NATIONAL BUREAU OF STANDARDS REPORT

10 478

EMERGENCY VEHICLE WARNING DEVICES:

Interim Review of the State-of-the-Art Relative

to Performance Standards

prepared by

Applied Acoustics and Illumination Section
Sensory Enviornment Branch
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Institute for Applied Technology

prepared for

Law Enforcement Standards Laboratory
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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EMERGENCY VEHICLE WARNING DEVICES:

Interim Review of the State-of-the-Art Relative to Performance Standards

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ABSTRACT

This interim progress report describes the activities carried out, from the initiation of the program through July 1971, concerning the preparation of performance standards for emergency vehicle warning devices (lights and sirens). A partial survey of present standards and specifications indicated that there now are very few meaningful performance standards for emergency warning lights and essentially none for sirens. Brief descriptions of those standards which were found are included. Manufacturer's literature on available warning devices rarely includes meaningful quantitative data on the physical performance characteristics of either lights or sirens. The program strategy described in this report includes (a) quantitative physical characterization of the spectral content, directionality, level, and time duration of the signals from a representative sampling of emergency vehicle warning equipment; (b) literature and laboratory study of the effectiveness of representative signals in alerting drivers to an emergency situation requiring appropriate reactions; and (c) development of draft standards. In conjunction with the physical characterization of lights and sirens, examples are given of the type of data which will be taken and detailed descriptions are given of the facilities which will be used for these measurements. A discussion is given of the various factors which influence the effectiveness of warning signals. It is proposed to study both the time elapsing between the occurrence of a signal and the completion of the required response (complex reaction time) and the distance at which an observer first notices and correctly interprets a signal (recognition distance). Performance standards can then be prepared which are clearly related to the appropriate human responses.

CONTENTS

GLOSSARY

Abbreviations of Associations

1. ANSI: American National Standards Institute, formerly United States of America Standards Institute (USASI) and American Standards Association (ASA).

2. ASTM: American Society for Testing and Materials.

3. CIE: International Commission on Illumination.

4. SAE: Society of Automotive Engineers.

Acoustical Terms

5. attenuation: Reduction of signal amplitude while retaining the characteristic waveform. It implies deliberately discarding a part of the signal energy for the sake of reduced amplitude.

6. A-weighted sound level (dB(A)): A single number rating often used to describe measured sound levels. For certain types of sounds, it corresponds to the human response. The reading obtained when using the A-weighting scale of a sound level meter fulfilling the requirements of ANSI Standard S1.4-1961.

7. decibel (dB): A division of a logarithmic scale used to express the ratio of two like quantities proportional to power or energy. The ratio is expressed in decibels by multiplying its common logarithm by ten.

8. free field: Field in a homogeneous, isotropic medium free from boundaries. In practice it is a field in which the effects of the boundaries are negligible over the region of interest.

9. frequency analysis: An indication of how the sound energy is distributed over the audible range of frequencies. In this analysis, the acoustic energy is electronically separate into various frequency bands, e.g., octave bands, each of which covers a 2-to-1 range of frequencies. For more detailed analysis, narrower bands such as one-third octave or one-tenth octave are used.

10. hertz (Hz): A unit of measure of frequency which is the time rate of repetition of a periodic phenomenon (cycles per second).

11. linear analysis of sound: Linear analysis provides a measure of the overall sound-pressure level. Instruments used to measure sound-pressure level have an overall response that is uniform or flat as a function of frequency.

12. real-time spectral analysis: real-time analysis implies that the rms levels in all frequency bands are derived simultaneously with the spectrum-level outputs presented in a period of milliseconds.

13. signal conditioning: Bringing the signal into proper condition prior to any readout device. Typical conditioning devices include damping networks, attenuator networks, preamplifiers, excitation and demodulation circuitry, equalizing or matching networks, and filters.

14. sound pressure: Fluctuating pressure superimposed on the static atmospheric pressure in the presence of sound.

15. sound pressure level (L_p): Squared ratio, expressed in decibels, of the sound pressure under consideration to the standard reference pressure of 20 μN/m2.

16. white noise: Noise with a continuous frequency spectrum and with equal energy per constant bandwidth.

Lighting Terms

17. candlepower: Luminous intensity, usually expressed in candelas.

18. chromaticity coordinates: Ratio of each of the three tristimulus coefficients to their sum. The chromaticity coordinates indicate the hue and saturation together of a color.

19. CIE Illuminant A: Colorimetric illuminant defined by the CIE in terms of relative spectral energy (power) distribution; CIE Illuminant A represents the full radiator (thermal radiator which absorbs all incident radiation completely) at T_{68} = 2,855.6 K.

20. effective intensity: The effective intensity of a flashing light is equal to the intensity of a steady-burning light that will produce the same visual effect as does the flashing light.

21. luminous intensity distribution: Intensity of a light source expressed as a function of viewing angle.

22. tristimulus coefficients: Measures of three reference stimuli whose mixture color matches a certain color stimulus.

Miscellaneous

23. Emergency vehicle: A motor vehicle that uses the emergency warning devices discussed here. For example, a police sedan, station wagon, van, truck or motorcycle.

24. Target vehicle: A motor vehicle (other than the emergency vehicle) toward which the emergency message is directed. A response is desired from the operator of the target vehicle that is appropriate for the emergency situation.

25. Test vehicle: A motor vehicle on which emergency warning devices are mounted. May be a regular emergency vehicle or another vehicle selected for test simulation.

1. INTRODUCTION

The Law Enforcement Standards Laboratory of the National Bureau of Standards, under the sponsorship of the Law Enforcement Assistance Administration, Department of Justice, is conducting a research program to develop standards for vehicle emergency warning devices, including warning lights and sirens. The program will identify and quantify the physical parameters of the vehicle emergency warning devices, and will determine system effectiveness in enabling police personnel to perform their duties with efficiency and safety. The approach will be to determine the current state-of-the-art by compiling presently available information, and to develop further technical information describing the devices and determining signal effectiveness, leading to the program goal of improved performance standards for the devices.

The effectiveness of an emergency vehicle warning system is determined by how well it performs two functions: alerting other drivers and pedestrians to the presence or approach of an emergency vehicle, and enabling a path to be cleared for the emergency vehicle through the general traffic pattern. The ability to accomplish these two functions is influenced by a multitude of parameters. For example: type of emergency vehicle, types of warning devices on the vehicle, weather conditions, time of day, road and traffic conditions, and the destination of the emergency vehicle. In addition, the transmission of the warning message must overcome many distracting influences. Among these are flashing neon signs, car radios and tape players, and air conditioning systems (which along with flow-through ventilation systems and heaters cause many operators to keep their car windows closed most of the year). If in addition to all the other distractions, a driver is handicapped by being tired, partially deaf or color blind, the transmission of the warning message is made especially difficult, thereby reducing the probability that the driver will respond appropriately.

It may happen that even the best emergency warning devices currently in use will prove to be inadequate and inefficient for the task of warning other drivers of the presence of an emergency vehicle in time for them to take evasive action. Thus, the possibility exists of having to develop alternative emergency warning systems to those presently being used. Not only might this be necessary in terms of developing an effective emergency vehicle warning system, but in light of certain recommendations made at the May 1971 Urban Technology Conference held in New York City, it may become mandatory to develop some alternative warning systems. An example of one such recommendation is the use by emergency vehicles of a light beaming and sensing system to regulate traffic lights in their path, the goal being to abate noise pollution by reducing or eliminating noise from horns and sirens.

Unfortunately, there seems to be no reliable agreed-upon means for determining how effectively a device or combination of devices has fulfilled the required functions. It is the task of this program to overcome this deficiency by developing performance standards for these devices.

2. PROGRAM STRATEGY

2.1. OVERVIEW

As already noted, this program is designed to develop performance standards for emergency vehicle warning devices. A preliminary survey, of which this report includes the beginning, will show the present state-of-the-art, and will include the compilation of information on presently used standards, specifications and hardware. A literature search will provide background information on the attention-demanding characteristics of, and subject reactions to the various kinds of signals. Technical back-up information will be developed to specify the physical characteristics of the signals and to relate this information to device effectiveness. Related information to be developed may include interviews to determine user needs and preferences, records of accident rates and time elapsed to arrive at destination. Draft copies of standards will be circulated among interested users, so that their experience and appraisals may benefit later revisions. Further technical information will be developed as required, and interim performance standards will be presented.

2.2. CHARACTERIZATION OF SIGNAL

There is an urgent need for quantitative characterization of the spectral content, directionality, level and time duration of the signals of emergency vehicle warning equipment. To date not enough work has been done in this area, particularly for sirens. Without a physical data base for emergency devices, there is little point in doing research on signal effectiveness, because the characteristics of the signal (stimulus) being presented to subjects would be unknown. It follows that no performance standards specifying the "ideal" characteristics of a siren or a flashing light could be written, since there would be no basis for determining why subjects reacted as they did. In short, the physical characteristics of a signal are the reference points to which all other data gathered in this project can be compared and analyzed.

2.3. DETERMINATION OF EFFECTIVENESS

In addition to gathering sufficient data to adequately characterize the signal output of the different warning devices, study will be needed to relate this information to the effectiveness of the signal in alerting drivers to an emergency situation requiring appropriate reactions. These data will be collected by means of simulation techniques and under actual field conditions. A literature search will provide additional information on subjective response and reaction.

3. DEVELOPMENT OF STANDARDS

3.1. INTRODUCTION

Police departments now employ a variety of warning devices. Various combinations of devices are utilized, even within the same department. When the required technical information has been developed to specify the physical characteristics of the warning signals, and to describe signal effectiveness in achieving the desired response, a logical outgrowth will be the development of performance standards for the devices. Such standards, supported by reliable technical data, will be an aid to law enforcement agencies in the updating and revision of their own device standards and specifications.

3.2. SIRENS

A preliminary survey of the available standards and specifications revealed that little information was available. There were no standards found on sirens in particular, but one standard-SAE J377, Performance of Vehicle Traffic Horns - is relevant to the problem. One military purchase specification on vehicular sirens - MIL-S-3485B - was also identified. These two documents represent the only pertinent literature on this topic found to date. Both are summarized in Appendix B.

3.3. LIGHTS

In a preliminary survey of the available standards and specifications, two standards were found concerning flashing lights and one for spotlights. These are SAE J595 - Flashing Warning Lamps for Authorized Emergency, Maintenance, and Service Vehicles: SAE J845, 360 Degree Emergency Warning Lamp; and SAE J591, Spot Lamps. These standards, as well as standards written for testing this equipment, are summarized in Appendix B. It is our impression that these are the only standards available in the category of emergency lights.

3.4. PLANNED ACTIVITIES

As an outgrowth of the experimental programs described in section 4 on the physical characterization of the signal and section 5 on the determination of signal effectiveness, it is planned to write performance standards for sirens and flashing lights. A performance standard differs from an ordinary standard in two major ways. First, the performance standard states what a device does, not what it is. For example, a performance standard would not specify that a siren must use an aluminum rotor or that a flashing light must use a 25 watt incandescent bulb. Rather, it would specify that an emergency vehicle warning device should conform to some indicator of effectiveness. (This indicator will probably be an outgrowth of the studies which will be performed at NBS on emergency vehicle warning devices). The second distinction between a performance standard and an ordinary standard is that it takes account of both physical and subjective data rather than just the physical data. This, of course, is vitally important to specifying sirens and lights because of the function that they serve -- warning other drivers of the presence of an emergency vehicle. A standard should not be written for emergency warning devices without taking account of peoples' reaction to them.

4. CHARACTERIZATION OF SIGNAL

4.1. SIRENS

4.1.1. Hardware State of the Art

There are a number of manufacturers and distributors of sirens (see Appendix A). The devices which they market consist basically of two main types: mechanical and electronic. Both types of siren have a number of different voices (e.g., rumble, yelp, wail and high-low sounds), and the chief difference between them is in the method of sound production. The mechanical sirens use a combination of single or double rotors, air flow modulators, clutches and brakes, whereas the electronic sirens produce their warning signals by means of signal generators and loudspeakers. Both types of sirens can be operated on a manual or an automatic cycle.

4.1.2 Background Literature

It appears from a preliminary survey of the literature that little work has been done to date on characterizing the physical properties of sirens for emergency vehicles. One article by D. B. Callaway, entitled the "Spectra and Loudnesses of Modern Automobile Horns", reports some results from a noise survey made in the Chicago area [1] (see Bibliography).

The automobile horns which Callaway measured consisted of three main types, as classified according to the method of sound production. From his data, Callaway came to the conclusion that all three types of horns were too loud, and that the higher frequency components of their output signals contributed considerably to the annoying character of the sound. He recommended the use of filters to remove frequency components above 1200 hertz, so as to make the sound more pleasing. The report is pertinent because many emergency vehicles use their horn in addition to the siren as a signaling device. Unfortunately, in terms of our ever-increasing noise problem, a less pleasing signal may prove to be a more effective one.

Several other research reports (about 10) have been cited in the literature but these have not been obtained as yet. Hopefully, they will provide other literature references, but from evidence to date, there appears to be little literature available on the characterization of the siren signal.

4.1.3. Review of Measurement Problem

As stated above, there is a definite lack of data in the public domain on the signal generation characteristics of sirens. There are several physical parameters which must be studied in order to adequately characterize the siren signal, and these are the frequency, intensity, direction and time variations of each component of the signal. These physical characteristics will, in turn, be affected by such variables as type or model of siren, location of the siren on the vehicle, obstacles near the emergency vehicle, road surface on which the emergency vehicle is travelling, speed of the vehicle and ambient noise in the target vehicle. Methods must be developed and a field investigation must be conducted in order to study these parameters and obtain the information necessary for establishing a physical data base for siren signals.

A siren signal will generally have one (sometimes two) fundamental frequencies generated mechanically or electronically. The fundamental will be accompanied by one or more harmonic multiples. Other frequencies that are not integer multiples of the fundamental may also be present. For the present discussion, the signal will be considered to consist of a single fundamental frequency, and any other frequencies that may be present may be thought of as the harmonic content of the signal, whether or not such other frequencies are related by integer multiples to the fundamental.

The intensity of each frequency component will depend on the method by which the signal is generated and on the power and efficiency of the mechanical or electrical transduction process. Each individual frequency component will have its own distribution pattern, which will be different owing to the directionality of its generation and to differences in transmission characteristics for the different frequencies. For example, diffraction around obstacles and refraction by atmospheric density gradients are both strongly frequency dependent.

As the signal varies with time the radiation patterns change, and an observer at some distant point may hear a somewhat different signal from that which was sent out. Suppose that for a siren under consideration the radiation patterns at some frequencies were relatively smooth ellipses, while for other frequencies the radiation patterns consisted of a number of petal shaped lobes. The shape and strength of a lobe may be strongly frequency dependent. Suppose now that our sample siren is cycled up and down in frequency. That is, either manually or automatically the siren fundamental frequency is caused to vary from a low "growl" to a high "shriek". If the radiation distribution patterns are symmetrically located so that each frequency has a principal propagation direction straight ahead, then a microphone that is straight ahead of the siren will receive a time-varying signal that is rather like the one that left the siren, except that certain frequencies will be less attenuated in propagation than others as a result of the differences in reflection, diffraction and refraction which they undergo along their path. Off at an angle to one side, however, the signal would be more unlike that sent out, because the location chosen may be one of good transmission for some frequencies but poor for others. That is, for certain frequencies, the location selected may fall on a lobe of high intensity, while for others it will fall between lobes at a region of minimum intensity. As the siren is cycled, the relative intensities within the harmonic structure will change for this location, so that for a certain pitch or frequency of the fundamental the third harmonic may predominate, while when the fundamental shifts to a different pitch, the second harmonic may be equally strong.

When a siren is not mounted on the center line of the emergency vehicle, the radiation pattern will be non-symmetric and may be more complex. In any case changing road and traffic patterns will modify the intensity distribution patterns of the changing siren frequencies, so that the signal that reaches a target vehicle (see Glossary) will have a different character from that which left the emergency vehicle.

The sound transmission loss characteristics of the target vehicle cab will be frequency dependent. Both the siren signal and other ambient noise external to the cab will be attenuated differently for different frequencies on passing through the wall of the target vehicle cab. Additional noise may be generated within the cab, and this too will tend to mask the siren signal.

The quality of the siren signal will also be dependent on speed. That is, the pitch and harmonic structure and intensity radiation pattern of the signal generated by the siren may be a function of the speed of the emergency vehicle, so as to change the characteristics of the signal sent forth. The relative speeds of emergency and target vehicles will determine the amount of doppler shift in the pitch of the frequency components. The relative motion of the two vehicles determines how the spatial distribution patterns are directed across the target vehicle or how the target vehicle cuts across the spatial distribution pattern.

Thus the quantities that must be measured in order to characterize the siren signal are the intensity, pitch and harmonic structure, radiation patterns, variation with time, and the effects of speed. During propagation, the absorption and reflection of the road surface, the effect of wind, the bending of direction resulting from diffraction around obstacles and refraction in air pressure gradients all require study. The relative speed and direction of the emergency and target vehicles will result in doppler shifts, but also must be studied from the point of view of the effectiveness of the warning signal. That is, given the path and speed of each vehicle, what signal will the target vehicle receive, and will it be able to stop or take other appropriate action in time (such as a maneuver to avoid collision with the emergency vehicle)? Noise levels within typical target vehicles must be determined, as well as the sound transmission loss characteristics of the exterior envelopes of the target vehicles.

Sirens could be tested in a number of test configurations. A free field test would be least influenced by factors other than the design of the siren. This could be done with the siren and microphones suspended high in the air, or else suspended in an anechoic chamber. Siren and microphones could be mounted on test stands at the normal operating and receiving heights. The siren could be mounted on a stationary or moving emergency vehicle, or both siren and microphones could be on moving test vehicles. Finally, perhaps the siren could be tested in a wind tunnel, although here reflections from the tunnel walls would make the data more difficult to interpret.

4.1.4. Test Program

In order to design an appropriate test program, a pilot field test study was conducted to identify the important parameters that may influence the sound output characteristics of an emergency warning siren. The study was performed at the Wallops Station, Virginia facility of the National Aeronautics and Space Administration. Details relating to the field test site, as well as a discussion of the test procedure, measurement methodology and instrumentation utilized for data acquisition, reduction and analysis are contained in Appendix C.

Several types of sirens were tested under various operating conditions. An array of six microphones was used in recording the data, and the sirens were studied on both stationary and moving test vehicles. Results for both an electronic and a mechanical type siren were obtained. It should be noted that although the siren models tested are representative of those utilized on emergency vehicles on the road today, the sample is so small that their characteristic output may not be typical of the entire population. Future testing will provide an opportunity to test a statistically significant sample of emergency warning sirens and at that time more generalized conclusions can be made.

The results shown in figures 1 and 2 are based on the preliminary analysis of the data obtained from a single microphone. More detailed analysis of the results is presently underway.

