

April 14, 1936.

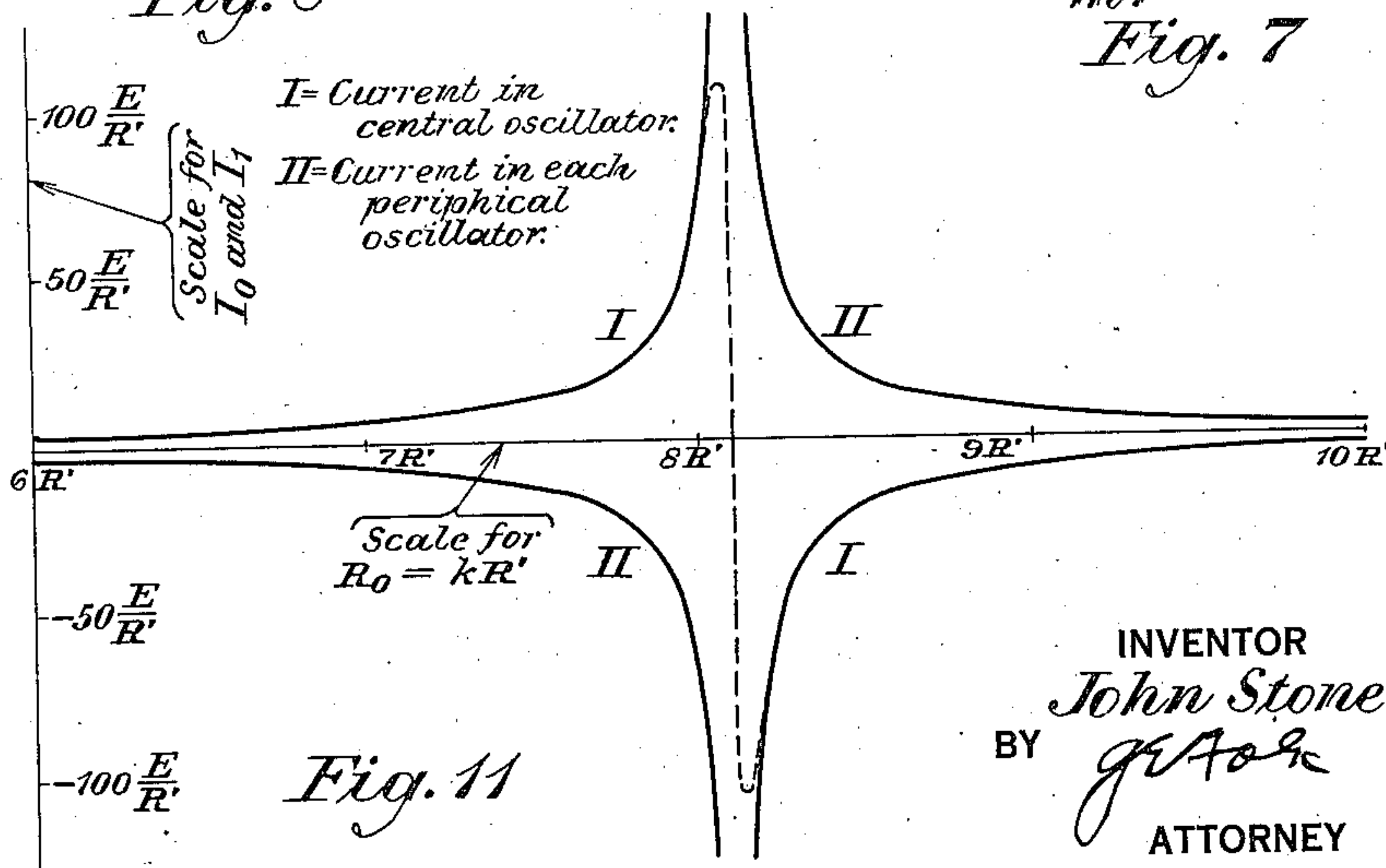
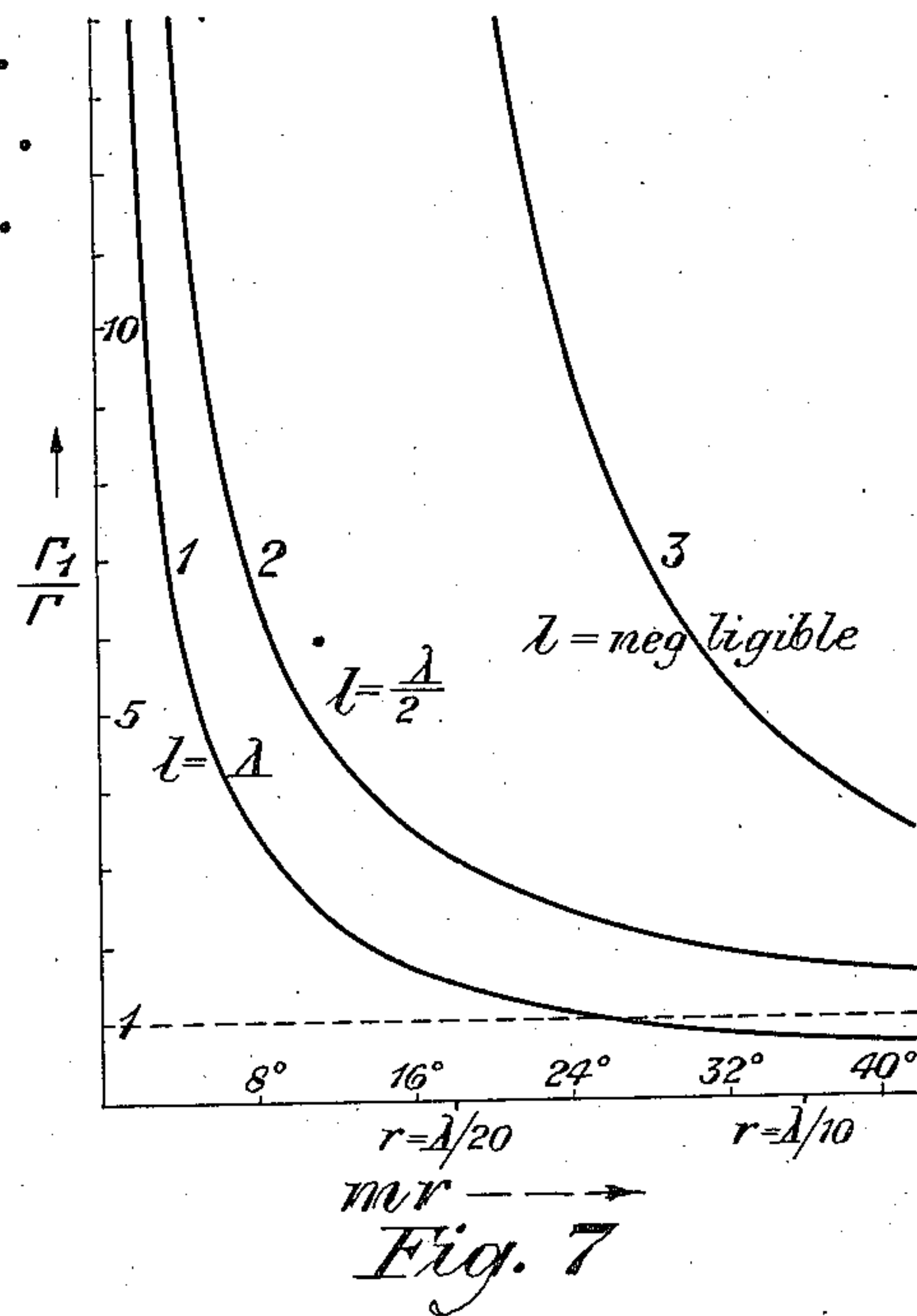
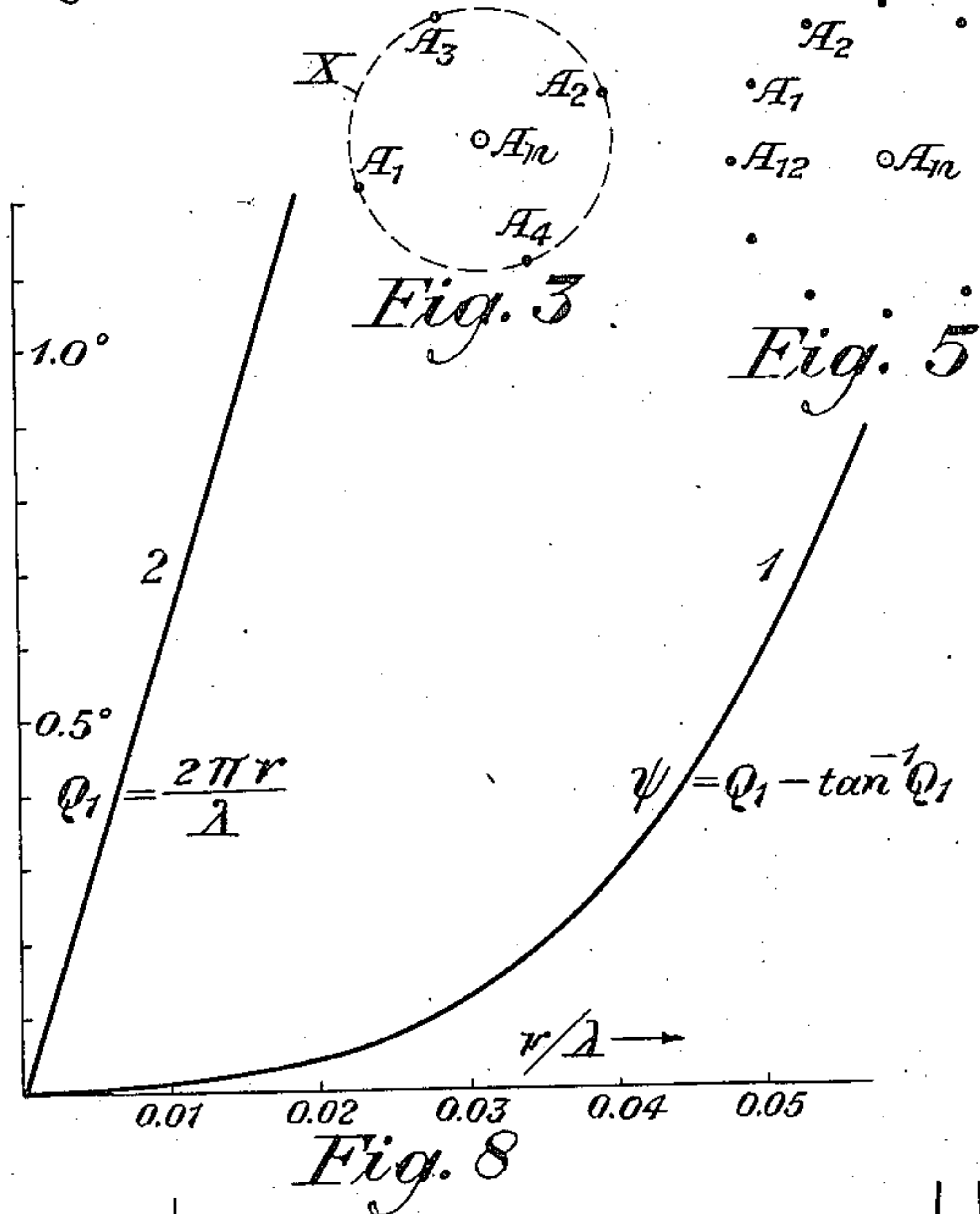
