NASA TECHNICAL NOTE

NASA TN D-3062

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NASA TN D-3062

AN ELECTRONIC MEANS OF PROVIDING BINAURAL INDICATION OF THE DIRECTION OF RADIO TRANSMISSIONS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1965

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SUMMARY

The use of two hearing characteristics, by which humans normally detect the point of origin of a sound, is investigated as a means for detecting the point of origin of a radio signal. Provision was made to rearrange the audio output of a radio communication receiver in such a manner that the user, by listening to a pair of earphones, could determine the direction from which the transmission was coming. This device has potential application in providing orientation information to members of a space ship crew, or members of lunar exploration parties. A simulator with low power and lightweight equipment was developed to provide transmitter localization over short ranges.

INTRODUCTION

Convenient coordination of efforts among a group of people frequently depends on their knowing their orientation with respect to each other. The normal transmission of sound provides directional information to the ears. The desire to maintain the directional advantages of normal audible communication during space operation in a vacuum led to the investigation described herein.

A radio transmission concept that utilized earphones was investigated because a person using both ears can locate the origin of noises, in a normal atmospheric environment, and because radio transmission techniques are highly adaptable. The advantage of this type of scheme over those that employ visual indicators, such as meters, is that it leaves the other senses free for other tasks, since it uses only the ears which are needed for the communication anyway, and the direction indication is acquired simultaneously as added information. To provide a convenient and natural directional indication, only those concepts were investigated that could vary the relative sound output of two earphones as the transmitting source moved or the head rotated.

The ability of the ear arrangements and sensitivities of various animal forms to detect direction and distance, as well as the character of sound sources, has been investigated extensively (refs. 1-5). These investigations have generally indicated that the characteristics for highly accurate auditory localization are the time delay incurred by a distinctive pressure change as it reaches first one ear then the other, and the intensity difference between the ears. The pressure change is best brought about by a burst of sound, with comparative silence on either side, such as a tapping sound. Previous investigators have concluded that the difference in sound intensity between the ears is of value though of less importance for precise directional indication at low audio frequency. They have found that as the repetition frequency of a tapping sound is increased, the subject becomes unable to resolve the small time delay, and so the difference in intensity of the sound from ear to ear becomes the more distinguishable directional indication (see ref. 4, p. 357).

A number of tests were made in the laboratory to witness these hearing characteristics first-hand so that better judgments might be made as to how the ears could best be utilized. These measurements indicated the possibility of utilizing a particularly simple concept for providing directional information. This concept was then embodied in an experimental radio receiving system that could indicate direction to the user in a manner similar to normal hearing.

PREPARATORY PROCEDURES

For a better understanding of directional hearing phenomena, a number of bench experiments were devised, only two of which are reported here: (1) an electronic simulation of moving tapping sounds; and (2) a replacement of normal hearing with a microphone and amplifier for each ear.

The tapping sounds were simulated with a device arranged to supply a set of pulses to the experimenter's ears by means of earphones with the capability of displacing the pulses from each other in time. The device, schematically shown in figure 1, used the output of an audio frequency generator to produce a separate 7 msec pulse for each ear. The pulses could be displaced from each other continuously by a single knob which various operators were asked to adjust to bring the apparent sound source to the median line of their head. The actual time displacement was observed simultaneously on an oscilloscope unseen by the operator. These tests demonstrated to the investigators that at low frequencies the pulses could be brought to accurate coincidence repeatedly, but as the frequency was increased the reliability of the coincidence setting decreased, as did the illusion of sound source motion. With this pulse delay arrangement, the range of the most accurate coincidence setting was 10 to 30 cps.

The generator was then modified to allow two different pulse widths to be selected by a switch, 2 msec or 20 msec. The effect of pulse width was not greatly significant since it changed the character of the sound rather than the directional illusion.

An amplitude diminishing effect was then added that could be selected when desired so that when the pulses were driven apart the sound intensity diminished directly with their displacement. The combination of pulse displacement in time and the steady decrease in amplitude was applied to the ears through separate earphones. This was a more realistic simulation of a passing sound source and improved the coincidence setting at the higher frequencies (1500-5000 cps) because of the addition of an amplitude peak at coincidence.