Figure 1 shows three frequency spectra for an electronic siren as measured to the front, side, and rear of the siren. The siren was mounted on the roof of a 1963 station wagon (fire chief's vehicle). It was located on the vehicle center line approximately eight inches behind the windshield. During testing the vehicle was held stationary and the siren was operated at its highest frequency so as to produce a steady signal rather than cycling up and down in pitch. In each case the microphone was mounted on a tripod at a height of four feet above the asphalt ground plane and 21 feet from the siren. Similar spectra resulted from front (0°), side (90°), and rear (180°) measurements. There existed three peak frequencies -- a fundamental as well as its second and third harmonic multiples. The data provide some insight into the directional characteristics of the siren. The signal is strongest to the front, less strong to the side and weakest to the rear (where a warning

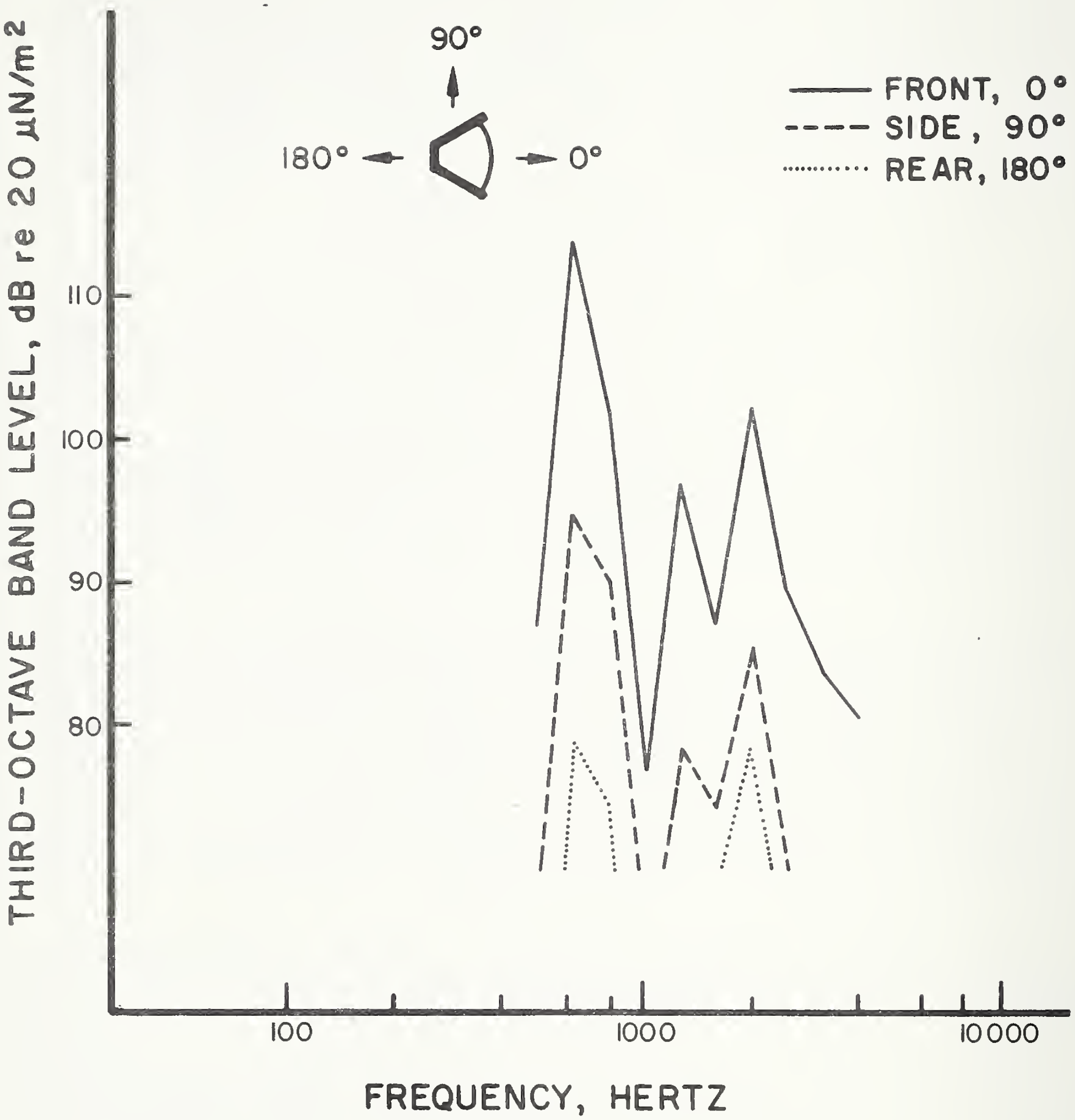

Figure 1. Sound pressure level vs frequency for an electronic siren operated steadily at its highest frequency. Measurements were made with the microphone located 21 feet to the front, side and rear of the siren, which was mounted on a stationary vehicle.

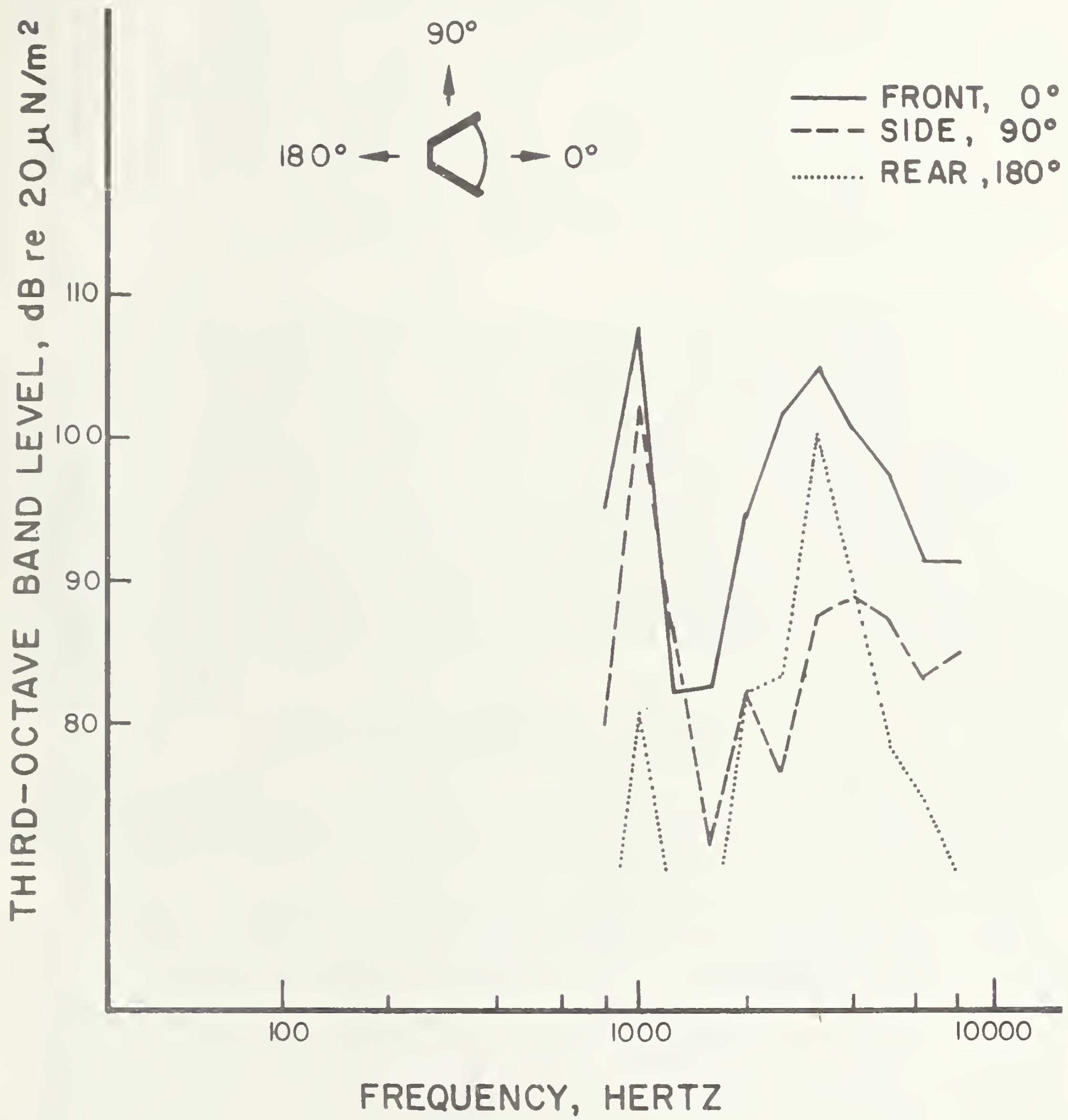

Figure 2. Sound pressure level vs frequency for a mechanical siren operated steadily at its highest frequency. Measurements were made with the microphone located 21 feet to the front, side and rear of the siren, which was mounted on a stationary vehicle.

signal is less needed). The corresponding A-weighted sound levels were 113, 96, and 82 dB(A) at 0°, 90° and 180° respectively.. One possible explanation of these results would be a radiation pattern consisting of smooth curves (without prominent lobes) that have either a modified heart shape (cardioid curve), or else a modified egg shape. The signal sent toward a target vehicle would be strongest to the front (0°) and progressively less strong as the direction toward the target vehicle is at an angle toward the side (for example, at 15°, 30° or 45°), as might be the case where both vehicles were approaching an intersection of two roads. Thus if an emergency vehicle had this siren in operation, the siren would be most effective in warning vehicles directly in front (0°), would be less loud as it passed abreast of vehicles (90°) and might not be discernable above the ambient noise after it had passed.

Figure 2 shows similar data for a mechanical siren. In this case the siren was mounted on the roof of a 1963 ambulance in approximately the same position as that of the electronic siren. The vehicle was stationary during measurements and the siren was operated at its top speed (or frequency) which provided a steady signal. The microphone was located as in the previous tests, 21 feet to the front, side and rear of the siren. As before, the signal is strongest to the front, less strong to the side and weaker to the rear (112, 104 and 102 dB(A) at 0°, 90° and 180° respectively), but the signal strengths in the three directions are now more nearly the same. Note, however, that the characteristic signal spectrum of the mechanical siren is more complex in its harmonic structure, and that different frequency distributions are now measured to the front, side and rear. To the front (0°), there is about equal intensity in the siren fundamental frequency and at the higher harmonics (the peaks differ by only 3 dB). The harmonic structure is broad or complex. To the side (90°), the fundamental is predominant above the harmonic content (the peaks differ by 14 dB). And to the rear (180°), the harmonic structure is predominant above the fundamental (the peaks differ by 20 dB), which is the reverse of the results to the side. Thus the signal output of the mechanical siren is more complex in the intensity distribution patterns for the different frequencies present, and the frequency spectra at small changes in angle are likely to differ significantly (for example, at 15°, 30° and 45°). As noted below, there may be certain angles toward which a less-than-adequate signal is directed. Since this siren is almost as loud after it passes and its warning function is completed as it is when the emergency vehicle is approaching, normal traffic flow may be unnecessarily disrupted. The signal toward the front is intended to enable other drivers to respond and take appropriate action, while a signal toward the rear may be wasted energy, and can cause confusion among following drivers, thereby disrupting the orderly flow of traffic behind the emergency vehicle.

Figure 3 shows the measured A-weighted sound level of the mechanical siren as it is driven past a microphone located 12 feet from the center-line of the vehicle path. The siren was mounted as before and was operated at its top frequency. As the vehicle approaches, the sound intensity rises to a level of approximately 104 dB(A), and maintains this level for some distance until the vehicle is approximately 20 feet from the microphone. Here the level rises and peaks at approximately 110 dB(A), and then the level falls as the vehicle drives farther away from the microphone. These results are similar to the conditions that might occur when an emergency vehicle overtakes and passes a target vehicle that is operating in the adjoining lane of a highway. If the driver of the target vehicle is unable to hear the 104 dB(A) signal above the noise background, he will not be warned in time, and may not react as he should.

One possible explanation of the results for the mechanical siren would be a sound radiation pattern with a long lobe to the front and additional lobes to the side. If this is the case, there may be regions at some angle to the front toward which the signal is less strong than it is to the front (0°) or side (90°). Thus the frequency spectra and radiation patterns of the mechanical and electronic sirens reported here show important differences, which could modify their effectiveness for different operating conditions. The purpose of reporting these results is to show examples of some of the types of measurement and analysis done to date, and generalized conclusions should not be drawn as yet. Plans for further testing and analysis are described below.

4.1.5. Planned Activities

The results of the pilot program have been encouraging, and unless major problems develop in the data acquisition process, it is planned to continue the testing program along the same lines as previously described.

In terms of analyzing the signal taken during the field tests, several types of analysis will be performed on the analog data tapes. A-weighted sound levels will be determined for comparison with past and future studies. In addition, because single number comparisons do not distinguish between signals of different spectral composition, a more detailed analysis is needed for an understanding of the mechanisms by which the warning signal is generated, propagated and perceived. For example, a signal that "warbles" up and down in pitch may have the same single number rating as a single-pitched signal, and yet be more effective in gaining attention. Finally, plots showing signal variation with direction are needed so that the signal effectiveness can be determined for traffic approaching from the side or rear as well as for traffic and pedestrians in front of the emergency vehicle.

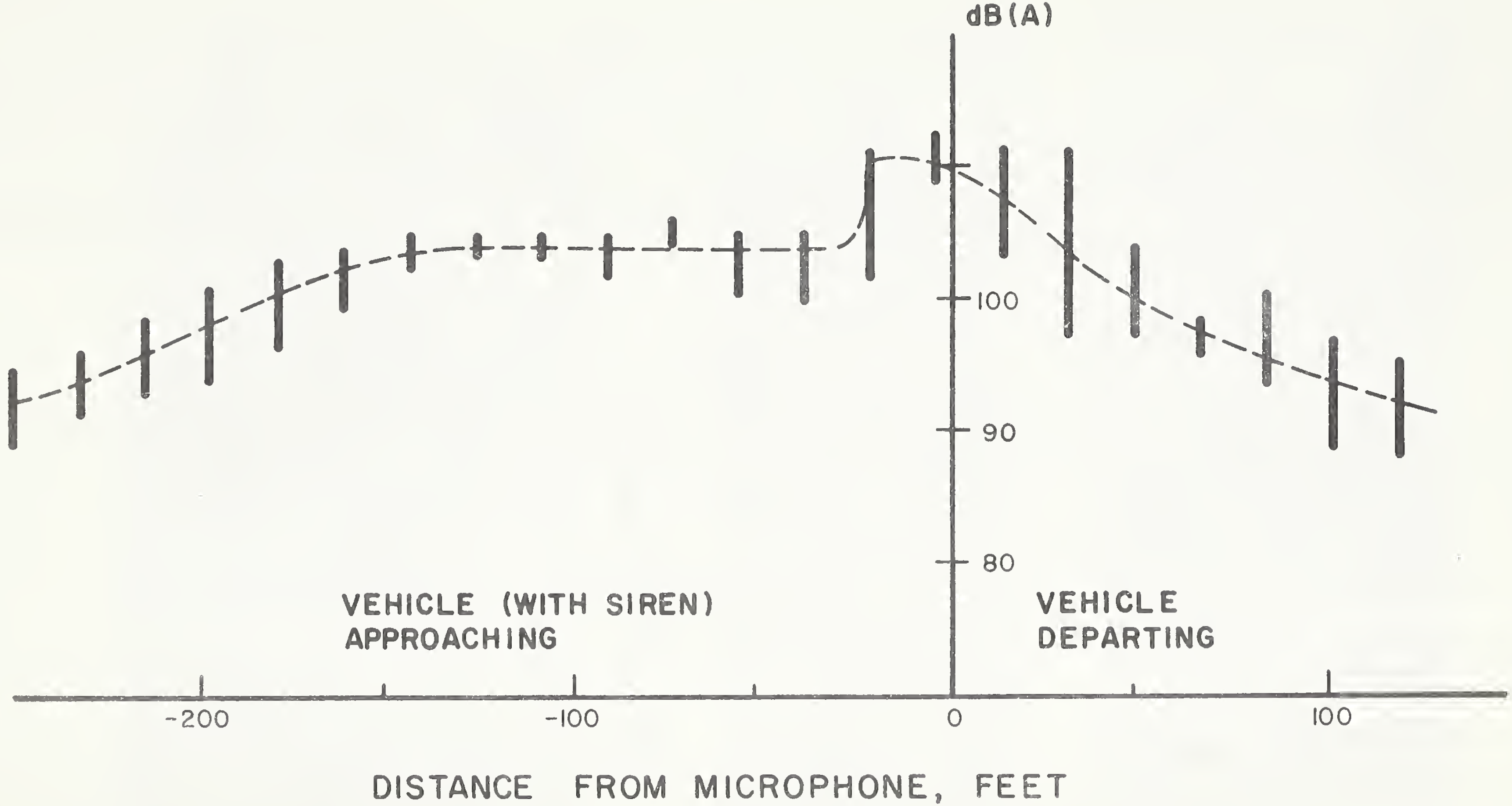

Figure 3. Sound level of a mechanical siren as a function of location of the emergency vehicle relative to the microphone. The microphone was located 12 feet from the centerline of the vehicle path while the vehicle was driven past with the siren operated at its highest frequency. The physical measure used is the A-weighted sound level, which weights various frequencies in a manner similar to that of the human ear. In this particular case, the dashed line (faired by eye) indicated that the useful sound level produced is approximately 104 dB(A).

Previous investigations of the sound intensity from loudspeakers, horns and sirens frequently have been carried out in an anechoic space, so as to determine the radiation profile from the source in the absence of any reflections. In the present study, however, it is proposed to make the majority of the measurements outdoors with the siren mounted on a typical police vehicle and the sound propagating over a hard, paved surface. This condition is much more typical of the actual usage of sirens, in that it allows for reflections from both the vehicle and the pavement. But in order to compare the results obtained under these simulated use conditions with those obtained in the absence of reflections, consideration will be given to testing a limited number of sirens in the NBS anechoic chamber (see Appendix C).

In addition to the testing aspects of the program, it is planned to visit other manufacturers of siren devices, as well as to continue the literature search which is currently underway. With the information which is obtained from the testing program and the literature search, there should be sufficient grounds on which to base a draft interim standard for sirens.

4.2. LIGHTS

4.2.1. Hardware State of the Art

The same situation that exists for sirens is also true for lights: there are a number of manufacturers and distributors of emergency vehicle lighting devices (see Appendix A). Emergency lights consist of four main types -- rotating, flashing, oscillating and spotlights -- and each of these categories is further subdivided as follows:

1. Rotating

   a) Base with two, three or four sealed beam incandescent lamps; faces of lamps or dome are colored.

   b) Single incandescent bulb; three or four concentrating lenses rotate around bulb; lenses or dome are colored.

   c) Single incandescent bulb; parabolic reflector rotates around bulb; dome colored.

2. Flashing

   a) One, two, three or four sealed beam lamps flash; lamp faces or dome are colored.

   b) Single incandescent bulb flashes; parabolic reflector; dome colored.

   c) Single incandescent bulb flashes; double prismatic lens (360° coverage); lens (dome) are colored.

d) Single incandescent bulb flashes; one or two concentrating lenses; lenses colored.

e) Gaseous capacitor discharge flash tube (e.g., xenon); different types of colored lenses.

3. Oscillating

a) Base with three or four sealed beam lamps turns 95° to 110°, then returns; faces of lamps or dome colored.

b) Base with two, three or four sealed beam lamps rotating, while one lamp is oscillating vertically through 90°; dome clear.

c) Sealed beam lamp moves to make "figure - 8"; lens colored.

4. Spot or Floodlights (attached to vehicle)

a) Remotely operated spot; incandescent.

b) Spot on flexible mount; incandescent.

c) Flood; incandescent or steadily-operated gaseous discharge lamp.

4.2.2. Background Literature

In comparison to the work on sirens, much more has been done on characterizing the signals of flashing lights, particularly in the areas of aviation and of harbor warning lights. Although most of the papers collected thus far do not pertain directly to emergency vehicle warning lights, the papers do provide insights for our work (see Bibliography [2-14]). These articles are being studied, and other reports of a similar nature have been ordered. As in the case of the documentation on sirens, there appears to be very little research that is specific to vehicular warning lights.

4.2.3. Review of Measurement Problem

Owing to the dearth of material available on the signal characterization of emergency vehicle warning lights, it is planned to carry out a series of tests on representative samples of the different types of lighting units. Where several lighting units use the same model of source (lamp, tube or bulb), a single source will be selected that is typical of that model, and it will be mounted in each lighting unit while under test. The evaluation of each lighting unit will include a determination of the chromaticity coordinates, intensity (candlepower) distribution and effective intensity.

Chromaticity coordinates can be determined, in the case of a unit using an incandescent source, by using spectroradiometric instrumentation to determine the spectral distribution of the integral source/filter unit. These data are directly reducable to chromaticity coordinates. For capacitor discharge sources (e.g., xenon), which cannot be steadily burned, chromaticity coordinates can be closely approximated using published data on the spectral distribution of the xenon source.

The chromaticity of a color consists of the hue and saturation aspects specified by the chromaticity coordinates (x,y,z) of the color taken together. Chromaticity coordinates of a light are the ratios of each of the tristimulus values of the light to the sum of the three tristimulus values. The tristimulus values of a light are the amounts of each of three primaries required to match the color of the light.

Intensity distribution measurements will be made on the NBS 100 meter photometric range (see Appendix D for description) equipped with an automated goniometer and data recording instrumentation. Intensity (candlepower) distribution curves are drawn from data obtained by a test on a goniophotometer. Distribution curves indicate the intensity produced by the source/fixture in any direction relative to its conventional position in service.

The intensity of a flashing light varies during the duration of the flash. When the eye views a flashing light at near threshold levels, the visual effect depends upon the flash length and the shape of the illumination profile (intensity, as a function of time). The following relationship has been developed to predict the effective intensity of the flashing light:

$$I_e = \frac{\int_{t_1}^{t_2} I\,dt}{0.2 + (t_2 - t_1)}$$

where I_e is the effective intensity,
I is the instantaneous intensity, and
t_1 and t_2 are time limits in seconds corresponding to the beginning and end of the flash.