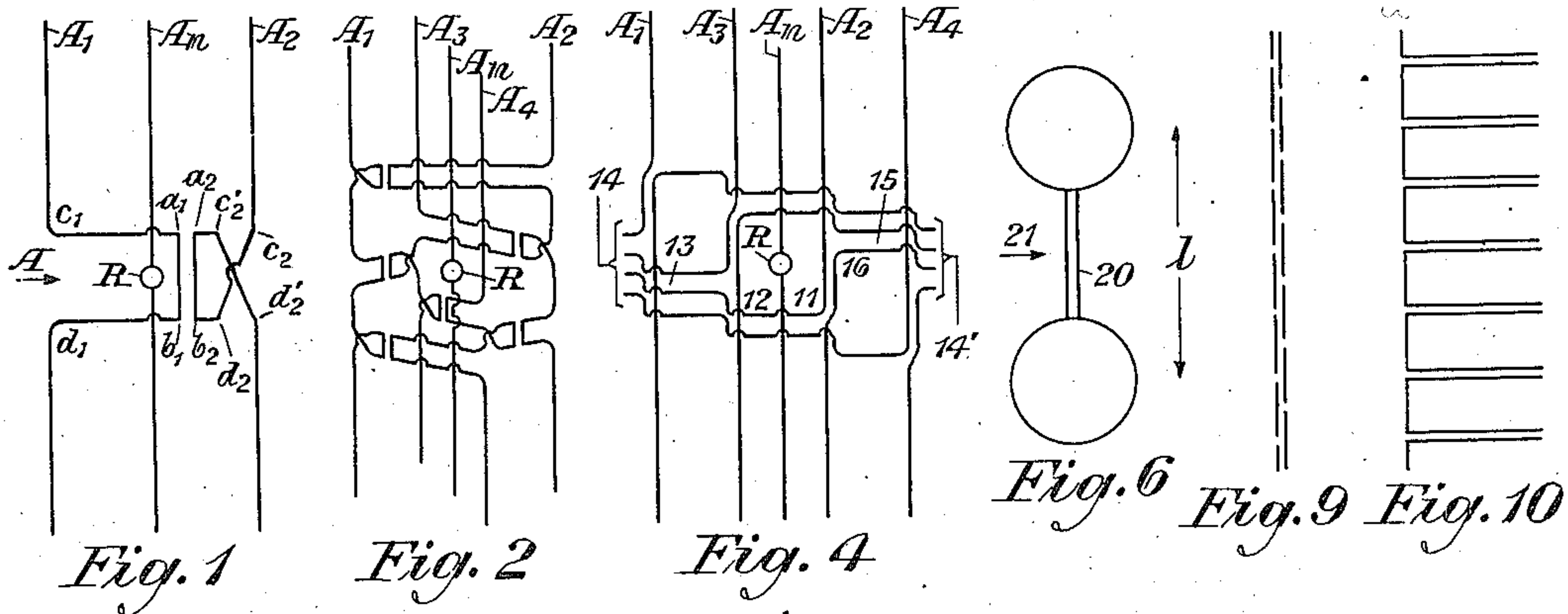
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2,037,154

