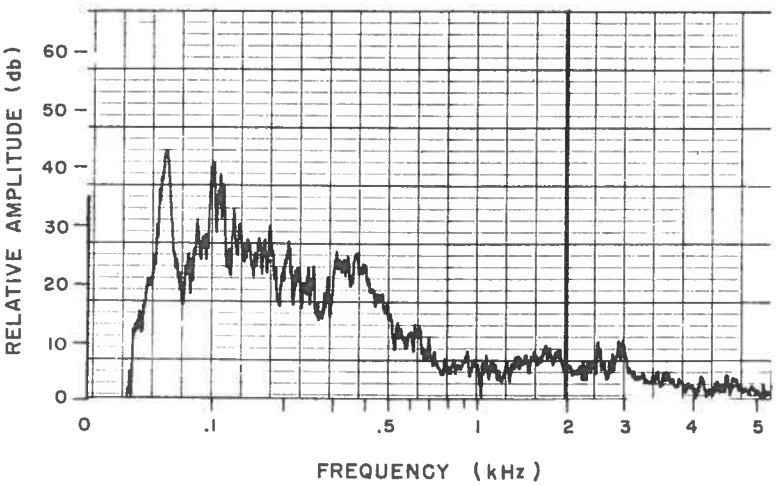


Fig. 8 Frequency spectrum of noise aboard a typical survey launch

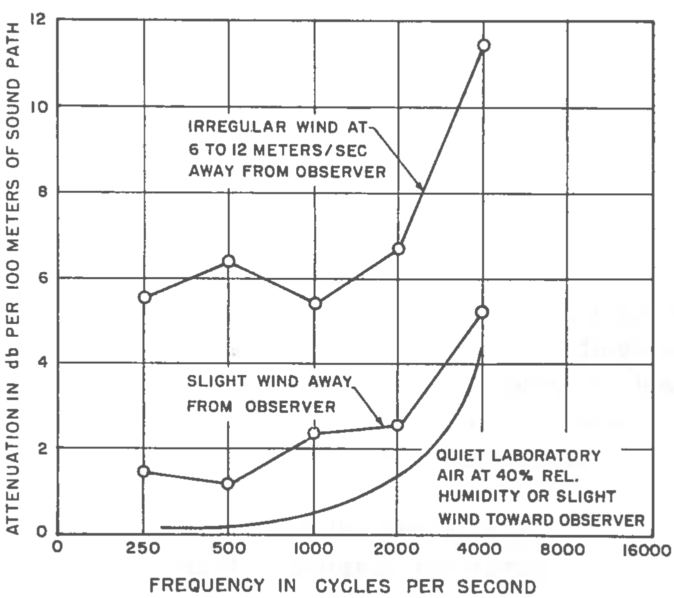


Fig. 9 Effect of frequency on attenuation of sound in air

operating frequency would be desirable. However, attenuation of sound in air increases rapidly with frequency as shown in Fig. 9. An operating frequency of 2 kHz appeared to represent a satisfactory compromise.

For maximum noise rejection a very narrow-band amplifier in the receiver would be desirable. Since an inverse relationship exists between pulse width and optimum receiver bandwidth (bandwidth should be the inverse of the pulse width), a narrow bandwidth implies that a wide pulse has to be transmitted. Under these conditions the range indications would be ambiguous because the output from the receiver would have a rise time approximately equal to the pulse width making it difficult to determine the beginning of the pulse. A pulse width of 5 ms was chosen and the optimum receiver bandwidth is then approximately 200 Hz.

Pulse Repetition Rate

Since the maximum operating distance is about 900 feet, a 1000-foot maximum operating range should be satisfactory. At 20°C in still air sound requires 0.866 sec to traverse this distance and, allowing some time for synchronization of the system, a repetition period of 1.2 sec was chosen.

