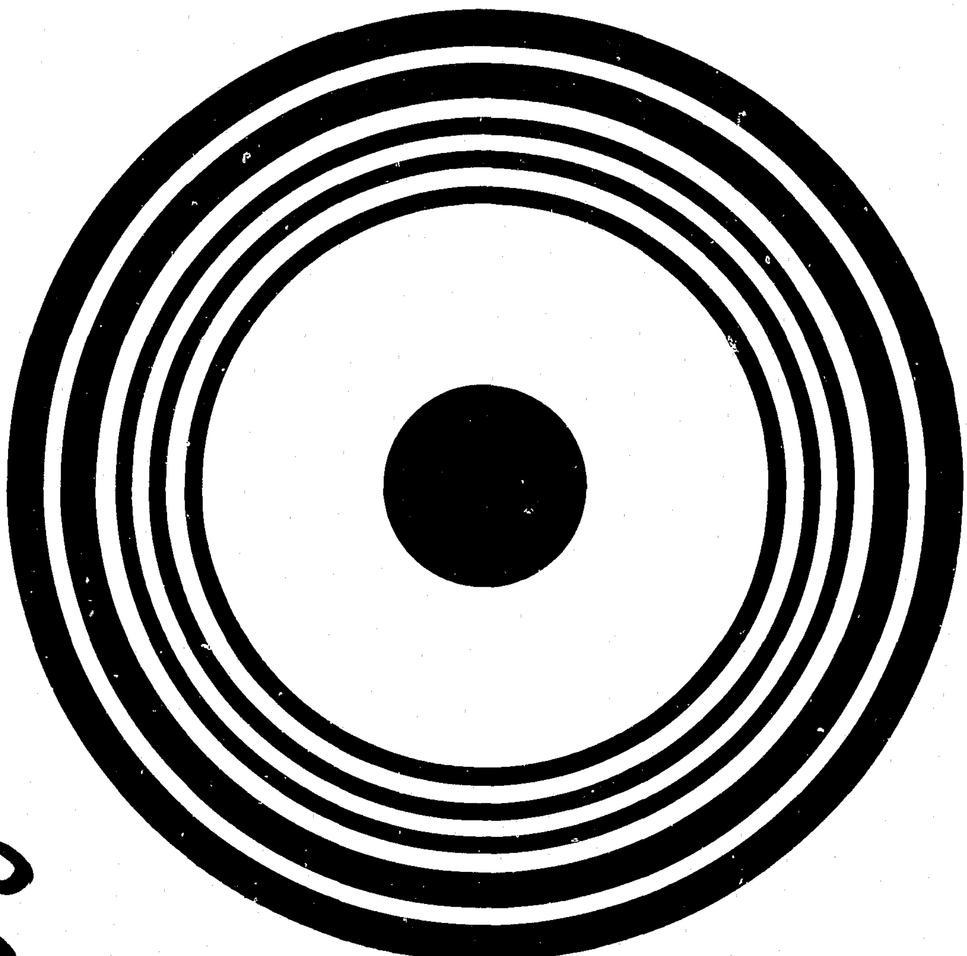
SIREN STANDARDS

California Highway Patrol

July 1978



PREFACE

This report on siren standards was prepared for presentation at the workshop on Optimization of Emergency Vehicle Audible Warning Devices on June 22, 1978, in Boston, Massachusetts.

The workshop was sponsored by the United States Department of Transportation, Transportation Systems Center in conjunction with the Society of Automotive Engineers.

Mr. Little is an Associate Automotive Equipment Standards Engineer for the California Highway Patrol. He has been responsible for the States Siren Approval Program for many years and has directed much of the research on sirens.

ABSTRACT

The background of the California siren approval program is described along with the results of many years of siren research which has never been published. The problem of sound cancellation resulting from the use of two siren speakers mounted side by side is discussed in detail as well as other problems with speaker mounting common in industry.

SIREN STANDARDS

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California Highway Patrol

BACKGROUND ON SIREN REGULATIONS

Siren audibility has been a major concern of the California Highway Patrol for many years. The California legislature first required the Patrol to approve sirens in 1923.

The first siren tests were made by ear. Vehicles with sirens installed were driven up on a levee, two observers listened to the siren and decided if it was acceptable, and the siren was approved or rejected.

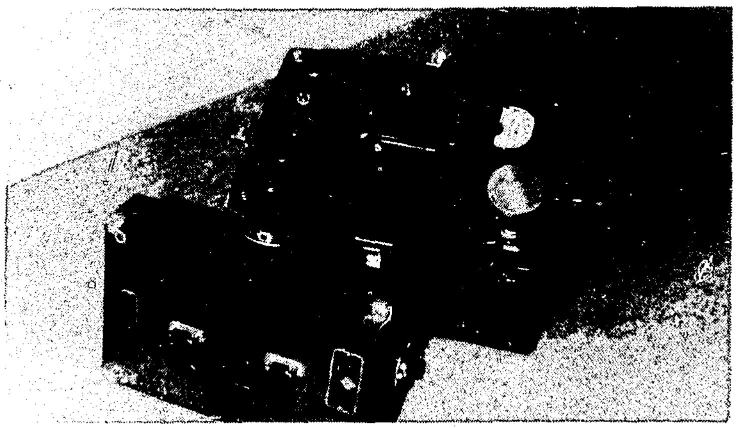


Figure 1. General Radio 759-B Sound Level Meter

In the early 1940's, the Department bought a General Radio 759-B sound level meter and made a study of sirens on stationary and moving vehicles. In January, 1947, regulations were adopted establishing sound level limits for sirens. The regulations required sound level output to be measured on the C-weighting network with measurements made at 100 feet on the siren axis and at 90 degrees right and 90 degrees left. Tests for approval were conducted over a wide paved roadway at the Highway Patrol Academy.

The regulation also established two classes of sirens based on a previous study that had shown that about 10 dB was lost when the siren was placed under the hood behind the radiator. Sirens with a minimum sound output of 85 dB(C) were given a Class II rating and could be mounted only on the outside of the vehicle. Sirens with a minimum sound output of 95 dB(C) were given a Class I rating and could be mounted anywhere on the vehicle, including in the engine compartment.

In 1955, the siren classifications were changed to Class A and Class B, and the test at 90 degrees was dropped because high sound level at 90 degrees to the emergency vehicle was not effective in warning traffic. The siren output requirements were also raised so that Class A was required to produce 100 dB(C) on the axis and 95 dB(C) at 45 degrees. Data from sirens approved showed that 100 dB at 100 feet was achievable by the better sirens.