RADIO RECEIVING SYSTEM

Filed Oct. 30, 1934

2 Sheets-Sheet 1



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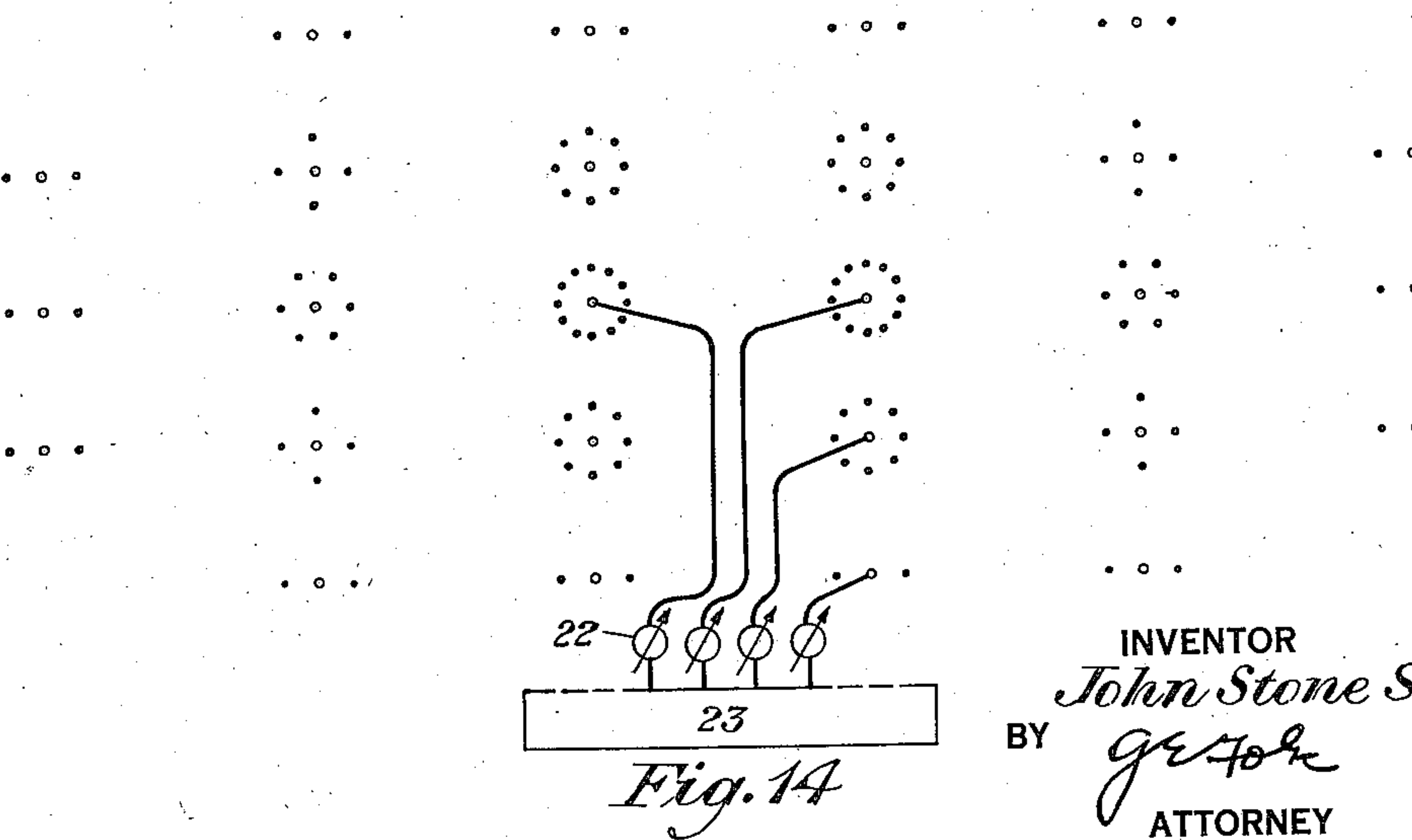
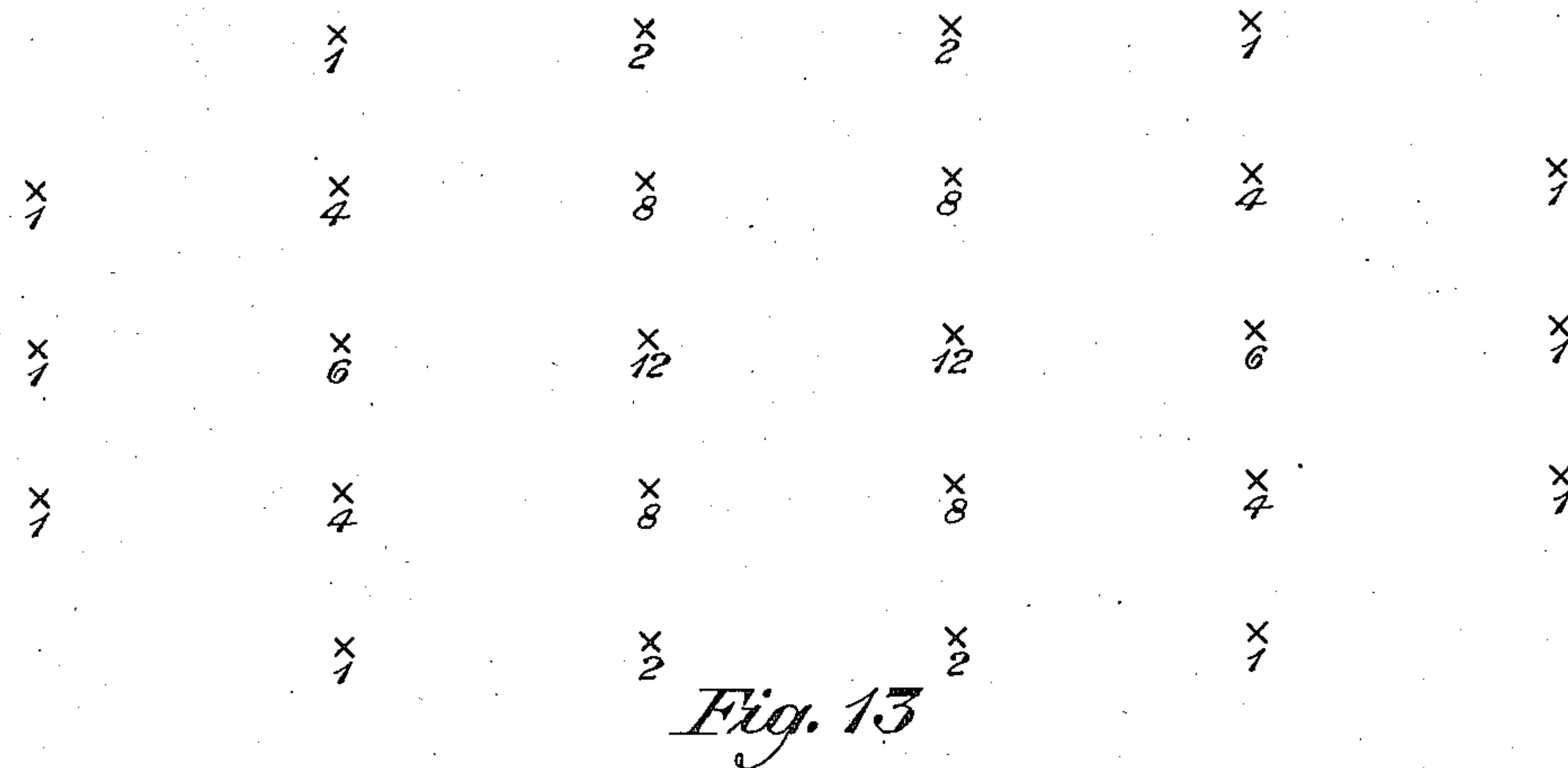
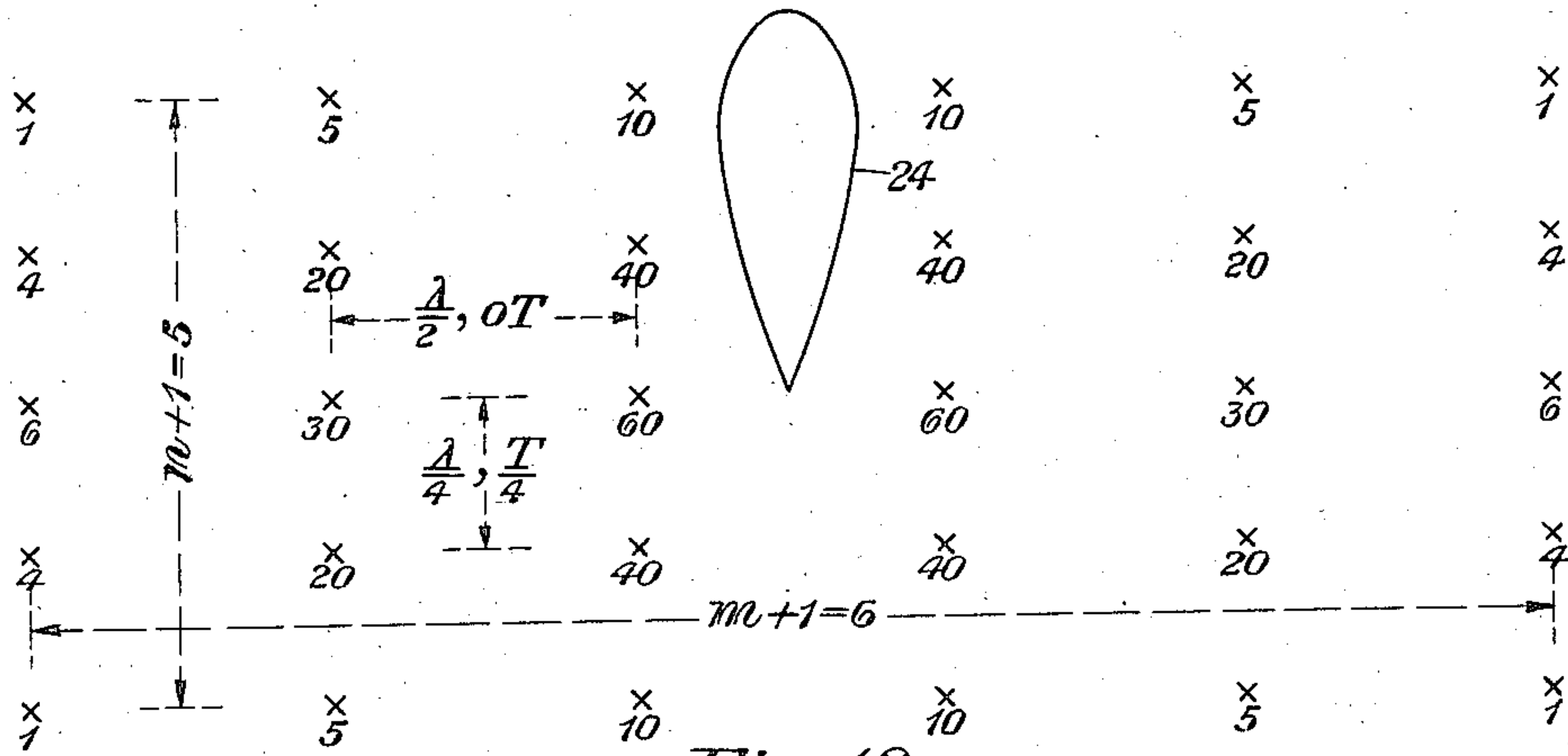
J. S. STONE

