I M P E R I A L   C O L L E G E   S U B M A R I N E   A R C H Æ O L O G I C A L   G R O U P

Sponsored by:-
Imperial College Exploration Board
London Institute of Archæology

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IMPERIAL COLLEGE UNION,
PRINCE CONSORT ROAD,
LONDON - - - S.W.7.

Telephone: KEN 5111
Ext: 296

Chairman & Members,
I.C.Exploration Board.

Malta expedition 1961

Dear Sir,

I should like to report briefly on the research work carried out since the return of the 1961 Malta expedition, supported by the Exploration Board.

Communication Equipment

Work on a diver communication apparatus has reached the sea trial stage. Papers describing the system have been presented to the UNDERWATER EQUIPMENT RESEARCH SOCIETY of London, and the WORLD CONGRESS of UNDERWATER ACTIVITIES. Reprints of these are not yet available, but typed summaries are enclosed for the Board files.

Acoustic surveying equipment

During the summer vacation of 1962 a prototype divers' sonar set was used in the Mediterranean with considerable promise. It was also used in conjunction with an acoustic transponder to achieve strong reflections at a range of 150 ft. This has to be further developed to its ultimate configuration, part of an acoustic surveying system for marine archaeologists.

The final report is nearly finished and will be available within a short time. The Xlendi material is still being studied at the London Institute of Archaeology and British Museum.

Yours sincerely,

John Woods

John Woods

Undersea Communications

An analysis of possible systems and a summary of recent work at the Imperial College, London

by J.D. Woods
Department of Physics, Imperial College, London

- A number of groups of British universities undertaking undersea research on a spare-time basis are now planning ambitious projects requiring equipment that would never have been considered a few years ago. In many cases the new equipment to be-used is being developed by the potential users, who are in the position to take advantage of their university laboratories and workshops. The Imperial College has been active with projects involving aerodynamic techniques, electronics, and surveying among others; the author has concentrated on the development of communication systems.

Up to 1961 a succession of college expeditions have used handsignals, formica conversation-boards and, on towed research vehicles (aquaplanes), a telephone. Ideally, the free diver requires a self-contained system that will allow full and continuous conversation with his partner and the surface; a team of divers so equipped will immeasurably improve its working capability. An earlier project* aimed at adapting the deep-current "Swallow-float" to diver location from the surface, provided the necessary introduction to the present project, which uses modulated 50 kc/s acoustic carrier wave. The design of the basic system may conveniently be divided into three aspects, each depending upon and limiting the other two, (a) physics of the sound wave, (b) transducers and (c) eletronic circuitry.

(a) Physics

The carrier wave is transmitted through the sea with a velocity of 1,500 m/s, thus the wavelength corresponding to the 50 kc/s signal is 3 cm. allowing easy beaming if required. Beaming the signal would save power, but would require the divers to point their transducers like torches when conversing. The present design effects a compromise with no beaming of the transmitted wave, but a mild selectivity in the receiver orientation.

The attenuation of a sound wave in seawater (see appendix) requires that the lowest practicable carrier frequency be used, and that the suggested 50 kc/s would not suffer serious attenuation over a range of 100 metres or more. The mean level of sea noise in the 50 kc/s region cannot be predicted, but should not be noticeable if 100 dB below the transmitter power. If this condition is not satisfied the signal power can be increased by beaming or circuit modification.

(b) Transducers

The transmitter feeds a spherical $BaTiO_4$ transducer, which offers high efficiency in the 10 - 100 kc/s range; the receiving transducer is a plane slab of $BaTiO_4$ giving a degree of beaming depending upon its dimensions. It should be noted that the spherical signal from the transmitter presents an effectively plane wavefront to the receiver even at close range.

The diver wears a Normalair full-face mask and speaks into a crystal microphone inside the mask (a cheaper alternative with lower efficiency is a free-flooding throat microphone). He receives speech by bone conduction from a free-flooding electrodynamic transducer. These have all been tested during earlier work on telephones.