For the second item, that is, the replacement of normal hearing, tests were conducted with an acoustic simulation of a radio frequency directional communication system using microphones, amplifiers, earphones, and most important, keeping the motion of the head directly connected to the sensing of sound. A pair of small crystal microphones were mounted back-to-back on the headband of a pair of earmuffs. The microphones faced the same direction as the ears when the muffs were worn. The microphone outputs were separately amplified and applied to their respective earphones inside the muffs. The earmuffs were the type used by jet engine service personnel, and were used in this instance to keep out as much sound as possible except that which the microphones sensed. When worn around the laboratory with its usual sounds, this arrangement provided the wearer with an adequate directional hearing system. The microphones were positioned at various distances from each other along a horizontal bar affixed to the top of the earmuff headband. The spacing ranged from a somewhat greater spacing than the average human ears to a minimum of approximately 1/2 inch. The microphones used in this arrangement have a directional sensitivity pattern, as shown in figure 2, such that sounds of equal intensity coming from different directions produce different signal levels.

The most effective directional characteristics were experienced on the tests conducted with the microphones placed at minimum spacing in the center of the head, as shown in figure 2. This demonstrated to the experimenters that the difference in amplitude of a specific sound from ear to ear could adequately indicate the angle θ to the sound source. In the experiments the front-to-back ambiguity could be resolved in the same manner as in normal hearing, that is, turning the head slightly and noting a rise in amplitude in the microphone that is oriented closer to the sound source direction, as well as a corresponding decrease in amplitude in the opposite microphone. The major difference between this and natural localization is that in the latter the intensity difference is brought about by the "shadowing" effect of the head positioned between the two sensors, the ears. With the present instrumentation, however, the intensity differences do not depend upon human anatomy nor upon frequency, as does "shadowing" which is most effective with higher frequency. Since the intensity differences are now independent of natural constraints, they can be augmented so as to enhance localization capability. These tests supported a concept of indicating direction by amplitude variation only, directly to the ears during communication, and led to the hope that directional difference could be generated very simply from a radio transmission with a directional radio receiver coupled to each ear.

RADIO FREQUENCY FEASIBILITY MODEL

A program therefore was undertaken to construct and test an experimental model that would provide a realistic sound amplitude difference as the apparatus was rotated with respect to a source of radio waves.

Radio direction finding is used extensively in short-range navigation and many techniques have been developed that operate at a variety of frequencies.

The direct use of any of these methods for personnel orientation involves three major problems:

(1) The directional sensing must be physically suited to be worn on the head.

(2) It must retain its directional capabilities to within a few feet of the source.

(3) It should perform reliably among reflecting obstacles.

Consideration of these requirements led to the choice of a comparatively low radio frequency (1700 kc) for the experimental model. The usual method for determining the direction of radio frequency radiation at this frequency employs a loop antenna (ref. 6) which has a double lobe pattern as shown in figure 3. Summing of the signal from such an antenna with that of a second antenna that has omnidirectional characteristics produces a unidirectional reception pattern, as illustrated in figure 3, that is desirable for unambiguous determination of direction.

A special radio transmitter was constructed for this investigation and was used to supply a portable source of radiation at 1700 kc modulated by either a tone or voice, as desired.

Two small receivers with loop antennas enclosed were mounted on headphones. Two omnidirectional whip antennas were then mounted on the headband of the earphones. The combination of these antennas generated the unidirectional reception pattern required for the experimental program. The output of the right receiver was connected to the right earphone and the output of the left receiver was connected to the left earphone. The directional antenna patterns of the receivers were oriented in such a way that the right receiver detected only the signal coming to the right side of the head, and the left receiver only the signal coming to the left side of the head. The automatic gain control circuits of the two receivers were cross-connected to accentuate the amplitude difference produced by the directional reception patterns of the antennas. This allowed the receiver with the highest level signal to overpower the other receiver, leaving the wearer with a strong signal in one ear and a negligible signal in the other. For small angular displacement, this condition enhanced the change in the output and provided dependable location of the transmitting station. The antenna and head receiver arrangement is shown schematically in figure 4 and a picture of the assembly is shown in figure 5.

A response curve is shown in figure 6. It displays the difference in audio level between the earphones as the receiver is rotated with respect to the transmitter. The system was operated successfully over restricted ranges in the laboratory, enabling a blindfolded operator to point immediately in the general direction of the transmitter when it was turned on. This was done repeatedly with reasonable accuracy which made it possible to approach the radiating source at will.

The laboratory model was operated mostly with the reference transmitter radiating a carrier signal modulated with a tone of approximately 400 cps.

