Jan. 7, 1936. J. S. STONE 2,026,712

COMPOSITE OSCILLATOR FOR ELECTROMAGNETIC WAVES

Filed June 1, 1933 3 Sheets-Sheet 1

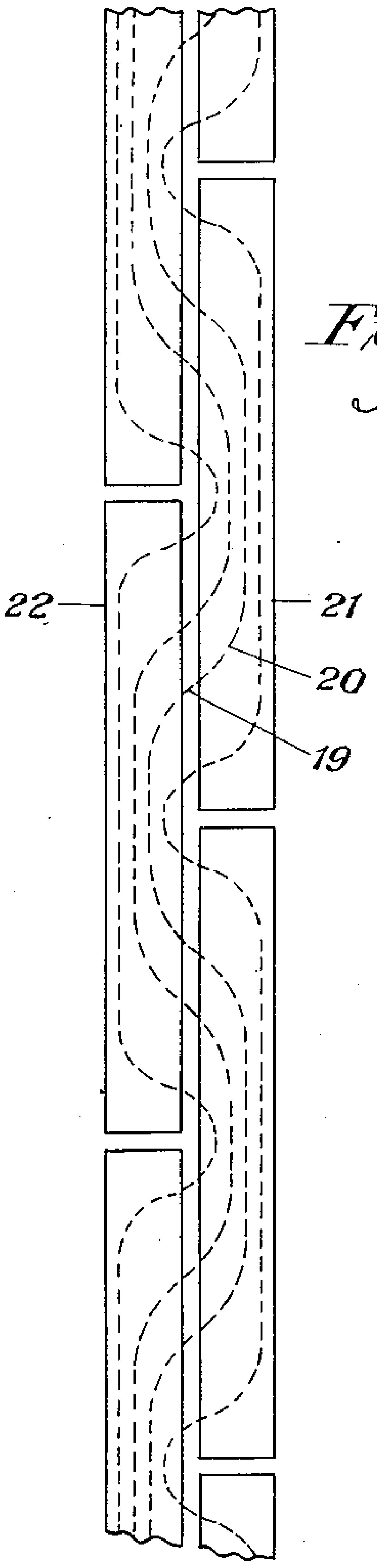


Fig. 4

