RESEARCH ON GUIDANCE DEVICES FOR THE BLIND

A Progress Report
of work done at the

HASKINS LABORATORIES
New York City

Between
February 15, 1944 and December 1, 1946

under the Auspices of

THE COMMITTEE ON SENSORY DEVICES
The National Academy of Sciences

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I. INTRODUCTION

A. THE CENTRAL LABORATORY

Studies on sensory devices have been in progress at the Haskins Laboratories under contracts[1] administered by the Committee on Sensory Devices since February, 1944. As central laboratory for the Committee, the Haskins group was directed at the beginning of its assignment (1) to act in a general technical advisory capacity to the Committee, (2) to undertake the critical evaluation and study of the usefulness to the blind of devices produced by other contractors sponsored by the Committee, and (3) to carry on collateral technical and psychological research on guidance devices and reading machines for the blind.

The Haskins Laboratories maintain engineering and psychological testing facilities on three floors of the building at 305 East 43rd Street in New York City. The personnel of the Laboratories, most of whom are concerned with work on sensory devices, includes seven engineers and physicists, four psychologists, two physiologists, seven technical and laboratory workers, six shop workers, and four clerical workers. A number of blinded veterans are employed by the Laboratories on a part time basis to act as subjects in the testing program.

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[1] Work by the Haskins Laboratories for the Committee on Sensory Devices has been supported through the following contracts:

Contract No. VAm-21223, administered through the National Academy of Sciences, under sponsorship of the Veterans Administration. July 1, 1946 to June 30, 1947.

Contract No. W-49-007-MD-347, administered through the National Academy of Sciences, under sponsorship of the Office of the Surgeon General, U.S. Army. November 1, 1945 to June 30, 1946.

Contract No. OEMcmr-522, administered through the National Academy of Sciences, under sponsorship of the OSRD. October 16, 1945 to October 30, 1945.

Contract No. OEMsr-1316, administered through the OSRD. February 15, 1944 to October 15, 1945.

The program of work at the Haskins Laboratories falls broadly into three categories: (1) guidance devices, (2) reading machines, (3) cooperation with the Armed Services and certain other extra-mural agencies. The present report concerns itself with the first category and to some extent with the third.

B. THE GUIDANCE DEVICE PROGRAM

When the Committee's work on guidance devices was initiated, the objective was set in rather general terms as the development of a portable device which would enable the average blind person to find his way about with more ease and efficiency than with the aid of the traditional cane or the seeing-eye dog. In the initial stages of the program, it was felt that a hand-held "probe" capable of locating objects and giving range information up to distances of perhaps fifty feet would prove useful. The possibilities were considered of using optical, supersonic, radar, or proximity fuse techniques. Supersonic methods appeared to warrant major attention, particularly in view of the rather considerable maximum range thought to be necessary. Since the signals given by such a device would be rather complex, varying rapidly in intensity, frequency, and quality, it was decided to use auditory presentation at the start, partly for convenience, but mostly in the hope that the user could integrate the detailed point-by-point information into a helpful mental construct of his environment. The extent to which point-by-point information can be so integrated remains one of the outstanding fundamental problems.

It became apparent during the course of the work that there are two specific and quite different requirements for guidance devices. The first is for what might most accurately be called a short-range obstacle locator, i.e., a simple, highly portable unit which could be used to locate objects and obstructions and to give tactile indications of range up to about ten feet. It could be used continuously or intermittently in familiar surroundings to check the location of landmarks and to avoid moving obstacles.

The second and more difficult requirement is for a recognition device which can provide "patterned" information, i.e., a plan impression good enough to be useful in identifying objects and in forming a mental construct of a new environment.

Devices to meet the first requirement have received major emphasis, and most of the tests have been directed to their evaluation in the detection and location of obstacles at short ranges. The devices thus far available for testing have been comparatively crude and, until the recent use of tactile stimulators, have employed the auditory entry portal. However, the results have been definitely encouraging on two counts: (1) the blind subjects can learn to use the devices with considerable success in many types of situations, (2) the power and weight requirements of the devices are small enough that final models can be expected to be quite readily portable.

Thus the prospects seem good for the development of a successful general-use short-range obstacle detector. Whether the final device will utilize light or supersonics is not yet clear; experience thus far, and user reaction to the devices tested, appear somewhat to favor the supersonic method.

The prospect for a successful pattern device is more difficult to assess since the determining factor is the perceptive process for auditory or tactual patterns. Theory and analogy, as far as they go, are favorable. On the instrumental side the development seems straightforward and quite feasible. The tests have not yet gone far enough to give a reliable indication, although the results are as good as one could expect from the first comparatively crude apparatus. The sound spectrograph and play-back techniques being developed in connection with the reading machine program will be extremely useful in evaluating some of the fundamental points involved in pattern systems.

C. THE PRESENT REPORT

Work is continuing actively on the guidance device project. The present progress report is a synoptic review of the work on this subject up to December 1, 1946. Since the Haskins Laboratories were charged with primary responsibility for the evaluation of devices, whereas development of the devices was assigned principally to other contractors under the Committee, the present report is largely concerned with the methods and results of the psychological testing program. In addition, a reasonably full account is given of the devices tested and the physical principles on which such devices must be based.

The guidance devices discussed in this report were, for the most part, developed under contracts, arranged and recommended by the Haskins Laboratories and sponsored by the Committee, with the Brush Development Company, the Hoover Company, and Stromberg-Carlson, Inc. The contracts were for the development of experimental models of small portable devices which would give the blind man more information about his environment than he could obtain through the use of dogs, canes, or the usual auditory cues. Each of the companies was to approach the problem of developing a supersonic device from a special technical angle, i.e., Brush -- crystal transducers; Hoover -- mechanical transducers with gating mechanisms; Stromberg-Carlson -- magneto-striction transducers. Each of the companies has delivered several models to the Haskins Laboratories for testing. In all models tested, deficiencies and areas for improvement have been revealed, and design and constructional suggestions have been made to the various contractors. A recent contract with the Franklin Institute Laboratories for Research and Development provides for a broad study of the possibilities of employing optical means in the operation of a short-range obstacle locator. There has not yet been time for the development of models for test under this contract.

The guidance device program at Haskins Laboratories includes research activities which are directed toward:

(1) The identification of the objects and situations which are considered by the blind to create serious problems for them. The design of guidance devices, and the test procedures for their evaluation have been based to a large extent on the results of a preliminary investigation into the kinds of practical problems for which guidance devices might provide solutions.

(2) Initiation of the engineering development of promising guidance devices by other contractors, and, when appropriate, the development of experimental models of new types of devices at the Laboratories.

(3) An evaluation of experimental models of guidance devices on the basis of relatively standardized tests. The tests measure the performance of blind subjects with and without the devices in situations in which the subjects are required to avoid obstacles, detect step-downs, judge obstacle size, negotiate doorways, judge range, and move about in outdoor situations.

(4) The development and application of procedures calculated to train blind persons for the most effective use of guidance devices. Such procedures are developed on the basis of experience with the various devices; adequate training appears to be essential to the fair evaluation of any guidance device.

(5) The determination of how best to present to the user the information which is collected by a guidance device. These studies, utilizing actual and simulated signals[1], are aimed primarily at determining those characteristics of auditory, tactile, and electrical stimuli which are most nearly optimal for use in connection with the several types of guidance devices now under consideration.

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[1] Special equipment was developed by Columbia Broadcasting System under a contract administered by the Committee on Sensory Devices.

(6) A study of auditory patterns to determine how readily such patterns, and hence the objects from which they are derived, can be recognized. Variations in the auditory pattern due to the distance, aspect, and illumination of the object must be considered in determining the feasibility of developing a pattern optical device.

(7) A preliminary study of "obstacle sense" in the blind. A test of ability to avoid obstacles has been developed which is based on a comparison of obstacle avoidance when all normal cues are available with performance when all such cues are effectively eliminated. The results of this test provide a reference level of proficiency against which performance with guidance devices may be compared, and provide also a basis for a further investigation of the nature of the skills involved in obstacle avoidance by the blind.

(8) Design and construction of special test equipment and electronic devices necessary for the psychological research outlined above; maintenance and repair of guidance devices during the testing and training programs. Together, these functions constitute a very substantial part of the total program on guidance devices.

The present progress report covers the work done along most of these lines.

D. FUTURE WORK

The plans for future work are elaborated in a separate prospectus, "A Research and Development Program on Guidance Devices for the Blind", which indicates projects now under way and additional projects needed to ensure a well rounded program.

II. PHYSICAL ASPECTS OF GUIDANCE DEVICES

A. GENERAL STATEMENT OF THE PROBLEM

The purpose of this section is to discuss the physical aspects of guidance devices, particularly of those which have been developed and tested to date.

There are two major and basically separate requirements for a guidance device: (1) to serve as an anti-collision obstacle locator for the blind; (2) to provide a unitary mental construct of the environment. Although it would be desirable to incorporate these functions into a single device, it became apparent during the investigation that attention should be concentrated on the construction of a suitable device meeting the first requirement, since such a device could be put into use while the requisite research on a patterning device was in progress. Hence, the major emphasis of this section is on anti-collision obstacle locators; however, a device providing an auditory pattern representative of the environment is discussed briefly since some of its physical aspects are essentially similar to those of an obstacle locator, and since a device of this type is currently under test.

Early considerations of obstacle location suggested the use of supersonic or electromagnetic radiation, particularly in view of the extensive developments and applications of sonar and radar during World War II, and of the familiar principles of optical range-finders. There are, however, significant differences between the requirements of sonar and radar systems, for example, and those for an obstacle locator. Thus, the range of distances to be gauged by an obstacle locator is zero to ten or fifteen feet; the output signal is to be tactile or auditory (while minimizing interference with the normal uses of hearing); and complete portability (hence small size, convenient shape, minimum weight, and low power requirements) is essential. Fulfillment of these requirements introduces problems peculiar to the development of an obstacle locator.

B. PROPAGATION OF RADIANT ENERGY

1. General Properties of Wave Propagation

Propagation properties refer to the various factors which affect radiant energy from the time it leaves the transmitting system (a light source and associated lens; a transmitting antenna, or a sound source) until it reaches the receiving system (a lens and photocell, antenna or microphone); that is, the properties of the transmission of energy through space together with the properties of the target or reflecting object.

Supersonic radiation (sound of frequency too high to be audible) consists of longitudinal vibrations of the particles in a medium giving rise to alternate compressions and rarefactions. Electromagnetic radiation, on the other hand, consists of rapidly varying electric and magnetic fields which are at right angles to each other and at right angles to the direction of propagation. It might be expected that the propagation properties of these two kinds of radiation would be quite different. Such is indeed the case, although identical categories of properties exist for both. Thus, overall propagation characteristics are in general determined by: (1) frequency, (2) intensity, (3) velocity, (4) attenuation, (5) scattering, (6) the nature of the medium, including variation in the index of refraction for electromagnetic radiation and variations in density for supersonic radiation, (7) atmospheric effects, including wind, rain, and ambient radiation, (8) effect of nearby objects, including walls (giving rise to multiple reflections, for example), (9) the nature of the target or object itself, including scattering cross-section, the angle at which it is viewed, the size of surface irregularities compared with the wavelength of the radiation (i.e., specularity), and reflectivity, and (10) relative motion of target and observer (Doppler effect).

Many of the above factors have been investigated extensively from the viewpoints both of physics and of engineering applications. However, some physical factors of particular interest to the guidance device problem have not yet been studied despite the remarkable strides in related fields during the War. For example, the design of highly efficient electromagnetic or supersonic transmitters involves fundamental problems of physics[1]. The computation of scattering cross-section (the percentage of energy scattered back in the direction of a beam) of typical objects, for a variety of aspects, is at best laborious and in many cases not possible. There are as yet no suitable sources or detectors in the far infra-red region of the electromagnetic spectrum, and therefore no means of utilizing the thermal radiation properties of different objects.

2. Propagation Properties of Supersonic Radiation

a. Frequency, Attenuation and Intensity

The lower limit on frequency for a guidance device using supersonic radiation is determined by the requirement that the radiated energy shall be inaudible; consequently, the lower limit is approximately 20 kc. The upper limit of the transmitting frequency is determined by the magnitude of the attenuation which can be tolerated, since the absorption increases rapidly with frequency. Fig. 2.1 shows attenuation in decibels per foot as a function of frequency in kilocycles per second. From this it is seen that the attenuation for a total distance of 20 feet (i.e., for an object 10 feet away) is 0.3 db at 20 kc and is 7.7 db at 100 kc. These values of attenuation can also be stated

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[1] See, for example, the basic study on supersonic transducers conducted as a part of the Committee's program on guidance devices by Stromberg-Carlson: "Directional Characteristics of a Free Edge Disc Mounted in a Flat Baffle or in a Parabolic Horn", F.H. Slaymaker, W.F. Meeker, and L.L. Merrill, J. Acous. Soc. Am. 18, 355 (Oct., 1946).

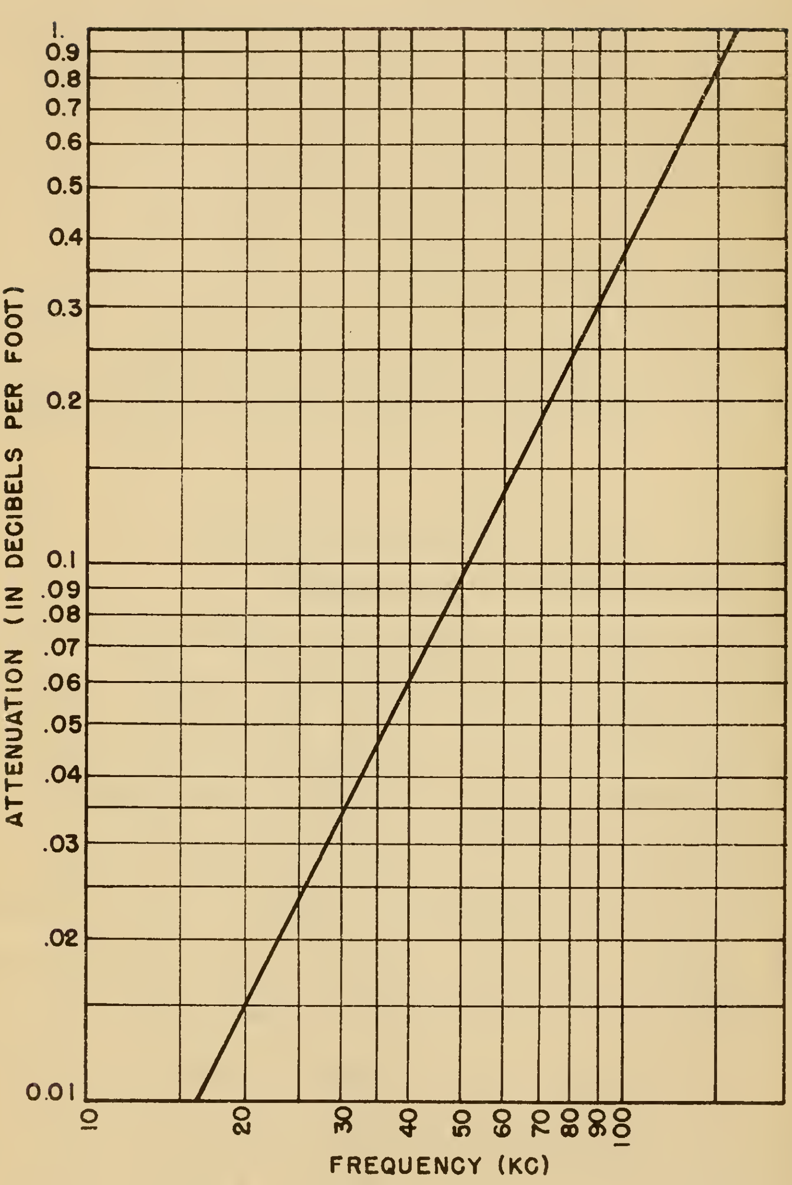

FIG. 2.1
ATTENUATION IN DECIBELS
PER FOOT VS. FREQUENCY
IN CYCLES PER SECOND

as power losses; Fig. 2.2, a plot of attenuation (in decibels) against the percentage of the power absorbed, shows that for a loss of 0.3 db (corresponding to a frequency of 20 kc and an object at 10 feet) 6.5 percent of the total power is absorbed, whereas for a loss of 7.7 db (corresponding to a frequency of 100 kc and an object at 10 feet) 83 percent of the power is absorbed. Thus powerful sources (or very sensitive receivers) are required if the higher frequencies are used. On the other hand, an advantage may be gained by using frequencies which are attenuated rapidly with distance since multiple reflections and the consequent possibility of ambiguous signals is minimized. Moreover, the size of the radiator can be reduced at higher frequencies without increasing the width of the beam.

The discussion of attenuation thus far has assumed a transmission path in dry air under standard conditions of temperature and pressure. However, the attenuation is affected also by temperature and humidity. For example, in air at 20°C the attenuation of 20 kc radiation increases by a factor of two when the relative humidity changes from 20% to 50%; the effect is greater at higher frequencies. An increase in temperature also causes a marked increase in attenuation.

b. Velocity and the Doppler Effect

For most purposes it is sufficiently accurate to take the velocity of sound as 344 meters per second (1130 feet per second). For precise measurements small variations due to temperature and humidity must be taken into account. Barometric pressure does not affect the velocity.

The velocity of a sound wave is given by

$$V = \sqrt{\frac{K}{\rho \, \beta_{is}}} \qquad (2.1)$$

where K is the ratio of specific heat at constant pressure to that at constant volume,

ρ is the density, and

β_{is} is the thermal compressibility.

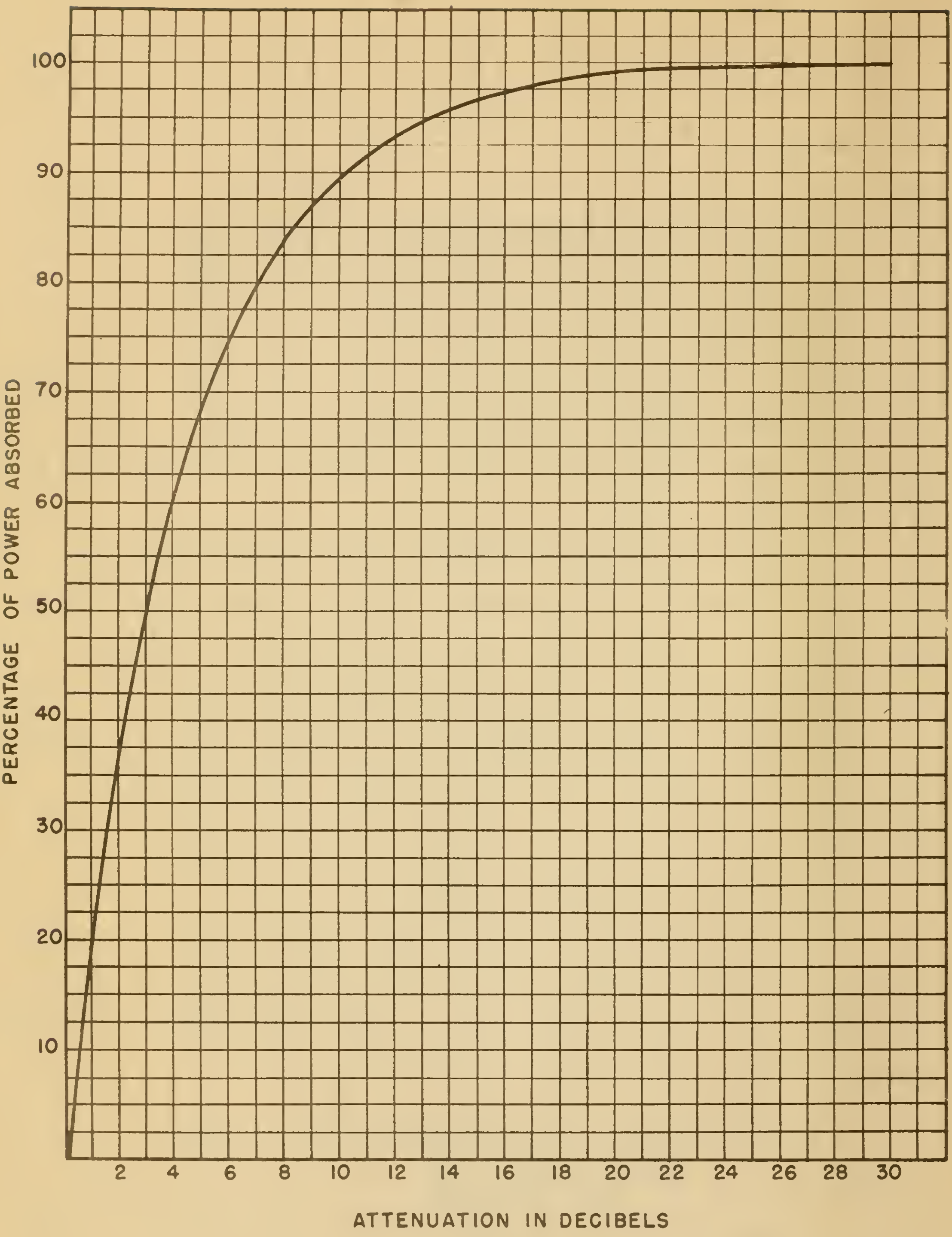

FIG. 2.2
ATTENUATION IN DECIBELS
VS.
PERCENTAGE OF POWER ABSORBED

Assuming that air behaves as an ideal gas the expression for the velocity becomes

$$V = \frac{p K}{\rho} \qquad (2.2)$$

where p is the pressure of the gas. The velocity is not affected by changes in barometric pressure since the density is changed in the same proportion so that P/ρ is a constant. On the other hand the velocity is affected by changes in temperature since a temperature change influences the density without affecting the pressure; the variation is 0.6 meters per second per degree Centigrade change in temperature. The velocity is affected by changes in humidity also.

The relative motion of an observer and a source of sound produces an apparent change in frequency at the observer - the Doppler effect. In the case of a blind person using a device while walking, both source and receiver are moving (since both are carried by the user) producing a two-fold shift in frequency. In addition, the object may be moving relative to the user, producing a further shift. Finally, a strong wind may cause an additional change. Guidance devices utilizing frequency modulation are limited by the Doppler shift in frequency; the limitation is not serious when the operating frequency is 20 kc, but it is severe at higher frequencies.

If a source is moving relative to a stationary receiver the change in frequency at the receiver is given by

$$\Delta \nu = \frac{\pm \nu \, v_s}{V \mp v_s} \qquad (2.3)$$

where ν is the transmitting frequency,

v_s is the velocity of the source, and

V is the velocity of sound.

The upper signs are for a source approaching a receiver; the lower signs for a source receding from the receiver.

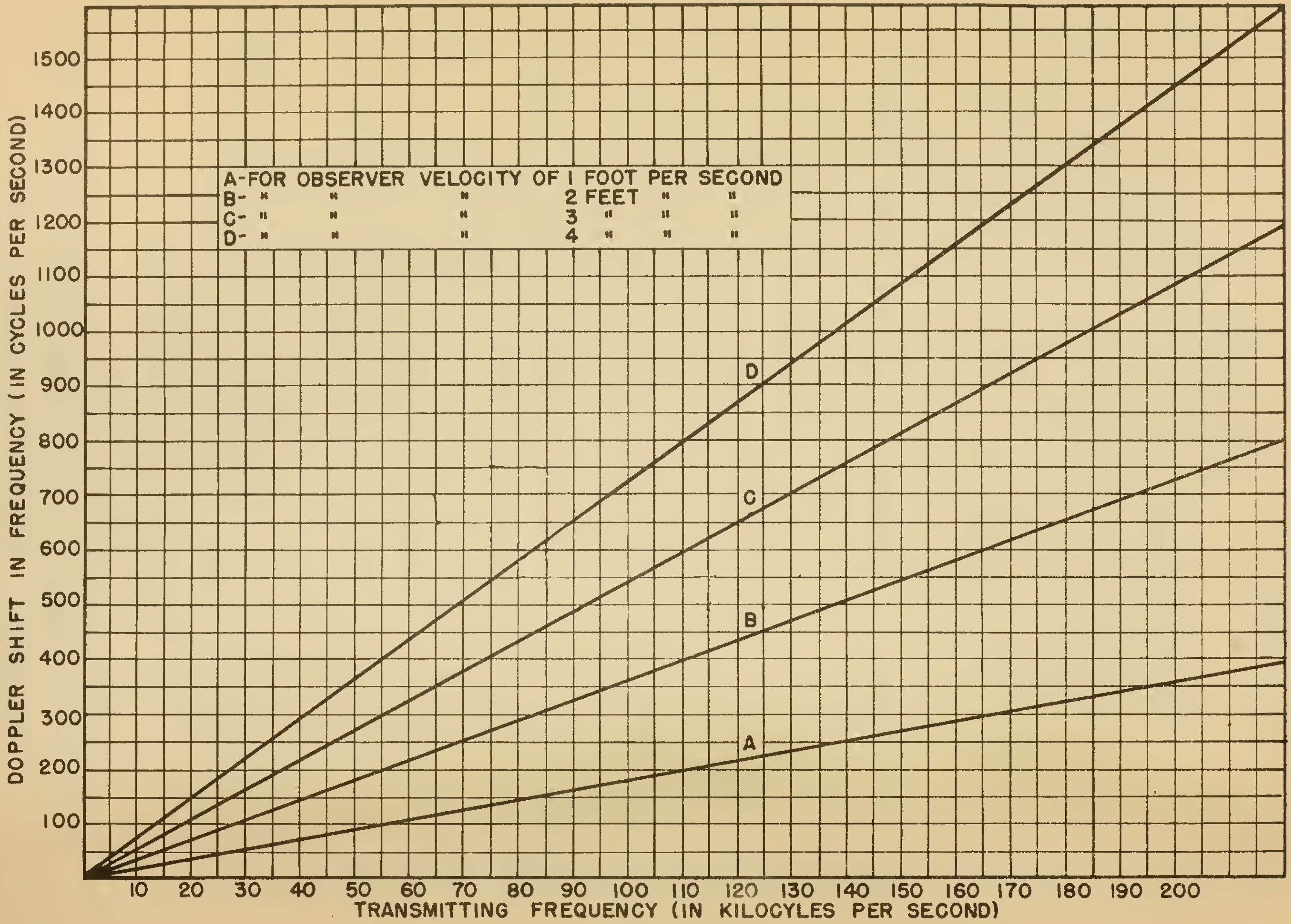

FIG. 2.3
DOPPLER SHIFT IN FREQUENCY (IN CYCLES
PER SECOND) VS. SUPERSONIC TRANSMITTING

Correspondingly, if a receiver is moving relative to a stationary source the change in frequency at the receiver is given by

$$\Delta \nu = \frac{\pm \nu v_r}{V} \tag{2.4}$$

where v_r is the velocity of the receiver. The positive sign is for approach, the negative sign for recession. If both the source and the receiver are in relative motion, and if in addition there is motion of the air, the change in frequency at the receiver is given by

$$\Delta \nu = \frac{\nu (v_s - v_r)}{V + W - v_s} \tag{2.5}$$

where W is the component of wind velocity parallel to the line between source and observer, and the positive direction of the velocities is measured from the source to the observer. In guidance device applications the observer carries the source of sound with him, and the reflecting object serves as a virtual source whose radiation is received by the observer. For an observer in motion toward a stationary object there is, then, a change in frequency at the object. The radiation of this new frequency at the object serves as a secondary source which the moving observer receives at a higher frequency, resulting in a twofold shift in frequency (the frequency increases if the observer approaches the object, and decreases if he recedes). Fig. 2.3 shows the Doppler shift plotted against the transmitting frequency for an observer carrying a source and receiver toward a stationary reflector at different velocities. The frequency shift is 120 cycles per second for 20 kc radiation for an observer velocity of 3 feet per second; it is 560 cps for 100 kc radiation for the same observer velocity.

c. Scattering and the Nature of the Medium

Attenuation may be due, among other causes, to scattering. When a plane wave strikes an obstacle, some of the radiation is scattered in all directions, distorting and interfering with the initial plane wave. For obstacles which are small compared with the wavelength of the radiation there is a uniform distribution of the scattered radiation (rather than sharp shadows); for obstacles which are comparable in size with the wavelength various interference phenomena occur. In either case, energy is removed from the useful beam and the effect is the same as if the attenuation had occurred by absorption of the radiation.

On the other hand, it is the portion of the radiation scattered directly back to the guidance device which constitutes the echo from a diffuse reflector, i.e. from a rough object such as the ground or other surfaces having irregularities of a few millimeters to a few centimeters in size. A number of surfaces commonly encountered, e.g. walls and table tops, do not have irregularities of this size, and hence give little or no diffuse back-scattering of supersonic radiation to reveal their presence. (See: g. Nature of the Target.)

In non-homogeneous air where there are marked velocity gradients (inhomogeneities large compared with the wavelength) scattering occurs primarily by refraction. Some of the energy may be refracted backwards, giving rise to spurious echoes. These effects have been observed occasionally.

d. Multiple Reflections

Although extensive measurements on reverberation have been made for sound waves in the audible range of frequencies, the seriousness of this phenomenon in reference to supersonic guidance devices has not been explored systematically. Some ambiguity may be caused by the presence of multiple reflections; on the other hand, advantage has been taken of this feature in the detection of low obstacles. (See III-D-1-d-2.) Further, it is expected that troublesome multiple reflections can be minimized by the increased attenuation at the higher supersonic frequencies.

e. Atmospheric Effects

Limited experience under various atmospheric conditions has not indicated that any important difficulties are to be expected from these causes, with the possible exception of air turbulence.

Consideration has been given to variations in temperature, humidity, and wind velocity averaged over large areas and for relatively long times. Inhomogeneities in the atmosphere near the surface of the earth (within an altitude of ten feet) give rise to sharp temperature, humidity, and velocity gradients.

There are two types of temperature fluctuations: (1) rapid variations in the temperature itself at a given point: (2) variations in the temperature gradients. Investigations on Ultrasonic Signalling conducted by The Pennsylvania State College (under OSRD contract) have shown that the temperature of the air at a point near the earth's surface may vary as much as 10°C over a period of one or two seconds; the variations are greatest in the sunlight and approach zero as the temperature gradients approach zero. Variations in temperature gradients may be of two types: those for which the temperature decreases for increasing heights (called lapses), and those for which the temperature increases for increasing heights (called inversions). In general, these temperature gradients are never uniform, continually undergoing small scale changes, and indicate a stratification of the air, since at one region a lapse may occur while an inversion exists nearby. The lapses are greatest in the sunlight, decrease for cloudy weather, and are nearly zero for rain.

Studies have not been reported on the effect of variations in humidity near the earth's surface, but inhomogeneities in the watervapor content are to be expected.

The wind varies rapidly and erratically near the surface of the ground due to turbulence in this region; the variations are large for large temperature fluctuations.

Although the effect of rain on supersonic radiation has not been investigated, weather conditions are in general more uniform during rainy seasons than during dry ones.

f. Ambient Noise

No interference due to ambient noise has been noticed with the supersonic devices during the tests thus far undertaken.

The effect of ambient radiation would be to limit the useful range of a guidance device, since the signal-to-noise ratio would be lessened and any increase in the sensitivity of a receiver would, for a given selectivity, increase the noise in the output. It is desirable, therefore, to have information on the spectral distribution of sonic energy in the 20 to 100 kc region. Extensive measurements have been made on the frequency distribution in the audio-frequency range of sounds such as street noise in metropolitan areas. Few measurements have been made on the distribution in the supersonic frequency range. The measurements which have been made indicate that supersonic noise is usually associated with audible noise; insect noises, for example, resemble random noise. In general, little difficulty is to be expected from ambient supersonic radiation if narrow-band receivers are used.

g. Nature of the Target

The surface irregularities of many objects are small compared with the wavelength of the supersonic radiation used (1.6 cm for 20 kc radiation); hence, many objects will serve as mirrors for supersonic radiation. That is, if a beam of supersonic radiation is directed perpendicular to a plane surface, the beam will be reflected back toward the source. If, however, the beam strikes a plane surface at an oblique angle, the energy will be reflected from the surface at an angle equal to the incident angle, and consequently will not return to the transmitter-receiver unit. This specular reflection may set a serious limitation on the use of supersonic radiation for guidance devices[1]. Of course, the degree of specularity decreases as the frequency of the radiation increases, but an increase in frequency is associated with an increase in attenuation, so the problem can not be solved completely by utilizing higher frequencies.

However, there is some scattering of the radiation from most objects, and some of the radiation will therefore be scattered back in the direction of the receiver. Consequently, high-powered beams and highly sensitive receivers are needed, and automatic volume control will be useful in covering the intensity variation from weak (scattered) echoes to strong specular echoes. Also, since the beams of sonic radiation are not pencil beams but have a finite width, the effects of specularity are somewhat reduced in many of the usual situations. Few computations have been made on the scattering from different objects; in general it is simpler to make measurements on a variety of objects, variously oriented[2].

The detection of supersonic echoes is complicated by interference between the reflected radiation and the incident radiation, or between the radiation reflected from different parts of the target. The interference may

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[1] Specularity is also a problem with the usual type of sonar and radar systems. The problem is solved by using high power transmitters, pulsing techniques and very sensitive receivers. In general this means weight and power requirements which can be tolerated for airborne or shipborne equipment but which are prohibitive for a guidance device. On the other hand, the ranges of interest for a guidance device are far different from those in a radar or sonar system. The relationship between peak power, range, and received signal intensity are considered in section II-C.

[2] The Stromberg-Carlson Company is currently engaged in theoretical and experimental studies of this nature.

be destructive or constructive; that is, the phase relationships of the two radiations may be such as to cause cancellation or reinforcement. Hence, fluctuations in signal intensity at the receiver are to be expected.

The absorption of supersonic radiation is a factor to be considered in the problem of detecting obstacles. Again, ample data on the absorption coefficients of different materials at audible frequencies are available; few are available on absorption coefficients at supersonic frequencies[1]. However, most materials cause very little absorption.

3. Propagation Properties of Electromagnetic Radiation: Visual Region

a. Attenuation and Scattering

Losses due to attenuation of visible light (4000 - 8000 Å) in air are negligible. Losses due to scattering by rain, snow and fog may occasionally be troublesome to about the same degree that they affect visibility for sighted persons. To a limited extent, the effects of scattering can be minimized by using light at the red, rather than blue, end of the visible spectrum. Fortunately, this coincides with the choice of frequency dictated by lamp efficiency and by photocell sensitivity.

b. Velocity and the Doppler Effect

The velocity of light (3×10^{10} cm/sec.) and the frequency of 6000 Angstrom radiation (5×10^{14} cycles/sec.) result in a Doppler shift of the order of 2 megacycles per second, or roughly four parts in a hundred million. Thus, the effect is negligible and frequency-modulated systems could be used without difficulty from this cause, if appropriate light sources were available.

c. Ambient Radiation

Ambient radiation plays two quite different roles in connection with guidance devices using visible radiation. On one hand, the effect of

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[1] The Stromberg-Carlson Company is currently engaged in theoretical and experimental studies of this nature.

ambient radiation must be minimized, if a device employing its own light source is to be used; on the other hand, ambient radiation provides the only illumination for those devices designed to operate without their own light sources.

The spectral distribution of daylight and diffuse sunlight indicates very little energy below 3000 Angstroms. The amount of ambient energy increases with increasing wavelength and is considerable in the near infra-red region. Most visible light sources also emit radiation in the infra-red and in the ultra-violet. The principal effect of ambient radiation, particularly of sunlight because of its very high intensity, is to reduce substantially the signal-to-noise ratio. Even with highly selective receivers and a very narrow light beam, ambient light effects remain a major design problem.

In devices designed to utilize ambient light, differential reflection of the ambient radiation from various objects is of primary importance. The spectral distribution of the ambient radiation is also significant, and largely determines the selection of a detector with high sensitivity in the wavelength regions of maximum radiant energy, i.e. the visible and near infra-red.

f. Nature of the Target

The most significant target characteristic is reflectivity. Specularity is of little consequence since the surface irregularities are in most cases large compared with the wavelength, except for mirror surfaces. Most targets are detected by diffuse reflections (scattered radiation). The differences in the reflectivity of various materials indicate that the amount of light reflected from an object cannot be used per se as a source of range information. Also, the wide differences in reflectivity impose a further requirement on a device using its own light source in addition to the requirement imposed by the tremendous differences in the intensities of ambient illumination encountered under various circumstances.

Ambient light devices based on range-finder principles or longitudinal magnification cannot detect a uniform white wall, for example, since they are dependent on sharp changes in contrast. Although ambient light guidance devices have the inherent advantage of low power requirements and small size, the contrast requirement for such devices is a fundamentally restrictive factor.

4. Propagation Properties of Electromagnetic Radiation: Non-visual Region

a. Ultraviolet Radiation

The ambient radiation usually encountered, i.e. daylight and incandescent lamps, contains comparatively little ultraviolet, and practically none below 3000 Angstroms. This suggests the development[1] of a device with self-contained light source operating in the ultraviolet, perhaps utilizing the mercury resonance radiation (2536 Å). The advantages of freedom from ambient radiation would be considerable; there would, however, be special development problems to be solved. An efficient low power (ca. one watt) lamp would be required, and preferably it should operate at low voltage and be capable of modulation at several hundred cycles. Also, little information is available about absorption and reflection by common materials at short wavelengths.

b. Infra-red Radiation

Sunlight and the light from incandescent lamps is rich in infra-red radiation; a large fraction of the total radiant energy lies in the region of the spectrum just beyond the deepest visible red, i.e. the near infra-red. The absorption and reflection of infra-red radiation by various surfaces differs widely and does not always correspond with the absorption and reflection of visible light.

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[1] A project along these lines is under consideration by the Franklin Institute under CSD contract.

Small incandescent lamps provide convenient and comparatively efficient sources of infra-red light, though the light output is not readily modulated except by mechanical interruption. Detection of infra-red radiation is easily accomplished with common types of photo-cells. Hence, guidance devices with self-contained infra-red sources can readily be designed, but they must operate in a spectral region for which ambient radiation is most intense. On the other hand, devices designed to utilize ambient radiation would probably take advantage of the near infra-red in addition to visible light.

c. Thermal Radiation

All objects, even those at room temperature, are continuously emitting electromagnetic radiation, and absorbing it from surrounding objects. However, the intensity of the radiation falls off very rapidly with decreasing temperature, and the wavelength at which most of the energy is radiated becomes greater. Hence thermal radiation (from objects near room temperature) is rather weak, and, moreover, lies in a spectral region for which neither concentrated sources nor sensitive and convenient detectors are as yet available. A further difficulty in the possible use of thermal radiation for an ambient light type of guidance device lies in the fact that all the objects in a room, if they were at the same temperature, would appear equally "bright", i.e. show no contrast, since the sum of the thermal radiation emitted and that reflected would be independent of the surface characteristics of the object, and dependent only on the temperature.

d. Radiation in the millimeter region

Guidance devices employing electromagnetic radiation in the millimeter region have been given passing consideration. Frequency-modulated systems might be used since the Doppler shift in frequency would be very small. However, the same problems of specularity would exist as with supersonic radiation of approximately the same wavelength. It would be possible to use increasingly shorter wavelengths without the limitations due to the attenuation of supersonic radiation at higher frequencies. Two important difficulties would have to be met: (1) no suitable transmitters of reasonable efficiency and low power requirements are as yet available in the millimeter region; (2) a strong absorption band for water vapor exists at about 8 mm, and strong oxygen absorption bands exist for shorter wavelengths (although there is a gap between the water vapor and the oxygen absorption regions). It appears that marked superiority of electromagnetic radiation in this region would have to be demonstrated before the development of a device should be considered seriously.

C. ELEMENTS OF SYSTEM ENGINEERING

The design considerations applicable to guidance devices depend largely upon the design objectives. It is desirable, therefore, to specify the design objectives even though many of them can be stated only tentatively.

1. Design Objectives of a Short-Range Obstacle Locator

The design objectives of a short-range obstacle locator may be tentatively specified as follows:

a. Weight: Not to exceed 2 lbs.

b. Form Factor: Two packages; one, the "prospector" housing the transmitting and receiving transducers; the other housing the remainder of the system, including the batteries and electronic components. The weight of the prospector should not exceed one-half pound and should be shaped to provide the greatest facility in use, even over extended periods. (A suitable form would be a cylindrical tube approximately two inches in diameter and five inches long.) The second package should be shaped to fit in a hand bag or pocket, or to be carried on a shoulder strap (like a miniature camera).

c. Battery Life: The A and B batteries should have a life of at least ten hours each, under a normal use cycle.

d. Indication: Tactile, located on the prospector.

e. Output power: Between 30 and 50 milliwatts, depending on the tactile stimulator used; the output signal should be readily perceived under all conditions.

f. Range: 0 to 10 feet, approximately (decreased accuracy can be tolerated for ranges in excess of 10 feet).

g. Range Accuracy: To be specified after additional tests.

h. Antenna diameter: Approximately 2 inches.

i. Beam width: Approximately 10 degrees (between half-power points).

j. Reliability and Performance Checks: The device should be stable and consistent in performance; insensitive to weather and rough treatment; and subject to quick overall performance checks.

k. Replacement of parts: It should be possible for a blind user to replace batteries easily and quickly.

l. Controls: Front-panel controls should be kept to a minimum.

2. Supersonic Systems

Some of the design considerations for a supersonic system, to fulfill the above objectives are as follows:

a. Antenna Gain

A directional sound source and receiver, i.e. an "antenna", is required to permit the location and, to a degree, the identification of objects; it serves also to minimize the power requirements. The power at a point distant from a directional antenna differs from that produced by an antenna radiating the same total power in all directions. The ratio of the power from a directional antenna to that from an isotropically radiating antenna, is defined as the gain of the antenna, and designated by G. If the antenna has a well defined beam, the maximum gain, G_o, is related to the aperture, A, and the wavelength, λ , as follows:

$$G_o = \frac{4\pi A F}{\lambda^2} \tag{2.6}$$

where F is a constant depending upon the form of the radiating source and the phase and intensity relationships over the entire aperture; it is 1 for uniform phase and intensity relationships over the entire aperture, but usually varies between 0.5 and 0.7.

The effective receiving cross-section of an antenna, A_r, is intimately related to the gain of the antenna:

$$A_r = \frac{G \lambda^2}{4 \pi} \qquad (2.7)$$

where G is the gain of the antenna (not the maximum gain since this relationship is not restricted to any given direction)[1].

b. Beam Width

The beam width of an antenna, the angular separation between the half-power points in the antenna pattern, is approximately

$$\theta = 70 \frac{\lambda}{D} \text{ degrees} \qquad (2.8)$$

where D and λ are in the same units and D is the diameter of the antenna. For 1 cm radiation and an antenna diameter of 7.5 cm the beam width is approximately 9°. Fig. 2.4a shows the radiation pattern of a parabolic reflector, and its beam width; Fig. 2.4b shows a polar plot of the radiation pattern of a parabolic reflector.

c. Ratio of Received Power to Transmitted Power

Assuming free-space propagation[2] the ratio of the power received from an obstacle, p_r, to the power output at the transmitter, P_t, when the transmitter and receiver are at the same location is directly proportional to

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[1] If F = 1, a comparison of equations (2.6) and (2.7) shows that the effective receiving cross-section of an antenna in a given direction is $A\,G/G_0$

[2] Conditions for free-space propagation are fulfilled if: (1) there are no obstacles present between the transmitting and receiving horns and the object, (2) there is no alternative transmission path, (3) the atmosphere is homogeneous, and (4) there is no absorption by the atmosphere. It is assumed here that the object is large compared with the beamwidth, that is, the object intercepts the entire beam, and only a relatively small area of the object is illuminated.

