ULTRASONIC COMMUNICATIONS

An analysis of the principal factors and equipment involved in conveying intelligence at ultrasonic frequencies through mediums such as liquids, gases, or solids.

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IN ORDER to convey intelligence or to "communicate" through a medium, be it a liquid, gas, or solid, it is expedient first to establish in the medium, as a "carrier", some form of periodic wave motion which can be propagated to and detected at a remote point in the medium. Secondly, it is necessary to modify the existence or character of this wave motion in some pre-arranged, decipherable manner, or "modulate" the wave motion. Obviously, modifying the existence of the wave may be accomplished by alternately starting and stopping its generation; whereas, modifying its character may be accomplished by changing its amplitude, frequency, phase, or velocity. However, since the velocity of a wave in a homogeneous medium is fixed, the other aforementioned forms of modulation are relied upon.

In the art of radio communication, such "carrier" waves are electromagnetic in character, transmitted through the ether at a uniform velocity and modulated to carry intelligence by code or telephone.

In the art of sonic communication, such carrier waves are "compressional" in character, wherein the propagating medium suffers a sort of rectilinear deformation, which may be transmitted through various liquids, gases, and solids at velocities determined by the characteristics of the medium, and modulated to carry intelligence. While electromagnetic and sound waves may be essentially different in character, they are alike in that they may each be propagated in suitable media. Quite obviously, the most universal form of sonic communication may be exemplified by a conversation between two or more people. The vocal cords, as well as the configurations and appurtenances of the oral cavity, cooperate to represent the compressional wave generator, which is both amplitude and frequency modulated. The air represents the gaseous medium through which such modified compressional waves are transmitted at a velocity of some 1100 feet-per-second. The human ear represents the receiver, which is capable of detecting and, perhaps, demodulating these compressional waves.

In the art of ultrasonic communication, so designated by virtue of the fact that the human ear will not respond to the higher frequencies, such waves still are compressional in character and may be transmitted through liquids, gases, and solids. It will be appreciated that ultrasonic communication, while not popularized, has been known and used for many years. The early work of Langevin, Florisson, and others describes and discloses means and apparatus to communicate through a water medium via ultrasonic waves. Part of this work was directed toward submarine detection and signalling, as well as echo depth sounding, in which the principles involving the use of compressional water waves are truly the forerunners of the present-day principles involving the

MEDIUM	FREQ. (k.c.)	DISTANCE (FT.)
WATER	10	1,312,400
WATER	100	13,124
WATER	500	525
WATER	1000	131
AIR	10	722
AIR	100	7.22
AIR	500	0.157
AIR	1000	0.072

Table 1. The distance sound travels before its intensity is reduced to one-half.

Fig. 1. Two types of reproducers (loudspeakers) that can be used to communicate via a 20 kc. ultrasonic sound beam. (A) The magnetostriction reproducer and (B) the piezoelectric reproducer. Photographs of these units are shown in Figs. 2 and 4 respectively.

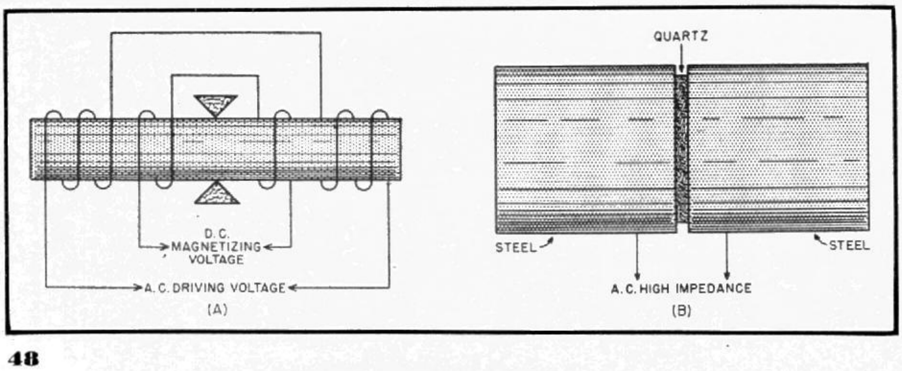
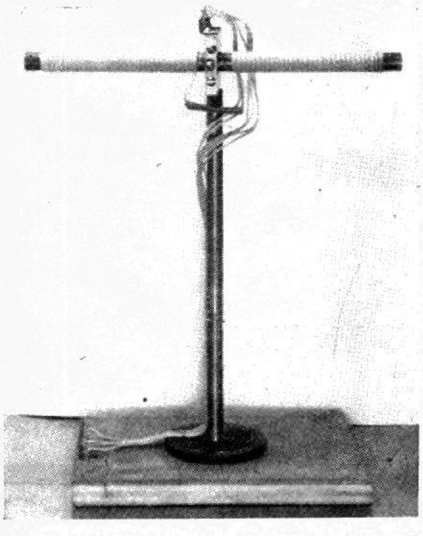


