

Aug. 15, 1933.

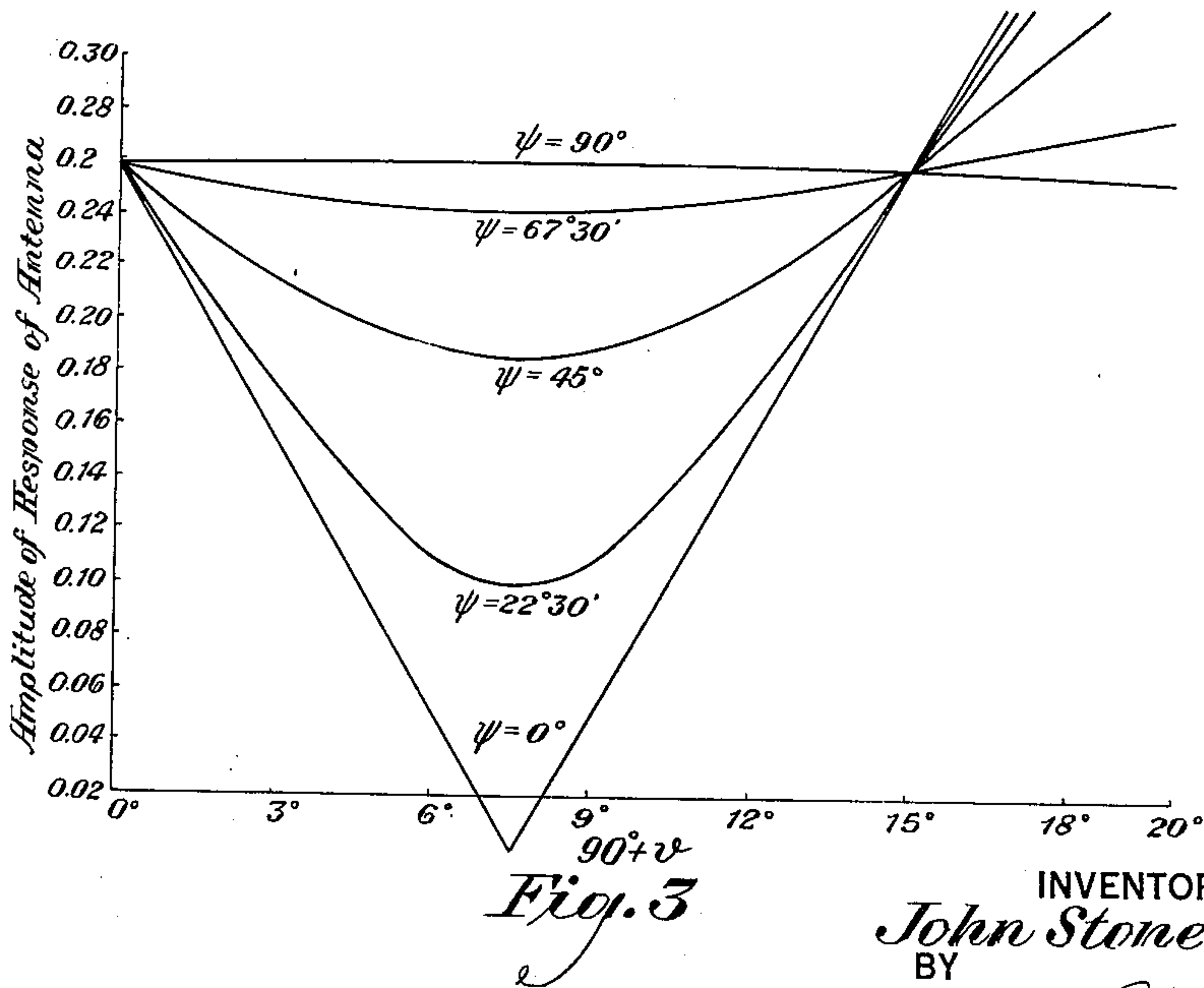