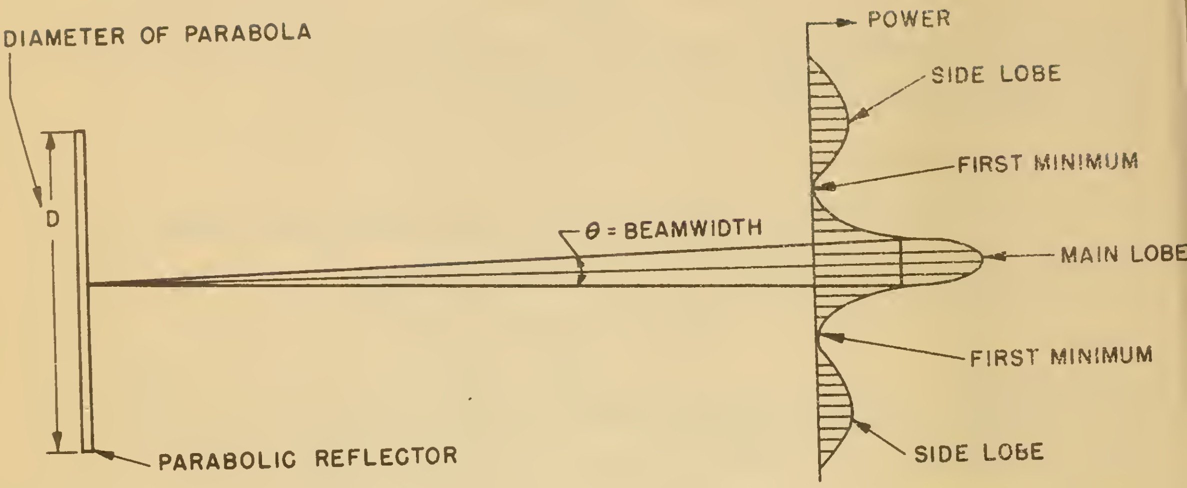

FIG. 24A

RADIATION PATTERN OF A PARABOLIC REFLECTOR

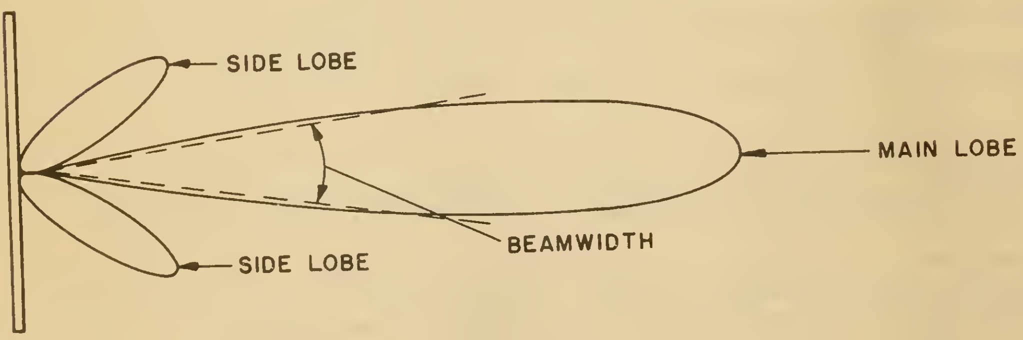

FIG. 2.4B

POLAR PLOT OF RADIATED POWER VS DIRECTION FOR A PARABOLIC REFLECTOR the reflection coefficient of the object and the square of the effective receiving area of the antenna, and inversely proportional to the square of the distance of the object. As a numerical example, 1.32×10^{-6} watts are received at the input terminals of the receiver for a power of 0.1 watt transmitted at normal incidence to a highly reflecting object ten feet away.

The power received from an object, p_r, is related to the power output at the transmitter, P_t, as follows:

$$p_r = \frac{P_t G_o}{4\pi R^2} \sigma A_o \frac{A_r F}{\pi R^2} \qquad (2.9)$$

where p_r is the received signal power at the input terminals to the receiver,

P_t is the transmitter power,

G_o is the maximum gain of the antenna,

R is the distance from the source to the object,

A_o is the effective area of the object illuminated by the beam (A_o = K times the true area of the object, where $0 < K < 1$; $K = 0.75$ for a parabolic reflector).

A_r is the effective cross-section of the receiving antenna, and,

σ is the reflection coefficient of the object in the direction of the beam; it is a function of the radiation frequency, the geometry of the object, and the angle from which the object is viewed.

In this equation, $\frac{P_t G_o}{4\pi R^2}$ is the power density (power per unit area) in the incident beam at the object (at distance R). $\frac{P_t G_o}{4\pi R^2} \sigma A_o$ is the power density reflected by area A_o of the object. $\frac{A_r F}{\pi R^2}$ is the fraction of this reflected energy intercepted by the antenna.

Using equation 2.6 equation 2.9 becomes

$$P_r = \frac{P_t \sigma A_o A_r^2 F^2}{\pi R^4 \lambda^2} \qquad (2.10)$$

According to this expression, the ratio $\frac{P_r}{P_t}$ appears to vary inversely with the fourth power of the distance of the object and the square of the wavelength of the radiation. However, R^2 and λ^2 are implicit in A_o; consequently $\frac{P_r}{P_t}$ varies inversely as the square of the distance of the object.

The numerical example given above for $\frac{P_r}{P_t}$, viz., 1.32×10^{-5} is based upon the following values substituted into equation 2.10:

A_r = 0.047 square feet (D = 7.5 cm.)

A_o = 0.59 square feet

F = 0.6

R = 10 feet

$\lambda = \frac{1}{30}$ feet (1 cm.), and

σ = 0.98, an assumed value for the reflection coefficient (order of magnitude is sufficient for illustrative purposes).

If the transmitter is pulsed (see Fig. 2.5), P_t (in equation 2.10) is the peak power in the pulse. Only 0.03 watts average power are required to give a peak power of 0.1 watt if the transmitter is pulsed 100 times per second with pulses of 0.003 seconds duration. Thus, pulsing techniques represent a considerable economy in input power requirements.

The peak power in the pulse is related to the average power transmitted by

$$P_t \mu = P_{ave} T \qquad (2.11)$$

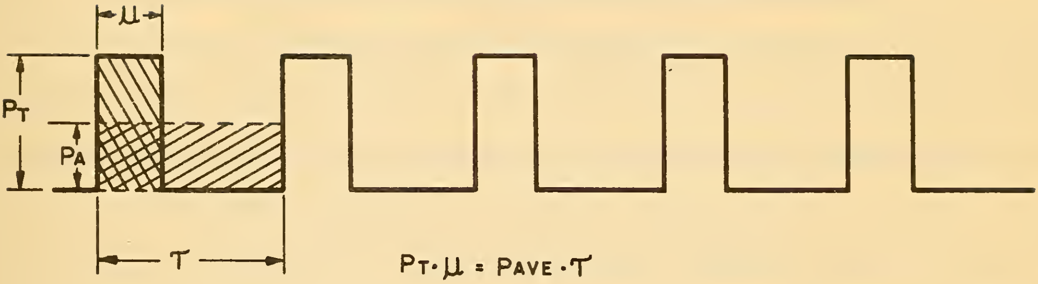

FIG. 2.5 DIAGRAM ILLUSTRATING PULSE MODULATION

where τ is the duration of the cycle in seconds = $\frac{1}{prf}$,

prf is the pulse recurrence frequency in cycles per second

P_t is the peak power in watts, and

P_{Ave} is the average power in watts

μ is the duration of pulse in seconds.

However, the receiver sensitivity is higher for continuous wave operation than for pulse modulation. Consequently the saving on input power has to be balanced against the loss in receiver sensitivity, although usually some receiver sensitivity can be sacrificed since the loss can be compensated by increasing the gain of the audio amplifier.

Unfortunately the equations obscure the effect of specular reflections at supersonic frequencies since the quantities of interest in discussing specularity are implicit in σ . This is a complicated function of the wavelength, the angle from which the object is viewed, and the geometry of the object[1]. To some extent, the effect of specular reflection can be minimized by utilizing higher transmitted powers (which suggests the use of pulsing techniques) and more sensitive receivers.

The above discussion of the ratio of received to transmitted power has included simplifying assumptions and has omitted a number of factors of practical importance; hence, for design purposes, the power transmitted should be increased by perhaps 10 db (or the receiver sensitivity increased by 10 db).

d. Receiver Sensitivity

The discussion thus far has been restricted to the received signal power at the input terminals to the receiver. It is necessary, of course, to

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[1] Experiments are currently in progress at Stromberg-Carlson and at Haskins Laboratories to study overall specularity effects.

consider the signal power of the output of the tactile stimulator (or earphones). If the value of output signal power required to give a reliable indication is assumed, then either the transmitter power or the receiver sensitivity can be adjusted to provide this requisite final output signal power.

The maximum useful gain of the receiver is limited by the ambient supersonic radiation (within the pass band of the receiver), and by the thermal noise in the first stage. This upper limit on receiver sensitivity, taken in conjunction with the ratio of received to transmitted power, sets a limit below which the transmitted power may not be reduced. In the practical case, the optimum balance between receiver sensitivity and transmitted power will depend on additional considerations. The principal objectives are reliability of operation and minimum total power drain (including filament power), hence, total weight of batteries. Since there is not much advantage in reducing transmitted power far below the power required to heat tube filaments, the receiver sensitivity is not usually pushed to the limit. By way of illustration, receiver gains for two of the supersonic devices thus far developed are 70 and 90 db.

3. Optical Systems

a. Systems with Self-contained Light Source

The design considerations for an obstacle locator having its own light source are analogous to those for a supersonic system. The transducers, or "antennae", are replaced by transmitting and receiving lens systems, and beam width refers to the divergence of the light beam after it leaves the transmitting lens. In considering the transmitted power from the time it leaves the transmitting lens until it reaches the receiving lens, free-space propagation can be assumed.

If a small light source radiating light uniformly in all directions is placed at the focus of a transmitting lens of area A_t, and if the quantity of light emitted per second is I_s, then the quantity of light per second entering the lens is

$$\frac{I_s}{2}\left[1-\frac{f_t}{\sqrt{r^2+f_t^2}}\right] \qquad (2.12)$$

where f_t is the focal length of the lens, and r is the radius of the lens. The quantity of light reaching unit area of the target per second is

$$\frac{2\,I_s}{\pi\,D^2}\left[1-\frac{f_t}{\sqrt{r^2+f_t^2}}\right] \qquad (2.13)$$

where D is the diameter of the illuminated area on the object. The quantity of light per second in the received wave intercepted by the receiving lens is

$$\frac{I_s}{2\pi R^2}\,\rho A_r\left[1-\frac{f_t}{\sqrt{r^2+f_t^2}}\right] \qquad (2.14)$$

where ρ is the reflection coefficient of the target at normal incidence, A_r is the area of the receiving lens, and R is the distance from the lens to the target. (It is assumed that the only light reaching the target is that transmitted by the transmitting lens, that is, the effect of ambient light is neglected; both the transmitting and receiving lenses are assumed to be illuminated uniformly.)

The ratio of the light received to the light transmitted varies directly as the reflectivity of the object and inversely as the square of its distance. In a typical case, $\frac{I_r}{I_s} = 4.45 \times 10^{-4}\,\sigma$ for an object at 10 feet.

These calculations are based on the following values:

A_r = 3.14 sq. in. (2 in. diameter lens)

f_t = 2 in.

r = 1 in., and

R = 10 feet

The reflection coefficient, ρ , varies from approximately 0.85 for a highly polished surface to 0.05 for black paper. Thus, the quantity of light received per second varies between 11.4×10^{-4} and 0.67×10^{-4} candles (between 22 and 1 microwatt) if the intensity of the source is 3 candles. An amplifier with a gain of 60 db is required to provide an output of 1 watt; additional gain (at least 10 db) will be needed to compensate for losses in the optical system, attenuation, and in modulating the light.

Modulation of the light in an optical guidance device serves a different purpose than does frequency modulation in supersonic devices; in the optical device, modulation is a means of minimizing the interference from ambient light. The level of ambient light in the visible and infra-red regions of the spectrum is very high; indeed, in many cases it will be considerably higher than the intensity of the beam transmitted by the device. Discrimination between the transmitted and the ambient light can be achieved if the light source is modulated at a constant rate and the receiver is tuned to pass only this frequency. It would be desirable also to reduce the input power requirements by modulating the light source. However, the small incandescent lamps which are otherwise suitable for guidance devices are not susceptible of rapid modulation in a manner which will conserve the input power; that is, they cannot be turned on and off rapidly enough to permit "pulsed" operation at frequencies of several hundred cycles[1]. There is therefore need for a light source which can be modulated easily and, preferably, in a manner to conserve power.

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[1] The Western Union zirconium light source can be modulated easily, but it is not a very efficient source and requires high operating potentials.

The remarks concerning receiver sensitivity of supersonic devices apply also to optical guidance devices. More detailed attention must be paid to the signal-to-noise ratio, however, in determining the probable range of useful signals. In all applications the photoelectric cells employed in optical obstacle locators will respond to ambient light and indeed may become saturated under some conditions of ambient illumination to such an extent that the device will be inoperative. The discrimination between modulated light and ambient light is accomplished by a highly selective pre-amplifier section of the receiver (immediately following the photocell pick-up). The signal-to-noise ratio for an optical obstacle locator using its own light source depends upon: a) the candle power of the source, b) the F number of the transmitting and receiving lenses, c) the reflectance of the object, d) the intensity of the ambient light, e) the range of the object, f) the band-width of the amplifier, and g) thermal noise in the phototube and first stage.

The optimum balance between receiver sensitivity and power supplied to the light source depends, as with the supersonic device, principally on reliable operation with minimum total power (and battery weight), but with the added factor of ambient light effects.

b. Systems using Ambient Light

Discussion of the design considerations for an optical obstacle locator using ambient light follows generally the corresponding discussion for an optical device with its own light source, but is simplified by the omission of such factors as light source, transmitting lens, and tuned receiver.

The light received from an object depends on the intensity of the ambient light and the color and reflectivity of the object. If an area of the object surface in a plane at right angles to the line joining it and a receiving lens is reflecting diffusely, and if the quantity of light per second reflected toward the lens per unit area of the object is I, then the quantity of the light entering the lens per second is

$$\frac{I A_o A_r}{\pi R^2} \tag{2.15}$$

where A_r is the area of the lens,

A_o is the area of the object as seen by the lens, and

R is the distance of the object from the lens.

I is a function of the reflectivity of the object, and the intensity and the incident angle of the ambient light on the object.

Thus, the quantity of light per second entering the lens varies directly as the reflectivity of the object and inversely as the square of the distance of the object. However, the apparent brightness remains constant, and hence gives no information on which a range indication could be based.

The percentage of "white light" diffusely reflected by different surfaces varies widely, ranging from 60 to 70% for white cloth and white paper to 0.4% for black velvet. The character of the surface (rough or smooth) is also important. Hence, the brightness of the image depends on both the characteristics of the reflecting surface and on the intensity of the ambient illumination; consequently an ambient light device must operate over a very wide range of brightness. Further, if two or more objects at different distances are in the field of view of the lens, the received information may be ambiguous.

The modulation of received light in an ambient light device would serve a different function than in the case of either a supersonic device or an optical device with its own light source. Indeed, the only role of modulation which has been considered at all is in conjunction with systems employing the principle of longitudinal magnification (depth of focus). For such systems light in different image planes may be modulated at different rates as a means of indicating the range of an object. Systems employing modulation in this way have the advantage that, in principle, the possibility of ambiguous information is somewhat reduced, since the images of two or more objects at different ranges, even when viewed simultaneously, will be modulated at different rates.

The problems associated with receiver sensitivity are similar to those for devices with self-contained light sources. However, the range of illumination, from dim indoor lighting to brilliant sunlight, is a complicating factor.

FIG. 2.6
SUBJECT CARRYING STROMBERG-CARLSON SUPERSONIC DEVICE, YA-3ST.

D. GUIDANCE DEVICE SYSTEMS

A number of guidance devices have been proposed; some of them have been developed and tested[1]. In the discussion which follows, the devices developed to date are grouped according to the kind of radiation and the type of system employed and are assigned a code designation for ready identification. (See Table 2.1, at end of volume.)

1. Supersonic Guidance Devices

An important property of supersonic radiation, for guidance device applications, is the velocity of propagation in air, approximately 344 meters per second. This is low enough to permit the easy use of echo ranging techniques; a measure of the time required for sound to travel from the device to an object and back provides a measure of the distance to the object. In round numbers, a time interval of two milliseconds corresponds to an object distance of one foot. The two principal techniques which have been developed for measuring the time intervals are pulse and frequency modulation. The principles involved will be evident from the descriptions of the various systems.

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[1] See Part III of this report.

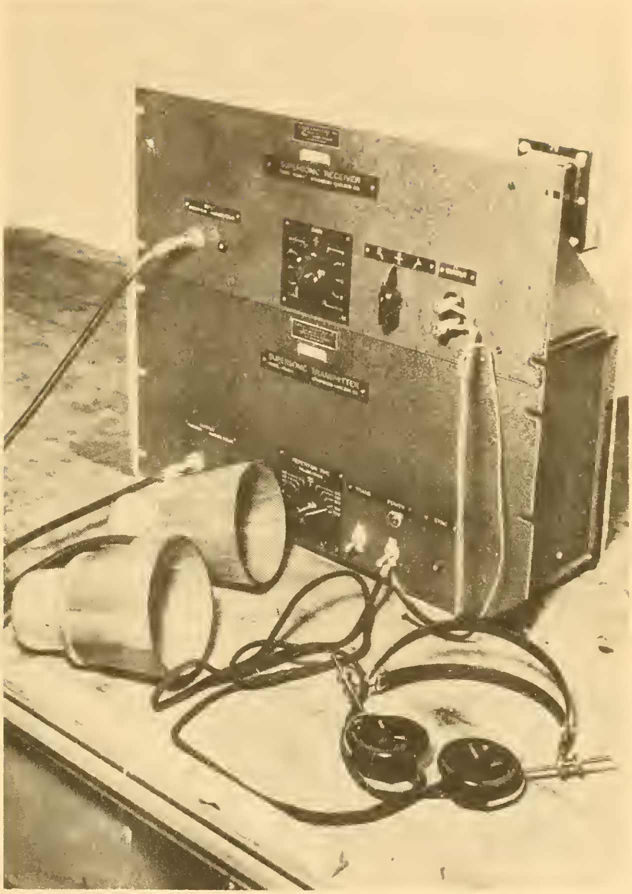


FIG. 2.7
NON-PORTABLE MODEL OF STROMBERG-CARLSON'S TWO-CLICK SYSTEM, YA-1ST.

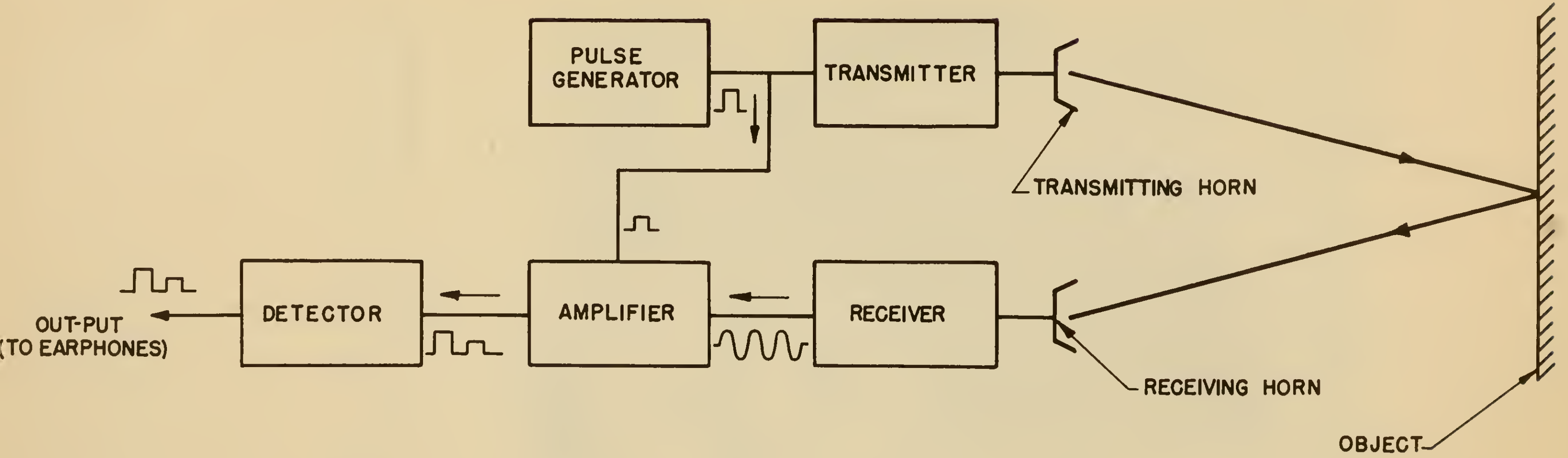
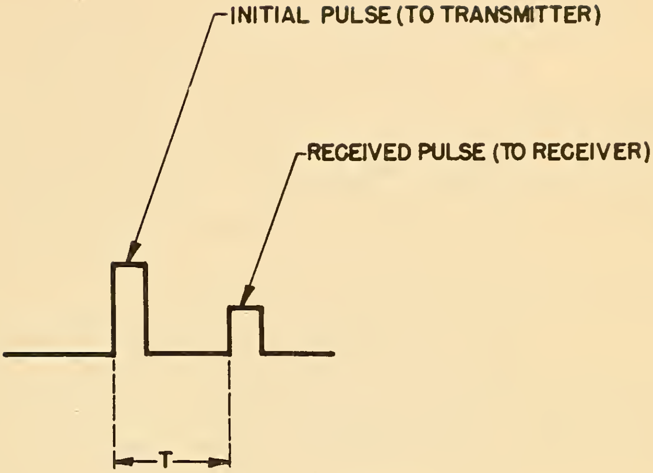
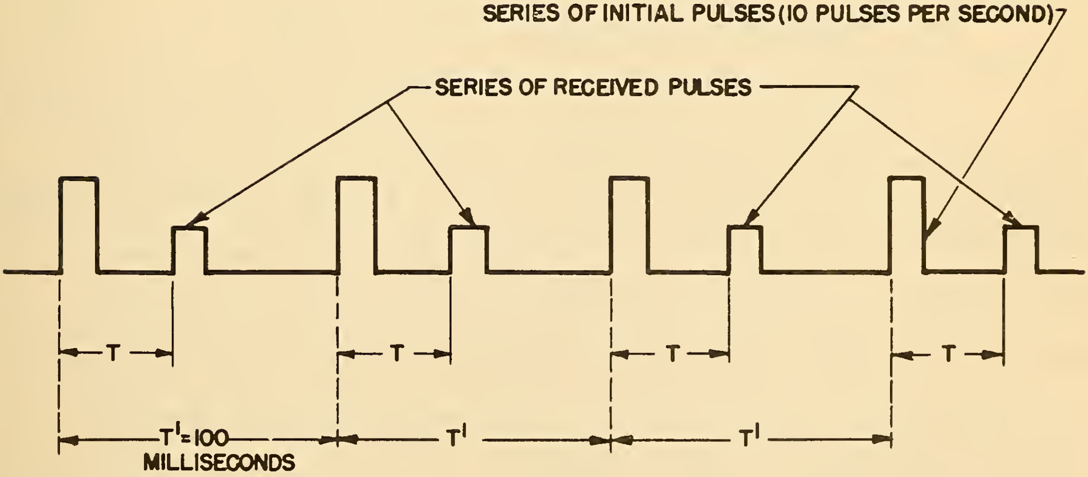


FIG.2.8

BLOCK DIAGRAM OF STROMBERG CARLSON
"TWO CLICK" SYSTEM, YA-1ST



T= TIME INTERVAL BETWEEN TRANSMITTED AND RECEIVED PULSE



T= TIME INTERVAL BETWEEN TWO PULSES IN A PAIR
T' = TIME INTERVAL BETWEEN EACH SUCCESSIVE TRANSMITTED PULSE

FIG. 2.9
DIAGRAMMATIC SKETCH SHOWING THE SIGNALS
IN THE "TWO-CLICK" DEVICE

a. Pulse Modulation Systems

1. Stromberg-Carlson "Two-Click" System: YA-1ST

This is a non-portable device, working at the low end of the supersonic range (Fig. 2.7). It employs a pair of magnetostriction transducers, and presents an auditory signal consisting of repeated pairs of pulses or clicks separated by a time interval proportional to the distance of the object from which the supersonic radiation is reflected.

A 22 kc oscillator is pulse modulated by a rectangular pulse of about one millisecond, at a repetition rate adjustable between 5 and 50 pulses per second. The transmitted pulse reaches the receiver via two channels: by direct connection (appropriately attenuated), and by way of a supersonic souhd wave which travels to a reflecting object and back. The output signal from the receiver and detector consists, therefore, of a pair of pulses separated in time by an amount proportional to the distance of the reflecting object (Figs. 2.8 and 2.9).

2. Stromberg-Carlson Echo-Pulse System: YT-4ST

This is a portable device operating at the low end of the supersonic range. It consists of a supersonic transmitter and receiver in one container carried on a shoulder strap, and a pair of magnetostriction transducers carried in the hand and used as a probe (Fig. 2.10). The subject receives either a tactile or auditory signal consisting of a series of pulses which repeat at a faster and faster rate as an obstacle is approached. The range of repetition rates is from about 4 to 30 per second. Objects beyond the maximum range (adjustable) give no signal.

The operation of the device is indicated in Fig. 2.11. A multivibrator generates a square wave which is then differentiated, the negative part being suppressed. The differentiated pulse serves as the modulating voltage for the transmitter, so that a sharp pulse at supersonic frequency is transmitted.

At the same time that the pulse is transmitted, the square-wave generator has turned on the receiver by means of the gate. A signal returning from an obstacle can now pass through to the stimulator; the same pulse also passes to the multivibrator and causes the next pulse to be transmitted after a very brief delay (about 0.025 seconds). In this way the interval between pulses is shortened for near objects.

The received signal also turns off the receiver so that only the first echo is utilized. If no echo at all is received, the multivibrator causes another pulse to be transmitted after a comparatively long time interval (adjustable; a typical value is 0.25 seconds).

The transmitted pulses are not passed on to the stimulator or earphones, since the receiver is blocked momentarily. The time interval between a transmitted and a received pulse, which is a function of range, is measured in terms of the number of pulses per second at the output of the receiver. Thus the subject receives nothing if there is no obstacle, a slow rate of pulses for a far object and an increasingly faster rate of pulses for near objects. Fig. 2.12 shows the time relationship between pulses. A manually operated control (called a "distance cut-off") is provided to so adjust the device that any obstacle beyond a specified range will not result in a signal.

The tactile stimulator used with this device is a modified Astatic L-72 crystal phonograph pick-up cartridge, with a short length of L-shaped wire used as a stylus in place of the needle[1]. As shown in the

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[1] Several kinds of tactile stimulators have been used in the development and testing program at Haskins Laboratories, e.g., a magnetic speaker unit with balanced armature, an Astatic crystal cutting head, and a Shure earphone unit. There are objections to these units on the basis of size and power requirements. Experiments are in progress to develop a suitable stimulator, with characteristics determined by the psychological requirements and by performance tests. In addition, work is in progress on a bench model tactile stimulator to be used in determining optimum frequency and amplitude ranges for tactile stimulation.

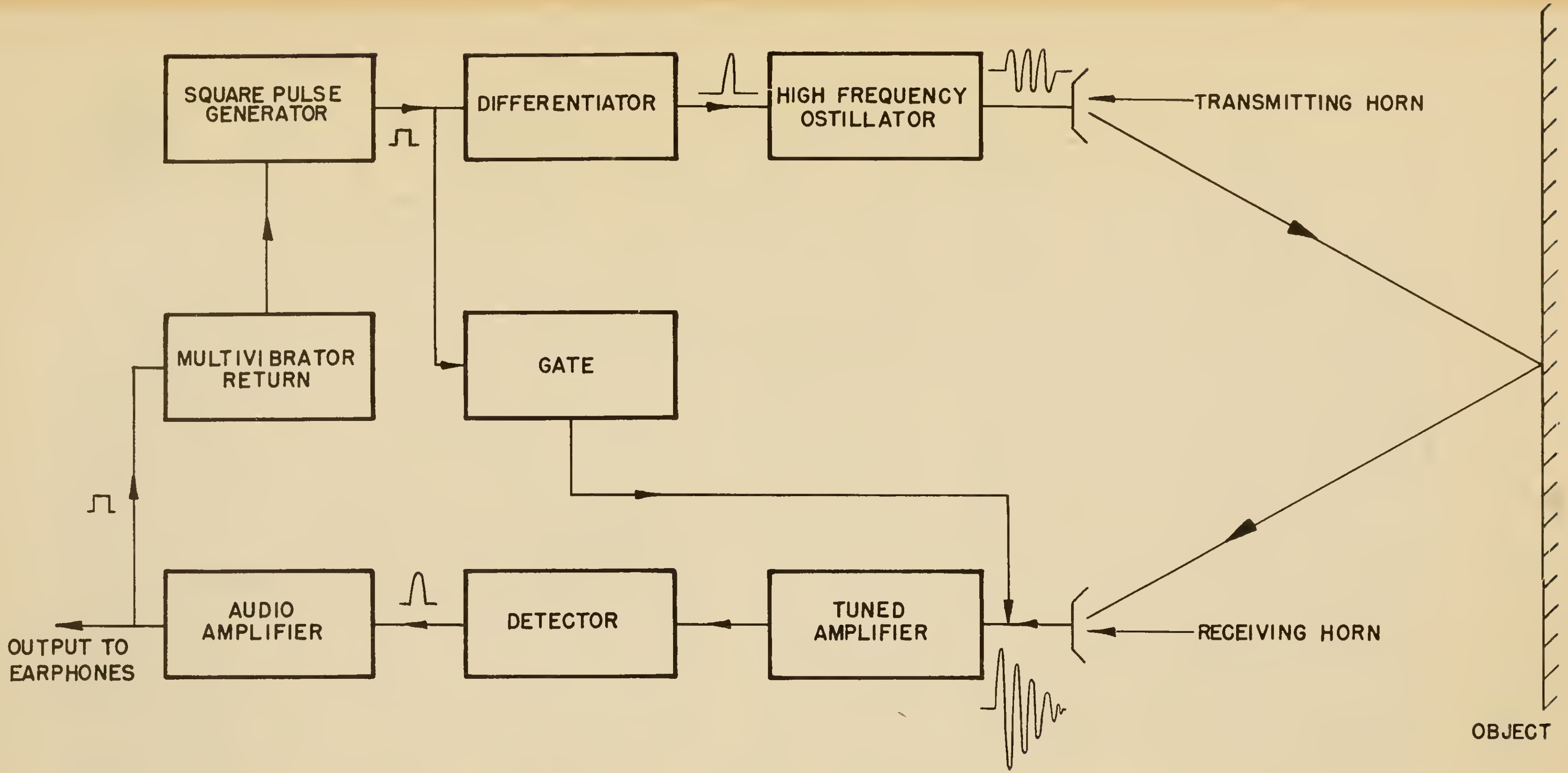

FIG. 2.11

BLOCK DIAGRAM OF STROMBERG-CARLSON ECHO PULSE SYSTEM: YT-4ST

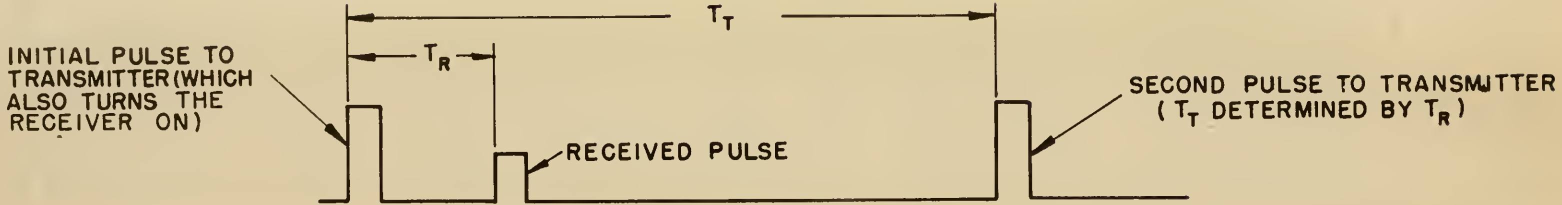

FIG. 2.12
PULSE-TIME RELATIONSHIPS

photograph (Fig. 2.10) the stimulator is mounted on the transducer with the stylus at the front and top of the handle. This position permits holding the thumb on the handle with the side of the thumb touching the stylus lightly.

3. Hoover Supersonic Guidance Device: YA-1HC(M1)

This is a portable device operating at the low end of the supersonic range of frequencies. It consists of a supersonic transmitter and a microphone in a hand-held unit used as a probe, and a receiver and batteries in another container carried on a shoulder strap. (Fig. 2.13).

An auditory signal is presented which consists of a series of pulses. The signal is heard whenever an object is present within the range of the device. To learn the distance of the object, the user raises the lever on the handle (which causes the signal to disappear), and searches for a position of the lever at which the signal reappears. The angle through which the lever has been raised is related to the distance of the object from the microphone, and, with the help of a series of raised pins on the handle, the operator can judge the distance of the object.

The primary features of this device are that (a) the supersonic radiation is generated by mechanically striking a metal bar, and (b) provision is made for searching in range.

The spring mounted core of a solenoid strikes a steel bar suspended at its mid-point, thereby generating a pulse of supersonic energy. The received energy is amplified and mixed with the output of a local oscillator, producing an audio frequency beat tone which is amplified and fed to earphones (Fig. 2.14). A gating switch mechanism, by which range selection is achieved, is placed across the output.

The gating switch (Fig. 2.15) consists of a wedge-shaped cam coupled to the timing motor and mounted to operate two sets of contacts (B and C)

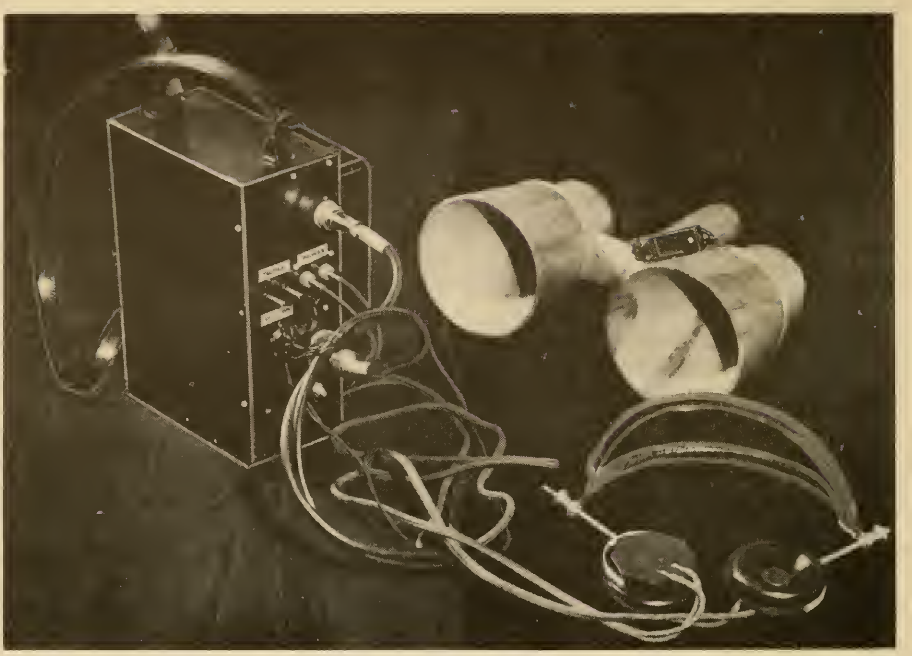

FIG. 2.10
STROMBERG-CARLSON "ECHO-PULSE" GUIDANCE DEVICE, YT-4ST.

FIG. 2.13
HOOVER'S SUPERSONIC GUIDANCE DEVICE, YA-IHC(MI).

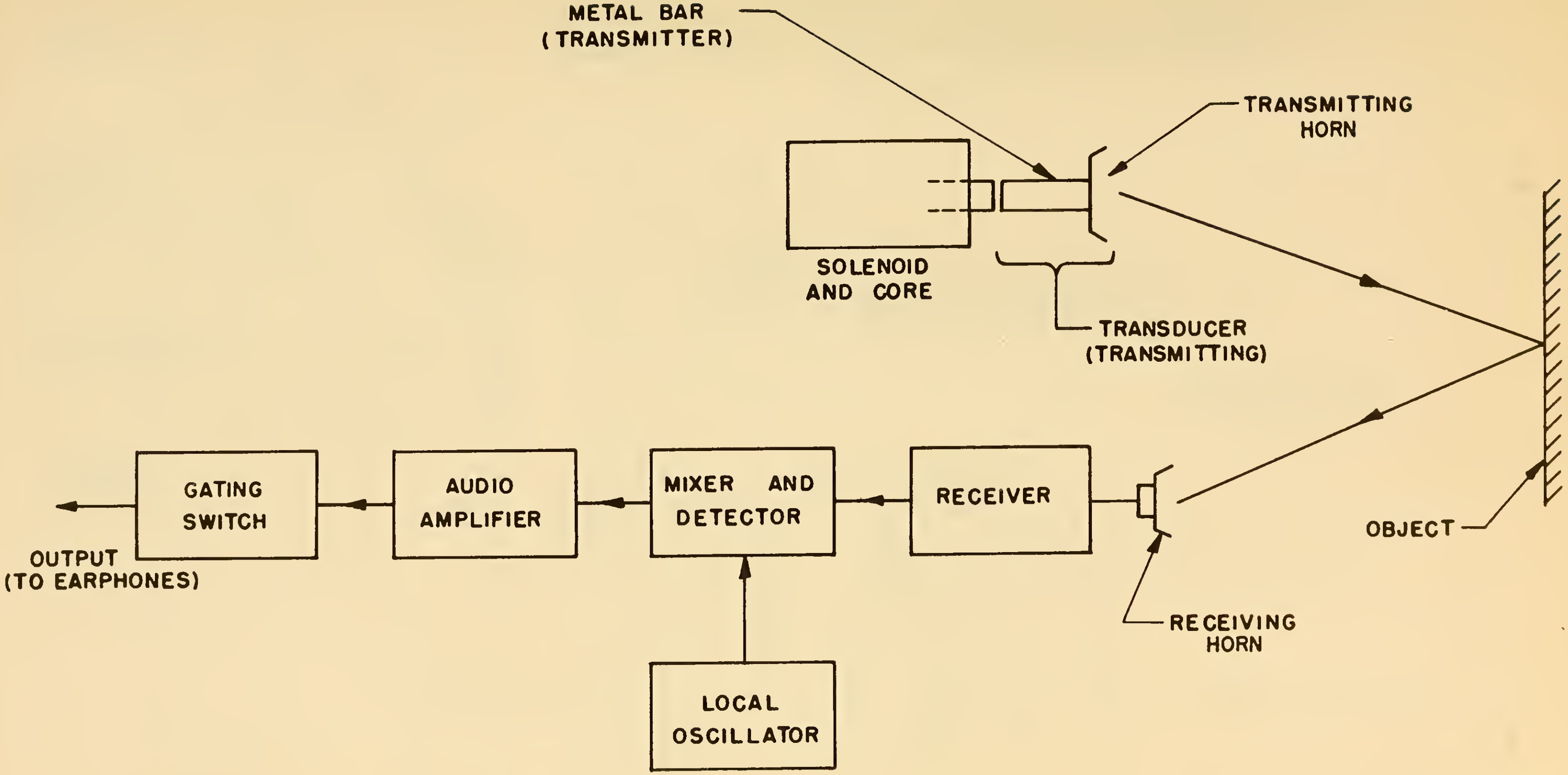

FIG. 2.14
BLOCK DIAGRAM OF THE HOOVER–SUPERSONIC
GUIDANCE DEVICE: YA-1HC

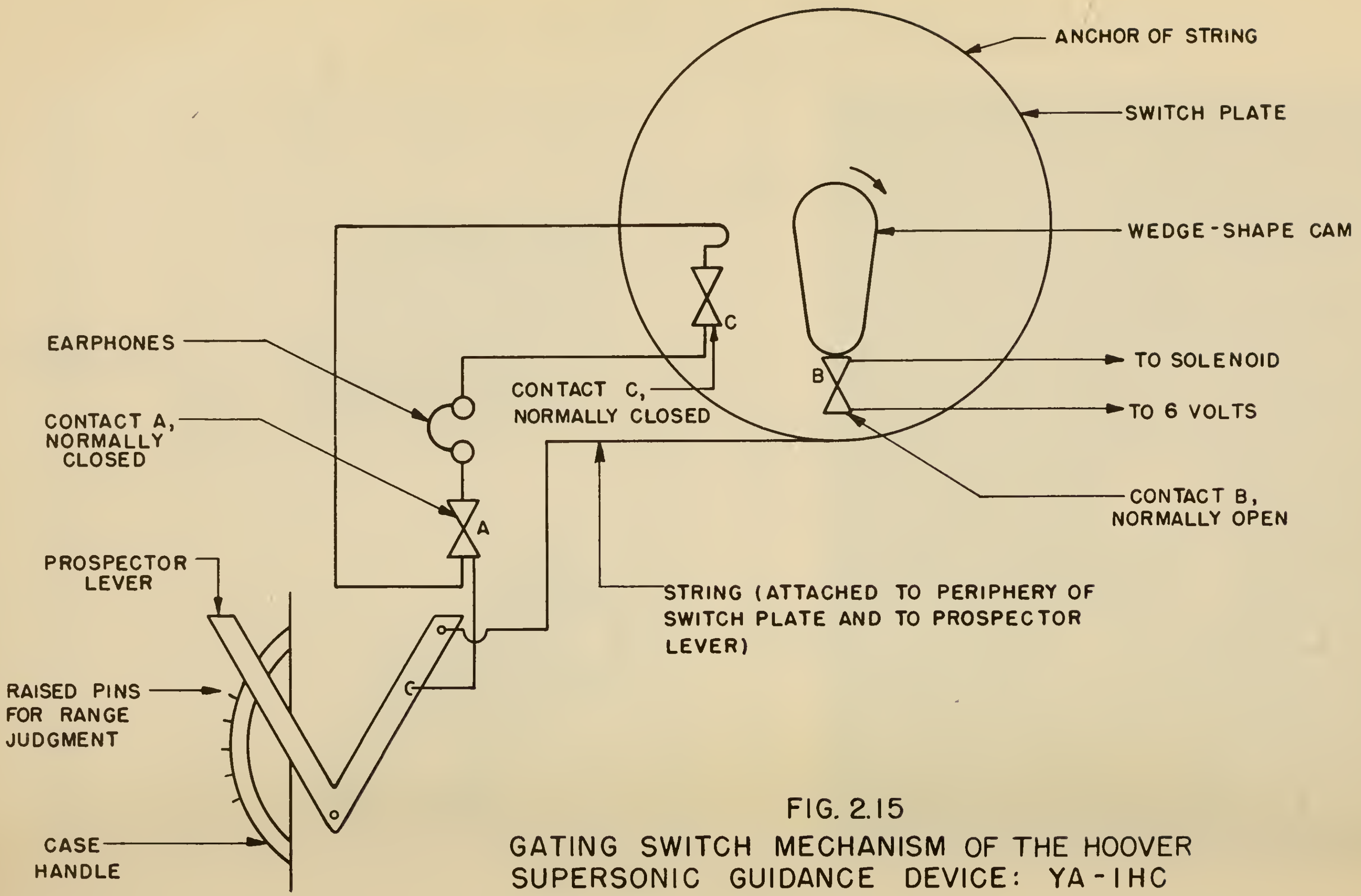

FIG. 2.15

GATING SWITCH MECHANISM OF THE HOOVER SUPERSONIC GUIDANCE DEVICE: YA-1HC [SCHEMATIC] as it rotates. One contact, C, is mounted on a circular plate, rotatable by a lever mechanism called the "prospector lever". When the cam passes contact B (which is not mounted on the plate) the solenoid circuit is closed, the core strikes the metal bar, and a pulse of supersonic energy is transmitted. For the prospector lever in the rest position, the contact A is open and all of the received supersonic pulses appear as auditory signals in the earphones. When the lever is raised from the rest position, contact A is closed and the phones are shorted except momentarily when the wedge on the cam shaft opens contact C. Hence, there is a signal in the headphones only if the gating circuit is opened at the same instant that a reflected supersonic pulse is received; i.e., the time interval between the closing of contact B by the cam and the closing of contact C by the wedge is equal to the time of flight of the supersonic pulse, and is indicated by the position of the "prospector lever".