By definition, the effective intensity of a flashing light is the intensity of a steady-burning light that will produce the same visual sensation (range) as does the flashing light. Variations of the foregoing equation have been developed to permit rapid calculation of the effective intensity for the special cases of capacitor discharge lamps with short flash durations and revolving incandescent beams. In the case of devices employing multiple flashing units, it will be necessary to evaluate the effects of the synchronous relationships on the phasing of flashes.

Some commercially available units employ a steadily burning incandescent source with movable lenses or reflector for a directional flashing effect. These units will need to be evaluated for proper alignment of the concentrating lenses or reflector and optical quality and durability of the lens-reflector systems.

Power supplies for both incandescent and capacitor discharge sources will have to be evaluated to determine their output characteristics.

4.2.4. Test Program

Some figures are included as examples of the type of data on emergency flashing lights which might be expected from the test procedures which have just been presented. Figures 4 and 5 are representative of intensity distribution measurements. Figure 4 shows both the horizontal and vertical intensity distribution of a steady-burning 1000 watt tungsten filament sealed-reflector incandescent lamp. Figure 5 is the horizontal and vertical distribution of a flashing capacitor discharge lamp (e.g., xenon). The time constant on the photometer circuitry was adjusted to give a smooth curve. Note that since the lamp is flashing, the distribution is in units of effective intensity. Figures 6 through 8 represent typical time-intensity distribution for the most common types of emergency flashing light units. Figure 6 is a typical time-intensity curve for a rotating incandescent lamp. Figure 7 portrays the time-intensity curve for a typical flashed incandescent lamp. Figure 8 is a time-intensity curve for a typical pulsed krypton (capacitor discharge) lamp.

4.2.5. Planned Activities

It is planned to complete the listing of emergency vehicle warning lights from all manufacturer's catalogs on hand. Items not already on the master list (summarized in section 4.2.1) will be added to it. This list will then contain all the different lighting units for which data must be obtained according to the testing procedure previously described.

It is also planned to visit various manufacturers of emergency warning lights as well as to complete the literature survey presently under way. The information generated from these endeavors will form the basis for writing the draft interim standards.

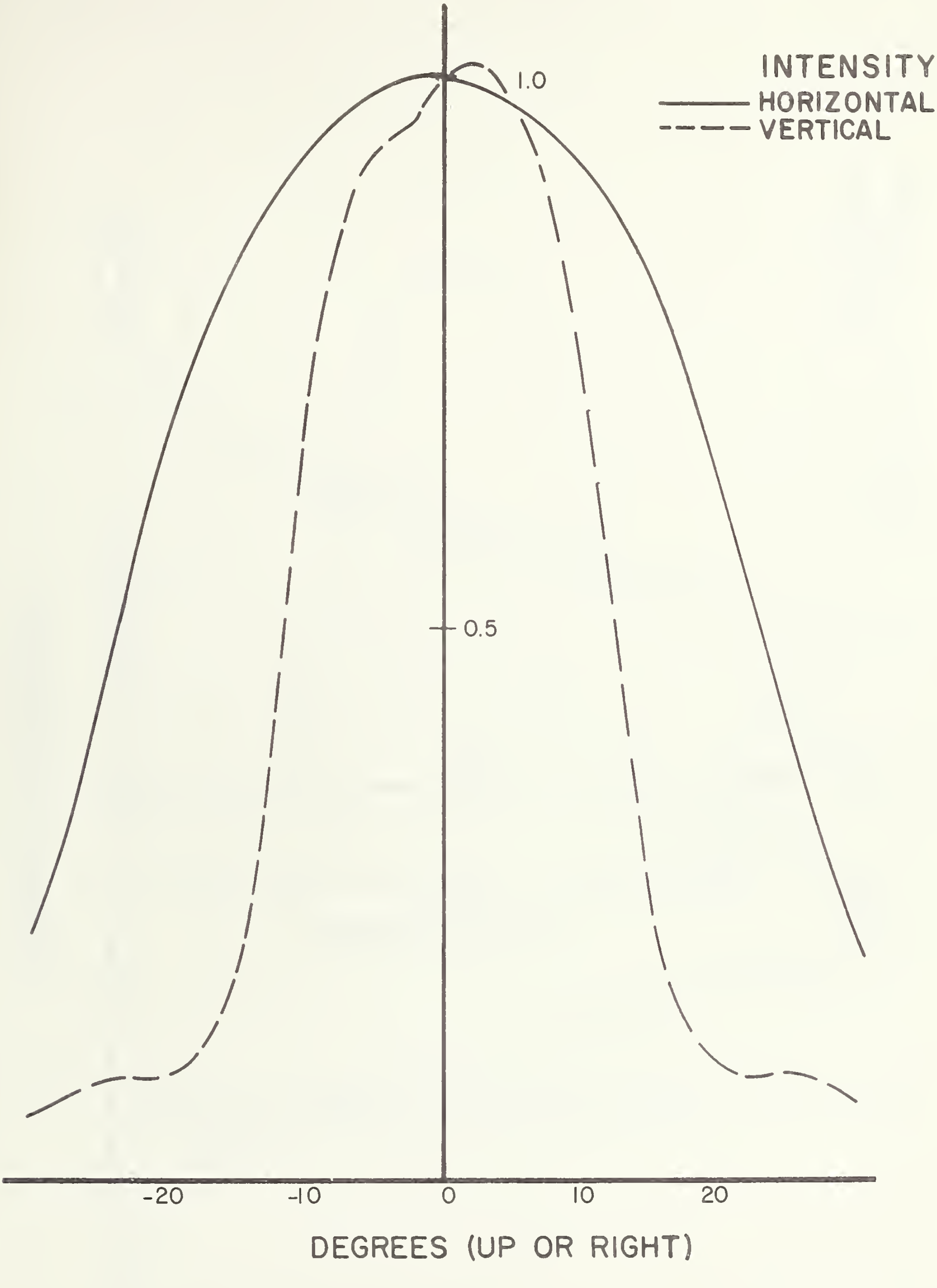

Figure 4. Variation of light intensity from a sealed beam flood lamp as a function of angular position. This represents an example of the measurement of horizontal and vertical intensity distributions. The intensity is normalized relative to the maximum value in the horizontal plane.

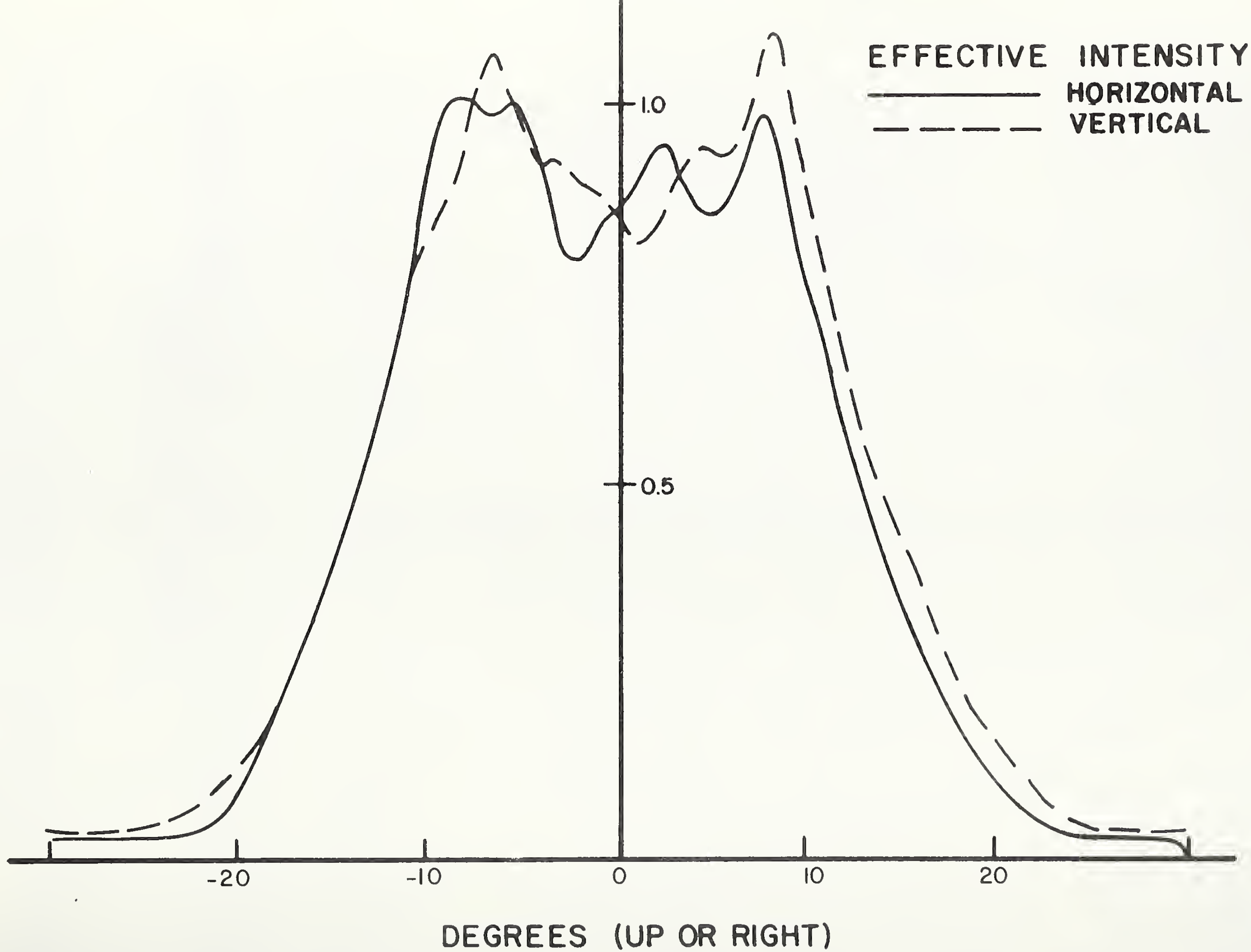

Figure 5. Variation of the effective intensity of the light from a xenon flash lamp as a function of angular position. This represents an example of the measurement of horizontal and vertical effective intensity distributions. The effective intensity is normalized relative to the maximum value in the horizontal plane.

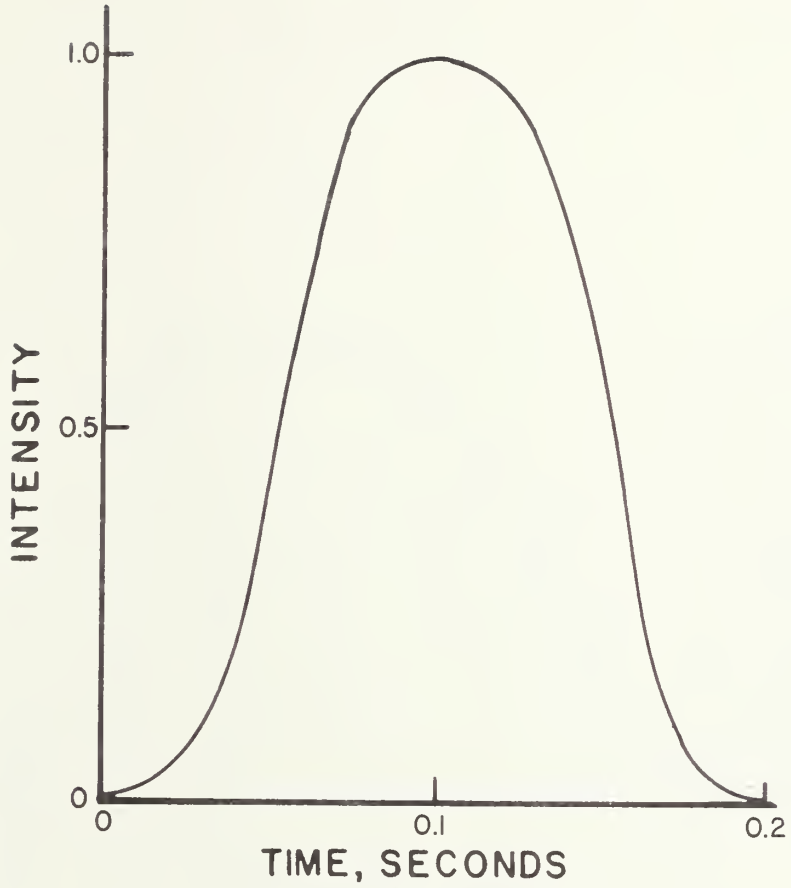

Figure 6. Example of time variation of light intensity from an incandescent lamp, rotated past the detector. The intensity is normalized relative to the maximum value.

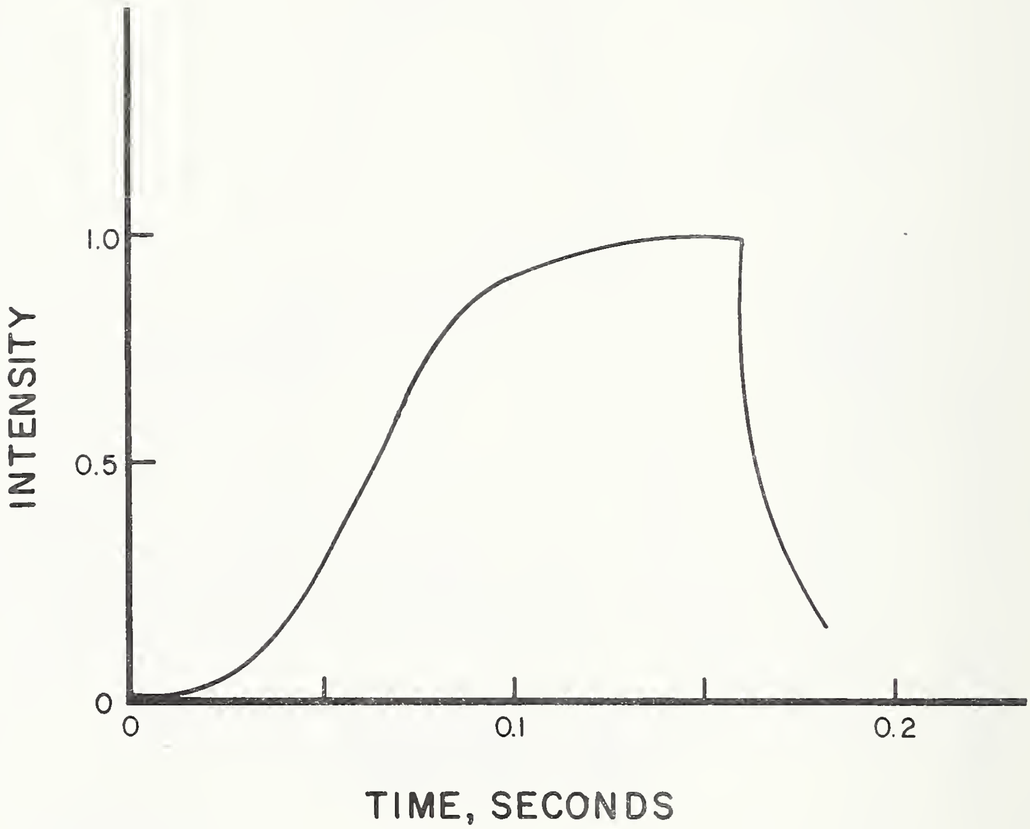

Figure 7. Example of time variation of light intensity from an incandescent lamp flashed on and off. The intensity is normalized relative to that at time of shut-off.

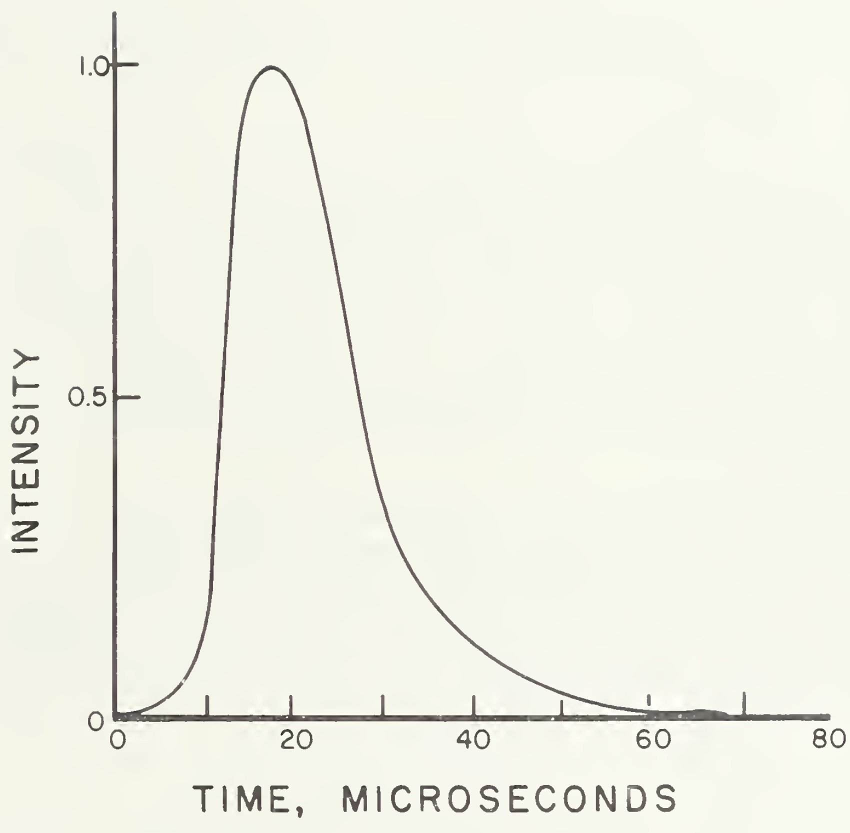

Figure 8. Example of time variation of light intensity from a krypton flash lamp. The intensity is normalized relative to the maximum value. Note that the units of the time axis are microseconds.

5. DETERMINATION OF EFFECTIVENESS

5.1. INTRODUCTION

At least four distinct phases of the process by which a signal transmits information to a person can be distinguished. First, the signal must activate the person's sensory system (detection). People are very complex detecting devices, however, and can block out through inattention a signal that is well above the threshold level. (We have all had the experience of failing to see something that was right in front of us). Thus a second stage is necessary, in which the presence of the signal is noticed (attention) The third stage in a successful signaling event is the process by which the observer recalls or deduces the meaning to be attached to the signal (interpretation). In most cases, and certainly in the case of warning signals, the meaning attached to the signal is that the observer should take some particular action. Therefore, the fourth stage is that in which the observer actually takes the action called for by his interpretation of the signal (reaction).

The detection phase of the signal transmission process has been the subject of much work in hearing and vision, both at absolute thresholds and at higher intensities. The objective of work at absolute thresholds is to determine the level at which sound or light just barely can be detected, and at higher intensities the objective is to determine when two signals seem equal. Additional phases of the signal transmission process have been more pertinent during certain other work, such as studies of speech intelligibility, human factors research concerned with displays and controls, and studies of a person's reaction in an emergency situation.

All phases of the signal transmission process are of concern in determining the effectiveness of emergency warning signals. The effectiveness will be determined from objective measures of driver reactions to the signals. For example, we will study the time elapsing between the occurrence of a signal and the completion of the required response (complex reaction time). In addition, we will study the distance at which an observer first notices and correctly interprets a signal (recognition distance). Other objective measures of driver reactions include the time from notification of the police until their arrival at an emergency site, and accident frequency statistics involving emergency vehicles. A related question would be whether drivers react differently to different signals, and how this affects the objective results.

Complex reaction time is a useful measure of signal effectiveness for several reasons. First, we want to know this characteristic of the signal transmission process. It is objective, quantitative, and does not require elaborate measurement equipment. Finally, it has a helpful kind of universality, and applies a single scale of measurement to any signal. Any two signals, such as a red light and a siren, can be compared by determining the corresponding complex reaction times during similar test situations.

The recognition distance is also a useful measure of signal effectiveness, and for similar reasons. It determines how much space a driver will have in which to take appropriate action. It too is objective, quantitative, easy to measure and universal. The fundamental standard for any signaling device might well be one of a single minimum recognition distance. Through experiments, a relationship between recognition distance and physical measures, such as the illuminance produced by lights or the sound levels produced by sirens -- both measured at some standard distance from the source, would permit the standard minimum recognition distance to be translated into minimum illuminance or minimum sound pressure level.