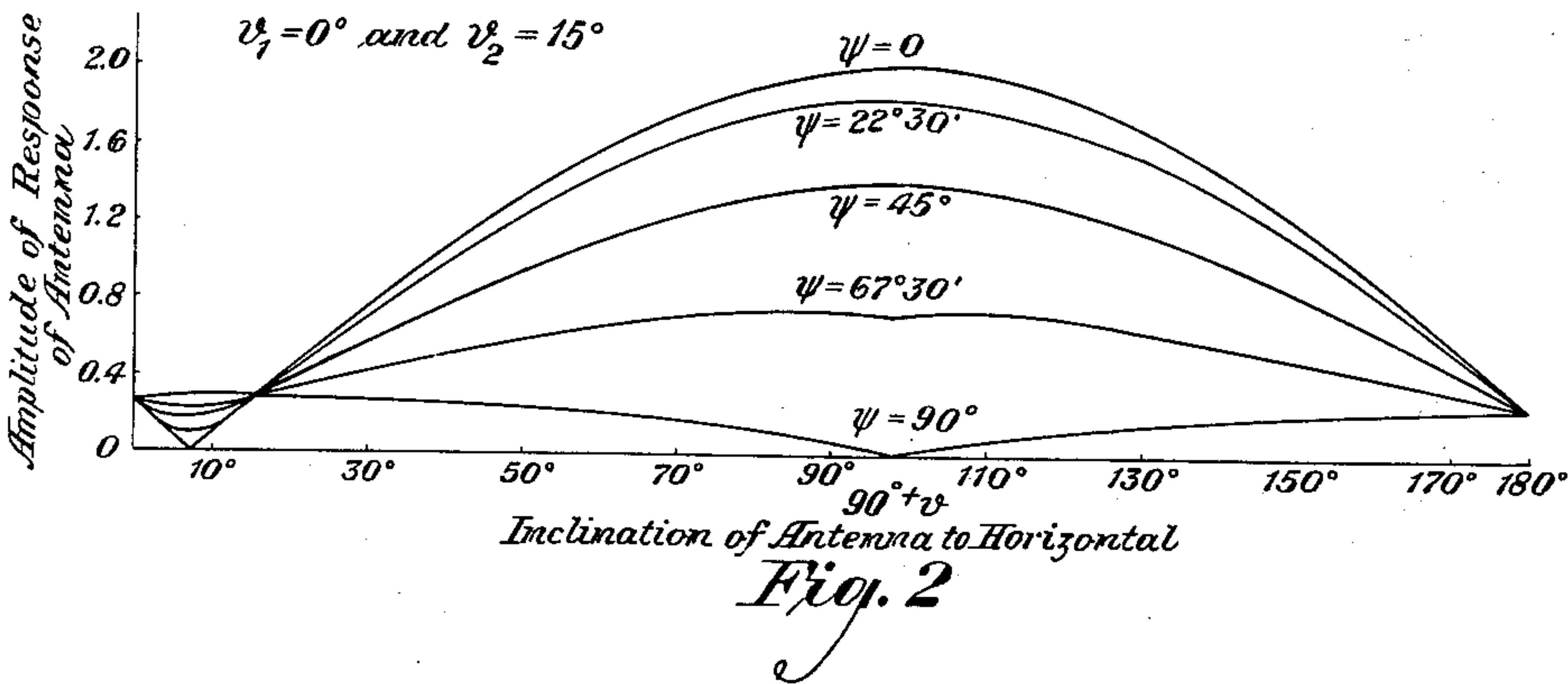
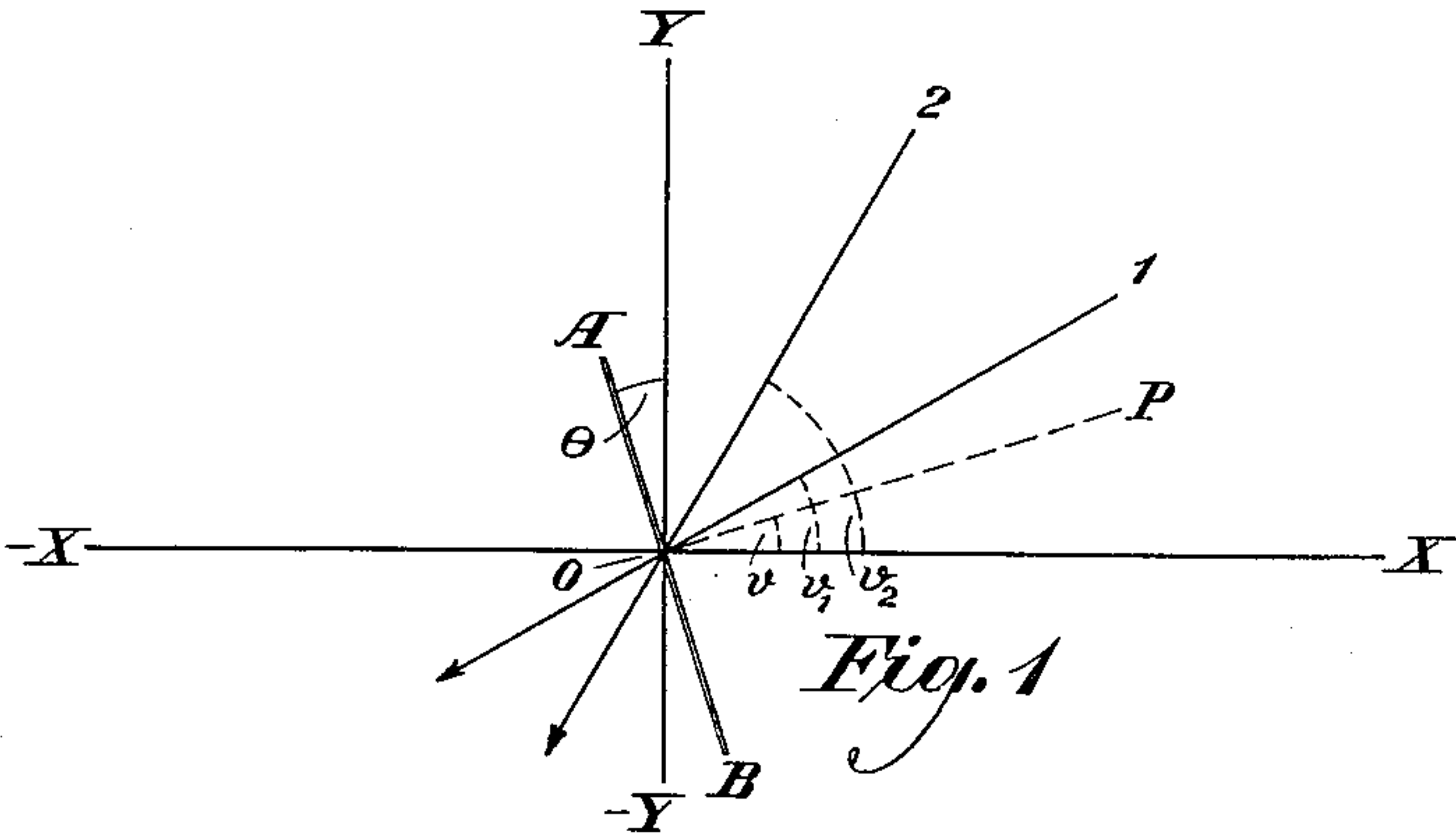
J. S. STONE