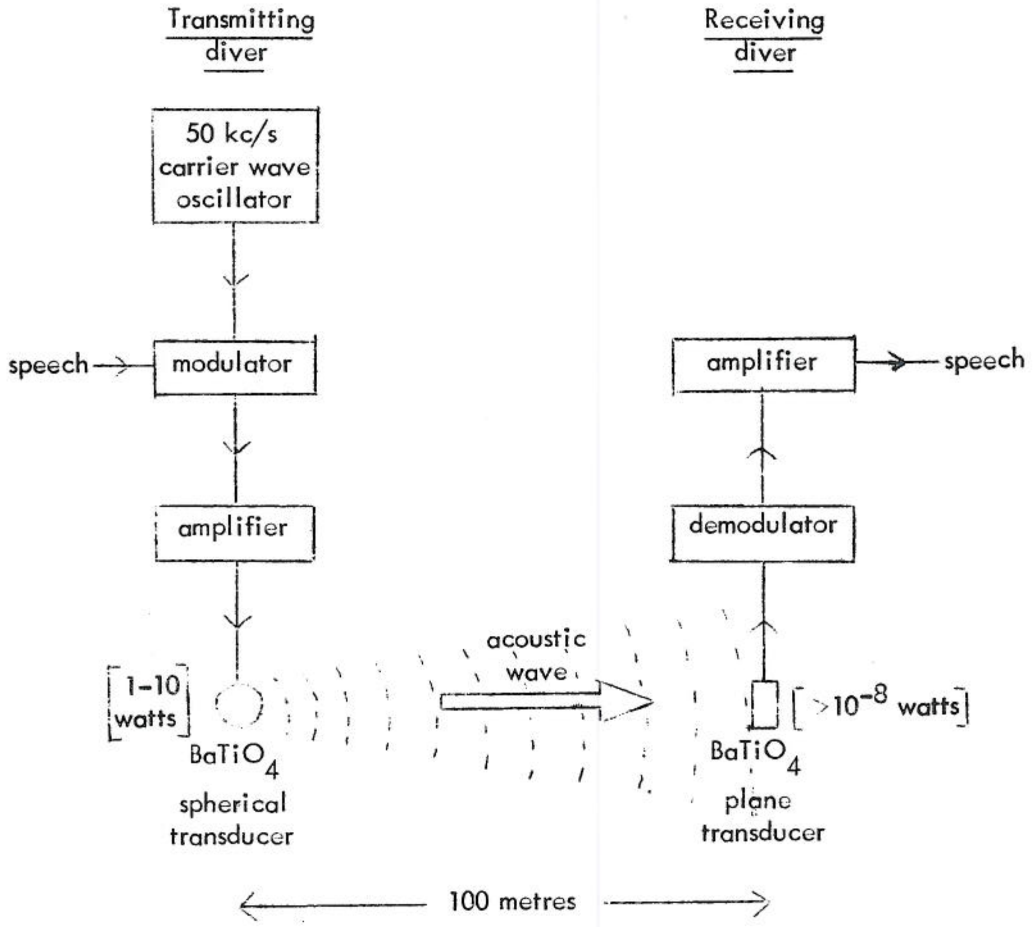
* Later abandoned through lack of funds.

(c) Circuitry

The advantages of using a fully transistorised system need not be emphasised. The present design uses a single amplifier with frequency response covering the audio range and up to the carrier frequency; it is switched for receive or transmit. The supply is twelve volts, two 6 volt lantern batteries being used at present. The output is of the order of one watt, but this can be increased to ten watts without difficulty. The receiver circuit is capable of detecting a signal 100 dB below this, although even at 100 metres range without beaming the level should only be 85 dB down.

Layout

The system may be represented in block form as shown:-



Conclusion

The equipment described has been constructed at the Imperial College and is now undergoing sea tests. Similar work is being undertaken at Cambridge by N.C. Flemming and others; the author is working in collaboration with O. Lloyd also of the Imperial College physics department.