The regulations were later amended to require measurements to be made on the A-weighted network. The A-weighted network was chosen because it rates sounds more as the human ear does by weighting out the low frequencies.

Complaints from enforcement personnel and other operators of emergency vehicles that people did not hear sirens were periodically received over the years. These complaints resulted in efforts to improve siren performance.

Tests of siren effectiveness were conducted with both electronic and electromechanical sirens mounted on a vehicle in a simulated chase in an attempt to determine which types of sirens and mounting locations were best. It was determined from these tests that the electronic siren speakers are quite directional and the speaker should not be mounted under the hood.

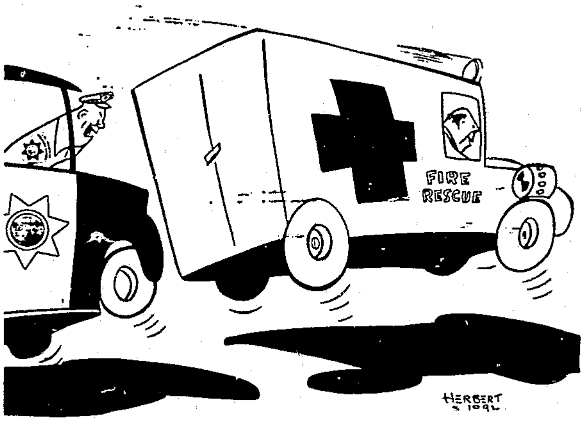


Figure 2. Simulated Chase

In order to remove some of the variables in siren testing, an electromechanical siren was used with carefully controlled voltage in an attempt to calibrate the site. Results of tests with this device showed that sound level readings of sirens tested over pavement would shift as much as 10 dB between tests at 7 a.m. and tests at 10 a.m. as shown in Figure 3.

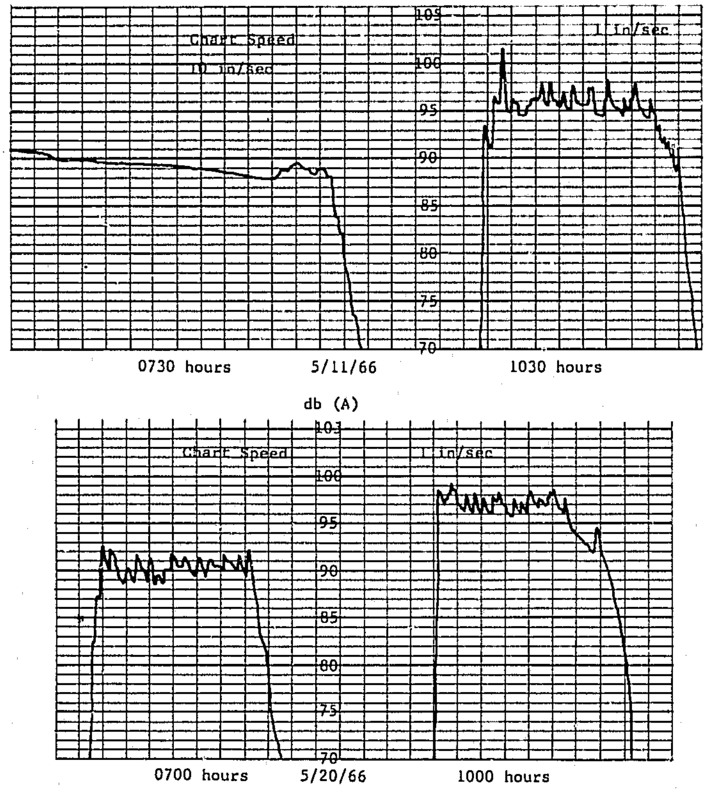


Figure 3. Sound Level of Reference Siren at beginning and end of test at 100 feet on axis over pavement clear hot days.

Further research to improve the test procedures resulted in several day-long evaluations of the siren test area in an attempt to remove some of the variables. These studies showed that sound levels read over a four-hour period varied less when measured over grass than when measured over pavement.

Newer equipment was purchased, and tests were conducted in various anechoic chambers with measurements made at 10 and 12½ feet. Several day-long tests were conducted to determine the stability of an electronic siren amplifier. Finally, the anechoic chamber at the California State University, Sacramento, was rented for siren tests. (see Figure 4) Research proved that test data were consistent from day to day and hour to hour in the anechoic chamber.

In 1975, the regulations were amended to require sirens submitted for approval after July of that year to be tested in the anechoic chamber. Under the present regulations, sound level output is measured with the microphone at 3 meters from the edge of the speaker bell with minimum output requirements established at 10-degree increments from 50 degrees right to 50 degrees left of the siren axis.

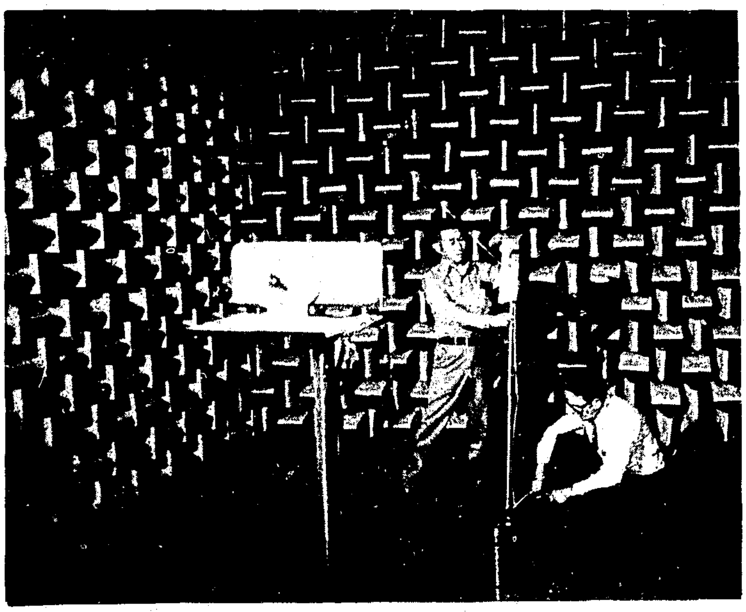


Figure 4. Anechoic Chamber, Sacramento State University

DUAL SPEAKERS

A major discovery during the previous experiments was that dual speaker installations (see Figure 5) produce a much poorer warning signal pattern than the single speaker installations because of sound cancellation.