1,922,116

ANTENNA ARRAY

Filed April 12, 1930

2 Sheets-Sheet 1



INVENTOR
John Stone Stone
BY
J. E. Stone
ATTORNEY

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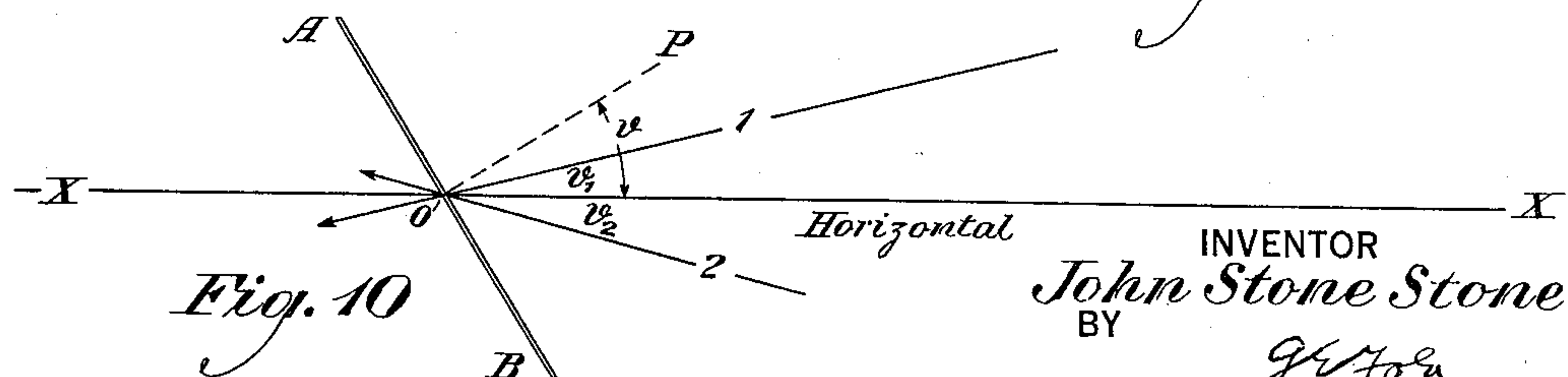
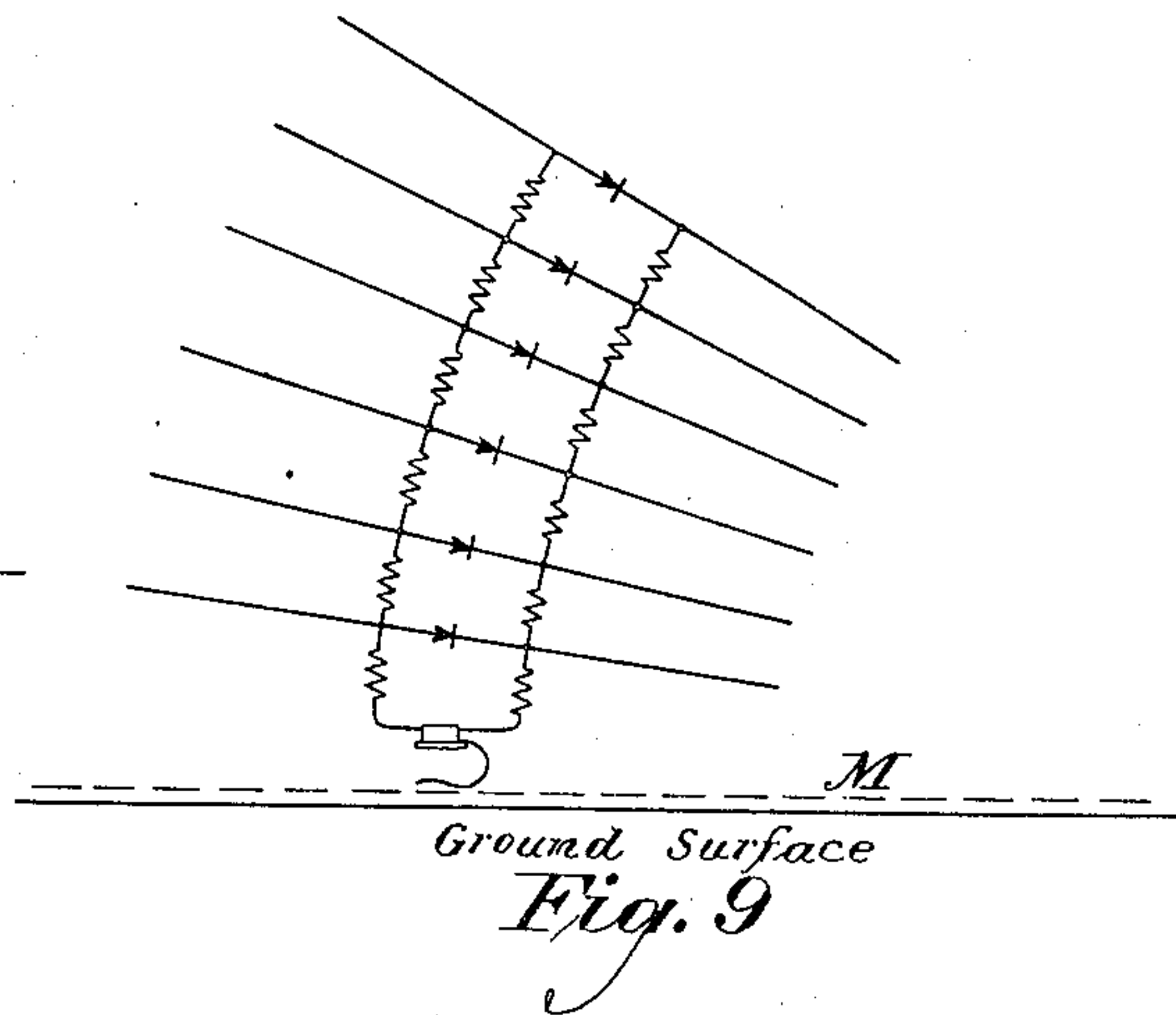