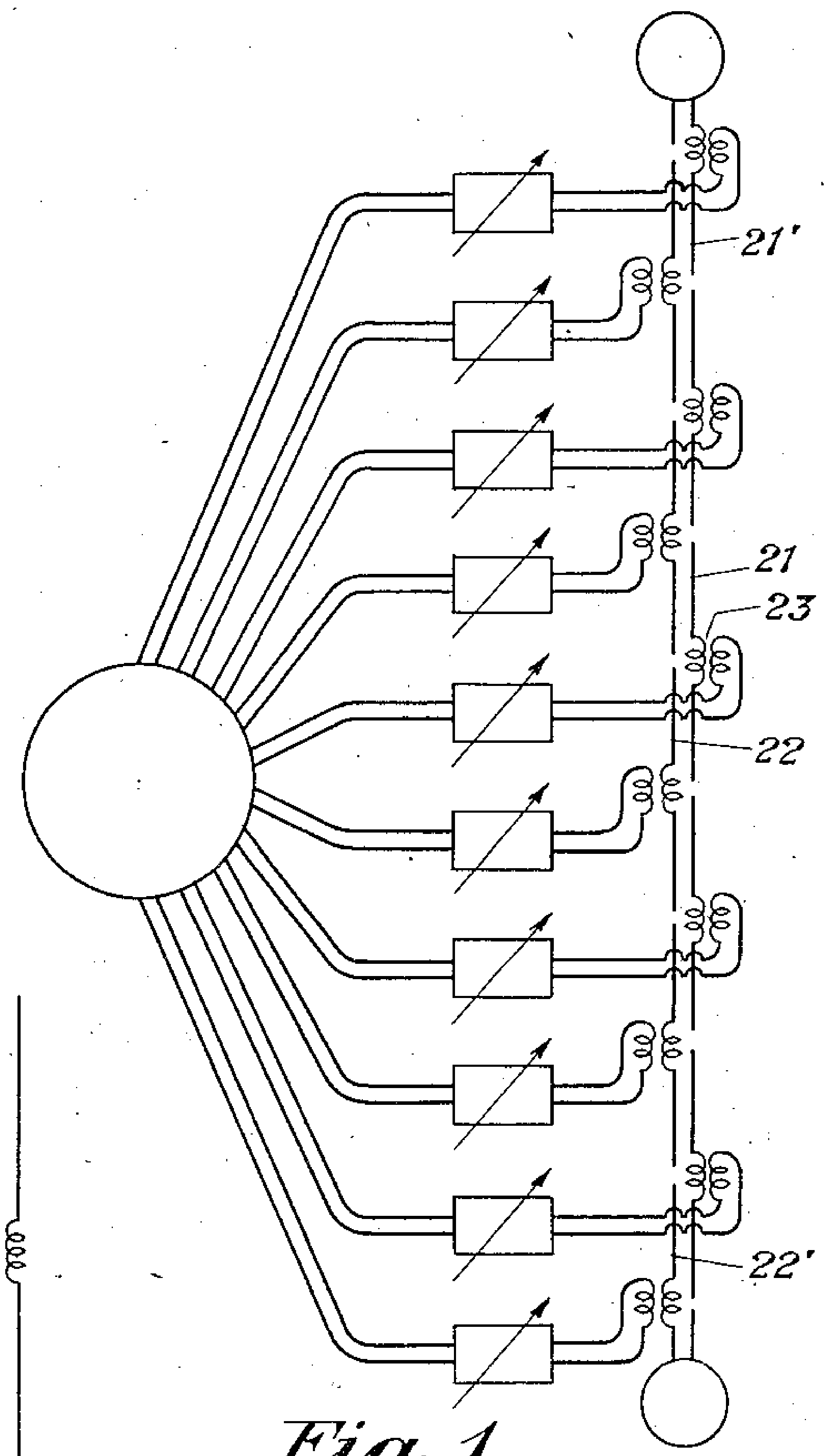


Fig. 1

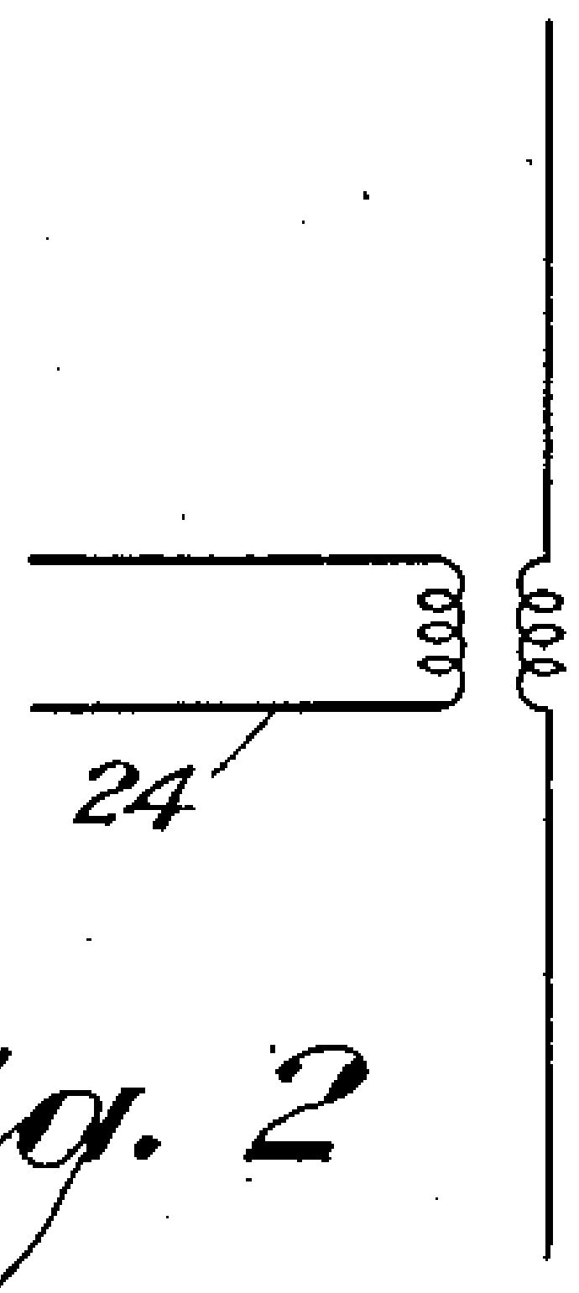


Fig. 2

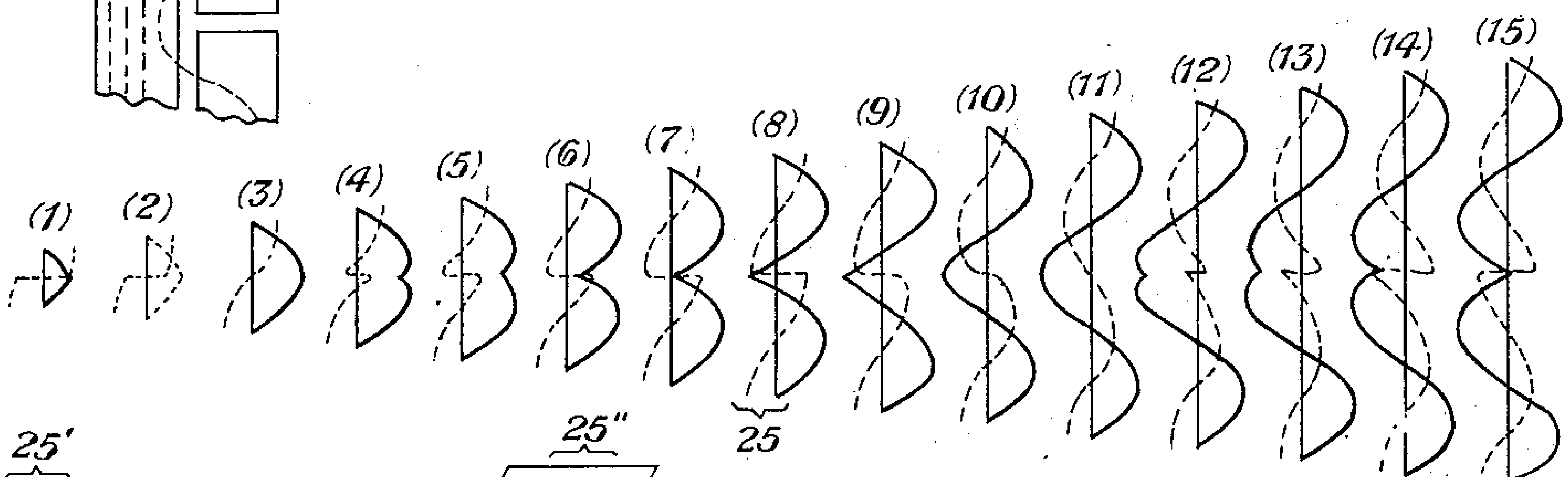


Fig. 3

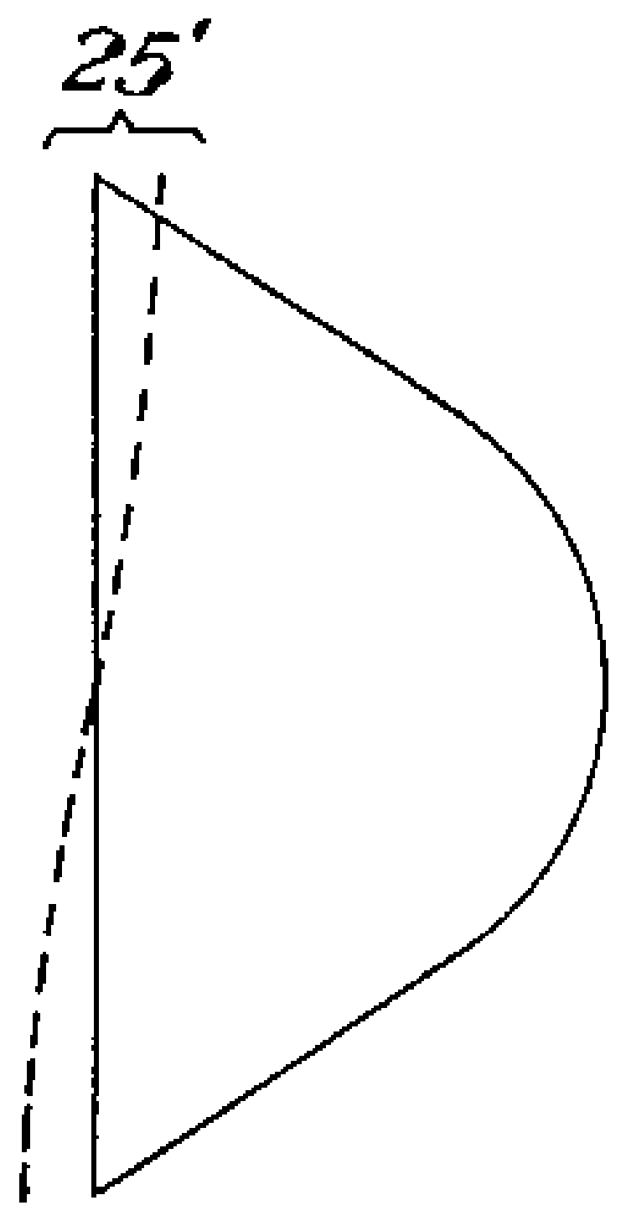