An earlier model, YA-1HC, operates on the same principle.

4. Continuous-Tone Supersonic Device: YA-3HL

This is a non-portable device operating at the low end of the supersonic range. A pair of magnetostriction transducers is used as a probe (Fig. 2.16). It can be adapted to present either of the two following types of signals:

(a) An auditory signal consisting of a sine wave tone which varies continuously in frequency with the distance of an object from the transducers. A high-pitched tone indicates a near-by object; a lower tone indicates a more distant object.

(b) A tactile signal consisting of a series of pulses with the time interval between the pulses varying as the distance of an object from the transducers. A low repetition rate indicates a distant object; a higher repetition rate indicates a near-by object.

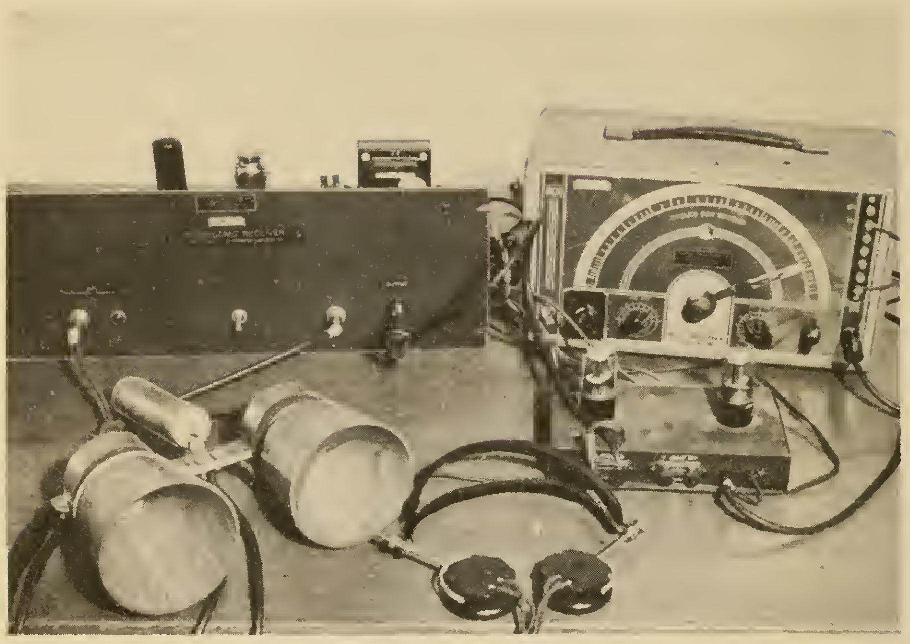

FIG. 2.16

CONTINUOUS-TONE SUPERSONIC DEVICE, YA-3HL

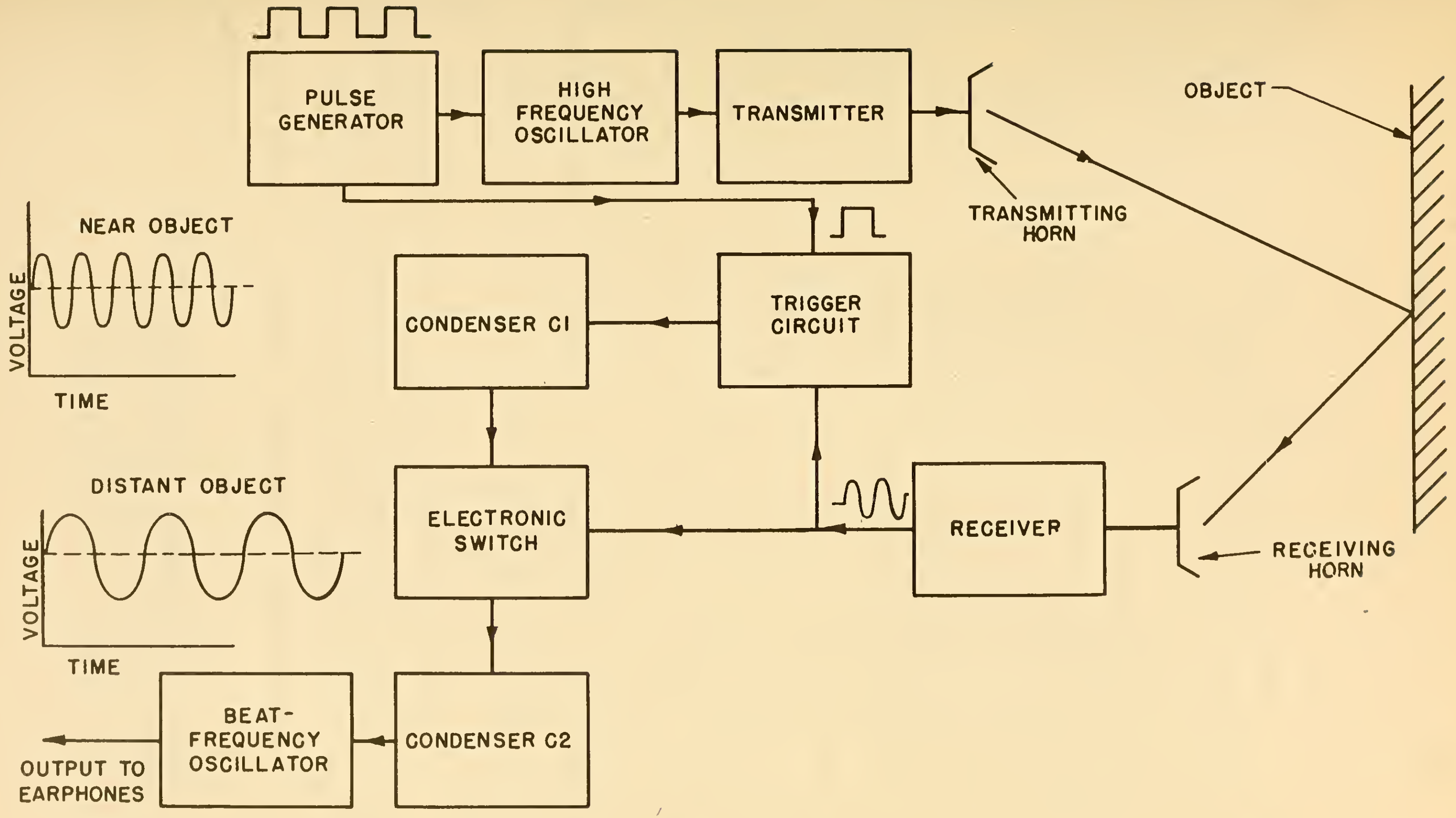

FIG. 2.17

BLOCK DIAGRAM OF CONTINUOUS TONE
SUPERSONIC DEVICE: YA-3HL

A pulse generator simultaneously modulates a supersonic transmitter, and trips a trigger circuit which starts charging condenser C_1 (Fig. 2.17). In the absence of a received signal, the condenser charges to a maximum voltage. If, however, a reflected signal is received some time after the transmitted pulse (hence, some time after condenser C_1 starts to charge), part of the receiver output switches the trigger circuit so that condenser C_1 starts to discharge, and simultaneously operates an electronic switch to bring a smaller condenser C_2 to the same voltage as C_1. The voltage across C_2 controls the frequency of a beat-frequency oscillator (BFO); the magnitude of this voltage is proportional to the time of charging of C_1, which in turn is proportional to the time-of-flight of the transmitted pulse. Hence, the frequency of the BFO indicates the distance to the reflecting object, varying almost linearly from about 2000 cycles per second for an object one foot away to about 200 cycles per second for an object at fourteen feet (the BFO is tuned to give zero beat, hence no signal, when no objects are present). When the device is adapted to tactile presentation a blocking oscillator replaces the BFO and a variation in pulse repetition rate is obtained, the rate varying between 30 pulses per second for an object one foot away to 4 pulses per second for an object at fourteen feet. An Astatic Crystal cutting head is used as tactile stimulator.

One property of the trigger circuit is that after the first received pulse operates the trigger circuit, succeeding received pulses have no effect until the circuit is restored to its original condition, that is, until another pulse is transmitted. Consequently, the device responds only to the nearest obstacle in its path. Fig. 2.18 shows a theoretical curve of signal plotted against range, for both auditory and tactile presentation.

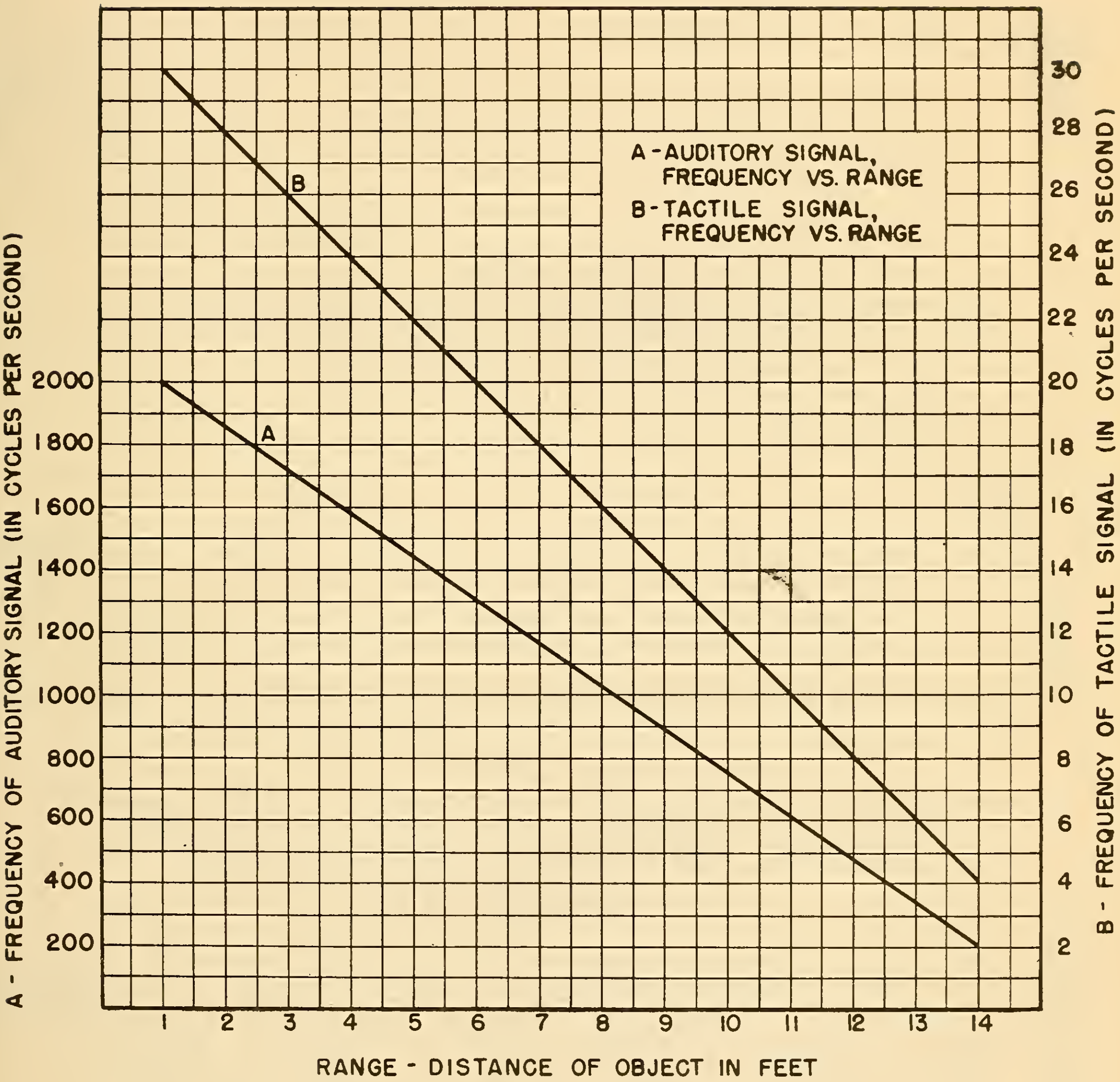

FIG. 2.18
THEORETICAL CURVE OF SIGNAL VS. RANGE FUNCTION FOR THE CONTINUOUS TONE SUPERSONIC DEVICE: YA - 3HL

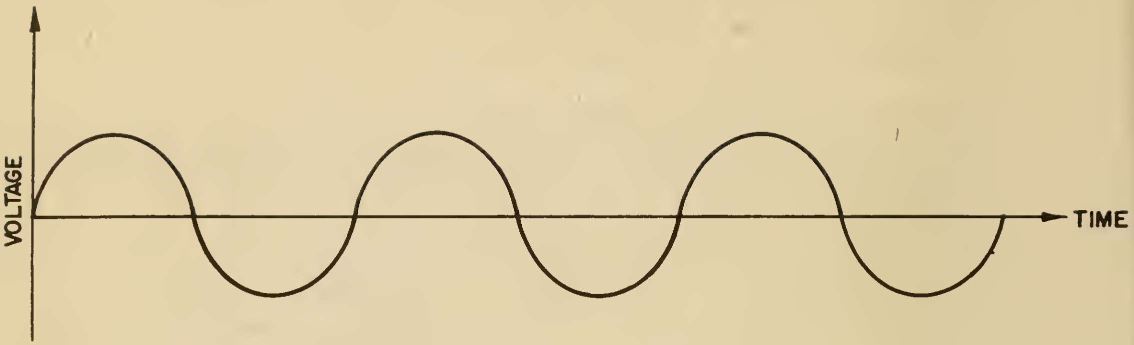

FIG. 2.19A
LOW-FREQUENCY SINE WAVE USED TO MODULATE A SUPERSONIC TRANSMITTER

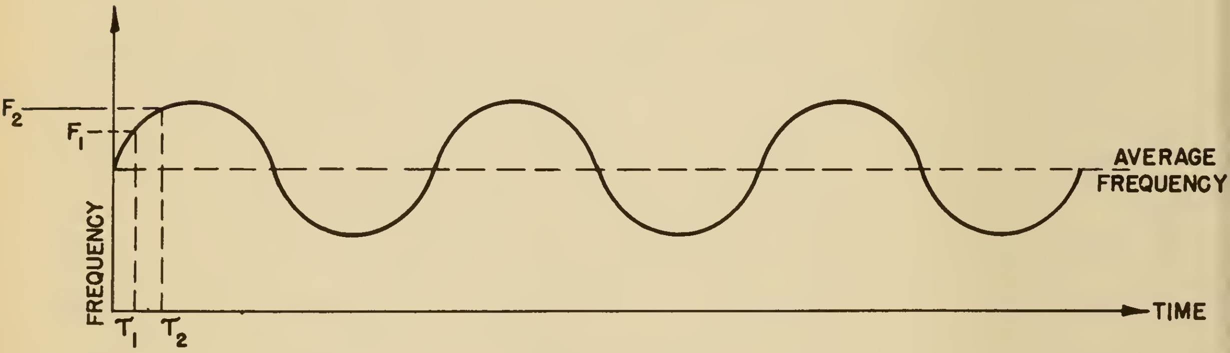

FIG. 2.19B

VARIATION IN FREQUENCY WITH TIME FOR THE HIGH FREQUENCY OSCILLATOR OF THE SUPERSONIC TRANSMITTER

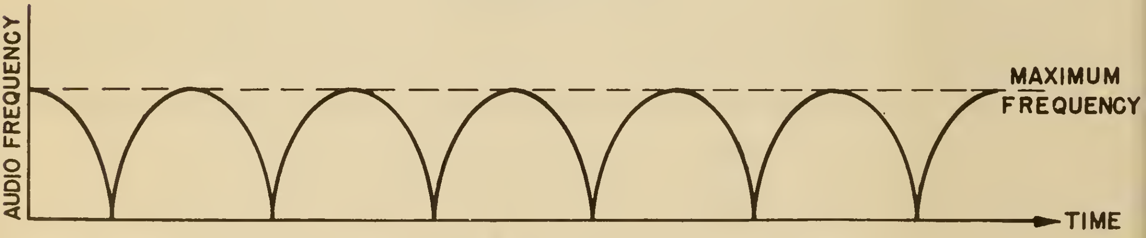

FIG. 2.19C
VARIATION IN OUTPUT SIGNAL FREQUENCY WITH TIME FOR A SINE-WAVE MODULATED SYSTEM

b. Frequency-Modulated Systems

1. Sine-Wave Modulated System: Brush Supersonic Guidance Device: YA-1BD

This is a non-portable supersonic device (Fig. 2.20). It presents an auditory signal consisting of a warbled tone; the highest frequency of the warble-tone provides an indication of the distance of the object from the transducers. A low tone indicates a near-by object; a higher tone indicates a more distant object.

In all frequency-modulated systems the frequency of the transmitter is made to vary with time above and below an average value; the variation is usually accomplished by modulating the transmitter with a sine wave, or a sawtooth wave. Thus, the transmitted frequency varies periodically between values f_1 and f_2. As an example, if the transmitted frequency changes from 30.0 kilocycles per second at time t_1 to 30.5 kilocycles per second at time t_2, and, if, during this time interval, the sound radiated at 30.0 kc/sec has traveled from the source to an obstacle and back, the sound will arrive at a time when the transmitter frequency has changed to 30.5 kc/sec, and a beat frequency of 500 cycles/sec can be obtained by mixing the two supersonic frequencies. That is, the difference in frequency between the transmitted and received signals is a function of the distance of an object: the difference is small for an object which is close; it is large for a distant object. The difference frequency is also a function of the rate at which the frequency of the transmitter is changed; the signal in the headphones is a warbled tone because the transmitter frequency varies sinusoidally with time. Fig. 2.19a shows the sine wave voltage (from a low frequency oscillator) which modulates the transmitter. Fig. 2.19b shows the variation in frequency of the transmitter with time. The difference frequency varies as shown in Fig. 2.19c. Fig. 2.21

FIG. 2.20
BRUSH SUPERSONIC SINE-WAVE MODULATED GUIDANCE DEVICE, YA-1BD.

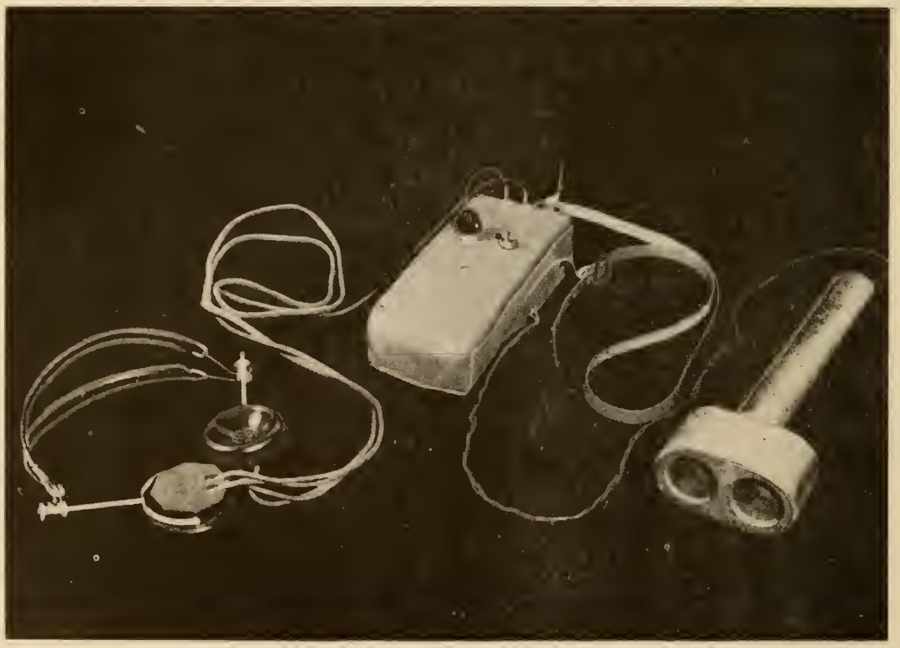

FIG. 2.22
BRUSH SUPERSONIC SAW-TOOTH MODULATED GUIDANCE DEVICE, YA-5BD.

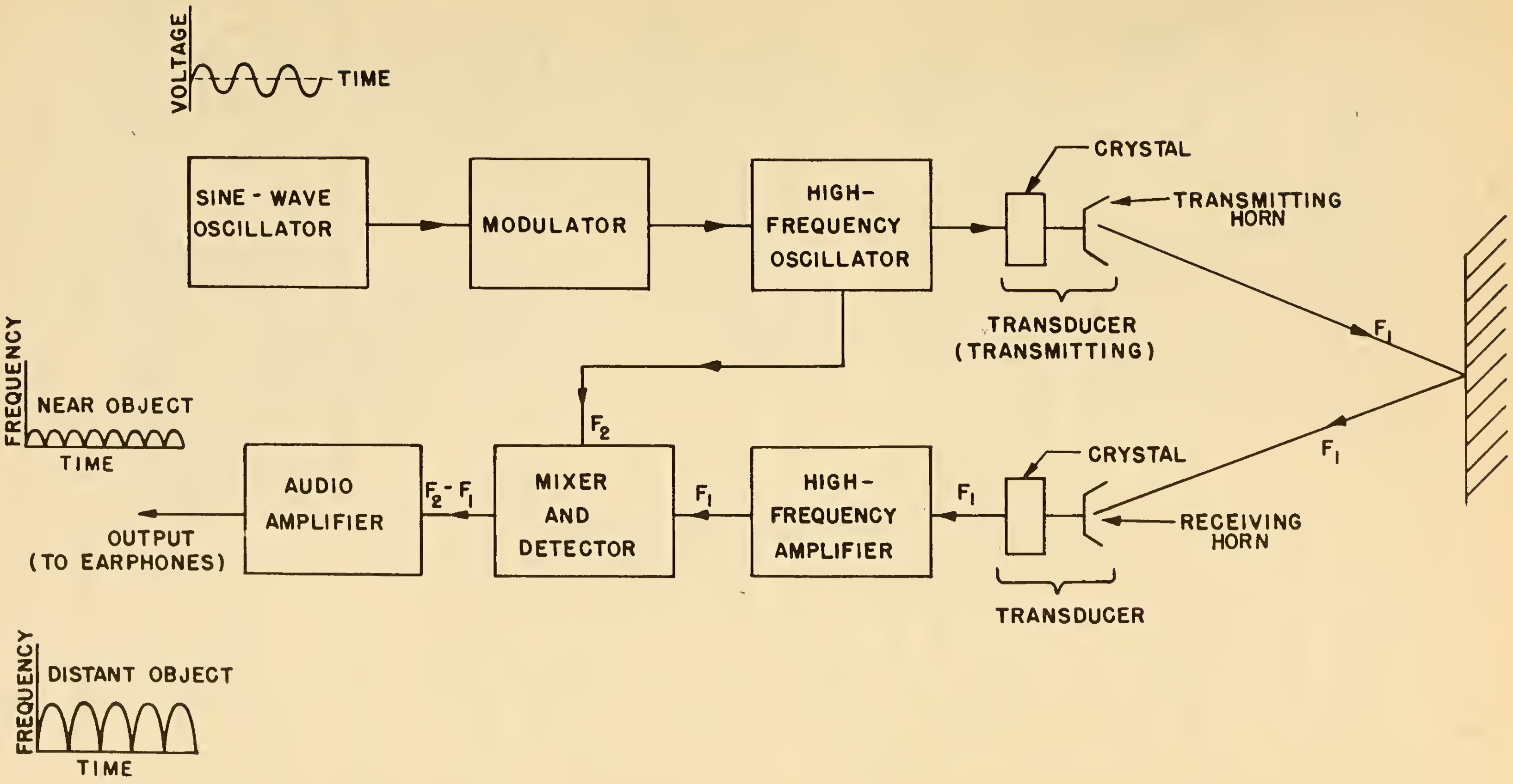

FIG. 2.21 BLOCK DIAGRAM OF THE BRUSH SUPERSONIC GUIDANCE DEVICE: YA-1 BD.

is a block diagram of the Brush Supersonic Guidance Device YA-1BD, indicating how frequency f_1 is transmitted and received. By the time f_1 is received, the transmitter has changed to the new frequency f_2, which is mixed with f_1 and detected and amplified, providing an audio output signal.

The Doppler shift in frequency (see Section II-B-2-b and Fig. 2.3) for an observer moving at a velocity of 3 feet per second, and for a transmitter frequency of 30 kc is about 170 cycles per second. This frequency is superimposed on the audio-frequency difference between the transmitted and received frequencies (f_2 - f_1) thereby making the range indication ambiguous and dependent upon the relative velocities of observer and object. All frequency-modulated systems have this limitation; it becomes progressively worse at higher supersonic frequencies.

2. Constant-Rate-of-Modulation System

The principles of operation of systems frequency-modulated at a constant rate are the same as for sine-wave-modulated systems. In this case, however, the transmitter is frequency-modulated with a sawtooth wave rather than a sine wave; the sawtooth wave may be a regular or a clipped sawtooth, as shown in (a) and (b) of Fig. 2.23. The advantage of a constant rate of modulation is that the individual audio pulses are of constant frequency (indicative of range) rather than warbled in frequency (range indicated by the maximum frequency attained).

a. Brush Supersonic Guidance Device: YA-5BD

This is a portable device operating at a high supersonic frequency. It consists of a supersonic transmitter, receiver, and crystal transducers in one container held in the hand and used as a probe, and a battery supply carried on a shoulder strap. (Fig. 2.22.)

An auditory signal is presented which consists of a series of pulses of a frequency dependent on range. Low-pitched pulses indicate a near-by object; high-pitched pulses indicate a more distant object.

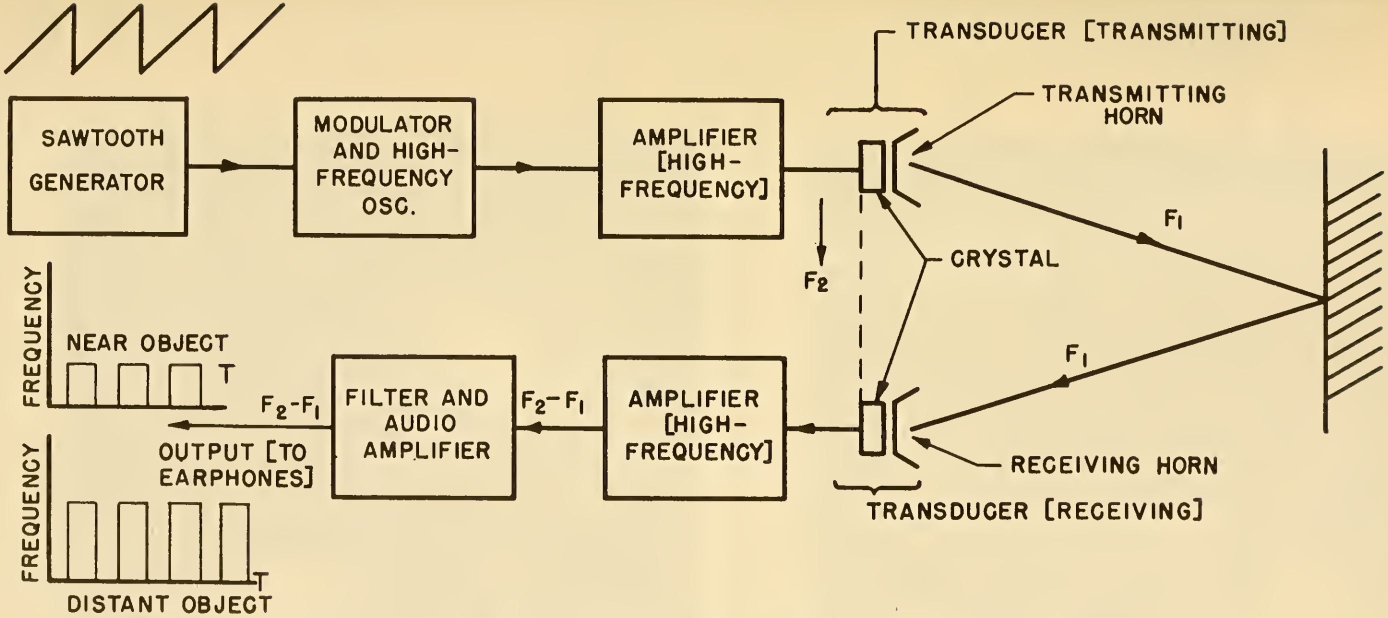

FIG. 2.24 BLOCK DIAGRAM OF BRUSH SUPERSONIC GUIDANCE DEVICE YA-5BD


[A] REGULAR SAWTOOTH

[B] CLIPPED SAWTOOTH

FIG. 2.23 SAWTOOTH WAVES

A sawtooth-wave generator frequency modulates a high-frequency oscillator (ca. 80 kc/sec) the output of which is amplified and applied to a crystal transducer (Fig. 2.24). The signal reflected from an object enters the receiving transducer after a time interval which depends on the distance to the object. A portion of the outgoing signal (at a frequency different from the frequency of the received signal) is mixed with the received signal, producing an audio frequency beat. After amplification, the high-frequency components are filtered out and the audio signal, proportional to the distance of the object, appears in the earphones.

The Brush Supersonic Guidance Devices, Fig. 2.25, YA-3BD and YA-4BD, operate on the same principle.

b. Stromberg-Carlson PFM Supersonic Guidance Device: YA-3ST

This is a portable device operating at the low end of the supersonic range. It consists of a supersonic transmitter and receiver in one container carried on a shoulder strap, and a pair of magnetostriction transducers carried in the hand and used as a probe (Fig. 2.26).

An auditory signal is presented which consists of a series of pulses of a frequency dependent on range. Low-pitched pulses indicate a near-by object; high pitched pulses indicate a more distant object; the repetition rate of the pulses remains constant.

A sawtooth-wave generator modulates a high-frequency oscillator, sweeping it from ca. 20 to 22 kc. After amplification, this signal drives the transmitter (Fig. 2.27). The envelope of the transmitted wave, due to the finite bandwidth of the transducer, is shown in Fig. 2.28; the designation pulsed-frequency modulation (PFM) has been applied to systems of this type. The signal received from a reflecting object enters a tuned amplifier and is then mixed with the transmitter frequency outgoing at the instant the reflected signal is received. The audio beat frequency is detected, amplified, and fed

FIG. 2.25
BRUSH SUPERSONIC GUIDANCE DEVICE, YA-2BD.

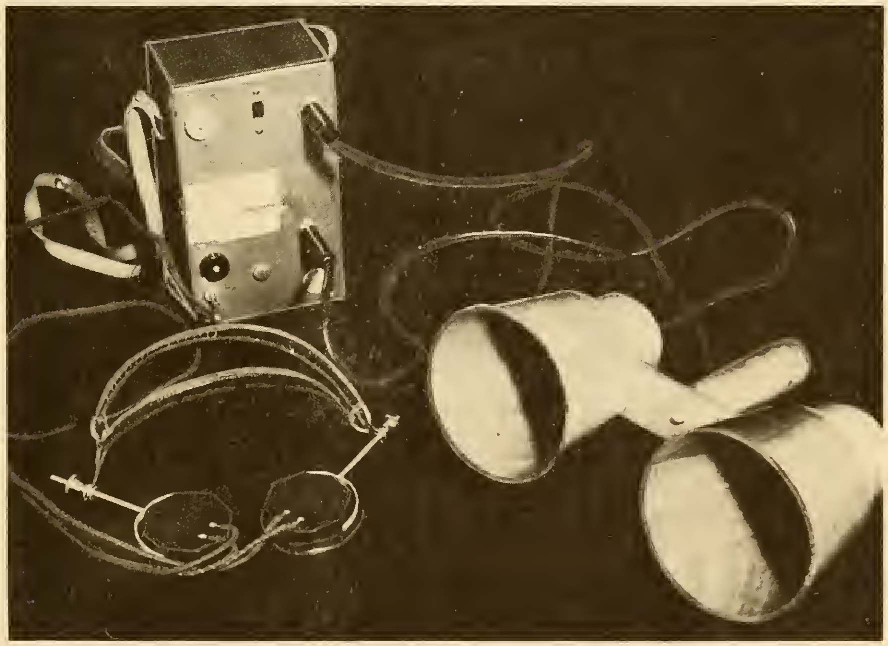

FIG. 2.26
STROMBERG-CARLSON "PULSED-FM"
SUPERSONIC GUIDANCE DEVICE, YA-3ST

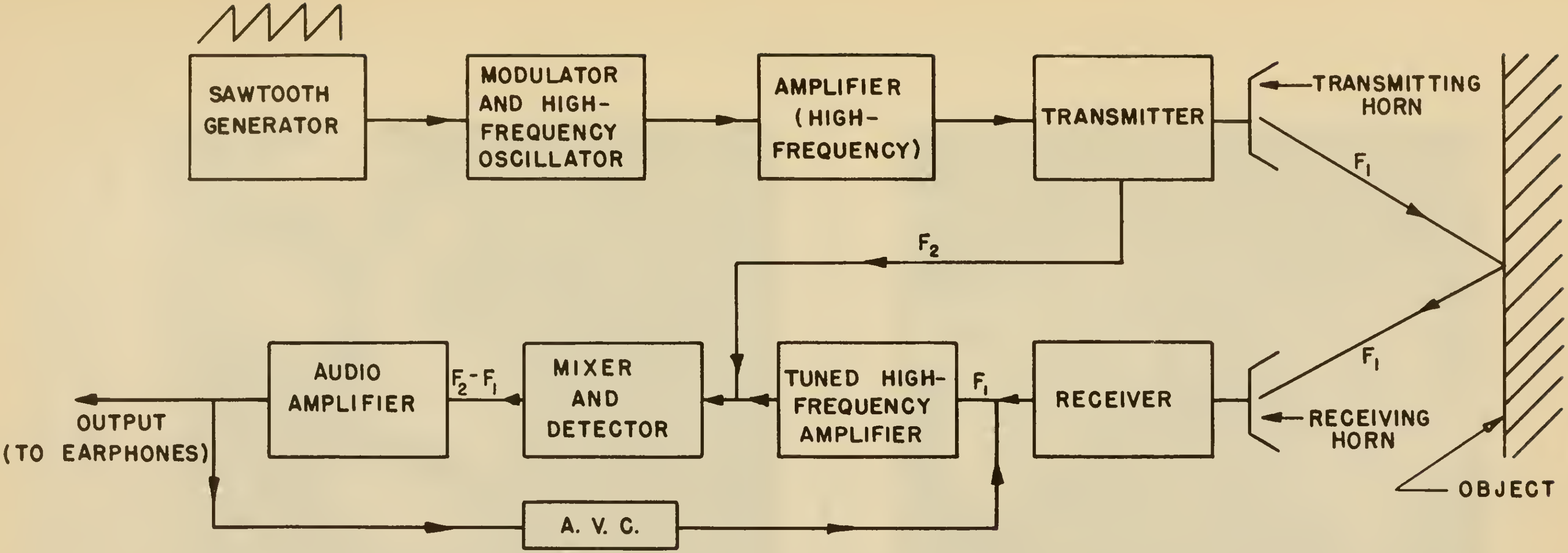

FIG. 2.27 BLOCK DIAGRAM OF STROMBERG-CARLSON SUPERSONIC GUIDANCE DEVICE: YA-3ST.

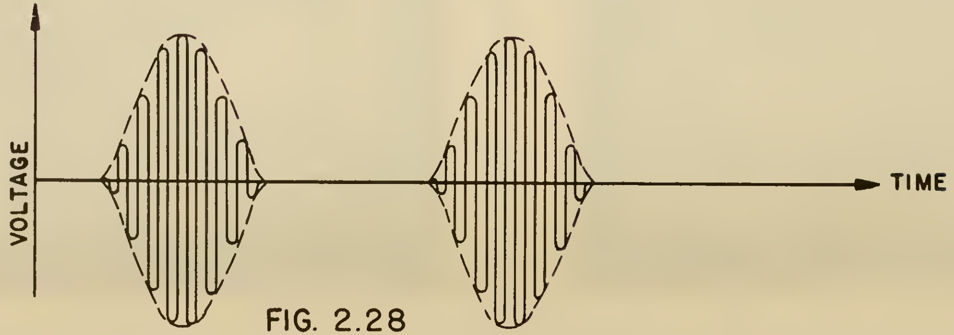

FIG. 2.28

SHAPE OF THE AUDIO OUTPUT VOLTAGE WAVE IN STROMBERG-CARLSON SUPERSONIC GUIDANCE DEVICE: YA-3ST.

FIG. 2.29

STROMBERG - CARLSON SUPERSONIC GUIDANCE DEVICE, YA-2ST.

to the earphones. An automatic-volume-control circuit is inserted between the tuned amplifier and the output of the audio amplifier to compensate for variations in the amplitude of the received signals. The other Stromberg-Carlson PFM systems (YA-2ST) and YA-3ST(M1)) operate in the same manner.

2. Audio-Frequency Devices

Many blind people detect and localize large objects by listening to the sounds reflected from them. The sounds may be generated by footsteps, by finger snapping, by an audio-frequency source, or they may be traffic noises (if not too loud or continuous). In the first of the two devices described below, efforts were made to enhance the use of sounds normally generated by a listener (footsteps, for example) or normally available (such as street noises); in the second, an audio-frequency source was used to aid in the detection of obstacles.

a. The Pan-audio Device: YA-5HL

The device consists of two hearing aids, placed on opposite sides of a baffle, to simulate the binaural effects characteristic of normal hearing. The hearing aids are so carried and connected that the one which is directed toward the user's right side is connected to the head phone on his right ear, and similarly for the left. It was planned that the gain of the hearing aid amplifiers would be set so that the volume of sound reaching the user's ear would be about the same as without a hearing aid most of the time. However, the gain of the hearing aids was to increase sharply for a few milliseconds following a pulse of sound such as a heel click, thereby enabling the user to hear highly amplified reflections of the sound pulse from near-by objects.

Development proceeded as far as the stage of evolving adequate acoustical shielding for the hearing aids. A few tests were made with the gain set higher than originally planned, but the automatic gain control feature was not tried. Difficulties were encountered in securing useful directional reception, and further development was deferred.

b. Audio-Frequency Obstacle Locator ("Tweeter"): YA-1HL

In this device an audio-frequency source (ca. 10 kc/sec) is used as an aid in the detection of obstacles by audible echoes (Fig. 2.30). A saw-tooth generator and a differentiating circuit were used to produce a series of sharp pulses which were amplified and fed to the type of high-frequency horn-type speaker which is commonly called a "tweeter" (Fig. 2.31). The user determined the presence or absence of an obstacle by the intensity of the reflected signal[1].

3. Optical Guidance Device Systems

Two major classes of guidance device systems using electromagnetic radiation in the visible or optical region of the spectrum are (a) ambient light devices and (b) light source devices.

a. Ambient Light Devices

1. Size-Shape Device: XA-2HL

The Size-Shape device, as implied, is used to determine the size and shape of various obstacles (Fig. 2.32). Light reflected from an obstacle enters a phototube, the direct-current output voltage of which is directly proportional to the received light intensity; the voltage is applied to a reactance tube which controls the output frequency beat-frequency oscillator (BFO) (Fig. 2.33). A constant frequency signal is obtained as long as the received light intensity remains constant, but the signal frequency changes when the received light intensity changes, as in scanning from a light to a dark object. Thus, the outline of an obstacle can be traced. Narrow beam widths are achieved by placing appropriate diaphragms in front of the phototube (in the image plane of the collecting lens).

---

[1] A development in progress at the College of the City of New York (with the co-operation of Haskins Laboratories) uses an 8000-12000 cycle oscillator and a quasi-directional horn to detect obstacles. Although quantitative tests are incomplete some outdoor obstacles can be detected; multiple reflections and standing waves limit the indoor use of the device somewhat. The high frequency note would appear to be distracting or annoying to others than the user.

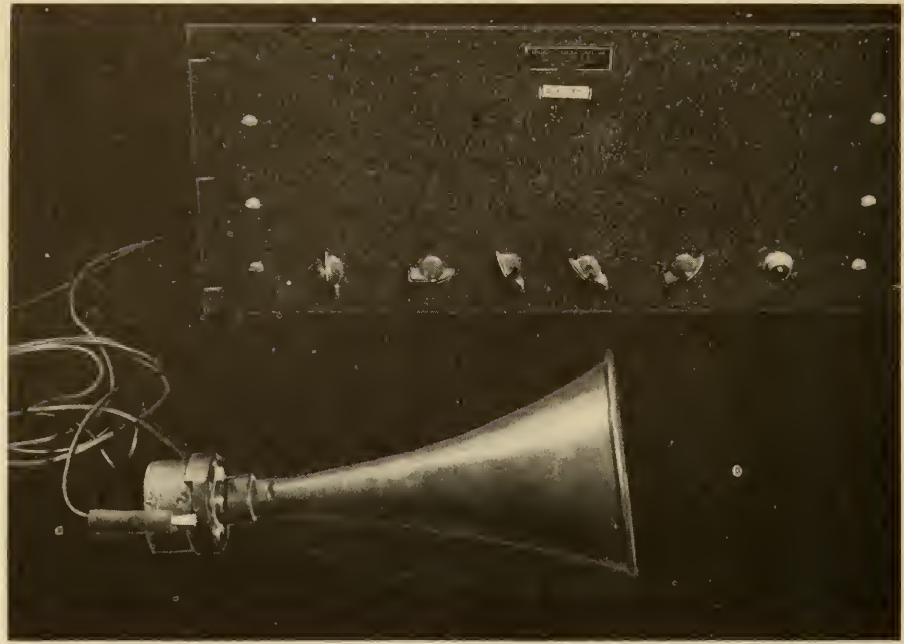

FIG. 2.30
HIGH-FREQUENCY-AUDIO OBSTACLE (TWEETER) GUIDANCE DEVICE, YA-IHL.

