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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
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Letter
Circular
LC-685

DEVICES FOR AIR RAID WARNINGS

As a result of the present war, civilian authorities are anxious to obtain information concerning devices suitable for air raid warnings. Many requests for such information have been addressed to the National Bureau of Standards. In response to this demand the Bureau has undertaken a study of such devices and tried to collect as much information as possible about the most desirable type of signal.

This work has not been completed, but as the need is urgent, all of the information and data which have been obtained up to the present time are presented in this letter circular. As fast as additional data are obtained, supplements will be issued.

To aid in deciding on the type of warning device that should be used in any locality, it seems desirable to discuss a number of facts which have been listed under the following headings:

1. Frequency
2. Quality of sound
3. Loudness
4. Ease of coding signal
5. Type of device
6. Effects of weather
7. Directional characteristics
8. Sound intensity measurements

1. Frequency

In deciding on the type of signal that is to be used for air raid warnings, one of the first considerations should be its frequency characteristics.

Experiments by Knudsen and others show that there is a decided absorption of sound at frequencies above 1000 cycles per second, and as a result these higher frequencies are attenuated quite rapidly. This would indicate that as the frequency is decreased the sound energy which is lost becomes smaller. Reasoning along these lines would indicate that the lower the frequency of the signal, the better would be its transmission.

However, the frequency of a warning signal should be such as to stimulate the nerve terminals in the ear. Work by Fletcher and many others has shown that at lower frequencies the ear becomes less sensitive; hence a signal having a frequency too low is not satisfactory.

For the above reasons it is necessary to compromise between loss due to air absorption and loss in sensitivity of the ear.

Experimental work by this Bureau in cooperation with the former Bureau of Lighthouses indicated that the most desirable frequency range for warning signals lay between 200 and 500 cycles per second. More recent work, which has been done on this present program, where shorter distances are involved, indicates that this upper limit might be raised to 700 cycles. (A 200-cycle note is about 2 tones below middle C, and a 500-cycle note is about an octave above middle C.) Surveys of signals in Boston and by the Northern Electric Company, Ltd., in Canada, confirm the Bureau's findings that signals in this frequency range carry better than those having frequencies outside this range.

Another reason for choosing a signal with a comparatively low frequency is that the signal should be heard inside buildings. Studies made by the Bureau on sound transmission through different types of building construction indicate that the average transmission loss of sound through such structures is about 8 decibels less at 200 cycles than at 1000 cycles, and therefore a low frequency sound is more likely to be heard inside a building than one of high frequency.

Low frequency sounds also give a better coverage within a definite area, as buildings and natural obstacles produce less of a shielding effect than when a higher frequency is used. Also, directive effects caused by horns and other radiating surfaces are considerably less when a low frequency sound is used.

2. Quality of sound

Having chosen the band of frequencies which is most likely to be heard, consideration should be given to the quality of the tone; that is, should it be a pure tone or should it be a complex tone made up of inharmonic components. Tests again show that an inharmonic combination of tones or a pure tone which is being constantly varied in frequency arrests the attention more quickly than a pure tone or a tone with overtones which are exact harmonics of the fundamental. Also, a combination of tones which are separated by a half octave or more can be selected which will sound louder than a pure tone which has the same amount of energy. If, in addition to the use of two tones, these tones can be varied in frequency the signal becomes very distinctive.

The character of the signal should also be such that it cannot be confused with the signals used by fire trucks, ambulances. Moreover, it should not be similar to surrounding noises since these would mask the warning signal.

3. Loudness

To be heard above other noises, it is necessary that the signal be sufficiently loud. There is very little information to indicate how loud a signal should be, but it would seem desirable that the loudness level of the signal should be at least equal to the loudness level of the noise at a point where the signal is to act as a warning. (In very quiet areas the signal, of course, should be louder than the surrounding noise.) In areas where there is considerable traffic the average noise level is 80 decibels or more. In a residential area, off arterial highways, the average noise level is approximately 60 to 70 decibels in Washington, although in some very quiet areas this level may be as low as 50 decibels.

If a signal level of 80 decibels is chosen as a minimum level for noisy locations and 70 decibels as the minimum level for residential districts, there will be a positive warning to persons out-of-doors and probably to any one located in an outer room with windows. It is unlikely, however, that such signals will penetrate rooms in the interior of a building.