Fig. 5

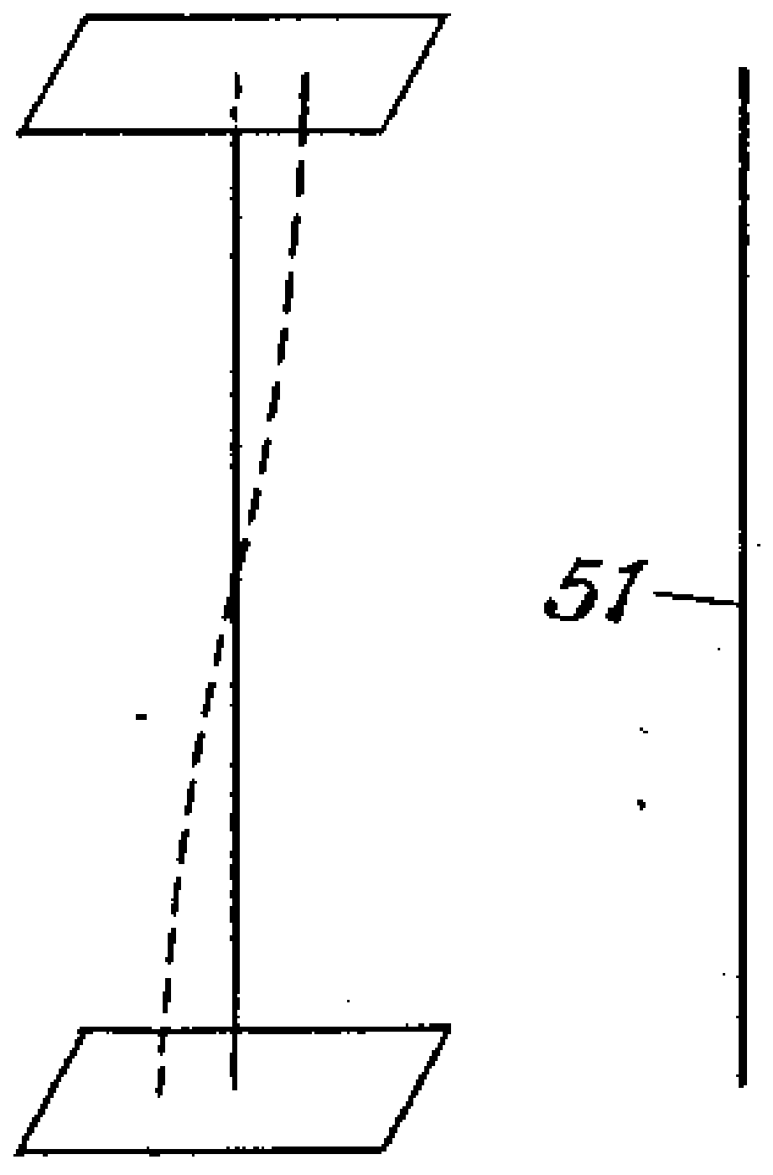


Fig. 6

INVENTOR
John Stone Stone
BY
ATTORNEY

Jan. 7, 1936. J. S. STONE 2,026,712

COMPOSITE OSCILLATOR FOR ELECTROMAGNETIC WAVES