Nature of display

A great number of schemes for measuring and displaying the time lag between received radio and sound signals can be envisaged. The system described has the advantage of reliable operation even in the presence of considerable interfering noise. Furthermore, a permanent record of the range indication is valuable if a side vessel should err from its prescribed course, since appropriate corrections can be made when the soundings are plotted.

APPENDIX II

ERROR DUE TO TEMPERATURE AND WIND VARIATION

Table I indicates errors caused by temperature deviations and wind. The indicator is initially calibrated to give correct readings at 20°C and no wind. Generally, if the sound is slowed down owing to low temperature or opposing wind the indicator reading will be high. Conversely, high air temperatures and aiding wind will give a low indication.

It is to be noted that the magnitude of the error is greatest at maximum working distance of 900 feet. At this distance the error in the indication due

TABLE I

Temperature (°C)		Error at 300 feet	Error at 600 feet	Error at 900 feet
0		+10.0	+20.0	+30.0
5		+ 7.5	+15.0	+22.5
10		+ 5.0	+10.0	+15.0
15		+ 2.5	+ 5.0	+ 7.5
20		0	0	0
25		- 2.5	- 5.0	- 7.5
30		- 5.0	-10.0	-15.0
35		- 7.5	-15.0	-22.5
40		-10.0	-20.0	-30.0
Wind Speed				
mph	ft/s			
0	0	0	0	0
5	7.5	2.0	4.0	6.0
10	14.5	4.0	8.0	12.0
15	21.5	6.0	12.0	18.0
20	29.0	8.0	16.0	24.0
25	36.5	10.0	20.0	30.0
30	44.0	12.0	24.0	36.0

to temperature is ±1.5 feet/°C. Further, the error in the indication due to wind in the direction of the sound path is ±12 feet for a 10 mph wind. Thus if air temperature can be measured with an accuracy of ±1°C and wind speed can be estimated to within ±10 mph, the maximum error in the indication after corrections have been made will be less than ±13.5 feet. This falls within the accuracy required of the system.

At shorter working distances the problem of error is proportionately reduced. The graph (Fig. 10) illustrates one possible method of presenting these figures to simplify computation of appropriate corrections under given conditions. For example, assume the working distance to be 900 feet and the temperature and wind conditions to be such as to indicate an error of about -30 feet. This means that the indicator will show a distance of 870 feet when the true distance is 900 feet. Similar graphs can easily be constructed for other working distances such as 300 feet or 600 feet.