2,037,154

RADIO RECEIVING SYSTEM

Filed Oct. 30, 1934

2 Sheets-Sheet 2



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RADIO RECEIVING SYSTEM

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Application October 30, 1934, Serial No. 750,717

19 Claims. (Cl. 250—11)

An object of my invention is to provide new and improved apparatus and a corresponding method for radio reception with a high degree of effectiveness. In one aspect, my invention involves magnifying the available space energy at a receiving station and receiving the magnified space energy on suitable apparatus. In another aspect my invention involves receiving the energy on an antenna and transmitting it thence to another antenna, or others, with enhanced effect. A group of antennas for receiving, according to my invention, may be called an "antenna nest." These and other objects and aspects of my invention will become more readily apparent on consideration of a limited number of specific examples of practice which I have chosen for disclosure herein. The following specification will refer to these examples in particular terms, with the understanding that the scope of the invention is indicated in the appended claims.

Referring to the drawings, Figure 1 is an elevation diagram of an antenna nest having 2 auxiliary antennas; Fig. 2 is a similar diagram with 4 auxiliary antennas; Fig. 3 is a plan diagram corresponding to Fig. 2; Fig. 4 is an elevation diagram of another nest of 4 antennas showing it as developed from a cylindrical shape; Fig. 5 is a plan diagram of an antenna nest having 12 auxiliary antennas; Fig. 6 is a diagram of a Hertz oscillator or doublet; Fig. 7 is a curve diagram showing the intensity of the field re-radiated or reflected from an oscillator of various lengths, as a function of the distance therefrom; Fig. 8 is a curve diagram showing phase retardation as a function of distance for the case considered (curve 1) as compared with the case of a phase velocity equal to the velocity of light (curve 2); Figs. 9 and 10 are diagrams of composite antennas by which virtual uniformity of intensity and phase may be secured along the antenna length; Fig. 11 is a set of curves showing oscillator currents as determined by certain resistance relations; and Figs. 12, 13 and 14 are plan diagrams of an antenna array with progressive modifications embodying features of my invention.

With respect to the structure of the apparatus involved and the practical effects gained by its use, reference may be made to Figs. 1 to 5. The scientific principles involved in the practice of the invention will be discussed later in this specification.

Referring to Fig. 1, consider the two receiving antennas or oscillators A_1 and A_2 positioned comparatively close together and both tuned alike to the incoming waves which it is desired to re-

ceive; these have any horizontal direction of propagation such as represented by the arrow A. Each of the two antennas will be set in oscillation by the incoming radiation and will re-radiate. Each has an offset portion of the same conductor length; in the antenna A_1 the offset portion is $c_1a_1b_1d_1$, and in the antenna A_2 the equal length offset portion is $c_2d_2b_2a_2c_2'd_2'$. The parts a_1b_1 and a_2b_2 are in close inductive relation; as will be explained later, the effect of this connection is to annul in each antenna the effect of the field developed by the other, so that each will be fully responsive to the radiation indicated by the arrow A.

At a distance from an oscillator such as A_1 or A_2 , the lines of force of the field are detached from the oscillator and closed on themselves. Here the field may be referred to very properly as radiated. But close to the oscillator the lines of force, for the most part, have their ends on the oscillator, and it may not be equally proper to refer to the field as radiated. In either case the field is derived indirectly from the incoming waves and may be said to be reflected or induced.

Now consider the third antenna A_n , standing midway between the other two and comprising a detector-receiver at R. This antenna A_n receives the full effect of the field that is reflected or induced from the antennas A_1 and A_2 ; as will be explained later, this is an enhanced effect so that the system constitutes a very sensitive and effective receiver.

Fig. 2 shows four receiving oscillators or antennas A_1 , A_2 , A_3 , and A_4 , each with an inductive cross-connection to each of the others, as will be apparent after the foregoing explanation of Fig. 1. The system of Fig. 2 is shown in plan in Fig. 3. Centrally located with respect to the four reflecting antennas A_1 , A_2 , A_3 and A_4 stands the ultimate receiving antenna A_n with its detector-receiver R.