To obtain signals of this level will require a considerable acoustic output, and it becomes necessary to consider the economic side of the question so as to decide whether a large number of small signals placed close together would be more economical than a few large signals spaced considerably farther apart. The answer to this question might be very different in different localities. This subject will be discussed further under parts 5 and 6.

It is the Bureau's belief that in a down-town section, where the buildings are continuous and high and the streets are narrow, relatively small signaling devices, placed at street intersections, might give the best coverage. The number of intersections between signaling devices would depend on the size of the signaling device, and whether locations could be worked out so as to give uniform sound coverage for all streets.

For other locations where a uniform coverage is desired in all directions, it is believed that a device which will give a signal level of approximately 110 decibels at 100 feet will give, on the average, a satisfactory warning signal up to a distance of one-quarter mile if the average noise level does not exceed 80 decibels, and up to one-half mile if the average noise level does not exceed 70 decibels. If the signal strength is 100 decibels at 100 feet, these distances will be about one-half as great, and for a level of 120 decibels at 100 feet the distances could be doubled, but the uncertainty due to weather conditions will be somewhat greater at these longer distances. This point will be discussed further under 6.

The above statements are rather general and may not apply exactly to any given location. The distribution of signaling devices in any city is an individual problem, and it may be necessary to make trial installations at some points before the best results can be obtained.

4. <u>Ease of coding signals</u>

A signaling device should be chosen which can be easily operated so as to give coded signals.

5. Type of device

In considering the type of device which should be used it is desirable to make a survey of existing facilities. An attempt should be made to lay out a warning system which will require the purchase of a minimum amount of new equipment and still give an efficient warning. For instance, if there are steam plants which have steam up all of the time, a steam whistle or steam siren might be used. In many cases a factory might have a whistle or siren, and it would not be necessary to purchase additional equipment for that locality. In many other locations it might be possible to use air horns, such as are listed in the report at the end of this circular. The necessary air to blow such horns might be obtained at a filling station or a bus terminal, provided an extra air tank were installed. There might also be other factors which could be taken advantage of in any given city to lessen the amount of equipment which it would be necessary to buy.

6. Effects of weather

One of the most important factors in the propagation of acoustic signals over large distances is the weather, or more specifically the humidity, wind, and temperature variations in the atmosphere. The amount of moisture in the air, the temperature, the direction and velocity of the wind, the presence of ascending or descending air currents, the existence or absence of stratified layers, all affect the transmission of sound through the air.

It has been observed that under favorable atmospheric conditions a powerful signal may be heard many miles. In fact, some of the devices on which the Bureau is reporting have been heard for distances up to 8 miles, yet under some of the unfavorable conditions mentioned above they have not been heard for one-quarter of a mile. On account of these atmospheric vagaries it would seem that a number of medium sized signaling devices, spaced in some form of a grid pattern, would give a more positive coverage than a few very large devices spaced relatively far apart.

7. Directional characteristics

The directional characteristics are given in the discussion of each device.

8. Sound intensity measurements

Sound intensity measurements and a frequency band analysis have been made at 100 feet on devices supplied by the following companies. These measurements were made in an open field with the device mounted about 20 feet above the ground and the microphone about 7 feet above the ground. Many other measurements have been made at greater distances to determine the attenuation loss with distance. As the difference in attenuation loss of the signals from the various devices tested is less than the variation in attenuation due to varying weather conditions, these measurements are not given.

Bendix-Westinghouse Automotive Air Brake Co.,
Elyria, Ohio.
Air-head with horn.

Defiance Alloyed Products Company,
Defiance, Ohio.
4-horn unit.

Dilks Sales Company,
South Norwalk, Conn.
Air-head with horn and special oscillator to produce signal.

Doran Company,
75 Horton Street,
Seattle, Washington.
Doran-Cunningham whistle Size 3A.
Cunningham whistle Size 4.

Federal Electric Company,
8706 South State St.,
Chicago, Ill.
2 hp electric siren.

Foster Engineering Company,
Newark, N. J.
Steam siren.

The Gamewell Company,
Newton Upper Falls, Mass.
Type B diaphone.