FIG. 2.32
"SIZE-SHAPE" OBSTACLE DEVICE, XA-2HL.

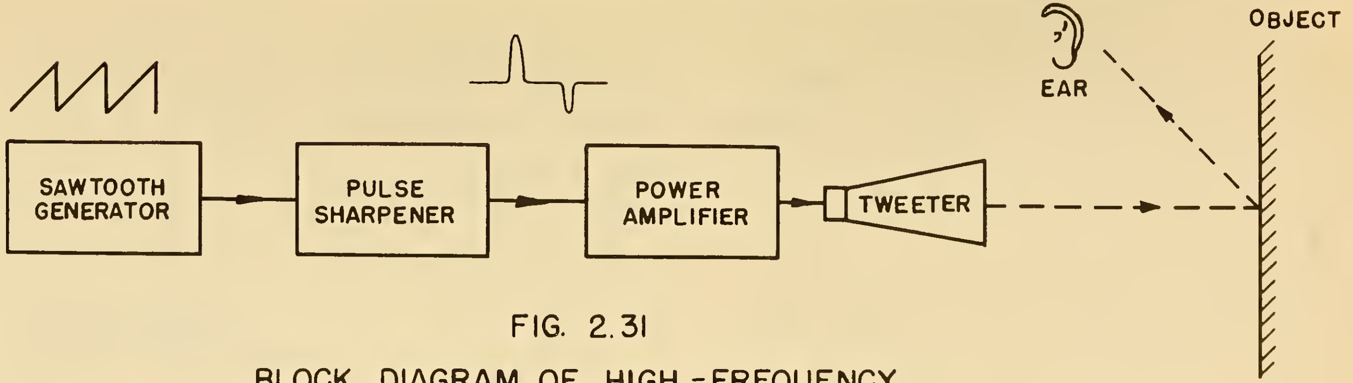

FIG. 2.31

BLOCK DIAGRAM OF HIGH-FREQUENCY OBSTACLE LOCATOR [TWEETER]: YA-1HL

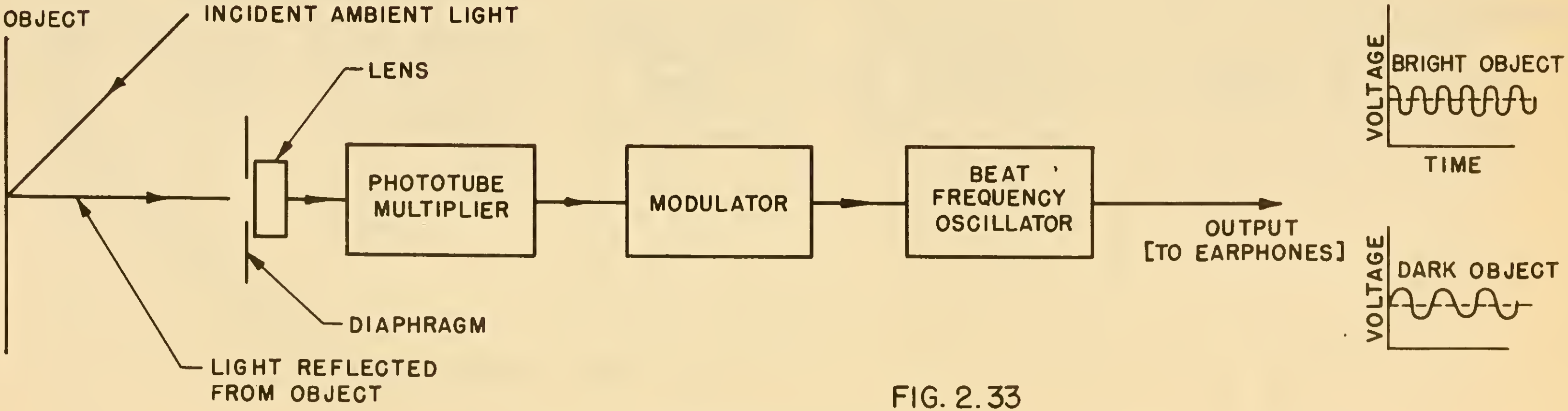

FIG. 2.33

BLOCK DIAGRAM OF SIZE-SHAPE DEVICE: XA-2HL

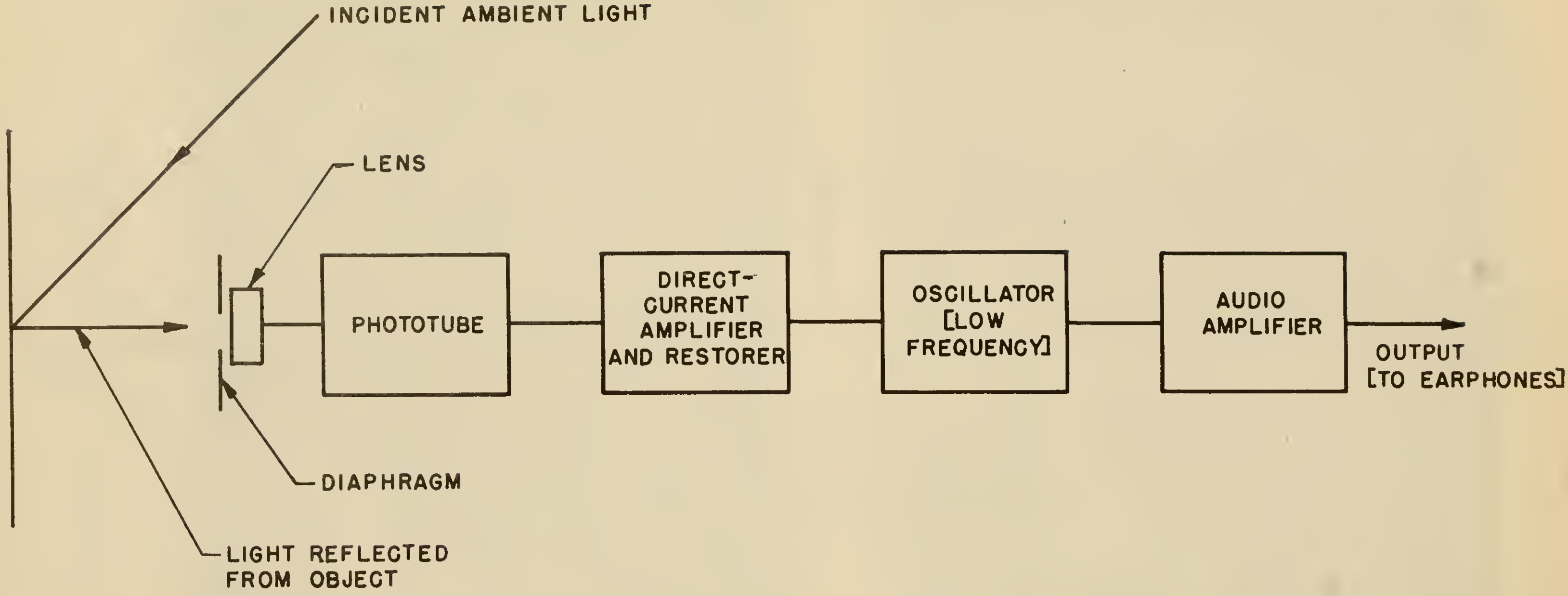

FIG. 2.35

BLOCK DIAGRAM OF LASHLEY AMBIENT LIGHT GUIDANCE DEVICE XA-IIE(MI)

2. Lashley Ambient Light Device: XA-1IE(M1)

This device was suggested by Dr. Lashley; it was built by Instrument Electronics, Inc. to Haskins Laboratories' specifications. This is a portable optical device consisting of a prospector carried in the hand and a small container carried on a shoulder strap (Fig. 2.34). The device consists of a collecting lens, aperture phototube, a direct-current amplifier (two stage, with a long time-constant network between the first and second stages), and an audio-frequency oscillator and amplifier (Fig. 2.35). The device produces a steady audio signal of predetermined pitch, so long as it receives constant light from an object. If the received light changes (for example, if the device is scanned from a brighter to a darker portion of an object), the pitch falls sharply and then returns slowly to its original level. Conversely, if the device is scanned from a darker to a brighter portion of an object, the pitch rises sharply and then falls to its original level. Thus, the change in pitch is a function of the change in brightness of an object. The pitch is set initially for approximately 800 cycles per second (adjustment is provided by a manual control); the initial change in pitch (either up or down corresponding to an increase or decrease in object brightness) covers approximately one octave on either side of the mid-frequency.

The original model (XA-1IE (Fig. 2.36)), operates on the same principle; however the initial pitch was considerably higher than in the second model (approximately 2000 cycles), the pitch change increased for a decrease in illumination), and the device was about twice the size of the newer model (XA-1IE(M1) (Fig. 2.34)).

b. Light Source Devices

1. The Signal Corps Optical Guidance Device: XA-1SC

This is a portable optical device consisting of a light source, lens system, photocell, and receiver in one container carried in the hand and

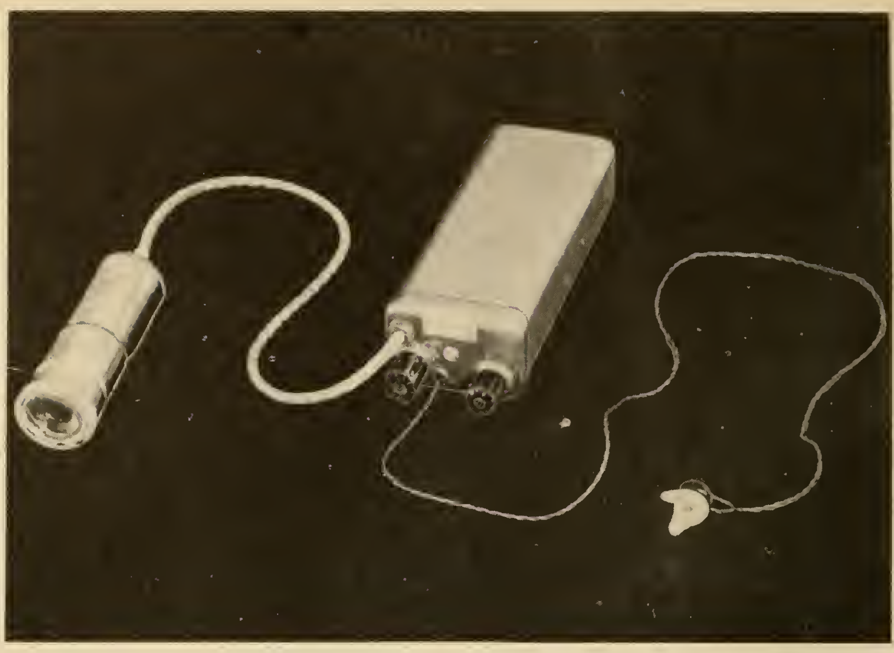

FIG. 2.34
LASHLEY "CONTINUOUS-TONE, AMBIENT LIGHT" OPTICAL DEVICE, XA-1 IE (MI)

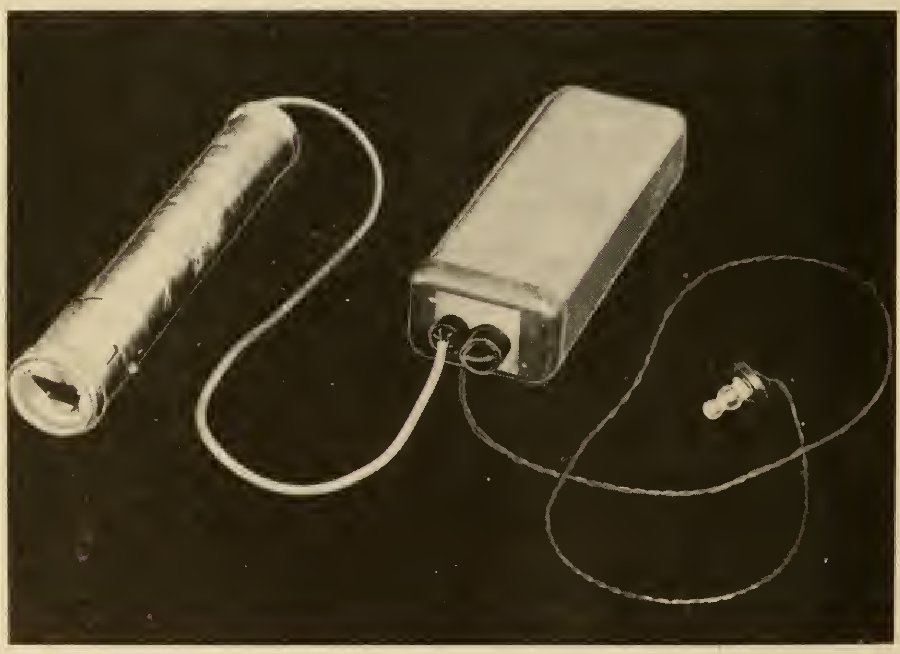

FIG. 2.36
EARLY MODEL OF LASHLEY OPTICAL DEVICE, XA-1 IE.

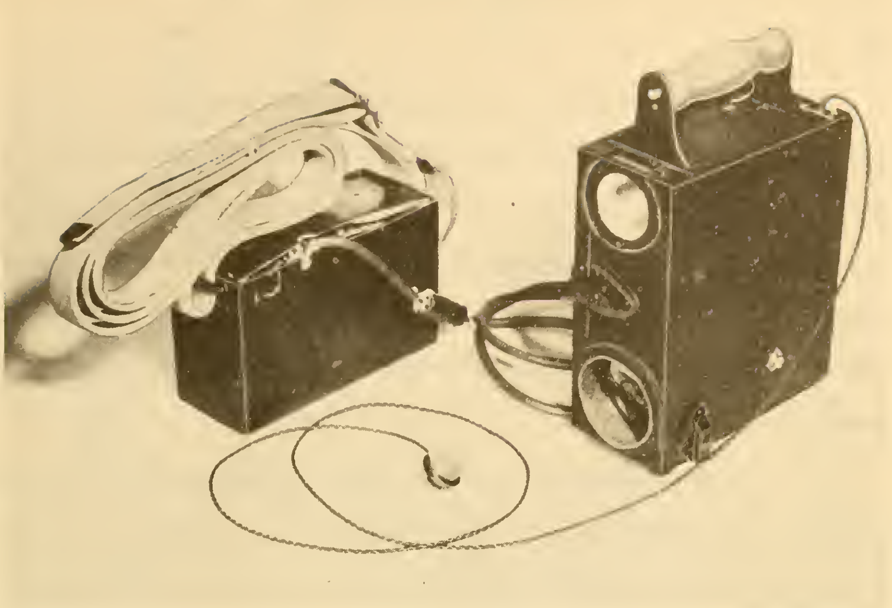

FIG. 2.37
SIGNAL CORPS OPTICAL GUIDANCE DEVICE, XA-ISC.

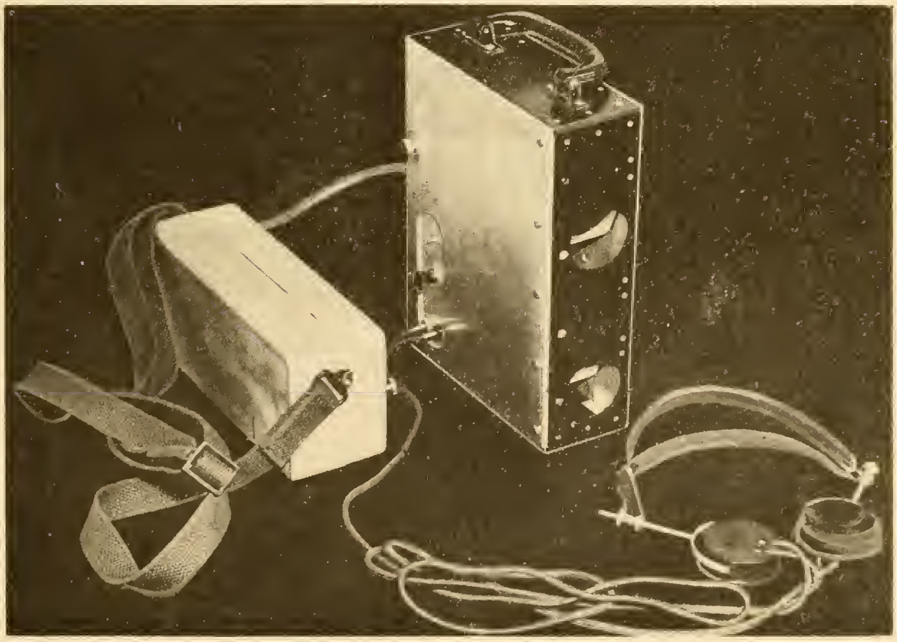

FIG. 2.40
CONTINUOUS TONE OPTICAL DEVICE, XA-4HL.

used as a probe, and a battery supply in another container carried on a shoulder strap (Fig. 2.37).

An auditory signal is presented which consists of a series of pulses with the time interval between pulses varying in discrete steps from 32 pulses per second for an object at 3 feet to 2 pulses per second for an object at 15 feet. The Signal Corps Optical Guidance Device was the first practical guidance device making use of an independent light source in that it was the first in which range information could be obtained directly from the signal without manual searching.

A light source (a 6 volt, 3 watt lamp) placed at the focus of a transmitting lens projects a very narrow beam of light which is modulated at approximately 500 cycles per second (by interposing between the lamp source and the lens a motor-driver rotating disk with a series of holes near its periphery). The transmitted light falling on an obstacle is partly reflected to a receiving lens which forms an image of the illuminated spot in its focal plane (Fig. 2.38). The centers of the transmitting and receiving lenses are 5 inches apart. By triangulation, the angle at which the reflected beam enters the receiving lens depends upon the distance of the object; hence, the image is shifted as the angle of reception changes, and the displacement of the image is directly related to the distance of the object.

A "coding disc" (Fig. 2.39) is placed between the phototube and the receiving lens. This disc, (driven at 2 revolutions per second by the same motor which rotates the modulating disc), is divided into concentric rings with different numbers of holes in each ring: the ring of smallest radius has one hole, the next 2 holes, the next 4 holes, the next 8, and the outermost ring has 16 holes. For objects farther than 15 feet from the device, the received image strikes the disc near its center and no light reaches the phototube. As an

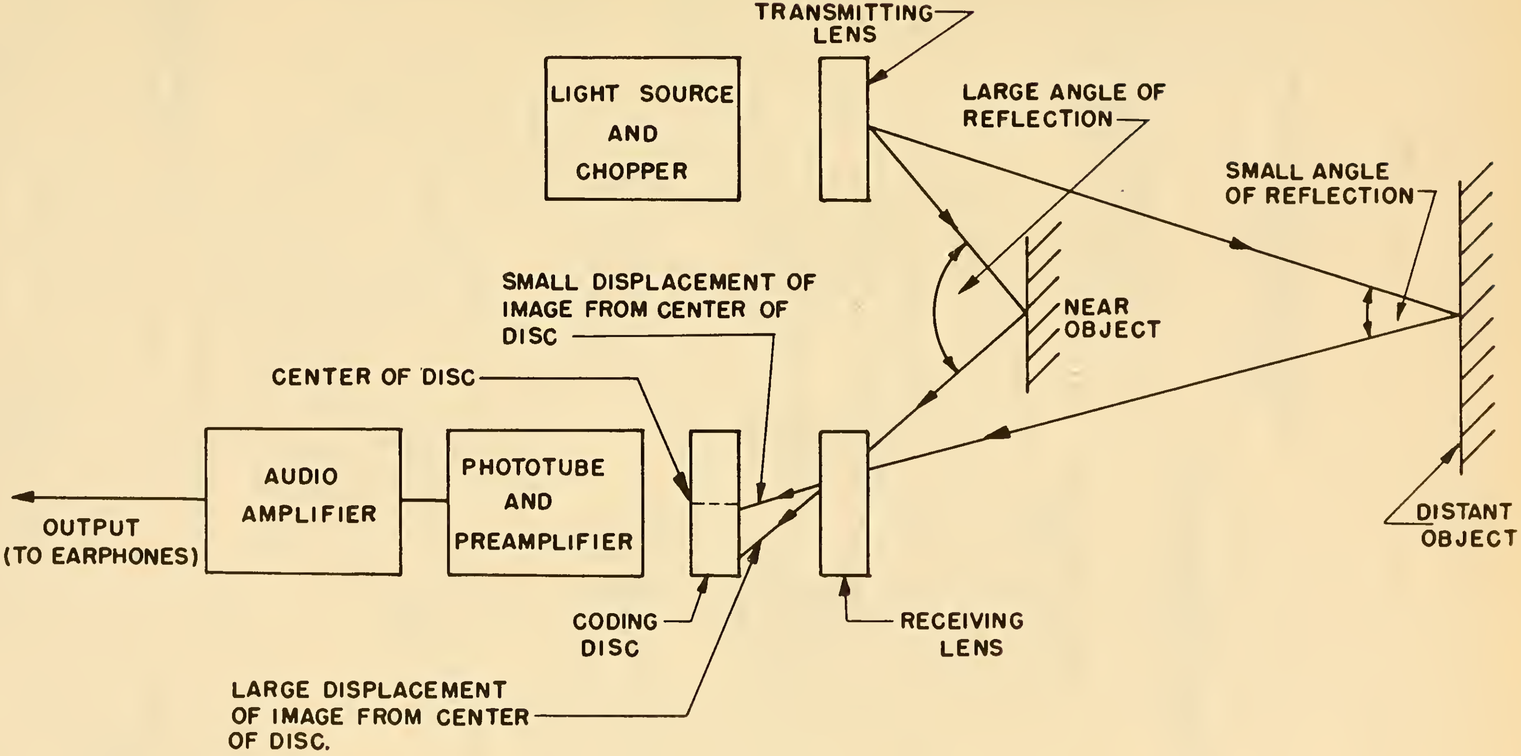

FIG. 2.38

BLOCK DIAGRAM OF SIGNAL CORPS OPTICAL DEVICE XA-ISC

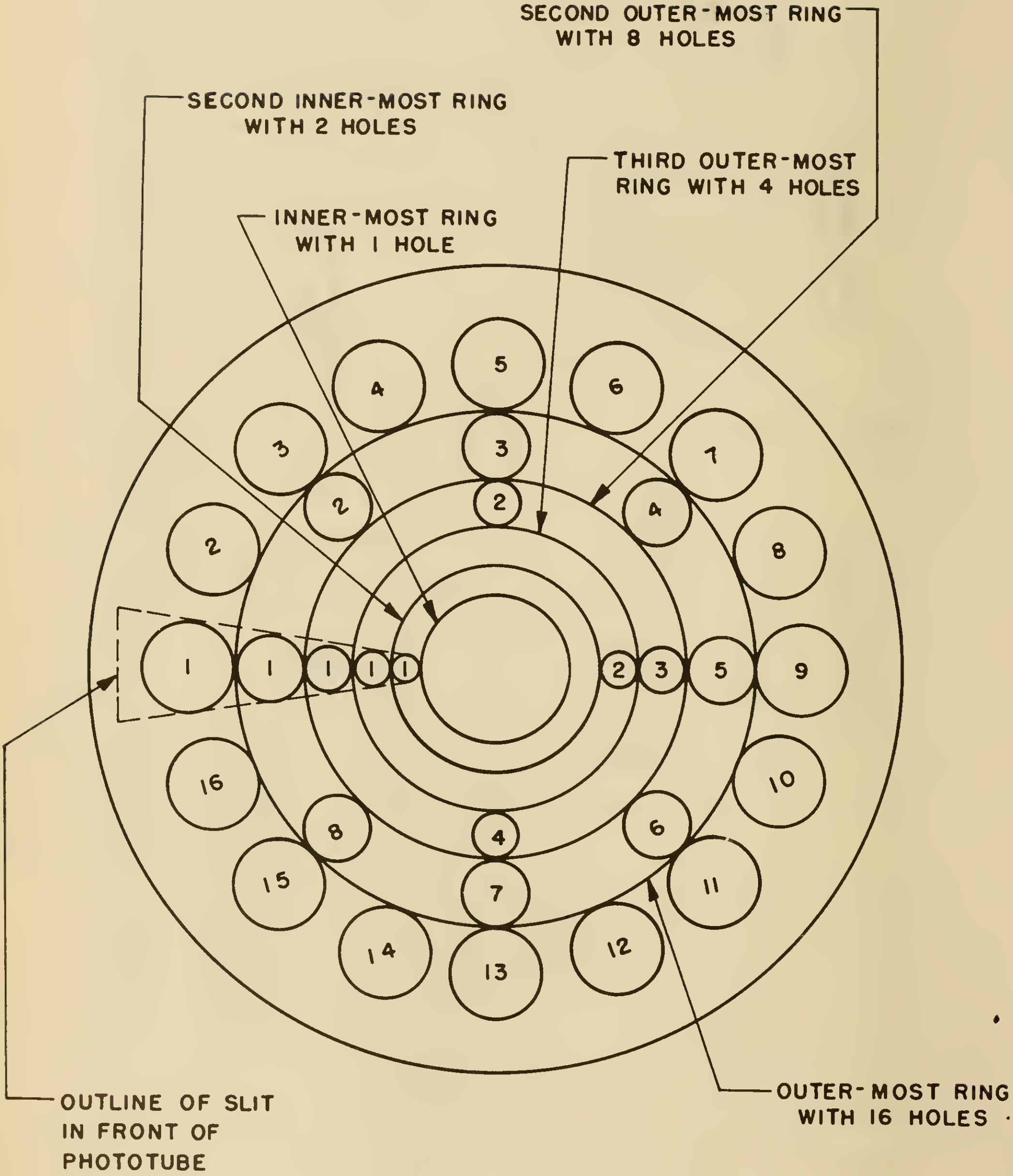

FIG. 2.39
DIAGRAM ILLUSTRATING ONE TYPE OF CODING DISC USED WITH THE SIGNAL CORPS OPTICAL DEVICE XA-ISC

object moves closer to the device, the image moves outward from the center of the disc and the modulated light reaches the photocell through the hole in the innermost ring; the light is then interrupted twice a second (since the disc is rotating at two revolutions per second). For successively shorter object distances the received light illuminates successive rings until, for an object at 3 feet (the minimum distance for which range is indicated), the outermost ring with its sixteen holes is illuminated. The received light from an object at this distance is interrupted 32 times per second.

Since the transmitted light beam is modulated at 500 cycles per second, a brief 500 cycle note is heard in the earphones from 2 to 32 times per second, depending on object distance. Thus, the change from one pulse repetition rate to another (corresponding to a change in object distance) is not abrupt since two of the rings on the disc may be illuminated simultaneously. A mixture of pulse repetition rates will then be heard for certain positions of an object.

A pre-amplifier, peaked at 500 cycles per second, follows the photo-cell, and accepts only the modulated light. It is by this means that the distinction between the modulated transmitted light and the ambient light is achieved. In practice selectivity is not perfect; some ambient light does get through the pre-amplifier resulting in a distinct "hiss" when the device is used in bright sunlight.

2. Continuous-Tone Device: XA-4HL

This is a portable device consisting of two parts: (1) a hand-held probe containing a light source, lens system, photocell, and receiver, (2) a container with battery supply, carried on a shoulder strap (Fig. 2.40).

This device also uses a modulated beam of light and depends on the principle of triangulation but employs a "follow-up" mechanism rather than

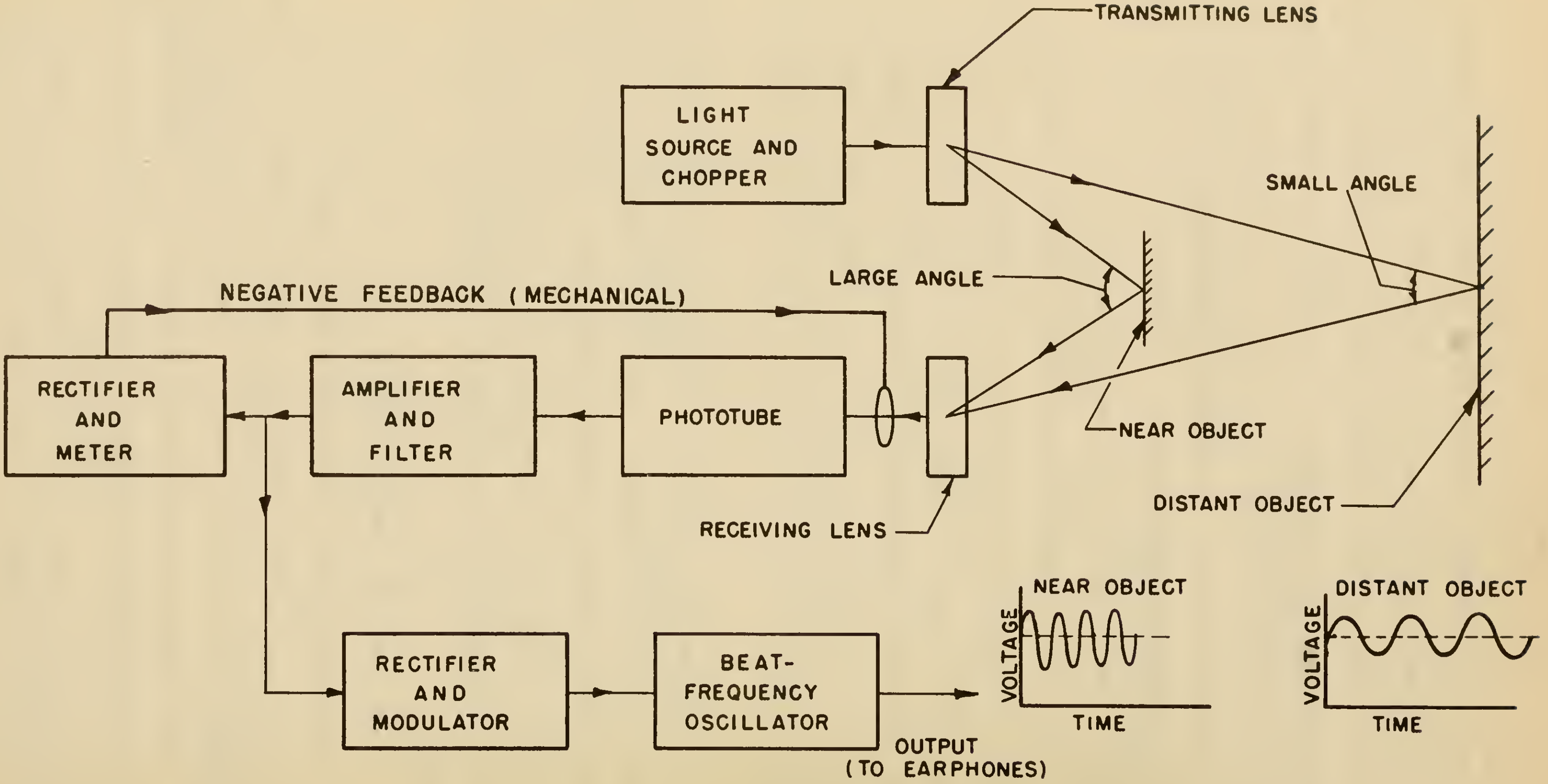

FIG. 2.41

BLOCK DIAGRAM OF CONTINUOUS-TONE OPTICAL SYSTEM XA-4HL.

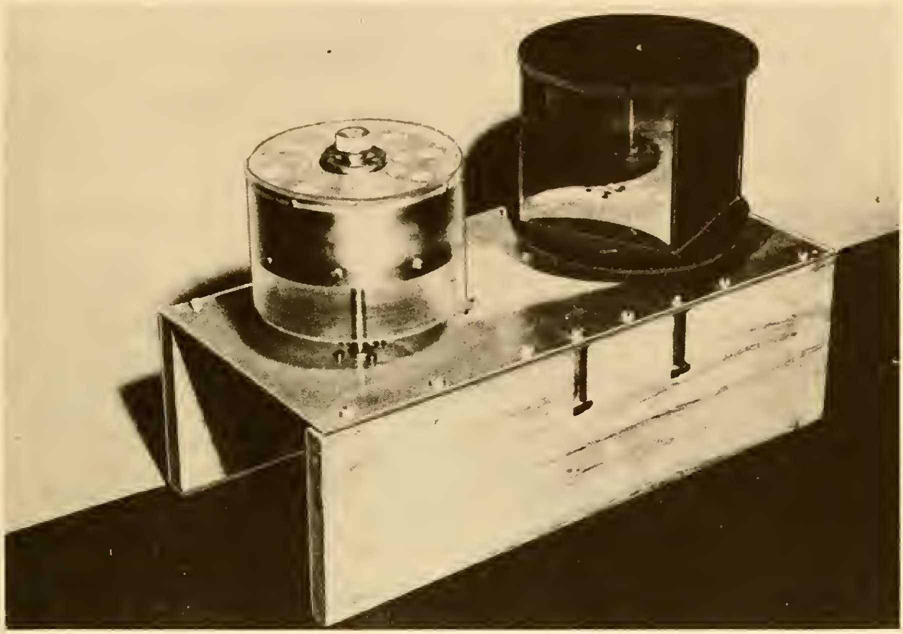

FIG. 2.42
EARLY MODEL OF
OPTICAL SCANNING DEVICE,XA-5HL.

a coding disk. The pointer of a milliammeter carries a light-weight mask across an aperture in front of a photocell. The beam of light reflected from an obstacle reaches the photocell through the aperture. The photocell output, after amplification and rectification, deflects the meter needle until it intercepts most of the reflected beam and an equilibrium is reached (Fig. 2.41). There is, then, a unique value of meter current for each object distance, since the slit is arranged so that the meter current will vary with the displacement of the image. Part of the meter current is applied to a reactance tube which controls a beat-frequency oscillator (BFO). The BFO is tuned to zero beat for no meter current, i.e., no light falling on the photocell.

The equilibrium of the meter pointer and masks will depend somewhat on the reflectivity of an object, due to finite image size. There is, therefore, a slight ambiguity in the range indication. Moreover, it was found that under conditions of relatively intense ambient radiation, the photocell tends to saturate and its sensitivity to the modulated light decreases causing irregular variations in the frequency of the signal.

4. The Pattern Optical Device (Recognition Device): XA-6HL

This is a non-portable device (Fig. 2.42) which incorporates automatic scanning.

An auditory signal is presented which consists of combinations of frequencies, the particular combinations depending on the size and shape of the object and its position in the field of view.

All of the devices discussed thus far are probe devices in which information about a very limited region of space is provided as the device is pointed in a given direction; all scanning (searching in azimuth and elevation) must be performed manually. The desirability of presenting information concerning a large number of points in space, either simultaneously or in sufficiently rapid succession to provide an auditory pattern of the environment, has been recognized;

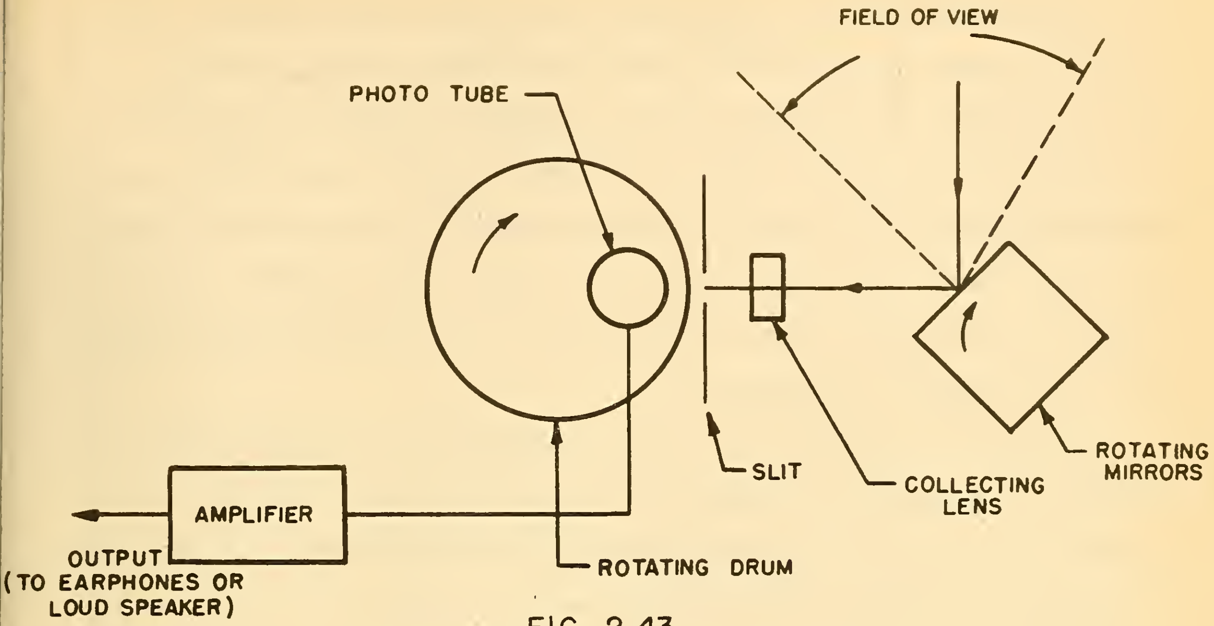

FIG. 2.43
DIAGRAM OF PATTERN OPTICAL DEVICE: XA-5HL

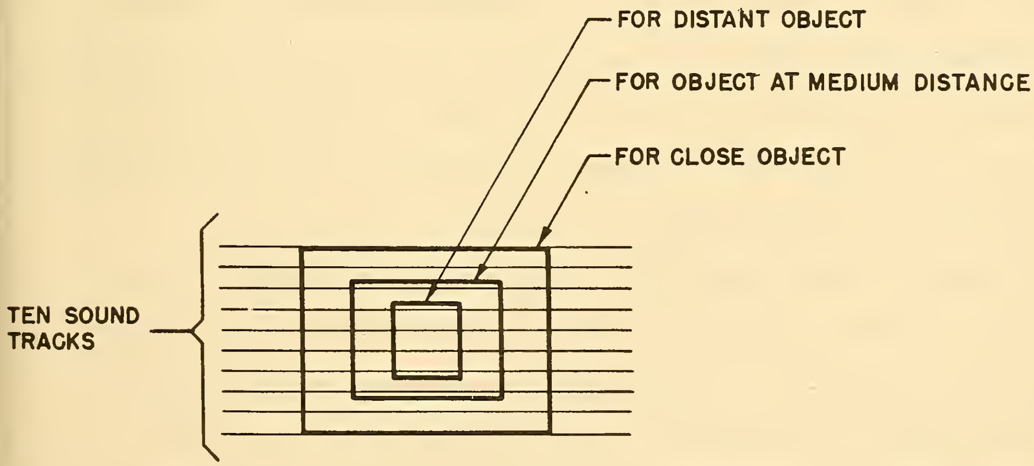

FIG. 2.44

SCHEMATIC SHOWING SIGNAL CHANGE VS. OBJECT DISTANCE the feasibility has yet to be demonstrated. The pattern optical device is an automatic scanning device utilizing ambient light which presents such an auditory pattern. Scanning is achieved by rotating a cubical mirror (the cube is mounted on a circular disc which rotates about a vertical axis) at 9 revolutions per minute. Each of the four mirrors "look" at the forward environment in succession, scanning it from left to right, in 1.7 seconds[1]. A marker signal is used to indicate the start of each scan. Thus, constant and automatic searching in azimuth is accomplished.

The vertical position of an object is indicated by a frequency (one component of the complex tone comprising the "pattern") which is high or low to accord with high or low object position. This is accomplished by a combination of lens, slit, rotating cylinder, and photocell (Fig. 2.43). The lens forms an image of the object at a point on a vertical slit which corresponds with the vertical position of the object. Behind the slit is a transparent cylinder which carries a series of variable density sound tracks past the slit, thereby modulating the light which passes through to a multiplier photocell. Since the ten sound tracks (in the present model) modulate the light at different frequencies ranging from 400 to 1700 cycles per second, light from a bright object will generate one or more frequencies which depend on the elevation of the object, and the corresponding position of its image on the slit.

The apparent vertical extent of an object is determined by the size of its image, and indicated in terms of the number of frequencies excited. Thus, the image of a given object at a given distance illuminates, say, four sound tracks, giving rise to four frequencies simultaneously. As the object moves closer to the device, the image size increases so that first five and then six sound tracks are illuminated, and five or six frequencies are heard; for closer

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[1] The scanning time can be readily adjusted to any desired value.

approach, the image size is further increased until all of the sound tracks are illuminated and ten frequencies are heard simultaneously.

Azimuth localization is given by the time interval between the start of a scan (indicated by a marker signal) and the instant when the signal from an object is first heard; the time interval is short for objects on the left, it is longer for objects toward the right of the field of view. For an object at a given distance a definite fraction of the total scan time is spent "looking" at the object; that is, the signal from an object will have a definite duration (0.3 seconds, for example). As the object approaches the device the fraction of the total scan time spent "looking" at it increases, and the signal duration increases until a fairly large object (such as a person), directly in front of the device, utilizes almost all of the scan time. The signal pattern is extended in both duration and total frequency range (Fig. 2.44).

In summary, it can be assumed that different objects at given distances from the device will have distinctive auditory patterns; as an object approaches (or recedes from) the device the over-all pattern remains essentially the same, but frequencies are added to (or subtracted from) the top and bottom of the pattern and the duration of the pattern increases (or decreases). Experiments are in progress to test the ease of recognition of such patterns.

5. Characteristics of Guidance Device Systems Thus Far Developed

The salient characteristics of guidance device systems which have been developed thus far are summarized in Table 2.2 (at end of volume).

6. Maintenance of Guidance Device Systems

Continuous maintenance of guidance device systems is necessary to secure peak performance, and to ensure reliability and reproducability in day-to-day use of the devices. Ultimately, of course, a guidance device should be at least as reliable and trouble-free as a hearing aid or a good portable radio; moreover, very simple checks on the over-all performance of the device should be easy for a blind user to make. The character of maintenance operations during the development program is, however, considerably different from that expected of a device for regular use by the blind. During development, two mutually exclusive requirements have to be fulfilled: on the one hand, it is urgent that design engineers produce devices as quickly as possible for the psychological testing program; on the other hand, careful engineering is required if the devices are to be reasonably reliable during the tests. A judicious compromise between these two requirements has been attempted, not always with success. Consequently difficulties and delays have been encountered occasionally in the testing program while emergency repairs were being made.