The task of noticing and correctly interpreting a signal is made much easier when no aspect of the total sensory environment changes, other than the particular aspect which is meant to convey information. In everyday life, however, there are always other changes occurring in the environment of the observer. It is traditional to regard all aspects of the sensory environment other than the aspect to be used as the signal as the background against which the signal is occurring. Since changes are constantly occurring in the background, an important part of the actual task faced by an observer receiving a signal is to discriminate the signal from the various background changes. It is traditional to refer to all of these irrelevant background signals as noise, and the terms "noise" and "background" are used for any mode of signal, including both light and sound.

A driver will detect many changes (and constancies) in his environment. He will then pay attention to certain ones and exclude others, scanning his attention over all or part of his total sensory environment. When he notices a particular signal, he must decide whether it contains important information, and react appropriately. If the driver is looking for a particular type of signal, he will reject not only background changes in the environment, but also changes that he recognizes as meaningful signals, but signals of the wrong kind. If the driver must monitor a great many changes in the environment, if there is a lot of "noise", his complex reaction time for a given signal will be longer, because he requires more processing time.

5.2. SIRENS

5.2.1 Review of Problem

As described above, much of the work in the study of hearing has dealt with the detection of sounds at threshold levels with no external background noise. It is hoped that as the literature search continues, research reports on the determination of siren effectiveness will be located, but it initially appears that the field has not been heavily researched.

The requirements of a siren are that, by itself or in combination with a flashing light, it should be noticed by drivers in the general traffic situation and be recognized as warning of the approach of an emergency vehicle. The criterion for rating the desirability of such signals would be the rapidity with which the combined detection and recognition processes take place. The rapidity of response can then be correlated with the amount of time a driver takes to perform any maneuvers he deems necessary to make way for the emergency vehicle. Unfortunately it appears that, because of ambient street noise, the intensity of sound at the position of the target driver's head will often be below the threshold of noticeability until the emergency vehicle is relatively close to the target vehicle. This is further complicated by the prevalence of closed windows (air conditioners, flow-through ventilation systems, and heaters cause many cars to be operated with closed windows all year) and high sound levels within the passenger compartments (such as caused by radios and tape players). This combination can mask any but the most intense external sounds. It would seem that the solution would lie in making the siren loud enough to overcome the closed windows and high ambient noise levels, but to avoid excessive annoyance and community disturbance, there is an upper limit to the source intensity of a siren. Thus experimentation is needed, in order to determine how to optimize the effectiveness of sirens without raising the intensity above acceptable levels.

5.2.2. Test Program

The immediate problem which must be handled is to conduct a systematic, parametric study of auditory signals until a body of data has been established that permits evaluation of a siren directly from physical measurements of the sound output, and also permits the selection of an optimum siren for any specified type of background.

One means of collecting data would be through the use of simulation techniques. The simulator could be based on one of the training simulators now in use for driver education, or on a modification of a driver training car. Less sophisticated simulations could be done in the laboratory using high fidelity speakers or stereophonic earphones. The simulation would be the sound of an approaching emergency vehicle with siren in operation, as superimposed on typical traffic noise. A given signal could be tested for effectivensss against different backgrounds.

5.2.3. Planned Activities

Up to the present time, this program has included no experiments to determine device effectiveness in communicating the warning signal. Unlike the sections on the physical characterization of the signals, in which figures were presented, it is premature to predict complex reaction times or recognition distances for an auditory signal.

It is planned to conduct a literature search on the "noticeability" of sirens. Other related work will be reviewed (for example, work in perceived noise levels), in order to evaluate its application to siren effectiveness. Some form of simulation experiment will be developed and applied.

5.3. LIGHTS

5.3.1. Review of Problem

As was described in section 5.1, warning light signal information is transmitted in four distinct stages -- detection, attention, interpretation, and reaction. A great deal of the work which has been done in vision has, like research in hearing, been devoted to determining absolute thresholds or discriminating between different intensity levels and frequencies (colors) of light. There has also been a considerable amount of work devoted to studying the apparent brightness of flashing lights by setting a steady light to have equal visual impact. All of this work is restricted to the detection stage. It has application to real signaling in the situation of signal lights seen at night in an approximately known direction. In a situation in which the light appears in an unknown part of the visual field, against a background full of other lights, the use of a flashing light as a signal no longer involves simply the impact of the light on the visual system. What is important, once we assume that the light is bright enough to be seen, is its attention-attracting power (phase 2).

In the 1950's, a series of studies was conducted by Gerathewohl (see Bibliography). He compared flashing lights to steady lights, but presented them against a fairly complex background of visual and auditory "noise". The observers had to respond to all the signals in different ways. The target lights, both flashing and steady, appeared peripherally and required the same response. Comparative reaction times were thus determined. The distracting "noise" signals required different responses. Although somewhat simplified, the similarity of these experimental conditions to the situation of driving an automobile is clear.

Gerathewohl used the term "conspicuity" to refer to the attention-attracting power of the target signals as measured by the brevity of the reaction time in each situation. He found that of two lights having equal objective luminance, one being flashed and one steady, the flashing light usually had greater "conspicuity"; that is, the observers reacted to it sooner. This is in direct opposition to the established finding in absolute-threshold or equal-brightness studies that the flashing light has <u>less</u> visual effect. Although Gerathewohl could not explain exactly what it is about a flashing light that makes it more attention-attracting than its brightness would lead one to expect, the fact of a discrepancy between brightness and conspicuity (or "noticeability") is hardly surprising in view of the complexity of the reactions involved.

It is our opinion that complex reaction time experiments patterned fairly closely after Gerathewohl's work are needed to determine the noticeability of visual emergency vehicle warning devices.

The more complex the sensory environment to which an observer is reacting, the more difficult it becomes to predict his reaction to particular signals. In the 1960's, Crawford (1962,1963) studied complex reaction times to steady and flashing amber lights appearing randomly within a background of red and green lights that shifted repeatedly and contained a varying proportion of flashing lights. Four of Crawford's findings were of particular interest. (1) The mean complex reaction time to the appearance of the amber light when there were no background lights was 0.8 seconds, but with 21 red and green background lights, the complex reaction time rose to almost 2 seconds. (2) Regardless of whether the amber signal was flashing or steady, a background of flashing lights increased the complex reaction time more than a background of steady lights. (3) When there was a possibility of recognizing the signal by either its color or its flashing, recognition was on the basis of flashing, not color. (4) The advantage of flashing a light over leaving it steady, suggested by Gerathewohl's work, was shown by Crawford to be lost if other lights in the background were flashing. It is hoped that more work of this kind will come to our attention as the literature search continues.

With lights as with sirens, their function is to be noticed and recognized by drivers as warning of the presence of an emergency vehicle. However, as suggested above, any but the most intense signal lights may be masked by a complex pattern of commercial and street lighting at night, or by a high ambient illuminance of sunlight during the day. Again, as in the case of sirens, it is tempting to solve the problem by increasing the intensity of the signal, but there is a maximum level for community acceptance.

5.3.2. Test Program

In planning an experimental program, simulation experiments that measure complex reaction time are being considered, but obtaining experimental data on the effectiveness of flashing lights may present more intricate problems than the parallel effort for sirens. One suggested experimental procedure would be to use simulation techniques in driver-education training equipment. The equipment already exists, and could be modified for this work. An example of an alternative simulation experiment might be to project a simpler, artificially generated pattern of lights similar to the stimulus fields used by Gerathewohl and by Crawford. Another possibility would be to monitor the progress of an emergency vehicle through actual traffic (see section 5.4).

5.3.3. Planned Activities

As was stated earlier, determining the effectiveness of flashing lights will require a carefully considered experimental design. The coming phase of this program will include the search of related literature, and beginning a pilot program to see if it will be feasible to use automobile simulators as outlined above. As an experiment of this type has not been done, to our knowledge, it will be necessary to see if it can be accomplished with available equipment at a reasonable cost.

5.4. SIRENS AND LIGHTS COMBINED

Up to now, sirens and lights on emergency vehicles have been spoken of as if they were distinctly separate entities. However, sirens and lights make up a communication system, and this fact cannot be abandoned merely for the sake of simplicity in designing an experimental procedure. For example, when a person is driving a car and hears a siren, he does not just pull over to the side, but rather looks around until he finds a flashing light. Then on the basis of where the flashing light tells him the emergency vehicle is located, he makes a judgment as to what is an appropriate maneuver to make with his car. Thus it will be necessary to ascertain the effectiveness of a total signaling system. Driver-training simulators might be particularly appropriate devices for such a combination experiment. Another possibility is to equip vehicles with varying configurations of warning devices and have them travel predetermined routes in regular traffic. Measures of effectiveness would be based on the time required to arrive at their destinations.

The basic situation in which we are interested is that of a driver sitting in his car in moving traffic. We want to know how soon the driver notices that one or more emergency signals are occurring, or the distance at which he notices them. Through experiments, the recognition distance or the reaction time will be related to such physical measures as the illuminance or the sound level of the warning devices under study.

6. SUMMARY

Several problem areas have been identified. A number of warning device designs are offered on the market, but there is little agreement among users as to which ones are best, or how they should be configured. No workable performance standards exist that enable the user to evaluate device effectiveness.

Program goals have been developed in response to these problems. The present state-of-the-art for standards and hardware is being compiled. Improved standards for hardware will be developed in terms of performance criteria. Preliminary copies of the standards will be circulated among users, so that their experience and appraisals may benefit later revisions.

The present report sets forth the overall program and accomplishments to date. A portion of the state-of-the-art information has been assembled, the methods and staffing for programs to measure signal characteristics have been planned, and a review of the literature related to device effectiveness has been begun. Several sirens have been tested and further analysis is in progress.

The overall program objective is to establish performance standards for warning devices. These standards will be based on studies that provide a description of the physical characteristics of the light or sound patterns, and on the results of investigations designed to evaluate these characteristics in terms of appropriate responses by other drivers.

APPENDIX A.

COMPANIES WHICH MAKE OR DISTRIBUTE EMERGENCY LIGHTS OR SIRENS

The following is a list of companies that are manufacturers or distributors of emergency vehicle warning equipment and from which we have already received or requested catalog literature. It is highly possible that this list does not contain all the manufacturers and distributors of emergency warning equipment, and every effort will be made to be sure that no manufacturers are overlooked.

Ed Agramonte, Yonkers, New York (sirens)
ATO, Willoughby, Ohio (sirens) (American LaFrance)
Auto-Matic Alarm Systems, Chicago, Illinois (sirens)
Automotive Conversion Corp., Troy, Michigan (sirens)
Auto Safety, Inc., Cumming, Iowa (both)
Casell Company, Napa, California (lights)
W. Darley and Co., Melrose Park, Illinois (both)
Dazl-Ray Corp., Kansas City, Missouri (lights)
Dictograph Security, Florham Park, New Jersey (both)
R. Dietz Co., Syracuse, New York (both)
Dominator Co., Red Bank, New Jersey (sirens)
Dominion Traffic Sign and Signal, Richmond, Virginia (lights)
Federal Sign and Signal Corp., Blue Island, Illinois (both)
FEDTRO, Inc., Rockville Centre, New York (both)
Fire-Call Electronics, Rochester, New York (sirens)
Home Safety Equipment, New Albany, Indiana (lights)
Industrial Electronics Service, Schaumburg, Illinois (sirens)
K-D Lamp Co., Cincinnati, Ohio (lights)
Walter Kidde and Co., Belleville, New Jersey (lights)
Kustom Signals, Chanute, Kansas (both)
Macchi Corp., San Francisco, California (lights)
Mars Signal Co., Chicago, Illinois (both)
Motorola, Chicago, Illinois (both)
Muni Quip by Tribar Industries, Buffalo, New York (sirens)
North American Signal Co., Chicago, Illinois (both)
Northern Signal Co., Saukville, Wisconsin (lights)
On-Guard Corp., Carlstadt, New Jersey (sirens)
Paralta Equipment, Hammond, Indiana (both)
Pichel Industries, Pasadena, California (lights)
Portable Light Co., Kearny, New Jersey (lights)
Rochester Safety Equipment, Rochester, New York (both)
Safety Guide Products, Scottsdale, Indiana (lights)
Safety Products, Chicago, Illinois (both)
SArgent-SOwell, Arlington, Texas (sirens)
Sireno, Kearny, New Jersey (both)
Spartan Manufacturing Co., Flora, Illinois (lights)
Stephenson Co., Eatontown, New Jersey (both)
Sterling Siren Fire Alarm Co., Rochester, New York (both)
Tripp-Lite Div., Chicago, Illinois (both)
UNITROL-Dunbar-Nunn, Anaheim, California (both)
Unity Manufacturing Co., Chicago, Illinois (both)
Werlin Safety Products, Folcroft, Pennsylvania (lights)
Whelen Co., Deep River, Connecticut (lights)

APPENDIX B.

SUMMARIES OF EXISTING STANDARDS

B.1. INTRODUCTION

It appears that few standards have been issued in the areas of emergency sirens, warning lights and spotlights. The standards located thus far have all been issued by the Society of Automotive Engineers in New York. In addition to these, one military purchase specification on vehicular sirens has been obtained. Other standards and specifications are now being sought, but it is believed that most of the standards have been located, and that the other pertinent documents to be found will be purchase specifications for emergency warning equipment. Thus, it would seem useful to summarize the standards and specifications located to date.

B.2. SIRENS

There is no SAE standard for emergency sirens, but there is one for vehicle horns, and as this is oftentimes part of an emergency vehicle's communication system, it is discussed here briefly. SAE Standard J377 on the Performance of Vehicle Traffic Horns establishes the minimum operational life cycle, corrosion resistance, and sound level output for electric vehicle traffic horns. The standard specifies three performance requirements for horns: (1) complete 50,000 cycles of laboratory operation (0.75 sec. on, 3.25 sec. off) without loss of more than 6 dB(A) output; (2) complete a 72 hr. salt spray exposure test (in accordance with ASTM B117) after which the horn must operate "without a loss of more than 6 dB(A);" and (3) produce a sound level of 82-102 dB(A) at a distance of 50 ft. directly in front of the vehicle. The instrumentation and test procedures are described in the text of the standard.

A military purchase specification, MIL-S-3485B -- Sirens, Electric-Motor-Operated, Vehicular (September 1, 1966), has also been obtained and studied. Basically, the specification says that a siren shall consist of a body, rotor, electric motor, mounting bracket (all of which shall not weigh over 35 lb.), and, if specified, a motor control switch and motor cable and/or a flashing light. The siren must be capable of operating in any ambient temperature from 125 F to -40 F. The ability to operate under extreme temperature conditions is tested by placing the siren in a temperature-controlled chamber where it is subjected to a temperature of 155 F for 4 hr. and then to -65 F for 12 hr. The siren is then allowed to return to room temperature, at which time it is examined for physical defects. If any are found, the siren fails the test. In order to meet the specification, the siren must also produce a sound that starts with a "heavy growl" and rises in pitch to a "shrill shriek". This sound must be "110 dB at 6 ft." and the highest fundamental tone must be 1000 cps ± 100 cps. To test this feature, the siren is operated at 10% below rated voltage and the sound level and pitch peak are determined in accordance with ASA S1.2 (except the distance of the microphone from the source is only 6 ft.) The body of the siren itself must be made from either steel with a rust-resistant coating or aluminum in order to prevent corrosion, and the electrical circuitry must be treated with a special varnish to prevent fungus or moisture accumulation. The motor of the siren must be d-c and, depending upon whether the voltage of the siren is 6, 12, or 24 volts, the current consumption (expressed in amperes) must not exceed certain amounts detailed in the specification. The electric load is determined by inserting a calibrated ammeter in the line and observing the readings. Finally, if there is a flashing light included with the siren, it is required to be red and to flash at a rate of 75 to 100 flashes/minute.

B.3. FLASHING LIGHTS

The greatest number of standards issued in the area of emergency warning equipment has been in the category of flashing lights. The standard on which the other standards for vehicle lights are based is SAE J575 -- Test for Motor Vehicle Lighting Devices and Components. In this standard, it is a requirement that all samples and bulbs used for testing should be representative of equipment which is regularly manufactured and marketed. One of the tests applied to the lighting device is a vibration test, in which the sample is mounted on the anvil end of a vibration test machine and vibrated approximately 750 cpm through a distance of 1/8 in. for 1 hr. The unit is then examined for physical defects, and if any are in evidence (except for bulb rupture), the unit fails. The test specimen is also subjected to a moisture test, where all the drain holes of the test unit are opened and precipitation of 0.1 in. of water per minute is sprayed over the lighting unit at an angle of 45 deg from a nozzle with a solid cone spray. The test is run for 12 hr., at which time the water is turned off and the device is permitted to drain for 1 hr. If, at the end of an hour, moisture has accumulated more than 2 cc in the bottom of the unit, it is failed. In a dust test, the unit is placed in its normal operating position in a box containing 10 lb. of fine powdered cement. At 15 minute intervals, the dust is agitated for 2 sec. in such a way that the dust is completely and uniformly diffused throughout the box. The test is run continuously for 5 hr., after which the exterior of the test surface is cleaned. The unit is then placed in operation, and if the maximum candlepower is within 10% of the maximum when the unit is cleaned both inside and out, then the unit will have passed the test. The unit is also subjected to a corrosion test in which a salt spray is applied for two 24-hr. periods. After each 24-hr. period, the unit is dried for 1 hr. If there is no evidence of excess corrosion which would affect the unit's operation, then the unit passes the test. Photometric measurements are made on the test unit as well, and the minimum candlepower requirements for passing this test are summarized in a table in the standard. A warpage test is conducted on the units which have plastic lenses or domes. In this test, a lighting unit is placed in an oven at 120 F ambient temperature and operated for 1 hr. The unit passes the test if no warpage occurs which would affect the proper functioning of the lighting device. The final test included in this standard is an out-of-focus test. This test is not used in any of the standards reviewed to date on emergency flashing lights.

A second standard which has applicability to emergency warning lights is SAE Recommended Practice J576 -- Plastic Materials for Use in Optical Parts, such as Lenses and Reflectors, of Motor Vehicle Lighting Devices. In this test, a sample of the plastic is molded into 3-in. diameter discs. These samples are then subjected to an outdoor exposure test and a heat test. In the outdoor exposure test, the samples will be weathered for two years in Florida and Arizona. After two years, the samples will be compared with a control sample for luminous transmittance using CIE Illuminant A (there must not be more than 25% difference between the control and test samples). Also, the physical appearance of the test sample will be compared with the control sample, and the trichromatic coefficients will be measured to see if they conform to SAE J578 (to be discussed). In the heat test, the test sample will be placed in a circulating air oven at 175 ± 5 F for two hours. After the exposure in the oven, the sample will be compared to a control sample for appearance and the trichromatic coefficients will again be measured.

Another standard which relates to emergency flashing lights is SAE Standard J578, Color Specification for Electric Signal Lighting Devices. The purpose of this specification is to define and provide for the control of colors used in motor vehicle lighting equipment. The colors defined are red, yellow (amber), and white (achromatic), and they are specified in terms of the chromaticity coordinates of the 1931 CIE standard colorimetric system. There are three methods listed for measuring the colors. One is called the visual method, in which the test sample is compared visually to a control sample whose chromaticity coordinates have been determined spectrophotometrically. A second method of measurement is the tristimulus method which is based on photoelectric receivers with response curves matching the CIE standard tristimulus curves. The last method is the spectrophotometric method in which the chromaticity coordinates are computed from the spectral energy distribution curve.

SAE Recommended Practice J945 -- Vehicular Hazard Warning Signal Flasher -- is also pertinent to this study. This practice mainly stipulates the starting time of the flashers, the allowable voltage drop, and the flash rate and percent current "on" time. Also, the flashers are required to pass a durability test -- they must be able to flash continuously for 36 hr. in an ambient temperature of 75 ± 10 F.

There are two SAE standards that apply specifically to emergency flashing lights. One of these is SAE J595, Flashing Warning Lamps for Authorized Emergency, Maintenance, and Service Vehicles. In this standard, all the tests of Standard J545 except the out-of-focus test apply. The warning lamp color should be amber or red, and each vehicle should be equipped with two flashing lights in front and two in back. These lights should be mounted as high and as far apart as possible, and the front warning lamps should be clearly distinguishable from the low-beam headlights. In addition, the standard recommended that the warning lights should be unobstructed by any part of the vehicle 10 deg above to 10 deg below the horizontal of the vehicle and from 45 deg to the right to 45 deg to the left of the centerline of the vehicle. Finally, it was stated that the lamps should flash no less that 60 but no more than 120 flashes per minute, and that the vehicle surface area on which the flasher is mounted should be painted black. The minimum candlepower requirements of a flasher are summarized in Table 1 of the standard.