Fig. 2. The magnetostriction reproducer.



use of electromagnetic "ether" waves for radar. Early forms of "absolute altimeters" for avigation also employed sound waves, but their velocity was too low to render them practical for the vehicular velocities encountered in practice.

Compressional waves, in passing through any medium, are absorbed to an extent dependent upon the frequency of the waves, the nature of the medium, and the distance travelled. All mediums have a certain "compressibility" and "viscosity" whereby all of the compressional energy imparted to displace the medium is not returned to the wave but is partially transformed into heat. From Rayleigh[1], the amplitude A of plane waves at a distance x from the generator, is:

$$A_x = A_o e^{-KN^2X} \qquad (1)$$

where A_o is the original amplitude, e is the base of the natural logarithms (2.718), K is a coefficient depending upon the density, compressibility, and viscosity of the propagating medium, and N is the frequency of the wave motion. By inspection, the amplitude of the wave at a distance is inversely proportional to the square of the frequency, so that high frequency compressional waves fade out in much shorter distances than low frequency waves.

The factor K for a water medium has such a relatively low value that appreciable distances may be covered by compressional water waves at frequencies of from 20 to 50 kilocycles. The factor K for an air medium has a much higher value so that air distances must be measured in feet rather than in miles. The relative efficiency of the two mediums, as well as the effect of frequency, may be seen by examination of Table 1, which shows the approximate range at which the original sound intensity has been reduced to one half[2].

A redeeming feature of ultrasonic sound waves, like high frequency electromagnetic waves, is that they are easily directed and formed into a cone or beam by conveniently small radiators. Provided that the vibrating surface producing the wave is moving like a piston with all surface elements in phase, the directivity of the reproducer may be roughly calculated from

$$\sin\theta = .61 \frac{\lambda}{r} \qquad (2)$$

where θ is the half-apex angle of the cone, λ is the wavelength and r is the piston radius[3].

With the foregoing considerations in mind, various apparatus for communicating via a 20 kilocycle ultrasonic soundbeam has been constructed and employed. The frequency generator to produce the carrier wave consists of a commercial audio oscillator and ten-watt audio amplifier. In order to amplitude modulate the carrier wave, provision is made for plate modulating the output tubes of the ten-watt amplifier, in accordance with conventional AM radio transmitter practice.

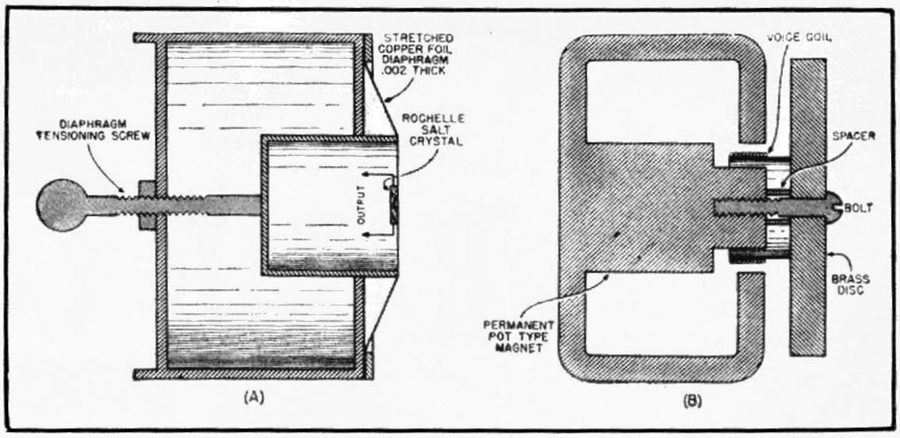


Fig. 3. (A) Mechanical arrangement of the mechanically resonant microphone. (B) Cross section view of the dynamic reproducer. Photographs shown in Figs. 6 and 5 respectively.