This enabled operation with only one experimenter where normally two would be required, one to transmit and one to receive. When normal conversation was used for modulation, auditory localization was generally satisfactory; however, it was found to leave moments of directional uncertainty because of the quiet moments in normal speech. If while the head was moving a lull occurred in the transmitter's modulated output, it was necessary to wait for the next few words, before it was possible to continue approaching the transmitter with certainty.

The directional characteristic of the receiver was the most difficult part of the concept to implement. The desire to keep the radio frequency low and at the same time keep the antennas small enough to be worn on the head created a severe trade-off problem, since the efficiency of the receiver-transmitter suffered because of the small antenna size. A short whip antenna gave sufficient directivity in the laboratory model at 1700 kc, but the low radiation efficiency indicated that the limiting factor on the antenna would be its ability to radiate enough energy to cover a useful area when transmitting.

CONCLUDING REMARKS

The tests demonstrated a means for locating the origin of radio transmission by use of a receiver coupled to the ears to provide sound waves of varying amplitude. Accentuating the amplitude difference by cross-connecting the receivers appeared to be important to the accuracy and reliability of the localization.

The hesitations encountered in normal conversation were found to be disconcerting during the initial determination of direction. It is expected that this could be overcome by a steady background tone modulation with speech applied on top of the tone that would be present only during that member's transmissions. Another possible arrangement would be to share transmission time with voice and tone, one or the other being present while transmitting. Both of these approaches would replace the quiet periods with a sound of some type that would allow directional indication to continue, but their use would be dependent upon human tolerance to a steady sound and the possible confusion of the mixed tones during communication. Slightly different tones might also serve to identify a certain member of a group, obviating the necessity of self-announcement.

It seems to the authors that this effort should provide background for further investigation not only of the need for such equipment but also of the most logical method of implementation. Also, since the intensity differences generated by this system depend completely on head position and are independent of anatomy and frequency, there is a possible application in providing more accurate auditory localization under ordinary atmospheric conditions.

Current miniaturization techniques can extend the limited range of the laboratory apparatus while keeping the size small enough for convenient use. Figure 7 is a conceptual sketch of a complete miniaturized system mounted in a helmet that could be worn by an astronaut.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., July 22, 1965

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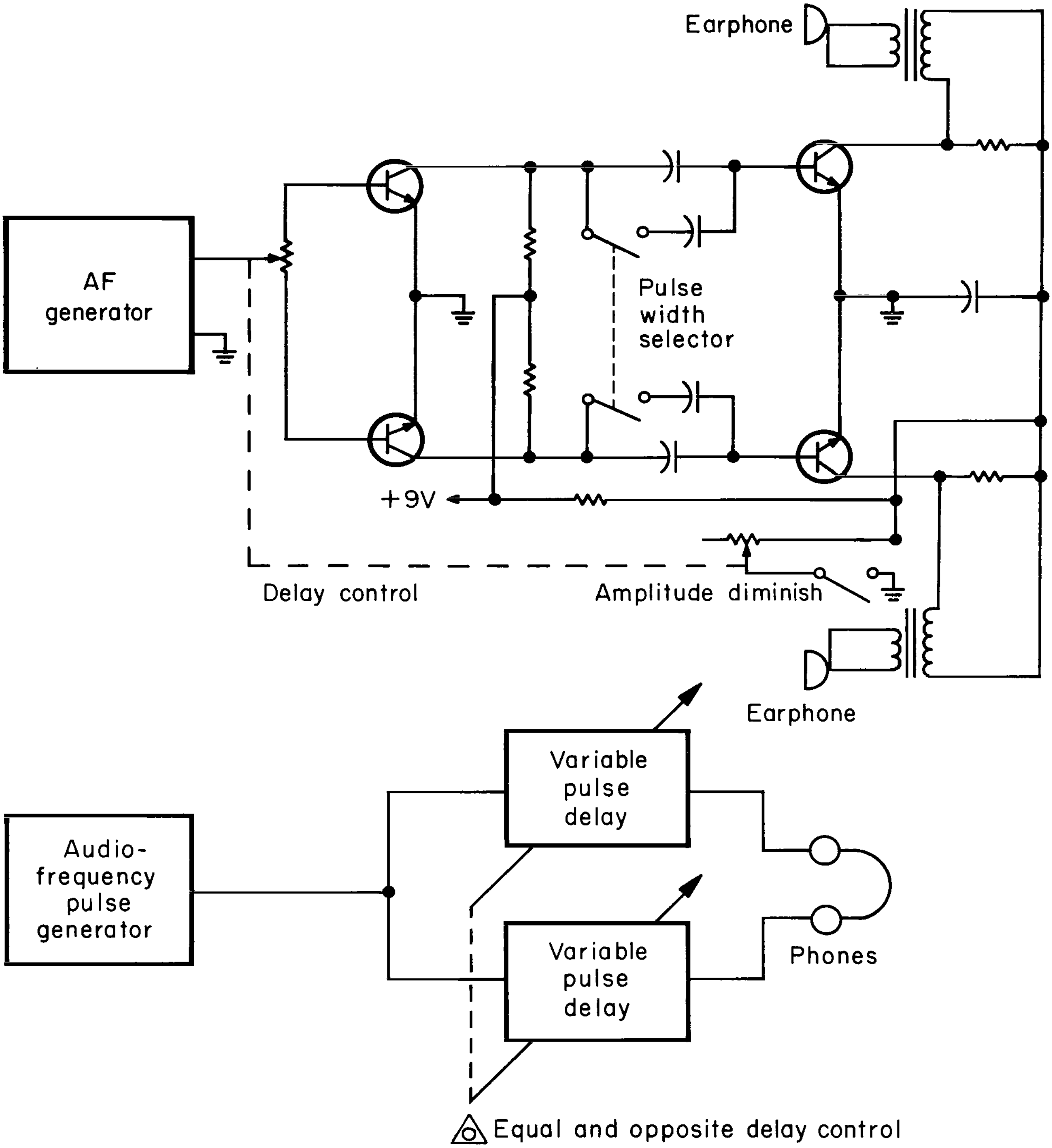