Filed June 1, 1933 3 Sheets-Sheet 2

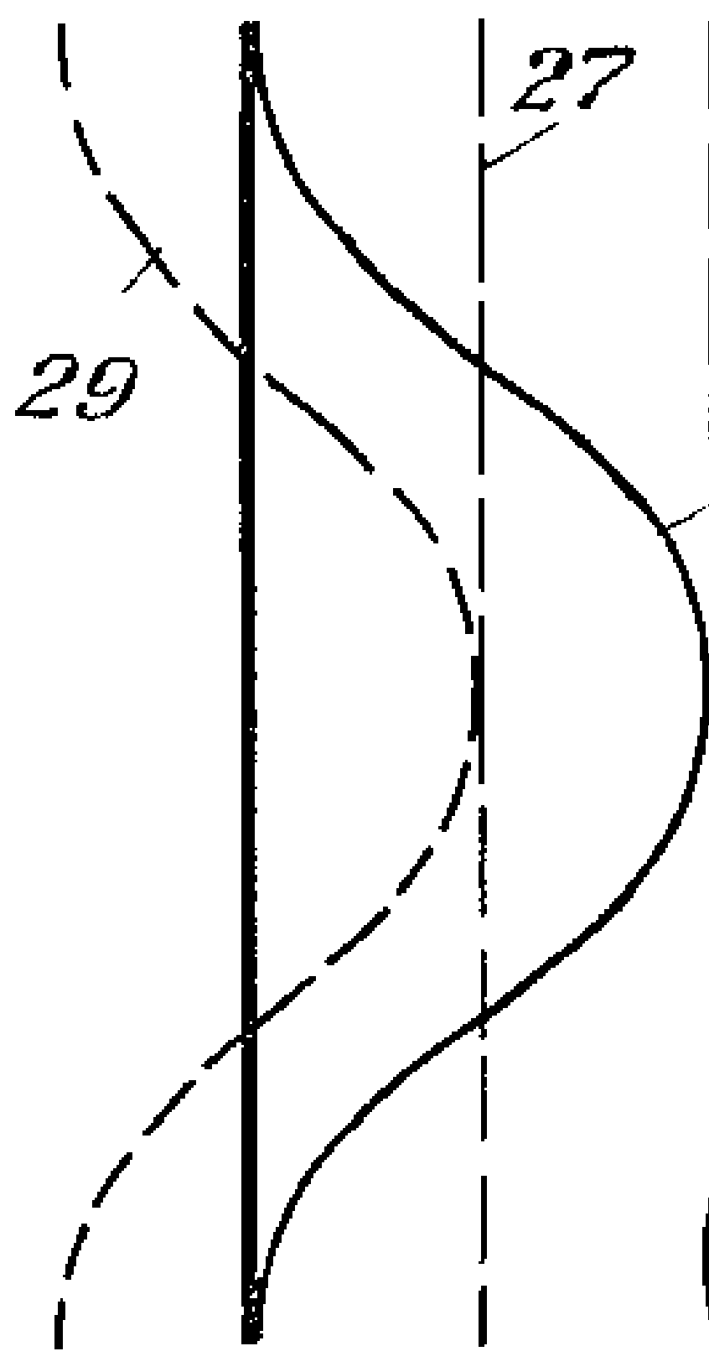


Fig. 7

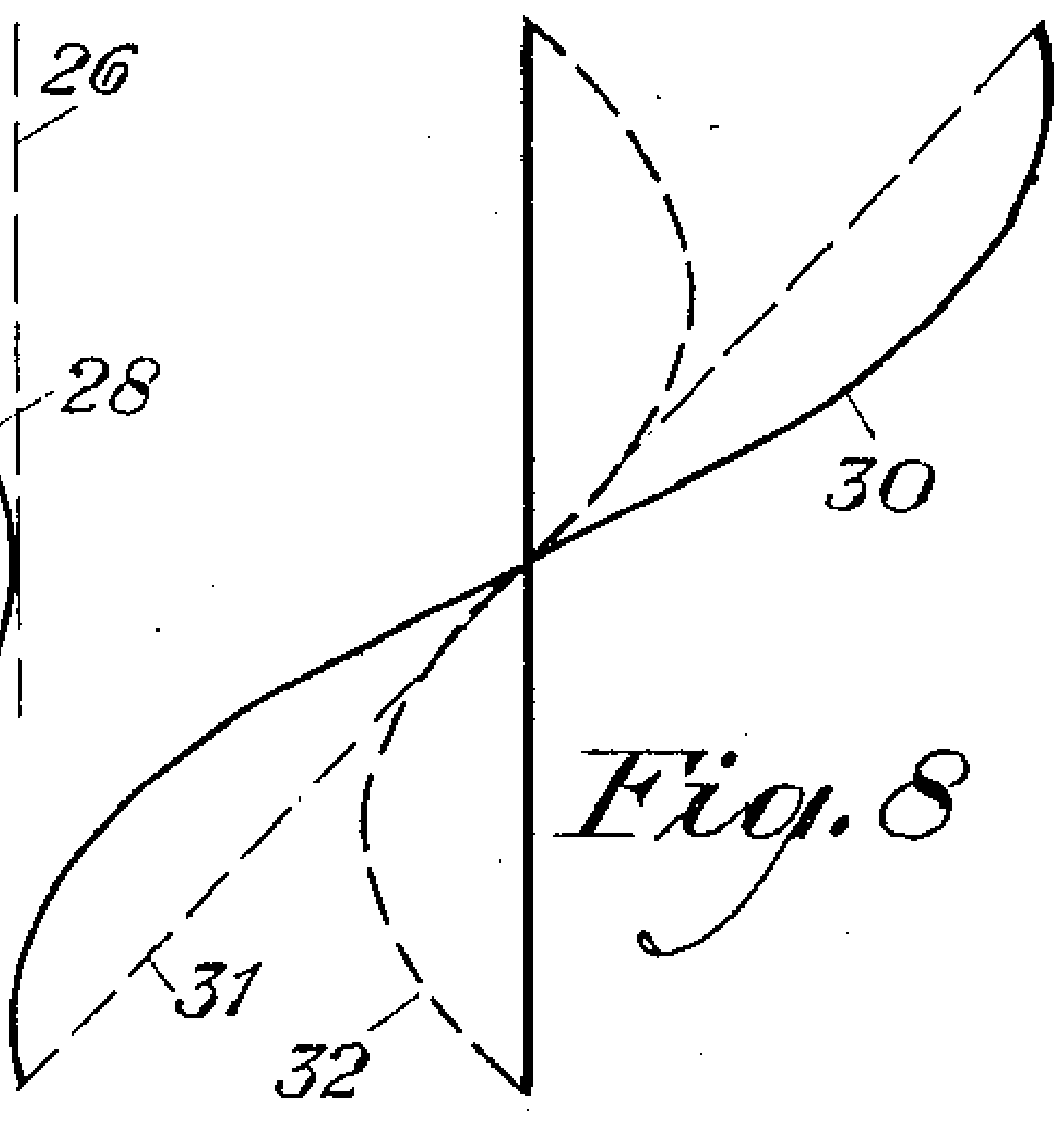


Fig. 8

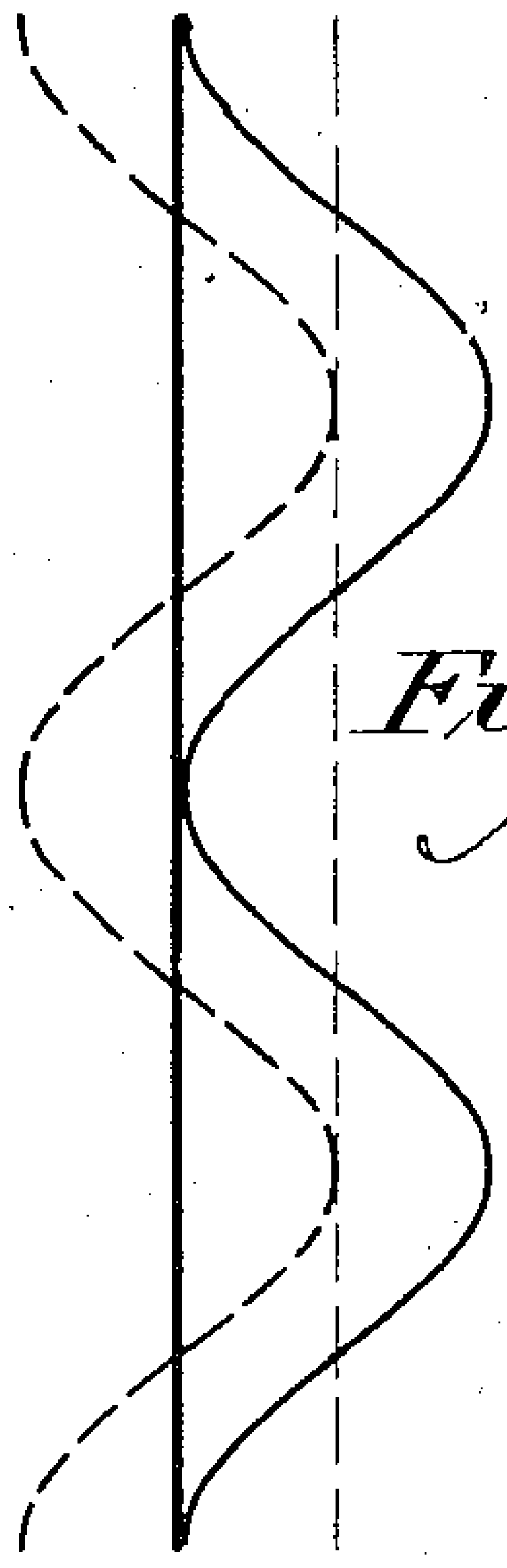