Three general types of reproducers or "loudspeakers," namely magnetostrictive, piezoelectric, and dynamic, have been used. With regard to these reproducers, magnetostriction refers to that phenomenon in which there is a change of length in a bar of ferromagnetic material attending magnetization. If the magnetic field is alternating (at 20 kilocycles in this case), the amplitude of longitudinal vibration in the bar will be maximum when the frequency of the applied field is equal to the fundamental elastic period of the bar. In accordance with the formula:

$$f = \frac{1}{2l}\sqrt{\frac{E}{d}} \qquad (3)$$

where f is the frequency in cycles per second, l is the length of the bar in centimeters, E equals its modulus of elasticity in dynes per-square-centimeter and d its density in grams per-cubic-centimeter, the length of a bar for resonance at 20 kilocycles is approximately 5 inches. This reproducer is shown in Figs. 1A and 2, clamped for support at its nodal midpoint and strongly magnetized by an additional direct current magnetic field. In general this simple type of magnetostriction reproducer is unsatisfactory because of extreme eddy-current heating. Further, this particular bar, having an o.d. of one-half an inch, has a poor match with the air load. Better loading may be obtained with the addition of a larger diameter thick disc at one end.

The piezoelectric reproducer, illustrated in Figs. 1B and 4, consists in a 3.5 megacycle X-cut quartz plate cemented between two identically di-

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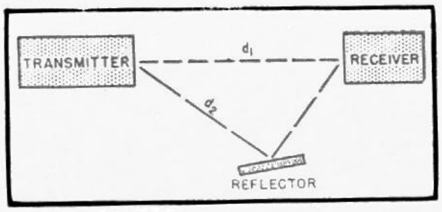
Fig. 7. When sound-waves along paths D_1 and D_2 arrive at the receiver out of phase, as can occur as shown in diagram, fading and phase distortion occur.



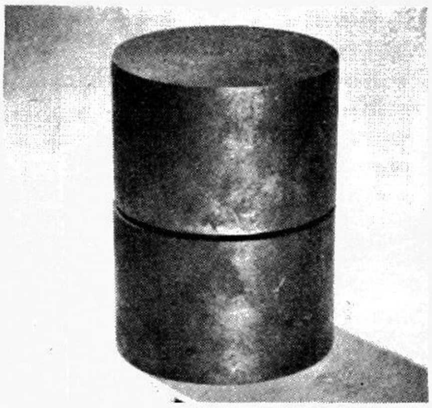


Fig. 4. The piezoelectric reproducer.

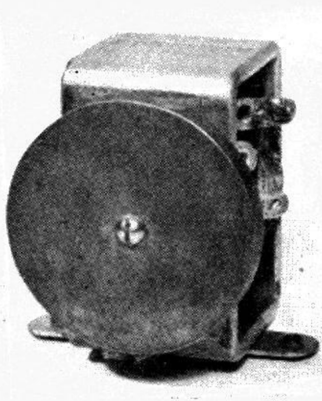
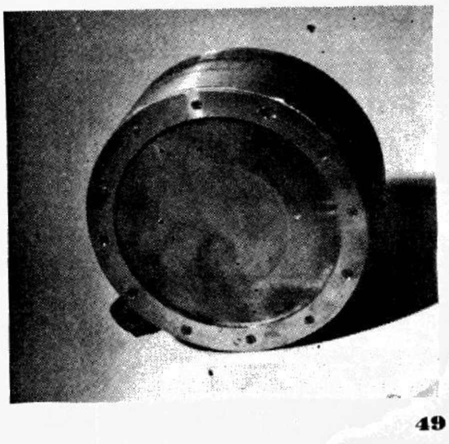


Fig. 5. Dynamic reproducer.