H.O.R. Company, Inc.,
6-8-10 Broad St.,
Stapleton, S.I., N. Y.
5 hp electric siren.

Line Material Company,
E. Stroudsburg, Pa.
Electric siren.

Westinghouse Air Brake Co.,
Wilmerding, Pa.
E-2, 157-cycle air horn
E-2, 250- " " "
E-2, 440- " " "
A-2, 397- " " "

BENDIX-WESTINGHOUSE AUTOMOTIVE AIR BRAKE CO.

Only an air-head (air operated loudspeaker unit) and horn were furnished.

As there was no means supplied of generating a signal, the oscillator, amplifier and compressor furnished by the Dilks Sales Company were used.

With an air pressure of 27 pounds and 34 volts across the voice coil the signal strength at 100 feet and on the axis of the horn was 106 decibels, 45° off the axis 93 decibels, and 90° off the axis 86 decibels.

The harmonic content of the signal was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	95
500 - 1000 " " "	102
1000 - 2000 " " "	100
2000 - 4000 " " "	98
4000 " " "	94

DEFIANCE ALLOYED PRODUCTS COMPANY

This device consisted of a 4-horn unit, the horns being 90° apart in a horizontal plane, having a fundamental frequency of about 225 cycles per second. The signal strength at 100 feet was 99 decibels, when the air pressure was 35 lb per sq in. and the air consumption 0.5 cu ft of free air per second. This device was non-directional.

The harmonic content of this signal was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	83
250 - 500 " " "	83
500 - 1000 " " "	96
1000 - 2000 " " "	95
2000 - 4000 " " "	93
4000 " " "	87

DILKS SALES COMPANY

This device consisted of an air-head (air operated loudspeaker unit), horn, amplifier, oscillator, and a small air compressor. When tested, the oscillator gave a tone which was constantly shifting from about 435 to 660 cycles per second.

With an air pressure of 22 pounds and 37 volts across the voice coil the signal strength at 100 feet and on the axis of the horn was 107 decibels, 45° off the axis 99 decibels, and 90° off the axis 90 decibels.

The harmonic content of the signal was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	95
500 - 1000 " " "	102
1000 - 2000 " " "	100
2000 - 4000 " " "	98
4000 " " "	94

DORAN COMPANY

The devices submitted by this company consisted of two whistles marked as follows:

Doran-Cunningham Whistle Size 3A
Cunningham Whistle Size 4

The air pressure used when the tests were made on these whistles was 80 lb per sq in.

The signal strengths of these whistles at 100 feet and the air consumption in cu ft of free air per second were as follows:

	Signal Strength	Air Consumption
Size 3A	106 decibels	0.53
Size 4	113 "	0.73

The harmonic content of the Size 3A whistle was as follows:

Band	Level in decibels
0 - 125 cycles per second	69
125 - 250 " " "	-
250 - 500 " " "	102
500 -1000 " " "	97
1000 -2000 " " "	93
2000 -4000 " " "	89
4000 " " "	76

The harmonic content of the Size 4 whistle was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	102
250 - 500 " " "	99
500 - 1000 " " "	107
1000 - 2000 " " "	106
2000 - 4000 " " "	103
4000 " " "	99

FEDERAL ELECTRIC COMPANY

This device was a 2 horsepower vertical electric siren submitted by the District of Columbia. The fundamental tone was about 550 cycles per second. The power consumption was 2.8 H.P. The signal strength at 100 feet was 98 decibels. This device was non-directional.

The harmonic content of the signal was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	-
500 - 1000 " " "	94
1000 - 2000 " " "	90
2000 - 4000 " " "	92
4000 " " "	88

FOSTER ENGINEERING COMPANY

This device was a steam siren with a 4 1/2-inch rotor with heavy brake shoes. The steam pressure in the chest of the siren was approximately 100 lb per sq in. The signal strength at 100 feet was 125 decibels when tested on the roof of the power plant at the National Bureau of Standards. For all practical purposes this device was non-directional.

This signal was so annoying that it was deemed inadvisable to blow it long enough to make a harmonic analysis.

THE GAMEWELL COMPANY

This device was a Type B diaphone with an aluminum piston. The air pressure used when testing was 35 lb per sq in. and the air consumption 1.2 cu ft of free air per second. The signal strength at 100 feet was 114 decibels. For all practical purposes this device was non-directional.