Fig. 9

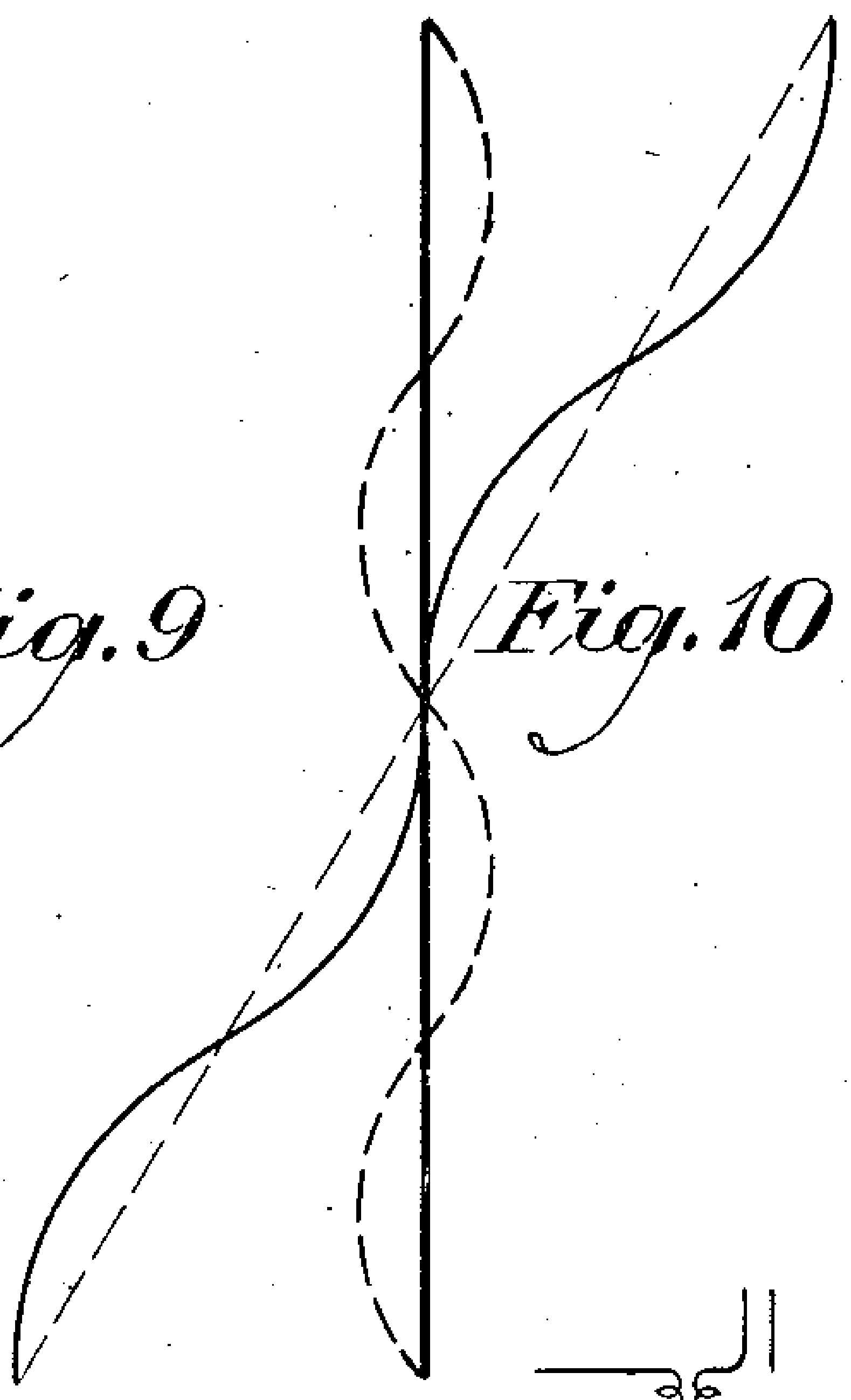


Fig. 10

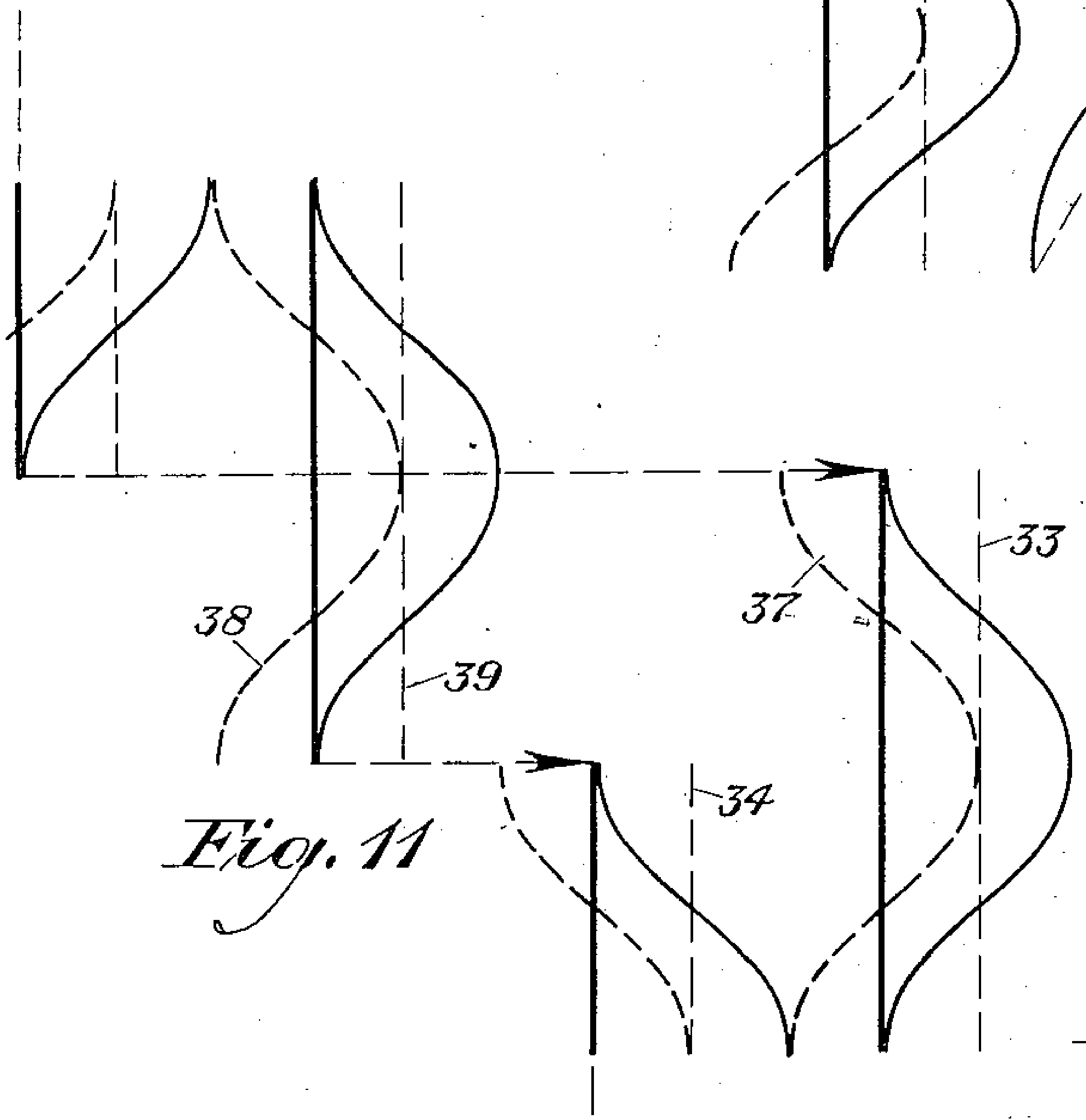


Fig. 11

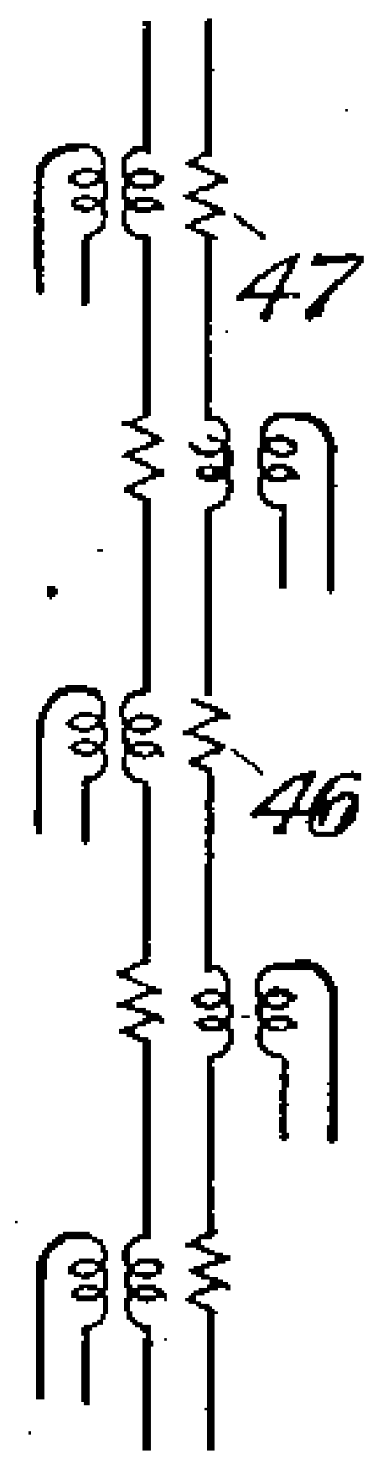


Fig. 14