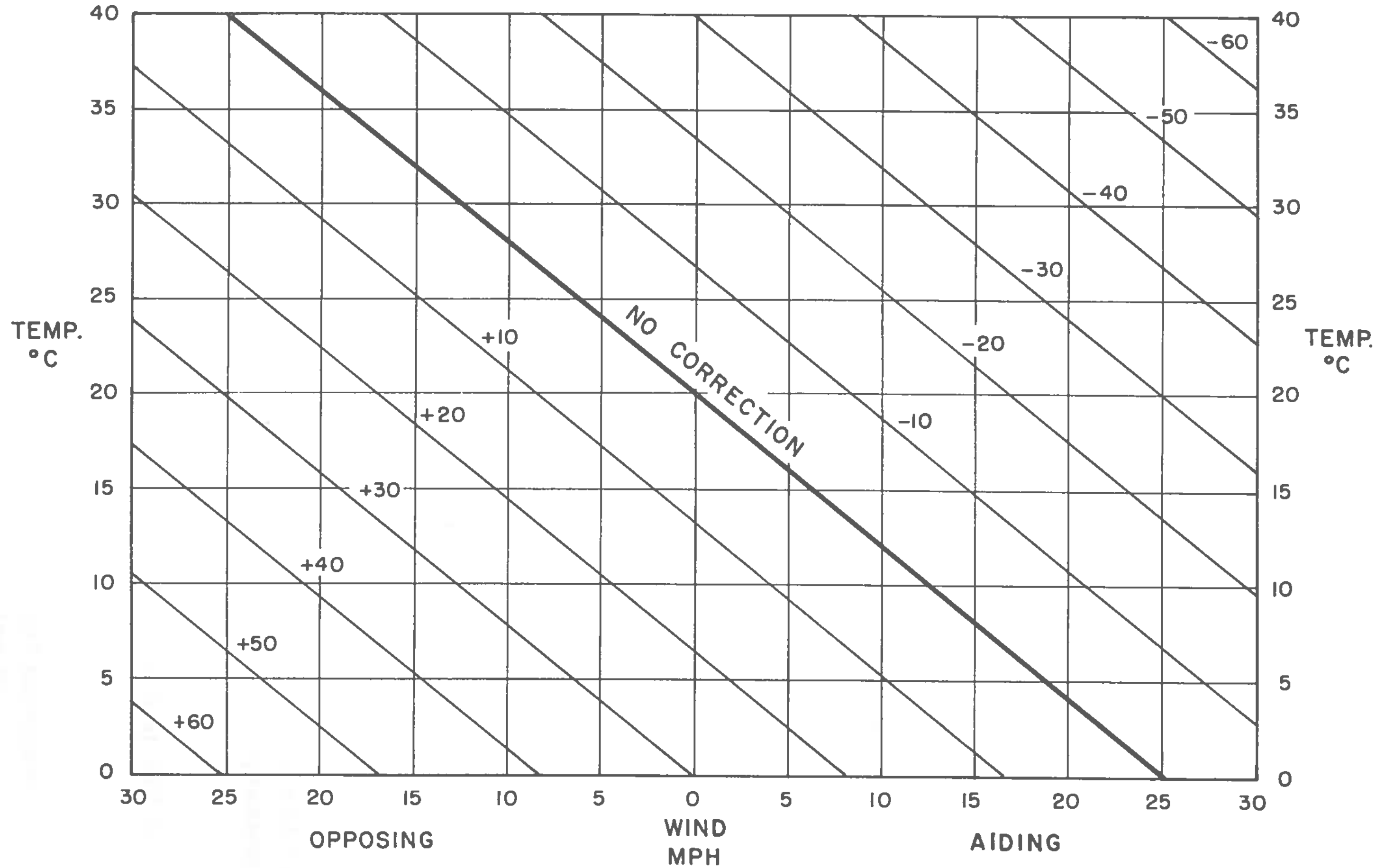


Fig. 10 Corrections for wind and air temperature valid at working distance of 900 feet only

APPENDIX III

SPECIFICATIONS

MECHANICAL

1) Tone-Burst Transmitter

(a) Modulator

dimensions	6 × 10 × 4 inches
weight	4.5 lb
operating controls	power ON-OFF, "FIX", push-button

(b) Loudspeaker — 8-inch horn with driver

2) Indicator

dimensions	15 × 7 × 10 inches
weight	20.5 lb
operating controls	gain, range
recording paper	Bendix A.E.L. 1036436

3) Inverter

dimensions	4 × 8 × 8 inches
weight	10 lb
operating controls	power,ON-OFF

ELECTRICAL

1) Tone-Burst Transmitter

frequency	2 kHz
pulse width	5 ms; 25 ms with "FIX", push button depressed
repetition rate	50 ppm
peak power output	40 W
power consumption	250 mA at 12V dc

2) Indicator

receiving horn beamwidth	30° horizontal and vertical
receiver bandwidth	200 Hz
receiver maximum gain	90 db
power consumption	100 mA at 115 V ac