With the same plan view that is shown in Fig. 3 a somewhat different system of cross connections is indicated in the development of Fig. 4. That is, Fig. 4 is an elevation, as if the dotted cylinder seen in section in Fig. 3 were broken at the point X and opened out right and left. Following down the antenna A_2 in Fig. 4, it is turned aside at 11, and at 12 it comprises a part extending up and very close to a part of the antenna A_3 . Similarly, at 13 there is a part extending up and very close to a part of antenna A_1 . The complete antenna A_2 continues from the point 14 to 14' and has a part at 15 extending up and very close to a downwardly extending

part of antenna A_4 . At 16 the antenna A_2 is brought back close to its original part and continued downwardly. Each antenna has the same conductor length and each antenna has a part in close inductive relation to a part of each other antenna but oppositely directed thereto.

Fig. 5 is a plan view of an antenna nest having 12 field developing antennas $A_1, A_2 \dots A_{12}$ arranged as elements of a cylinder, and one central main ultimate receiving antenna A_n in the axis of the cylinder. Each of the 12 antennas $A_1, A_2 \dots A_{12}$ of this nest may be cross-connected to each of the others, according to any suitable plan such as that of Fig. 2 or that of Fig. 4.

Further structural and operating features will be mentioned after a discussion of the scientific principles involved.

Considering the relatively simple case of the reception and reflection of the energy of received waves by a simple Hertz doublet or oscillator, such as 20 in Fig. 6, assume that there is an incident wave train consisting of plane polarized waves whose electric force is parallel to the axis of the doublet or oscillator 20 and whose direction of motion 21 is perpendicular thereto. Assume further, in accordance with the usual well-known theory in relation to the Hertz doublet, that it is resonant to the periodicity of the received waves and that its length is negligible compared to the wave length so that the current flowing in it at any moment will be substantially the same throughout its length.

If the length of the oscillator is taken to be l , and the maximum current therein to be I , so that the current as a function of time t is $I \cos \omega t$, then the magnetic force in the equatorial plane of the radiator at a radial distance r from the midpoint of the oscillator will be given by the equation

$$\gamma_1 = \frac{Ilm^2}{\phi_1} \left(\sin(\omega t - \phi_1) - \frac{1}{\phi_1} \cos(\omega t - \phi_1) \right) \quad (1)$$

where $\omega = 2\pi f$, f being the frequency, and $m = 2\pi/\lambda$, λ being the wave length, and $\phi_1 = mr$. Assuming that the conductor resistance R of the oscillator is negligible compared to its radiation-resistance R' , that is, that R is negligible in the equation $R_0 = R + R'$, the foregoing Equation (1) can be conveniently thrown into the form

$$\gamma_1 = \frac{3\Gamma}{2\phi_1} \left(\sin(\omega t - \phi_1) - \frac{1}{\phi_1} \cos(\omega t - \phi_1) \right) \quad (2)$$

where Γ is determined by the equation

$$E = \Gamma I c \quad (2a)$$

Here E is the electromotive force corresponding to the current I as related by the equation $I = E/R_0$, R_0 is the total effective resistance of the oscillator, and c is the velocity of light. The foregoing expression for E is in electromagnetic units; in electrostatic units the relation would be

$$E = \Gamma I / c \quad (2b)$$

Another convenient form in which the foregoing expression for γ_1 may be shown is given in the following equation:

$$\gamma_1 = \Gamma_1 \cos(\omega t - \psi) \quad (3)$$

where

$$\frac{\Gamma_1}{\Gamma} = -\frac{3}{2} \sqrt{\frac{1 + \phi_1^2}{\phi_1^2}} \quad (4)$$

and

$$\psi = \phi_1 - \tan^{-1} \phi_1 \quad (5)$$

By well-known methods the foregoing Equations (5) can be expanded in series form as follows:

tion (5) can be expanded in series form as follows:

$$\psi = \frac{\phi_1^3}{3} \left(1 - \frac{3}{5}\phi_1^2 + \frac{3}{7}\phi_1^4 - \frac{3}{9}\phi_1^6 + \dots \right) \quad (6)$$

From the foregoing Equations (2a) and (2b) it is seen that Γ is the intensity of the magnetic force of the incident wave train at the oscillator. The ratio Γ_1/Γ in Equation (4) is the intensity of the field of magnetic force induced by the oscillator to that of the incident wave train at varying radial distances $r = \phi_1/m$ in the equatorial plane from the center of the oscillator; its value is given by the curve 3 in Fig. 7. The phase lag ψ of the induced or reflected wave train at different radial distances r from the center of the oscillator in its equatorial plane is given by the curve 1 in Fig. 8.

For the purposes of this specification, notice the obvious inference from curve 3 of Fig. 7 that in the immediate vicinity of the oscillator the intensity of the field of magnetic force induced by it is much greater than that of the incident wave train, and that this disparity of intensity increases with the degree of proximity to the oscillator.

With respect to the phase of the induced or reflected wave train, we have the foregoing Equation (6). For points in the equatorial plane close enough to the center to make $3\phi_1^4/7$ negligible, we may neglect all the terms of the series within the pair of braces, except the first two, and still be correct to within 1 per cent, for radial distances in the equatorial plane up to about $r = \lambda/16$. At this distance the angle of lag ψ of the magnetic force is slightly more than 1 degree instead of about 22.6 degrees which it would have been had the phase of the induced wave traveled with the velocity c of light. The actual phase velocity v of the reflected train according to the usual theory of the Hertz doublet is given in the following equation:

$$v = c(1 + \phi_1^2)/\phi_1^2 \quad (7)$$

At the value of r mentioned above, namely $r = \lambda/16$, this phase velocity v is about $7.55c$. Thus at this radial distance in the equatorial plane, the phase velocity of the induced wave train is more than seven and one-half times the velocity of light, and the phase lag of these waves is less than a twenty-first part of what it would have been had their velocity been that of light. This contrast is shown by the curves 1 and 2 of Fig. 8.

Summarizing what has been said in connection with curve 1 of Fig. 8, it is to be noted that for such oscillators as have been under discussion, the phase difference of the induced waves at different radial distances from the oscillator in its equatorial plane and in its immediate vicinity, is substantially negligible from point to point and as compared with the current in the oscillator.

There is another pertinent fact to be mentioned with respect to the oscillator-generated wave train in the immediate neighborhood of the oscillator: The vectorial relations between the magnetic forces of the incident and oscillator-generated wave trains, and the directions of their motions, for any point in the equatorial plane and in the immediate vicinity of the oscillator, are such that the electromotive force which the oscillator-generated wave train will induce in a conductor situated at such point and having its axis parallel to that of the oscillator, will be

very nearly opposite in phase to that induced in such conductor by the incident wave train.