The following provisions should be included in future designs in order to minimize maintenance difficulties: (1) a limited number of test points should be accessible on the chassis (through a door in the instrument case); (2) sub-assemblies should be employed to facilitate bench-servicing.

Standardized physical tests are being developed for each of the devices; performance specifications for new devices should be considered in connection with the design of the device. These will expedite the testing of the devices.

III. EVALUATION TESTS

A. ORIENTATION

1. Some sources of difficulty for blind persons

It is clear that a meaningful evaluation of guidance devices can be made on the basis of standardized tests only insofar as those tests are relevant to the practical problems of the blind. In an attempt to secure some knowledge concerning the specific nature of such problems, the following preliminary study was carried out.

Five blind informants were asked to note and report the kinds of objects involved in their daily collisions for a period of two weeks. They were asked then to include in their reports all troublesome objects and situations, whether or not they had been encountered during the assigned two-week period of observation. These reports of the informants were used as the basis for a master list of objects and situations which are considered by the blind to present significant difficulties for them. It seems that the informants, in assigning importance to the various items, were primarily concerned with the physical harm that results from inadequate adjustment when these objects are encountered. The frequency with which the objects are encountered was considered to be of secondary importance. Since the informants found this the proper way to regard the problem, no attempt was made to influence them. Thus, though an open manhole is not a common source of difficulty, it is considered important, because, if encountered, it leads to serious trouble.

The various items are arranged in Table 3.1 according to their average ratings. All of the items in Group A received an average rating of five, meaning that there was complete unanimity of opinion concerning these items. Those assigned to Group B received an average rating of four or greater but less than five. The average ratings for items in Groups C and D were from three to four, and from two to three respectively. No average rating less than two was obtained.

TABLE 3.1

Relative Importance of Objects and Situations Considered Troublesome to Blind Persons

Group A

(1) Crossing streets safely.

(2) Adequate warning of the edge of a platform.

(3) Mail-boxes.

(4) Open manholes.

(5) Open cellar doors.

Group B

(6) Telephone and light poles.

(7) Curbs.

(8) Doors half open.

(9) Pipes or ropes at head-level--awnings.

(10) Stairs--detect presence of step-down.

(11) Differences in curbs--low on one side of the street and high on the other.

(12) Mantelpieces.

(13) Beams at an angle to a wall--flying buttresses.

(14) Stands on the street.

(15) Finding entrances to stores-i.e., doorway entrances.

(16) Saw-horses.

Group C

(17) Hydrants.

(18) Half-open drawers.

(19) Ropes, chains.

TABLE 3.1 (cont.)

Group D.

(20) Walking Straight

(21) Refuse boxes.

(22) Subway turnstiles.

(23) Small tables.

(24) Chairs.

(25) Footstools.

2. Summary

A list of objects which constitute very common sources of difficulty has been developed from the introspections of a number of blind persons. They are presented in the approximate order of their importance.

B. EVALUATION OF A SUPERSONIC GUIDANCE DEVICE WITH REGARD TO ITS USE IN LOCATING DOORWAYS.

1. Purpose.

It was intended that this experiment should provide preliminary data concerning the effectiveness of the Stromberg-Carlson, "pulsed FM" supersonic device (YA-2ST), as an aid to the blind in the detection of doorway-like openings.

2. Procedure.

The subject was required to proceed along a 40-foot course, through 33-inch openings in each of six rows of barriers which were so arranged as to be perpendicular to the general direction of progress through the course. Each of the six barrier-rows extended across the entire 12-foot width of the course, and was made up of plane-surface sections of sheet-rock placed end to end. The sheet-rock sections which comprised each barrier-row varied in height, randomly within and among the rows, from one to six feet (See Fig. 3.9). There was but one opening in each barrier-row, and the location of that opening was varied unsystematically from trial to trial.

Each subject went through the course an equal number of times with and without the guidance device. Trials with and without the device were so arranged in the order of trials as to preclude the possibility that practice effects could introduce a systematic bias into the results for either condition.

It was counted an error whenever any part of the subject's body or the guidance device touched any of the barriers.

The two subjects had only casual and limited experience with the guidance device prior to this experiment. While a trial was in progress, no attempt was made to communicate to the subject the nature of or possible reasons for any of the errors he may have made. After each trial, however, the experimenter rehearsed some of the subject's errors with him, and undertook, wherever possible, to suggest apparently reasonable means for avoiding those errors.

FIG. 3.1
SUBJECT CARRYING SIGNAL CORPS OPTICAL GUIDANCE DEVICE, XA-1 SC.

FIG. 3.2
SUBJECT CARRYING MEEKS' CONTINUOUS-TONE
OPTICAL DEVICE, XA-4 HL.

FIG. 3.3
SUBJECT CARRYING STROMBERG-CARLSON "PULSED FM" SUPERSONIC GUIDANCE DEVICE, YA-3 ST.

FIG. 3.4
SUBJECT CARRYING BRUSH SUPERSONIC GUIDANCE DEVICE, YA-5 BD.

FIG. 3.5
SUBJECT CARRYING BRUSH SUPERSONIC GUIDANCE DEVICE, YA-3 BD.

FIG. 3.6
SUBJECT CARRYING HOOVER MECHANICAL SUPERSONIC GUIDANCE DEVICE, YA-1 HC.

FIG.3.7
SUBJECT CARRYING "CONTINUOUS-TONE" OPTICAL DEVICE, XA-11E(M1).

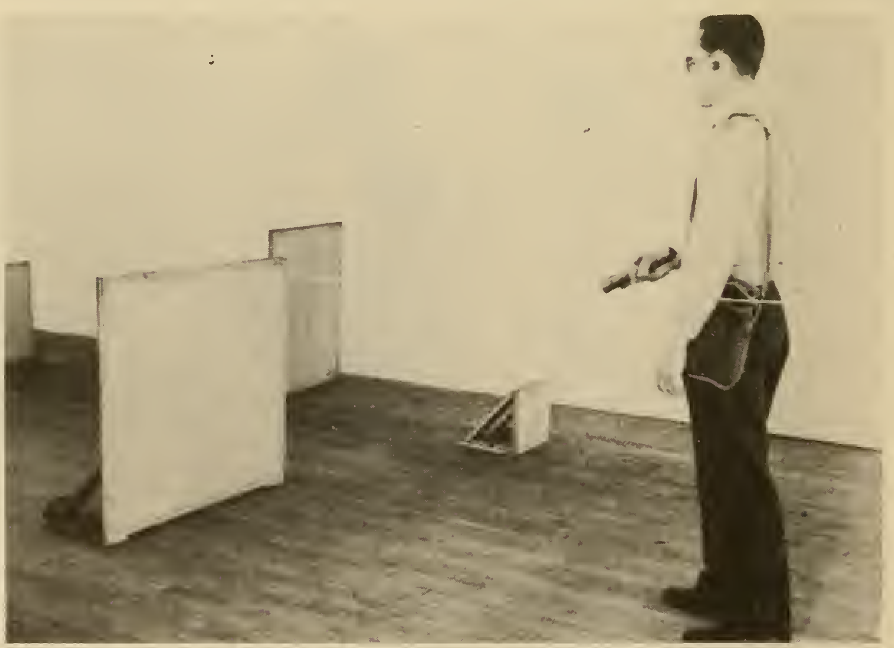

FIG.3.8

SUBJECT CARRYING EARLY MODEL OF "CONTINUOUS-TONE" OPTICAL DEVICE, XA-11E.

FIG. 3.9
OBSTACLE COURSE, SIMULATING DOORWAYS

3. Subjects.

Two subjects were used in this experiment: M.C. (who is blind) and S.E. (who is sighted). For descriptions of these subjects see III-N.

4. Results and discussion.

In Tables 3.2 and 3.3 are to be found the data which describe the performance of the two subjects under the two conditions of this experiment.

TABLE 3.2

Total Errors Made and Total Time Taken on Each Successive Group of Three Trials by Blind Subject (M.C.)

Trials	Total Number of Errors		Total Time in Minutes	
	With Device (YA-2ST)	Without Device	With Device (YA-2ST)	Without Device
1-3	11	10	30.17	6.17
4-6	4	15	21.29	14.90
7-9	7	9	21.11	13.63
10-12	2	8	12.50	14.88
13-15	0	4	11.83	11.98
16-18	2	6	13.17	10.13
Totals	26	52	110.07	71.69

The data of Tables 3.2 and 3.3 refer to the blind subject (M.C.) and to the blindfolded sighted subject (S.E.), respectively. The total numbers of errors made in each successive group of three trials are presented in the second and third columns of each table. In the fourth and fifth columns of Tables 3.2 and 3.3 are the total times (in seconds) taken by the subject to complete each group of 3 trials.

TABLE 3.3

Total Errors Made and Total Time Taken on Each Successive Group of Three Trials by Sighted Subject (S.E.)

Trials	Total Number of Errors		Total Time in Minutes	
	With Device (YA-2ST)	Without Device	With Device (YA-2ST)	Without Device
1-3	10	44	17.85	6.35
4-6	18	35	32.60	7.58
7-9	2	22	19.50	7.93
10-12	6	23	18.58	7.25
13-15	15	37	20.43	6.23
16-18	5	31	17.60	4.92
19-21	7	34	19.68	4.47
22-24	3	29	18.66	4.00
25-27	0	32	14.08	7.48
Totals	66	287	178.98	56.21

It is seen that fewer errors are made, by either subject, in the "with device" condition than in the "without device" condition. In the case of each subject, the discrepancy in total numbers of errors between the "device" and "no-device" conditions is such as could have arisen less than one time in 100 by any combination of uncontrolled factors.[1.]

Practice in the task set by this experiment results, for both subjects, in a reliable reduction in errors under the "with device" condition. A comparison of the discrepancy in the numbers of errors between the first and second halves of the training indicates, according to a Chi-square analysis, that a

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[1.] This estimate of the statistical significance of the discrepancy in numbers of errors was made by the method of Chi-square. In making this estimate, the data were analyzed separately for each subject; therefore, statements concerning the statistical significance of the results have reference only to the population of scores for a single subject, not to the population of subjects.

discrepancy in error frequency as large or larger than the one obtained would have arisen by chance less than one time in 100 for the blind subject, and less than five times in 100 for the sighted subject. In the "without device" condition, neither subject shows a reliable practice effect: the reduction in errors between the first and second halves of the "without device" condition is such as to yield a probability of 20 in 100 for the blind subject, and 80 in 100 for the sighted subject, that the discrepancy is accountable to chance. These data indicate that practice in this situation has the effect of increasing the advantage of the "with device" over the "without device" condition.

The amount of time taken by either subject to traverse the course is reliably greater in the "with device" than in the "without device" condition. The mean times taken with and without the device are such that, for either subject, differences as large or larger than those obtained could have arisen less than one time in 100 by chance. It is worth noting, perhaps, that the time taken by the blind subject in the "with device" condition diminishes rather steadily with practice, and the difference in time between the "with device" and "without device" conditions becomes progressively less. The time taken with the device appears to be reduced by practice for the sighted subject also, but, at the end of training, there remains a considerable discrepancy between the times taken with and without the device.

The comparisons between the "with device" and "without device" conditions which may be made from the data in Tables 3.2 and 3.3 must be qualified by the specification that, on a few trials at least, the use of the device presented for the subject a serious difficulty which is not adequately reflected in the data. It frequently happened, while the subject was using the device, that he would become almost completely disoriented with respect to the correct direction of progress through the course. In most cases the subject succeeded ultimately in reorienting himself, frequently as a result of his having walked directly into the lateral boundary of the course or into the backs of obstacles. When this happened, the errors or the time taken to traverse the course (or both) were increased. On one trial for each subject, however, the disorientation was so nearly complete, and the subject was so apparently unable to reorient himself, that the trial had to be discontinued. The data for these two trials are not included in the tabulation. Both of these trials occurred within the first three trials of the entire training series. It is the experimenter's impression that those disorientations which did not require discontinuation of a trial became less frequent with continued practice.

It was apparent to the experimenter and to the subjects that the most efficient use of the device would require the development and employment of adequate scanning procedures. It frequently happened, for example, that the subject would keep the beam aimed rather fixedly dead ahead, and would then collide with a large plane surface, having approached the plane surface at an angle which was other than normal. It seemed that this type of error occurred less frequently when both subjects had learned to scan the beam right and left. Such scanning is calculated to increase the probability that the beam will be at right angles to the obstacle at some point in the scan cycle, and, therefore, to increase the probability that the subject will get a signal return from the obstacle.

5. Summary.

Each of two subjects (one blind, the other blindfolded) was tested repeatedly with and without the Stromberg-Carlson supersonic (YA-2ST) device to determine the accuracy and speed with which he could make his way through a series of doorway-like openings.

Neither subject had received pre-experimental training in the use of the device.

By comparison with the accuracy and speed attained without the device, both subjects made reliably fewer errors and took reliably more time when they used the guidance device.

With continued practice, the accuracy and speed of the blind subject, and the accuracy (but not the speed) of the sighted subject, were improved relatively more in the with-device condition than in the without-device condition.

It was apparent to the experimenter and to the subjects that the careful development and application of appropriate scanning procedures was a most important prerequisite to the reasonably efficient use of the Stromberg-Carlson supersonic guidance device.

C. COMPARISON OF SEVERAL GUIDANCE DEVICES AS AIDS TO THE BLIND IN THE AVOIDANCE OF STATIONARY OBSTACLES.

1. Introduction.

The inability to detect and avoid stationary obstacles in his path is one of the more obvious and commonly mentioned sources of difficulty for the blind individual. Although obstacle avoidance is not the only problem confronting him, it is clear that any practical guidance device must, among other things, enable the blind individual to cope successfully with this problem. In any case, it is reasonable to assume that if a device enables the blind person to solve the problem created by the presence of more or less randomly distributed objects in his path, such a device is at least feasible, whereas if it fails in this connection, the device is quite clearly in need of further development.

2. Purpose.

These experiments were designed to evaluate the several devices in terms of the respective degrees in which they aid a blind man to avoid obstacles arranged at random in his path. It was intended, also, that these experiments, which are among the first we have made on guidance devices, should furnish the experimenters with a background of experience in terms of which they could more intelligently set up training procedures. Finally, these experiments were carried out on two types of obstacle courses in order to determine whether a denser or less dense distribution of obstacles afforded a more nearly adequate and practicable test of the guidance devices.

3. Description of Obstacle Course A.

This course consisted of 32 obstacles, ranging in size from one foot by one foot to five feet by five feet, and distributed more or less randomly over an area 48 feet in length and 16 feet in width. The entire course was contained in a room which was 62 feet long and 23 1/2 feet wide. The various sizes and shapes of obstacles used in this experiment were chosen so as to represent, at least approximately, the several types of objects which our subjects had pre-

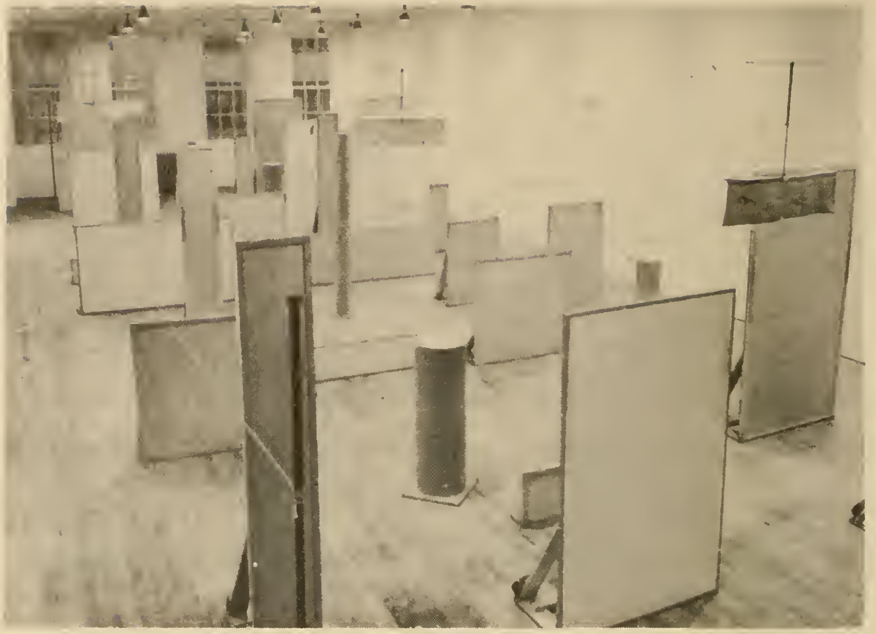

FIG. 3.10
OBSTACLE COURSE A

FIG. 3.11
OBSTACLE COURSE B

viously specified (See III-A, Table 3.1) as among the more troublesome classes of obstacles (Fig. 3.10). The following is a list of the objects that were simulated in their essential characteristics:

Obstruction from open cellar doors
Telephone and light poles
Awnings (over-head obstacles)
Stands on the street
Hydrants
Refuse boxes
Small objects (general)

4. Description of Obstacle Course B.

In this obstacle course there were 24 obstacles distributed more or less at random over two indoor areas, each of which was 48 feet in length and 9 feet in width (Fig. 3.11). These two areas were almost immediately adjacent to each other, and, together, they comprised a course which was longer, narrower, and less densely populated with obstacles than Course A. A single obstacle course trial in Course B consisted in having the subject go through one and then the other area of the course. The obstacles used in Course B were the same as those used in Course A, except that the over-head obstacles were eliminated from the former because they were not searched for and, consequently, were not detected by any subject with any device. It was clear, moreover, that if the subjects searched adequately for overhead objects, the efficiency of their performance with respect to the rest of the course would suffer to such an extent as to invalidate the test.

5. General procedure.

Each subject was put through Obstacle Course A for a total of 40 trials, 10 trials under each of the following conditions: (1) with the Brush supersonic sawtooth modulated device (YA-2BD), (2) with the Stromberg-Carlson "pulsed FM" supersonic device (YA-2ST), (3) with the Signal Corps optical device (XA-1SC), and (4) with no device. In course B the same procedure was used with the following devices: (1) the Hoover mechanical, supersonic device (YA-1HC), (2) the Stromberg-Carlson "pulsed FM" supersonic device (YA-2ST), (3) the Signal Corps optical device (XA-1SC), and (4) with no device.

On each trial, the subject made his way from one end of the course to the other, under instructions to try to avoid collision with the obstacles. In general, the pace was not prescribed, although a subject was occasionally urged to go faster when the experimenter felt that he was lingering unnecessarily. Such urging was seldom necessary.

The arrangement of obstacles in the course was changed in random fashion after each trial by a given subject.

An error was charged against a subject whenever any part of his body or his device touched an obstacle, provided the contact was made with an obstacle which was in the path of the subject's general direction of progress through the course. It was not counted as an error when the subject backed or side-stepped into an obstacle.

Inasmuch as the experimenters were, themselves, quite uncertain as to how the devices could most effectively be used, almost no attempt was made to train the subjects in the "proper" use of the devices. Pre-experimental "training" of the subjects was limited to a 10- to 20-minute orientation period, during which the subject was acquainted with the most general operating aspects of each device. He was shown what kinds of signals he could expect to hear when the obstacle was at different distances from him, and he was permitted briefly to "try" each device on several obstacles.

In going through Course B, all subjects had prior practice in Course A. Two of the devices (Hoover and Stromberg-Carlson) which were used in Course B had not been used in Course A. Before test trials were begun on Course B, the subjects were acquainted with these "new" devices according to the procedure described in the preceding paragraph.

6. Subjects.

In Course A six totally blind subjects were used; A.C., A.H., W.H., W.L., J.M., and V.T. None of these subjects had any previous obstacle course experience.

For work in Course B only four subjects were available. They were A.C., A.H., W.H., and J.M., all of whom had experience in Obstacle Course A.

7. Results.

The total number of errors made on 10 trials by each subject with each device and with no device are shown for both Course A and Course B in Table 3.4. This table also shows the total number of errors and the average number of errors per trial made in each of the conditions.

TABLE 3.4

Total Number of Errors in Ten Trials

Subjects	Conditions			
	Course A			
	No Device	Brush (YA-2BD)	Signal Corps (XA-1SC)	S-Carlson (YA-2ST)
A.H.	95	83	48	71
A.C.	84	74	79	65
W.H.	89	87	74	67
J.M.	90	89	70	67
W.L.	93	83	75	75
V.T.	102	92	94	104
Total	553	508	440	449
Average/Trial	9.2	8.5	7.3	7.5

TABLE 3.4 (cont.)

Subjects	Conditions			
	Course B			
	No Device	Hoover (YA-1HC)	Signal Corps (XA-1SC)	S-Carlson (YA-3ST)
A.H.	39	56	26	63
A.C.	96	63	49	74
W.H.	83	53	39	72
J.M.	60	72	88	81
Total	278	244	202	290
Average/Trial	7.0	6.1	5.1	7.3

The most direct method of treating the data shown in Table 3.4 is in terms of a null hypothesis to the effect that if a device has no particular obstacle-avoidance value for a given subject, then his total errors with that device should approximate his total errors with no device. For each entry, in Table 3.4, which refers to performance with a device, there is an observed disparity between the device-errors and the no-device errors for each subject. The Chi-square test is a convenient method for determining the probability of obtaining the various observed disparities by chance along[1]. These probabilities are given in the body of Table 3.5.

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[1] An example of the calculations follows. It will be seen in Table 3.4 that Subject A.H. had 95 errors with no device and 83 errors with the Brush (YA-2BD) device. When the results of the two conditions are combined, there is a total of 178 errors. If there were no real difference between the two conditions, it would be expected that 89 errors would be made under each condition, i.e., the total errors would be divided equally between the two conditions. There is, then, a difference of six errors between the number expected on the null hypothesis and the number obtained. The Chi-square test indicates that if, indeed, there were no difference between the two conditions involved, a difference as large as six errors in this instance would be expected to arise 38 times in 100 by chance alone. It is customary to accept five or less than five chances in 100 as suggesting doubt concerning the null hypothesis. Entries of five or less in Table 3.5, therefore, may be taken to mean that the differences in Table 3.4 to which they refer are significant.

TABLE 3.5

Probability of Obtaining the Differences
to be Observed in Table 3.4 (Chances in 100)

	Course A			Course B		
Subjects	Brush (YA-2BD)	Sig. Corps (XA-1SC)	S-Carlson (YA-2ST)	Hoover (YA-1HC)	Sig. Corps (XA-1SC)	S-Carlson (YA-3ST)
A.H.	38*	1*	6*	8	10*	2
A.C.	38*	70*	12*	1*	1*	9*
W.H.	89*	24*	18*	1*	1*	39*
J.M.	99*	11*	7*	30	2	9
W.L.	46*	17*	17*			
V.T.	48*	58*	89			
$\Sigma\chi^2$	86	1	2	1	1	2
χ^2 Total	17*	1*	1*	15*	1*	83
Interaction	99	11	62	1	1	1

Since there is nothing in these probabilities to indicate whether or not the differences to be derived from Table 3.4 are in favor of the device, asterisks have been affixed to those probabilities which refer to differences in favor of devices.

Although the large majority of the individual entries in Table 3.5 are in favor of the devices, only a few of them reflect reliable differences. When the individual Chi-squares are summated for each device, the probabilities entered in the rows labeled $\Sigma\chi^2$ are obtained. This treatment of the data provides an indication that, when the direction of the differences is disregarded, there is a significant deviation from the one-to-one hypothesis for all devices except the Brush device. Such a result, however, does not mean that the devices are superior to no-device, since any deviation from the hypothesis contributes to the sum of Chi-square.

The entries labeled "Total" were obtained by a procedure different from the one described above, and they have, accordingly, a different meaning. These entries are derived from the differences between the totals entered in Table 3.4, i.e., they express the probabilities of obtaining chance differences as large as those existing between the totals for no-device and the totals for the various devices in Table 3.4. It will be observed that these differences are always in favor of the devices, except for Stromberg-Carlson in Course B. These entries indicate that the Signal Corps device and the Stromberg-Carlson device in Course A, and the Signal Corps device in Course B, showed reliable superiority as compared with no device.

The entires labeled "Interactions" indicate whether or not the subjects differed reliably with respect to their ability to profit by the use of particular devices. The indications are that the subjects do not differ significantly in this respect in Course A, whereas in Course B such subject differences are quite significant.

In order to facilitate comparison between devices, an index of device efficiency has been presented in Table 3.6. These indices are derived from the raw data presented in Table 3.4 in the following manner. The number of errors made with a given device by a given subject is subtracted from the number of errors made by that subject with no device, and the remainder is divided by the number of errors made by this subject with no device. When these ratios (converted to percentages) are positive, they reflect the "percent reduction in error" which results from the use of the device. When they are negative, an advantage is shown for the no-device condition as compared with the device condition. Entries labeled "Combined" in Table 3.6 are obtained by operations similar to the foregoing performed on entries labeled "Total" in Table 3.4.

TABLE 3.6

Percent Reduction in Errors

Subjects	Conditions		
	Course A		
	Brush (YA-2BD)	Signal Corps (XA-1SC)	S-Carlson (YA-2ST)
A.H.	13	49	25
A.C.	12	6	23
W.H.	2	17	25
J.M.	1	22	26
W.L.	11	19	19
V.T.	10	8	-2
Combined	8	20	19
	Course B		
	Hoover (YA-1HC)	Signal Corps (XA-1HC)	S-Carlson (YA-3ST)
A.H.	-44	33	-62
A.C.	34	49	23
W.H.	36	53	13
J.M.	-20	-47	-35
Combined	12	27	-4

From the individual entries in Table 3.6 it will be observed, for Course A, that only subject V.T., when he worked with the Stromberg-Carlson Device, failed to do better with a device than without a device. All of the gains with devices on this course are small, except for subject A.H. with the Signal Corps Device. It may be noted, also, that subjects differ considerably with respect to their ability to profit by the use of the Signal Corps Device, whereas this differential reaction of subjects to the device is not so apparent in connection with the other devices. In Course B two of the four subjects made more errors with the devices (negative entries) than without a device.

The general implications of these data can be most easily observed by considering the indices obtained when the data for the various subjects are combined. The Signal Corps Device (XA-1SC) and the Stromberg-Carlson Device (YA-2ST) showed a small but reliable (Table 3.5) superiority over the no-device condition in Course A, whereas only the Signal Corps Device had a reliable advantage over no device in Course B. The error reduction to be expected as a result of using these devices is somewhere between 20 and 30 percent of the errors to be expected without their use.

It will be observed that the two Stromberg-Carlson devices differed in effectiveness as obstacle detectors. This was probably due to the fact that the first device (YA-2ST) had more power than the second (YA-3ST). It may be noted in passing, however, that the subjects learned to use the latter device with considerable effectiveness (See D and E).

It was the definite impression of both the experimenters and the subjects that the course with fewer obstacles (Course B) provided a more nearly adequate test for the devices. In this less obstructed course there appeared to be relatively more incentive and opportunity really to make use of the devices. There was so little clear space in Course A that the subjects were more than likely to hit one obstacle while in process of successfully avoiding another. As a result, the subjects began to feel that it was somewhat futile to try to make use of any aid in Course A. The decision was made, therefore, to use Course B in future work.

8. Summary

Several guidance devices are evaluated in terms of the reduction in the number of errors made while using the devices in obstacle courses as compared with the number of errors made when no device is used under otherwise comparable conditions. An index of efficiency called "percent reduction in errors" is used for this purpose. It is obtained by subtracting the number of errors made with a given device from the number of errors made with no device and dividing the remainder by the number of errors made with no device.

There were two obstacle courses arranged for these tests. One of the courses had more obstacles per unit of area than the other course. It was felt that experience with these two courses would help the experimenters to decide between them as tests of obstacle avoidance. The experience of both the experimenters and the subjects made it clear that the less obstructed course was much to be preferred.

The percent reduction ratios for several devices tested are given below:

	Device	Percent Reduction
Course A	Brush (YA-2BD)	8
	Signal Corps (XA-1SC)	20
	S-Carlson (YA-2ST)	19
Course B	Hoover (YA-1HC)	12
	Signal Corps (XA-1SC)	27
	S-Carlson (YA-3ST)	- 4

These results indicate that the Brush (YA-2BD), the Hoover device (YA-1HC) and the Stromberg-Carlson device (YA-3ST) were not helpful to the blind subjects in the obstacle course tests, whereas the Signal Corps device (XA-1SC) and the Stromberg-Carlson device (YA-2ST) both enabled the subjects to achieve a significant reduction in errors.

D. TRAINING IN THE USE OF PROBE DEVICES.

1. Training Procedure

It has been apparent from the very beginning of the guidance device testing program that there was a great need for the development and application of procedures designed to train the subjects in the most effective use of the various devices. The two subjects who worked with one guidance device in the doorway experiment (See III-B) made many errors which appeared to the experimenter to be avoidable. Only a limited attempt was made, in that experiment, to reduce the errors by giving the subjects careful training. Other subjects who were subsequently put through obstacle courses with several guidance devices (See III-C) were taught briefly how to interpret the signal and urged to scan with the devices, but beyond this, they were given no real training. These subjects, also, made many apparently avoidable errors, and everyone tended to develop his own highly individual and usually inadequate methods of using the devices. The experience gained with several different devices in the first obstacle course experiments greatly emphasized the need for training, and, in addition, served to develop the conviction that the several devices were sufficiently different in many significant respects as to require that the training on each device be highly specialized and tailored to the peculiar operating characteristics of that device.

The development of intensive training procedures had, necessarily, to be deferred until some background of experience had been acquired. Experimenters and subjects have had a considerable amount of that experience, on the basis of which training procedures have now been designed. In III-D-1 those procedures are described. In III-D-2 are presented some of the results of the training, as indicated by the performance of the subjects on tests which were interpolated at successive stages of the training procedure.

a. Initial Orientation

The personal problems that were encountered with each subject in the preceding two testing sessions indicated the need for an orientation period before training. Some of the subjects in the preceding obstacle course experiments had shown very little interest and cooperation in the testing. Another subject didn't "believe in guidance devices" and his performance was poor. A thorough preliminary orientation, it was hoped, would better prepare the blind individuals to work as subjects in tests of the devices. It was hoped, moreover, that since the subjects were emotionally involved in anything pertaining to their handicap, this orientation would direct this emotion positively with respect to guidance devices. Accordingly, the subjects were given one hour of orientation which included a discussion of the following topics:

1. The purposes of the guidance device program.
2. The importance of testing the devices.
3. The role of the blind subject in testing and improving the devices.
4. The need for objectivity on the part of the subjects.

b. First Experience with the Signal Corps and Stromberg-Carlson Devices

In this first period of training the subjects familiarized themselves with each of the devices. They were encouraged to examine the different parts of each device (probe, etc.). The subjects then tried on each device, and were shown how to wear it comfortably. In some cases subjects' preferences were allowed, e.g., some subjects preferred one shoulder to another, etc. They listened to the signals and were told briefly what happened to the signal when an obstacle was present.

When the preliminary familiarization had been completed, a more detailed explanation of the operation of each device was undertaken. The essential differences between an optical and a supersonic system were discussed. Problems such as how the devices sent and received a signal, and how the signal was created were also discussed. This somewhat technical explanation was given for two reasons; first, to prepare the subjects for the more intensive training to be given on interpretation of the signals, and second, to give them a general conception of the problems involved in the use of these types of guidance devices.

After this initial training period the subjects were tested in the obstacle course three times with each device and with no device.

c. Interpretation of the Signal

1. Signal Corps Device (XA-1SC)

a. Repetition Rate

All subjects listened to the signal and at the same time were given an explanation of what happens to it as an obstacle is approached. The change in repetition rate of the signal was emphasized as the important variable which provided the information concerning the presence or absence of an obstacle, as well as the distance from the obstacle. The fact that this device does not respond to objects that are less than three feet away from it was demonstrated to the subjects, and the consequences of this limitation were discussed. These explanations were supplemented by practice in approaching obstacles. They were further supplemented by having the subjects estimate the distance from an obstacle on the basis of the repetition rate of the signal. This practice was continued until each subject manifested proficiency in interpreting the repetition rate of the signal.

b. Intensity of the Signal

Since the obstacles were equal with respect to reflectance, the problem of the intensity of the signal was not too important. However, it had been observed in the testing of subjects in Obstacle Courses A and B that errors were being made because the subjects were responding to changes in the intensity of the signal caused by a lack of uniformity in the coloring of the floor. For this reason, time was spent explaining to the subjects how the intensity and the repetition rate of the signal could change. It was emphasized that a change in intensity of the signal was to be ignored in going through the obstacle course. The explanation was reinforced by having the subjects approach two obstacles, one of high reflectance (used in regular obstacle course) and another of low reflectance.

2. Stromberg-Carlson (YA-3ST)

a. Signal

Because the signal of this device was so complex, it was necessary to hook the device up to a loud speaker and have all the subjects and the experimenter listen to it together. During this demonstration the experimenter discussed the fact that the important variable in the signal was the pitch. The experimenter demonstrated this fact by having the subjects listen to the signal as an obstacle was being moved toward and away from the transducers of the device. Each subject was encouraged to practice approaching obstacles, when the demonstration was complete. They were trained further by having them estimate the distance from an obstacle as indicated by the pitch of the signal. The subjects spent three hours practicing with this device as compared with the one hour spent with the Signal Corps device. A longer practice period with the Stromberg-Carlson was necessary since the subjects found it more difficult to respond to the pitch of the signal than to repetition rate.

b. Specularity

One important limitation of the Stromberg-Carlson is the specularity of its beam. The device will not indicate the presence of an obstacle such as a flat wall if the device is not pointed perpendicularly to the surface. It can readily be seen that this presents a major problem for the subject in going through an obstacle course, since he may approach an obstacle from any angle. This limitation of the device was demonstrated to the subjects by having them approach obstacles at an angle. It was emphasized to them that unless the specularity of the device was kept in mind, they were bound to make many unnecessary errors in proceeding through the obstacle course. Further discussion on this problem was delayed until that part of the training program dealing with methods of scanning was reached.

After this period of training was completed the subjects were again tested in the obstacle course. Each subject was tested three times with each device and with no device.

d. Scanning with a Probe Device

Since the present probe devices are not constructed for automatic scanning, their efficient use depends to a large degree on how well the subject scans with the device. Just how inefficient the devices can be when not scanned properly was observed in the testing with Obstacle Courses A and B. Inasmuch as very little training had been given to the subjects, each subject adopted his own technique of scanning. Some subjects held the device at hip level and never moved it. Others moved it so rapidly that detecting changes in the signal was not possible. These methods, in most cases, were unreliable and caused the individual to make many errors. It was concluded from those tests that specialized training in how to scan the devices most effectively was necessary, and that training had to be done separately for each device, since the devices differed with respect to beam size, specularity, etc.

1. Signal Corps Device (XA-1SC)

The following four points were emphasized in scanning with the Signal Corps Device:

(a) The device should be carried at a level just above the knees, in either hand, with the arm fully extended downward in a relaxed manner.

(b) The device must frequently be pointed down (about 45 degrees) and scanned regularly from left to right.

(c) The angle of scanning should be as wide as possible.

(d) The device should be scanned at a rate that allows the best detection of the signal.

If the device be scanned in the manner outlined above, it is expected that the following errors caused by improper scanning techniques will be eliminated:

(e) Colliding with low obstacles because the device is pointed straight ahead, and the beam passes over these low obstacles (1 foot and 2 feet high).

(f) Bumping obstacles because the zone immediately in front of the individual has not been scanned completely.

(g) Bumping obstacles because scanning is done too rapidly and the change in signal is not detected.

Approximately six hours were spent in coaching the subjects in how to scan with the device. Each subject was put through a small section of the obstacle course with the device. Whenever an error occurred because of improper scanning, the experimenter called it to the attention of the subject and had him try again. For some subjects, the proper scanning technique was acquired easily; for others it was unecessary to drill them repeatedly. Intensive training in scanning technique was continued for each subject until he had developed and demonstrated considerable skill in scanning.

2. Stromberg-Carlson (YA-3ST)

This device, because its beam reflection was so specular, presented some special problems with regard to how the subject should scan with it. If the subject avoided the problem of specularity by holding the device at waist level and pointing it straight down the obstacle course, then he could not detect the low obstacles (one foot and two feet high). If he attempted to overcome this problem by pointing down at the floor in order to detect the low obstacles, then in many cases the specularity of the beam prevented him from detecting the obstacle. However, one of the subjects indicated that while he was being tested in Obstacle Course B, he was able to detect low obstacles with the device. His technique was to point the transducers at about a 40-degree angle to the floor, and then scan vertically with them until they were pointing straight ahead, repeating this procedure as he proceeded through the course. If, during this scanning the beam hit the angle formed by the floor and the bottom of the obstacle, the signal would indicate the presence of an obstacle. Each subject was encouraged to try out this scanning method with the device. In all cases the subjects had no difficulty in hearing the change in the signal when the device was scanned in this way and an obstacle was present. The following suggestions about scanning were made to the subjects:

(a) The transducers should be carried in either hand, at about hip level.

(b) The transducers should be pointed at the floor at about a 45 degree angle and scanned from this point until parallel to the floor. A change in signal as the subject scans with the device from the floor up will indicate the presence of an obstacle in his path.

(c) The transducers should be moved in a straight line from one side of the body to the other. They should not be swung in an arc by a wrist movement, because obstacles slightly to the side of the user will be struck at an angle and will fail to elicite a signal response from the device.

The subjects were practiced for a considerable period of time in developing skill in scanning the device as outlined above. When all of them manifested proficiency with the device, they were tested in the obstacle course for the third time.

e. Special Problems in Using the Devices

Since the devices did not scan automatically, and since they gave information on only one obstacle at a time, a great deal depended on the subject's ability to determine the best direction to proceed, once he had detected an obstacle. Many of the subjects lacked this ability and were making unnecessary errors despite the fact they were scanning the device properly. It seemed desirable at this point to give the subjects concentrated training so that these errors could be eliminated. However, before the actual training began, it was emphasized to the subjects that going through an obstacle course was more than just detecting obstacles. They were told that avoiding an obstacle depended on their ability to explore their immediate environment and determine the best direction of progress.

1. Avoiding Obstacles after Detection

The subjects were making errors because they were omitting two important steps necessary in avoiding obstacles. First, they were not scanning for the ends of an obstacle in order to determine how wide it was. This step is essential if the individual is to give himself enough leeway in going around the obstacle. Second, the subjects were not scanning for adjacent obstacles. Frequently, in hastening to avoid an obstacle, the subjects would walk into another adjacent obstacle. These two points were discussed with the subjects and the following training procedure set up:

(a) The subjects were given practice in scanning an obstacle from one side to the other, to determine its approximate width. Once having determined where its ends were, they had to avoid it. This practice was carried on for about an hour with each subject. In some cases other obstacles were placed near the one that was to be avoided. The subjects were encouraged always to scan their immediate environment before attempting to avoid any obstacle, so as not to hit any other nearby obstacles. This procedure of detecting an obstacle and scanning for its ends was drilled until each subject performed it automatically when going through the obstacle course.

(b) The subjects were next practiced in solving a "sagacious choice" problem. Two obstacles were set up, one on the left, close to the subject, and the second obstacle on the right, at a greater distance from him. The subject's task was to scan until both obstacles were detected and then to determine which obstacle was farther away from him. Having done this, he had to proceed in the direction (right vs. left) of the more distant obstacle and avoid it. If the subject selected the near obstacle by mistake, he had to avoid this one and also the one farther away. The purpose of this training procedure was to impress upon the subjects the importance of scanning the course before proceeding in a given direction. It was pointed out to the subjects that only if they "sized up their environment" could they proceed in the direction that promised the least difficulty. It was further pointed out that this was true of any situation in which they were using a guidance device.

2. Problem of Reversed Direction

Another difficulty the subjects had encountered in going through the obstacle course was that of becoming disoriented with respect to the correct direction of progress through the course. The problem was not a serious one, since many of these subjects improved with time. However, certain aids were given to the subjects in order to help them determine for themselves the correct direction of walking. Since the course was flanked on one side by a brick wall and on the other side by a rope, the subjects were instructed to scan for the wall whenever they became disoriented. If they were proceeding in the correct direction the wall was to be on their right side. All the subjects were trained to make use of this cue. They were placed facing all different directions in the course, and told to indicate to the experimenter, after inspection, which was the correct direction to walk in order to complete the course.

3. Doorway Problem

It was a natural occurrence in the obstacle course used here, that the subjects, at one time or another, would have to walk between two large obstacles (doorway). While the subjects were in most cases able to detect both obstacles, many of them made errors in going through the "doorway". Some of the subjects expressed concern about this problem, since it was once that occurred frequently in everyday life. For this reason, the problem was discussed at length with the subjects. Many of them felt that the devices were not capable of solving this problem. It was pointed out to them that errors were being made because of poor technique on their part, and that with proper training these errors could be eliminated. Following the discussion a number of "doorways" were set up and the subjects were given practice in the following procedure for going through a "doorway":

(a) First, detect both sides of the "doorway" and determine the location of the clear space.

(b) Place oneself directly between the two sides (obstacles) before approaching the clear space.

(c) Walk toward the clear space and scan the two sides in order to keep from going into them.

This procedure helped eliminate the errors subjects often made in getting through the "doorway". The subjects were practiced in this problem until all of them indicated that they no longer regarded the "doorway" as a difficult problem in the obstacle course.

Following this practice in the "doorway" problem, the subjects were again involved in a "sagacious choice" problem. Low obstacles were placed in the space beyond the opening of the "doorway", or on either side of the obstacles forming it. The subject's task was to determine whether it was better to go through the "doorway" or to avoid it and go around. It was not necessary to explore the space beyond the opening of the "doorway" before venturing through. Each subject took his turn at solving this problem as it was set up each time. The subjects encountered very little difficulty in solving this "sagacious choice" problem, since, by this time, they had acquired a degree of skill in using the devices. This procedure marked the end of the formal training program. Having mastered these techniques the subjects were given the final test.

f. Discussion

1. Observations Made During Training

Included in the first training session were two types of subjects: those who had participated in the testing completed with Obstacle Courses A and B, and new subjects who had never seen the devices prior to training. All the subjects were treated alike in the training so as to be certain that all of them received its full benefits. During the training the experienced subjects were urged to make comments. From time to time the subjects did make comments which gave some indication that we were emphasizing the correct things in the use of these devices. One subject A.H. remarked, "Now that we are getting the hang of these devices, I feel more confident when I go through the obstacle course".

The new subjects also introspected about the devices as the training progressed. When they were tested for the first time, that is, after their "first experience with the devices," they commented unhappily about guidance devices. One subject F.C. remarked, "I hear the signal and know what it means and yet I keep bumping obstacles." However, as the training progressed, and the new subjects became more skillful in using the devices, they began to regard them more favorably. They showed a great deal of enthusiasm about their improved performances and also began to make suggestions about how to improve the training.