3) Inverter

output	115 V at 60 Hz ±1%
power consumption	1 A at 12 V dc

ENVIRONMENTAL

Operating temperature range	-10°C to +50°C

PERFORMANCE

Maximum operating range	1000 feet
Estimated accuracy	±15 feet at 900 feet

Plate I   Sound transmitter modulator and loudspeaker

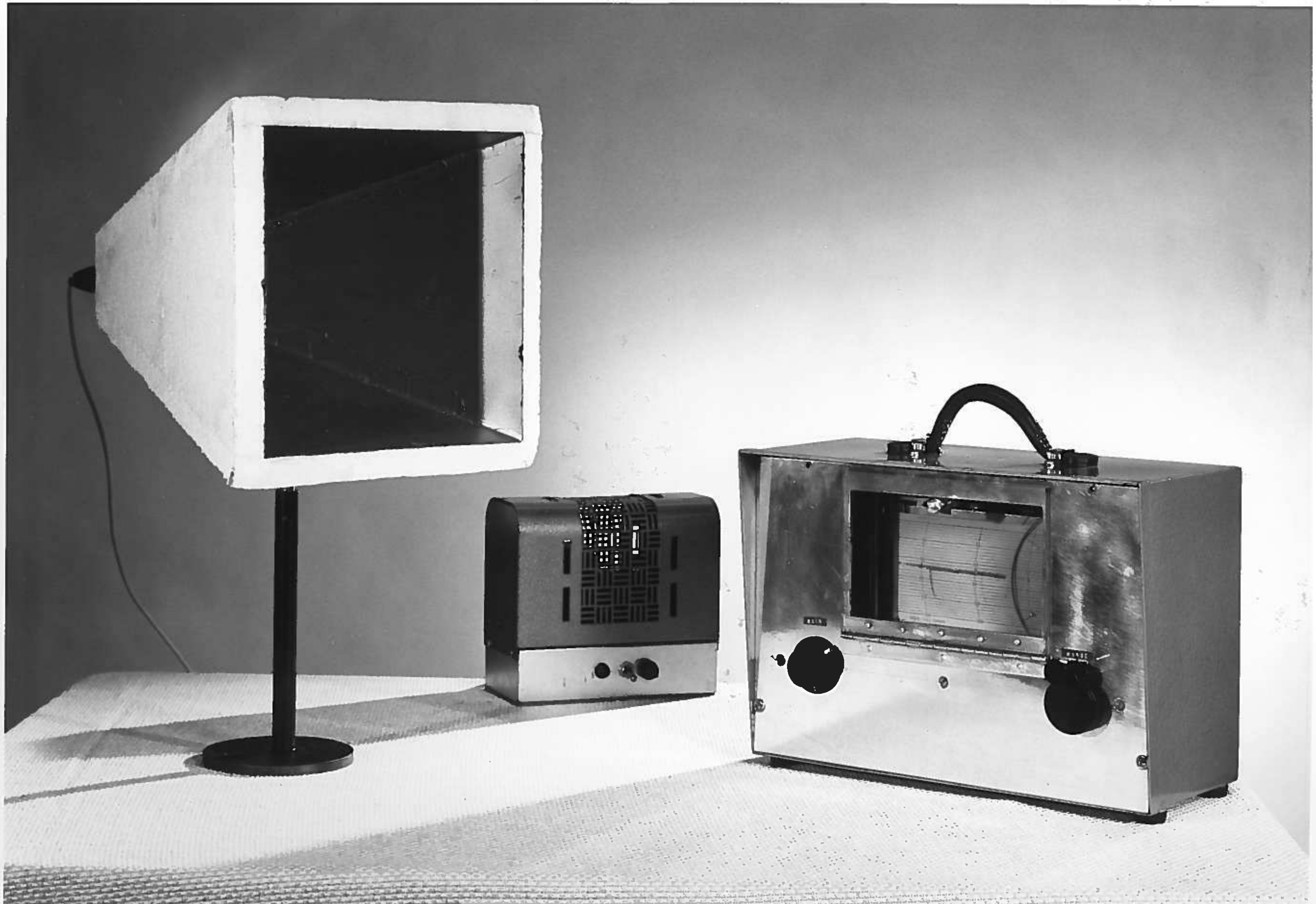


Plate II Microphone assembly, indicator unit, and 60-cycle inverter