Before proceeding to apply the principles developed to this point, it should be mentioned that two assumptions have been involved which require examination. One such assumption is that the radiation-resistance R' of the oscillator is the sole effective resistance. The other assumption will be mentioned presently. For the intensity of the current in the oscillator we have the equation $I=E/(R+R')$, where R represents the resistance corresponding to absorption of energy within the oscillator. In a well designed radio receiving oscillator system, approximately half of R would represent the dissipative factor introduced by the association of the detector, and the other half of R would represent the dissipative factor incidental to the production of adequate selectivity through resonance. The power consumption corresponding to the resistance component R is

$$P_1 = \frac{I^2}{2} R = \frac{E^2 R}{2(R'+R)^2} \quad (8)$$

and the rate of change of this power with change of R is given by

$$\frac{dP_1}{dR} = \left(\frac{1}{(R'+R)^2} - \frac{2R(R'+R)}{(R'+R)^4} \right) \frac{E^2}{2} \quad (9)$$

When the power in question is a maximum we equate the right side of Equation (9) to zero, whence it follows that $R=R'$. Hence the foregoing equation $I=E/(R+R')$ becomes $I=E/2R$. Thus it becomes apparent that the effect of giving the internal resistance R of the oscillator its maximum power absorptiveness is to halve the current intensity, as compared with the current which would be developed in the oscillator if there were no internal resistance and only its radiation-resistance were available to limit the intensity of the current induced in it by the incident wave train. This relation should be borne in mind in connection with the further discussion involving the intensity of the oscillator-generated wave train relative to that of the incident wave train.

The second of the two assumptions referred to is that the length of the oscillator is negligible compared to the wave length of the incident waves. It is entirely possible to have an oscillator of substantial length compared to the wave length and in such an oscillator to have the current sensibly the same throughout the length of the conductor. This may be done by placing a series of linear conductors in successively overlapping relation as shown in a formal manner in Fig. 9. Or, the conductors may be arranged with their overlapping parts offset to one side as indicated in a formal manner in Fig. 10. In these cases it is known that it is possible to have a substantially uniform instantaneous value of current along the length of the conductor as a whole even though it has a substantial length compared to the wave length. Such oscillators as indicated in Figs. 9 and 10 behave with respect to the space surrounding them as if the speed of propagation along them were infinite or substantially so.

Aside from the modifications of the linear oscillator which are indicated in Figs. 9 and 10, an inquiry may be directed to ascertain the general nature of the effect upon the neighboring magnetic field of the length of the Hertz oscillator, on the assumption that the current at any moment is uniform throughout its length. Though the classical theory of the Hertz oscil-

lator or doublet postulates in effect an oscillator that is infinitely short compared to the wave length, as a matter of fact any physical realization of the Hertz oscillator must have a finite length though it may be short compared to the wave length. From this point of view I have made a mathematical study which I will not report in detail here, but I will give only the results to which it leads.

Referring to Fig. 7, we have already mentioned that the ordinates of curve 3 give the ratio Γ_1/Γ ; this is when the oscillator length is negligible compared to the wave length. This ratio Γ_1/Γ is the ratio of the intensity of the magnetic field of force induced by the oscillator to the intensity of the magnetic field of force of the incident wave train corresponding to various distances r from the re-radiating oscillator. By means of the mathematical study mentioned above, curves 1 and 2 have been obtained, based on the assumption that the oscillator is of substantial length, more particularly that its length is $\lambda/2$ for curve 2 and λ for curve 1. For each of these three curves the phase and amplitude of the current is assumed to be constant throughout the length of the oscillator at any one instant of time. In other words, the current distribution is that which it would have if the velocity of its phase propagation along the oscillator were infinite. In the case of the extremely long oscillators corresponding to curves 1 and 2, this uniformity of phase and amplitude may be secured by such a construction as has been indicated formally in Fig. 9.

Thus it follows that, in general, as appears by comparison of curves 1, 2 and 3 of Fig. 7, the shorter the oscillator the greater the magnetic force of the reflected wave train at any given radial distance from the center of the oscillator for points in its immediate vicinity. This aspect is correlated with the fact that the radiation-resistance of the oscillator is proportional to the square of its length while the electromotive force induced in it by the incident wave is proportional to the first power of that length. A comparison of any two corresponding ordinates for curves 1 and 2 of Fig. 7 shows that the ordinate of curve 1 is about half that of curve 2, corresponding to the statement that the intensity of the induced magnetic force is very nearly inversely proportional to the oscillator length. It is further to be noticed that because the electromotive force developed in the oscillator by the incident wave train is proportional to the length of the oscillator, while the radiation-resistance is proportional to the square of the length, therefore the power of the reflected wave train is independent of the length of the oscillator.

All three curves of Fig. 7 illustrate the important fact that in the immediate vicinity of an oscillator the intensity of the induced magnetic field is far greater than that of the incident wave train.

While my invention may be realized and practiced advantageously with oscillators of the short or doublet type, having lengths negligible compared to the wave length, the foregoing study and the conclusions stated therefrom establish that the invention may be realized with oscillators of substantial length.

Consider two identical linear oscillators having their axes parallel and the same equatorial plane. Let them be brought close to each other and let them be acted upon perpendicularly by an incident train of waves whose wave length is long

compared to the distance between them. Then the effect of the magnetic field induced by each oscillator is to diminish somewhat the intensity of the current in the other oscillator without materially altering its phase. This inhibitory effect increases as the distance between the oscillators diminishes. It is the same as if a non-inductive resistance were introduced in the circuit of each oscillator, a resistance which may amount to as much as the radiation-resistance of the oscillator. That is, when the two oscillators are so close together that the ratio of the distance d between them to the length l of each oscillator is very small and the product md is also very small, then the virtual added resistance in each oscillator circuit is the radiation-resistance R' . This statement is made on the assumption that we are dealing with oscillators having no conductor or detector resistance. When the two oscillators have their conductor-resistances equal, their detector-resistances equal, and their radiation-resistances equal, and when these two oscillators are brought into very close proximity to each other, then the effect of this juxtaposition will be to double the virtual resistance of each. The foregoing statements can be readily established by a mathematical study which I will not put on record at this place. Stated concisely, the result of this mathematical study is to show that the effect of bringing two equal oscillators into extremely close proximity is to double the radiation-resistance of each oscillator and at the same time reduce the rate of radiation of energy therefrom. In an oscillator of negligible conductor-resistance, so juxtaposed to an equal oscillator, the current is thereby halved and the rate of radiation of energy is similarly halved.

Applying the same principles to n identical linear oscillators of the type heretofore considered instead of two such oscillators, and letting these oscillators be brought in close proximity to one another, then each will have developed in it a radiation-resistance n times as great as if it were isolated, so that the current induced in it by the incoming plane waves will be only $1/n$ th that which these waves would induce were it isolated. Accordingly, each of the n oscillators will re-radiate only $1/n$ th the power which it would re-radiate under the influence of the incoming waves if it were isolated.

The principles developed in the foregoing discussion will now be summarized briefly and applied in connection with Fig. 1 and other figures of the drawings.

We have found that when a tuned low resistance oscillator of the type considered is acted upon perpendicularly by a train of plane electromagnetic waves, then the intensity of the resulting induced field of magnetic force immediately adjacent to the oscillator is very much greater than the intensity of the magnetic force of the incident train of plane waves.

Also, the intensity of this induced field of force decreases very rapidly with increase of distance from the oscillator.

Also, at any point near the oscillator the direction of the induced field and its direction of motion are so related that the effect of the induced field at that point is opposite in sense to the direct effect of the incident train of waves in any conductor whose axis is parallel to the axis of the oscillator.

Accordingly, if without special modification to meet the difficulty, a number of tuned low resistance oscillators are gathered close together

with their axes perpendicular to a common equatorial plane, then the field of force of the re-radiated wave train from the group would not be materially greater than from a single oscillator of the group in isolation.