Figure 1.- Time-delay stereophonic system.

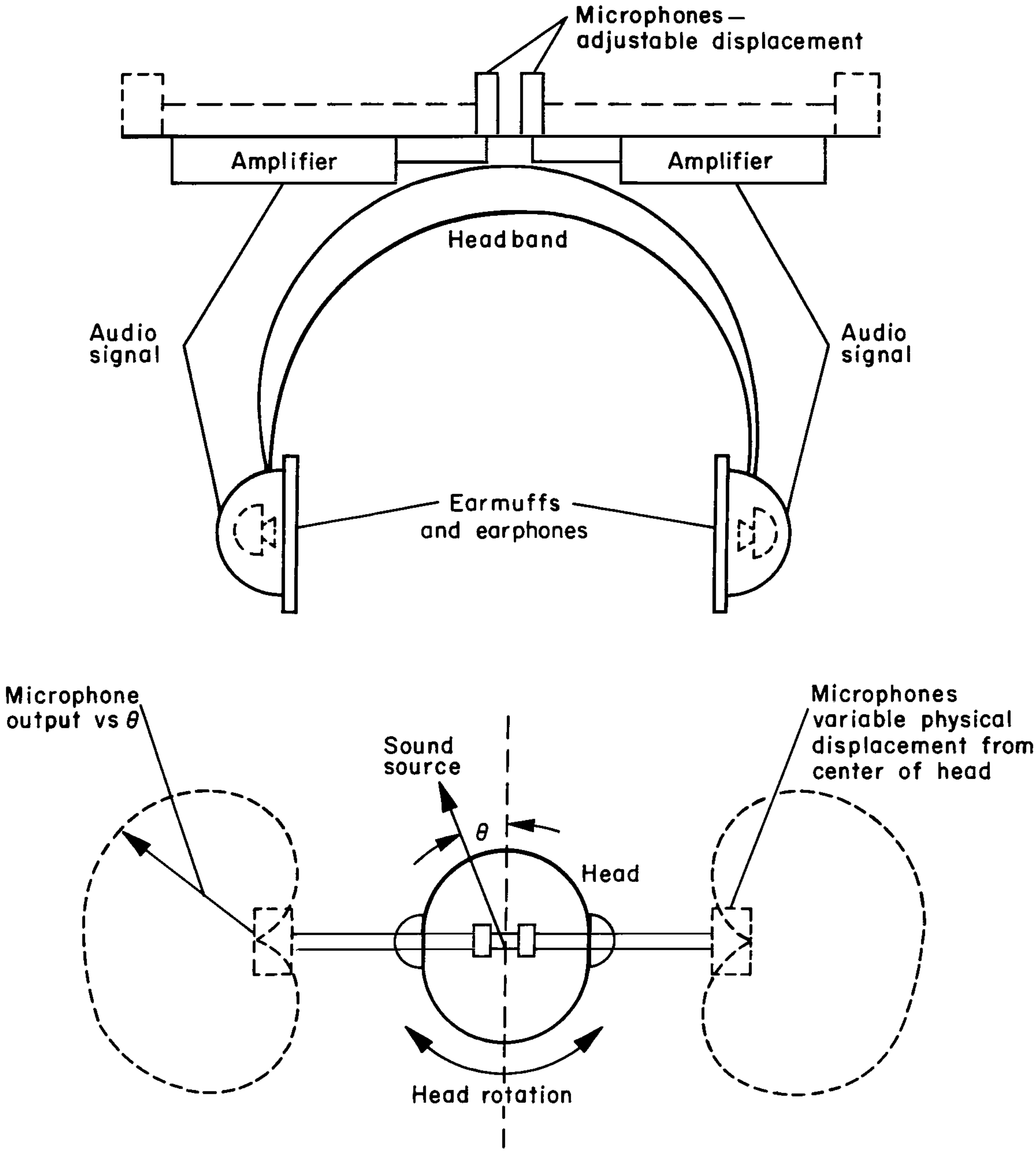

Figure 2.- Electronic listening system.

