SOUND SIGNALS

Extract from *Die Schalltechnik,* by RICHARD BERGER
(Vieweg Collection — N° 83. Braunschweig 1926) (*)

In connection with the preceding article on the reliance which may be placed in fog signals transmitted through the air, the following extract from the work, "*Die Schalltechnik*" by Dr Eng. Richard BERGER, Braunschweig, 1926, reproduced below, is thought to be of interest. It will be recalled that exhaustive studies of this question were made several years ago by Mr. ESCLANGON, Director of the Strasburg Observatory. All new research along these lines should be of interest in connection with the general problem of phonotelemetry.

Sound signals under water are an aid in avoiding dangers to coastal navigation in fog and severe weather. Sound signals transmitted under water have the advantage over radio signals that disturbances due to adjacent stations are eliminated. On the other hand, however, the temperature of the water exerts an appreciable influence on the effective range of such sound waves. On the average, sound waves are transmitted under water for distances of 10 to 40 km., and consequently greatly exceed the range of sound signals in the air. Variations in the velocity of sound in the different layers and its absorption by the conducting medium, greatly influence the range of the sound signals transmitted in a conducting medium which is at rest or subject to slight movements. In the air the additional action of the wind is to be considered.

A) *INFLUENCE OF THE ABSORPTION OF SOUND ON THE RANGE OF TRANSMISSION*

Experience has shown that in the case of direct auditive perception in the vicinity of a source of sound, the tone of 3200 hertz (number of vibrations per second) is the loudest. For indirect perception (telephone diaphragm, for example) at considerable distances from the source the tone of 1000 hertz necessitates the minimum expenditure of energy and is perceived with greater intensity.

As a result of the greater absorption of the short sound waves, the energy of the longer waves is less diminished at a great distance from the source. According to Aigner, (**) with the same strength of sound wave emitted at the source the tone of 1000 hertz is received through the air with the greatest intensity at a distance of 10 km. (for direct auditive perception), and the tone of 750 hertz for indirect perception, as a result of the absorption of sound. Under ordinary conditions, the absorption of sound in water is so slight that it may be neglected for all practical purposes. With regard to the propagation of seismic waves the longer waves predominate more and more as the distance from the source of seismic disturbance increases. The greater absorption of the short sound waves by the earth may well be the principal cause of this phenomenon.

(*) *The above extract is reproduced with the permission of the writer :* Dr-Eng. Richard BERGER, *Munich, and the publisher : Friedr. Vieweg & Sohn Akt-Ges. Braunschweig. Allemagne, from a pamphlet of* 115 *pages and* 97 *fig. which form Publication* 63, "Sammlung Vieweg — *Tagesfragen Aus Den Gebieten Der Naturwissenschaften und Der Technik*" — *Price : R. M.* 8.00.

(**) Aigner — *Unterwasserschalltechnik* — *Berlin* 1922.

B) *INFLUENCE ON THE RANGE OF TRANSMISSION OF THE VARIATIONS IN THE CONDUCTING MEDIUM.*

The variations in the velocity of sound exert a great influence on the range of transmission of sound signals.

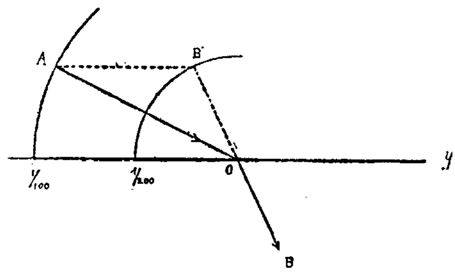

FIG. 1

It is known that the refraction in successive layers takes place according to the law of proportionality of the sine the inverse velocity of propagation: $1/V_1$, $1/V_2$, $1/V_3$, etc.... Therefore if the sound wave traverses a layer in which the velocity, $V = 100$, and then enters a layer in which $V = 200$, we obtain the refracted ray by drawing a parallel *A-B'* to *Oy* from the point *A* (fig. 1) to the point *B'*; where this parallel intersects the circumference of the circle described about *O* as a centre with a radius equal to 1/200, then joining point *B'* to the point *O*, and prolonging in the direction *OB* into the new medium. This well-known construction, giving the direction of the refracted ray, shows that where the wave enters a layer in which the velocity is reduced, the trajectory of the sound wave curves towards the layers in which the velocity is a minimum.