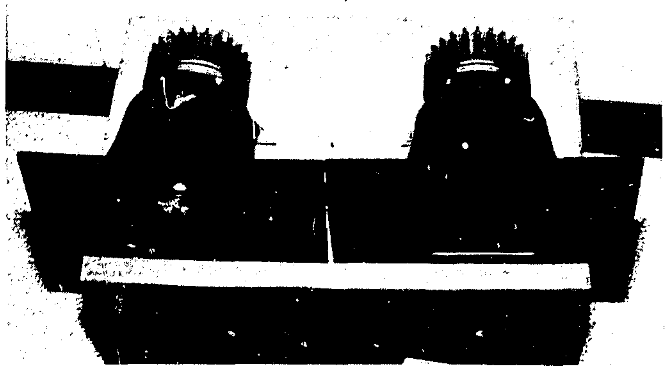


Figure 5. Dual Speakers

Most emergency vehicle operators believe that two siren speakers will produce twice the noise of a single speaker. Tests have shown quite clearly, however, that the dual speaker installation, particularly in the manual mode, is far less effective than the same siren with a single speaker. In some locations in front of the vehicle, the siren sound level output is higher, but the cancellation can be as high as 15 dB at some points to the right and left of the speaker axis. (See Figure 6)

Sound cancellation is a problem with all siren modes; however, cancellation of the manual mode is worse than the wail or yelp modes.

Figure 7 shows the cancellation patterns with both manual and yelp modes for the same dual siren installation.

At first, it was thought that cancellation might be lessened when

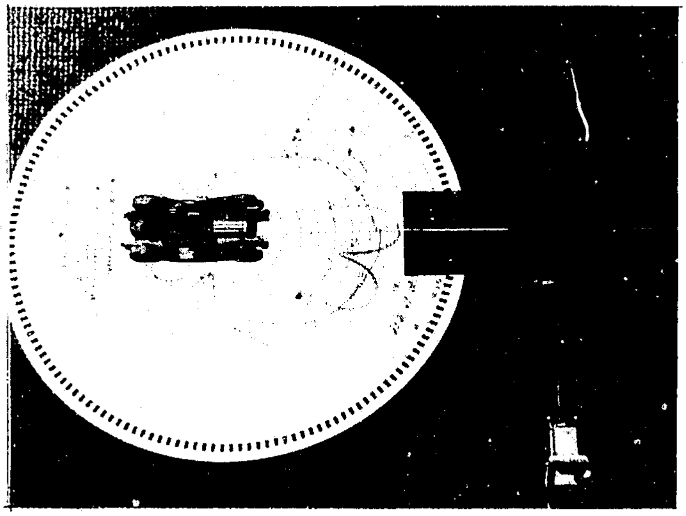


Figure 6. Effect of Sound Cancellation in Front of Emergency Vehicle

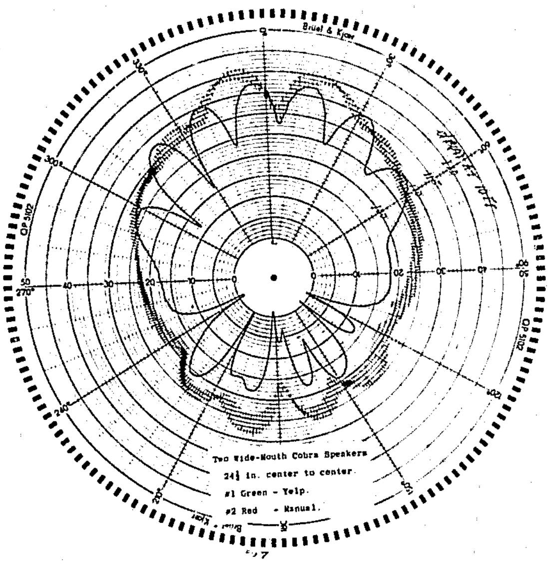


Figure 7. Sound Cancellation with Dual Speakers on Manual and Yelp Mode

dual speakers were mounted in a lightbar with a screen in front of the speakers, but tests show that the lightbar installation with dual speakers merely changes the shape of the curve and the cancellation is as bad as with the two speakers mounted outside the lamp housing. (See Figure 8 and 9)

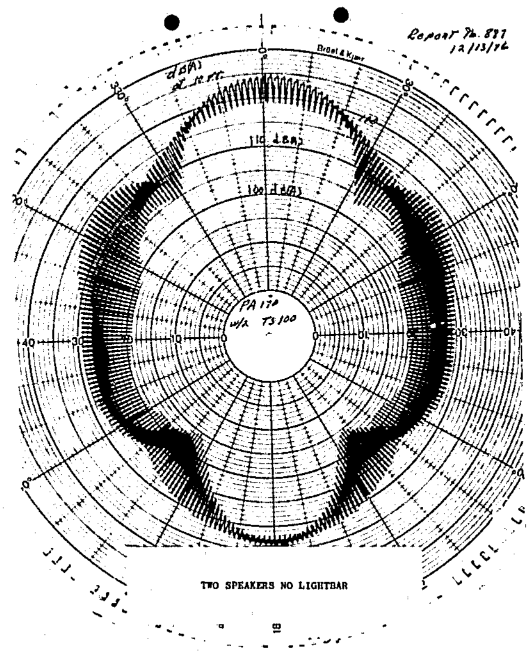


Figure 8. Sound Pattern Produced by Two Speakers No Lightbar

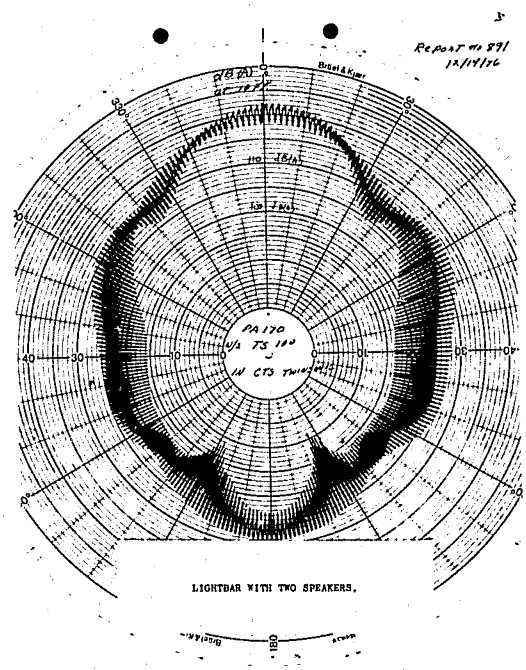


Figure 9. Sound Pattern Produced by Two Speakers with Lightbar

Experiments with the speakers mounted at different distances apart, pointed inboard and pointed outboard, showd cancellation still exists; although, the pattern shifts. Figures 10, 11 and 12 show the sound cancellation pattern for the manual mode with two speakers mounted at 0 degrees and at 10 degrees in and out.