Appendices

A) Absorption and refraction of sound waves in water

The intensity of a spherical wave at a distance d cm. from a transducer of radius r cm. can be written in the form:

$$\log_{10}\frac{(I_r)}{(I_d)} = 2kd + 20.\log_{10}\left(\frac{d}{r}\right)$$

The absorption coefficient, k, varies roughly as the square of the frequency, and at the chosen carrier frequency (50 kc/s) equals 0.3×10^{-4}. Thus the absorption term may be ignored, and the attenuation of the sound wave becomes:-

$$20.\log_{10}(d) \quad \text{dB.}$$

(transducer radius, r, roughly 1 cm.)

Other workers have reported difficulties arising from the refraction of sound waves at temperature discontinuities below the surface. The present work, however, is aimed at transmitting modulated sound waves between either two divers, or a diver and the surface tender. The two divers are likely to be at the same depth and the direct wave between them will not pass through any temperature discontinuity or gradient, so will not suffer refraction. Other paths may exist between the divers via the seabed, surface, or thermocline and the intensity of such "echoes" can only be determined by field tests, and it is hoped that they will not interfere with communications. In most cases the diving boat is kept directly over the divers, and consequently a wave between this boat and the divers will pass almost normally through temperature discontinuities, allowing only slight refraction.

B) The objections to an electromagnetic system

One reads that the Admiralty are having constructed a radio transmitter for contacting submerged submarines, and asks why divers should not use such a system.

Sea water, an electrolyte, behaves as a partial conductor to electromagnetic waves of radio frequencies, and the exponential attenuation of an incident wave with penetration can be described in terms of a skin depth, d cms., given by the expression:-

$$d = \left[\frac{c\lambda}{4\lambda^2 \mu \sigma}\right]^{\frac{1}{2}}$$

, where
c = speed of light in seawater
λ = wavelength
μ = permeability
σ = conductivity

(all in c.g.s. units)

typical values are:-

Frequency	skin depth	description
10 kc/s	300 metres	e.g. for submarines
100 kc/s	100 metres	long wave band
1000 kc/s	30 metres	medium band
100 Mc/s	3 metres	V.H.F.
1000 Mc/s	1 metre	U.H.F.

The only radio waves with a suitable penetration are the long waves now being used for submarine communication; these, unfortunately, are unsuited for short distance communications. The higher frequencies are more easily generated and used for short distances (e.g. the "walkie-talkie"), but have insufficient penetration in sea water.

The alternative is to turn to the very high frequencies of the visible spectrum, where the seawater may be treated as a Helmotz dielectric with preferential attenuation in the red end of the spectrum (giving the well known blue light at depth). In the near future it might be possible to use a blue carrier wave from a LASER modulated by speech or vision in the normal way. Considerable research is going into this technique, but even when produced the system may prove impracticable owing to high cost or power requirements.

At present the alternative, if one intends to use visual signalling, is to use a blue lamp flashing a Morse signal, to be received by a photcell/transistor feeding ear-phones via an amplifier. This apparently promising approach suffers from interruption due to poor undersea visibility (often under 10 metres), and the need for accurate alignment of transmitter and receiver.

The conclusion is that electromagnetic communication equipment could be developed, but that, at present, this would require considerable work with the prospect of rather limited systems unsuited to the free diver.

2nd World Congress of Underwater Activities

20th October - Tools for the Job

Demonstration of a new device for communication between divers

by J.D.Woods

Department of Physics, Imperial College, London

(Paper to be taken as read)

A cheap acoustic device designed to provide full two-way communication between divers has been developed at the Imperial College. Being fully transistorized, the instrument is compact and works at low voltage. An omnidirectional transducer is used at low ranges to avoid the need for alignment of two communicating sets.

Principle of operation

diagram 1

An 80 kc/s signal, modulated by the diver's speech, is injected into the sea by a barium titanate transducer. This ultrasonic wave spreads out in all directions at the speed of sound ($1\frac{1}{2}$ km/s in seawater) to arrive, considerably reduced in strength, at a second transducer, which changes it back to an electrical signal for detection and amplification to the original level. The speech is then presented at a bone-conduction headphone on the diver.