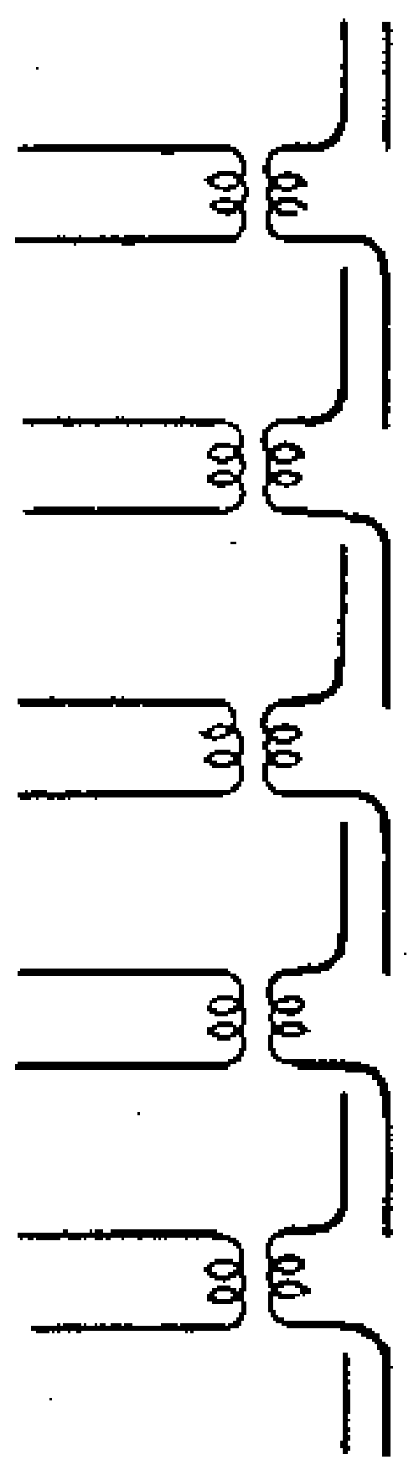


Fig. 15

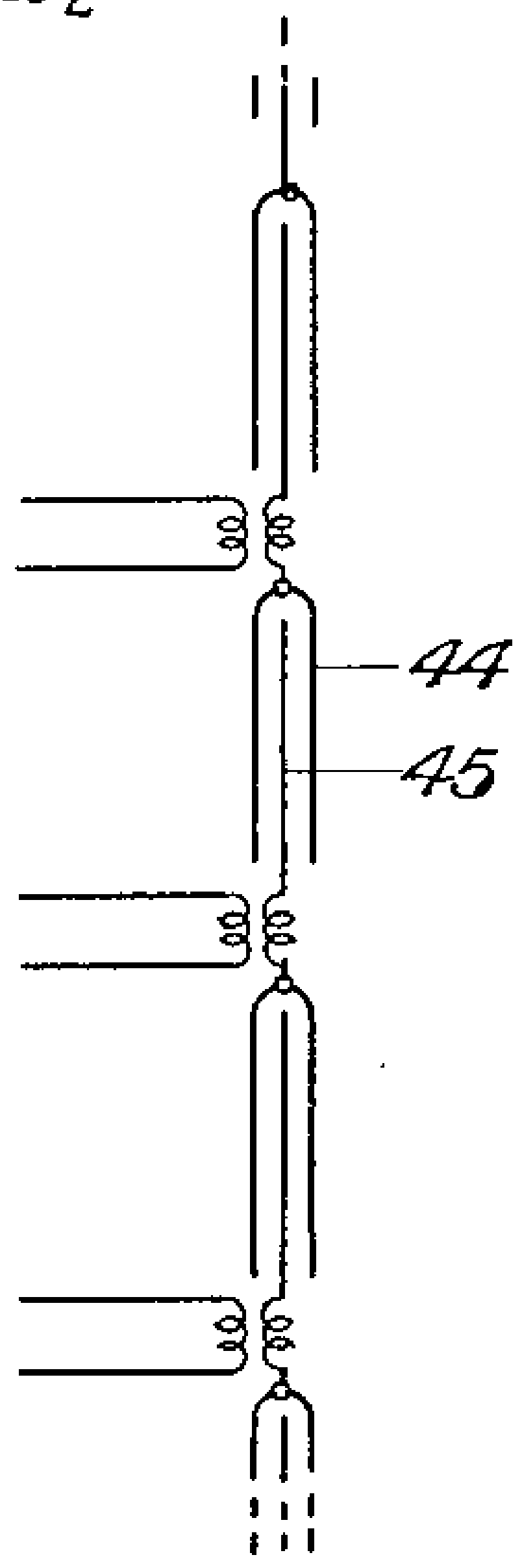


Fig. 13

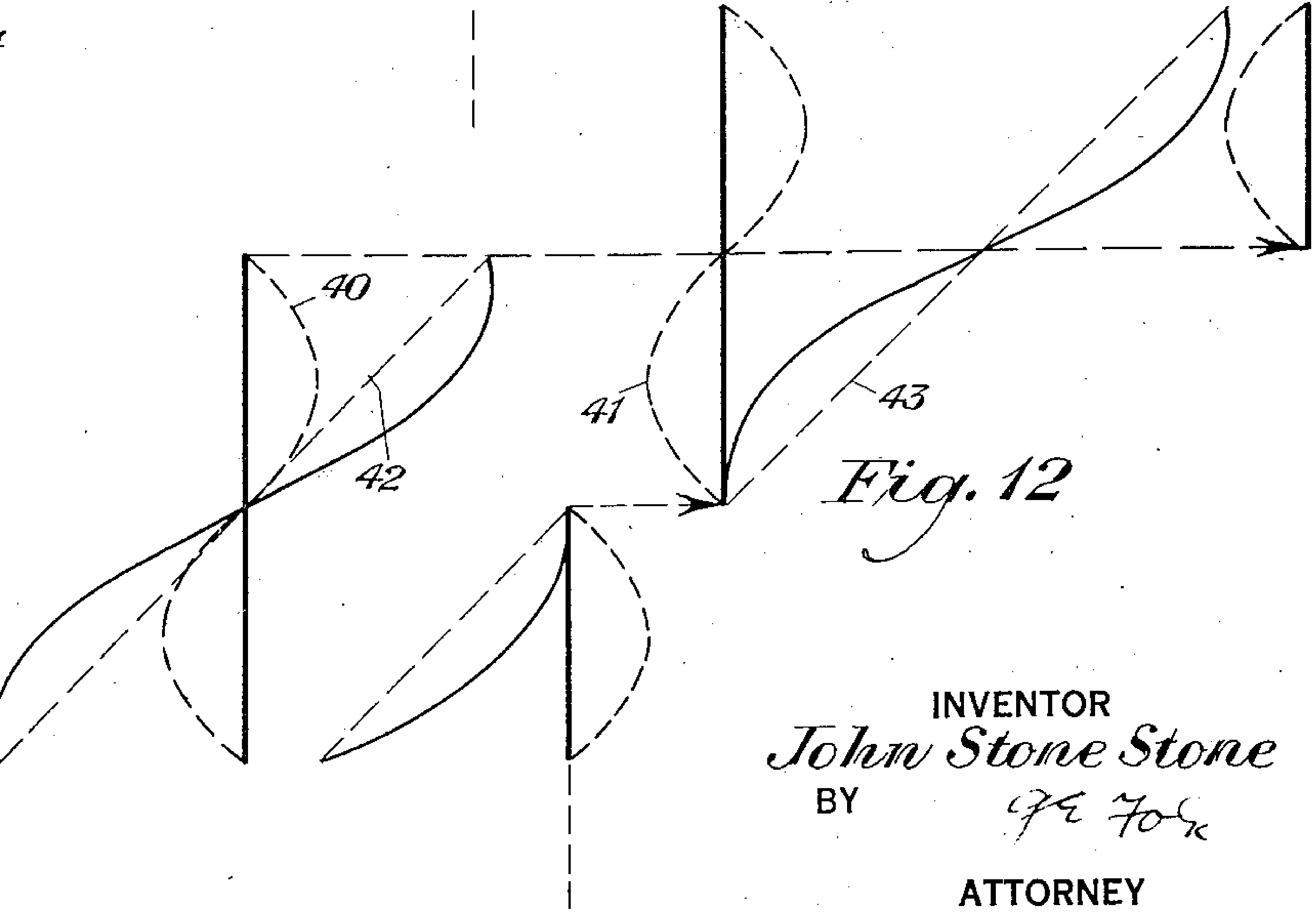
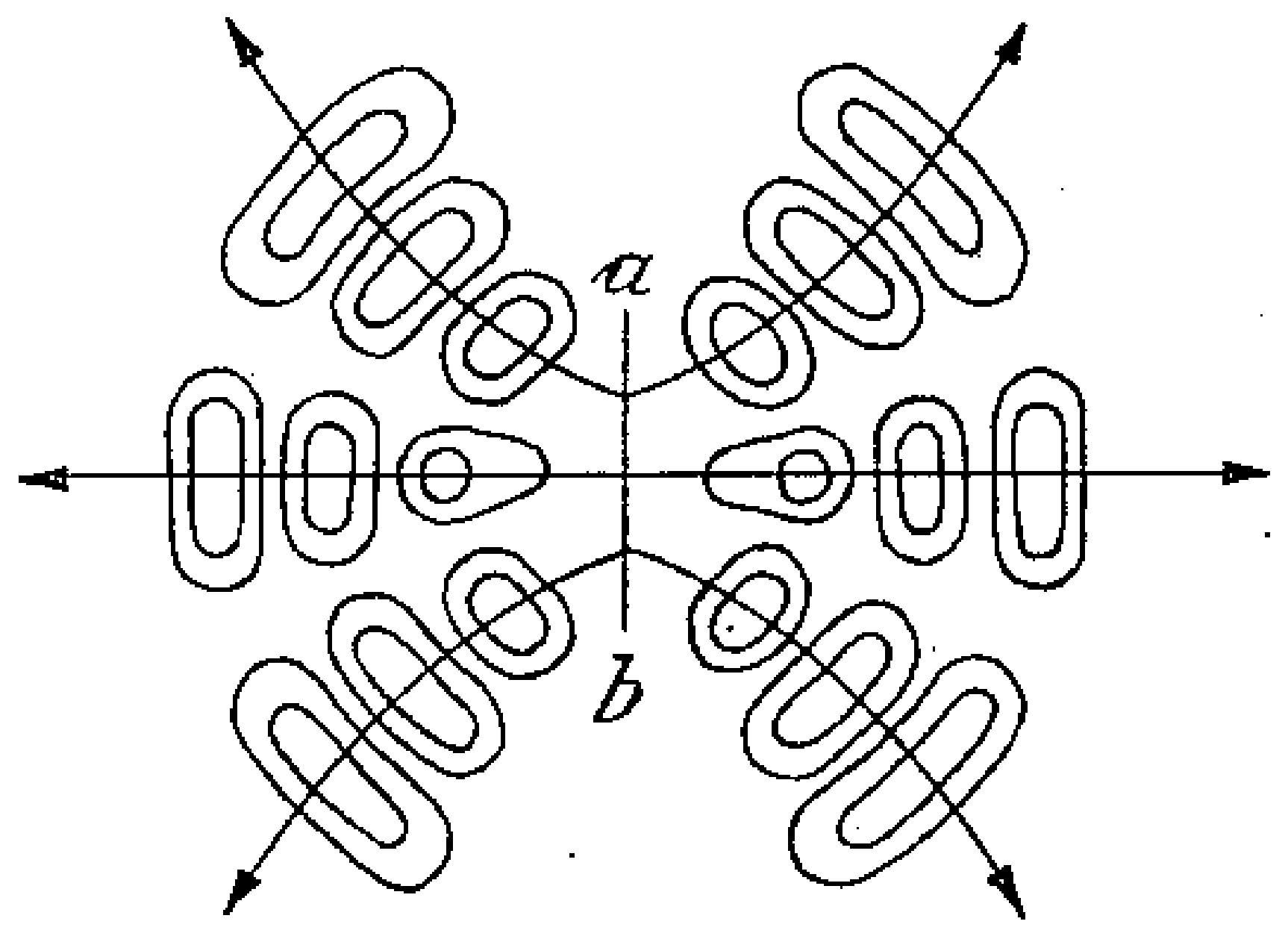