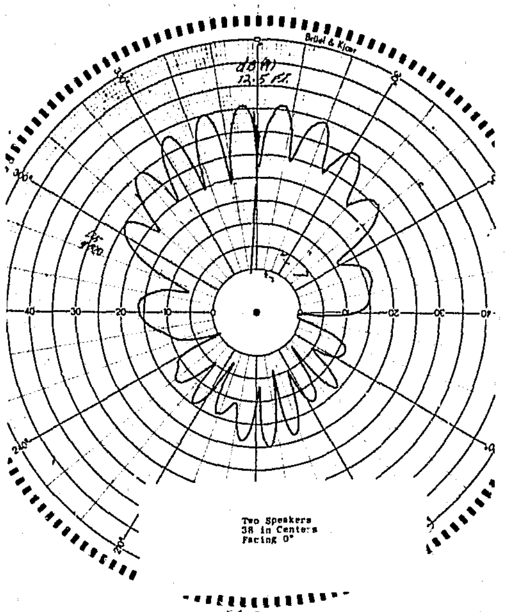


Figure 10. Sound Pattern Produced by Two Speakers 38 in Centers Facing 0 degrees

Dual speakers can however be mounted so that cancellation on the horizontal plane is minimized and that the optimum sound level can be obtained from the unit in the areas where needed most. Stacking the speakers, one on top of the other, as shown in Figure 13, eliminated cancellation on the horizontal plane and obtained the same sound pattern as a single speaker. (See Figure 14) This information was presented to the siren manufacturers; however, no manufacturer has developed a setup for siren speakers mounted in this manner.

One manufacturer recently developed a new speaker using two drivers connected to one speaker bell shown in Figure 15. This speaker mounted outside the lightbar produces twice the acoustical energy (3 dB) as the same

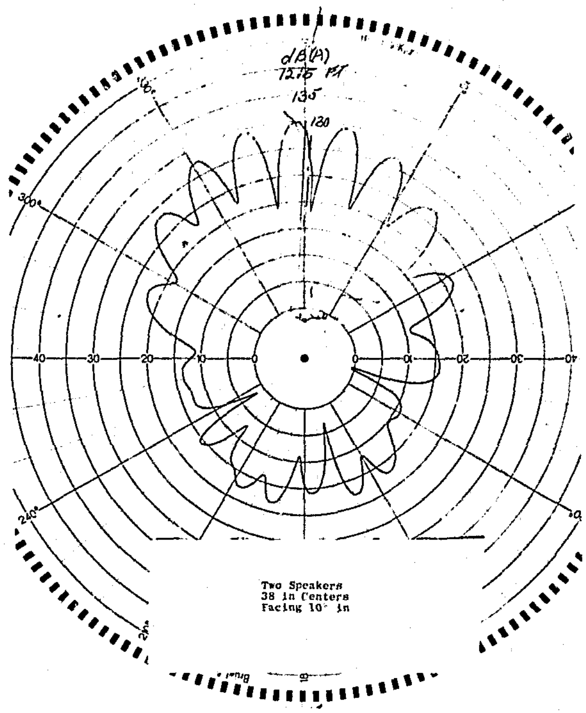


Figure 11. Sound Pattern Produced by Two Speakers 38 in Centers Facing 10 degrees in

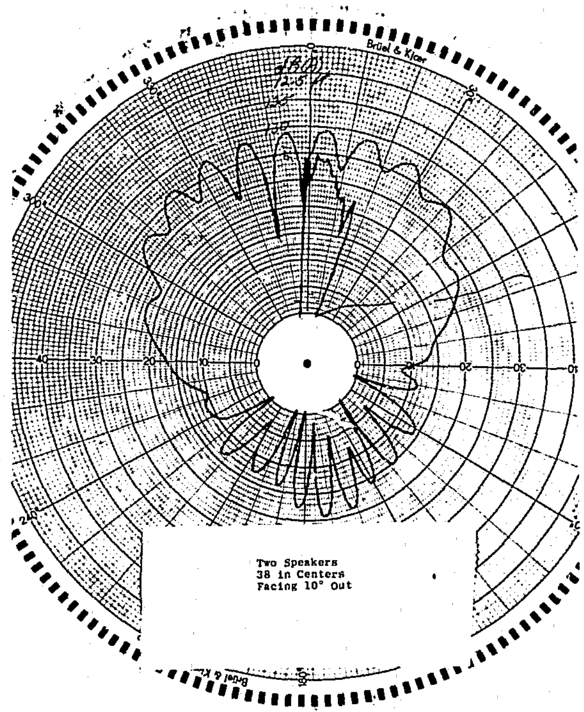


Figure 12. Sound Pattern Produced by Two Speakers 38 in Centers Facing 10 degrees out