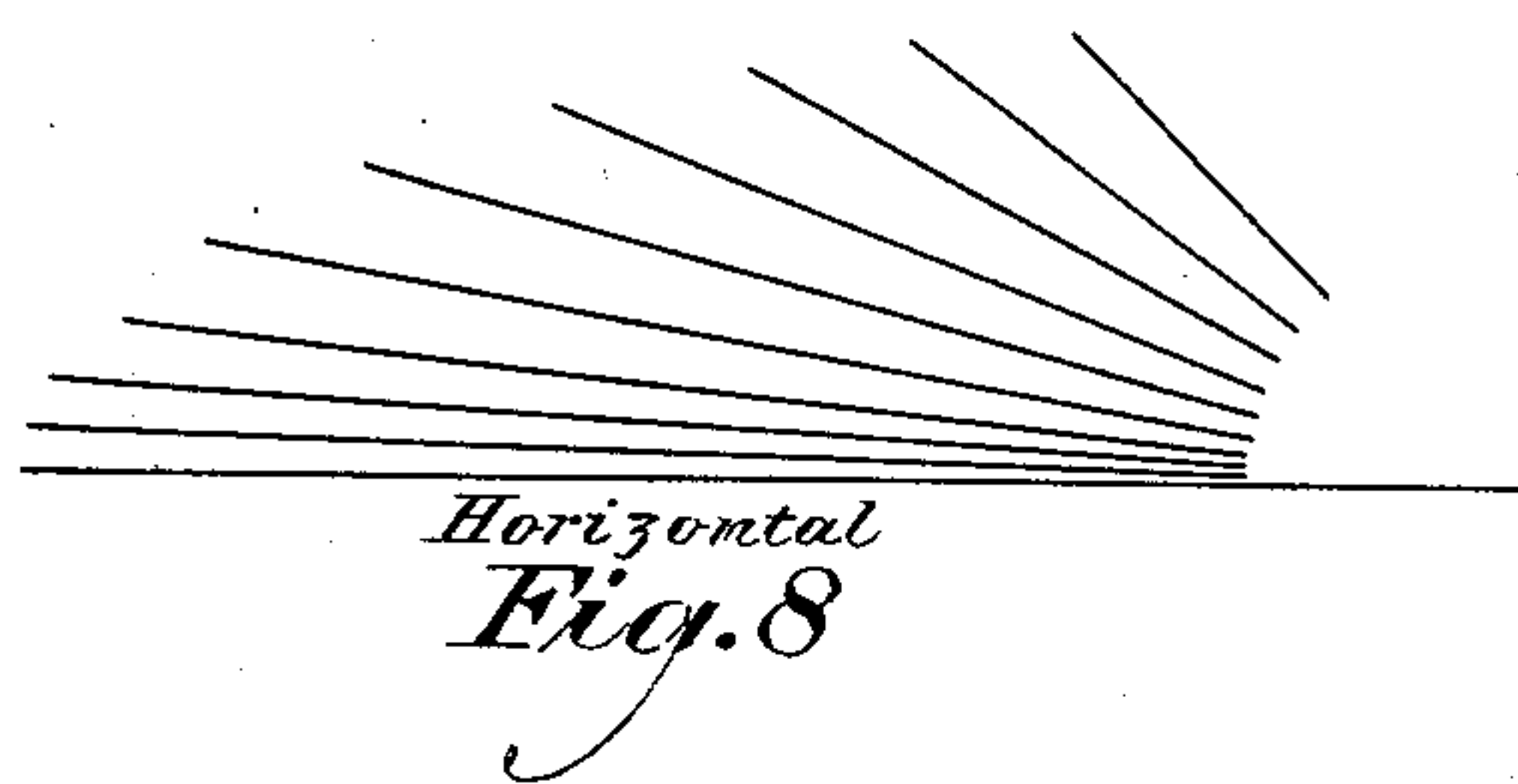
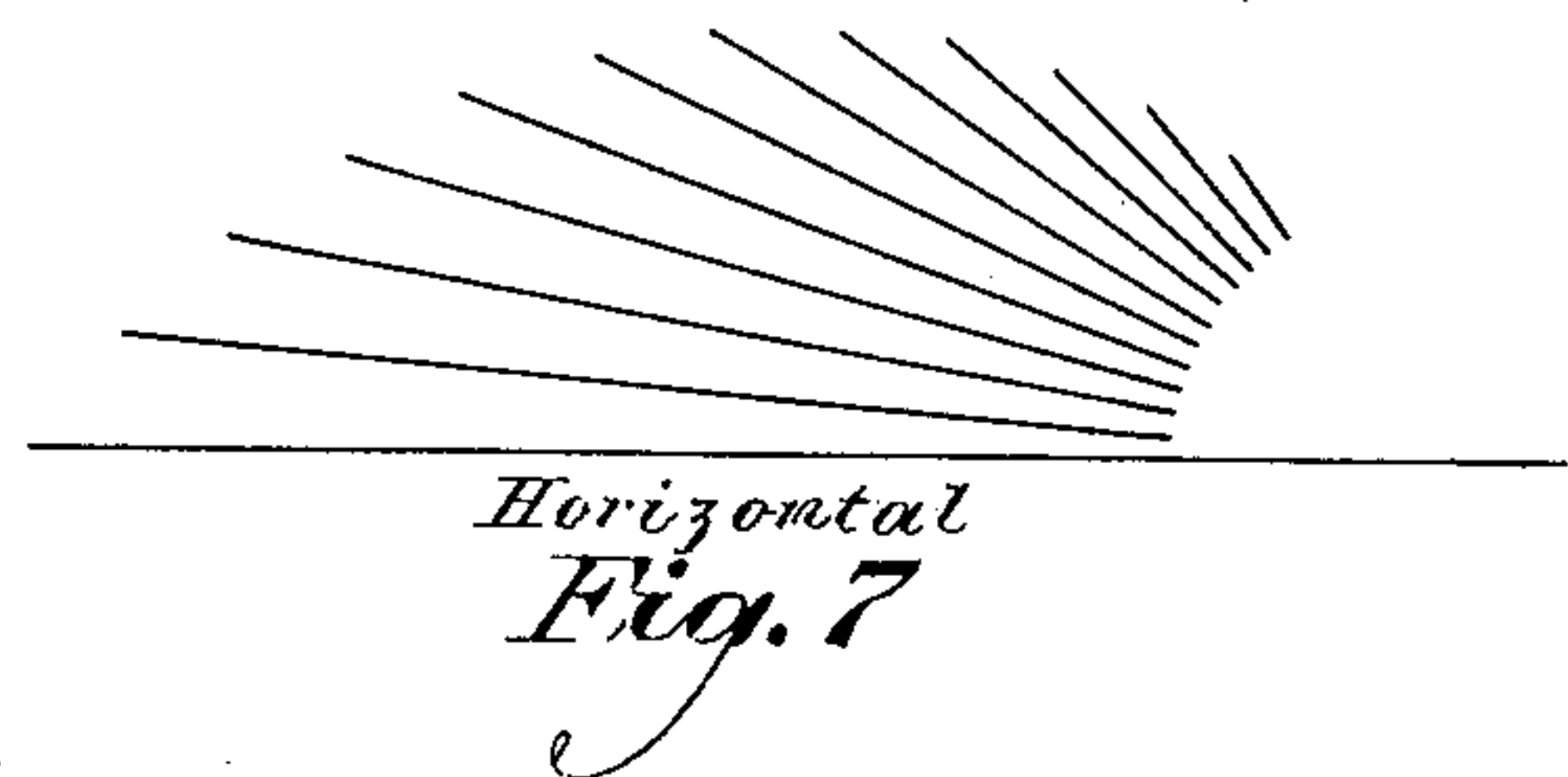