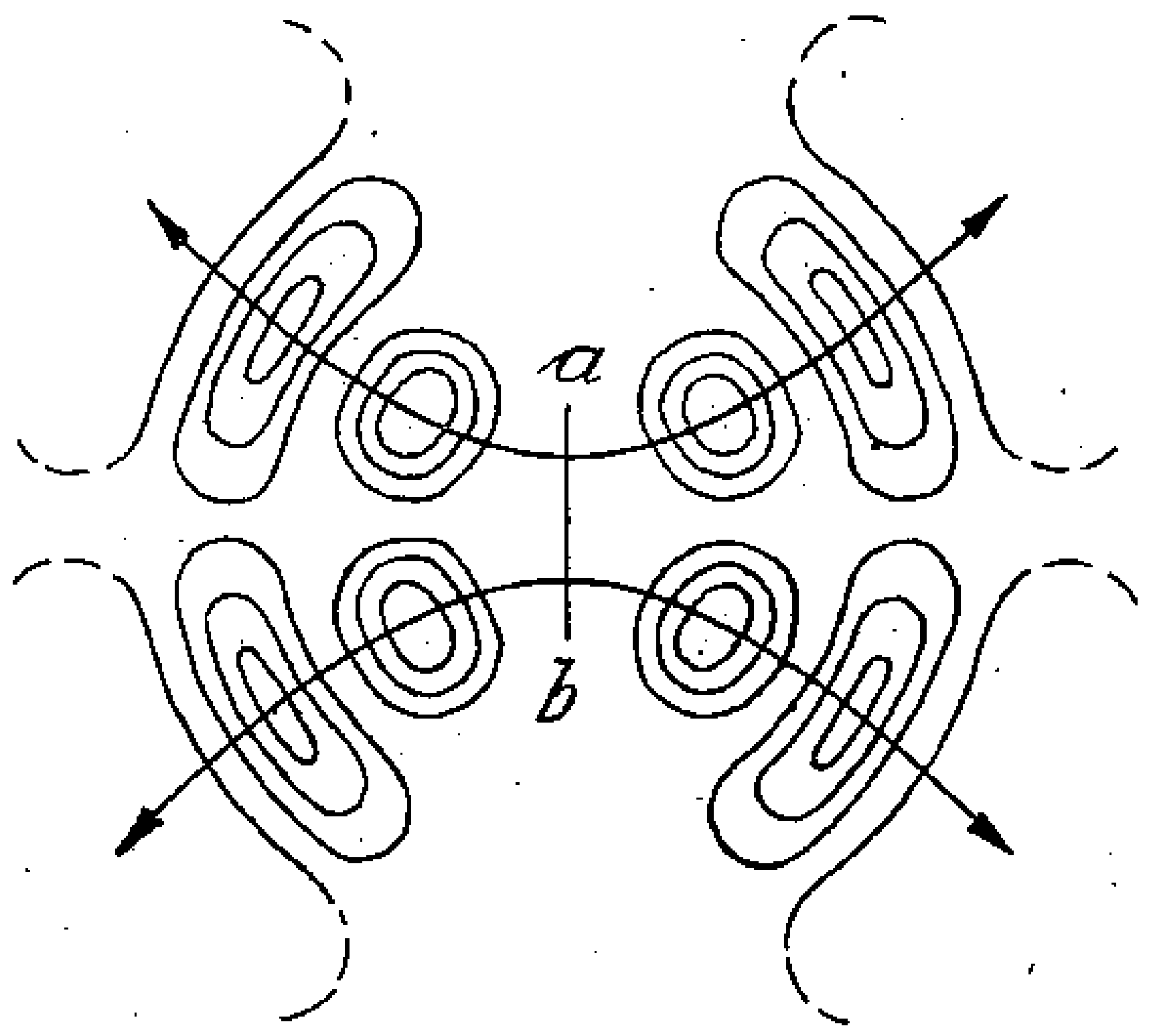
Fig. 12

INVENTOR
John Stone Stone
BY
ATTORNEY



$l = 3\lambda/2$ (approximate)

Fig. 16



$l = \lambda$ (approximate)