The power loss between transmitter and receiver is very large (at a hundred metres range the received signal may have only one millionth of the transmitted power) and considerable amplification is needed. This loss can be considerably reduced by using plane transducers that need to be aligned during conversation.

Circuitry

diagram 2

The equipment is fully transistorized to allow operation at low voltage (12 v.) In order to reduce the number of components the audio amplifier and headphone are used while both listening and speaking, as shown in the above diagram. This of course calls for switching between "transmit" and "receive", a simple manipulation that saves considerable trouble arising from the transmitted signal reflecting back into the receiver.

Transducer

The equipment is very similar in operation to the "walkie-talkie" set used by police, with the actual signal broadcast as a sound wave instead of a radio wave. To inject this acoustic wave into the sea the set uses a barium titanate sphere, 3 cms in diameter; considerably more compact than the long whip-aerial of its "walkie-talkie" equivalent. The sphere radiates the modulated 80 kc/s signal in all directions, and must be mounted well away from any obstacle (the diver's mask has been suggested as a suitable site).

At the receiving position the aerial is again a barium titanate sphere which vibrates in the incoming sound wave, and sends equivalent electrical oscillations to the amplifier.

In a complete set the same transducer is used both for transmitting and receiving. Because the sphere has the same response to waves arriving from any direction, there is no fading as the diver changes his attitude, unless of course his body comes directly between his transducer and his companion's.

For long range communication the spheres are replaced by plane transducers that must be aligned during conversation.

Headphone

The diver has to both speak into, and listen to his apparatus. The most elegant way of doing this is to strap a bone conduction phone to the top of his head, where it will detect the vibrations set up in his head when he speaks, and vice versa. This type of headphone will work satisfactorily through a thick head of hair (although a bald diver will no doubt tend to reduce the volume somewhat). It also helps to reduce demand valve noise experienced with some full-face mask aqualungs.

Dimensions

diagram 3

The electronic circuitry is fitted into a pair of tubes, of radius 4 cm. and length 30 cm (approx); the transducer is housed in a 5 cm cube; the microphone measures 3 cm across. The largest item, and the heaviest, is the battery pack, which is intended to take the place of an aqualung diver's weight pouch.

The equipment's potential

The original concept behind the reported project was to provide a compact, simple and cheap means of voice communication between divers. The advantage of such a system is obvious to anyone with experience of undersea work.

Since the work started the concept of omnidirectional aerials arose, and the gain from such a system has well outweighed the consequent complications in circuitry and power supply. Similarly with the bone conduction headphone, which has a poor efficiency when compared with more conventional mask microphones.

Despite the complications, apparatus has been constructed that can be worn by a free diver without hindering his work capacity. It allows him to converse freely with his partners whether they are with him under the sea, or sitting in the diving boat, and this without any wire connections to hinder his movements. He can broadcast a running commentary on his work and observations and receive instructions from the surface without stopping to orientate an aerial.

A boat fitted with a directional transducer should be able to locate a transmitting diver, and a suitable continuous transmission on a separate frequency might well be incorporated in later models for just this purpose.

Conclusion

A new device has been designed to help the working diver. The original electronic "lash-up" was used for full voice communication over a distance of thirty metres in a test tank, showing that with more power the original 100 metre range requirement should be readily attained. This has now been replaced with a pair of more powerful instruments incorporating many improvements in design; these are now undergoing field trials. By the summer of 1963 divers should be using the equipment during routine descents.

Further details of this project may be obtained from the author. The many technical aspects of this field are well covered in "The fundamentals of Sonar" by J.W. Horton, which also contains an exhaustive bibliography on the subject. The project described was first reported in a paper presented to the Undersea Equipment Research Society, London, in May 1962.