But, it has been established that in the immediate vicinity of each oscillator the induced magnetic field in the equatorial zone is of approximately constant phase and of an intensity which is approximately inversely proportional to the distance from the axis of the oscillator. Taking advantage of this principle, in the case of Fig. 1 with its two closely positioned oscillators A_1 and A_2 , we offset two centrally located and relatively short lengths, respectively, a_1b_1 and a_2b_2 , bringing them much closer together; also, we cross the conductors of one such offset as at c_2d_2 and $c_2'd_2'$; and, also, the offset lengths have been made equal, that is, $c_1a_1b_1d_1$ equals $c_2d_2b_2a_2c_2'd_2'$. Whatever the length ratio of the offset portion a_1b_1 to the entire antenna A_1 , the distance between the two offset portions a_1b_1 and a_2b_2 is adjusted in the same ratio to the distance between the antennas, each as a whole, A_1 and A_2 .

It will readily be seen that an incident plane wave traveling in the direction of the arrow A will have the same total effect on the two antennas A_1 and A_2 ; for the effect will be null on the transverse parts c_1a_1 , b_1d_1 , a_2c_2' and d_2b_2 ; and the effects will cancel out in any two oppositely directed longitudinal parts of the same antenna, such as b_2a_2 and either c_2d_2 or $c_2'd_2'$.

Thus, the coupling between the two antennas A_1 and A_2 described and shown in Fig. 1, serves to neutralize the effect of the induced magnetic field of each of those antennas upon the other. These two antennas constitute a simple form of an antenna nest.

In the axis, as a mid-parallel of these two antennas A_1 and A_2 , a third antenna is placed, A_n . On this third antenna A_n the intensities of the magnetic force components induced by the two antennas A_1 and A_2 are equal and in like phase but in opposite direction. However, the directions of motion of these magnetic force components from A_1 and A_2 are opposite, so that they cooperate to produce an electromotive force in the axial antenna conductor A_3 . This induced electromotive force is opposite in direction to that induced by the direct radiation, but greater in intensity, so that the ultimate effect in the axial antenna A_3 is substantially greater than if it stood quite isolated.

By the addition of the centrally located conductor A_n and tuning it to the frequency of the incident plane waves, we have completed in a simple form an antenna nest of the present invention. Referring to Fig. 1, the symbol R designates the detector-resistance, using the term to mean the dissipative component of the impedance introduced in the oscillator by virtue of the association therewith of the detector. The oscillators A_1 and A_2 may be regarded as gatherers of energy from the incident train of plane waves, while the centrally located oscillator A_n receives its energy by induction from them.

If an antenna nest is employed in the relatively simpler form that has no central uncoupled oscillator, then the detector-resistance R should appear equally in the two oscillators A_1 and A_2 . In this case the detector-resistance will have its optimum value when it is equal to the total resistance R_0 of the oscillator without an associated detector, and when isolated. But, in the case

shown in Fig. 1, the detector-resistance should be twice as great.

The application of the principles that have been discussed heretofore in cases of more than two re-radiating oscillators, such as illustrated in Figs. 2, 3, 4 and 5, will be readily apparent. By the neutralizing connections shown in Fig. 2, for example, each of the four oscillators of the nest receives as much energy from the incident wave train as if it were isolated, the current developed in each such oscillator being E/R_0 . Expressed mathematically, this means that the differential coupling introduces into the circuital equation of each oscillator,

$$R_0 i_1 + l c \gamma_{12} = e, \text{ or } R_0 i_2 + l c \gamma_{21} = e,$$

a term which cancels the mutual inductance term such as $l c \gamma_{12}$ or $l c \gamma_{21}$. In these equations the subscripts 12 and 21 are respectively for the effect of antenna 1 on antenna 2 and antenna 2 on antenna 1; in any antenna nest, if the antennas are numbered, these subscripts would correspond to the two antennas as considered in their proper order.

There is no reason why the differential coupling between the antennas of each pair may not be used to cancel more than the mutual induction term in the circuital equation of each of the oscillators. Such coupling may be made large enough to cancel in addition a part of the resistance term such as $R_0 i_1$ or $R_0 i_2$ in the foregoing equations. When this is done, the intensity of the current in each oscillator of the nest becomes greater than E/R_0 and the energy received by such oscillator is correspondingly increased. The physical significance of the effect of neutralizing in each oscillator not only the effect of its own natural coupling with all the other oscillators of the nest, but also a part of its resistance, depends upon the fact that when a wave train impinges upon the oscillator, an induced field of force is created about it with an intensity proportional to the intensity of the current induced in the oscillator by the passing wave train.

Any such antenna nest as illustrated in Figs. 1 to 5 may be provided with a central uncoupled oscillator as indicated in each case. When the detector-resistance is situated in this central uncoupled oscillator of the nest, the peripheral coupled oscillators act as energy gatherers for it and their conductor-resistances should, so far as possible, be minimized and neutralized if practicable. When the detector-resistance is equally distributed among the peripheral coupled oscillators, the central uncoupled oscillator is the one which acts as the energy gatherer for the peripheral coupled oscillators and its conductor-resistance should be minimized as far as possible.

The current in the central oscillator induces an electromotive force in each of the peripheral oscillators, just as the current in each peripheral oscillator induces an electromotive force in the central oscillator. For two open or linear oscillators in such relation as the central oscillator and one of the peripheral oscillators, the electromotive force in one, induced by the current in the other, is proportional to that current. Hence for the central oscillator and for one peripheral oscillator we have the respective equations

$$E - n \mu I_1 = R_0 I_0 \text{ and } E - \mu I_0 = R_1 I_1 \quad (10)$$

where E is the electromotive force due to the incoming waves, n is the number of peripheral oscillators, μ is a constant factor of proportionality, I_1 and I_0 are the currents respectively in the pe-

ripheral and central oscillators, and R_1 and R_0 are their respective resistances.

The factor μ would be a complex number, but with the oscillators close together its imaginary component would be small and it is neglected in setting up the foregoing equations. As a real number, μ cannot exceed R' , the radiation resistance of the central oscillator; but with the oscillators close together μ may approach R' in value. Therefore, for the purpose of a specific exemplification of the foregoing Equations (10), let $\mu = 0.9 R'$. Also let $R_0 = k R'$. Assume that in the peripheral oscillator, the conductor-resistance is negligible compared to the radiation-resistance, hence $R_1 = R'$. This is based on having all the detector-resistance in the central oscillator. Let the number of peripheral oscillators be $n = 10$. Substituting accordingly in the foregoing Equations (10), and solving for I_0 and I_1 , we get

$$I_0 = -\frac{8}{k-8.1} \frac{E}{R'} \text{ and } I_1 = \frac{k-0.9}{k-8.1} \frac{E}{R'} \quad (11)$$

These solutions are plotted with explanatory legends in Fig. 11. It will be observed that the current values I_0 and I_1 , become infinite when $R_0 = 8.1 R'$, that is, when $k = 8.1$; in the neighborhood of this value of k , the aforementioned neglect of the imaginary component of μ becomes apparent. Giving effect to this component for curve 1 would change the curve at and near the value, $k = 8.1$, to some such course as that shown by the dotted line curve. There would be a similar change for curve 2, but to avoid confusion, it is not shown.

Hence, in the case considered, the apparatus should be designed so that the central oscillator resistance R_0 approximates rather closely to $8.1 R'$. This will require the sum of the conductor and detector resistance of the central oscillator to be nearly equal to $7.1 R'$. It should be understood that E/R' , which appears as a constant factor in Equations (11), is the current which any one of the oscillators would have developed if were isolated from all the others, provided its conductor-resistance were negligible compared to the radiation-resistance R' .