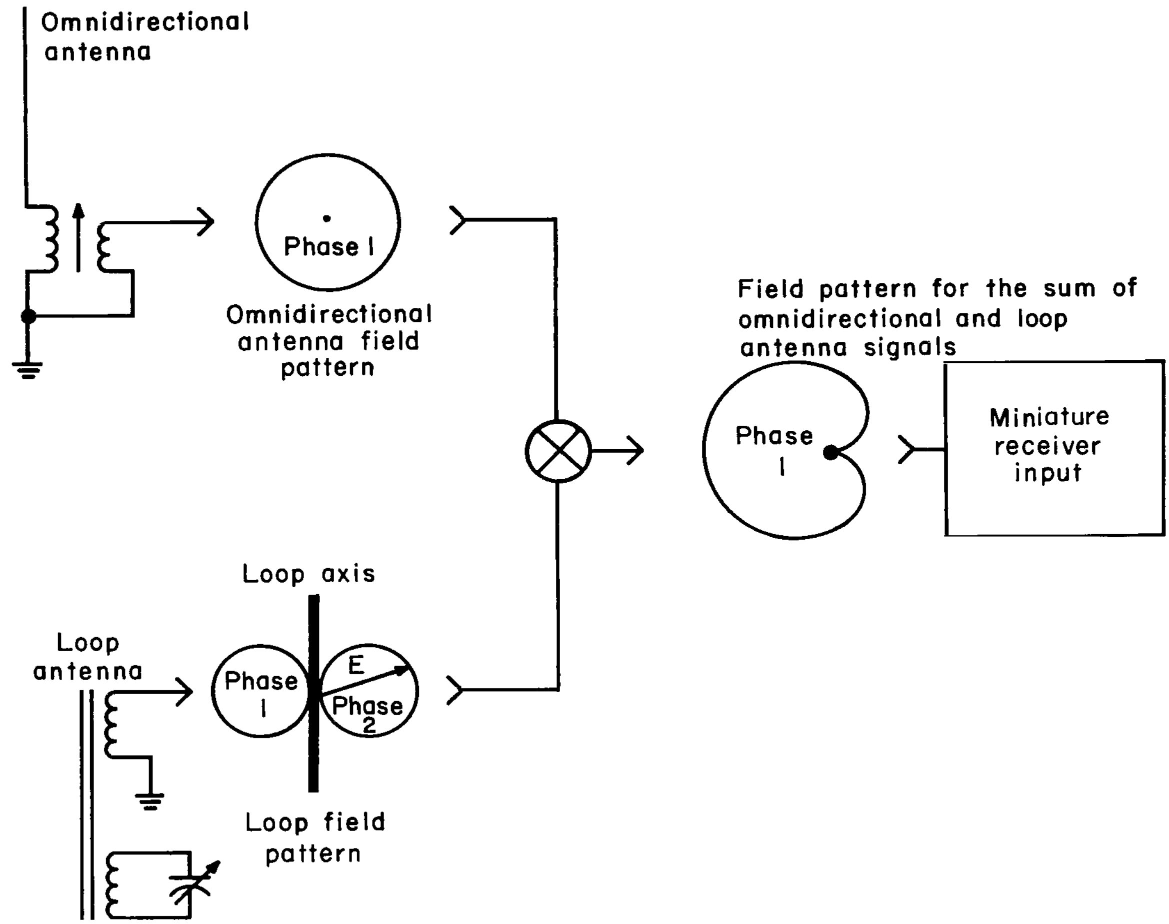

Figure 3.- One-half of dual receiver arrangement.

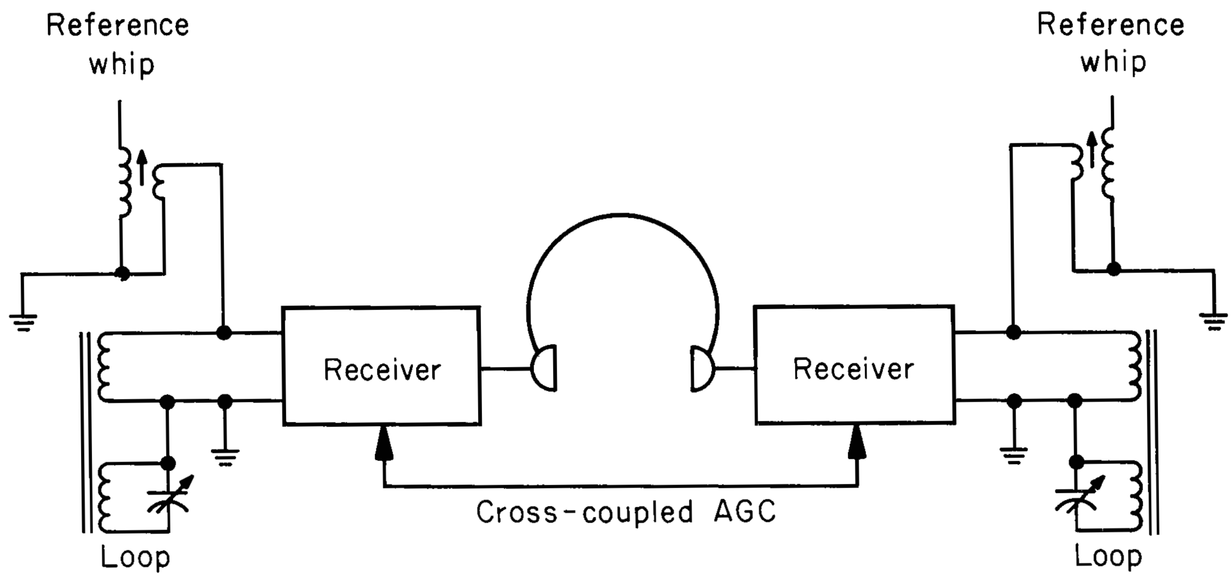

Figure 4.- Dual-receiver arrangement.