2. Other Devices

Specific reference is made in this report to only the Signal Corps device and Stromberg-Carlson device, because these were available when the training program was undertaken. When other devices were received in the Laboratories (Brush and Hoover), the subjects were given the same training as described above. Of course, no attempt was made to repeat the general aspects of training (orientation, etc.) given to the subjects when they were being trained with the Signal Corps and Stromberg-Carlson devices.

3. Learning Data

The results obtained as the training progressed are discussed in the next section. Data are presented for both the new subjects and the experienced subjects.

4. New Devices

From time to time new models of the same types of devices discussed in this report, have arrived at the Laboratories. For all these models the subject received specialized training, because in most cases these devices required different methods of scanning, interpreting the signal, etc. The subjects were practiced at length with these devices to insure that the new devices were being used as efficiently as the old models. It was not necessary in this training to repeat such general training procedures as orientation, avoiding obstacles after detection, etc.

2. Improvement in Performance as a Result of Training and Practice

a. Purpose of Tests Interpolated in Training

At successive intervals throughout the training, each subject was tested in an obstacle course in order (1) to provide a record of the progressive changes in obstacle course performance which result from directed training and practice with the Stromberg-Carlson (YA-3ST) and Signal Corps (XA-1SC) devices, (2) to make possible a further comparison of performance with these devices, (3) to secure an estimate of the amount of training and practice with the devices which is required in order that subjects be brought to a satisfactory practice level.

b. Test Procedure

The obstacle course used in these tests was identical with Course B, except that it was a single lane course in which 12 obstacles were distributed at random over an area which was 48 feet long and 9 feet wide. The distribution of obstacles was changed for each trial by a given subject, and the order in which the various devices were used within a test period was selected in such a way as to minimize the effect of within-test practice on the differences between devices.

Each of the obstacle course tests consisted in putting the subject through the single lane course three times with each of the devices and with no device. All subjects had four such tests. Between tests each subject was given a considerable amount of directed practice in the use of probe devices. (See III-D-1).

c. Subjects

Only the data from three newly blind subjects (F.C., F.K., and J.S.) who had no previous experience with guidance devices are given in this section of the report.[1]

d. Results

Table 3.7 shows the total number of errors made by each subject on each successive test of three trials, and the total number of errors made on each successive test when the results from the three subjects are combined. These data are presented graphically in Figure 3.12.

It is clear from these data that performance in the obstacle course improves considerably with continued training and practice. Although some improvement occurs even in the no-device condition (for which no specific training was given), that improvement does not extend beyond the second test. With the devices,

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[1] Additional data, on other subjects and other devices, are presented and briefly discussed in III-D-4.

on the other hand, improvement continues over a longer period, until a level of near perfection is finally reached with both devices.

TABLE 3.7

Number of Errors on Successive Tests

	Test	No Device	Signal Corps (XA-1SC)	Stromberg-Carlson (YA-3ST)
Subject F.K.	I	18	9	9
	II	9	6	7
	III	10	2	3
	IV	11	3	2
J.S.	I	17	9	19
	II	17	5	10
	III	12	5	5
	IV	15	3	3
F.C.	I	20	10	13
	II	11	9	7
	III	11	3	7
	IV	12	3	4
Subjects Combined	I	55	28	41
	II	37	20	24
	III	33	10	15
	IV	38	9	9

It will be noted from the data of Table 3.7 and Fig. 3.12 that two of the three subjects made more errors on the first test with the Stromberg-Carlson device than they made with the Signal Corps optical device. By the end of the fourth test, however, differences in the efficiency of the two devices had just about disappeared. This general effect can be most easily observed in the data for all subjects combined (Table 3.7 or Fig. 3.12). Hence, although the

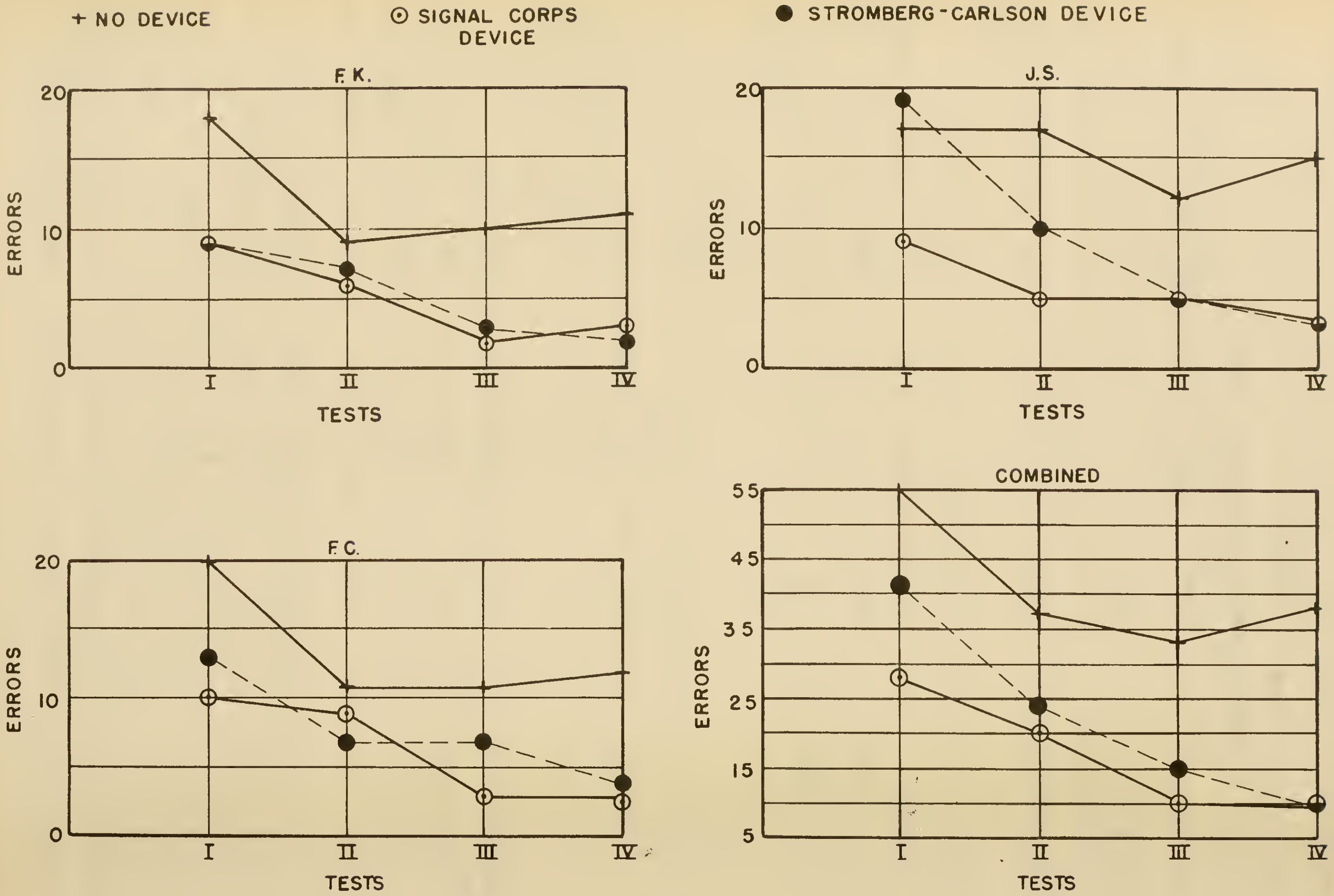

FIG. 3.12
EFFECT OF TRAINING WITH GUIDANCE DEVICES

Stromberg-Carlson appears to be the more difficult device to use without training, its relative efficiency is increased considerably by training.

The amount of training and practice that was given to the subjects in this study is apparently sufficient to bring them to a satisfactory practice level in obstacle course performance. Data which were obtained subsequently suggest that scores will fluctuate randomly between zero and three errors per test on all tests beyond the fourth. In this study the subjects were operating at approximately that level of performance on the fourth test.

Because the number of errors made with a device continues to decrease with training and practice after the number of errors with no device has reached a relatively stable level, the index of efficiency (described in connection with the obstacle course data in III-B) must be expected to increase with the training and practice of the subject. To illustrate this point, "percent reductions", based on the data of Table 3.7, are given in Table 3.8.

It will be noted that in all cases the indices of efficiency increase rather regularly over the training period (with slight inversions on the second test in some cases). The rate of this increase is seen most clearly in the "Subjects Combined" data which are plotted in Figure 3.13.

It follows, then, that adequate evaluation is possible only when it is reasonable to assume that the subjects have attained the limits of their proficiency in the use of the devices before the tests begin. This requirement renders the interpretation of test results somewhat more complex than it otherwise would be, because differences in the initial difficulty of use may give quite erroneous impressions concerning the ultimate merits of the devices.

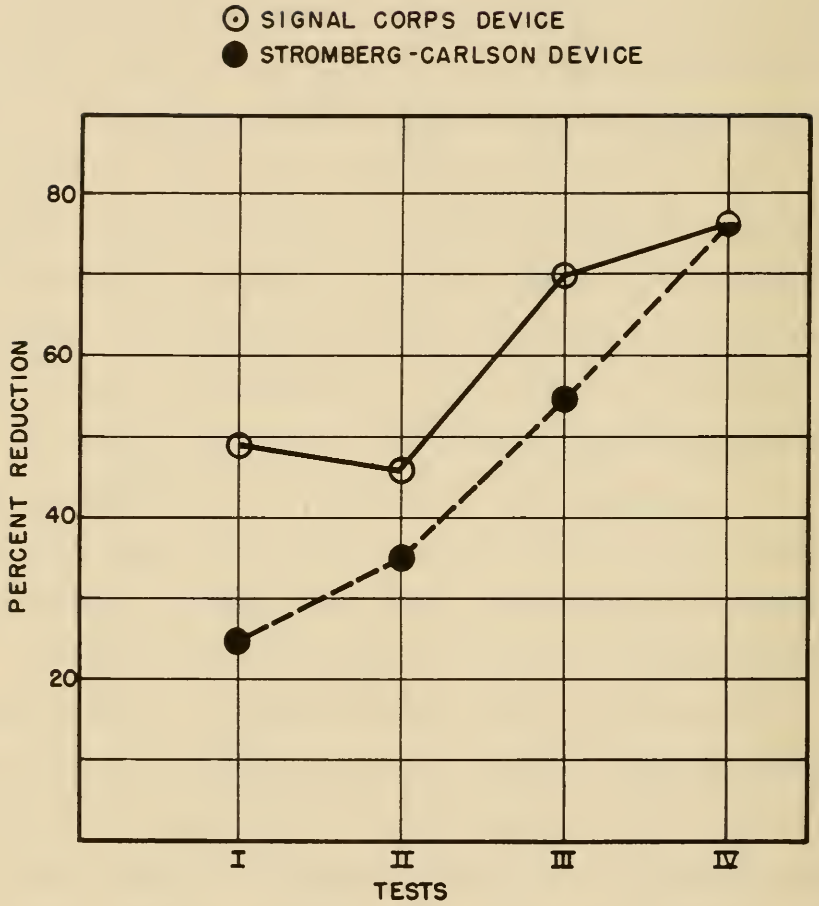

FIG. 3.13
PERCENT REDUCTION
ON SUCCESSIVE TESTS

TABLE 3.8

Percent Reduction in Errors

	Test	Signal Corps (XA-1SC)	Stromberg-Carlson (YA-3ST)
Subject F.K.	I	50	50
	II	33	22
	III	80	70
	IV	73	82
F.C.	I	50	35
	II	18	36
	III	73	36
	IV	75	67
J.S.	I	47	- 12
	II	71	41
	III	58	58
	IV	80	80
Subjects Combined	I	49	25
	II	46	35
	III	70	55
	IV	76	76

3. Summary

a. Section III-D-1

Experience in Obstacle Courses A and B (III-C) indicated quite clearly that the subjects were in need of training in the proper use of certain probe guidance devices. A training program was set up to provide three new subjects and two experienced subjects with specialized training in how to use the Signal Corps optical device (XA-1SC), and the Stromberg-Carlson supersonic device (YA-3ST) most effectively. The subjects were given the following phases of training:

1. Orientation

Since it was felt that some of the subjects were not taking a sufficiently active interest in the testing program, the following points were emphasized in a short orientation talk:

(a) In order to develop an adequate guidance device it is necessary to test a variety of different ideas and designs impartially.

(b) Since it is necessary that these devices be related to the needs of the blind persons, the active cooperation of blind subjects is needed in the process of selection from a variety of proposed designs for guidance devices.

(c) Because equally good devices may differ with respect to initial difficulties in use, it is necessary that the subjects avoid forming early subjective evaluations of them based on insufficient experience. It is clear that the value of the final device will in part be determined by intelligent and cooperative interaction between the designers and users of guidance devices.

After this orientation and preliminary acquaintance with the devices, the subjects were given Test I.

2. Interpretation of the Signal

The signal provided by each device was sufficiently complex to warrant that the subjects be given specialized training in the interpretation of signals. Situations designed to illustrate characteristic responses of the devices were arranged and the subjects were asked to explore and analyze them. This practice was continued until the experimenter considered each subject to be sufficiently competent in interpreting the signal of each device, at which time Test II was given.

3. Scanning Procedure

The efficient use of a probe guidance device will depend to a large degree on how well the individual scans with it. The importance of active and systematic scanning with the devices was emphasized and the following specific points were made:

(a) In order to avoid low obstacles the prospector must be pointed down (about 40 degree angle).

(b) A fairly wide azimuth angle must be scanned in order to make sure that there is a sufficiently wide clear path in front of the subject.

(c) The prospector must be scanned at a rate which will provide a period of time long enough for the subject to detect a change in the signal when an obstacle is present. If scanning is too rapid, the subject in many cases is unable to detect the difference in the signal which occurs in that small period of time in scanning when the prospector is pointing at the obstacle.

After the subjects had acquired the habit of active and accurate scanning, Test III was given.

4. Special Problems in Obstacle Avoidance

Errors were often made while avoiding a detected object, because the prospector was trained on the object being avoided rather than being used to search out the path that the subject must follow in order to avoid the obstacle. Problems designed to practice the subjects in determining the best path of progress were arranged and the subjects asked to solve them. This type of practice was carried on for a considerable length of time with each subject.

The subjects and experimenters spent over a week in going through these successive phases of training. Discussions were held with the subjects concerning the various techniques and problems involved in each device. The discussions were always followed by considerable practice for each subject with each device in the particular problem being discussed. After the subjects had learned to cope with these and similar problems, Test IV was administered.

b. Section III-D-2

The results of the tests given between the training periods showed a decrease in the total number of errors as training progressed. Although this decrease occurred in both the device and the no-device condition, it continued longer and reached a lower error level in the device condition; the efficiency indices increased rather regularly on successive tests.

An original superiority observed for the Signal Corps device (XA-1SC) as compared with the Stromberg-Carlson device (YA-3ST) decreased gradually and finally disappeared as training approached completion. By the end of the training period these two devices appeared to be equally efficient as obstacle detectors

4. Appendix

Because omission of existing data is open to a variety of interpretations on the part of the reader, some test results which were obtained during the training described in III-D-1 of this report, but which were excluded from III-D-2 for purposes of convenience, will be presented in this Appendix.

The results given in Table 3.9 below were obtained under exactly the same conditions as those reported in III-D-2. The entries show the total number of errors on successive tests, each test consisting of three trials in the single lane obstacle course.

TABLE 3.9

Number of Errors on Successive Tests

During Training

	Test	No Device	Signal Corps (XA-1SC)	S-Carlson (YA-3ST)	Hoover (YA-1HC-M1)	Brush (YA-4BD)
Subject F.K.	V	11	2	1	1	5
	VI	11	0	0	1	5
	VII	10	1	1	1	6
	VIII	11	4	1	2	4
	IX	7	0	2	0	3
J.S.	I	Presented in III-D-2			4	16
	II				6	9
	III				4	5
	IV				4	3
	V	11	1	2	4	3
W.H.	I	5	8	6	7	5
	II	8	0	3	3	5
	III	8	0	2	0	4
	IV	8	1	1	0	6
A.C.	I	9	3	6	3	6
	II	7	0	4	3	1
	III	9	1	3	1	1
	IV	7	0	1	0	2

Most of these data suffer from special difficulties of interpretation which are described below.

(a) Subject F.K.

This subject had completed the training and tests with the Signal Corps and Stromberg- Carlson Devices as described in III-D-1 and III-D-2 before the Hoover and Brush Devices were delivered to the Laboratories. When these latter devices arrived he was given formal training with them and was tested with the Signal Corps and Stromberg-Carlson Devices as well as with these new devices.

His data on tests V through IX with the Signal Corps and Stromberg-Carlson Devices may be accepted as indications of the fact that his performance had reached a fairly stable level with these devices by the time test IV had been given.

Because the training of this subject with the Signal Corps and Stromberg-Carlson Devices was complete before he began to work with the Hoover and Brush Devices (test V), his data on these latter devices cannot be accepted as training data. These data indicate, however, that he was proficient in the use of all four devices.

(b) Subject J.S.

This subject did not begin his training until after the Hoover and Brush Devices had arrived at the Laboratories. He was therefore trained with all four devices and his results on the Hoover and Brush Devices are acceptable as training data on these devices. This subject had five tests with all devices. The results of his fifth test with the Signal Corps and Stromberg-Carlson Devices are given in the above table.

(c) Subjects W.H. and A.C.

These subjects had experience in both obstacle course studies described in III-C and consequently their results are not to be considered comparable to those obtained from subjects who had had no experience with either the test or the devices. In this connection it is pertinent to note that there was no apparent decrease in their no-device errors on successive tests. Their data, however, make it clear that they had mastered the technique of using the devices by the time the fourth test was given.

E. TEST OF OBSTACLE COURSE PERFORMANCE OF FOUR PROBE DEVICES WITH HIGHLY TRAINED SUBJECTS.

1. Purpose

The data on the performance of probe devices in Obstacle Courses A and B given in III-C were collected with subjects untrained in the use of the devices. It was felt that these data may have under-estimated the value of the devices to subjects who have been trained in their use. This impression was largely confirmed by the results of the preceding study (III-D-2) on the effects of training, in which it was found, first, that the difference in performance between the device and no-device conditions increased markedly with practice; second, that, whereas the Signal Corps optical device showed an initial superiority over the Stromberg-Carlson supersonic device, the difference in performance between these two devices substantially disappeared with continued practice. It seemed highly desirable, therefore, to evaluate all of the devices on the basis of tests carried out with well-trained subjects. The following is a report on such tests using the Signal Corps optical device (XA-1SC), the Stromberg-Carlson "pulsed-FM" supersonic device (YA-3ST), the Hoover mechanical supersonic device (YA-1HC-M1), and the Brush sawtooth modulated supersonic device (YA-4BD).

2. Procedure

Obstacle Course B, described in III-C, was used in this study. It is a two-lane course, each lane having 12 obstacles distributed at random in an area 48 feet long and nine feet wide. The general procedure was identical with that used in III-C. Each subject had ten trials with each device and with no device.

3. Subjects

Five totally blind subjects were used in this experiment: A.C., A.H., W.H., F.K., and J.S. All of these subjects had been given the complete course of training outlined in III-D-1.

4. Results

The general form of the presentation of results in this study is identical with that used in III-C.

Table 3.10 gives the total number of errors made by each subject with each device and with no device on ten trials. It will be observed that for all subjects the device errors are less than the no-device errors, and that in some cases the differences are remarkably large.

The immediate impression is that the advantage shown for devices is much greater in this study than in III-C. This general impression may be obtained most easily by considering the entries labeled "total".

TABLE 3.10

Total Number of Errors in Ten Trials

Subjects	Conditions				
	No Device	Signal Corps (XA-1SC)	Brush (YA-4BD)	S-Carlson (YA-3ST)	Hoover (YA-1HC-M1)
A.H.	36	11	21	14	20
A.C.	39	5	22	14	4
W.H.	61	13	42	18	13
F.K.	91	17	38	7	16
J.S.	101	22	50	30	36
Total	328	68	173	83	87

When the various discrepancies existing between the number of no-device errors and the number of device errors observable in Table 3.10 are tested for reliability by the Chi-square method (discussed in III-C), the probabilities entered in Table 3.11 are obtained. The asterisks indicate differences in favor of devices.

This table indicates that not only are all of the individual differences in favor of devices, but also that all except one are reliable at the five percent level. All of the probabilities based on the totals are also significant, indicating that all devices tested are reliably better than no devices. The probabilities referring to the interactions indicate that the differential reactions of the various subjects to each device except the Brush are significant, i.e., the extent to which different subjects profit by the use of any device varies significantly.

TABLE 3.11

Probability of Obtaining Differences to be Observed in Table 3.10 (Chances in 100)

Subjects	Devices			
	Signal Corps (XA-1SC)	Brush (YA-3BD)	S-Carlson (YA-3ST)	Hoover (YA-1HC-M1)
A.H.	1*	5*	1*	3*
A.C.	1*	3*	1*	1*
W.H.	1*	6*	1*	1*
F.K.	1*	1*	1*	1*
J.S.	1*	1*	1*	1*
ΣX^2	1*	1*	1*	1*
X^2 Total	1*	1*	1*	1*
Interaction	1*	52*	1*	1*

In order to provide an indication of the extent to which the various devices reduce the number of errors as compared with the no-device condition, efficiency indices derived from Table 3.10 are given in Table 3.12.

It will be observed immediately that these ratios tend in general to be much higher than those appearing in Table 3.5. The indices labeled "combined" indicate that the over-all reduction in errors which results from the use of devices is about 75 percent for three devices, whereas in III-C comparable indices were in the order of 25 percent.

This study tends to strengthen quite considerably the impression that subjects trained to high proficiency should be used in all tests if the value of guidance devices is to be adequately estimated.

TABLE 3.12

Percent Reduction in Errors

Subjects	Devices			
	Signal Corps (XA-1SC)	Brush (YA-4BD)	S-Carlson (YA-3ST)	Hoover (YA-1HC-M1)
A.H.	69	42	61	45
A.C.	87	44	64	90
W.H.	79	31	70	79
F.K.	81	58	92	83
J.S.	78	50	70	64
Combined	79	47	75	73

5. Preliminary Evaluation Study of New Devices

As new devices were brought into the Laboratories, preliminary obstacle avoidance tests were made in a single lane of the obstacle course described in this report. Because these tests were made at various times the subjects were changed from test to test and a separate set of no-device data was obtained for comparison with each device tested. The various sets of no-device data were obtained by interpolating no-device trials among the trials made with the particular device tested.

a. Subjects

Subjects A.C., A.H., F.K., and J.S., who had been given the formal training described in III-D were used in these tests.

b. Results

The total number of errors made with the various devices and with no device are shown in Table 3.13. The entry marked N at the head of the several columns shows the number of trials by each subject with each device and with no device.

TABLE 3.13

Total Number of Errors

	N=15		N=10	
Subject	No Device	(YA-3HL) Dr. Witcher's	No Device	(XA-1IE) Dr. Lashley's
A.H.	9	3	3	15
F.K.	20	1	15	14
J.S.	20	3	44	32
A.C.	—	—	—	—
Total	49	7	62	61

	N=10		N=10		N=10	
Subject	No Device	Brush (YA-5BD)	No Device	Dr. Meeks' (XA-4HL)	No Device	S-Carlson (YA-4ST)
A.H.	12	12	15	4	4	2
F.K.	24	3	19	3	24	4
J.S.	—	—	—	—	—	—
A.C.	13	10	22	3	20	16
Total	49	25	56	10	48	22

Table 3.14 shows the percent reduction in errors for each of the devices tested.

These data indicate that, in so far as obstacle avoidance is concerned, two of the devices tested appear very promising. These are Dr. Witcher's device (YA-3HL) and Dr. Meeks' device (XA-4HL).

The Brush device (YA-5BD) although not quite as good as the above devices was used very efficiently by at least one subject, F.K. It was observed, however, that this device did not give an easily noticeable signal unless some movement was involved and it was consequently felt that considerable special training would be required before the subjects could be expected to use this device to its maximum advantage.

TABLE 3.14

Percent Reduction in Errors

Subject	Dr. Witcher's Device (YA-3HL)	Dr. Lashley's Device (XA-1IE)	Brush Device (YA-5BD)	Dr. Meek's Device (XA-4HL)	S-Carlson Device (YA-4ST)
A.H.	67	- 400	0	73	50
F.K.	95	7	88	84	83
J.S.	85	27	—	—	—
A.C.	—	—	23	86	25
Combined	86	2	49	82	54

The Stromberg-Carlson device (YA-4ST) also, though not among the best devices, definitely appears to be a device worthy of further development.

Dr. Lashley's device was not used at all efficiently by these subjects. Consideration of its operational design may explain the difficulty: it provides a signal for changes in illumination but no particular signal is associated with a change from obstructed to unobstructed space.

6. <u>Time Per Trial in the Obstacle Course</u>

In all obstacle avoidance studies the time required by each subject for each trial was recorded, but because these data were not found to be illuminating, they have not been reported. A sample of such data, obtained in the first study described in this report, is given below merely as an example of the sort of information provided by these indices.

Table 3.15 shows the average time per trial for each subject under each condition. These averages are based on ten trials per subject under each condition. For the purpose of estimating reliabilities the standard deviations of the various averages are also included.

TABLE 3.15

Average Time (in Minutes) Taken to Traverse the Obstacle Course

Subjects	No Device		Signal Corps (XA-1SC)		Hoover (YA-1HC-M1)		S-Carlson (YA-3ST)		Brush (YA-4BD)	
	Av.	SD	Av.	SD	Av.	SD	Av.	SD	Av.	SD
A.H.	3.91	.65	5.33	.66	6.12	1.00	5.30	1.10	5.82	.98
A.C.	2.70	.45	3.71	.41	3.98	.45	3.98	.47	4.03	.33
W.H.	3.85	.66	5.54	.67	5.24	.64	5.84	.67	6.60	.85
F.K.	1.88	.55	5.14	1.20	3.78	.41	4.38	1.00	5.42	.95
J.S.	1.95	.22	5.73	1.20	5.70	.75	5.75	.88	4.40	.51

It will be observed from this table that, when no device was used, all of the subjects used less time than when they were using some device. The importance of this fact is extremely difficult to evaluate, however, especially since many more errors were made with no device than with any device. It will further be noted that the newly blinded subjects, F.K. and J.S., used less time in the no-device situation than did the more experienced blind subjects. It is the impression of the examiners that this was due to the fact that the newly blind subjects felt the futility of the situation more acutely than did the more experienced blind subjects.

Finally, it will be observed that these time measures fail to distinguish between devices.

The following numbers may be useful in the evaluation of the various differences between the averages presented in this table:

(a) In making comparisons between subjects in the no-device condition, differences larger than 0.75 minutes are probably reliable.

(b) In comparing no-device averages with averages referring to performance with devices, differences larger than 0.96 minutes are probably reliable.

(c) In comparing averages referring to performances with devices, whether between subjects or between devices, differences larger than 1.15 minutes are probably reliable[1].

7. <u>Summary</u>

An extensive obstacle avoidance test was performed with five totally blind subjects who had previously been given considerable directed practice with the guidance devices used (III-C). The course used for this test was the two-lane obstacle course described in connection with III-C (Course B). Each lane was 48 feet long and 9 feet wide with 12 obstacles. The results are based on ten trials by each subject with each device and with no device.

The Percent Reduction scores are given below.

Signal Corps (XA-1SC)	Brush (YA-4BD)	Stromberg-Carlson (YA-3ST)	Hoover (YA-1HC-M1)
79	47	75	73

These results may be compared with those given for Course B in III-C. Such a comparison will make it clear that the trained subjects used the devices to much greater advantage than the untrained subjects. These results, besides providing an evaluation of the devices, emphasize the importance of training the subjects to be used in an evaluation test.

Preliminary evaluation tests on several new guidance devices were performed in a single lane obstacle course. The results of these tests, summarized in terms of percent reduction in errors, are given below.

Devices	Percent Reduction in Errors
Dr. Witcher's device (YA-3HL)	86
Dr. Meeks' device (XA-4HL)	82
Stromberg-Carlson device (YA-4ST)	54
Brush device (YA-5BD)	49
Dr. Lashley's device (XA-1IE)	2

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[1] These fiducial limits are derived from the average replication variances for the various categories of comparison indicated above.

Two of these devices, Dr. Witcher's device (YA-3HL) and Dr. Meeks' device (XA-4HL), were found to be very efficient obstacle detectors. The Stromberg-Carlson device (YA-4ST) and the Brush device (YA-5BD), though less effective, appear to merit further development. Dr. Lashley's device (XA-1IE) did not appear to be helpful to the blind subjects in these tests.

Data on the time required per trial under the various conditions of the test are given in part 6 of this report. Although these measures failed to distinguish between devices, they showed that the subjects, when working without devices, took significantly less time per trial than when they were using devices.

F. A COMPARISON OF THE EFFECTIVENESS OF TWO PROBE GUIDANCE DEVICES IN THE DETERMINATION OF OBSTACLE SIZE.

1. Purpose

A blind man's ability to avoid, and, further, to identify an object which is out of reach must depend, in part at least, on his being able to define the size of that object. It was the purpose of this experiment, therefore, to provide a basis for evaluating the Stromberg-Carlson supersonic device and the Signal Corps optical device in regard to the comparative accuracy and speed with which blind subjects can use either of these devices to determine the dimensions of square and rectangular objects.

2. Procedure

The subject's task in this experiment was to determine the height and width of square and rectangular plane-surface sections of sheet-rock. There were 25 of these sections, so constructed as to exhaust all combinations in height and width of one, two, three, four, and five feet.

Judgments as to the dimensions of the sheet-rock sections were made by the subjects under each of three conditions: (1) with the Signal Corps optical device (XA-1SC), (2) with the Stromberg-Carlson "pulsed FM" supersonic device[1] (YA-3ST-M1), and (3) with no device. The subject was shifted from one of these experimental conditions to another at the completion of each group of five trials. The sequence according to which a given subject was shifted from condition to condition was effectively randomized, as was the order in which the 25 sections of sheet-rock were presented for judgment. (The randomization of the presentation of sheet-rock sections was limited so far as was necessary to insure that all obstacles were represented an equal number of times in all conditions.) Each of three of the subjects (J.S., F.K., A.H.) made a total of 75 judgments under each of the three experimental conditions. The other subject (M.C.) made 50

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[1] Two different Stromberg-Carlson devices were successively available while this experiment was in progress. As a consequence, one of the subjects (M.C.) used the device which has been referred to in these reports as the Stromberg-Carlson supersonic device (YA-2ST). The remaining three subjects used the Stromberg-Carlson supersonic device (YA-3ST-M1).

FIG. 3.14

SIZE DETERMINATION WITH STROMBERG-CARLSON SUPERSONIC DEVICE, YA-3 ST.

judgments under each condition.

The distance of the subject from the obstacle was seven feet on all trials.

Before the experimental sessions began, each subject was given about 10 practice trials with each device and with no device.

It was made clear to the subjects at the beginning of the experiment that there were to be just 25 obstacles, and the heights and widths of these obstacles would be any combination of one, two, three, four, and five feet.

On each trial, the subject's judgment and the time taken to make it were recorded. After a subject had made his judgment, he was given the correct dimensions of the sheet-rock section and permitted, then, to "survey" the sheet-rock section once again.

3. Subjects

The data of this experiment were collected with four blind subjects: J.S., F.K., A.H., and M.C. Three of these subjects (J.S., F.K., and A.H.) had been given considerable training with the Stromberg-Carlson supersonic device and the Signal Corps optical device prior to the beginning of this experiment. One of the subjects (M.C.) had been previously trained with the Stromberg-Carlson device, but not with the Signal Corps device.

4. Results

In Table 3.16 are to be found the average errors of judgment made by each of four subjects with the Signal Corps optical device, with the Stromberg-Carlson supersonic device, and with no device.

Mean differences in average error of judgment of height and width for every pair of experimental conditions are presented in Table 3.17 together with the probabilities that differences as large or larger than those obtained could have arisen by chance.

TABLE 3.16

Average Errors of Judgment (in feet) for Each Experimental Condition

	Average errors (in feet)					
	Optical device (XA-1SC)		Supersonic device (YA-3ST-M1)[2]		No device	
Subject	Height	Width	Height	Width	Height	Width
J.S.	0.13	0.39	0.76	0.83	1.55	1.60
F.K.	0.20	0.29	0.69	0.75	1.33	1.50
A.H.	0.17	0.43	0.19	0.41	0.81	0.95
M.C.	0.04	0.38	0.16	0.30	0.52	0.72

TABLE 3.17

Mean Differences in Average Error for Every Pair of Experimental Conditions, and the Probabilities That Such Differences Are Attributable to Chance.

	Mean difference in error and "p"		
Subject	Supersonic minus optical	No device minus optical	No device minus supersonic
J.S.	h+0.63 (<.01)	+1.42 (<.01)	+0.79 (<.01)
	w+0.44 (<.01)	+1.21 (<.01)	+0.77 (<.01)
F.K.	h+0.49 (<.01)	+1.13 (<.01)	+0.64 (<.01)
	w+0.46 (<.01)	+1.21 (<.01)	+0.75 (<.01)
A.H.	h+0.02 (>.30)	+0.64 (<.01)	+0.62 (<.01)
	w−0.02 (>.30)	+0.52 (<.01)	+0.54 (<.01)
M.C.	h+0.12 (<.05)	+0.48 (<.01)	+0.36 (<.01)
	w−0.08 (>.30)	+0.34 (<.02)	+0.42 (<.01)

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[2] J.S., F.K., and A.H. used the Stromberg-Carlson supersonic device (YA-3ST-M1); M.C. used the Stromberg-Carlson supersonic device (YA-2ST).

In each column of Table 3.17 the figure on the left is the mean difference between the two conditions being compared, and the figure in parentheses, to the right of the mean difference, is the probability that a difference as great or greater than the one obtained could have arisen by chance.

The plus and minus signs attached to the mean differences in Table 3.17 indicate which of the two conditions being compared yielded the larger average error. Thus, for example, a positive mean difference in the "supersonic minus optical" column signifies that the average error for the supersonic condition was larger than the average error for the optical condition.

In Table 3.18 are the mean times taken by the subjects in each of the experimental conditions, with the standard deviation of the distribution which the mean represents.

TABLE 3.18

Mean Judgment Time in Minutes for Each Experimental Condition

	Mean times in minutes					
Subjects	Optical device		Supersonic device		No device	
	Mean	S.D.	Mean	S. D.	Mean	S. D.
J.S.	0.80	.34	1.03	.40	0.06	.03
F.K.	0.80	.34	1.90	.71	0.12	.10
A.H.	1.50	.59	2.44	1.01	1.51	.21
M.C.	1.56	.66	1.81	.67	1.57	.54

The results may be summarized as follows:

(a) All four subjects make reliably more accurate judgments of height and width with either device than with no device.

(b) Two of the four subjects are reliably more accurate for judgments of height and width with the Signal Corps optical device than they are with the Stromberg-Carlson supersonic device. No subject performs better with the Stromberg-Carlson device than he does with the Signal Corps device, not even M.C., who had been previously

FIG. 3.15

SIZE DETERMINATION WITH SIGNAL
CORPS OPTICAL DEVICE, XA-1 SC.

trained with the Stromberg-Carlson device and not trained with the Signal Corps device.

(c) The two recently blinded veterans (J.S. and F.K.) appear to be considerably less accurate in the no-device condition than are the two subjects (A.H. and M.C.) who have been blind for a number of years. The average errors made by the recently blinded veterans are numerically close to each other and to that average error (1.65) which might be expected by chance. The two subjects who have had long experience of blindness (A.H. and M.C.) have average errors in the no-device condition which are considerably lower than the comparable error scores for the veterans.

(d) The mean time taken to make the judgments is less for all four subjects with the Signal Corps device than with the Stromberg-Carlson device. For two subjects the least judgment time is taken under the no-device condition. It must be noted, however, that they are the two recently blinded subjects, described above, whose judgment accuracies in the no-device condition were low. These subjects repeatedly remarked that they had no basis for making the judgment in the no-device condition and, hence, usually tended to make quick and apparently unfounded guesses in this condition. The remaining two subjects (who made comparatively accurate judgments in the no-device condition) took approximately the same amount of time in the no-device condition as they took with the Signal Corps optical device, which is slightly less than the amount of time they required while using the Stromberg-Carlson supersonic device.

5. Summary

Measures were taken of the accuracy and speed with which four blind subjects were able to judge the height and width of square and rectangular objects. These judgments were made by each of the subjects with the Stromberg-

Carlson supersonic device, with the Signal Corps optical device, and with no device.

Three of the subjects had previously received considerable training with both devices; one of the subjects had been trained only with the Stromberg-Carlson device.

All four subjects made reliably more accurate judgments of height and width with either device than with no device.

Two of the four subjects were reliably more accurate with the Signal Corps device than they were with the Stromberg-Carlson device. The remaining two subjects were almost equally accurate with the two devices.

The mean time taken to make the judgments is less for all four subjects with the Signal Corps device than with the Stromberg-Carlson device.

G. A COMPARISON OF THE UTILITY OF THREE PROBE GUIDANCE DEVICES FOR THE DETECTION OF A STEP-DOWN.

1. Introduction

Blind individuals say that even after years of experience in interpreting the cues normally available in their everyday environments, it is still extremely difficult, if not impossible, to detect the presence of a step-down. Thus, although they may be able to avoid walls and large protrusions, they cannot anticipate curbs and subway entrances. It is highly desirable, therefore, that a guidance device should enable its user to cope adequately with problems of this nature.

The purpose of the following study was to obtain a quantitative measure of the extent to which several probe guidance devices provide blind subjects with adequate information about a step-down.

2. Procedure

A platform 16 feet long, four feet wide, and one foot high was used to simulate the curb or generalized step-down situation. The position of the platform with respect to a door could be varied from trial to trial, so that a subject entering the room through this door mounted the platform from one side at various distances from its "step-down" edge. Having thus assumed an unknown position on the plateform, the subject was oriented toward the edge and instructed to walk to a point four feet from the edge and then stop. The distance from the edge at which the subject stopped was measured, and that distance was taken as a "score" for the subject on that trial. Each subject had 60 trials under each of the following conditions: With the Signal Corps optical device (XA-1SC), with the Stromberg-Carlson "pulsed FM" supersonic device (YA-3ST), with the Brush sawtooth modulated supersonic device (YA-3BD), and with no device.

3. Subjects

Four totally blind subjects were used in this experiment: A.H., W.H., A.C., and M.C. For a description of these subjects, see III-N.

These subjects had been given only very limited training with the

FIG. 3.16

SUBJECT DETECTING STEP-DOWN WITH SIGNAL CORPS OPTICAL DEVICE, XA-1 SC.

guidance devices prior to the beginning of this experiment.

4. Results

The frequency of stops within various distance intervals for the individual subjects is shown in Table 3.19. Table 3.20 shows these frequencies when the results from all subjects are combined.

TABLE 3.19

Frequency Distributions of Distances from Edge of Platform at Which Subjects Stopped, Based on 60 Trials by Each Subject in Each Condition.

		Condition			
Subject	Feet from edge of platform	Signal Corps (XA-1SC)	No Device	Stromberg-Carlson (YA-3ST)	Brush (YA-3BD)
A.H.	0 - 1	0	22	26	22
	2 - 3	49	15	11	13
	4 - 5	8	12	16	13
	6 - 7	3	10	6	10
	8 - 9	0	1	1	2
W.H.	0 - 1	2	17	13	20
	2 - 3	16	17	23	18
	4 - 5	36	22	13	12
	6 - 7	5	2	7	9
	8 - 9	1	2	3	0
	10 - 11	0	0	1	1
A.C.	0 - 1	0	12	16	19
	2 - 3	41	26	6	22
	4 - 5	19	12	26	10
	6 - 7	0	8	11	6
	8 - 9	0	2	1	3
M.C.	0 - 1	2	7	25	14
	2 - 3	40	12	25	17
	4 - 5	14	29	4	20
	6 - 7	1	9	4	5
	8 - 9	3	3	2	4

TABLE 3.20

Frequency Distributions of Stop Distances for Four Subjects Combined, Based on 240 Trials in Each Condition.

	Condition			
Feet from edge of platform	Signal Corps (XA-1SC)	No Device	S-Carlson (YA-3ST)	Brush (YA-3BD)
0 - 1	4	58	80	75
2 - 3	146	70	65	70
4 - 5	77	75	59	55
6 - 7	9	29	28	30
8 - 9	4	8	7	0
10 - 11	0	0	1	1

Adequate performance would be represented in these data by a marked clustering of stops in the distance categories labeled two to six feet. Inadequate performance is represented by a high frequency of stops in the zero to two feet category, which includes all stops from "Step-Offs" (scored 0) to 1.99 feet. Inadequate performance is further shown by a wide spread of stops, since this indicates that estimation of the four-foot point is highly variable.

Examination of Table 3.20 reveals quite clearly a superiority for the Signal Corps device as compared with the other devices and the no-device condition. The stops made with the Signal Corps device appear to be normally distributed about a point somewhat less than four feet from the edge, whereas the distributions for the other three conditions seem to be somewhat rectangular, with a slight clustering in the "inadequate" distance category, zero to two feet.

A contingency Chi-square test was applied to the various distributions of Table 3.20 to determine the probability of obtaining distributions that differ as much as those observed if there were no real differences between the several conditions under which they were obtained. The Chi-square obtained for all conditions, in Table 3.20, was 137.9 with 12 D.F., which is significant at the less than one percent level. A similar test on a table from which the data on the

Signal Corps device were eliminated had a Chi-square of 9.20 for 8 D.F., the fiducial level of which is somewhat more than 30 percent. In short, then, differences as great as those observed between the obtained distributions of stops might be expected to arise by chance about 30 times in 100 when data for the Brush, Stromberg-Carlson and no-device conditions are considered, whereas, when the distribution obtained with the Signal Corps device is included in the table, the resulting differences would be expected to arise by chance less than one time in 100. This suggests clearly that the observed superiority for the Signal Corps device is statistically reliable.

These quantitative results received considerable introspective support from the subjects, who repeatedly complained that the Brush and Stromberg-Carlson devices failed to identify the edge, whereas the signal from the Signal Corps device did so quite distinctly. The ease and confidence with which the subjects approached the task with the Signal Corps device was in marked contrast to the caution and trepidation which they showed under the other conditions.

5. Summary

Several guidance devices, the Signal Corps (XA-1SC), the Stromberg-Carlson (YA-3ST) and the Brush (YA-3BD) devices, were tested with respect to their ability to provide an indication of the presence of a step-down at a short distance. Four totally blind subjects were used in these tests.

After entering the test room the subject immediately stepped upon a platform at an unknown distance from its edge. His task was then to move forward toward its edge and to indicate the fact that he had detected its presence by stopping at a point four feet from it. The distance between each stopping point and the edge was recorded for 60 trials by each subject with each device and with no device.