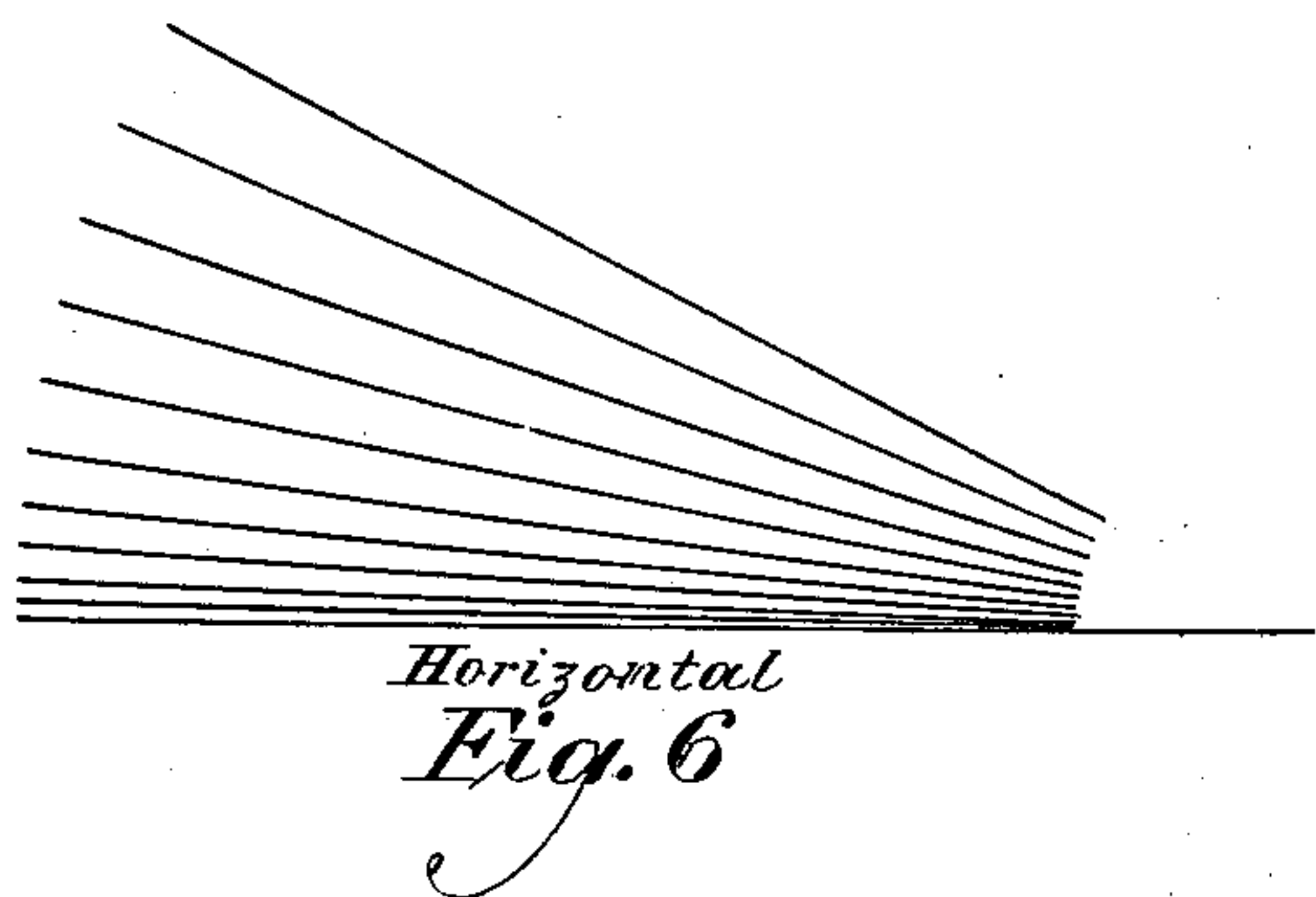
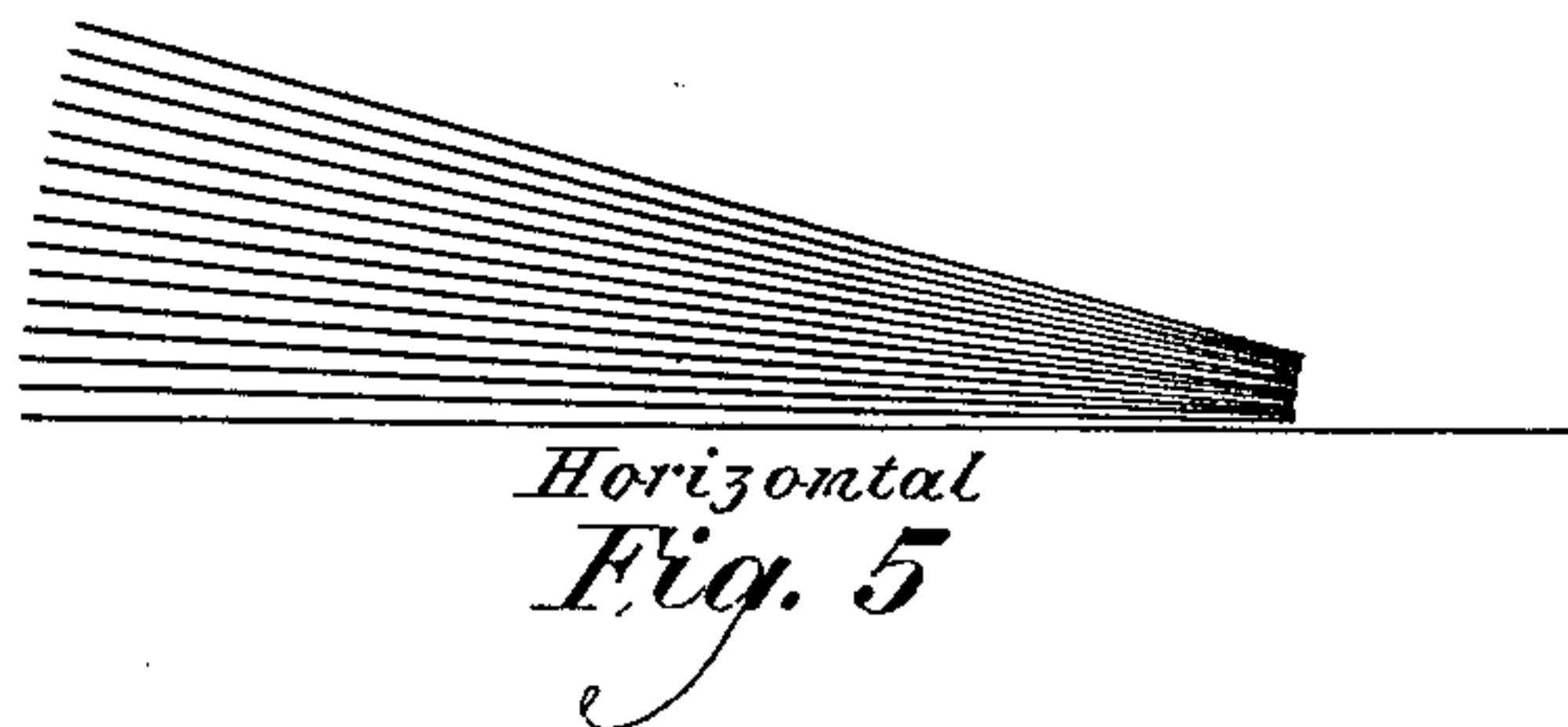
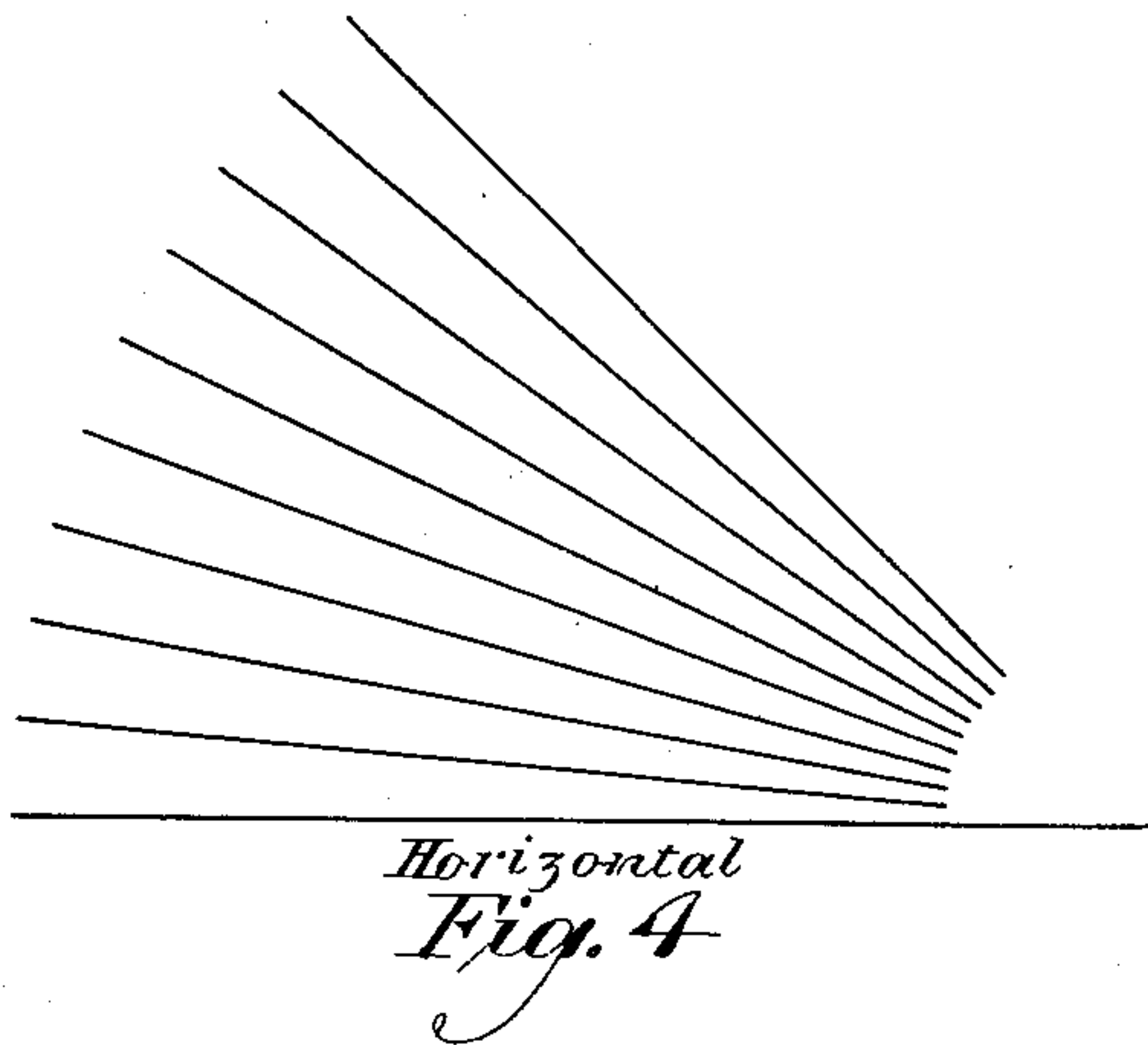
J. S. STONE