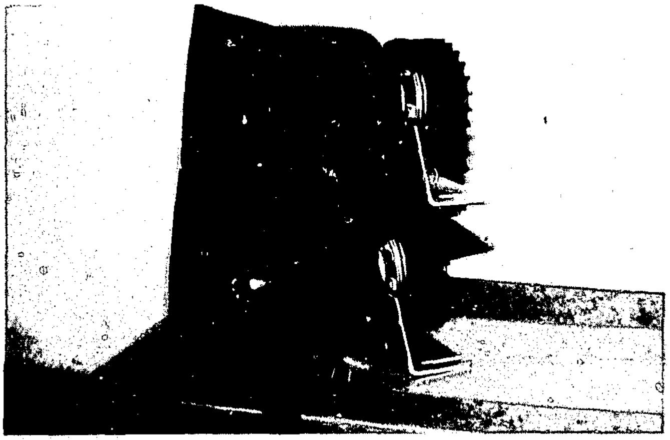


Figure 13. Dual Speakers Stacked

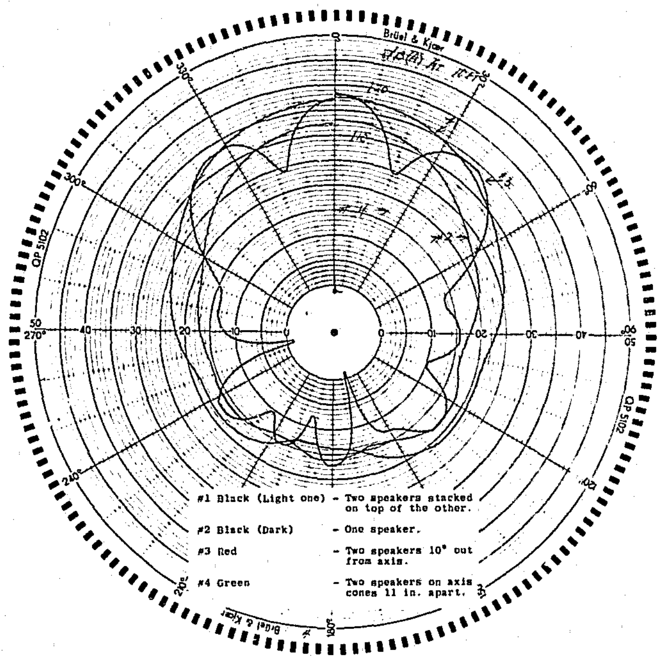


Figure 14. Sound Pattern Produced with Siren Speakers Stacked and Side by Side

unit with a single driver, yet does not have the cancellation problems associated with dual speakers. (See Figure 16)

The sound propagation pattern from the speaker is nearly identical to that of the electromechanical siren,

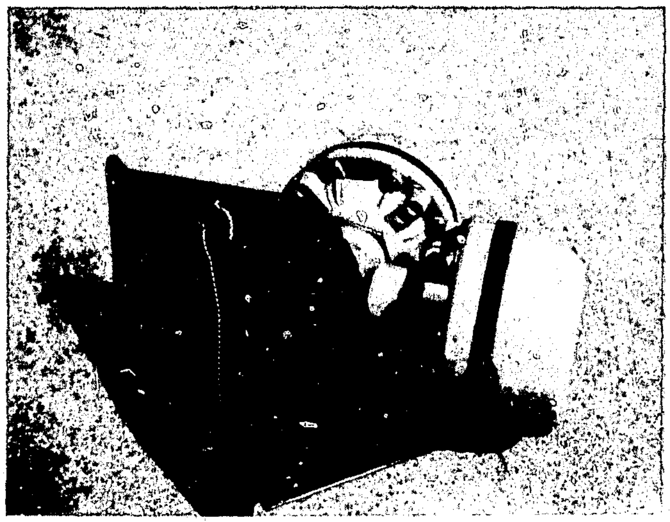


Figure 15. Single Speaker with Two Drivers

compare Figures 16 and 17, except that the sound level at angles behind the speaker is less than that of an electromechanical siren. High energy behind the siren is not particularly desirable because it does not warn approaching traffic and it creates undesirable sound levels in the operator's compartment and in the community.

SPEAKER SHAPES

The shape of the speakers makes a difference in the noise propagation in front of the vehicle. In order to provide the maximum warning to other vehicles, a siren should produce as much volume as can be achieved in front of the vehicle between 50 degrees right and 50 degrees left of the siren speaker axis. This is most desirable with respect to other vehicles crossing at intersections.

The wide-mouth Cobra speaker, (see Figure 18) used on several electronic sirens, is designed to be mounted flat, so the bell appears to project the sound to the side. This, however,