The distributions of these stopping distances are given for each device and for no device. A contingency Chi-square indicated that the distributions for the Stromberg-Carlson and the Brush devices were sufficiently similar to one another and to the distribution obtained with no device to justify the assumption that they had all been obtained from the same population, whereas the distribution obtained with the Signal Corps device was sufficiently dissimilar from these to make it appear unlikely that it also had been drawn from the same population. Thus it appeared that only the Signal Corps device was capable of providing an adequate indication of the presence of a step-down. This conclusion was amply supported by the introspections of the subjects.

H. A COMPARISON OF AUDITORY AND TACTUAL SIGNAL SYSTEMS IN OBSTACLE AVOIDANCE TESTS.

1. Purpose

Because the ambient noises normally present in the environment are used to considerable advantage by the experienced blind person, it is highly desirable that the use of a guidance device should not interfere with the reception of cues from this familiar source of information. Although from the engineering point of view it seems that auditory signals are most easily adapted to use in guidance devices, it has been clear for some time that ultimately some non-auditory type of signal would have to be employed and the tactual sense has long stood in the background as the most feasible substitute for audition in this connection.

A two-fold program for transferring from auditory to tactual signals has been undertaken at the Haskins Laboratories. One aspect of this plan consists in fundamental research on tactual sensitivity. These studies are designed to provide information for selecting efficient tactual signal systems in terms of the characteristics of the receptor system. The second aspect of this program consists in the construction and testing of tactual signal systems for guidance devices which are already available. It is quite clear that such systems may or may not be well adapted to the sensory system concerned.

The following is a report on some preliminary work on the latter aspect of the program. Tactual stimulators have been attached to two guidance devices originally designed to delivery auditory signals, and a short obstacle avoidance test has been performed with each signal system on both of these devices. The devices adapted for this purpose were the Signal Corps optical device (XA-1SC, auditory and XT-1SC, tactual) and Dr. Witcher's continuous tone supersonic device (YA-3HL, auditory and YT-3HL, tactual).

2. Subjects

Three totally blind subjects, A.H., F.K., and J.S. were used in this test. All of these subjects had considerable previous experience with guidance devices having auditory signal systems. They were not given any particular training with the tactual models of these devices.

3. Procedure

The test consisted of ten trials in the single lane obstacle course without a device and with each of the signal systems for each of the subjects. The order in which the trials with the various signal systems were performed was so randomized as to minimize the effect of order on observed differences in the results for the two modes of presentation.

4. Results

Table 3.21 shows the total number of errors on ten trials with no device and with each of the signal systems for each of the subjects[1].

TABLE 3.21

Total Numbers of Errors made in Ten Trials

Subjects	No Device	Signal Corps Device		Dr. Witcher's Device	
		Auditory (XA-1SC)	Tactual (XT-1SC)	Auditory (YA-3HL)	Tactual (YT-3HL)
A.H.	17	1	1	-	-
F.K.	32	3	3	1	0
J.S.	35	7	6	2	5
Totals	84	11	10	3	5

Table 3.22 shows the percent reductions in errors derived from Table 3.21.

TABLE 3.22

Percent Reduction in Error

Subjects	Signal Corps Device		Dr. Witcher's Device	
	Auditory (XA-1SC)	Tactual (XT-1SC)	Auditory (YA-3HL)	Tactual (YT-3HL)
A.H.	94	94	-	-
F.K.	91	91	97	100
J.S.	80	83	94	86
Combined	87	88	96	94

---

[1] Subject A.H. was not available for test with Dr. Witcher's device.

The results of this test indicate quite clearly that there is no reliable difference between auditory and tactual signal systems in so far as obstacle avoidance efficiency is concerned, at least for these two devices. Moreover, it was clear from the subjects' introspections, that there was a certain ease and freedom associated with the use of tactual as compared with auditory signals that elicited an enthusiastic preference for the former.

These findings suggest that the task of converting guidance devices from auditory to tactual signal systems will probably not be complicated by special difficulties arising from the peculiarities of the new sensory modality.

5. Summary

Tactual and auditory signal systems were compared in an obstacle avoidance test with two devices. For both devices, these two signal systems were about equally efficient in providing the information necessary to obstacle avoidance. The subjects, however, showed a marked preference for the tactual signal systems.

I. A TEST OF THE ADEQUACY OF THE SIGNAL-RANGE-RELATION IN TWO GUIDANCE DEVICES.

1. Introduction

Experience with blind subjects in the obstacle course and under other controlled conditions gives the impression that blind persons, even when using a device which supplies range information, adjust inadequately to the distance between themselves and objects in their immediate environment. When their attention was called to this discrepancy, experienced blind subjects evinced a somewhat disconcerting lack of concern with range information. Only after considerable discussion did they reluctantly admit that rough range information might be relevant to the problems they encounter while circulating in their environment.

This attitude is understandable in terms of their customary reaction to obstructions. The experienced blind person, when he suspects the presence of an object, usually approaches it rather closely, or actually contacts it, before making an overt adjustment. According to the subjects' report, this "approach and contact" behavior is their method of verifying somewhat suspect hypotheses concerning the location of obstructions. Though this procedure seems scientifically sound when no device is being used, it appears remarkably inappropriate when ranging information is available. If this "verification" procedure is the true explanation of the blind subjects' failure to use range information appropriately, a re-education program appears to be required.

In such a program the first step is to verify the assumption that the signal-range-relation built into the device by design is satisfactory, i.e., that the signal changes as a function of distance in a manner that can be appropriately differentiated by the subject. Having established that the signal-range relation is adequate, and that the subject's knowledge of this relation is sufficient to enable him to make accurate judgments of distance, it is desirable to know whether or not this adequacy persists in actual use, when the subject is carrying the device and is actively scanning with it.

2. Purpose

The following study had two purposes: (1) to provide for the subjects formal training in the signal-range relations and, (2) to provide a test of the adequacy of the signal-range relations in two devices, both of which had an auditory and a tactual signal system.

3. Procedure

The subject was seated at a table upon which the device being tested was arranged in a fixed position. Four feet from the prospector of the device was an easily removable object used to elicit a standard four-foot signal. Behind this object was a movable object that was placed at various distances from the prospector. These distances ranged from four to fourteen feet in steps of one foot (Fig. 3.17).

A trial consisted of the presentation of the signal from the four-foot object. This was followed immediately by the signal from an object at some distance within the test range described above. The subject then gave his estimate of the distance to the second object in feet. The time required by the subject to arrive at his decision also was recorded. After the judgment was given, the four-foot object was returned to its position while the second object was moved into position for the next trial[1].

Before each test session the subject was given from ten to twenty trials with information. During this pretest training an object was placed at various distances selected at random from the test range and the subject was asked to judge the distance. If his judgment was correct he was told that it was correct. If his judgment was incorrect he was told the actual distance. Any time that the time interval between two test periods was an hour or more this pretest training was given to the subject.

---

[1] The "anchoring signal" from the four foot object was used for several reasons, among which were: (1) It acted as a cut-off allowing the experimenter to move the second object without fear of being detected by the device. (2) The anchoring signal somewhere in the test range is known to have a stabilizing effect on the judgmental scale, and consequently has a facilitating effect on the judgmental process.

FIG.3.17

SUBJECT RANGING WITH SIGNAL CORPS
OPTICAL DEVICE, XA-1 SC.

For each subject there were ten test trials at each of the distances with each of four signal systems. This means a total of 400 test trials for each subject. It was convenient for the subjects to give about twenty judgments in succession. After this they were given a three-minute rest and another group of twenty test trials was given. After about 60 trials at this rate the subjects were given an hour's rest.

The order of working with the various signal systems was randomized so as to minimize the influence of this order on differences that might be observed between the signal systems.

4. Subjects

Three totally blind subjects were used in this experiment: A.H., F.K., and J.S. Subject A.H. had had considerable experience with the devices before beginning the study; subjects F.K. and J.S. had very little previous experience with the devices.

5. Results

Table 3.23 shows the mean judged distances corresponding to each of the actual distances in the test range for each subject with each signal system.

The differences between the mean judged distances and the actual distances are small for all signal systems. It appears, therefore, that the ranging information supplied by the various signal systems is adequate, at least in so far as the means are concerned.

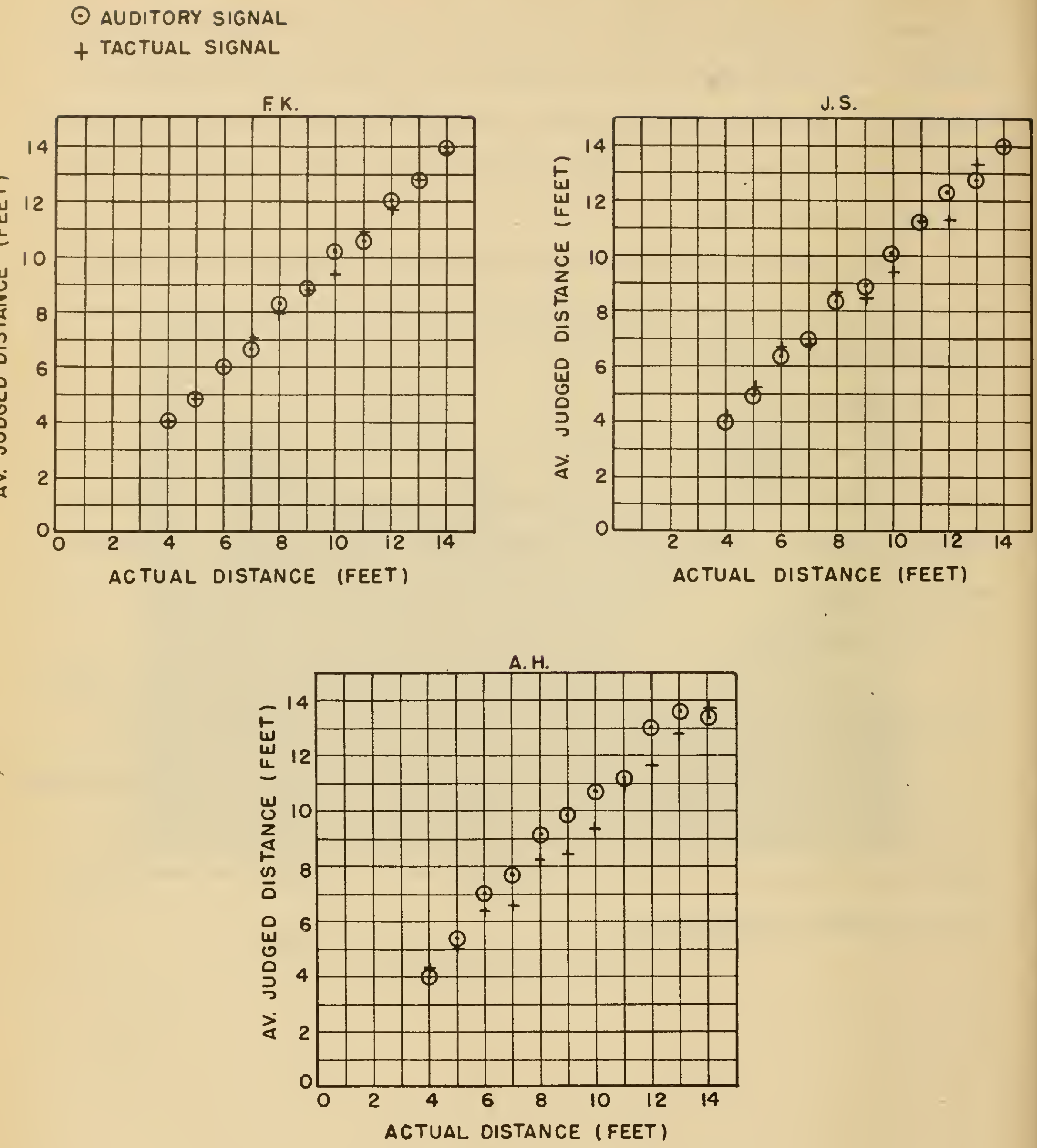

FIG. 3.18
JUDGED DISTANCE VS. ACTUAL
DISTANCE WITH SIGNAL CORPS
DEVICE,

TABLE 3.23

Mean Judged Distances Corresponding to Various Actual Distances (Feet).

Subject	Actual Distance	Signal Corps Device		Dr. Witcher-Device	
		Auditory (XA-1SC)	Tactual (XT-1SC)	Auditory (YA-3HL)	Tactual (YT-3HL)
A.H.	4	4.0	4.3	4.0	4.0
	5	5.4	5.1	5.3	5.0
	6	7.0	6.5	6.3	6.0
	7	7.7	6.6	7.0	7.2
	8	9.2	8.3	7.8	8.2
	9	9.9	8.5	9.2	9.5
	10	10.8	9.4	10.0	10.2
	11	11.2	11.0	11.1	11.3
	12	13.1	11.7	11.8	12.1
	13	13.6	12.9	12.3	13.2
	14	13.5	13.8	12.9	13.5
F.K.	4	4.0	4.0	4.0	4.1
	5	4.8	4.8	4.7	4.8
	6	6.0	6.0	5.8	5.9
	7	6.6	7.0	6.4	7.4
	8	8.3	8.1	8.1	8.0
	9	8.9	8.9	8.8	9.1
	10	10.2	9.4	9.6	9.6
	11	10.6	10.8	10.7	10.9
	12	12.0	11.9	11.8	12.1
	13	12.8	12.8	13.1	12.6
	14	13.9	13.7	14.0	13.9
J.S.	4	4.0	4.2	4.0	4.0
	5	5.0	5.1	5.0	5.1
	6	6.4	6.6	6.3	6.2
	7	7.0	6.9	7.2	6.9
	8	8.4	8.6	8.4	7.7
	9	8.9	8.6	8.6	8.5
	10	10.1	9.3	9.8	9.9
	11	11.3	11.4	10.8	10.9
	12	12.3	11.4	11.1	11.6
	13	12.8	13.3	12.5	12.9
	14	14.0	14.0	13.7	13.7

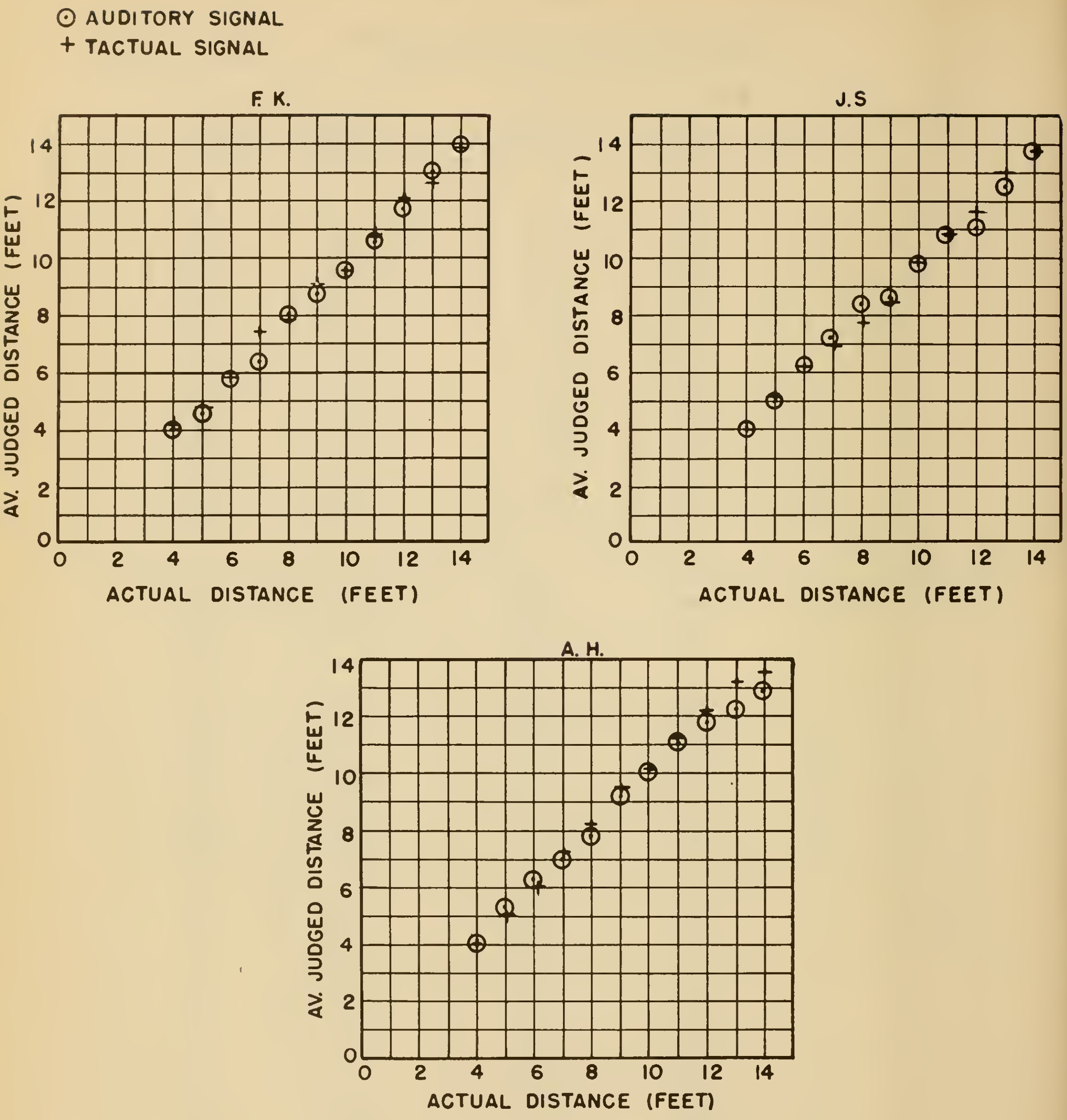

FIG. 3.19
JUDGED DISTANCE VS. ACTUAL DISTANCE, USING DR. WITCHER'S DEVICE

Table 3.24 shows the standard deviation of the judged distances for each of the presented distances.

TABLE 3.24

Standard Deviations of Judged Distances
for Various Actual Distances (Feet).

Subject	Actual Distance	Signal Corps Device		Dr. Witcher-Device	
		Auditory (XA-1SC)	Tactual (XT-1SC)	Auditory (YA-3HL)	Tactual (YT-3HL)
A.H.	4	.00	.40	.00	.00
	5	.66	.32	.63	.00
	6	.45	.40	.63	.63
	7	1.19	.40	.00	.77
	8	.60	1.00	.44	.89
	9	1.04	.40	1.18	1.48
	10	1.08	.63	.77	1.26
	11	.98	.77	.83	1.00
	12	1.04	.63	1.00	1.04
	13	.66	.55	.77	.63
	14	.81	.40	1.51	.44
F.K.	4	.00	.00	.00	.03
	5	.40	.40	.64	.40
	6	.44	.63	.74	.70
	7	1.01	.77	.66	.80
	8	.64	.70	.53	.63
	9	.89	.83	.60	.94
	10	.87	.80	.91	.80
	11	.66	.98	1.00	.53
	12	.77	1.04	1.03	.53
	13	.40	.74	.03	.80
	14	.03	.45	.00	.03
J.S.	4	.00	.40	.00	.00
	5	.00	.03	.44	.03
	6	.80	.49	.64	.75
	7	.89	.70	.60	.70
	8	1.11	.66	1.28	.45
	9	.70	.80	.80	.67
	10	1.04	1.10	.60	.53
	11	.90	1.02	1.32	.83
	12	.78	1.02	1.44	.66
	13	.60	.64	.92	.94
	14	.00	.00	.64	.45

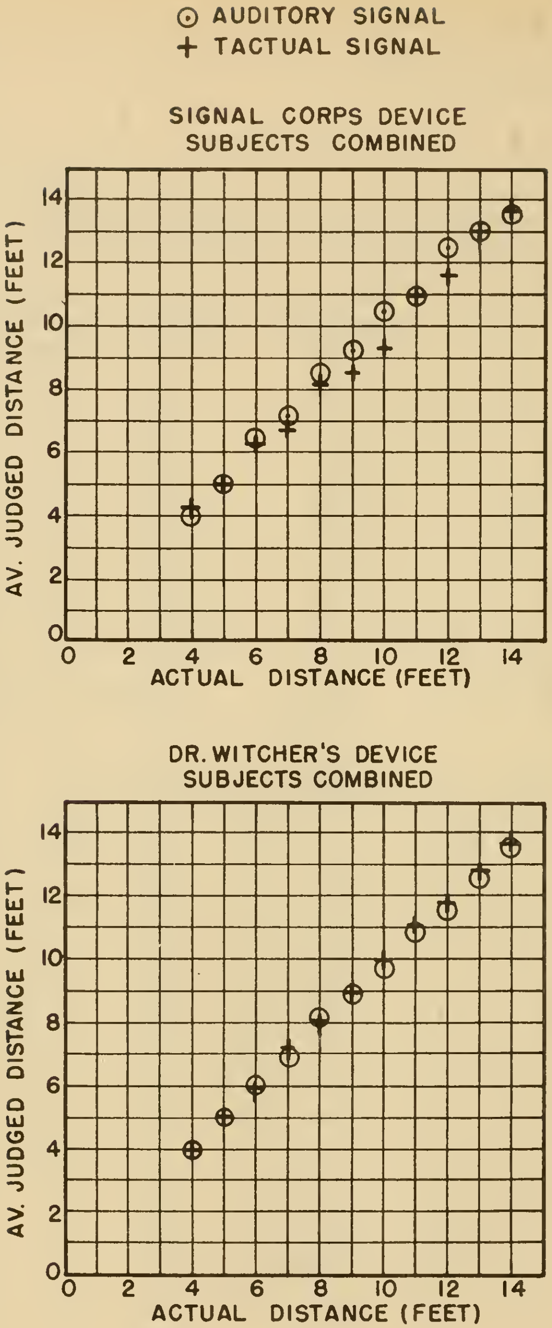

FIG. 3.20
JUDGED DISTANCE VS. ACTUAL DISTANCE, COMBINED RESULTS FOR ALL SUBJECTS

The standard deviations for distances at and near extremes of the test range tend to be smaller than those for the distances around the center of the range[1]. These data suggest that distances from four to seven feet can be well discriminated whereas distances from seven to twelve feet may be estimated with some confusion over a range of about one foot on either side of the point whose distance is to be judged. It is apparent that the various signal systems do not differ systematically in this connection. It is highly desirable, of course, to reduce this variability to a minimum in all devices, because it is really a variability in the accuracy of range estimations and as such must undermine the subjects' confidence in the device.

Figures 3.18 and 3.19 have been constructed from the data given in Table 3.23 in order to observe the form of the relation between average judged distance and actual distance. It is apparent that the most satisfactory simple function for representing these results is the one to one relation.

The several functions for the individual subjects, however, exhibit a tendency to discontinuity somewhere around the center of the test scale. With the Signal Corps device this tendency is understandable in terms of the signal system which is, by design, discontinuous at various points within the test range. In Dr. Witcher's device, on the other hand, the signal change as a function of distance is continuous. It is possible that the observed discontinuities are to be attributed to the idiosyncracies of the individual subjects. If this were so, averaging the data of the three subjects should decrease the apparent discontinuity, except in the unlikely contingency that all three subjects had a tendency to discontinuity at approximately the same place on the test scale. The results of such averaging are shown in Figure 3.20, wherein it will be observed that the apparent discontinuity remains in the data on the Signal Corps device, whereas it is decreased, if not completely eliminated from, the data on Dr. Witcher's device. It is suggested then that there is a genuine

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[1] Restriction of variability at the proximal end of the range is probably due to the use of the anchoring signal (four feet). Restriction of variability at the distal end of the range is probably due to a natural anchoring phenomenon resulting from the fact that the signals tend to be highly attenuated at these distances.

tendency to discontinuity traceable to the nature of the signal system in the Signal Corps Device.

Judgment time is often taken as an index of the ease with which discriminations or differentiations can be made. Although it is apparent from the above data that the various signal systems tested do not differ in terms of the accuracy or precision of estimates, it is possible that they do differ with respect to the ease with which the subjects can make estimates with them. Table 3.25 gives the mean judgment time, in hundredths of a minute, for two subjects[1] with each of the signal systems.

TABLE 3.25

Mean Judgment Times (Hundredths of a Minute)

Subject	Actual Distance	Signal Corps Device		Dr. Witcher-Device	
		Auditory (XA-1SC)	Tactual (XT-1SC)	Auditory (YA-3HL)	Tactual (YT-3HL)
F.K.	4	11.6	15.1	9.8	10.0
	5	12.4	16.9	14.6	10.9
	6	12.9	16.8	13.2	12.1
	7	16.1	22.4	19.4	13.1
	8	18.2	23.0	17.5	14.1
	9	16.4	21.6	19.1	16.1
	10	17.5	20.8	20.8	13.7
	11	18.2	21.6	22.0	15.1
	12	16.7	19.7	22.6	13.6
	13	15.6	20.7	20.9	13.9
	14	14.4	17.7	14.1	12.4
J.S.	4	10.9	17.4	11.3	9.1
	5	12.4	15.3	12.8	10.8
	6	13.2	14.6	17.9	11.5
	7	15.2	18.5	19.2	10.8
	8	16.6	20.9	25.4	14.8
	9	14.5	17.9	23.0	15.2
	10	16.6	23.5	21.2	16.3
	11	16.7	19.4	25.7	15.5
	12	13.9	22.0	24.1	15.0
	13	13.0	18.7	18.0	16.0
	14	13.9	23.0	16.5	17.0

---

[1] Because subject A.H. was used in preliminary work, no time measures were obtained for him with the Signal Corps Device. Consequently, time measures are reported for only two subjects.

It will be observed from this table that the judgment times tend to increase for distances around the center of the test range. This is true for all signal systems and all subjects and again is probably due to anchoring phenomena. Making comparisons between modes of presentation, tactual as compared with auditory, it will be observed that, with the Signal Corps Device, both subjects make their judgments more quickly with auditory signals than they do with tactual signals; this is true at all distances judged. With Dr. Witcher's Device, both subjects make their judgments more quickly with tactual signals than they do with auditory signals; this is true for all entries except two. Making comparisons between devices, but within modalities, it will be observed, for auditory signals, that judgments are made more slowly with Dr. Witcher's Device than with the Signal Corps Device, whereas with tactual signals the judgments are made more slowly with the Signal Corps Device than with Dr. Witcher's Device. Finally, it will be observed that judgments made with Dr. Witcher's Device using tactual signals are on the average made more quickly than with any other signal system tested.

Table 3.26 shows the standard deviations of the judgment times whose means are presented in Table 3.25. It will be observed that the size of the standard deviations changes in approximately the same way that the means change so that analysis of this table is not required. These data are presented in order to permit of an estimation of the reliability of the means presented in Table 3.25.

TABLE 3.26

Standard Deviations of Judgment Times (Hundredths of a Minute)

Subject	Actual Distance	Signal Corps Device Auditory (XA-1SC)	Signal Corps Device Tactual (XT-1SC)	Dr. Witcher-Device Auditory (YA-3HL)	Dr. Witcher-Device Tactual (YT-3HL)
F.K.	4	2.8	3.2	1.1	1.34
	5	2.7	6.7	5.0	1.46
	6	2.0	6.7	2.3	1.59
	7	2.9	4.4	5.9	3.37
	8	4.0	5.5	3.3	3.80
	9	3.3	6.6	4.4	3.27
	10	2.4	5.1	6.3	3.83
	11	3.4	5.7	5.2	3.19
	12	2.2	4.3	3.8	4.00
	13	3.1	4.6	5.3	3.64
	14	3.9	5.1	3.0	3.22
J.S.	4	2.6	6.3	4.2	1.89
	5	3.0	4.5	2.5	.73
	6	2.6	2.6	6.7	3.30
	7	3.8	4.1	6.4	2.17
	8	3.0	7.3	9.7	5.06
	9	2.2	5.6	9.1	3.55
	10	3.3	6.4	8.5	4.20
	11	3.1	6.7	10.0	3.37
	12	2.7	6.0	8.6	3.44
	13	2.6	4.9	8.0	3.60
	14	3.6	9.0	4.8	4.20

6. Conclusions

The general conclusions to be drawn from these data are the following:

(a) In terms of the average relation between judged distance and actual distance the various signal systems tested are adequate and equally good.

(b) The various signal systems tested also showed approximately the same variability of judged distance. It seems, desirable, however, to restrict this variability for all systems.

(c) In terms of the average judgment-time there is a marked differentiation between the signal systems tested. The indications are that for the Signal Corps Device the auditory signal is superior to the tactual signal that was substituted for it in this experiment. For Dr. Witcher's Device the tactual signal system was superior to the auditory.

(d) In terms of judgment time the best signal system tested was Dr. Witcher's tactual signal.

7. Summary

Absolute judgments of distance were obtained from three totally blind subjects using two guidance devices each of which was equipped with both an auditory and a tactual signal system. The devices were the Signal Corps optical device (XA-1SC and XY-1SC) and Dr. Witcher's supersonic device (YA-3HL and YT-3HL).

Objects were placed at various distances (4 to 14 feet in steps of 1 foot) from the prospectors of the devices and the subjects were asked to estimate these distances after some preliminary training. Both the subject's judgment and the time required to arrive at it were recorded for each estimate. Each subject judged each distance within the test range ten times with each signal system. Throughout the experiment a reference signal from an object four feet away preceded each of the distances to be judged.

The average judged distances for each of the actual distances were very accurate for all signal systems. The standard deviations of the judged distances varied from zero to slightly more than one foot depending upon the actual distances regardless of signal system used. It is clear that any adjustment of the devices that would lead to a reduction of these indices of dispersion would be desirable.

The time measures distinguished between the various signal systems much more clearly than the accuracy measures did. The following is the order of efficiency of the various signal systems based upon average judgment time:

1 - Dr. Witcher Tactual Signal
2 - Signal Corps Auditory
3 - Signal Corps Tactual
4 - Dr. Witcher Auditory

J. USE OF SUPERSONIC DEVICES AS RANGE INDICATORS

1. Purpose

One of the items of information which an effective probe device should yield is the range of the obstacle. It thus seemed desirable, in the course of the early work with supersonic devices, to determine whether they were capable of giving good ranging information. Accordingly the purpose of this experiment was to determine the accuracy with which a blind individual can approach to within specified distances of an obstacle when he is using the Stromberg-Carlson "pulsed FM" supersonic device (YA-2ST), the Brush sawtooth modulated supersonic device (YA-2BD), and no device.

2. Subjects

Five totally blind subjects were used in this experiment: E.C., A.H., E.J., M.M., and V.T. None of them had had any previous training with the devices.

3. Procedure

The experiment was performed in a room 20' x 20'. The subject was required to enter the room and approach a 6' x 3' obstacle, with instructions to stop at a definite distance from it. (This distance is referred to as the assigned distance). When he stopped, his distance from the obstacle was measured (this distance will be called the response distance), and the subject was told what his error was, if any. He was then assisted to move forward or backward to the correct distance. In order to prevent the subject from responding by approaching very close to the obstacle and then pacing backward (thus using cues other than the signal provided by the device at the assigned distance), he was not permitted to move away from the obstacle during his response.

In order to prevent the subject from learning its position, the distance of the obstacle from the door was varied from trial to trial, the subject remaining outside the room while it was being placed. The assigned distance was also varied from trial to trial, the distances used being 2, 3, 4, 5, 6, 7, 9, 11, 13 and 15 feet, in random order. Trials were given in groups of thirty, each group consisting of 20 trials with a device and 10 trials with no device. Each session consisted of two such groups of trials (one with each device), so that a session consisted of sixty trials, 20 with the Brush device, 20 with the Stromberg-Carlson device, and 20 with no device. Each of the ten distances occurred an equal number of times in each condition. The order in which the two devices were used varied from session to session.

4. Results

Table 3.27 shows the combined results for 5 subjects. The mean response distance for each assigned distance is shown in Column 2 for the Brush device, Column 4 for the Stromberg-Carlson device, and Column 6 for no device. Each of the means represents approximately 110 trials, distributed among the five subjects. The standard deviations of these means are shown in Columns 3, 5, and 7.

TABLE 3.27

Mean Response Distances and Their Standard Deviations

Assigned Distance (Inches)	Brush (YA-2BD) Mean	S. D.	Stromberg-Carlson (YA-2ST) Mean	S. D.	No Device Mean	S. D.
24	28.3	11.3	33.8	14.9	28.6	12.4
36	41.0	11.8	44.2	13.2	40.4	16.7
48	52.5	12.6	51.4	14.6	51.0	17.6
60	62.6	14.9	61.2	13.8	55.2	17.5
72	72.4	14.0	73.0	15.1	65.5	21.5
84	84.2	15.3	84.1	15.5	79.3	20.0
108	103.3	12.6	103.8	15.3	91.3	23.5
132	124.7	13.9	127.5	14.8	106.0	23.2
156	145.0	13.1	150.0	15.3	123.8	27.4
180	167.2	15.6	169.8	14.4	135.0	29.0

Column 1 - assigned distance (inches)
Columns 2, 4, 6 - mean response distance (inches)
Columns 3, 5, 7 - standard deviations of mean response distances (inches)

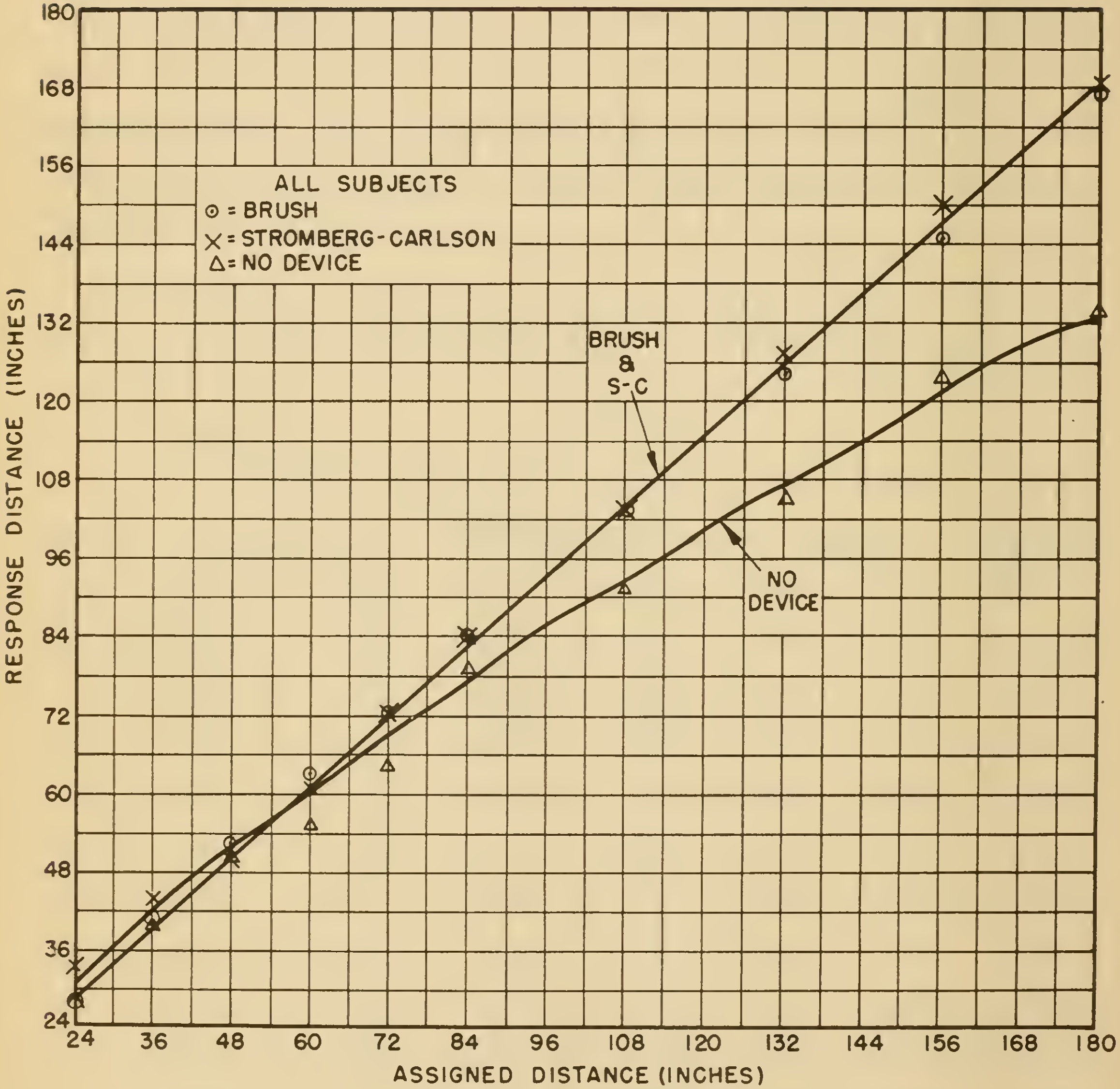


FIG. 3.21
RESPONSE DISTANCE = F(ASSIGNED DISTANCE)

Figure 3.21 shows the response distance as a function of the assigned distance, with a separate curve for each of the conditions (all curves derived from the data of Table 3.27). It will be seen that the response distance is very close to the assigned distance for each of the devices, and the function: response distance = f (assigned distance) is very nearly a straight line. With no device, on the other hand, the response distance tended to fall off as the assigned distance increased, so that at the higher assigned distances there was considerable error, all of it in the direction of too small a response distance. It is apparent that both of the devices improved the accuracy of the mean range estimation over that with no device, especially at the higher assigned distances.

Figure 3.22 shows the standard deviation of the response distance plotted as a function of response distance. With no device, the variability of the responses increases steadily and sharply with the distance. With either of the devices, however, the variability remains relatively low and constant, even up to distances of 15 feet.

It seems to be indicated that both of these devices increase the reliability of the subjects' estimation of range, for distances from two or three feet up to fifteen feet. The distance at which the superiority of "device" over "no device" was established varied somewhat from subject to subject. However, only one of the subjects (A.H.), did much better with no device than the combined performance shown in Fig. 3.22. This subject's responses were less variable with no device than with either device for distances up to six feet.

It should be pointed out that the small size of the only room then available acted as a limitation on the range of variation of the position of the obstacle. Since the room was 20 feet long, there was a total distance of 18 feet (from 2 to 20 feet from the door) through which the position of the obstacle could be varied for an assigned distance of 2 feet, while for an assigned distance of 15 feet, the obstacle could only be placed between 15 and 20 feet from the door (a range of 5 feet). The subjects could readily learn, for example, that there was

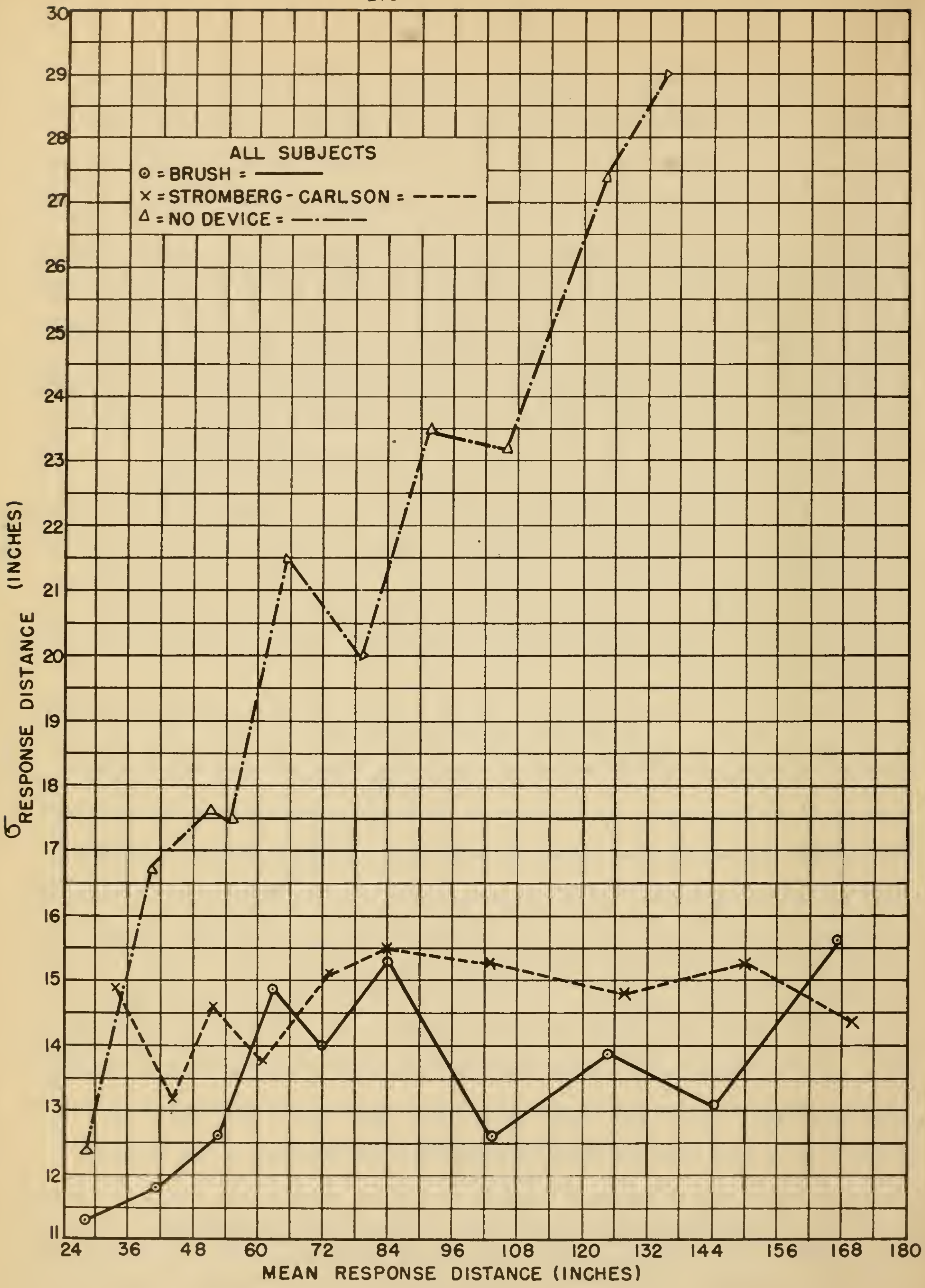


FIG. 3.22

$\sigma_{\text{RESPONSE DISTANCE}} = F\,(\text{RESPONSE DISTANCE})$

no point in walking more than five feet into the room when the assigned distance was fifteen feet. This might tend to increase the response distances at the higher assigned distances. It thus is quite possible that, if the experiment were to be repeated in a much larger room, the "no device" curve of Fig. 3.21 would begin to flatten out at some intermediate point, instead of rising steadily throughout the range.

The variability of the responses with the Brush device is less than that for the Stromberg-Carlson at distances less than four or five feet. This was true of all five subjects. From examination of the devices, and from remarks of the subjects, it appears that the reason for the superiority lies in a sharp change in the Brush signal (to a more "guttural" sound) as the distance decreases past 4-5 feet. This distance thus served as a marker distance for the shorter response distances.

5. Conclusions

The results appear to indicate that (a) the accuracy of estimation of the range of obstacles was increased by both the Brush and the Stromberg-Carlson device over the accuracy with no device, especially at distances over 5 feet, and that (b) the reliability of range estimations was also increased by each device, for distances beyond 2 or 3 feet.