1,922,116

ANTENNA ARRAY

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2 Sheets-Sheet 2



INVENTOR
John Stone Stone
BY
John Stone
ATTORNEY

UNITED STATES PATENT OFFICE

1,922,116

ANTENNA ARRAY

John Stone Stone, San Diego, Calif., assignor to
American Telephone and Telegraph Company,
a Corporation of New York

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7 Claims. (Cl. 250—33)

The principal object of my invention is to provide a new and improved system of antennas for receiving radio waves (or transmitting them) advantageously. Still another object of my invention is to provide an array of antennas adapted to compensate one another and receive as a whole in a manner to obviate "fading" and other drawbacks. Still another object of my invention is to provide "an antenna fan" for receiving that shall give a substantially uniform response notwithstanding conditions that might produce fading for a single receiving antenna. All these objects and other objects of my invention will become apparent on consideration of a limited number of specific examples of practice according to the invention, which will here be presented by way of example with the understanding that the scope of the invention will be indicated in the appended claims.

Referring to the drawings, Fig. 1 is a diagrammatic elevation showing an inclined antenna and two wave trains in different directions in relation thereto. Fig. 2 is a curve diagram showing intensities of response for the antenna of Fig. 1 at different angles of inclination thereof, and for different phase differences between the waves in the two wave trains. Fig. 3 is an enlargement of the left-hand portion of Fig. 2. Figs. 4 and 5 are diagrammatic elevations of antenna rays or fans at uniform angular spacing and of uniform length. Fig. 6 is a similar diagram except that the spacing is non-uniform. Fig. 7 has uniform spacing, but here the antennas are graded in length. Fig. 8 has non-uniform spacing and the antennas are of graded lengths. Fig. 9 is a diagram indicating how the antennas are to be connected to the common receiving instrument. Fig. 10 is another diagrammatic elevation similar to Fig. 1 in which wave trains approach at equal angles to the horizontal.

It is a commonly accepted theory for the fading of signals in long distance short wave radio transmission that it is due to interference at the receiver between two or more components of the radiation from the transmitter which reach the receiver at different varying angles of incidence relatively to the horizontal in the vertical plane that contains the transmitting and receiving stations, and that these components also reach the receiver in relatively varying phase relations. Such interference phenomena give rise to a shifting interference pat-

tern at the receiver which causes the waxing and waning of the signals known as fading.

Before indicating the precise composition of an antenna array according to my invention, I will give an introductory consideration of the effect of two wave trains coming down obliquely on a single antenna. The principle that will be established in this connection will be applicable in connection with the antenna arrays of my invention.

Referring to Figure 1, AB is an antenna, not grounded, inclined at an angle θ to the vertical. It is assumed that from the transmitting station which lies in the vertical plane containing AB, two wave trains come down in the directions indicated by the arrows 1 and 2, making the respective angles with the horizontal θ_1 and θ_2 . It will be assumed in this discussion that the two wave trains indicated by the arrows 1 and 2 are of equal intensity and differ in phase by a phase angle 2ψ and that the phase angle half-way between them is ψ_0 . On this basis it can be readily established that the electromotive force generated in the antenna AB by the two wave trains will be

$$e_1 + e_2 = lHc \cos \psi [\cos(\theta_1 - \theta) + \cos(\theta_2 - \theta)] \sin(\omega t - \psi_0) - lHc \sin \psi [\cos(\theta_1 - \theta) - \cos(\theta_2 - \theta)] \cos(\omega t - \psi_0)$$

In the foregoing equation l is the length of the antenna AB, H is a constant dependent upon the intensity of the received waves at the antenna, c is the velocity of light and ωt is the usual independent variable corresponding to the flow of time and to the frequency of the received waves.