The harmonic content of this signal was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	92
500 - 1000 " " "	106
1000 - 2000 " " "	111
2000 - 4000 " " "	106
4000 " " "	99

H.C.R. COMPANY, INC.

This device was a 5 horsepower vertical electric siren. The fundamental tone was about 500 cycles per second. The power consumption was 6.6 horsepower. The signal strength at 100 feet was 102 decibels. This device was non-directional.

The harmonic content was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	-
500 - 1000 " " "	101
1000 - 2000 " " "	91
2000 - 4000 " " "	83
4000 " " "	85

LINE MATERIAL COMPANY

This device was a 5 horsepower 2-tone horizontal electric siren. The fundamental tones were about 530 and 636 cycles per second when the steady tone was used. It also had a device to switch the current off and on, thus producing a warble tone. The power consumption on the steady tone was 12.2 horsepower. The average signal strength at 100 feet was 104 decibels. This device was slightly directional. The sound level varied about ± 2 decibels when measured around the siren in a horizontal direction, the maximum being in the direction of the shaft. When the warble was used this strength varied about ± 5 decibels, giving a signal strength varying from 99 to 109 decibels.

The harmonic content was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	-
500 - 1000 " " "	~~109~~ 103
1000 - 2000 " " "	93
2000 - 4000 " " "	72
4000 " " "	70

WESTINGHOUSE AIR BRAKE COMPANY

The devices submitted by this company consisted of four air-horns marked as follows:

Type E-2 Horn, Standard Type (157 V.P.S.)
Type E-2 " Special " (250 V.P.S.)
Type E-2 " " " (440 V.P.S.)
Type A-2 " " " (397 V.P.S.)

The air pressure used when the tests were made on these horns was 80 lb per sq in.

The signal strengths of these horns at 100 feet and the air consumption in cu ft of free air per second were as follows:

	Signal Strength	Air Consumption
Type E-2 (157 V.P.S.)	106 decibels	0.71
Type E-2 (250 V.P.S.)	109 "	.72
Type E-2 (440 V.P.S.)	110 "	.71
Type A-2 (397 V.P.S.)	101 "	.22

For all practical purposes these devices were non-directional.

The harmonic content of the Type E-2 (157 V.P.S.) was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	93
250 - 500 " " "	100
500 - 1000 " " "	100
1000 - 2000 " " "	95
2000 - 4000 " " "	96
4000 " " "	91

The harmonic content of the Type E-2 (250 V.P.S.) was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	97
250 - 500 " " "	102
500 - 1000 " " "	103
1000 - 2000 " " "	103
2000 - 4000 " " "	97
4000 " " "	93

The harmonic content of the Type E-2 (440 V.P.S.) was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	104
500 - 1000 " " "	106
1000 - 2000 " " "	100
2000 - 4000 " " "	101
4000 " " "	99

The harmonic content of the Type A-2 (397 V.P.S.) was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	95
500 - 1000 " " "	91
1000 - 2000 " " "	92
2000 - 4000 " " "	96
4000 " " "	92

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DEVICES FOR AIR RAID WARNINGS
SUPPLEMENT TO LETTER CIRCULAR LC-685
MAY 25, 1942

Measurements have been made on a number of devices for air raid signaling since Letter Circular LC-685 of April 1 was issued. The following is a list of these devices and the companies which manufacture them.

Buckeye Iron & Brass Works,
Dayton, Ohio.
- 2-inch plain whistle
- 2-inch chime whistle
- 4-inch plain whistle
- 4-inch chime whistle

E. D. Bullard,
275 Eighth St.,
San Francisco, California.
- 3-head siren driven by an automobile engine.

Clark Cooper Company,
1500 North Nascher St.,
Philadelphia, Pa.
- Type 6 air horn
- Type 8 air horn

Foster Engineering Co.,
Newark, N. J.
- Type 45 steam siren (No. 4 brake shoes)
- Type 45 steam siren (No. 3 brake shoes)
- Type 30 steam siren

Kiel Laboratory,
23-27 South Jefferson St.,
Chicago, Ill.
- Carl air horn (Fund. Freq. 220)
- Carl air horn (Fund. Freq. 275)

Large siren developed for N.D.R.C.