6. Summary

Ranging ability is a requirement for good probe devices. Subjects were required to approach a 6' x 3' obstacle, stopping at a preassigned distance from it. This was repeated with the Brush (YA-2BD) and the Stromberg-Carlson (YA-2ST) supersonice devices, and with no device. By accuracy of range estimation is meant the closeness with which the mean response distance for a given preassigned distance approximates the assigned distance. The reliability of range estimation is expressed in terms of the standard deviation of the mean response distances for each assigned distance. Both accuracy and reliability of range estimation were improved by both devices, over the no-device performance.

K. OUTDOOR TESTING PROGRAM

1. Introduction

Although the results of obstacle avoidance tests have suggested that several existing probe devices are effective in aiding the blind individual to overcome some of the problems he encounters in getting about in his environment, it is obviously desirable that such laboratory tests be supplemented by observations made in more natural or uncontrolled surroundings. By way of a first step in this direction an outdoor location for the obstacle course was found at Westport, Connecticut. It was believed that by performing a simple obstacle avoidance study out of doors, information would be secured concerning the effect of such general factors as sunlight, lack of reflecting walls, changes in atmospheric conditions, etc.

2. Observations made at Westport, Connecticut

The site used for the obstacle course was a bowling green whose dimensions were approximately 125 feet by 20 feet. The green was bordered on one side by a hedge about 15 feet high and by a wooded area (trees, hedges) on the other side. The course had the same dimensions as the single lane course used in the interpolated tests given during the training program in the Laboratories (III-D-2); thus, the obstacles were distributed over an area which was 48 feet long and 9 feet wide. The boundaries of the outdoor course were a 15-foot hedge on one side and a rope extending 48 feet on the other side. It should be pointed out that while the floor of the course in the Laboratories was hard wood, in the outdoor course it was grass-covered ground.

The obstacles used in this outdoor study were the same ones used for the previously reported Laboratories studies. There were 12 obstacles randomly distributed through the course. The general procedure was identical with that used in the indoor study performed with Obstacle Course C (III-E).

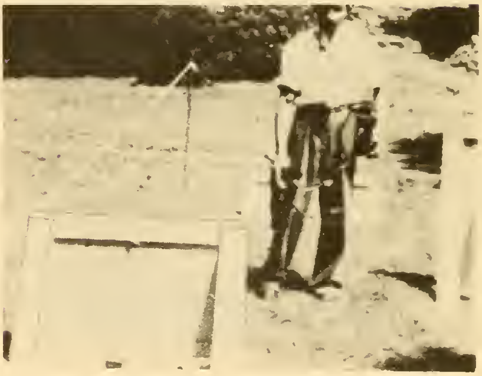
Three trained and totally blind subjects participated in this study: A.H., F.K., and J.S. Two devices, the Signal Corps device (XA-1SC) and the

1-STARTING DOWN COURSE.

2-IN MIDDLE OF COURSE.

3- SCANNING OBSTACLE.

4-DETECTING OBSTACLE.



5-CLEARING OBSTACLE.

6-HAVING PASSED OBSTACLE.

FIG. 3.23

USING HOOVER SUPERSONIC DEVICE, YA-1 HC(MI) AT OUTDOOR OBSTACLE COURSE, WESTPORT, CONN.

Hoover device (YA-1HC-M1) were used in this study. The Brush device (YA-3BD) and the Stromberg-Carlson (YA-3ST) were not included in this study because they were undergoing extended repairs.

Because of unavoidable complications attendant upon outdoor work this study had to be discontinued before a sufficiently large number of trials were taken. As a result, different numbers of trials were taken with the two devices, and consequently these data are not comparable with one another, nor with previous data in terms of absolute numbers of errors. Comparisons, however, can still be made in terms of indices of relative efficiencies or percent reduction in errors.

In Table 3.28 the percent reduction in errors for both indoor and outdoor performances are given for the two devices. The data for the indoor work have been taken from Table 3.10 of Report III-E.

TABLE 3.28

Percent Reduction in Errors

Subject	Signal Corps Device		Hoover Device	
	Indoors	Outdoors	Indoors	Outdoors
A.H.	69	84	45	39
F.K.	81	79	83	55
J.S.	78	63	64	39
Combined	78	74	68	45

These data suggest that the obstacle avoidance efficiency of the Signal Corps device is not affected by outdoor use. On the other hand, there is some suggestion that the efficiency of the Hoover device is slightly impaired out of doors.

The introspections of the subjects, however, indicate that the signal-noise ratio is increased for the Signal Corps device as a result of using it in the bright sunlight of the outdoors. From time to time as the experiment progressed the subjects complained about the fact that they were having difficulty in hearing the signal.

1-APPROACH

1-APPROACHING HEDGE

2-DETECTION

2-SEARCHING FOR ENTRANCE

3-AVOIDING

3-DETECTION OF ENTRANCE

FIG. 3.24
OUTDOOR TESTS AT THE N.Y. INSTITUTE FOR THE BLIND.
A. DETECTION AND AVOIDANCE OF PEDESTRIAN USING SIGNAL CORPS DEVICE, XA-1 SC.
B. FINDING ENTRANCE TO WALK WITH STROMBERG-CARLSON, YA-3 ST.

3. Observations Made at the New York Institute for the Blind

The second site made available for outdoor observations of guidance devices was the grounds of the New York Institute for the Blind. The campus offered a more complex environment than the Westport site because it had paved walks, lamp posts, buildings and such natural obstacles as boulders, trees and bushes and yet was sufficiently isolated to permit the blind subjects to work with the devices without undue embarrassment and interference from curious spectators.

Since the purpose of the outdoor observations was to evaluate the devices in their performance in real life situations, it was all but impossible to secure such scores or indices as are usually associated with more controlled but artificial situations. The subjects were simply required to make an excursion around the grounds and to try to use the device to assist them in getting about.

The experimenter's task in this situation is unusually important and complex because he not only is responsible for recording his observations on the performance of the subjects, but he must also make every effort to arrive at a valid interpretation of the difficulties experienced by the subjects. Consequently, the subjects were encouraged to talk out their difficulties in each specific problem with each device, and the experimenter questioned them persistently. The following observations should be interpreted in the light of the difficulties one encounters in observing and recording another individual's performance.

a. Excursions About the Grounds

1. Signal Corps Device (XA-1SC)

It was observed as each subject took his turn with this device, that the device was not operating so efficiently in the outdoor situation as it had in the Laboratories. The subjects experienced difficulty in detecting many of the natural obstacles which they encountered in walking about the grounds. After the experimenter tried the device for himself, a discussion was held with the subjects concerning the specific difficulties they were having. It was generally agreed by the subjects that the device seemed to have the following defects:

(a) Signal not clear. It seems smothered by a great deal of background noise.

(b) Signal changes even when obstacles are not present.

In order to be certain that these difficulties were not caused by some mechanical or electrical deficiency the device was checked in the Laboratories. The device was found to be operating normally, although subsequent observations suggested that these difficulties arose from the high ambient illumination from the sun. It was also observed that shadows and the different reflecting surfaces encountered outdoors caused the intensity of the signal to vary considerably. The change in intensity was in many cases confusing to the subject and caused him to make errors.

It should be kept in mind that the subjects were not incapable of detecting obstacles with the device out of doors, but simply said it was much more difficult than it was in the laboratory situation. All the subjects seemed less confident in using the device, not only because of these specific difficulties, but because they had difficulty in detecting obstacles such as railings, bushes, etc. The narrowness of the searching beam seemed to be a handicap in avoiding obstacles of this type.

When the device was used in the rain, the subjects felt that its effectiveness was decreased. It would appear that the intensity of the signal was reduced, because it was no longer possible to detect obstacles at distances greater than five feet.

2. Stromberg-Carlson (YA-3ST)

It was observed by subject F.K. and verified by other subjects and the experimenter, that wind blowing through the earphones made it extremely difficult to perceive the signal from this device. This difficulty was attributed

1-SEARCHING FOR ENTRANCE

1-PEDESTRIAN IN PATH, STROMBERG CARLSON

2-DETECTING ENTRANCE

2-PEDESTRIAN CROSSING PATH, STROMBERG-CARLSON

3-ON DESIRED PATH

3-PEDESTRIAN CROSSING PATH, SIGNAL CORPS

FIG.3.25
OUTDOOR TESTS AT N.Y. INSTITUTE FOR THE BLIND
A - ENTERING WALK WITH SIGNAL CORPS OPTICAL DEVICE, XA-ISC
B - DETECTING PEDESTRIAN

to "wind rush" in the earphones rather than to a distortion or interference with the transmitted beam, because when the subject cupped his hands over the earphones the difficulty was eliminated.

The Stromberg-Carlson device was capable of detecting most of the obstacles which the subjects encountered in moving about the grounds. Lamp posts, buildings, low stones, etc., were detected with a minimum of difficulty. Objects which were not solid structures, such as gates, bushes, railings, etc., were also detected with no difficulty. The subjects commented quite freely about the device and in most cases enthusiastically.

The device seemed to work just as well in the rain as it did during fair weather. Other factors such as sunlight had no effect on the efficiency of the device. The problem of specularity, which was reduced in the indoor obstacle course situation by the application of specific scanning procedures, was, because of these procedures, of minor significance in the outdoor situation. The subjects utilized the same scanning methods and consequently were able to detect low obstacles.

It can be stated with some certainty that the subjects had little difficulty with this device, and used it more confidently than any other device observed in the outdoor situation. In general they regarded the Stromberg-Carlson as the best device for the outdoor situation. This general impression can be summarized by a remark from F.K., "This device works pretty well".

3. Brush Device (YA-5BD)

The subjects felt that with this device information was slow in coming and indefinite when it arrived. Its signal was usually so near liminal that the general babbling of children in the vicinity almost completely masked it. Moreover, there seemed to be spontaneous changes in the signal content unrelated to any detectable characteristic of the environment. The general reaction to this device can be summarized by a remark by A.H., "This thing changes a lot and it is very hard to be sure you have picked up something".

Although the device was capable of detecting the usual obstacles (bush, posts, etc.), the subjects made many errors and exhibited very little confidence, because the device required optimal external conditions in order to perform successfully.

4. Stromberg-Carlson (YA-4ST)

A new echo-ranging pulse model from Stromberg-Carlson was found to be incapable of detecting objects unless they presented a flat surface and the searching beam was exactly normal to that surface. In short, the problem of specularity was especially acute with this device and could not be circumvented by the scanning methods found so effective with the PFM Stromberg-Carlson device (YA-3ST). As a result, the subjects had considerable difficulty in getting about the grounds. They exhibited very little confidence when using the device and in most cases claimed that it was just not operating. It can be stated quite confidently that the performance of this device in the outdoor situation was much less satisfactory than that of the earlier Stromberg-Carlson (YA-3ST) and the Signal Corps (XA-1SC).

5. Dr. Meeks' Optical Device (XA-4HL)

The last device to be observed in the outdoor situation was Dr. Meeks' Optical Device (continuous tone signal). The subjects reported that they encountered a great deal of difficulty in interpreting the signal. In most cases this resulted from the vastly different illuminations in various areas in an outdoor situation. For example, if the subject approached a deep shadow while walking in a sunny area, a signal change occurred when the light beam passed into the shadow. Such changes were invariably interpreted by the subject as indicating the presence of an obstacle and led to consequent confusion. Furthermore, it may be said that the signals given by the device are highly variable and, as a result, did not permit rapid and accurate obstacle detection.

b. Performance of Specific Tasks

In addition to observing the subjects moving about the grounds, the experimenter recorded their performances in specific real life situations.

In some cases quantitative data were obtained for these particular problems:

(1) Detecting an approaching individual.

(2) Detecting an individual crossing the path of the blind subject.

(3) Detecting and entering a "doorway."

1. Detecting an approaching individual

The subject's task in this situation was to indicate, as he walked on an open cement path or on a grass lawn, when he detected the presence of an approaching individual (experimenter). At different time intervals, unknown to the subject, the experimenter would walk toward the subject. Every effort was made by the experimenter to approach noiselessly so as to eliminate the possibility of the subject's responding to incidental auditory cues. When the subject detected the individual he indicated this by saying "stop". The experimenter stopped at this point and the subject gave an estimate, on the basis of the signal, of how far the experimenter was from him. The experimenter then recorded this judgment and his own estimation of the distance between him and the subject.

Data for this procedure were collected from two subjects, A.C. and F.K., using the Signal Corps Device (XA-1SC), Stromberg-Carlson device (YA-3ST), Brush device (YA-5BD) and Dr. Meeks' Optical device (XA-4HL). Each subject had 40 trials with each device.

Results. It was observed during the experiment that all the devices were equally capable of detecting an approaching individual. No device ever failed in this function. It was also found, by comparing the subject's estimation of the distances at which he detected the approaching individual with the distances estimated visually by the experimenter, that the average disparity between these two sets of judgments was less than half a foot.

Table 3.29 shows that the mean and standard deviations of the distances (visual estimation by experimenter), at which each subject detected the approaching individual.

TABLE 3.29

Mean and Standard Deviation of the Distance in Feet at which Each Subject Detected the Approaching Individual

Subject	Signal Corps Device		Stromberg-Carlson Device		Brush Device		Dr. Meeks' Device	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
F.K.	4.0	1.6	4.9	1.5	3.9	2.0	3.2	1.7
A.C.	4.1	1.8	5.3	2.0	3.6	1.7	3.6	1.6

From this table it will be observed that while working with the Stromberg-Carlson device the subjects tended to detect the approaching experimenter at greater distances than when they were working with other devices. For Subject A.C., the Stromberg-Carlson seems to be reliably[1] superior in this connection regardless of which device it is compared with, whereas for Subject F.K., its superiority is reliable only for comparisons with Dr. Meeks' device. It is desirable, of course, to have an early warning of the approach of an individual in order that he may be successfully avoided.

The results can best be summarized as follows:

(a) The four devices used in this study detected the approaching individual equally well.

(b) These four devices were equally accurate in providing the subject with distance information on the approaching individual.

(c) It is felt that the Stromberg-Carlson showed a slight superiority to the other devices in so far as it detected an approaching individual at greater distances than the other devices did.

2. Detecting an Individual Crossing the Path of the Blind Subject

The subject's task was to detect an individual crossing his path. Two devices were used: the Signal Corps device (XA-1SC) and the Stromberg-Carlson device (YA-3ST). The other devices previously reported were not included

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[1] When averages presented in Table 3.29 differ by 1.2 feet or more, the difference is probably reliable. This fiducial limit is derived from the average replication variance calculated from the standard deviations given in this Table.

in this study because they were undergoing extended repairs. The Signal Corps device and the Stromberg-Carlson were equally capable of detecting an individual crossing the path of the blind subject. There are motion pictures available at Haskins Laboratories illustrating this study.

3. Detecting and Entering a "Doorway"

The subjects were observed using the Signal Corps device (XA-1SC) and the Stromberg-Carlson device (YA-3ST) for the purpose of detecting and entering a doorway. The doorway was formed by a hedge on each side of the cement walk. Both devices performed this function, but the performance of the Stromberg-Carlson device was slightly better than that of the Signal Corps device. The subjects found it difficult to detect the hedge with the latter device. This was primarily the result of the inability of the Signal Corps device to provide definitive signal information about porous obstacles (bushes). Motion pictures on this aspect of the study are also available at Haskins Laboratories.

A remark made by one of the experienced blind subjects, A.H., may serve to illustrate one of the important advantages to be derived from guidance devices. On one of the many walks through grounds at the Institute, the subject was plying the experimenter with questions concerning the nature of various objects as they were passed on the way. The experimenter explained that stopping to discuss the nature of detected objects increased the time required to arrive at the assigned goal and consequently invalidated any time scores if comparisons were to be made with a no-device situation, because such discussions did not arise when no device was being used. The subject replied that such discussions did not arise because, not being aware of objects, he couldn't ask questions about them. He went on to indicate that he felt that the information obtained in answer to these questions was very important to him. In the light of this apparent need for information and discussion the time measures were discontinued as indices and every effort was made to satisfy the curiosity aroused by the use of the device.

L. EVALUATION OF THE "OBSTACLE SENSE" OF THE SUBJECTS USED AT HASKINS LABORATORIES.

1. Purpose

The blind person is traditionally supposed to have a special "obstacle sense", often called "facial vision", by virtue of which he is able to detect and avoid objects in his immediate environment. The present study is a preliminary attempt to discover to what extent this hypothetical sensory process influences performance in the obstacle avoidance tests used at the Haskins Laboratories. It is also expected that the method to be described can be developed into a standardized test for detecting and evaluating the "obstacle sense" of blind individuals so that some expression can be obtained for the distribution of this ability in the blind population as a whole.

2. Subjects

Three experienced blind subjects (A.C., R.F., and A.H.) and one newly blinded veteran (F.K.) were used in this experiment.

3. Procedure

In order to secure such an evaluation it is necessary to obtain a measure of performance under two conditions: (a) in which the hypothetical sensory function is free to operate and influence scores, (b) in which the operation of this sensory function is precluded by control of the sensory cues. The first of these conditions is easily secured by having blind subjects go through a typical obstacle course. The second condition was obtained by requiring them to negotiate a symbolic obstacle course in which the outlines of real obstacles were reproduced with cords on the floor of the test room.

On half of the trials real obstacle courses were used and on the other half only the symoblic obstacles were present. Each real course had its symbolic duplication which either preceded or followed it. In half of these pairs the symbolic course preceded the real course and in the other half the opposite was the case. This control of the order of presentation was employed to minimize the effect of order on differences between the scores for the two types of course. The subjects did not know that each real course was preceded or followed by an identical symbolic course. Each subject had ten trials in each type of course with each order of presentation.

When a subject made an error in the symbolic course, i.e., touched a cord with his foot, he was so informed and given verbal directions to help him orient with respect to the obstacle concerned. Such information was immediately available to the subject in the real courses and may, of course, have been of some value to him in avoiding other obstacles[1]. Since such information is not related to the "obstacle sense", it would be undesirable to have it present under one condition and not present in the other.

4. Results

Table 3.30 shows the total number of errors made by each of the subjects on ten trials under each of the conditions of the experiment.

TABLE 3.30

Number of Errors on Ten Trials

	F.K.		A.H.		A.C.		R.F.	
	Real	Symbolic	Real	Symbolic	Real	Symbolic	Real	Symbolic
Real 1st	41	29	9	30	22	28	30	39
Real 2nd	27	38	8	35	22	35	33	39
Total	68	67	17	65	44	63	63	78

On the symbolic courses, the total number of errors are about the same for all subjects, whereas the subjects differ markedly with respect to total errors on the real courses. This is what would be expected if, indeed, all sensory cues were voided by removing the obstacles and if the subjects possessed the hypothetical "obstacle sense" in various degrees.

For three of the four subjects there does not appear to be any effect of order of presentation on the total number of errors under the two conditions.

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[1] It should, perhaps, be remarked that all subjects, except R.F., had had considerable experience in obstacle courses very similar to those used in this study. It is quite possible, therefore, that information concerning the general distribution of obstacles in such courses had been acquired and that such information could be used to advantage by these subjects.

For subject F.K., however, the total number of errors are less for whichever condition was presented second, regardless of whether it was a real or symbolic course. According to this subject's introspections, he was not aware that there was any repetition of courses.

Table 3.31 presents a Chi-square analysis of the data given in Table 3.30. This analysis tests the assumption that there is an equal probability of error in both conditions of the experiment as, indeed, would be the case if the "obstacle sense" were operating in both or neither of the conditions. The Chi-squares so obtained are entered in the body of the table. Since they are based on 1 d.f., they must exceed 6.64 or 3.84 in order to satisfy the 1 or 5 per cent levels of significance respectively.

TABLE 3.31

Chi-squares Testing the Assumption That the Probability of Error is the Same in the Real and Symbolic Courses.

	F. K.	A. H.	A. C.	R. F.
Real 1st	2.06	11.30	0.72	1.18
Real 2nd	1.86	16.92	2.96	0.50
$\Sigma \chi^2$	3.92	28.22	3.68	1.68
χ^2 Total	.01	28.05	3.37	1.60
Interaction	3.91	00.17	0.31	0.08

Only two of the individual entries reflect significant deviation from the equal-probability hypothesis mentioned above. Both of these entries refer to subject A.H., who would, therefore, appear to have an "obstacle sense" of some value in this situation.

The entries labeled "chi-square of totals" are based on the totals entered in Table 3.30 and have the same fiducial limits as the individual entries, i.e., 6.64 and 3.84. In terms of these values only subject A.H. shows reliability with respect to the discrepancies between the two conditions of the experiment. Evidence for the operation of some sensory process in this subject is unequivocal. The chi-square of totals for subject A.C. almost reaches the 5 percent level of significance. It is possible that additional testing would have shown some effect of an obstacle-sense in this subject.

The entries labeled "sum of chi-square" have little direct meaning for our purposes, but are required for calculation of the interactions, which provide a test of the significance of the differences in the way in which the various subjects reacted to the two orders of presentation. Only subject F.K. showed a significant difference in this connection. Reference to Table 3.30 will show that this subject had less errors in whichever condition was presented second regardless of the presence or absence of obstacles.

It may be said then that the tests described in this report provided unequivocal evidence for the existence of an obstacle-sense in one (A.H.) of three experienced blind subjects. For one experienced and one newly blind subject (R.F. and F.K.) there was no evidence of such a sensory process. Another experienced blind subject (A.C.) showed what might be considered a tendency toward a reliable indication of the presence of some useful sensory process.

It is the impression of the examiner that an adequate testing of the blind population would reveal that only a fairly small percentage is capable of using to advantage the sensory cues available in this test situation. It also appears that considerable training and concentration is required to achieve the level of performance shown by subject A.H.

A review of the obstacle avoidance data in III-E will show that even a person who possesses the "obstacle-sense" to a marked degree (A.H.) is helped considerably by the use of a device. It will also appear that a device so compensates for the lack of this sense that a newly blinded person (subject F.K.) may be expected to do as well, or possibly better than, an experienced blind subject in an obstacle avoidance test when an adequate guidance device is used.

This compensation for years of experience and concentration may be considered of great importance in connection with the needs of the blind.

5. Summary

A test designed to detect the presence of an "obstacle sense" in blind persons was performed with three experienced blind subjects and one newly blinded veteran. One of the experienced blind subjects demonstrated the possession of this sensory function to a marked degree. Another experienced blind subject showed some tendency in this direction. One experienced blind subject and the newly blinded veteran showed no evidence that such a sense was operating.

M. ELECTRICAL STIMULATION OF THE OPTIC NERVE

The study of effects of electric currents on the retina and optic nerve of the eye is almost as old as the discovery of electricity itself. As early as the middle of the eighteenth century it was well known that a discharge passed through the head in the vicinity of the retina and optic nerve and in the general region of the visual cortex would produce a sensation of light. LeRoy[1], indeed, undertook the experiment on a subject with cataract, using what must have been relatively heavy discharges of direct current from a Leyden jar and described a sensation of flame observed by the patient. Since the patient also described a noise comparable to the firing of a gun, it is possible that the discharge was so heavy and so generalized in its path as to stimulate the auditory nerves also. It is possibly surprising that the subject remained conscious, as he appears to have done.

Experiments with direct currents of varying magnitude made on sighted subjects are described quite frequently in succeeding years, and a sensation of light on making or breaking circuit was quite usually reported. Ritter[2], as early as 1800, observed a general brightening of the whole field of vision in direct current of one polarity (phosphene effect) and a darkening when the field was reversed. Purkinje[3] investigated stimulation effects with a pointed electrode, with which the surface of the eyeball could be more or less quantitatively explored.

Recently, much further work has been done in the field of electrical stimulation by a number of workers, notably Bouman[4], Kohn[5], Müller[6], Schwarz[7],

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[1] Franklin, *Briefe über Elektrizität*, Leipzig, 1758. S. 312

[2] Ritter, *Beweis, dass ein beständiger Galvanismus den Lebensprozess im Tierreiche begleite*, Weimar 1798. S. 127.

[3] Purkinje, *Beobachtungen und Versuche zur Physiologie der Sinne*. Bd. I, Prague, 1819. S. 50

[4] Bouman, H.D., Experiments on the Electrical Sensitivity of the Eye. *Archives néerlandaises de physiologie de l'homme et des animaux*. 20:430-445. 1935. Psychological Abstracts *II*, 1108

[5] Kohn, H. A. Unpublished communications.

FIG. 3.26
OPTIC NERVE STIMULATOR

Bogolovski[8], Lohmann[9], and Bronstein[10]. This work has been undertaken from various standpoints and with a number of purposes, notably in the attempt to localize the phenomenon in the retina, optic nerve, or visual cortex, and comparative investigations of critical flicker fusion frequencies with electric currents and light.

In view of this situation, it is perhaps remarkable that more attention has not been paid to the electrical stimulation of the non-functional eye. Even if the work were entirely negative, it might prove helpful in localizing the portions of the visual system primarily affected in electrically stimulated functional eyes, while positive results might be of practical significance. Scattered references occur in the older literature to stimulation of non-functional eyes, nearly always with negative conclusions. More recently, a considerable amount of work with enucleated eyes has been reported by the Russians[11], but it is almost impossible of access and difficult to evaluate in any case.

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[6] Müller, G. E., Ueber die Entstehung der electriche Gesichtempfindungen - Z. Sinnesphysiol. 1934, 65, 274-92. (Concerning the origin of electrical visual sensations)

[7] Schwarz, F. Quantitative Untersuchungen über die optische Wirkung sinnesformige Wechselströme Z. Sinnesphysiol., 1940, 69, 1-26. (Quantitative investigations on the visual effects of sinusoidal A.C.)

[8] Bogolovski, A.I. Diurnal Changes in the Electrical Sensitivity of the Eye - Bull. Biol. Med. Exp., U.S.S.R., 1937, 3, 127-29. Also Ibid. 130-32

[9] Lohmann, H. Ueber die Sichtbarkeitsgrenze und die optische unterscheidbarkeit sinnesformiger Wechselströme - Z. Sinnesphysiol., 1940, 69, 27-40 (On the visibility threshold and the visual discriminability of sinusoidal A.C.)

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It seemed worth while, therefore, to undertake a little work in this field in connection with the regular program of the Laboratories. Accordingly, equipment was built capable of delivering a current of 0 - 400 micro-amperes to the eye either as dc or ac, with a provision for varying the frequency of the ac from 1 to approximately 70 cycles. Fusion took place for a sighted subject in the region of 60 cycles. The circuit used was so designed that it delivered constant current irrespective of the resistance in it, to provide for the highly variable skin and contact resistances involved. The electrodes consisted of two slightly concave cups approximately an inch in diameter in which pads saturated with a physiological salt solution could be placed. One of the pads was applied to the closed eyeball, and the other held at the base of the neck.

This equipment was used by seven normal subjects, to all of whom the ac flicker was clearly evident.

Preliminary tests have been made on four blind subjects, representing various types and degrees of injury, as indicated in the table below. Three of the subjects reported no "optical" sensations whatever at alternating currents up to 400 micro-amperes, the limit of the instrument, although they can detect purely tactual effects (tingling, muscle twitching) at currents lower than this. The fourth individual felt that he did have some light sensation with ac. It was not a flicker, however, and seemed to be independent of the frequency, and may well have been a subjective effect.

Tests on Optical Stimulation of Blind Subjects

Subject	Condition of Eyes	Reaction		Generalized Impression
		Right Eye	Left Eye	
F.K.	Prosthesis, both eyes; Right optic nerve intact.	Neg.	Neg.	Neg.
A.H.	Congenital cataract both eyes; phthisis bulbi; "left optic nerve."	Neg.	Neg.	Neg.
M.C.	Congenital buphthalmus, both eyes, right eye enucleated.	---	Neg.	Subjective constant light phenomena
R.F.	Left eye enucleated, glaucoma in right eye, optic nerve and retina presumably intact in right eye.	Neg.	---	Neg.

N. DESCRIPTIONS OF SUBJECTS

Subject	Participated in Following Experiments	Background
1. A.C.	Obstacle Course A and B (III-C) Training Program (III-D) Obstacle Course (III-E) Step Down (III-G) Outdoor Obstacle Program (III-K)	Born: 1920 Place: N.Y.C. Education: High School Graduate; 2 years college. History of Condition: Blindness caused by spinal meningitis in 1928. Had light perception until 1931, and totally blind since. Totally blind 15 years.
2. E.C.	Ranging-Approach (III-J)	Born: 1923 Place: N.Y.C. Education: High School Graduate History of Condition: Cause unknown; blinded at early age; light perception until 1932. Totally blind 16 years.
3. F.C.	Training Program (III-D) Obstacle Course (III-E)	Born: 1920 Place: N.Y.C. Education: High School Graduate History of Condition: Blinded by bullet which shattered glasses in battle. Totally blind in both eyes approximately two years.
4. M.C.	Doorway (III-C) Size Determination (III-F) Step Down (III-G)	Born: 1921 Place: Bedford Village, N.Y. Education: High School Graduate History of Condition: Blinded in accident with hayrake. Loss of sight in right eye first, then later on loss of sight in left eye. Light perception until 1941. Totally blind 5 years.
5. R.F.	New Subject	Born: 1898 Place: France Education: High School Graduate; 1 year college Electrical Engineer. History of Condition: Loss of sight in 1929 in chemical explosion. Light perception 1929-1934. Totally blind 12 years.
6. A.H.	Obstacle Course A and B (III-C) Size Determination (III-F) Step Down (III-G) Ranging - Absolute Judgment (III-I) Tactual vs Auditory Stimuli (III-H) Outdoor Testing Program (III-K) Training Program (III-D)	Born: 1925 Place: N.Y.C. Education: High School Graduate; 2 years college. History of Condition: Congenital cataracts. Loss of sight 1928. Loss of sight in right eye first; left eye about 1 year later. Light perception until 1938. Totally blind for 8 years.
7. W.H.	Obstacle Course A and B (III-C) Obstacle Course (III-E) Training Program (III-D) Step Down (III-G) Ranging - Absolute Judgment (III-I)	Born: 1915 Place: New Jersey Education: High School Graduate; 3 years college. History of Condition: Lost sight and right arm in 1922 in explosion. Regained sight after operation in 1926. Lost sight again and has been totally blind since 1931. Totally blind 15 years.

8. E.J.	Ranging - Approach (III-J)	Born: 1914 Place: N.Y.C. Education: No information History of Condition: Blinded at early age. Cause unknown. Lost sight in left eye in 1918; in right eye 1925. Totally blind in both eyes 22 years with no history of light perception.
9. F.K.	Training Program (III-D) Obstacle Course A and B (III-C) Obstacle Course (III-E) Ranging - Absolute Judgment (III-I) Size Determination (III-F) Auditory vs Tactual Stimuli (III-H) Outdoor Testing Program (III-K)	Born: 1925 Place: N.Y.C. Education: 1 year of high school. History of Condition: Blinded in 1945 at Okinawa. Both eyes removed. Totally blind 1 1/2 years.
10. W.L.	Obstacle Course A and B (III-C)	Born: 1920 Place: N.Y.C. Education: 10th grade. History of Condition: Lost sight 1945 in battle. Right eye removed; totally blind in left eye. Totally blind two years.
11. J.M.	Obstacle Course A and B (III-C)	Exact information not available. Born: about 1897 Place: Italy Education: in Italy about high school level. Blinded when about two months old. Totally blind about 48 years.
12. M.M.	Ranging - Approach (III-J)	Born: 1909 Place: Puerto Rico Education: Information unknown History of Condition: Blinded 1944 in battle. Totally blind in both eyes two years.
13. J.S.	Training Program (III-D) Obstacle Course (III-E) Size Determination (III-F) Ranging - Absolute Judgment (III-I) Outdoor Testing Program (III-K)	Born: 1923 Place: N.Y.C. Education: High School Graduate; 1 year college. History of Condition: Lost both eyes as result of war wounds. Totally blind 1 year.
14. V.T.	Obstacle Course A (III-C) Ranging - Approach (III-J)	Born: 1922 Place: N.Y.C. Education: High School Graduate; 1 year college. History of Condition: Blinded in 1944 in both eyes as result of war wounds. Totally blind two years.
15. S.E.	Doorway (III-C)	Born: 1923 Place: N.Y.C. Education: College Graduate Sighted subject.

IV. SUMMARY

Eighteen different models of guidance devices for the blind have been subjected to examination in the Laboratories during the last two years. Only thirteen of these were found to be functionally proficient enough to warrant tests on blind subjects. When so tested under standardized procedures, ten of the devices enabled users to perform significantly better than they did with no device. None of the devices, however, fully satisfies the requirements of an ideal guidance device.

Two of the devices performed sufficiently well to justify the hope that the beam-probe principle may yet yield a device of general usefulness to the blind. The first of these devices utilized a supersonic beam, the second, a beam of light. These two devices differ in their performance in certain type situations. For example, the Signal Corps device gives indication of the curb step-down, while the Stromberg-Carlson device does not. The latter, on the other hand, is superior in the step-up situation. The supersonic device has the advantages of but slight interference from ambient noise, and comparative independence from the effects of rain or fog. Its efficiency, however, is reduced by specularity, air turbulence, and by Doppler effects. The optical device has the advantage of non-specularity, but in performance may suffer from "saturation" due to bright sunlight. Also rain and fog adversely affect its performance.

Devices using ambient light as their source of energy have not, in general, given adequate environmental information, and specifically have not given useful range information.

The signals which the various devices present have been studied, with a view to discovering optimal stimuli. Complications due to differences in learnability, aesthetic preferences, fatigue, and interference with hearing have made this problem especially difficult. Both auditory and tactile stimuli have been investigated. The blind subjects have shown a marked preference for tactile stimuli; from the standpoint of proficiency in standardized tests the auditory and the tactile systems have been about equally good. Auditory signals in general allow for more variety of presentation than do the tactile, but at the expense of some interference with normal auditory cues.

All the devices developed so far have been probe devices which are inherently limited to point-by-point exploration. They give the blind man information about his environment somewhat analogous to that which a sighted person would get by viewing his environment through a soda straw. The problems of converting the resulting information into an integrated mental construct of the environment are considerable. Therefore, work has been initiated on devices which would provide a patterned impression of the environment.

In summary, probe devices have been of sufficient assistance in both indoor and outdoor test situations to indicate that they could, when technically perfected, be of important use to the blind in real-life situations. More adequate devices would be desirable but must be sought by experimentation along other lines.

Table 2.1

Guidance Device Nomenclature

System	Designation
1. Pulsed Stromberg-Carlson (non-portable)	YA-1ST
2. First Brush Device (sine wave modulated; semi-portable)	YA-1BD
3. Pulsed F-M Stromberg-Carlson (non-portable)	YA-2ST
4. Second Brush F-M Device (portable)	YA-2BD
5. Pulsed F-M Stromberg-Carlson (portable)	YA-3ST
6. Pulsed F-M Stromberg-Carlson (portable)	YA-3ST(M1)
7. Hoover Device (mechanical generator and range searching; portable)	YA-1HC and YA-1HC(M1)
8. Third Brush F-M Device (one unit; portable)	YA-3BD
9. Fourth Brush F-M Device (two units; portable)	YA-4BD
10. Fifth Brush F-M Device (portable searchlight device)	YA-5BD
11. Signal Corps Device	XA-1SC and XA-1SC(M1)
12. High (Audio) Frequency Tweeter - Haskins Laboratories	YA-1HL
13. Stromberg-Carlson Echo ranging pulse device (portable)	YT-4ST
14. Size-Shape Determining Device - Haskins Laboratories	XA-2HL
15. Continuous-tone supersonic device (non-portable) - Haskins Laboratories	YA-3HL
16. Continuous-tone optical device (portable) - Haskins Laboratories	YA-4HL
17. Pan-audio Device (portable) - Haskins Laboratories	YA-5HL
18. Lashley Ambient Light Device (portable) - Instrument Electronics, Inc.	XA-1IE and XA-1IE(M1)
19. Pattern Optical Device (automatic scanning; non-portable) - Haskins Laboratories	XA-6HL

Key to Code Designation

Y = Supersonic radiation

X = light

The number refers to the model number

The letters following the model number refer to the development laboratory:

ST = Stromberg-Carlson Company

BD = Brush Development Company

HC = Hoover Company

SC = Signal Corps

IE = Instrument Electronics, Inc.

HL = Haskins Laboratories

M (and associated number) in parentheses indicates modification of the model

TABLE 2.2 CHARACTERISTICS OF GUIDANCE DEVICES DEVELOPED

						Physical Properties							
System	Designation	Principle of Operation	Development Laboratory	Model Type	Type Radiation	Operating Freq.	Transmitter	Weight	Size (cu.in)	Input Power*	Type Signal	Signal Characteristics	Photograph and Figure Numbers
1. Stromberg-Carlson "Two-Click"	YA-1ST	Pulse-modulated supersonic	Stromberg-Carlson	Non-portable	Supersonic	Appr. 20 kc	Magneto-striction	Heavy	Large	High	Paired pulses, giving two auditory "clicks"	Time separation of two pulses as a function of object distance	Figs. 2.7; 2.8; 2.9
2. Stromberg-Carlson "Echo-Pulse"	YA-4ST YT-4ST	Pulse-modulated supersonic	Stromberg-Carlson	Portable	Supersonic	Appr. 30 kc	Magneto-striction	8 lb. 0 oz.	238	Low	Series of auditory or tactile pulses	Pulse repetition rate varies inversely as function of object distance	Figs. 2.10; 2.11; 2.12
3. Hoover Supersonic	YA-1HC YA-1HC(M1)	Pulse-modulated supersonic	Hoover Company	Portable	Supersonic	Appr. 20 kc	Mechanical	Appr. 12 lb.	Appr. 400	High	Series of auditory pulses	Position of gating-switch lever is a function of object distance	Figs. 2.13; 2.14; 2.15
4. Continuous Tone Supersonic Device	YA-3HL YT-3HL	Pulse-modulated supersonic	Haskins Laboratories	Non-portable	Supersonic	20 kc	Magneto-striction	Heavy	Large	High	a) Continuous-tone auditory signal b) Series of tactile pulses	a) Frequency of audible tone varies inversely as a function of object distance b) Pulse repetition rate varies inversely as a function of object distance	Figs. 2.16; 2.17; 2.18
5. Brush Sine-wave Modulated Device	YA-1BD	Sine-wave frequency-modulated supersonic	Brush Development Company	Non-portable	Supersonic	30 kc	Crystal	Heavy	Large	High	Series of warbled auditory pulses	Highest frequency of warble varies as a function of object distance	Figs. 2.19; 2.20; 2.21
6. Brush Supersonic Guidance Device	YA-5BD	Sawtooth-wave frequency-modulated supersonic	Brush Development Company	Portable	Supersonic	Appr. 80 kc	Crystal	4 lb. 5 oz.	88	Low	Series of auditory pulses	Frequency contained in the pulse varies as a function of object distance	Figs. 2.22; 2.24
7. Brush Supersonic Guidance Device	YA-2BD	Sawtooth-wave frequency-modulated supersonic	Brush Development Company	Portable	Supersonic	Appr. 30 kc	Crystal	7 lb. 2 oz.	209	Low	Series of auditory pulses	Frequency contained in pulse varies as a function of object distance	Fig. 2.25
8. Brush Supersonic Guidance Device	YA-3BD	Sawtooth-wave frequency-modulated supersonic	Brush Development Company	Portable	Supersonic	Appr. 80 kc	Crystal	Appr. 7 lb.	Appr. 250	Low	Series of auditory pulses	Frequency contained in pulse varies as a function of object distance	
9. Brush Supersonic Guidance Device	YA-4BD	Sawtooth-wave frequency-modulated supersonic	Brush Development Company	Portable	Supersonic	Appr. 80 kc	Crystal	Appr. 7 lb.	Appr. 250	Low	Series of auditory pulses	Frequency contained in pulse varies as a function of object distance	
10. Stromberg-Carlson PFM Supersonic Guidance Device	YA-2ST	Sawtooth-wave frequency-modulated supersonic	Stromberg-Carlson	Non-portable	Supersonic	Appr. 20 kc	Magneto-striction	Heavy	Large	High	Series of auditory pulses	Frequency contained in pulse varies as a function of object distance	Fig. 2.29
11. Stromberg-Carlson PFM Supersonic Guidance Device	YA-3ST YA-3ST(M1)	Sawtooth-wave frequency-modulated supersonic	Stromberg-Carlson	Portable	Supersonic	Appr. 20 kc	Magneto-striction	5 lb. 11 oz. 5 lb. 10 oz.	215 196	Low Low	Series of auditory pulses	Frequency contained in pulse varies as a function of object distance	Figs. 2.26; 2.27; 2.28
12. Pan-Audio Device	YA-5HL	Amplification of normal auditory cues	Haskins Laboratories	Portable	Ambient sonic	200-3000 cycles	----	5 lb. 8 oz.	830	Low	Auditory	Position of objects indicated binaurally	
13. High-Frequency (Audio) Obstacle Locator (Tweeter)	YA-1HL	Pulsed audio-frequency sound waves	Haskins Laboratories	Non-portable	Sonic	Appr. 10 kc	Tweeter	Heavy	Large	High	Auditory pulses	Intensity varies inversely as a function of object distance	Figs. 2.30; 2.31
14. Size-Shape Device	XA-2HL	Ambient light device	Haskins Laboratories	Non-portable	Ambient light	Visible and infra-red	----	Heavy	Large	High	Continuous tone, varying frequency	Signal frequency varies as a function of ambient light intensity	Figs. 2.32; 2.33
15. Lashley Ambient Light Guidance Device	XA-1IE XA-1IE(M1)	Ambient light device	Haskins Laboratories**	Portable	Ambient light	Visible and infra-red	----	3 lb. 3 oz. 2 lb. 3 oz.	70 58	Low Low	Continuous tone, varying frequency	Signal frequency varies as the rate of change of ambient light intensity	Fig. 2.36 Figs. 2.34; 2.35
16. Signal Corps Optical Device	XA-1SC XT-1SC	Modulated light source device using triangulation	Signal Corps	Portable	Light	Visible and infra-red	Light source and $1\frac{1}{2}$" lens	10 lb. 15 oz.	235	High	Series of auditory or tactile pulses	Pulse repetition rate varies (in steps) inversely with object distance	Figs. 2.37; 2.38; 2.39
17. Continuous Tone Optical Device	XA-4HL	Modulated light source device using triangulation	Haskins Laboratories	Portable	Light	Visible and infra-red	Light source and $1\frac{3}{4}$" lens	11 lb. 12 oz.	340	High	Continuous tone auditory signal	Frequency varies inversely as a function of object distance	Figs. 2.40; 2.41
18. Pattern Optical Device	XA-6HL	Ambient light device incorporating automatic scanning	Haskins Laboratories	Non-portable	Ambient light	Visible and infra-red	----	Heavy	Large	High	Combinations of auditory frequencies	Signal pattern changes in frequency and duration for changes in object size, shape, and distance	Figs. 2.42; 2.43; 2.44

** Built by Instrument Electronics

* High input power, greater than 3 watts; low input power, less than 3 watts