A study of Fig. 1 in connection with the foregoing equation leads readily to the inference that even in the extreme case of a complete interference between the wave trains, the antenna will still respond unless the wave trains coincide in the direction of their motion, which is a condition excluded by hypothesis in the present discussion, or unless the antenna is perpendicular to the line which bisects the angle between the lines of direction of the wave trains. In this case of complete interference of the wave trains, the maximum response of the antenna will be realized when it bisects the angle between the directions of the wave trains.

I have made a study of the effect of varying the parameters in the foregoing equation, and a few illustrative diagrams of my results will now be presented. Fig. 2 is a curve diagram showing the amplitude of response as a func-

tion of θ according to the foregoing equation, as a function of θ for several different values of ψ . In other words, Fig. 2 shows the intensity of response for various inclinations of the antenna and for several different values of the phase difference between the two wave trains. This figure is based on the assumed values $\theta=0$, and $\theta=15$ degrees, that is, one wave train comes in horizontally and the other comes downward at an angle of 15 degrees to the horizontal.

The curves of Fig. 2 show that as the phases of the waves of the two wave trains approach the condition of opposition ($\psi=90$ degrees), the more nearly must the antenna approach the angle of 7.5 degrees to the horizontal if its maximum response is to be secured. In other words, this is the optimum angle for the antenna to get the best effect if there is serious interference between the received waves.

For greater clearness, the portion of Fig. 2 at the left has been replotted on a larger scale in Fig. 3.

By continuing the study like that shown in Figs. 2 and 3, but with other angles for the directions of the waves, that is, other values for θ_1 and θ_2 , I find that in general the direction of the antenna for best response to interfering waves is such that it lies square across the bisector of the angle made by the directions of those waves, in other words, $(\theta_1+\theta_2)/2$.

Going on with this study, I try a plurality of antennas all lying in the vertical plane comprising the transmitting and receiving stations and appearing in elevation as shown in Figs. 4 and 5. Taking the arithmetical sum of the responses in the individual antennas of such an array or fan and adding them, I find that there is obtained a practically constant aggregate response for all values of ψ , the phase difference. In one case, the antennas change in position by an angular increment of 3 degrees and they extend over a span of 24 degrees, that is, the first one is at zero degrees and the last one of the array is at 24 degrees. The foregoing statement about the uniformity of response is true when the directions of the two wave trains are respectively $\theta_1=0$ degrees and $\theta_2=15$ degrees; likewise when $\theta_1=9$ degrees and $\theta_2=24$ degrees.

Again, similar results are obtained with an antenna fan more like Fig. 5 as compared with Fig. 4 for which the wave train directions are $\theta=0$, $\theta_2=5$ degrees. The particular fan here studied had 27 antennas whose span is 8 degrees.

Comparing the the fan of Fig. 5 with that of Fig. 4, we see that Fig. 5 has less total span and more of antennas per unit angle in the vertical plane. This change in the proportions of the fan corresponds to a reduction of the angle $\theta_1-\theta_2$ between the incident beams of radiation. This illustrates the proper relationship between the angular spans of the fans, the number of antennas per unit angle and the angle of divergence between the incident beams of radiation.

In view of the variability in receiving experience of certain of these factors, I resort to the plan exemplified in Fig. 6, which consists in making the angular spacing between the antennas progressively greater with departure from the horizontal.

Instead of varying the angular density of the antennas in their distribution, I may preserve a uniform angularity and vary the length of the antennas as shown in Fig. 7, so as to get the

same result as in Fig. 6. Again, as in Fig. 8, I may vary both the angular density and the length of the individual antennas.

The outputs from the respective antennas should first be reduced from radio frequency to audio frequency and then combined to the common receiver as indicated diagrammatically in Fig. 9.

For the wave trains coming down to the receiving station at an angle to the horizontal, there will, of course, be more or less reflection from the earth's surface in the immediate neighborhood. To make this reflection effect constant, and therefore predicable, an extensive wire mesh indicated at M in Fig. 9 should be laid over the ground around and beneath the antenna array. A study of the case when $\theta_2=-\theta_1$ may be taken as a special case of Fig. 1 in the foregoing equation and it shows that the behavior of the antenna fans of Figs. 4, 5, 6, 7 and 8 is substantially as already explained when due allowance is made for reflection from the ground up to its maximum value.

I claim:

1. An antenna array consisting of a plurality of ungrounded linear antennas all parallel with a single vertical plane, and respectively at various angles to the horizontal which are graded in their magnitudes with regularly increasing intervals.

2. An antenna array consisting of a plurality of ungrounded linear antennas all parallel with a single vertical plane and of graded lengths and respectively at angles to the horizontal which are graded in their magnitudes.

3. An antenna array consisting of a plurality of ungrounded linear antennas all parallel with a single vertical plane and of graded lengths and respectively at angles to the horizontal which are graded in their magnitudes with progressively increasing angular intervals.

4. The method of obviating fading in radio reception which consists in developing wire waves from the space waves along a variety of directions variously inclined to the intended direction of reception, and combining the effects of these wire waves by arithmetical addition whereby a null effect in certain directions is compensated by a reinforcing effect in other directions.

5. A receiving antenna array to obviate fading consisting of antennas at various angles to the desired direction of reception, and means arithmetically to add the effects in these antennas in a common receiver whereby a null effect in certain of the antennas will be compensated by a reinforcing effect in others.

6. An antenna array consisting of a plurality of ungrounded linear antennas all parallel to a single vertical plane and at respective angles to the horizontal which are graded in magnitude, respective radio frequency detectors for said antennas, and a single audio frequency receiving device connected to all said detectors.

7. The method of obviating fading in radio reception which consists in applying the received space waves to develop wire waves in directions at various angles to the received wave front, said directions all lying parallel with the common vertical plane of the transmitting and receiving stations, detecting said respective wire waves and reducing their frequencies from radio frequency to audio frequency, and combining the audio frequency waves arithmetically.

JOHN STONE STONE.