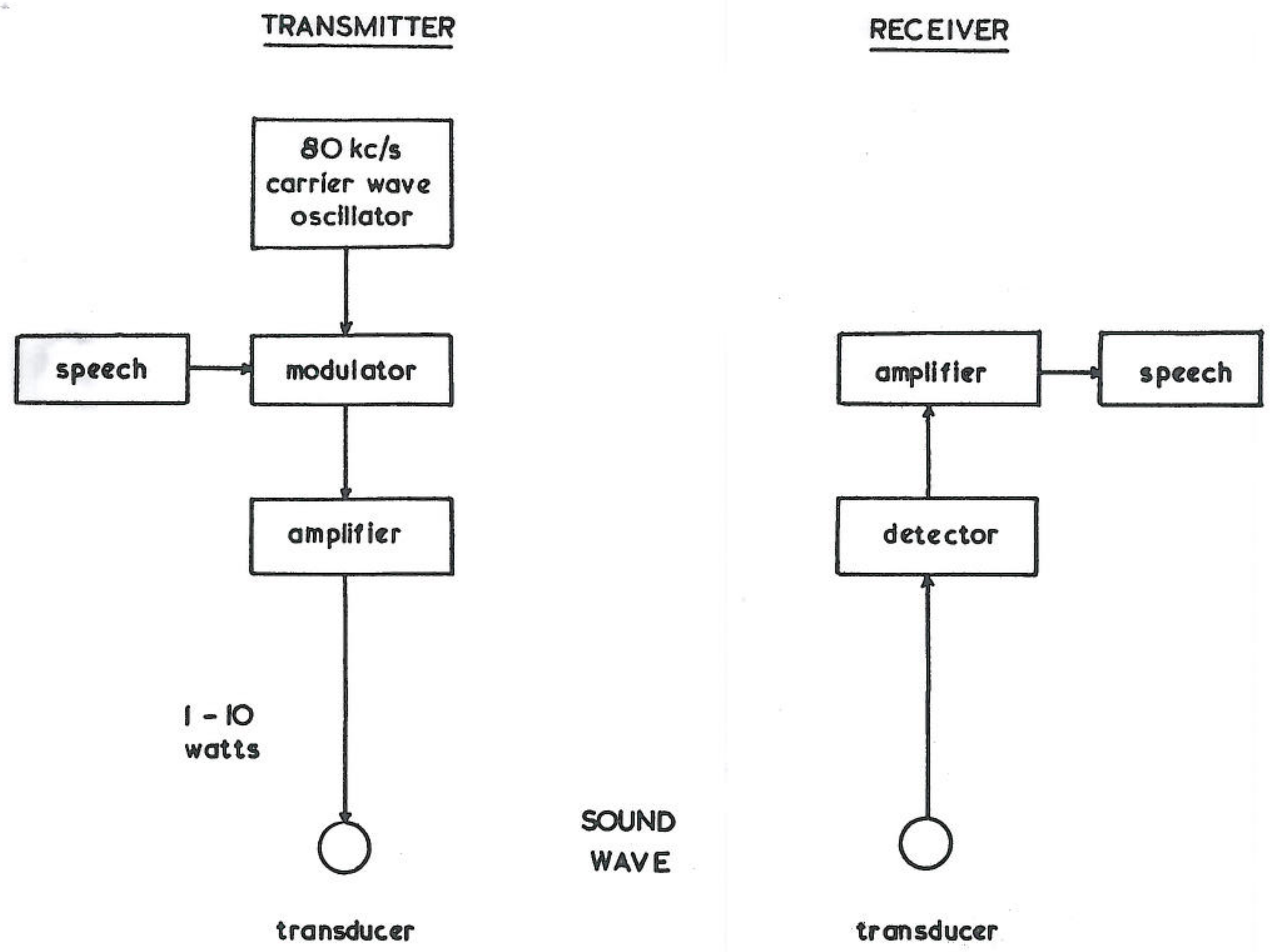


Diagram No. 1. Principle of operation.