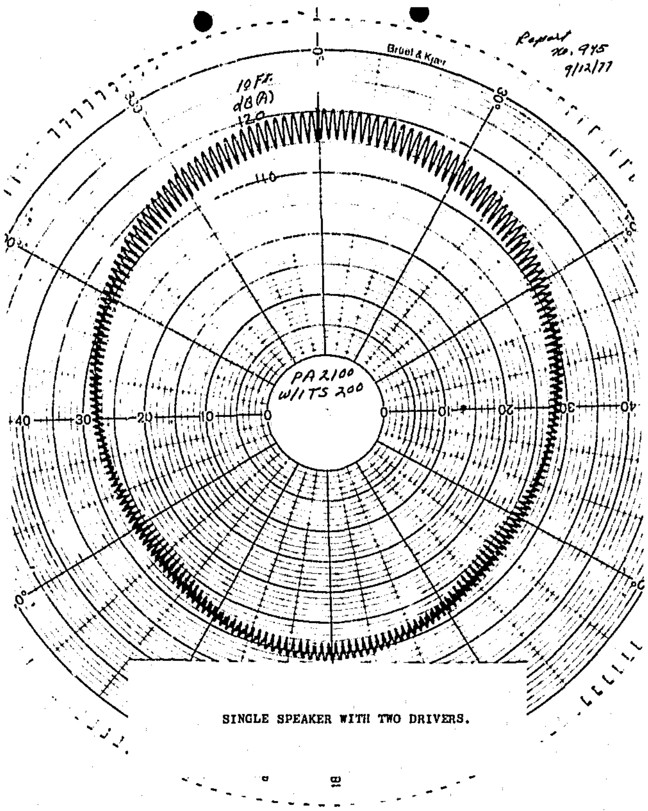


Figure 16. Sound Pattern Produced by Single Speaker with Two Drivers

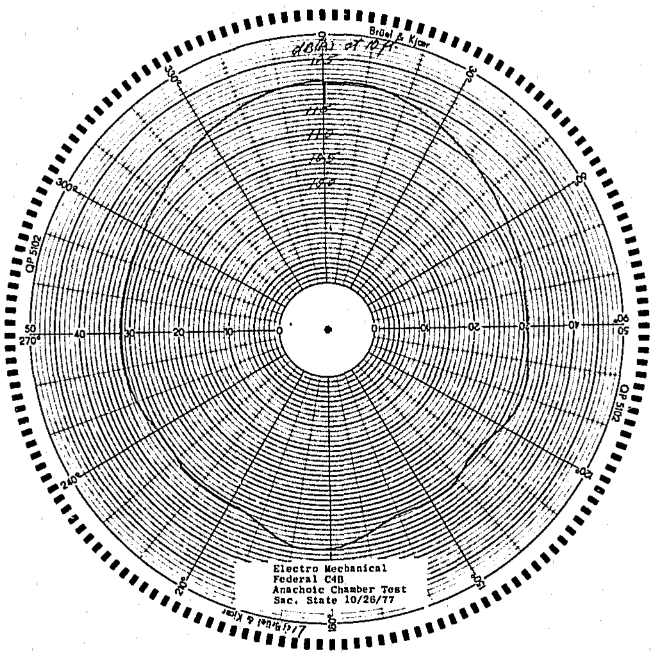


Figure 17. Sound Pattern Produced by Electromechanical Siren

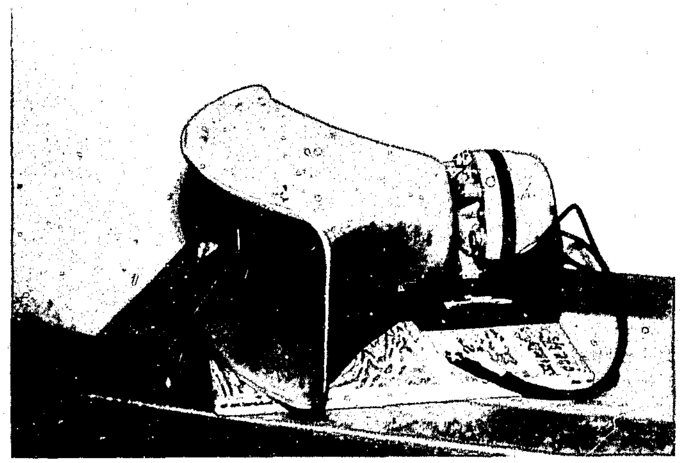


Figure 18. Wide-Mouth Siren Speaker

is an improper mounting for this speaker. To properly spread the sound at wide angles to the right and left of the emergency vehicle, the speaker must be mounted with the mouth of the bell up and down rather than horizontal. Installation of the wide-mouth speaker with the opening mounted vertical produces about 4 dB more than a good round speaker and 6 dB more than when the speaker is mounted in its customary flat mode. (See Figure 19)

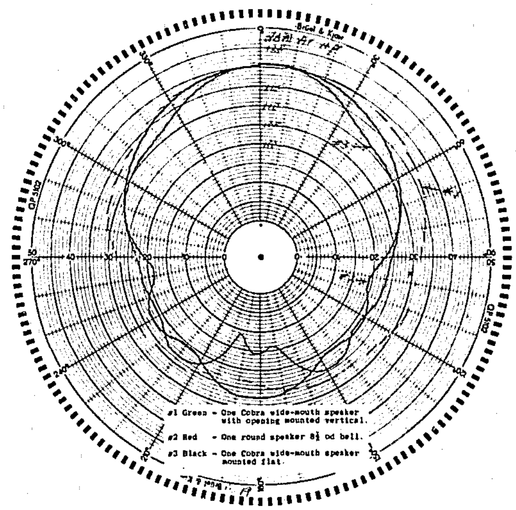


Figure 19. Sound Pattern Produced by Wide-Mouth Speaker

Additional experiments have been made with the undercover scoop type of speakers, shown in Figure 20, which are made to be mounted behind the grill and ahead of the radiator These speakers have sometimes been found to be mounted even behind the

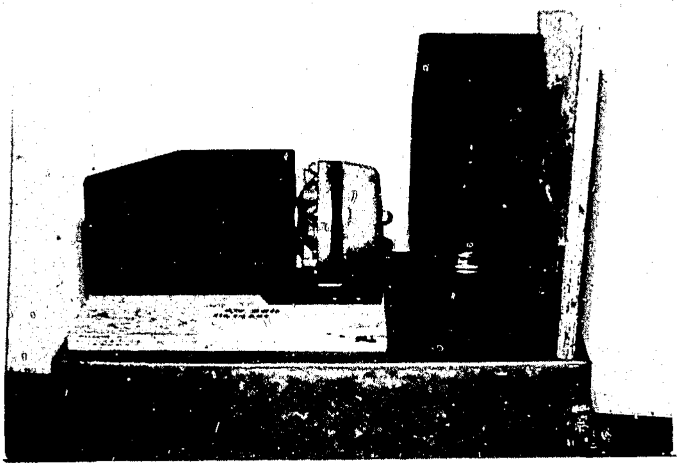


Figure 20. Undercover Scoop Speakers

bumpers. At best, these speakers are very inefficient; generally, they are mounted with the throat of the driver pointed either upward or downward. (See Figure 21) The best sound level output from these speakers is obtained when the speaker is lying down and the driver is pointing to the side with the horn opening facing forward.

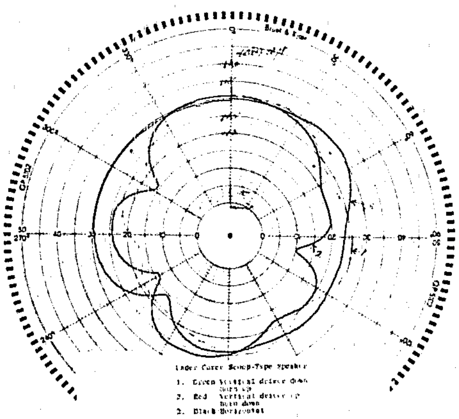
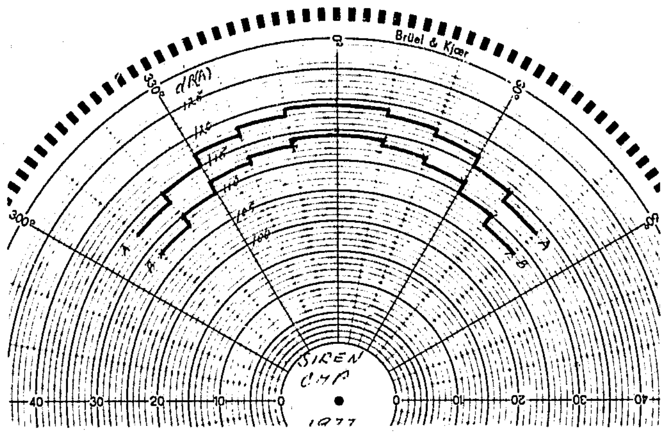


Figure 21. Sound Pattern Produced by Scoop Speakers

SIREN PERFORMANCE LEVELS

For a Class A siren approved for California, the minimum sound level output measured at 3 meters is 120 dB(A) on the axis and 113 dB(A) at 50 degrees right and left. (See Figure 22) These sound levels were established after many electronic sirens had been examined. Only the best sirens in production today reach these values, and very few



Rotation deg	Class A siren	Class B siren
0	120	115
10	119	114
20	118	113
30	117	112
40	115	110
50	113	108

Figure 22. Minimum A-Weighted Sound Level at 3.0 m

SIREN SOUND PATTERNS

Several different siren modes have been examined by the Department. When electronic sirens were first becoming popular, the "yelp" function was presented for approval. Since the public was unfamiliar with this sound, the Department did not accept the "yelp" function as a siren, but the "yelp" was allowed to be installed in the electronic siren control and used in conjunction with other approved siren sounds.