The other standard directly applicable to emergency warning lights is SAE Recommended Practice J845, 360 Deg Emergency Warning Lamp. This standard, like J595, includes all the tests of J545 except the out-of-focus test. The lamp should be red or amber in color (using one of the test methods of J678) and should flash between 60 and 120 flashes per minute. In addition to the tests from SAE J545, the unit also has to pass extreme temperature tests. The test unit is first subjected to an ambient temperature of 120 F for 6 hr. From the beginning of the sixth hour to the conclusion of the test, the unit will be operated continuously and the flash rate must not be greater than 130 flashes/minute. In the cold test, the device is subjected to an ambient temperature of -25 F for 6 hr. As in the heat test, from the beginning of the sixth hour to the end of the test the unit will be operated continuously; the flash rate must not be less than 50 flashes/min. Photometric tests are specified both for devices that flash by current interruption and for those that flash by rotation or oscillation, and the photometric minimum candlepower requirements are listed in Table 1 of the standard. In addition to the requirements of the standard, it is also recommended that the emergency warning lamp be mounted so as to provide 360 deg visibility at all times.

B.4. SPOTLIGHTS

One standard on spotlights has been obtained and that is SAE J591, Spotlamps. This standard defines a spotlight as a lamp which provides a parallel beam of white light, can be aimed at will, and is essentially round or oval in shape. The tests of a spotlight are those listed under SAE J575 with the exception of the photometer, out-of-focus, and warpage tests.

B.5. CONCLUSIONS

In conclusion, the standards and specification which have just been summarized appeared to be too brief in most cases to be very helpful; this was further complicated by the use of confusing and unclear language in the text of the standard. Too often, more questions were raised by a standard than were answered. For example, why are only red and amber lights permitted on emergency vehicles? Why were blue lights not specified at all? Why was the 360 deg warning lamp subjected to extreme temperature tests when the emergency warning flashers were not? What constitutes a "heavy growl" or a "shrill shriek"? These and other questions of this same nature will have to be answered by the National Bureau of Standards if a creditable standard for emergency warning equipment is to be written.

APPENDIX C.

NBS ACOUSTICS FACILITIES

C.1. FIELD TEST SITE AND PROCEDURES

The research runway at the Wallops Station, Virginia, facility of the National Aeronautics and Space Administration was used as a pilot test site for the field testing phase of the program. This location provided an adequate stretch of pavement and a flat terrain which had a well-defined reflecting surface without any unusual reflection and attenuation effects. An agreement was reached with NASA for utilization of this facility for this phase of the program.

On the 8750 foot length of research runway 4-22 (bearing 040° and 220°), a 1000 foot test section was established. The test section begins 5700 feet from the northeast end of the runway and extends to 6700 feet. The nominal runway width is 150 feet. The test vehicle ran on the asphalt surface, where a lane was marked which was 12 feet wide and 12 feet in from the edge of the runway. Figure 9 shows an overall view of the research runway and the location of the test section.

C.1.1. Instrumentation and Siren Test Procedure

Prior to a discussion of the test procedure, a few words of description are necessary to establish the placement of all instrumentation at the test section. Figure 10 shows the placement of the microphones, photosensors, and the path of the test vehicle. The same instrumentation was used for passbys and for tests with the test vehicle stationary.

The microphones, six in all, were located along a line perpendicular to the path of travel of the test vehicle. The array itself was located 250 feet from the northeast end within the test section. Photosensors, activated by a light beam from a spotlight mounted on the side of the test vehicle, were located along the test lane parallel to the path of the vehicle. Although not shown in figure 10, the mobile instrumentation van was located 500 feet back from the edge of the runway. Coaxial cables connected the microphones and photocells with the tape recording and monitoring equipment housed in the instrumentation van. The 500 foot distance complied with an airfield ruling and also avoided unwanted reflection effects.

When a passby test was performed, as the test vehicle passed the initial photocell a signal was generated which commanded the tape recorder (located remotely in the instrumentation van) to turn on. The initial photocell was located so that by the time the vehicle passed photocell No. 2, the tape recorder was up to speed and data could be recorded. The signal from each microphone was recorded on one of the six channels of an F.M. tape recorder. The siren noise was recorded during the entire passby over the 1000 foot section. When the light beam struck the photocells, voltage spikes resulted which were recorded

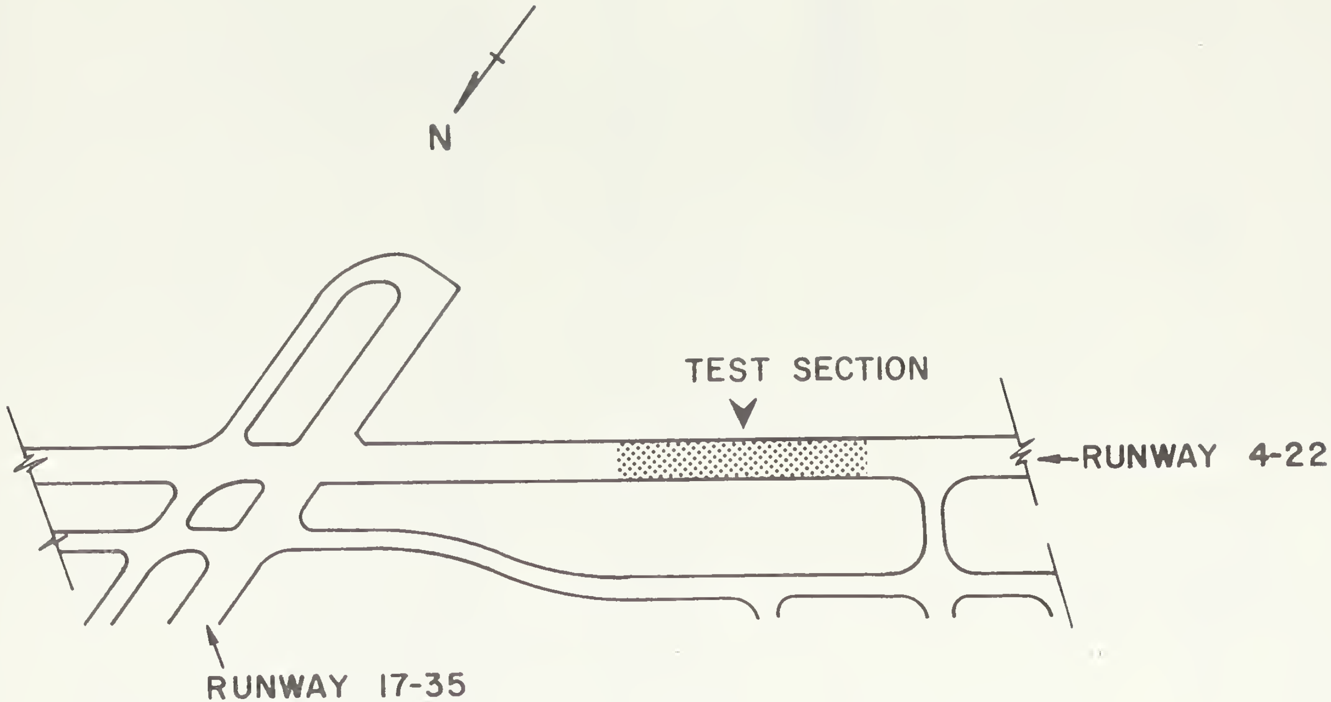

Figure 9. Plan of research runway 4-22 Wallops Station, Virginia, showing the location of the test section used for field measurement of the sound levels produced by sirens.

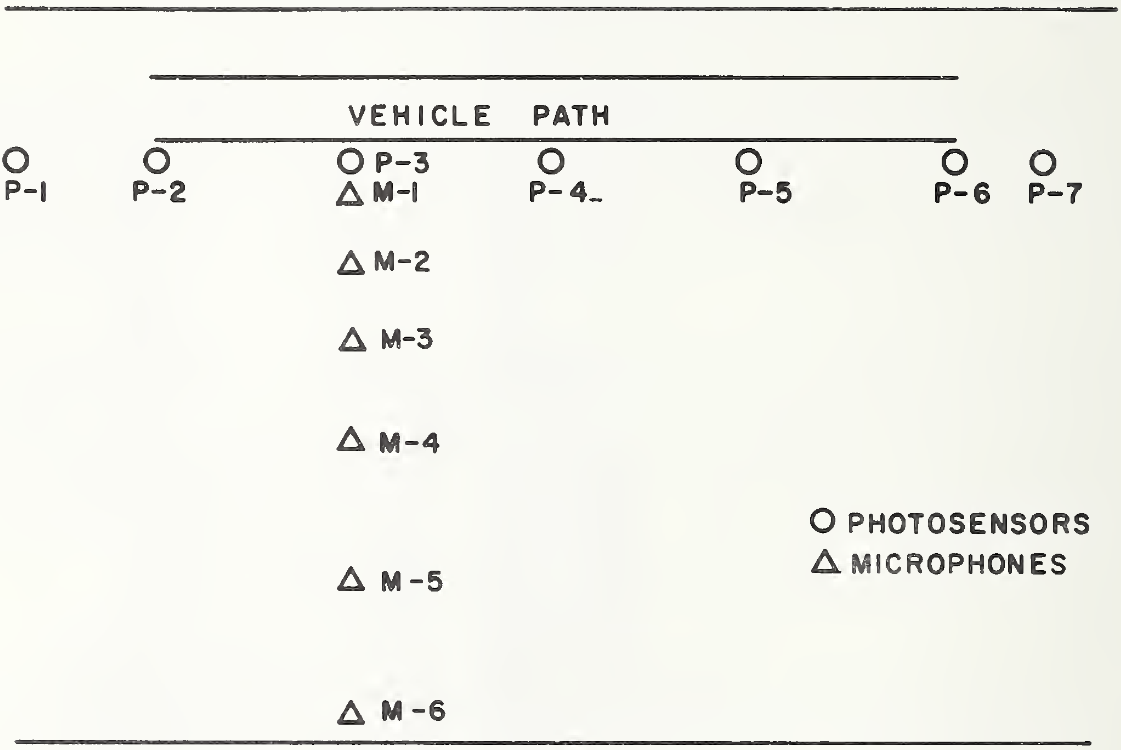

Figure 10. View of test section utilized for field measurement of the sound levels produced by sirens. The drawing shows instrumentation placement and vehicle path (not to scale). Microphones were spaced at various distances as measured from the center line of the lane in which the test vehicle travelled and along a line perpendicular to the path of the vehicle. Photocells 2, 3, 4, 5, and 6 were spaced 250 feet apart. Photocell No. 1, which remotely turned on the tape recorder, was placed far enough before photocell No. 2 to provide the five seconds necessary for the tape recorder to come up to an operating speed of 30 in./s. The final photocell, located immediately adjacent to photocell No. 6, remotely turned off the tape recorder.

on the seventh channel (direct record) of the tape recorder. The photocells (photocells No. 2, 3, 4, 5, 6) were located 250 feet apart along the test section. The "blips" produced by the photocells provided information on vehicle position versus time which was used for the calculation of vehicle speed and position. As the vehicle left the test section, a final photocell was triggered which remotely stopped the tape recorder. The function sequence of the photocells was reversed for passbys in the opposite direction.

C.1.2. Recording Instrumentation

Figure 11 identifies the components that constituted the data acquisition system. All microphones were mounted on tripods at a height of 48 inches above the surface of the roadway. All microphones were located along a line perpendicular to the path of the vehicle and spaced at distances of 6, 12, 25, 50, 80, and 130 feet from the centerline of the lane in which the test vehicle traveled. The rationale behind the horizontal locations was as follows. The 6-foot location was as near as the microphone could be placed to the passing vehicle. The 130-foot location represented the limit of the hard surface before the grass began. For tests with the test vehicle stationary, the siren on the vehicle was centered 21 feet from the single microphone which was used.

Consider a test vehicle passing an array of microphones as in figure 12. As the siren is sounded, it causes pressure fluctuations which travel as waves and activate the microphone's diaphragm into vibration. These variations are transduced into an AC voltage which is recorded for analysis at a later time. The microphone itself is a three-part subsystem comprised of a free-field microphone cartridge, protecting grid, and a microphone preamplifier. Long cables carry the signal from the microphone to the recording facility. To maintain the voltage level of the signal, some line amplification is essential. The microphone energizers, in addition to supplying the polarization voltage to the microphones, provide the capability for 20 dB amplification. Once the signal reaches the tape recorder, there exists a need for signal conditioning prior to actual recording. The electronic voltmeters provide the capability for amplification/attenuation. The meter scale gives an indication of whether or not a tape channel has become saturated (i.e., a signal exceeds the dynamic range of the recorder). The signal is then recorded on one track of the F.M. tape recorder. As the measurements are performed out-of-doors, windscreens are placed over the microphones to minimize the noise produced by wind passing over the microphone.

Figure 13 gives an overall view of the equipment arrangement within the mobile instrumentation van. All instruments are mounted in such a manner as to be easily accessible to the operator. Figure 14 shows a view of the instrument racks which contain the F.M. tape recorder as well as some calibration and system checkout instrumentation.

Calibration and system checkout are performed in two steps. The pistonphone produces a 124 dB sound pressure level (re 20 $\mu N/m^2$) at a frequency of 250 Hz. This single point calibration is used for system calibration in the field. Figure 15 shows a pistonphone calibration

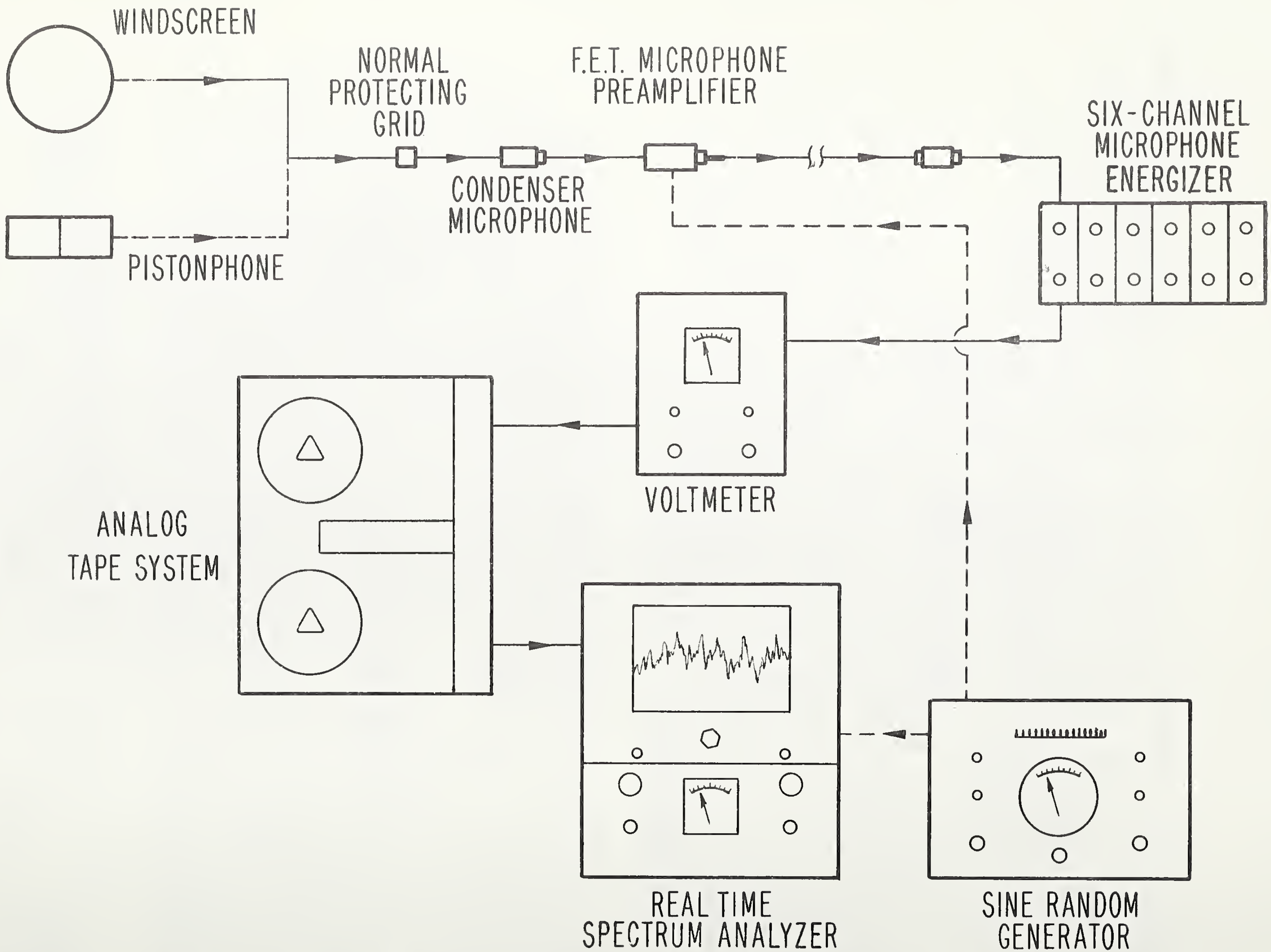

Figure 11. Data acquisition and recording system used for field measurement of the sound levels produced by sirens.

Figure 12. Overall view of the microphone array used to measure the sound levels produced by sirens -- a test vehicle (in this photograph, a truck rather than an emergency vehicle) is approaching. The array consisted of six tripod-mounted microphones located at various distances from the center-line of vehicle travel along a line perpendicular to the vehicle path.

Figure 13. The interior of the mobile instrumentation van used for recording the sound levels produced by sirens -- the instrument mounting arrangement is shown. The operator is adjusting the gain of the signal conditioners to insure optimum signal-to-noise radio. To the right of the operator is the real time spectrum analyzer including both the amplifier-filter section and the cathode ray tube display unit.

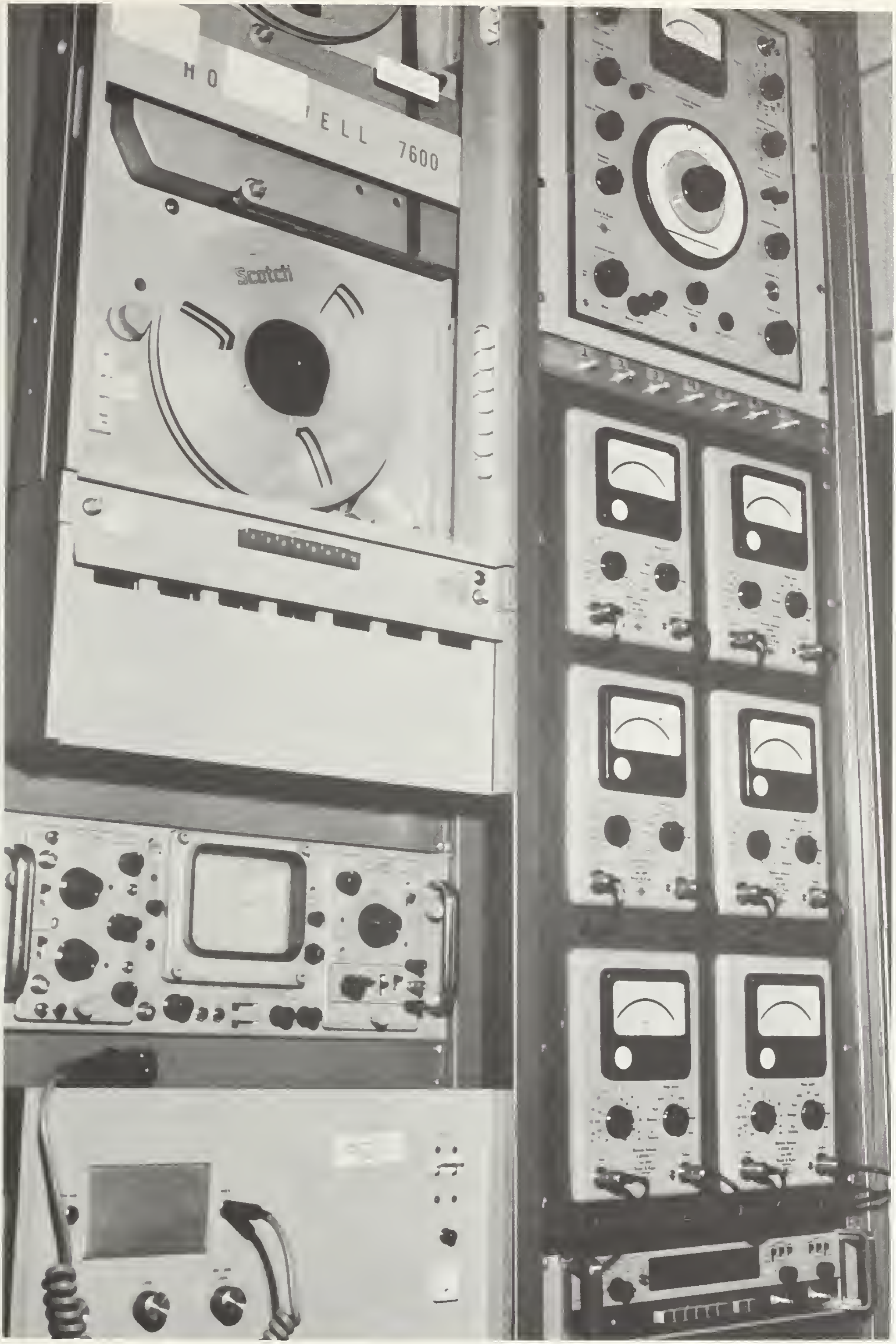

Figure 14. A detailed view of the recording and system checkout instrumentation used in conjunction with field measurement of the sound levels produced by sirens. The left rack contains the seven channel F.M. tape recorder plus an oscilloscope. A signal generator, six signal conditioners, and a digital counter are housed in the remaining rack.