In the air and in the water the velocity of sound increases with the temperature, while in solid bodies the velocity diminishes with an increase in temperature. In pure water, the velocity of sound increases as much as 10 % up to a temperature of 65° but after that it again diminishes and at a temperature of 90° it has the same value as at 44°. Contrary to the condition in water, the velocity of sound decreases with the temperature, in all other liquids in which experiments have been conducted to date. In all liquids, including water, the velocity of sound increases in proportion to the solid bodies in solution in the liquid.

From the above it follows that in the air, during the day, the temperature diminishes with the altitude and consequently the velocity of sound also diminishes with the altitude. Therefore, during the day, a horizontal wave of sound will gradually curve upward. (see fig. 2). The construction of the refracted ray permits an easy determination of the inclination of the waves according to the index of refraction due to variation in velocity. (see figure on the left).

If the source and the observer are both on the surface of the ground and separated by a great distance, the observer, under the most favourable conditions, can only hear the sound as a result of this bending of the wave. For this reason it has been the practice from times immemorial to place the sources of sound, such as church bells, etc., as high as possible.

At the moment of sunset, it frequently happens that a state of equilibrium is established in the air temperature which increases the range of the sound over that which obtains during the day. On clear starlight nights the opposite case may easily occur; *i.e.*, the colder layers are

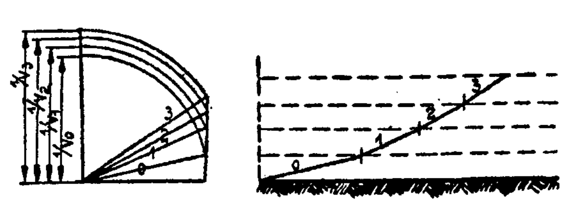

FIG. 2.

Curvature of the ray in the air during the day. Deviation upwards towards the colder layers.

found below the warmer layers of air. In that case the conditions represented in Fig. 3 will hold; the sound wave being directed towards the earth, giving rise to an appreciable increase in the range.

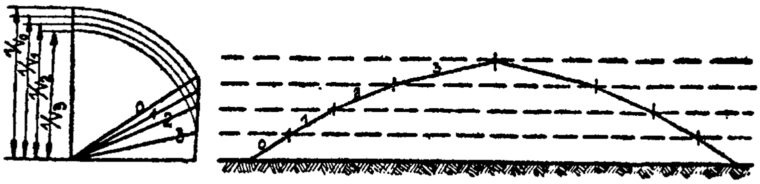

Fig. 3.
Curvature of the ray towards the earth in clear starlight nights.

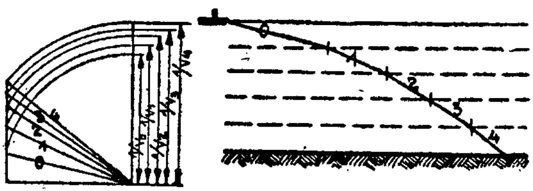

Fig. 4.
Deviation of the sound wave in water in summer towards the colder underlying strata.

In the ocean, in summer, the temperature diminishes with the depth. As a result during the summer months, the sound wave is deflected gradually towards the colder layers of water near the bottom, and becomes absorbed by the bottom of the sea. (Fig. 4). In winter the temperature of the water diminishes towards the surface. Under these conditions a sound wave is deflected towards the surface. Arrived at the surface between the air and water it is reflected towards the bottom and again recurves towards the surface. Such reflections from the surface may be repeated several times. (Fig. 5.)

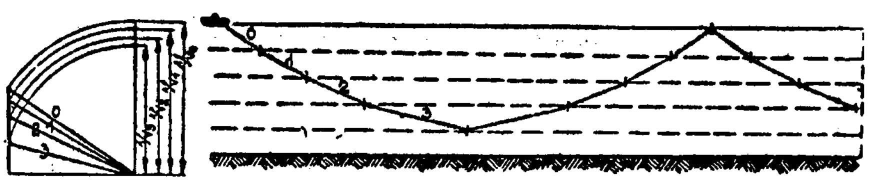

Fig. 5.
Deviation of the sound wave towards the colder layers near the surface in the winter.

For this reason sound signals under water have a much greater range in winter than in summer. The range obtained in February, for example, which is the coldest month, is three or more times greater than the range in July, the warmest month. The range is also influenced by the salinity, although to a lesser extent.

c) *INFLUENCE OF THE WIND ON THE RANGE.*

In the air, even where the temperature is constant, the sound wave may be deflected by the wind.