Research conducted by students at California State University, Sacramento, showed that the "hi-lo" function commonly used in Europe is not an adequate readily recognized warning signal for authorized emergency vehicles. The November, 1977, revision of the California siren regulations eliminated the "hi-lo" mode from approved sirens. The "wail" function is a required mode, and the "manual" and "yelp" functions are permitted on sirens approved after January 1, 1978.

The data in Figure 23 is an excerpt from Report No. DOT-TSC-OST-77-38, Effectiveness of Audible Warning Systems, U.S. Department of Transportation. This data supports the CHP findings that the hi-lo sound is not as effective as the wail and yelp sounds.

TABLE 14. SUMMARY OF WARNING EFFECTIVENESS DISTANCES FOR REPRESENTATIVE SITUATIONS

URBAN SITUATION[1]

Source	Straight Ahead Distance Between Vehicles	Crossroads Distance Between Vehicles Developed Along Road
Electronic Wail	123 ft (37m)	39 ft (12m)
Electronic Yelp	120 ft (37m)	38 ft (12m)
Electronic Hi-Lo	81 ft (25m)	26 ft (8m)
Mechanical Wail	146 ft (44m)	40 ft (12m)

SUBURBAN SITUATION[2]

Source	Straight Ahead Distance Between Vehicles	Crossroads Distance to Corner
Electronic Wail	440 ft (134m)	>106 ft (32m)*
Electronic Yelp	426 ft (130m)	>106 ft (32m)*
Electronic Hi-Lo	257 ft (78m)	78 ft (24m)
Mechanical Wail	445 ft (136m)	>106 ft (32m)*

*Detected as vehicles emerge from behind assumed barrier.

RURAL SITUATION[3]

Source	Straight Ahead Distance Between Vehicles	Crossroads Distance to Corner
Electronic Wail	33 ft (10m)	14 ft (4.3m)
Electronic Yelp	32 ft (9.7m)	12 ft (3.5m)
Electronic Hi-Lo	24 ft (7.3m)	<12 ft (3.6m)
Mechanical Wail	33 ft (10m)	<12 ft (3.6m)

[1]Urban Traffic - Window Open - No Radio.

[2]30 MPH - Window Open - No Radio.

[3]55 MPH - Window Closed - Radio On.

Figure 23. Siren Warning Effectiveness Distance

In California, the "hi-lo" signal is recommended as a sound for vehicle theft alarms. Theft alarms cannot legally make the types of sounds produced by sirens required on authorized emergency vehicles.

OSCILLATION RATE

The oscillation rate of the "wail" and "yelp" functions has also been examined. Present California regulations require the wail to oscillate at a rate of no less than 10 and no more than 30 cycles per minute. Originally, the automatic "wail" function of an electronic siren was designed to sound like the manual wailing of an electromechanical siren. Some of the original electronic sirens tested had an oscillation rate of as low as five oscillations per minute. Some are still manufactured with rates as low as eight; however, even 10 oscillations per minute is a little slow to adequately warn vehicles entering intersections when the authorized emergency vehicle and the approaching vehicle are traveling at speeds of more than 30 miles per hour.

The present regulations establish the oscillation rate for "yelp" at no less than 150 and no more than 250 cycles per minute. Most emergency vehicle operators using electronic sirens use the "yelp" mode when entering an intersection and the "wail" while traveling down the highway. The rapid oscillation of the "yelp" mode is a good attention-getter and does a fair job of moving traffic at an intersection.

TESTING OF SIRENS

Testing of sirens for approval in California continues with tests performed in the anechoic chamber