These results show how greatly the currents in both the central oscillators and the peripheral oscillators are enhanced as the value of R_0 is made to approach $8.1 R'$, or more generally expressed, as the value of R_0 is made to approach $n \mu^2 / R'$. It is the great magnification which results in the current I_1 (as R_0 is made nearly equal to $8.1 R'$) that permits the peripheral oscillators through their correspondingly enhanced magnetic fields to divert the enhanced energy component from the passing incident wave train in toward the central oscillator under these conditions. Through the interaction of the reflected field of force of the peripheral oscillators, with the field of force of the passing wave train, a portion of the energy of the latter is diverted into those oscillators instead of sweeping past them as would happen if no such reflected field were present. The amount of the energy so diverted is proportional to the intensity of the induced field of force, and this in turn is proportional to the intensity of the current induced in the oscillator by the passing train of waves. Therefore, when we succeed in increasing the intensity of the current in each of the oscillators of a nest to a value higher than E/R_0 , which is the value each such oscillator would have were it quite isolated from the others, we raise the rate of absorption of energy by the oscil-

lators above the rate of which they would be capable were they all isolated.

When the central oscillator is made the chief energy gatherer, and the peripheral oscillators each contain a part of the "detector-resistance", a similar analysis shows how to adjust the relative resistance components to secure the optimum enhanced effect.

In addition to the great gains in received energy which may be effected by the use of antenna nests, they introduce versatility and flexibility in the mode of associating the detector-resistance with the receiving oscillator system, which is of convenience especially in connection with the reception of short wave and ultra short wave radio. While antenna nests are peculiarly useful in connection with short wave and ultra short wave reception, they may be employed in connection with radio receivers for waves of any length whatever.

Where it is desired that the reception shall be selective in a particular direction and directionally selective antenna arrays are to be built up accordingly, the units of such arrays may be antenna nests such as herein disclosed. Each nest will then simply take the place of an individual antenna or oscillator in the array. In Fig. 12 a rectangular antenna array is diagrammatically indicated in plan. Each of the numerals in parentheses, alongside the respective antenna, indicates the intensity of desired reception at the corresponding antenna. It will be seen that in each column and each row of the diagram these intensities are graded in proportion to the coefficients of the well-known binomial expansion. In practice, the antennas of lowest intensity may be discarded and the others may have their values altered slightly without substantial impairment of the desired directional effect. Accordingly, if each antenna of intensity "1" is discarded and if each intensity 4 or 6 is changed to the value 5, all the intensities become multiples of 5 and, in terms of a new unit, the slightly modified array may be diagrammatically represented as in Fig. 13 where the intensities are proportioned in values from 1 to 12.

Now let each antenna of Fig. 13 be represented by an antenna nest, as in Fig. 14. Then, quite conveniently, the number of re-radiating antennas in each nest (except those of lowest intensity "1") of Fig. 14 may be the corresponding intensity number of Fig. 13. In the array of Fig. 14, the intensity at each position is (with the exception noted) determined by the number of re-radiating antennas in the corresponding antenna nest.

Inasmuch as an antenna nest must have at least two antennas, the intensities "1" in Fig. 13 are obtained by using two antennas in each corresponding nest and cutting down the intensity of reception at each such position to get the corresponding intensity "1".

The central antenna of each nest in Fig. 14 is connected through a phase adjuster 22 with a common receiver 23. The effect is highly unidirectional, as indicated by the loop 24 in Fig. 12.

I claim:

1. High intensity radio receiving apparatus comprising a plurality of antennas subject to incoming radiation, and means to compensate at each antenna for the induced field from the other antenna or antennas, so that each antenna will re-radiate at high intensity in substantial response to the directly received radiation.

2. High intensity radio receiving apparatus

comprising a plurality of antennas subject to incoming radiation, and cross-connections from each antenna to each other antenna to compensate the effects of reflection from one to another which would otherwise oppose the effects of directly received radiation.

3. High intensity radio receiving apparatus comprising a plurality of antennas subject to incoming radiation, and phase-adjusted cross-connections from each antenna to each other antenna to oppose and annul the effects of reflection of wave energy from such antenna to such other antenna.

4. High intensity radio receiving apparatus comprising a plurality of antennas subject to incoming radiation, and means to compensate at each antenna for a part of its resistance and for substantially all of the reactive effect of the induced field from the other antenna or antennas.

5. High intensity radio receiving apparatus comprising a plurality of antennas subject to incoming radiation, compensatory cross-connections between each such antenna and the others, and an auxiliary antenna sensitive to the induced field from the first mentioned antennas.

6. An antenna nest comprising a plurality of closely spaced antennas around a mutual axis, and cross-connections to annul the effect of reflection in each such antenna from the others.

7. High intensity radio receiving apparatus comprising a plurality of antennas subject to incoming radiation, each such antenna being adapted to operate as a reflector of wave energy, means to make each such antenna effective over counter effects due to the other antennas, and means to detect the relatively high induced field close to these antennas.

8. High intensity radio receiving apparatus comprising two antennas subject to incoming radiation, two short lengths of each antenna being offset and brought in close reactive relation, the offset connections from one antenna being crossed whereby each antenna is compensated for the reflected field of the other antenna.

9. High intensity radio receiving apparatus comprising a plurality of antennas subject to incoming radiation, each antenna having offset portions, such portions of each antenna being respectively in close reactive relation to corresponding portions of the other antennas, and phase adjusting means in at least one of each pair of related portions.

10. High intensity radio receiving apparatus comprising a plurality of antennas subject to incoming radiation, means to compensate each antenna for the induced field from the other antenna or antennas, so that each antenna will reflect wave energy at high intensity in substantial response to the directly received radiation, and a central antenna subject to such reflection from the other antennas.

11. High intensity radio receiving apparatus comprising a plurality of antennas subject to incoming radiation, means to compensate at each antenna for the induced field from the other antenna or antennas, so that each antenna will reflect wave energy at high intensity in substantial response to the directly received radiation, a central antenna subject to such reflection from the other antennas, and a detector associated with said central antenna.

12. In combination, a plurality of interconnected receiving antennas adapted to reflect a

relatively intense field in their immediate vicinity compared to the incoming field, and means to detect the electromagnetic forces in such intense induced field.

5 13. The method of radio reception which consists in receiving the incoming waves on a plurality of interconnected oscillators each adapted freely to reflect wave energy, and detecting the relatively intense induced field in close proximity to such oscillators.

10 14. The method of radio reception which consists in receiving the incoming waves on a plurality of oscillators each adapted to reflect wave energy freely, counterbalancing in each antenna the effect of such reflection from the other antennas, and detecting in an auxiliary antenna the induced field from all the others.

15 15. The method of radio reception which consists in reflecting the wave energy of the received waves from a plurality of neighboring centers, annulling at each such center the effect of such reflection from the other center or centers, thereby generating a comparatively intense field within the region of such centers, and receiving and detecting the electromagnetic forces in said field.

20 16. A receiving antenna nest comprising a

central oscillator and peripheral oscillators, the total resistance R_0 of the central oscillator being related to its radiation resistance R' so as to approach the relation $R_0 = n\mu^2/R'$, where n is the number of peripheral oscillators and μ is a constant factor of proportionality whose value approaches that of R' .

17. A rectangular array of antenna nests, the number of re-radiating antennas in each such nest being approximately proportional to the corresponding coefficient of the binomial expansion along the corresponding column and row.

18. An array of antenna units graded from one to the next in intensity approximately according to the coefficients of the binomial expansion, each unit being an antenna nest with a number of oscillators therein proportional to the required intensity of the unit.

19. An array of antenna units graded in intensity, each unit being an antenna nest, the component antennas of all the nests being substantially alike and the appropriate intensity of each unit being approximately determined by the number of antennas belonging thereto.

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