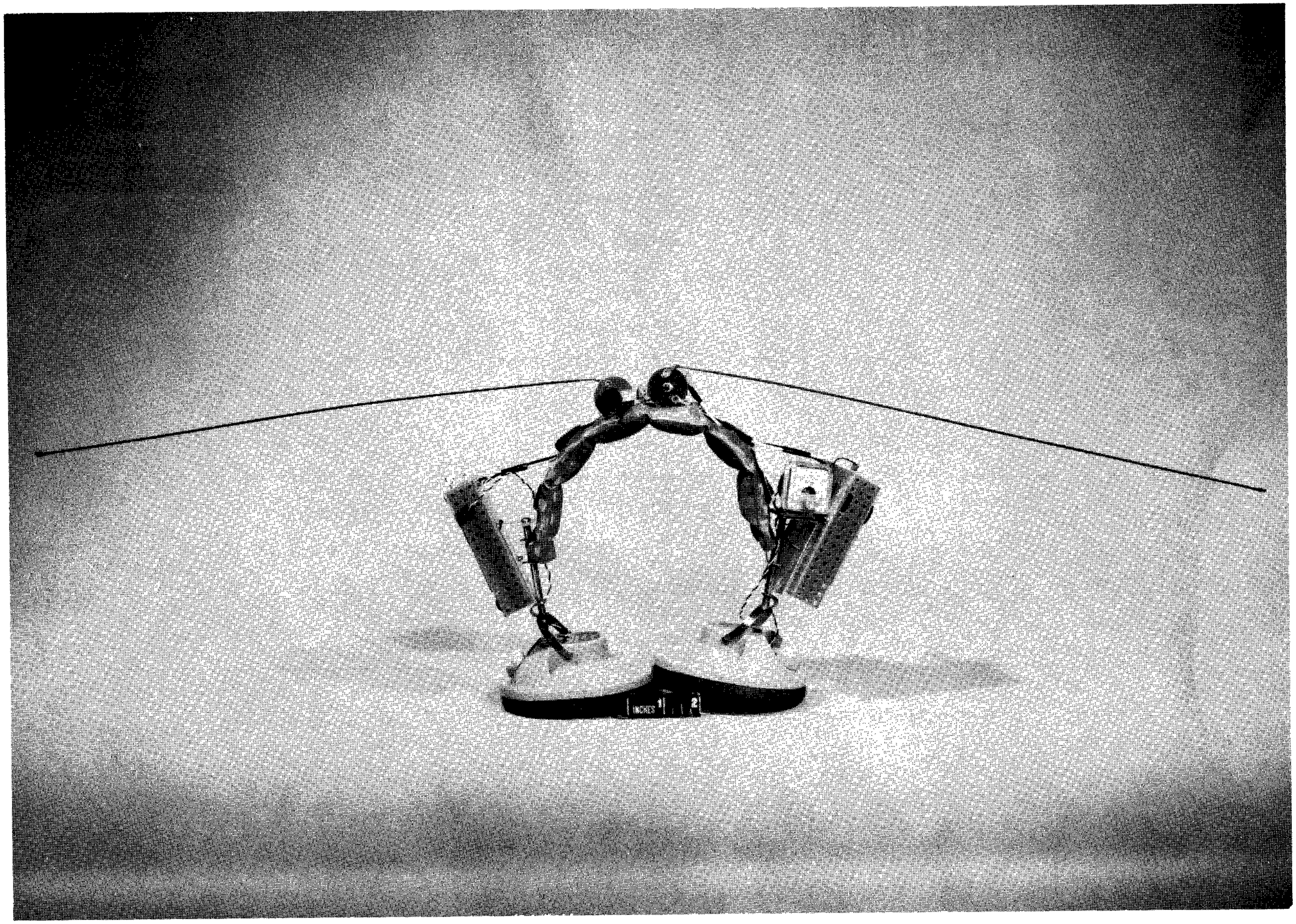

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Figure 5.- Laboratory model.

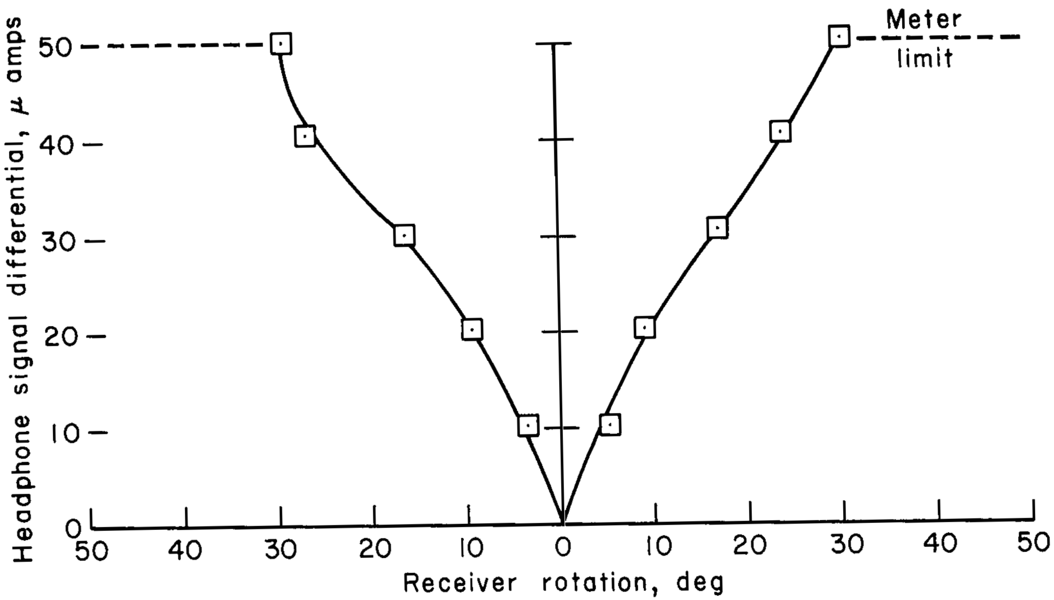

Figure 6.- Directional response of the constructed model.