Figure 15. The pistonphone, which delivers a 124 dB sound pressure level at 250 Hz, is shown being coupled to the microphone for the one-point calibration of the system utilized for field measurement of the sound levels produced by sirens.

being performed on one of the microphones. The system checkout also involves running a frequency response on the system. To perform this checkout, the microphone cartridge is removed and replaced with an adapter which allows the sine-random signal generator to be coupled into the system. The sine-random generator is capable of producing wide band "pink noise" which is white noise passed through a network which weights at -3 dB per octave. When a display unit, such as a real-time analyzer is coupled to the output terminals of the tape recorder, a flat frequency response (constant energy per octave of bandwidth) can be observed. In general, a lack of low frequency response would be indicative of overloading of an amplifier and a lack of high frequency response would be indicative of an amplifier failure. This operation also establishes the integrity of all connecting cables. During actual testing, the real-time analyzer is used to provide some data with which to judge the progress of the testing prior to the later reduction and analysis of the data on the computer.

The real time analyzer in its mounted configuration is shown to the right in figure 13. The instrumentation van in its field configuration is shown in figure 16. Brief descriptions of the instruments are contained in section C.2 of this appendix. Reference to the schematics provides an understanding of the contribution of each instrument to the overall system.

C.1.3 Position - Velocity Sensing System

A battery-operated photosensor system for the determination of vehicle velocity and position with time during each run was designed and is shown in figure 17. A light source on the vehicle activated the photosensor and an appropriate signal was recorded on the direct channel of the tape recorder. The first sensor the vehicle passed was interfaced with the analog tape system so that activation of this sensor remotely started the tape transport and record electronics. This sensor was appropriately located so that when the vehicle passed the second sensor, the tape system was up to speed and data were taken. The final photosensor commanded the tape system to stop.

C.1.4. Data Reduction System

Once the preliminary data had been recorded at the test site, the analog tapes were returned to NBS for reduction and analysis. Figure 18 defines the equipment which was utilized for analysis purposes. Each was played back, a channel at a time, through the real-time analyzer. An interface-coupler was necessary to make the real-time analyzer compatible with a mini-computer. When a timing signal appeared on the analog tape, the real-time analyzer was commanded to begin analysis; once all data had been analyzed in one-third octave bands, the computer stored the data and dumped it onto digital magnetic tape. This tape was formatted to be acceptable to the large NBS computer which was utilized for further analysis and graphical plot generation. This instrumentation system provided for efficient data acquisition and data handling of the thousands of data points generated for each vehicle passby or stationary-vehicle test.

Figure 16. The mobile instrumentation van, utilized for measurement of the sound levels produced by sirens, is shown in its field station. The wires strung on stakes in front of the truck are the signal wires between the microphone array and the recording facility within the van.

Figure 17. A closeup of one of the photosensors used to determine the position and velocity of emergency vehicles during field testing of the sound levels produced by sirens, shows the ± 18 volt battery pack and the tripod-mounted photodetector. The minibox contains the electronics while the integrating sphere houses the photodetector.

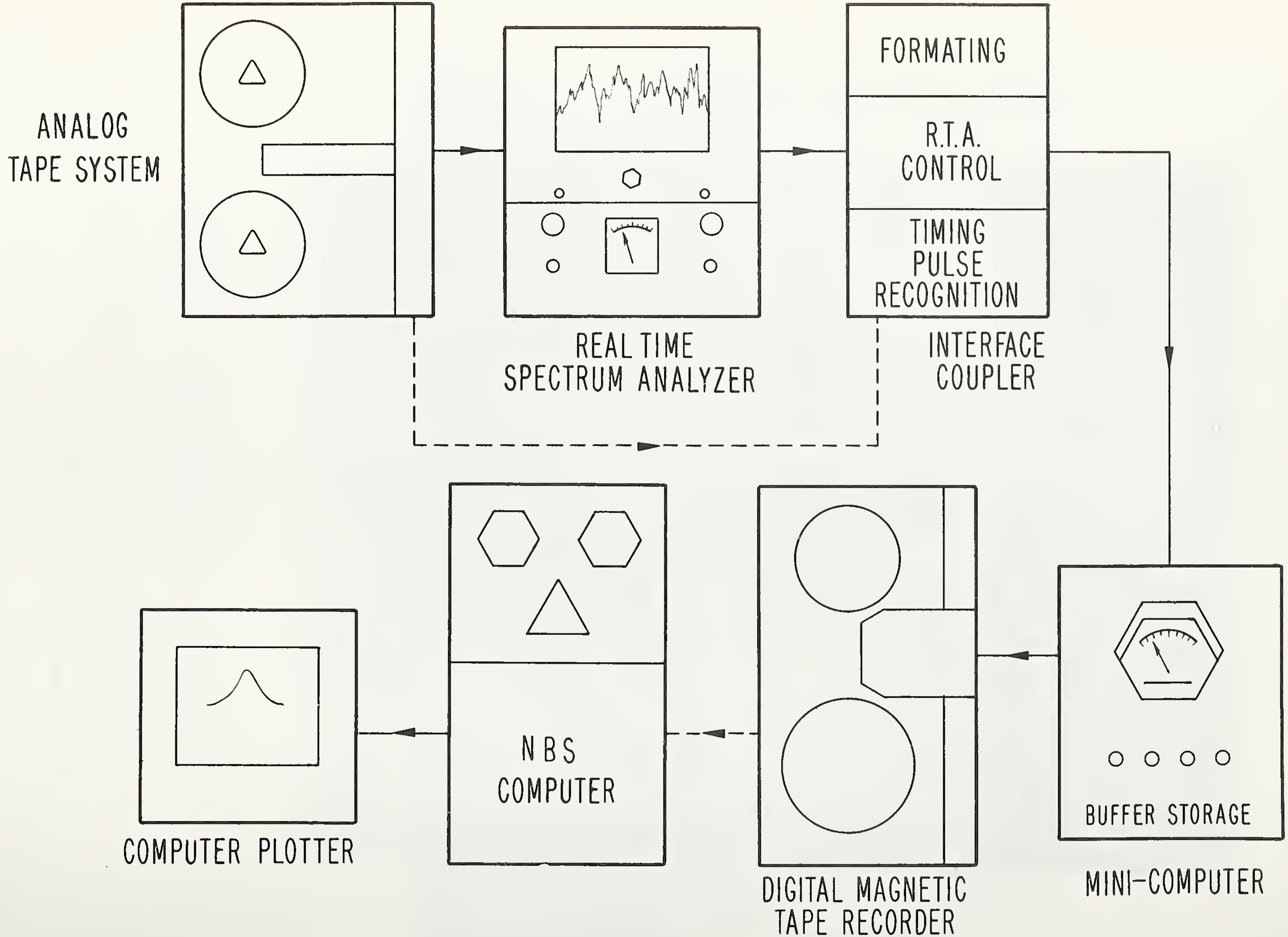

Figure 18. Data reduction and analysis system utilized to analyze tape recordings of the sounds produced by emergency vehicle sirens under simulated field conditions.

C.2. DESCRIPTION OF ACOUSTIC TESTING INSTRUMENTATION

Unless otherwise stated, all instruments are Bruel and Kjaer* (B&K).

Type UA 0207 Windscreen

When a microphone is exposed to wind, the turbulence created around the microphone and wind velocity variations cause a noise to be generated due to a variation of air pressure on the diaphragm. To reduce this extraneous wind noise, a spherical windscreen constructed of specially prepared porous polyurethane sponge was utilized.

The use of any windscreen requires that corrections be made to the sound pressure level measured to account for the presence of the windscreen. Free field corrections for the windscreen will be made.

Type 4220 Pistonphone

This instrument is a small, battery operated precision sound source which provides quick and accurate direct calibration of sound measuring equipment. When fitted to a B & K microphone, the pistonphone produces a sound pressure level of 124 ± 0.2 dB, re 20 $\mu N/m^2$, at a frequency of 250 Hz ± 1% (controlled by means of a transistor circuit). Maximum stability and very low distortion (less than 3% at 250 Hz) result from the piston arrangement consisting of two pistons moving in opposite phase. The calibration of the pistonphone is performed at normal atmospheric pressure. Ambient pressure corrections are necessary for pressures other than 760 mm Hg. This calibration is not influenced by relative humidities up to 100% or temperatures within the range of 0 - 60 °C (32 - 140 °F).

Microphone

When one speaks of a microphone, a three part system is implied: (1) a protecting grid; (2) a condensor microphone cartridge; and (3) a microphone preamplifier or cathode follower. For this testing the following components were utilized.

Type 4145 one-inch condensor microphone

The one-inch free-field condensor microphone is of the omnidirective type possessing relatively high sensitivity and covering a range of applicability from 20 Hz to 18 kHz (frequency) and 15 dB to 146 dB (pressure). The most outstanding feature of these microphones is long term stability under a variety of environmental conditions and insensitivity to temperature variations. Condensor microphones, in addition, were chosen because of their higher dynamic range, ease in calibration and uniform frequency response. The cartridge which houses the microphone diaphragm is protected by the grid on one side and on the other is screwed onto the preamplifier.

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*Commercial instruments are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the equipment identified is necessarily the best available for the purpose.

Type 2619 half-inch FET preamplifier

This preamplifier features a very high input impedance field effect transistor input, which presents virtually no load to the microphone cartridge. To mate the 2619 with the 4145 a suitable adapter must be utilized (Model DB-0375).

Built onto the preamplifier itself is a 6.3 V heating coil to prevent condensation when operation must be carried out in cold or humid environments.

The above described microphone subassembly provides reliable operation over a wide range of temperature, humidity and vibration and allows precision sound pressure measurements to be made over a wide frequency and dynamic range.

Type 221 microphone energizer

This unit houses a six channel microphone power supply with individual line driving amplifiers. In conjunction with the type 2409 signal conditioners, the microphone energizer provided the necessary gain and impedance match to supply the multi-channel tape recording system.

Type 2409 electronic voltmeter

These vacuum tube voltmeters cover the frequency range from 2 Hz to 200 kHz and provide signal conditioning (signal amplification or attenuation) prior to F.M. tape recording. The instrument consists of a calibrated attenuator, a stabilized amplifier with cathode follower stages in the input and output circuits and a moving coil meter equipped with special rectifier circuits for the measurement of true RMS, average or peak values with either small or high meter damping characteristics. The screened output terminal enables the instrument to operate as a calibrated amplifier featuring a low output impedance and an amplification of 60 dB max., variable in 10 dB steps. A built in reference voltage makes it possible to check the sensitivity of the instrument by simply turning a knob. A screwdriver operated potentiometer is available to correct any possible deviations.

Frequency response	:	Linear to within ± 0.2 dB from Hz to 200 kHz.
Meter accuracy	:	Better than 1% of full scale at 1000 Hz.
Distortion	:	Less than 0.2% with an output voltage of 10 volts.
Stability	:	For a 10% variation in the line voltage the meter deflection will change less than 2%.

Model 7610 medium band magnetic tape system (Honeywell)

A seven-channel instrumentation tape recorder with a bandwidth range from 0 - 80 kHz was selected for this program because of its low and uniform frequency response. The model purchased can be expanded to a full fourteen channels with the addition of the record/reproduce electronics for the additional channels and a modification of the heads and hub to accomodate the one-inch tape (7 channel recording utilizes 1/2 inch tape).

The wide bandwidth range results from a feature which allows the selectability of three different modes of operation:

(1) Standard : 0 - 20 kHz at 120 ips
(2) Extended : 0 - 40 kHz at 120 ips (0 - 10 kHz at 30 ips)
(3) Double Extended: 0 - 80 kHz at 120 ips

The present unit has six channels of F.M. record electronics and one channel of direct record electronics. One channel of F.M. and one channel of direct reproduce electronics are in the system. In addition, a voice record/reproduce amplifier unit is included. The voice is recorded on the edge track of the tape.

Additional features include a phase lock servo control system, a tape footage counter, a shuttle, electrically selectable tape speeds (seven in all) ranging from 1-7/8 ips to 120 ips, and pushbutton selectability of the reproduce channel.

Type 3347 real time analyzer

The real time analyzer is composed of two basic units: (1) type 2130 frequency analyzer and (2) type 4710 control and display unit.

The 2130 contains a measuring amplifier, filter channels with 1/3-octave bandwidth, a linear channel, weighting channels, true RMS detectors and the synchronization system for scanning the channels.

The analyzer contains 38 parallel channels. 33 of these channels contain 1/3 octave filters with center frequencies from 12.5 Hz to 20 kHz. The remaining five channels are reserved for the four weighting network filters -- A, B, C and D -- and one linear response channel.

The 4710 contains the circuitry for the 12-inch cathode ray tube (CRT), the Nixie displays, digital readout, and the logic control. The logic control section controls the analog/digital conversion and the communication sequence for external systems, as well as the internal synchronization in the 3347 during display or read-out modes.

The level in each channel can be read in dB directly on the screen, while a Nixie display shows the output level of any selected channel. This channel is indicated on the CRT as a brighter trace. The complete channel display is renewed every 20 msec.

Outputs are provided for both analog instruments (X-Y or level recorders) as well as digital (on-line computer or tape puncher). The digital output is in binary coded decimal (BCD) code.

Time constants may be selected from 20 msec to 20 sec so that confidence limits can be maintained throughout the frequency range.

Type 1024 sine-random generator

This audio frequency generator is a multipurpose signal source. It covers a frequency range extending from 20 to 200 kHz and consists of a wide band noise generator, a beat frequency oscillator, several filters, amplifiers and an automatic output regulator. It is capable of producing three types of output signal: (1) sine waves, (2) narrow bands of random noise and (3) wide band random noise. Since this unit was utilized for calibration purposes (frequency response testing), wide band random noise or "pink noise" was generated. Pink noise is noise whose spectrum level decreases with increasing frequency to yield constant energy per octave of bandwidth. When in the wide band random noise mode, the frequency range is 20 Hz to 20 kHz with the frequency spectrum flat to within ± 1 dB.

Model 704 Raytheon Computer System

The Raytheon 704 computer system is a general purpose digital system that provided a 16-bit central processor unit with 900 nanosecond cycle time for on-line, real time applications.

The hardware configuration includes an 8K (expandable to 32K) memory system, direct input/output bus, automatic priority interrupt, direct and indexed addressing, and byte and word addressing and instructions. Standard peripherals such as high speed paper tape, ASR-33 teletype, card equipment and a magnetic tape unit are also included.

C.3. NBS ANECHOIC CHAMBER

The NBS Sound Section has recently completed the installation of a new, large anechoic chamber which is specifically designed to enable accurate, free-field calibration of acoustic transducers. This large, isolated chamber is lined with 6-foot deep fibrous glass wedges which absorb effectively all (more than 99%) of the incident sound energy at frequencies above 50 Hz. The free-field dimensions of the chamber are 33 ft. x 22 ft. x 22 ft. This chamber, used in conjunction with calibrated microphones and measuring systems, permits accurate determination of the free-field sound radiation characteristics of loudspeakers, horns and sirens.

APPENDIX D.
NBS PHOTOMETRY FACILITIES

D.1. INTRODUCTION

An emergency warning light consists of a light source and an optical system which together produce a beam of light. In the photometry of these devices, the intensity of the device as a function of angle of viewing is measured. A variety of techniques and equipment have been developed for tests on various types of sources.

Photometric testing is carried out on a photometric range by comparison of device output with a standard lamp of known luminous intensity in a specified direction. These comparisons are made with photosensors which are color corrected by filters so that the spectral response is similar to the CIE luminous efficiency function. Considerable care is required to keep the experimental errors within the desired limits.

A common example of an emergency warning light source is the PAR-type lamp which is a sealed reflector lamp consisting of a filament placed at the focus of a parabolic reflector with a glass cover. Another example is a light source placed at the focus of a Fresnel lens.

For measuring the luminous intensity of such a device, a photometer employing an electrical photosensor is used. The response of the photosensor is read or recorded on an electrical measuring device such as a self-balancing recording potentiometer. This response is a function of the illuminance on the face of the photosensor, and the illuminance is expressed by the inverse-square law as follows:

$$E = \frac{I}{d^2} \tag{2}$$

where $\underline{E}$ is the illuminance at the photosensor,
$\underline{I}$ is the luminous intensity of the light source, and
$\underline{d}$ is the distance between the light source and the photosensor.

The photometer is calibrated against a standard lamp of known luminous intensity in a specified direction, oriented in that direction at a known distance from the photosensor.

The emergency warning lights are mounted at one end of a photometric range. There are two ranges for the photometric measurement of these devices at the National Bureau of Standards. On the shorter range, the distance between the source and the photosensor can be varied to a maximum of 100 meters. On the longer range, this distance is a fixed 363 meters.

NBS has made photometric measurements of various kinds of sources, particularly those units used in airfield and aircraft lighting. Since these sources have been of many sizes, shapes, beam characteristics and intensities, a variety of corresponding procedures, techniques and equipment have been developed for their measurement. When photometric measurements are to be made, each source must be considered individually, and it is not possible to put forth any one general method for testing them. The intent of this appendix, therefore, is first to describe the photometric equipment most commonly used, with emphasis on its application to particular types of sources. Next, the theory and practical considerations of the various calibration procedures are discussed. Finally, there is a general description of the procedures used in these measurements.

The information and data contained herein have been obtained from many photometric tests of sources at NBS. Although this appendix deals specifically with photometry of emergency warning lights, the techniques and equipment mentioned are also adaptable to the photometry of other kinds of light units.

D.2. EQUIPMENT

D.2.1. Ranges

100 Meter Range

The 100 meter range is located in the basement of the NBS Metrology Building. The photosensor and standard lamp for calibrating it are mounted on a movable "photometer bar", shown in figures 19 and 20. By moving the photometer bar, a maximum distance of 100 meters can be obtained between the unit under test and the photosensor. The standard lamp can be moved in and out of the calibration position by remote control.

Test units are mounted on a goniometer, a device which can rotate the unit through known angles about a horizontal and a vertical axis. The test unit can then be set at a given angle with respect to one axis, and when photometric measurements are made, a traverse can be taken at this angle by rotating the goniometer about the other axis, thus obtaining an intensity distribution.