The wave which is propagated in the direction of the wind curves downward, while the wave propagated in the opposite direction is curved upwards. It is well to study the path of such a wave propagated with the wind, since this is frequently the cause of abnormal ranges of sound waves.

Let v_1 and v_2 equal the velocities in two layers of air and u_1 and u_2 be the respective velocities of the wind. The layers are assumed parallel to the earth's surface. θ_1 and θ_2 are the angles made by the sound waves with the normal to the earth's surface ; w_1 and w_2 are the components of the wind in the direction of the sound waves. Therefore from Fig. 6 we have for the distances m_1 and m_2 and the components of the wind, w_1 and w_2, the following.

$$\sin \theta_1 = v_1/m_1 = w_1/u_1$$
$$\sin \theta_2 = v_2/m_2 = w_2/u_2$$

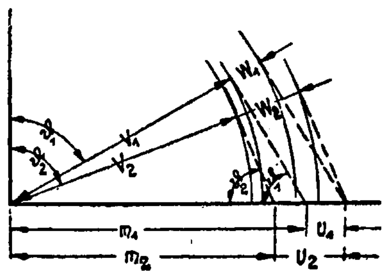

FIG. 6.

In the case of refraction with the wind the following is applicable ; — the projections of the velocities of wind and sound along the surface dividing the layers are equal. Consequently :

$$m_1 + u_1 = m_2 + u_2, \text{ and}$$
$$v_1 / \sin \theta_1 + u_1 = v_2 / \sin \theta_2 + u_2$$

We find that the rule of sines is not applicable when we take the velocities of wind parallel to the ground. But replacing these velocities with their components in the direction of the sound waves, we obtain :

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1 + w_1}{v_2 + w_2}$$

We obtain therefore a new sine rule which may be formulated as follows. The sine of the angle of the incident ray and the sine of the angle of the refracted ray have the same ratio as the sums of the components of the velocity of sound and the velocity of the wind in the direction of the ray. Total reflection occurs when $\theta_2 = 90°$.

In that case :

$$\sin \theta_1 = \frac{v_1}{v_2 + u_2 - u_1}$$

In the case, for example, where,

$$v_1 = v_2 = 335 \text{ m/sec} ;$$
$$u_1 = 0$$
$$u_2 = 7 \text{ m/sec}$$

We have :

$$\sin \theta_1 = 335/ (335 + 7) = 0.978$$

And therefore :

$$\theta_1 = 78°$$

A sound wave at an angle of 90° — 78° = 12° to the horizon, will be totally reflected in a moderate wind having a velocity of 7 m/sec. The abnormally long range of the sound of gun-fire may be explained in a similar manner.

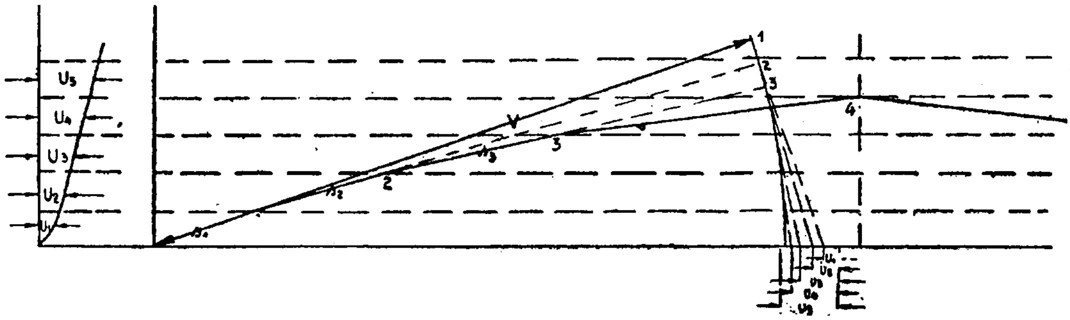

FIG. 7.
Curvature of the ray of sound in a wind increasing with altitude.

Fig. 7 shows the deviation of a sound wave in the direction of the wind. The velocity of sound, U_5 falls within the arc of a circle of the velocity of sound in that layer (in this particular case we have assumed the velocities in all the layers to be equal amongst themselves) and for that reason the layer is not penetrated by the sound wave; — it is totally reflected.