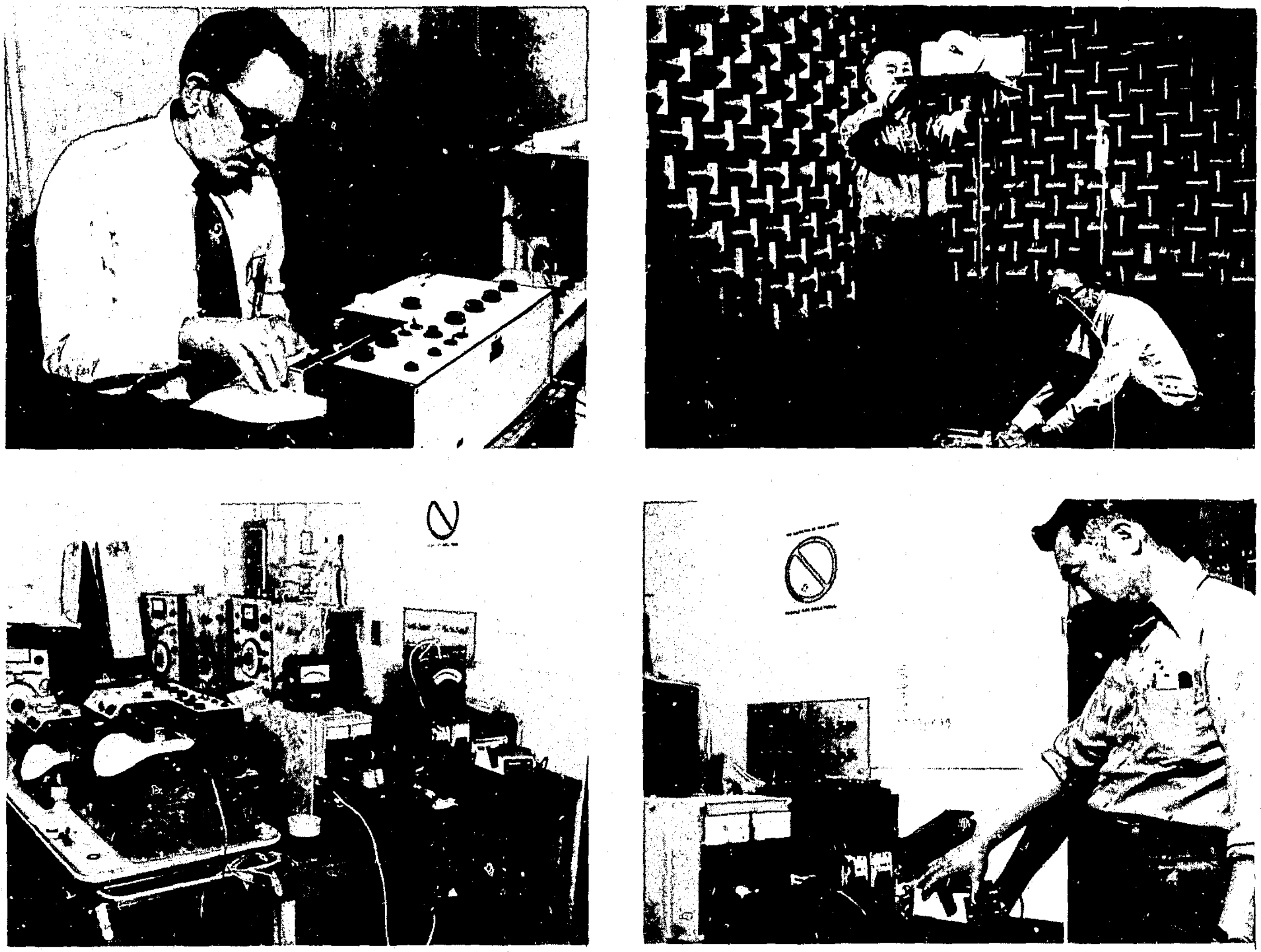


Figure 24. Siren Tests at Sacramento State University

at California State University, Sacramento. Highway Patrol Engineers conduct the tests with CHP equipment, thereby controlling the calibration and repair of the instruments. (see Figure 24)

A recent test of the same siren at three different laboratories, Federal, Atlas, and CHP showed excellent correlation of data. (See Figure 25)

SIRENS ARE NOT HEARD

Even with the best siren on the market today, people occasionally do not hear an approaching emergency vehicle. Their first impulse is to believe that the sound level output should be increased to some much higher value. However, this solution would create even more serious problems. The public

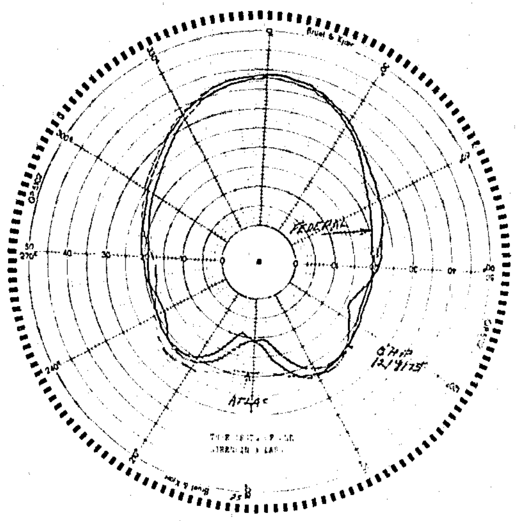


Figure 25. Tests of One Siren in Three Laboratories

presently complains about noise from excessive use of sirens on ambulances and fire equipment. Operators complain of hearing problems caused by siren noise in the vehicle. Increasing the sound level produced by the siren does not appear to be the answer and the problem of adding more speakers has already been discussed.

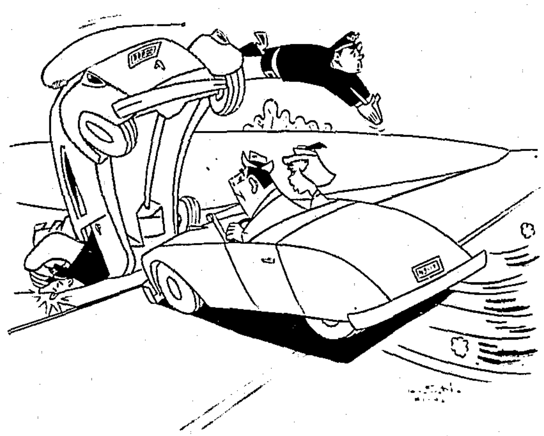


Figure 26. Sirens Are Not Heard

One proposal by the National Bureau of Standards would have established a minimum sound level for sirens of 132 dB measured at 10 feet. This level would likely be unacceptable to most citizens living beside the pathway of emergency vehicles, and the sound could endanger the hearing of emergency vehicle operators. There is, no doubt, a maximum level that a siren should be permitted to produce, and perhaps we have reached that level.

Of utmost importance is the training of emergency vehicle operators in the use of the siren so that they will understand that a siren does not guarantee a clear traffic lane and that there is no substitute for defensive driving.

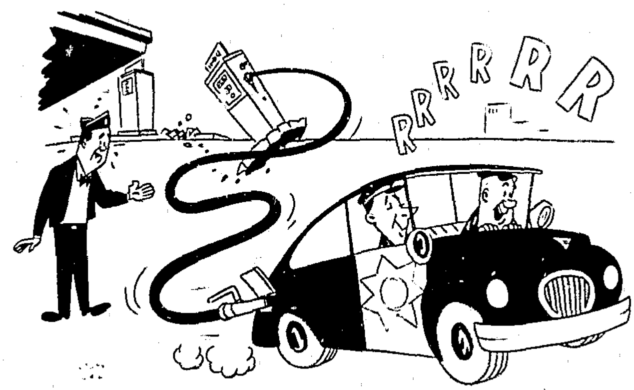


Figure 27. Training is the Key to Safe Operation

While driving an emergency vehicle, the operator is greatly stimulated by the siren and the chase; he is sure that everybody in the world can hear him coming. However, tests and experiments have proved that people do not always hear the siren in time to react. In one case, on a summer day with the car windows rolled down, a citizen violated the emergency vehicle's right-of-way. No one would purposely drive in front of a rapidly moving police vehicle with siren screaming, the driver could not have heard the siren.

Figure 28. Accidents Occur

CONCLUSION

Most studies of the California Highway Patrol have concentrated upon testing the acoustic output of sirens and will likely continue along this line for the present.

A siren installation manual should be published explaining the information discussed here about the problems of improper mounting of siren speakers and particularly explaining the fallacy of using two speakers mounted side by side.

More psychoacoustic studies should also be conducted to determine the warning system that is most audible without creating a nuisance in the community. The work reported by Mr. Henry C. Aulwarm, University of Oklahoma Research Report T-71-2, and the work reported by Bolt, Beranek and Newman in Report No. DOT-TSC-OST-77-38 to the U.S. Department of Transportation should be expanded to determine the most effective siren characteristics.

Precise standards with carefully controlled tests and frequent surveillance testing results in the best sirens being made available to the users. In-depth training programs for operators demonstrating the inability of an audible system to guarantee a clear path will assure safe proper use of the siren.