BUCKEYE IRON AND BRASS WORKS

The devices submitted consisted of 4 whistles marked as follows:

2" plain whistle
2" chime whistle
4" plain whistle
4" chime whistle

These whistles were operated with steam from a boiler used for heating purposes and blown on the roof of the building. The intention was to operate as nearly as possible at a pressure of 100 lb/in^2, but as there was no reducing valve and the load on the boiler varied, it was not possible to hold the pressure constant. Fortunately a change of 5 to 10 lb/in^2 in steam pressure did not change the acoustic output to an appreciable extent.

The signal strengths of these whistles at 100 feet were as follows:

Whistle	Signal strength
2" plain	99 decibels
2" chime	101 "
4" plain	109 "
4" chime	104 "

The harmonic contents of these devices were as follows:

Band	Level in decibels			
	2" plain	2" chime	4" plain	4" chime
0 - 125 cycles per sec.	-	-	-	-
125 - 250 " " "	-	-	-	-
250 - 500 " " "	-	-	104	100
500 - 1000 " " "	98	90	99	100
1000 - 2000 " " "	85	100	104	98
2000 - 4000 " " "	83	93	95	90
4000 " " "	78	82	83	84

E. D. BULLARD

This siren had three heads and was driven by a standard automobile engine. When tested, the gears driving the three heads had the ratio values of 21, 24, and 27. The throttle on the engine was fixed so as to hold it approximately at a constant speed of 3400 rpm.

This device was directional. When the measurements were taken at 100 feet on a line perpendicular to the face of the siren and starting at the central point for the three heads the level was 125 decibels. This level was approximately constant over an angle of 45° to either side of the perpendicular. For greater angles the level gradually decreased and was a trifle over 10 decibels lower at the rear of the siren than it was directly in front of it.

The harmonic content of this signal was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	112
500 - 1000 " " "	122
1000 - 2000 " " "	119
2000 - 4000 " " "	114
4000 " " "	114

CLARK-COOPER COMPANY

The devices submitted consisted of 2 air horns marked as follows:

Clark Cooper Type 6
Clark Cooper Type 8

The air pressure used when the tests were made on these horns was 90 lb/in^2.

The signal strength of these horns at 100 feet and the air consumption in cubic feet of free air per second were as follows:

	Signal strength	Air consumption
Type 6	109	2.0
Type 8	110	3.0

The harmonic contents of these devices were as follows:

Band	Level in decibels	
	Type 6	Type 8
0 - 125 cycles per second	-	-
125 - 250 " " "	-	100
250 - 500 " " "	100	100
500 - 1000 " " "	104	106
1000 - 2000 " " "	102	103
2000 - 4000 " " "	99	100
4000 " " "	97	96

FOSTER ENGINEERING CO.

Further tests were made on the devices submitted by this company as the tests made and reported in Letter Circular LC-685 were incomplete.

The devices tested were as follows:

Type 45 steam siren (No. 4 brake shoes)
" 45 " " (No. 3 " ")
" 30 " "

These sirens were operated from the same boiler as the whistles. Owing to the quantity of steam used for the Type 45 siren, the drop in the pipe line to the roof was such that the average pressure at the siren when blowing was about 90 lb/in^2. The average steam pressure for the small siren was 100 lb/in^2.

The signal strengths of these sirens at 100 feet were as follows:

	Signal strength
Type 45 (No. 4 brake shoes)	125 decibels
" 45 (No. 3 " ")	127 "
" 30 (1/8" valve opening)	116 "
" 30 (1/4" " ")	120 "

The harmonic contents of these devices were as follows:

Band	Level in decibels			
Cycles per sec.	Type 45 (No.4 shoes)	Type 45 (No.3 shoes)	1/8" Valve Opening	1/4" Valve Opening
0 - 125	-	-	-	-
125 - 250	118	-	-	-
250 - 500	122	124	-	-
500 - 1000	114	122	115	-
1000 - 2000	112	116	105	120
2000 - 4000	*	105	97	106
4000	*	*	98	111

*The energy at these frequencies was so small that it was not measured.

KIEL LABORATORY

The devices consisted of 2 air horns, one having a fundamental frequency of 220 cycles per second and the other a fundamental frequency of 275.