Fig. 6. Mechanically resonant microphone.



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mensioned sections of steel rod. In order to determine the resonant frequency, the required over-all length of this steel-quartz-steel "sandwich" may be approximated from the previously mentioned formula, because the velocity of sound in quartz and steel is about the same. This unit has an inherently high impedance requiring a high driving voltage and necessitating the incorporation of a special matching transformer as used with piezoelectric instantaneous record cutting heads. The high voltage appearing across the quartz engenders difficulties in mounting the reproducer.

The dynamic reproducer, illustrated in Figs. 3B and 5, consists essentially of a small permanent magnet loudspeaker with the cone replaced by a resonant brass disc one-quarter inch thick and two inches in diameter, pinned at its center to the central pole piece of the permanent magnet, and carrying the voice coil. This unit has given excellent service in practice with relatively high output.

Various receivers for receiving the 20 kilocycle sound waves have been employed, all of them requiring some type of microphone, a carrier amplifier, a demodulator, a carrier filter, and an audio system, as in conventional radio receivers. Two different microphones have been successfully used, both being the Rochelle salt crystal type. The first unit is an unmodified commercial crystal microphone (Astatic WR-20) having dual crystals and diaphragms, having good response in the 20 kilocycle region. The second unit, shown in Figs. 3A and 6, employs a stretched foil diaphragm with a small Rochelle salt crystal cemented directly to the inside face. Provision is made, as illustrated, for varying the tension on the diaphragm to permit adjustment for some mode of mechanical resonance at 20 kilocycles. This mechanically "tunable" microphone has considerably higher output on equivalent sound intensities than the standard commercial unit, with the added feature of tending to reject lower, non-resonant frequencies.

Two types of receivers, one rather unusual in design, have been employed. The first type consists of several stages of tuned audio amplification, followed by a diode detector, carrier filter, and audio amplifier. As an interesting experiment, in an effort to improve sub-harmonic rejection, improve selectivity, and eliminate the necessity for a 20 kilocycle carrier filter, another receiver was designed in which the output from the microphone is successively doubled to 160 kilocycles, amplified with a two-stage 160 kilocycle r.f. amplifier, demodulated, and passed to the conventional audio system. As expected, in this particular arrangement, rather severe audio distortion is caused by the carrier doublers if a high percentage of modulation is used. In subsequent experiments it is proposed to use either push-push doublers or full-wave rectification to elevate the carrier to the higher frequency. With the frequency raised to around 160 kilocycles, standard 175 kilocycle i.f. transformers provide conveniently packaged, high-Q tuned circuits for amplification.

Up to the present time, out-of-door tests with the disclosed equipment have not been made, but experiments which have been performed are of great interest. The 20 kilocycle carrier has been modulated with both tone and phonograph signals and received exceedingly well over distances of some thirty to fifty feet. Modulation does not render the carrier audible to the ear. However, with the unmodulated carrier directed toward the receiver, speaking into the carrier microphone produces audible signals in the receiver audio output system. With the carrier removed, the audible signal disappears.

Remarkably pertinent effects may be produced by reflecting a second carrier wave path, in addition to the original path, from reproducer to microphone, as shown in Fig. 7. Fading and phase distortion, such as encountered in standard radio reception, may be produced realistically in the ultrasonic receiver by varying the position of the reflector, the motion of the reflector being somewhat analogous to the motion of the Heaviside layer. The movement of people within range of the apparatus produces like results and indicates the potential utility of ultrasonics for intrusion or passage detection in air mediums, using the beam-of-sound rather than the beam-of-light principle.

In the near future it is proposed to conduct out-of-door tests in an effort to empirically determine the range of such apparatus.

REFERENCES

1. *Lord Rayleigh, "Theory of Sound."*
2. *Dr. L. Bergmann, "Ultrasonics,"* P. 195.
3. *Ibid. (2)*, P. 194.