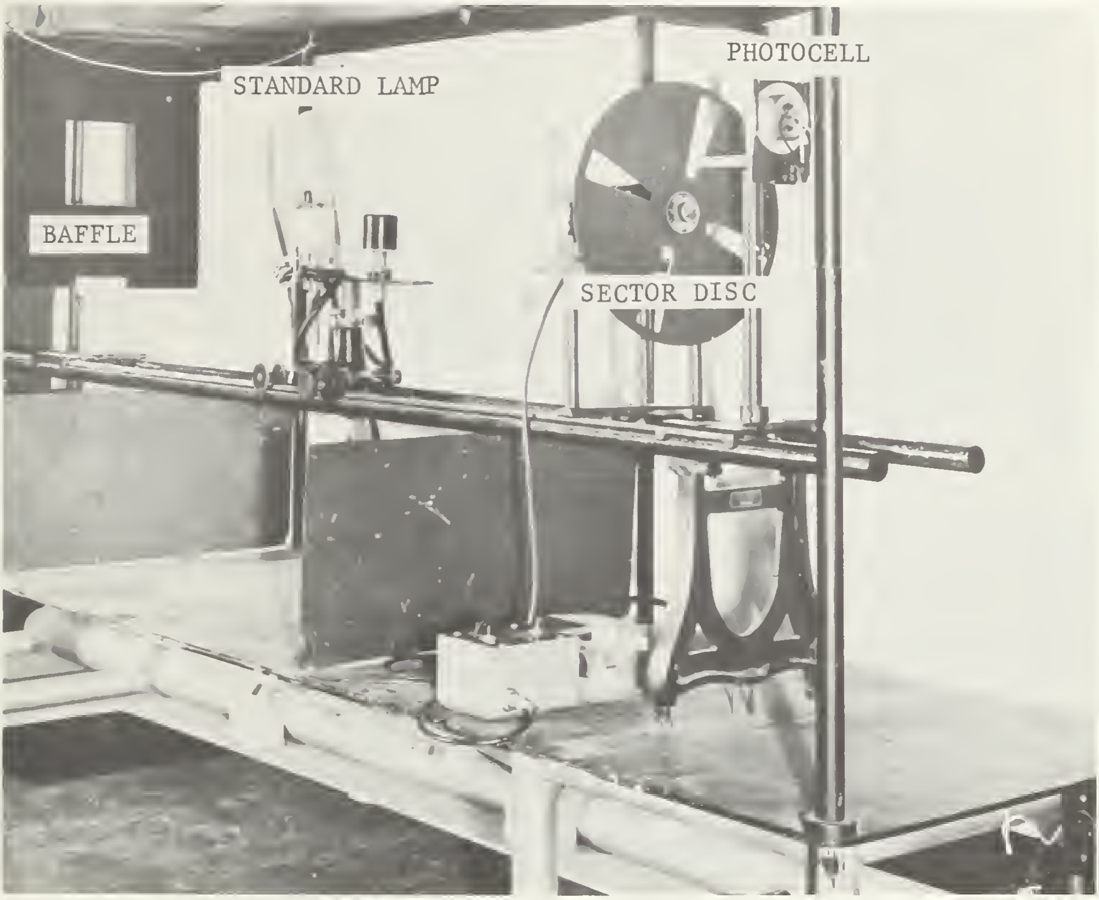

Figure 19. The Photometer Bar of the NBS 100-meter Range which can be utilized for photometric testing of emergency warning lights. Mounted on the bar is the equipment used in calibrating; however the shielding for stray light between the standard lamp and the photocell has been removed and a white background has been substituted for the normally black one.

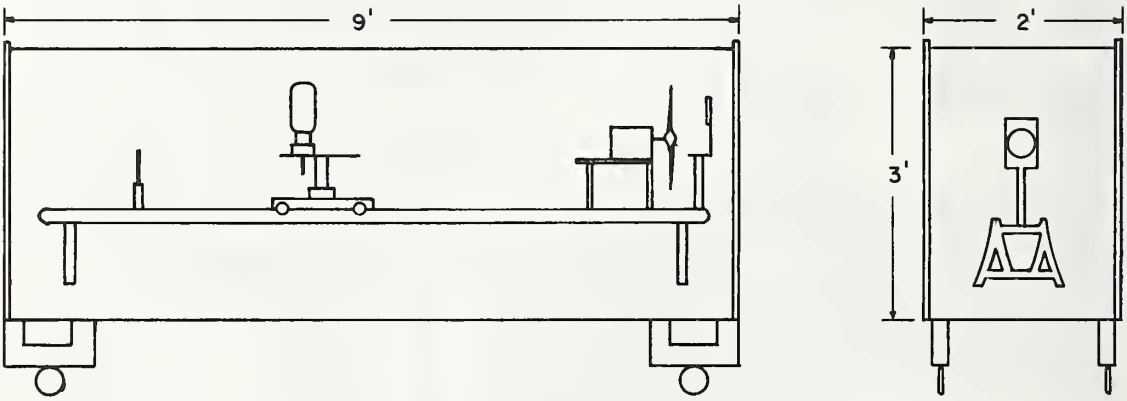

Figure 20. Dimensional diagram of the photometer bar in the NBS 100-meter Range. This bar supports the photosensor, and the standard lamp for calibrating it, which can be used to measure the output of emergency warning lights.

The goniometer which is located at one end of the 100-meter range is shown in figure 21. Units mounted on it can be rotated about a horizontal axis through two pivot points on the U-shaped inner frame. There are two rotary tables for horizontal traverses which permit the goniometer to be used as either a class A or class B goniometer as described by Projector [42]. The inner table on which the test unit is mounted is used almost exclusively, however. This table provides rotations about a secondary axis corresponding to the vertical, perpendicular to the horizontal axis which in this case is fixed. When the goniometer is operated in this manner, it is a class A goniometer.

Horizontal traverses obtained by rotating the larger table on which the outer frame is mounted result in rotations about a fixed vertical axis. When the goniometer is operated in this manner, it is a class B goniometer.

The goniometer is gear-driven in the horizontal and vertical directions and is usually turned by means of synchronous motors. When a self-balancing recording potentiometer is used to record the output of the photosensor, the recorder chart of the potentiometer is driven by another synchronous motor which is powered from the same source as is the goniometer motor. Gear ratios for the recorder and the goniometer can be varied to make available several choices of speed of rotation and chart speed, and hence provide a range of angular scales (degrees per division) on the chart.

One source of error in goniometry is the backlash of the driving gears. For horizontal traverses, the errors caused by backlash are minimized by running traverses in only one direction. In the vertical direction, backlash can result from inconstant torque and from the goniometer cradle passing through a balance position in the course of the traverse. To minimize these effects, with the test unit mounted on the goniometer the pinion gear on the vertical drive is disengaged, and the inner frame is balanced by means of the counterweights at the top of the goniometer. After this balancing, a constant torque is applied by means of a small weight at the end of a cable, which passes over a pulley connected to the vertical drive shaft [42]. The pulley and weight are seen to the left of the goniometer (figure 21).

In order to minimize the errors caused by stray light from spurious reflections, the photometer bar is provided with a series of baffles. One of these baffles is seen in figure 19 . In addition, there are adjustable baffles situated along the range between the goniometer and the photometer bar. The walls behind and around the goniometer and the background of the photometer bar are black. Additionally, there is a black curtain behind the goniometer that is pulled across when testing revolving or double-ended lamps.

The minimum test distance used in photometry of these sources is called the "minimum inverse-square distance" [43]. The illumination from the light source, measured at distances greater than this minimum, obeys the inverse-square law which is a necessary criterion for the determination of luminous intensity. The photometric distance is made greater than this minimum distance. The minimum inverse-square distance is determined by the type and size of the light source, lens, reflector, etc., and must be considered individually for each unit. If this distance is more than 100 meters (330 feet), the 100-meter range cannot be used.

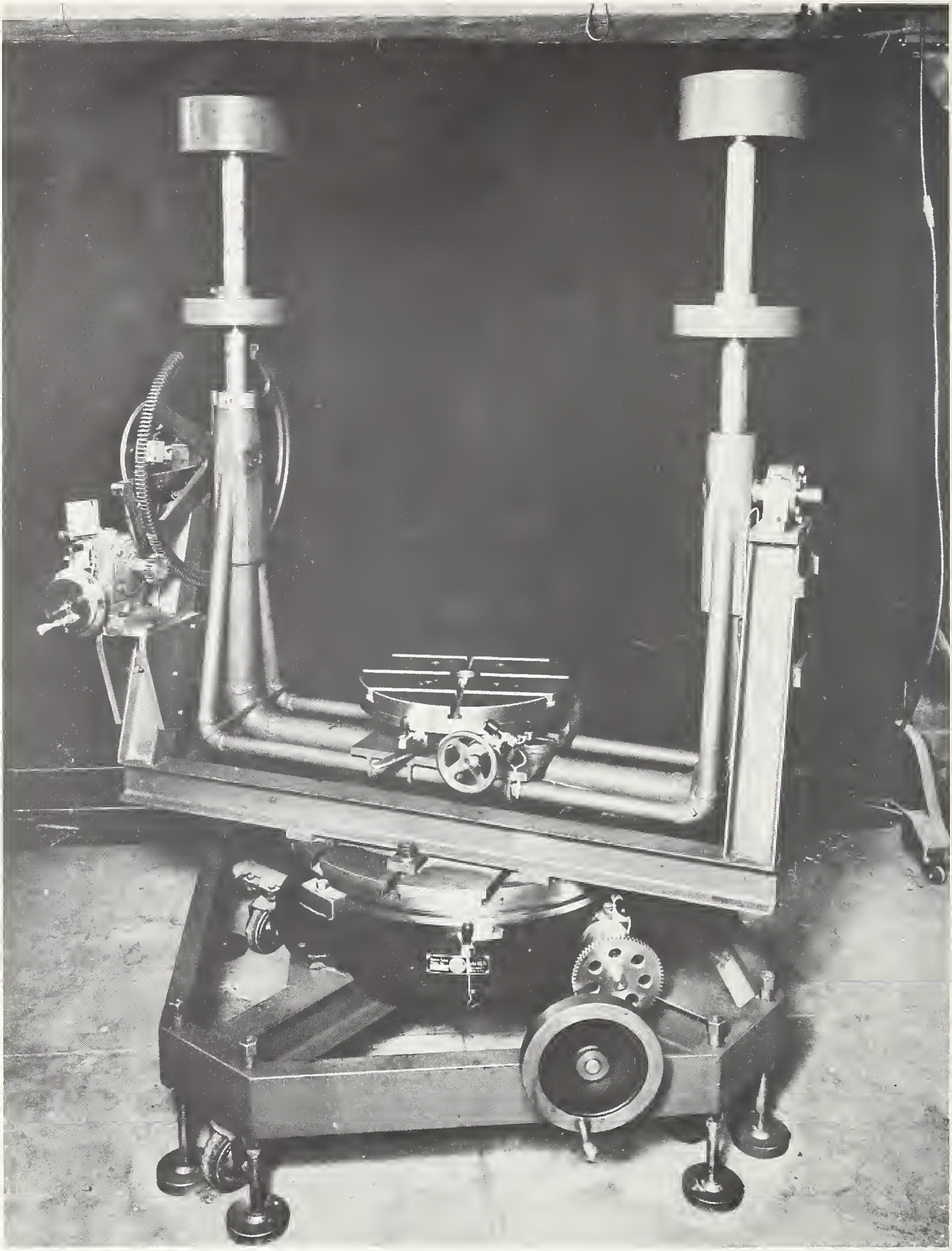

Figure 21. The Goniometer of the NBS 100-meter Photometry Range. This unit can be utilized to rotate on emergency warning light, through known angles about a horizontal and vertical axis, to enable determination of the angular variation of light intensity.

The case of the photometry of a searchlight with a finite sized light source and emitting a collimated beam is shown in figure 22. For this light source, the angle subtended by the optic (reflector) of the searchlight at the photosensor must be less than the angle subtended at the point on the reflector farthest from the light source by the smallest projected dimension of the light source. If the reflector is viewed through a telescope at the position of the photosensor, the reflector will then appear bright over all the aperture.

From these considerations, the minimum inverse-square distance, L_o, is given by

$$L_o = \frac{ad}{6s} \qquad (3)$$

where L_o is the minimum inverse-square distance (in feet),
a is the distance from the point on the reflector that is farthest from the light source to the axis of the searchlight (in inches),
d is the distance from the light source to point "a" (in inches),
s is the smallest projected dimension of the light source as viewed from point "a" (in inches).
and $\underline{6}$ results from the mixture of length units.

To illustrate, these considerations may be applied to the photometry of two different sealed reflector lamps of the PAR-64 type, one with a 300 watt, 6.6 ampere (45 volt) filament, and the other with a 120 watt, 20 ampere (6 volt) filament. These lamps have the same overall dimensions and differ only in the size and construction of the filaments. Both lamps have clear covers and parabolic reflectors, and both emit collimated beams of light. For both lamps, the dimension a is 3.7 inches and the dimension d is 3.8 inches.

The filament of the 300 watt lamp is of the CC-6 type. That is, the filament wire is wound in a helix, and the helix is again wound into a larger helix. The axis of the larger helix is perpendicular to the axis of the reflector. The smaller helix is wound so tightly that its diameter can be considered the smallest dimension of the light source, and its projected dimension, dimension s, is this diameter, 0.033 inch. L_o is therefore 70 feet, which permits the lamp to be photometrically measured on the 100 meter range.

The filament of the 120 watt lamp is of the C-6 type. The filament wire is wound into a single helix. This helix is wound so loosely that the single turns of the coil can be discerned. Therefore, the diameter of the filament wire itself, 0.020 inch, is considered its smallest projected dimension. L_o is 120 feet, and on this basis this lamp also could be tested on the 100 meter range.

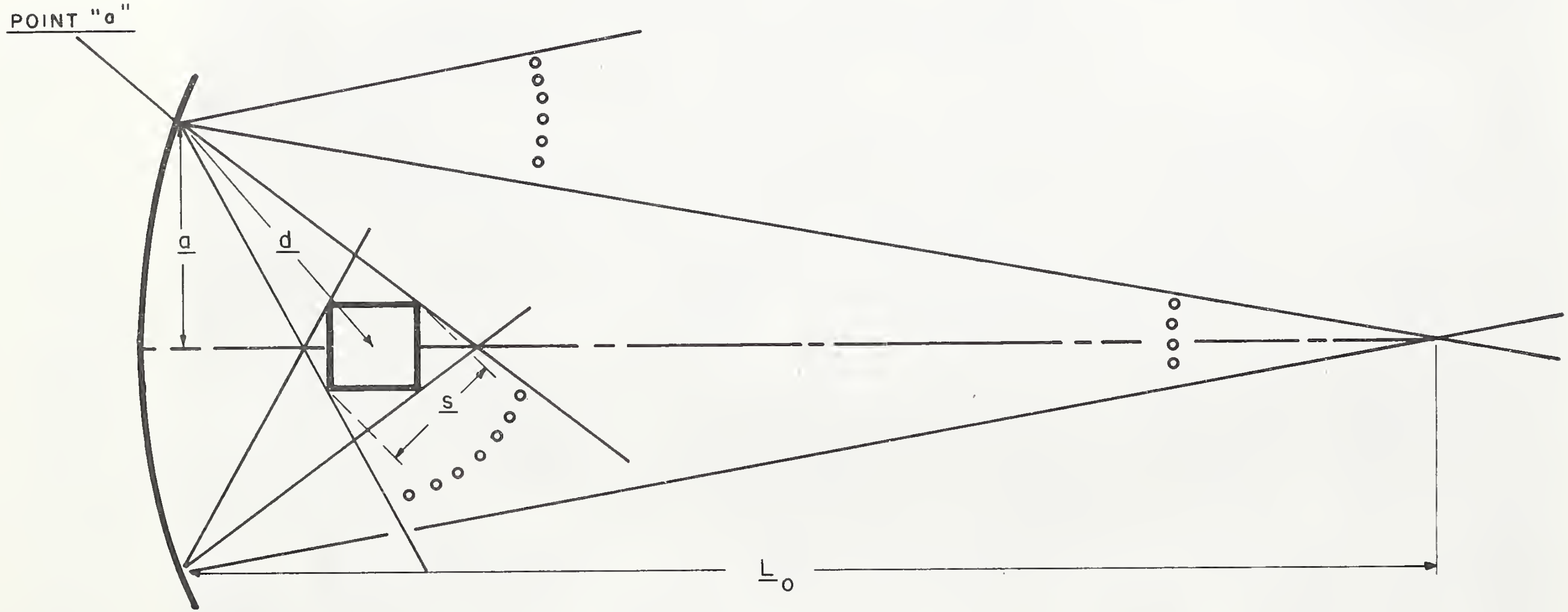

Figure 22. Diagram for the determination of the "Minimum inverse square distance"- The dotted lines subtend equal angles. This diagram assists in determining how far one must be from an emergency warning light in order to make measurements of light intensity which can confidently be extrapolated to still longer distances.

The above discussion for the determination of the minimum inverse square distance is exact only for axial measurements. For measurements off the axis, test distances of two or three times these computed minimum inverse square distance are sometimes required but are often impractical. Measurements near the axis are usually the most important in the testing of these sources; test distances only slightly greater than the computed minimum inverse square distances are necessary for most practical purposes [44].

363 Meter Range

As discussed above, a longer range may be required where the device to be tested has a broad source. Larger lights are usually tested on the 363 meter range. The detector and standard lamp are located in the attic of the Polymers Building. The goniometer, recording potentiometer and all electrical controls are located in the attic of the Chemistry Building. The distance between the photocell and the goniometer is fixed at 363 meters.

D.2.2. PAR Lampholder

A special holder for PAR-type lamps is used to facilitate the mounting of lamps of this type. The holder has been designed to be mounted easily on the goniometer on the 100 meter range and is shown in figure 23. A set of removable mounting rings makes it possible to mount any of the several sizes of PAR lamps on the holder.

The holder contains a telescope which is used to align the holder with a mark at the other end of the range so that the axis of the PAR lamp reflector will coincide with the photometric axis. It is therefore possible to remove the holder from the goniometer and to replace it at some future time, aligned as before.

D.2.3. Photosensors

The photosensors used in the photometric measurements are constant current devices which produce currents proportional to the illuminance on their faces. All photosensors used are color corrected by means of optical filters in order to make their spectral response similar to the CIE spectral luminous efficiency function. Two different types of photosensors are in general use, the barrier layer photocell and the vacuum phototube. Although photomultiplier tubes have a higher signal-to-noise ratio at low illuminance levels and a fast photo-optical response, the present detectors are superior, on balance, within their limits of operation. This superiority is based on a combination of stability, simplicity of power supply circuitry, and relative ease of correcting their color response to correspond closely to the CIE luminous efficiency function.

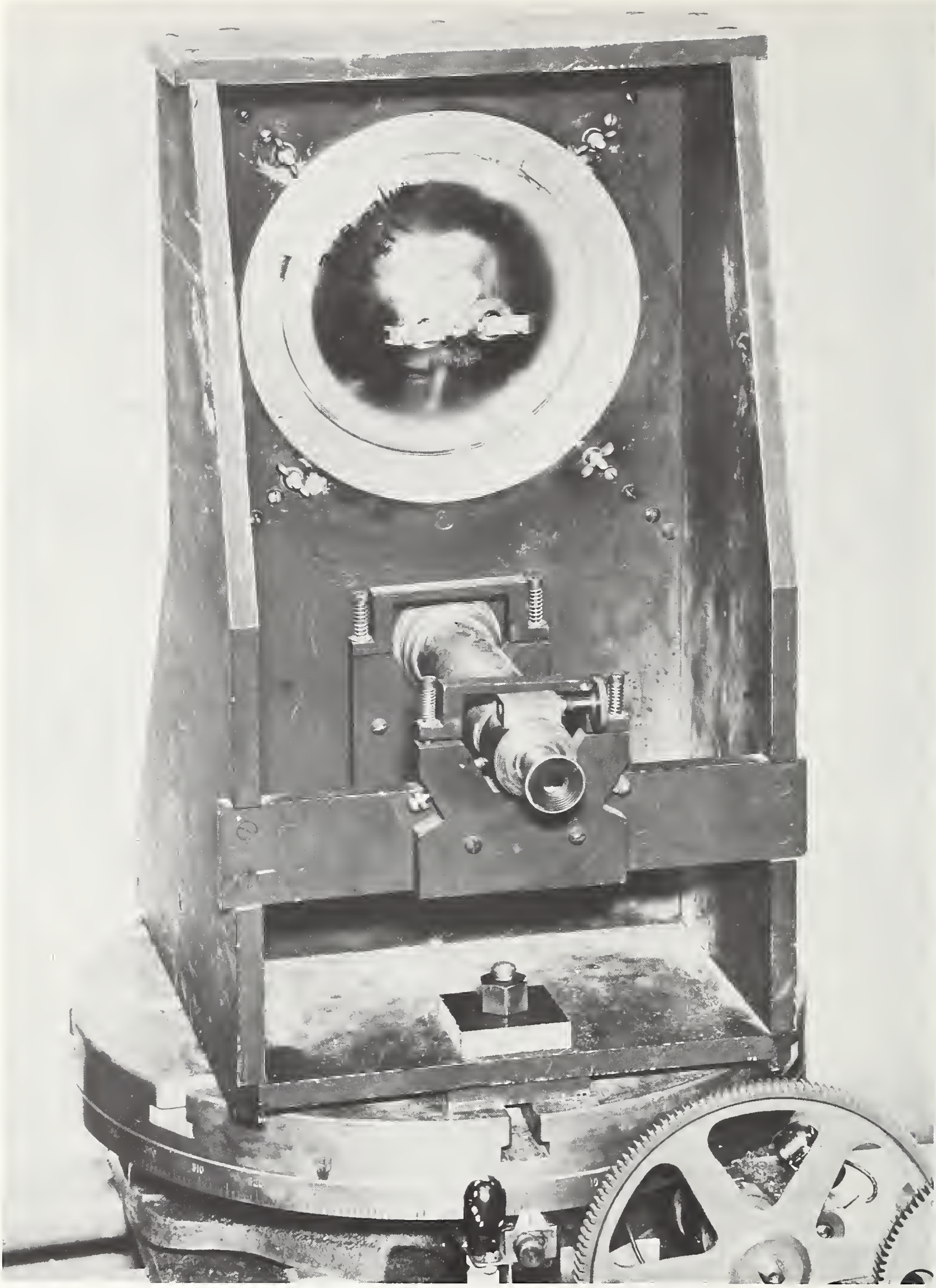

Figure 23. A rear view of the PAR Lamp Holder used to facilitate mounting of PAR-type lamps for testing in the NBS 100-meter Photometry Range. Seen are the telescope for aligning, the mounting ring, and the back of a PAR-56 lamp which has been mounted on the holder.