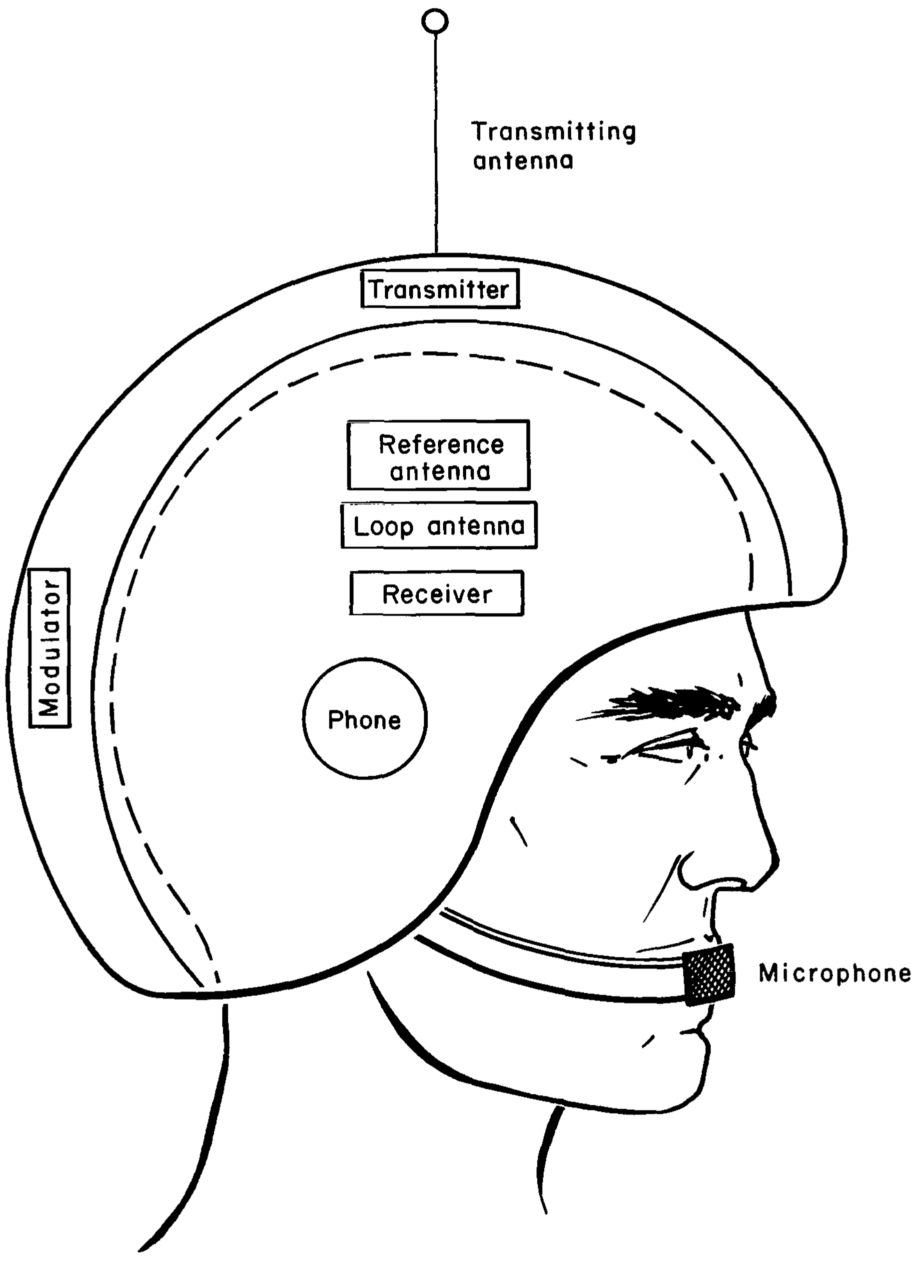

Figure 7.- Amplitude stereophonic system.

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