The air pressure when the tests were made on these horns was 30 lb/in^2.

The signal strength of these horns at 100 feet and the air consumption in cubic feet of free air per second were as follows:

	Signal strength	Air consumption
Carl Horn (220 V.P.S.)	101	.23
" " (275 V.P.S.)	105	.23

The air consumption varied considerably with slight changes in adjustment of the diaphragm.

The harmonic contents of these devices were as follows:

Band	Level in decibels	
	Carl Horn (220 V.P.S.)	Carl Horn (275 V.P.S.)
0 - 125 cycles per second	-	-
125 - 250 " " "	86	-
250 - 500 " " "	89	92
500 - 1000 " " "	97	101
1000 - 2000 " " "	97	101
2000 - 4000 " " "	89	91
4000 " " "	85	90

LARGE SIREN DEVELOPED BY N.D.R.C.

This siren had a single head and was supplied with air by a blower. The source of power was a gasoline engine. A short horn was used to increase the efficiency, and this made the device directional. The average signal strength at 100 feet was found to be 133 decibels when measured in front of and on the axis of the horn. The sound level 45° off the axis decreased about 6 decibels. 90° off the axis the decrease was 23 decibels and 180° off the axis 21 decibels.

The harmonic content of the signal was as follows:

Band	Level in decibels
0 - 125 cycles per second	-
125 - 250 " " "	-
250 - 500 " " "	124
500 - 1000 " " "	129
1000 - 2000 " " "	118
2000 - 4000 " " "	114
4000 " " "	115

Loss of Intensity with Distance.

The signal strengths which have been given in Letter Circular LC-685 and this supplement are valuable in comparing the acoustic output of different types of signaling devices, but fail to answer one important question: At what distance can these different signals be heard? In an attempt to answer this question, measurements of the sound levels were made at varying distances up to 2 1/2 miles and observations of the audibility of the signals have been made up to distances of over 8 miles.

It was found, as mentioned in Letter Circular LC-685, that changes in weather changed the sound level of a signal by a marked amount. At 1/2 mile a reversal in direction of a breeze of 10 miles an hour or less changed the level of a signal 10 decibels or more. All of the data obtained in these tests have been compiled, and the form of an equation which seems to fit the data best is as follows:

Loss in decibels from signal strength at 100 ft =
Loss due to distance (inverse square law) + the loss due to the sound passing through the air.

It was found that for signals having a fundamental less than 700 cycles per second the average loss due to the sound passing through the air is about 0.2 decibel per 100 feet for conditions of good transmission. Under unusual conditions this loss is occasionally smaller. Under the worst conditions encountered, on a warm day with a 20 mile per hour adverse wind, the loss was 1.0 decibel per 100 feet. Under some conditions this loss might be somewhat greater. Many cases are recorded by other observers where this factor must have been 2.0 decibels per 100 feet or more. A strong, gusty, adverse wind with low humidity appears to represent the worst conditions for the transmission of sound. Cloudy weather, a light mist, or even rain and snow, often represent good conditions.

Using the values 0.2 decibel and 1.0 decibel per 100 feet as representing the extremes which would ordinarily be encountered, the following table has been computed to show what the loss in signal level might be at different distances under the above conditions.

Distance	Loss due to distance (inverse square law)	Total loss for factor of 0.2 db per 100 ft	Total loss for factor of 1.0 per 100 ft
1/2 mile	28.2	33.2	53.2
1 "	34.2	44.4	85.2
1 1/2 "	37.7	53.1	114.7
2 "	40.2	60.8	143.2
3 "	43.7	74.7	-
4 "	46.2	87.6	-
8 "	52.2	135.2	-

Using the above table and the source strength one can compute the probable limits for the signal level at a given distance under varying weather conditions.

It is believed that the losses indicated above apply to city areas as well as the country areas where the measurements were made. In city areas, however, there are additional losses which are caused by buildings and other obstacles which create definite acoustic shadows. When a listener is within an acoustic shadow there will be an additional loss in sound level which may vary from a few decibels up to 20 decibels or more. Where powerful signaling devices are used, spaced relatively far apart, it may be necessary to use small supplementary devices where bad sound shadows are found.