Barrier Layer Photocell

The barrier layer photocell, a solid state photoelectric device, is used in most of the photometric measurements. In the selection of a photocell for photometric testing, several cells which have been color corrected by means of color-correcting filters are checked for linearity and similarity of spectral response to the CIE luminous efficiency function. In order to check the adequacy of the color correction, the luminous transmittance of several colored filters for light of a specified color temperature is measured with these photocells. These measurements are compared with transmittances determined from spectrophotometric measurements. The results of one such series of measurements, using a lamp operating at Source A (color temperature 2854 K) are given in table 1.

The photocells with good color response are then tested for linearity and the one most nearly linear in its response is selected for use. The response of the photocell being used at present, cell number 3 of table 1 was found to be linear to better than 0.1% in the most useful range. This is sufficiently linear for photometric testing. The linearity was tested using several standard lamps of known horizontal intensity in turn at distances from 1 to 30 meters from the photocell. The results of the linearity measurements of this photocell are shown in figure 24.

The barrier-layer photocell is used with two different circuits. For most photometric work with this type photocell, an external shunt is used. The voltage drop across the shunt is amplified by means of a linear amplifier, and the output of the amplifier is recorded on the recorder chart of a self-balancing potentiometer. This circuit is shown in figure 25. However, when greater precision is required in the measurements, or when the illumination of the face of the photocell is either very large or very small, a "zero resistance" circuit is employed, and intensity measurements are made by using a Kohlrausch potentiometer [45 46]

Vacuum Phototube

For flashing lights of short flash duration such as condenser-discharge lights, and for lights of very low intensity, a G.E. type PJ-14B vacuum phototube is used [47]. In the photometry of flashing lights, it is desirable to compute the effective intensity of the flash which is determined from a measurement of the average intensity of the flash. The effective intensity of a flashing light is equal to the intensity of a steady-burning light of the same color which will produce the same visual effect under identical conditions of observations [48].

Table 1. Color Response of a Group of Barrier-Layer Photocells with Filters

Color	Filter Characteristics for Source A			Transmittance Ratio #					
	x*	y**	T***	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Red	.725	.275	.0410	1.17	1.04	1.00	1.20	1.13	.98
"	.687	.313	.222	1.07	1.00	1.00	1.07	1.05	1.03
"	.648	.351	.324	.97	.95	.94	.94	.96	.94
Yellow	.630	.370	.427	1.02	1.00	.99	1.02	1.01	1.00
"	.578	.421	.612	1.02	1.01	1.01	1.02	1.01	1.01
"	.554	.444	.725	.97	.97	.97	.97	.96	.95
Green	.233	.679	.0370	.98	.98	1.01	.96	.94	.96
"	.310	.573	.201	.97	.97	1.00	.96	.94	.96
"	.350	.450	.409	1.00	1.01	1.02	1.00	.99	1.00
Blue	.160	.080	.020	1.01	.98	.99	.95	.96	1.00
"	.162	.293	.140	.90	.90	.92	.87	.88	.97
"	.320	.329	.250	.87	.88	.88	.88	.87	.87

Ratio of transmittance measured by photocell to transmittance determined from spectrophotometric measurements

* x-coordinate on the CIE chromaticity diagram

** y-coordinate on the CIE chromaticity diagram

*** Luminous transmittance of the filter as determined by spectrophotometric measurements

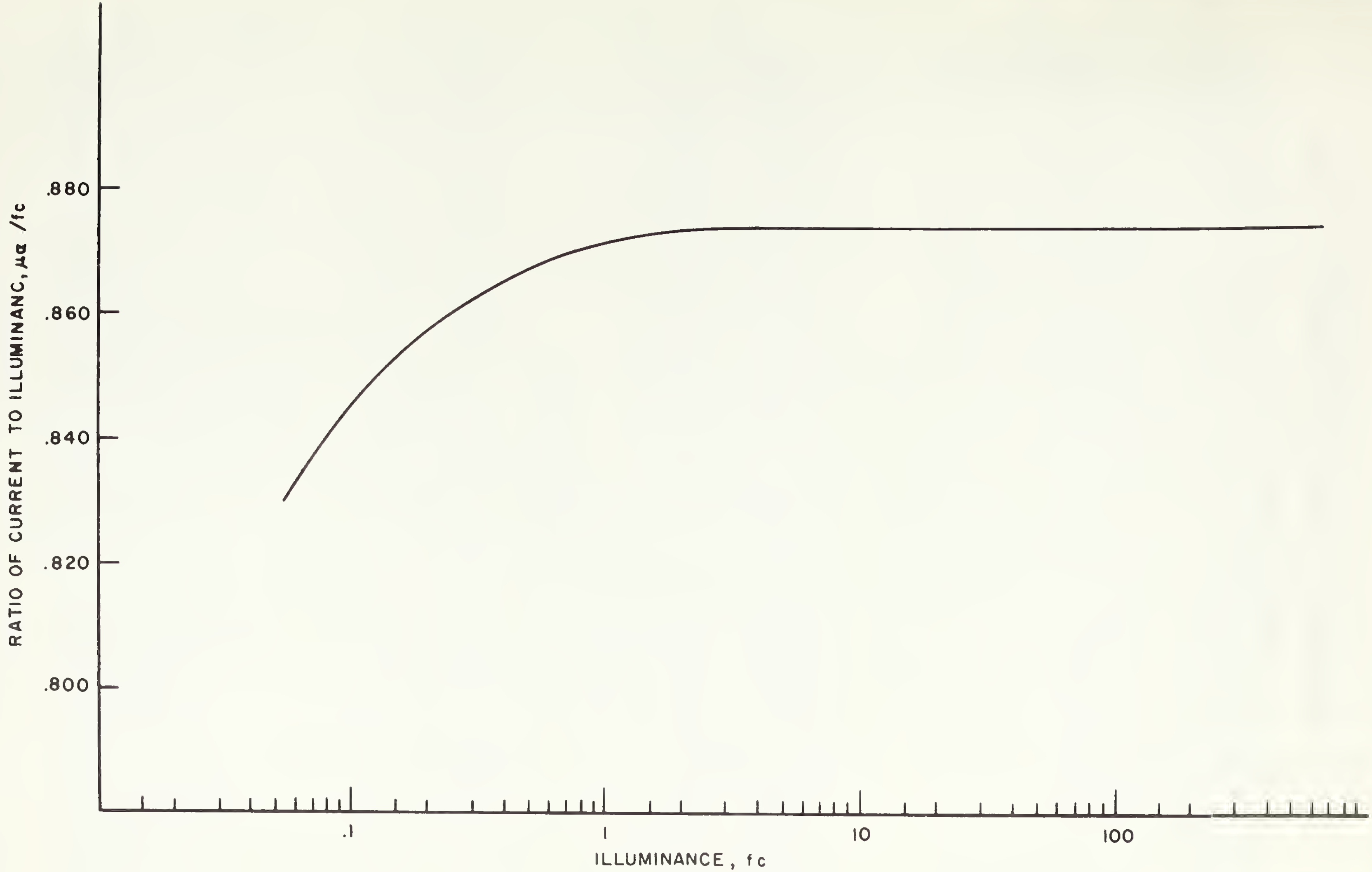

Figure 24. Linearity of response for a selected barrier-layer photocell of the type used as a detector in photometric testing of many types of lights. Note--Voltage drop across photocell did not exceed 1 millivolt.

D.3 CALIBRATION OF THE PHOTOMETRIC SYSTEM

D.3.1. Introduction

Lamp standards of luminous intensity are used to calibrate the photometric testing equipment; a separate calibration is made before each test, and a record is kept of the photometer sensitivity in order to detect any irregularities. The illumination of the photosensor produced by the standard lamp is adjusted to some typical value of the illumination produced by the test light, usually in the range of 75% to 100% of the peak illumination produced by the test light. This procedure minimizes errors resulting from nonlinearity of the response of the photosensor. The adjustment of the illumination of the standard lamp on the photosensor is accomplished by varying the distance of the standard lamp from the photocell and by using optical attenuators. The photometer is usually calibrated so that it is direct reading in luminous intensity.

D.3.2. Standard Lamps

The standard lamps used are "working standards" whose luminous intensity in a given direction has been determined at a given voltage. Standard lamps are available ranging in intensity from about 8 to 900 candles. When a colored light is being tested, a filter is placed between the standard lamp and the photosensor, which results in a standard lamp-filter combination having approximately the same spectral characteristics as those of the light to be tested. This procedure minimizes errors resulting from inadequate spectral correction of the photosensor. In this procedure, a standard lamp of known color temperature as well as of known luminous intensity is needed.

D.3.3. Attenuators

Sector disks are almost always used for light attenuation, although neutral filters are also available. A sector disk is usually placed between the standard lamp and the photosensor to calibrate the photometer for the proper range of illumination. However, when the intensity of the light being photometrically measured is unusually high, the sector disk may be used to attenuate the illumination from the test light. The range of sector disks available is from 1% to 80% transmittance.

When a sector disk is used, it is placed within a few inches of the photocell in order to reduce error from stray light. The disk is rotated at a few hundred revolutions per minute, which is fast enough to minimize error from apparent flicker. When a high illumination is attenuated by a sector disk of low transmittance, there is an error which results from only one part of the photocell being illuminated at a time; this error is successfully eliminated by placing a condenser of about 4 mfd. across the output of the photocell. (In utilizing this technique, one must be careful to obtain a capacitor which does not itself generate an emf.)

D.3.4. Calibration Procedure

The calibration involves illuminating the photosensor with light from a standard lamp placed at a given distance from the photosensor, and then adjusting the sensitivity of the photometric system to some desired value.

If $\underline{i}$ is the photosensor current,
$\underline{I}$ is the intensity of the light illuminating the photosensor,
and $\underline{D}$ is the distance from the test unit to the photosensor,
then, since the photosensor produces a current proportional to the illuminance on its face,

$$i = kI/D^2 \quad (4)$$

where $\underline{k}$ is the sensitivity of the photosensor.

It is usually convenient to calibrate the photometer to be direct reading, so that

$$I = N\delta \quad (5)$$

where $\underline{\delta}$ is the reading of the potentiometer of the measuring circuit, and where $\underline{N}$ is an integral power of 10 or the product of an integer, usually 2 or 5, and an integral power of 10.

The photometer is then calibrated with a standard lamp of known horizontal luminous intensity. If

$\underline{I_s}$ is the luminous intensity of the standard lamp,

$\underline{D_s}$ is the distance of the standard lamp from the photosensor,

$\underline{\delta_s}$ is the potentiometer reading and $\underline{i_s}$ is the photosensor current when the photosensor is illuminated by light from the standard lamp placed at the distance $\underline{D_s}$ from the photosensor, then

$$i_s = k\, I_s/D_s^{\,2} \quad (6)$$

and since the potentiometer reading is proportional to the photosensor current,

$$i_s/\delta_s = i/\delta \quad (7)$$

Combining (4), (5), (6), and (7),

$$\delta_s = I_s D^2/N D_s^{\,2} \quad (8)$$

Calibration is accomplished by the following procedure: $\underline{I_s}$ and $\underline{D_s}$ are chosen so that $I_s/D_s^{\,2}$ will be approximately equal to I/D^2, where $\underline{I}$ is some typical value of the intensity of the light to be tested. A suitable value of N is then selected. Calibration to make the photometer direct reading is completed by one of the three following procedures, depending on the photometer circuit used.

a. External Shunt Circuit

A diagram of this circuit is shown in figure 25. In this circuit

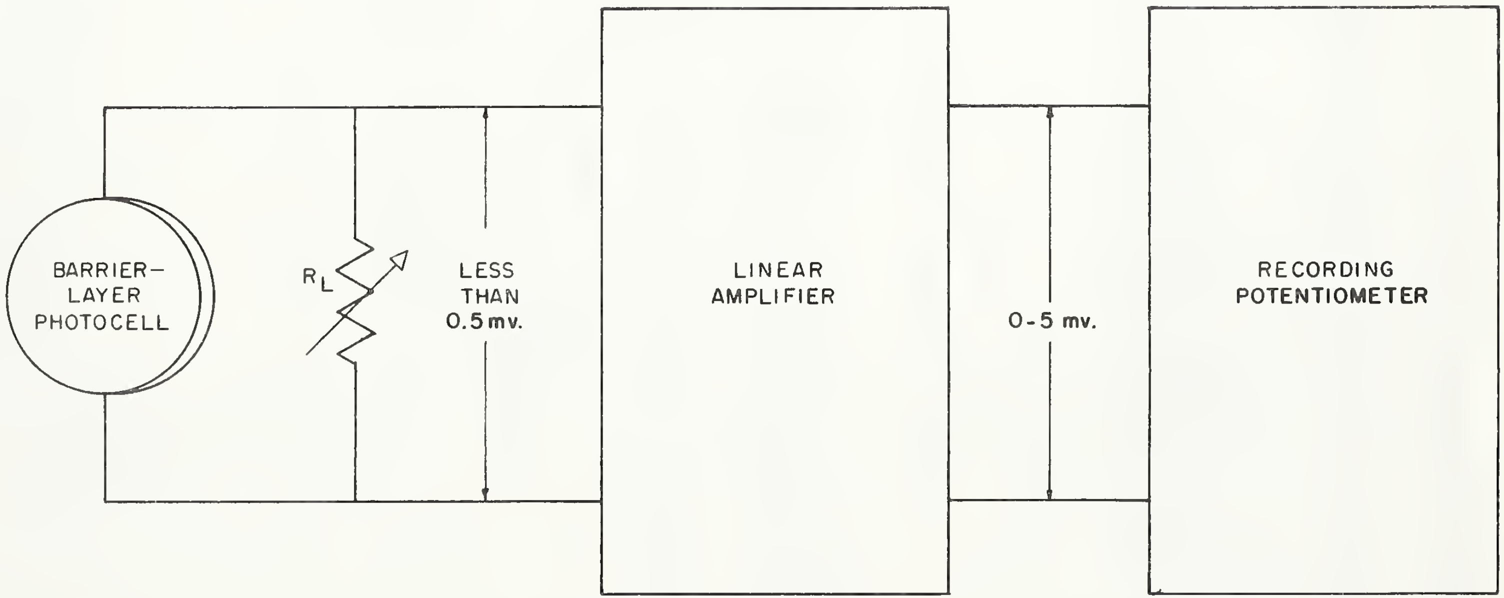

Figure 25. Block diagram of a barrier-layer photometer such as that used for measuring the output of many types of lights.

$$\delta_s = \frac{R_L S k I_s}{D_s^2} \qquad (9)$$

where $\underline{S}$ is the sensitivity of the photometer circuit and R_L is the resistance of the shunt.

Calibration, therefore, requires that, with the photocell illuminated by light from the standard lamp, the external shunt resistance is set so that the potentiometer indicates the value δ_s given in equation (8). The other parameters of the calibration are usually chosen so that the shunt resistance will be of the order of a few ohms. This order of resistance is used as it is large enough to be set accurately, and small enough so that the voltage developed across the photocell will not cause the photocell to respond nonlinearly. The practice is to maintain the sensitivity of the recorder at a fixed value of 5 millivolts for full-scale deflection. The sensitivity of the preamplifier is therefore set so that this recorder sensitivity and desired range of resistance may be used.

b. Phototube with Electrometer Amplifier Circuit

The procedure for calibration is the same as that for procedure a. The load resistor on the phototube and the controls of the amplifier are adjusted for the optimum performance range of the amplifier. Also, the output of the amplifier should not exceed 5 milliamperes. Hence, other parameters are adjusted so that R_L is greater than 1 ohm and is less than 5 ohms.

c. Zero-Resistance Circuit

In this circuit, if the photometer is balanced so that no current flows through the galvanometer, then

$$i = i_a a / r_x \qquad (10)$$

where

$\underline{i}$ is the photocell current,
i_a is the current through the slidewire between 0 and A,
$\underline{a}$ is the resistance of the slidewire between 0 and A,
and r_x is the resistance of the resistor, r_x.

Equation (10) is an approximation which depends on i_a being much greater than $\underline{i}$. In practice, i_a is kept at about 10 milliamperes, and the range of $\underline{i}$ is from 1 to 20 microamperes. If $\underline{i}$ is 20 microamperes, the error resulting from the use of this approximation will be 0.3%. For larger values of $\underline{i}$, a correction in the calibration can be made [47].

Assuming the slidewire is graduated from 0 to 100, the reading of the indicator of the slidewire is

$$\delta = a/a_o \qquad (11)$$

where a_o is the total resistance of the slidewire.

Then, combining (4), (10), and (11),

$$\delta = \frac{r_x kI}{i_a a_o D^2} \tag{12}$$

In the calibration of the zero-resistance circuit, i_a is usually kept constant and r_x is varied.

When the photocell is illuminated by light from the standard lamp, r_x is adjusted to obtain a zero reading of the galvanometer when the slidewire is set at the value δ_s of equation (8) for a given test distance, D. With the photometer thus calibrated, the intensity of the test light is given by equation (5).

d. Special Procedures

While photometric data are usually presented for a test light operating under the design condition, photometry of the test light under operating conditions other than the design condition is often desirable. Equation (8) can be generalized, taking into account this condition as well as the transmittance of any filters or sector disks used in calibrating, so that

$$\delta_s = \gamma_c \gamma_s FI_s \frac{D^2}{ND_s^2} \tag{13}$$

where γ_c is the transmittance of the color filter at the color temperature of the standard lamp, γ_s is the transmittance of the sector disk, and F is the ratio of the output of the light under test when it is operated under the design conditions to the output of the light when it is operated under test conditions. This ratio may be, for example, the ratio of the rated lumen output of the test lamp to the output of the lamp at the test voltage. It also may be the ratio of the intensity in a given direction at the operating voltage to the intensity in this direction at the test voltage.

In the case of lights which are flashed in service but on which photometric measurements are made with the light burning steadily at a selected voltage, the factor F is the ratio of the effective intensity of the flash in a given direction to the steady intensity at the selected voltage in this direction of view.

D.4. TESTING PROCEDURES

The photometer is calibrated as described above (D.3.4. Calibration Procedure) to an illuminance range determined by the intensity of the light being tested, the test distance and the information desired.

The test unit is mounted on the goniometer and is aligned. The angular settings of the goniometer are adjusted so that the origin of the goniometer settings will correspond to the desired axis. This axis usually is chosen with respect to either the seating plane of the unit or some characteristic of the beam such as its peak.

The baffling for stray light is put into place. The eye is placed in the position normally occupied by the photosensor. Examination can then be made to insure that the baffling is properly placed so that no obstructions exist between the light and the photosensor and that reflections from the walls, floor, and ceiling of the range are intercepted before they reach the photosensor.

If a sealed-reflector lamp is being measured photometrically, the lamp is usually operated at either rated voltage or rated current. Other lamps, such as those used in combination with an optical system, are usually operated at or corrected to rated lumen output. Power for the test and standard lamps is usually obtained from storage batteries, which are periodically recharged. Voltage and current are measured on a potentiometer, and photometric measurements are not made until the lamp has reached stability.

If the goniometer is to be motor driven, the gear ratios are chosen so that the traverse will be slow enough to insure the accurate recording of the characteristics of the light.

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