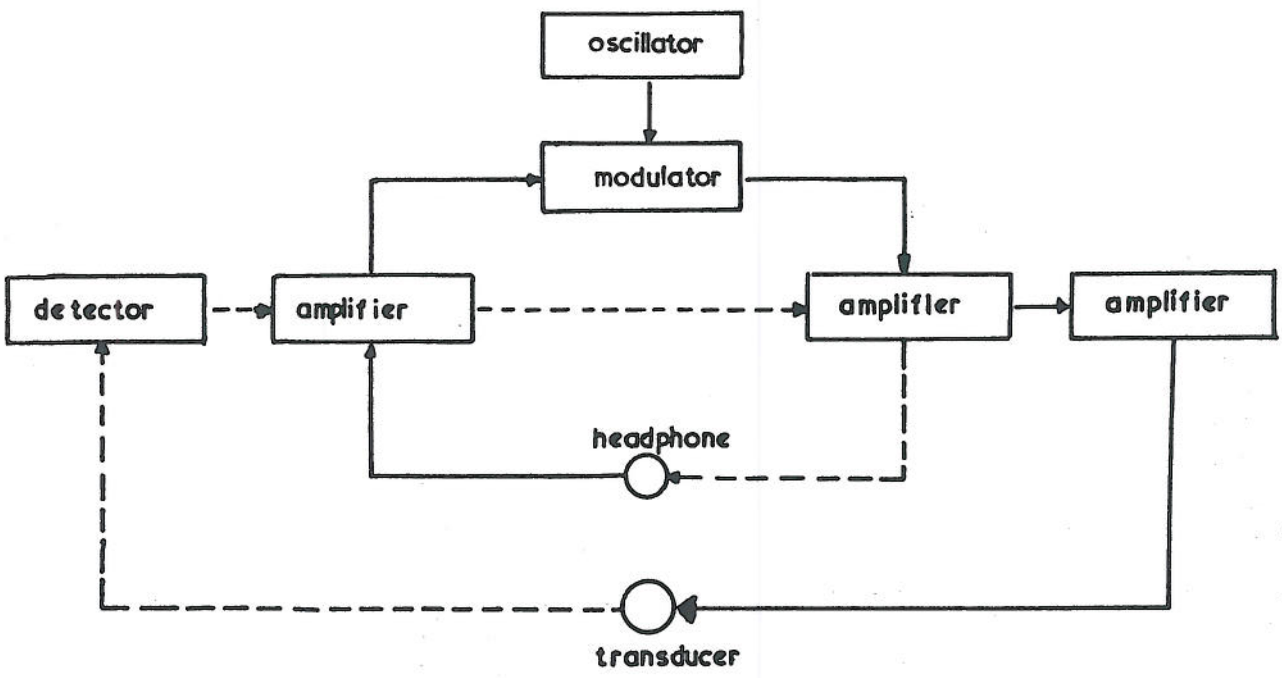


Diagram No.2. Circuit during transmit [——→] and receive [- - - -→].

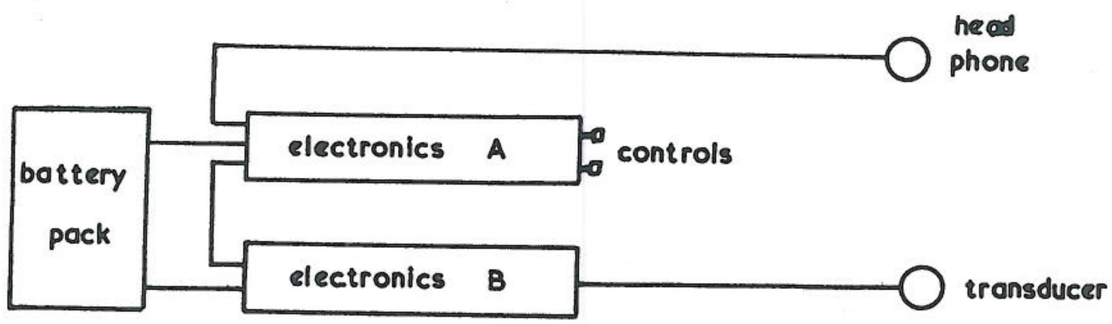


Diagram No.3. Layout.