Fig. 17

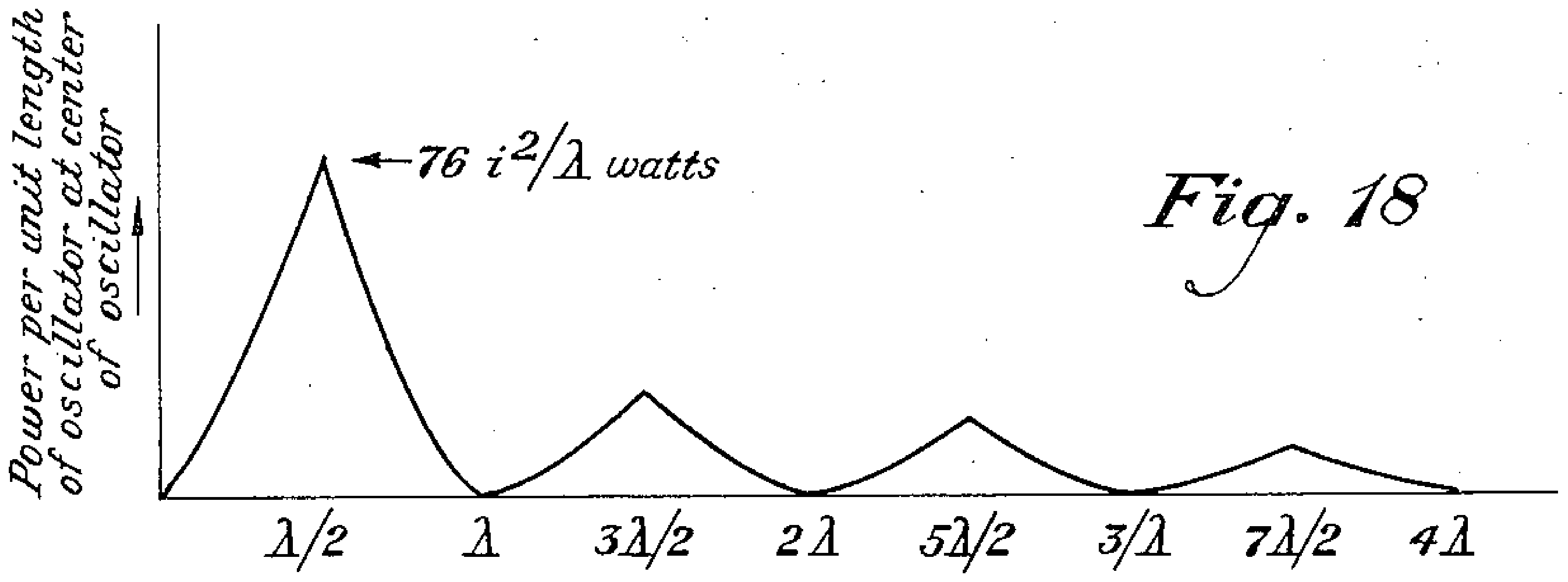


Fig. 18

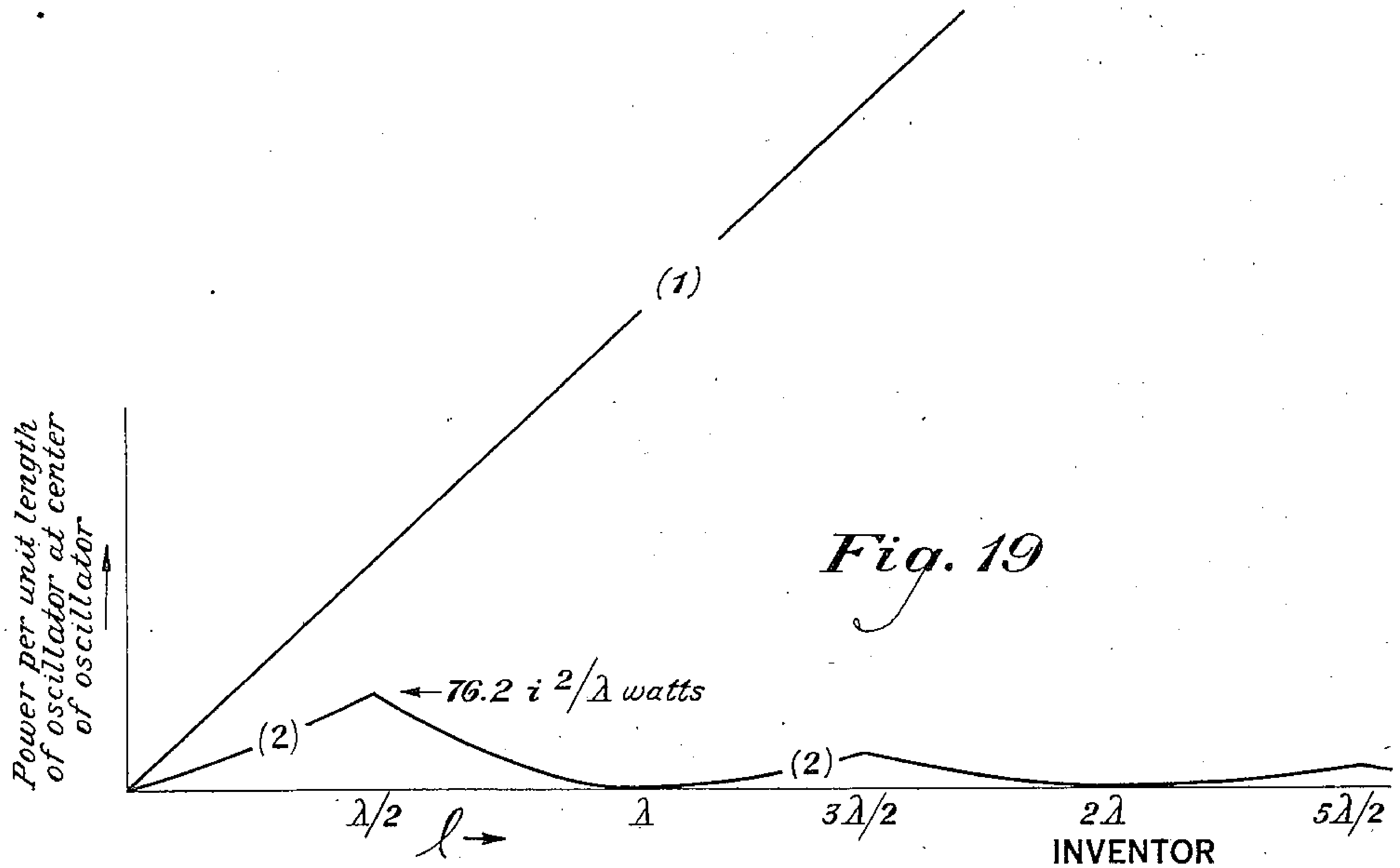


Fig. 19

INVENTOR
John Stone Stone
BY
ATTORNEY

UNITED STATES PATENT OFFICE

2,026,712

COMPOSITE OSCILLATOR FOR ELECTROMAGNETIC WAVES

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

Application June 1, 1933, Serial No. 673,926

4 Claims. (Cl. 250—33)

An object of my invention is to provide a new and improved system for generating and radiating electromagnetic waves. Another object is to accomplish the radiation of such waves with substantial energy. My invention may be practiced advantageously for the effective generation and radiation of waves of comparatively short length. In one aspect this invention involves providing an effective radiating oscillator of a length considerably greater than a half wave length. This oscillator may comprise adjacent oscillators lapping past each other and each shorter than the overall length of the composite oscillator. The foregoing statement of objects and advantages of my invention has been made with reference to radiation or transmission of energy, but it is well known that in general any good radiator of energy is an equally good absorber of energy. Any system will have the same absorption spectrum as its radiation spectrum. Accordingly, it will be understood that structures to operate as composite radiators embodying my present invention will be readily applicable to operate as receivers. For convenience I shall make the following description principally for radiators. All the foregoing and other features, objects and advantages of my invention will become apparent in connection with the following disclosure of a few examples of practice according to the invention which I have chosen for presentation in this specification. It will be understood that the following description relates principally to these particular embodiments of the invention, and that the scope of the invention will be indicated in the appended claims.

Referring to the drawings, Figure 1 is a diagrammatic elevation of an oscillator and associated circuits adapted for the practice of my invention; Fig. 2 is a diagrammatic elevation of a single component tuned oscillator; Fig. 3 is a set of diagrams showing wave shapes for currents and electromotive forces in simple oscillators of various lengths compared to the wave length for which they are tuned alike; Fig. 4 is an enlarged diagrammatic elevation of a section of the oscillator of Fig. 1 showing conduction and displacement currents; Figs. 5 and 6 are diagrams showing desirable wave shapes for current and electromotive force in an oscillator; Fig. 7 is a diagram showing current wave shapes in a component oscillator whose length is one wave length; Fig. 8 is a corresponding diagram for electromotive forces; Fig. 9 is a diagram showing current wave shape in a component oscillator whose length is two wave lengths; Fig. 10 is a corresponding diagram for electromotive forces; in Fig. 11 the diagram of Fig. 7 has been extended to several adjacent and consecutive component oscillators; in Fig. 12 the diagram of Fig. 8 has been similarly extended; Fig. 13 is a diagrammatic axial or longitudinal section of an oscillator built according to the principle of my invention; Fig. 14 is a diagram illustrating how the various component oscillators may be marked off from each other by impedance connections instead of by physical discontinuities; Fig. 15 is a diagram in which the representation is changed somewhat from that of Fig. 1; Figs. 16 and 17 are diagrams showing radiated wave shapes corresponding respectively to parts (11) and (7) of Fig. 3; Fig. 18 is a diagram showing the power from the central part of a well-known type of oscillator as a function of its length; and Fig. 19 is a similar diagram with comparison of a radiator made according to my invention.

An embodiment of my invention is shown diagrammatically in Fig. 1. Side by side are two rows of component oscillators, such as the oscillator **21** in one row or the oscillator **22** in the other row. Each such oscillator consists of a length of straight conductor with a coil **23** interposed at its middle, and each oscillator in one row laps half-way past each of two consecutive oscillators of the other row. At the ends, top and bottom, the half-length conductors **21'** and **22'** are terminated by capacity areas. The distance between these two capacity areas is considerably greater than the half wave length in free space to which each component oscillator is tuned.

The principles involved in the composite oscillator of Fig. 1 and the mode of its operation will be developed in the discussion which follows in connection with Figs. 2 to 12.

A single simple oscillator is shown in Fig. 2, a straight length of conductor wire with a tuning coil interposed at its middle and an associated inductively related circuit **24** by which alternating current energy may be fed into the oscillator. Assuming that various lengths are given to the oscillator of Fig. 2 but that in each case the tuning coil is adjusted so that the wave length in free space will be the same, diagrams are shown in Fig. 3 for the current wave shapes and the electromotive force wave shapes.

In each of these diagrams the continuous line curve shows the current wave shape of maximum values, and the dotted line shows the electromotive force wave shape of maximum values. But, of course, the maxima of one curve do not occur at the same instant of time as for the other curve, but are 90° apart in phase. The current is at or near zero when the electromotive forces are at or near their maximum. The dotted lines may also be regarded as representing conditions of static charge when the current is at or near zero, as well as representing electromotive forces.

The third part of the diagram of Fig. 3, for an oscillator of length equal to a half wave length in free space, shows a simple readily understood current wave form and electromotive force wave form. Making the oscillator a little longer, as in the fourth part of the diagram, that is, five-eighths of a wave length instead of one-half of a wave length, it is necessary to interpose a substantial amount of tuning coil inductance at the middle point to preserve the same wave length in free space. There will be a sharp potential drop across this inductance coil which is represented by the part of the dotted line extending at a right angle to the length of the oscillator.

Starting with the tuned linear oscillator of the first part of Fig. 3, whose effective length is a quarter wave length, and increasing this length by one-eighth wave length at each step, but keeping the wave length in space the same by means of the adjustable tuning coil at the middle of the oscillator, we proceed from left to right through all the parts of Fig. 3, and at the extreme right we have the case of an oscillator whose length is full two wave lengths. In all these parts of Fig. 3 we assume the same maximum terminal difference of potential, that is, the ordinates at the ends of the dotted line curves, for example at 25, are all equal in absolute magnitude.

From the first part of Fig. 3 at a quarter wave length to the third part at one-half wave length, the intensity of the radiation in the equatorial plane of the oscillator will increase very rapidly. Going on, the intensity decreases until it becomes practically nil in the seventh part of the figure. Going on, it waxes and wanes as before. There is a maximum at each length of the oscillator that is an odd multiple of a half wave length and a null value at each length that is equal to an even number of half wave lengths.

Certain considerations leading to the present invention will now be mentioned with reference to Figs. 16 to 19.

The maximum possible radiative power per unit of length of a straight conductor is given by the expression $40\pi^2 l i^2/\lambda^2$ watts, in which l is the length of the conductor, λ is the wave length of the radiation in free space, and i is the current amplitude throughout the conductor expressed in amperes. We see therefore that for a given current amplitude and wave length, this maximum possible radiative power per unit of length of the conductor is proportional to the length of the conductor. But the condition of the foregoing expression is only true, and the maximum possible radiative power of a given linear oscillator is therefore only attainable when the amplitude i of the current is constant throughout the length of the conductor.

Furthermore, an ordinary linear conductor executing oscillations whose wave length λ is small compared to twice the length of the linear conductor, has a current amplitude distribution which is far from uniform throughout the length of the conductor. Under these circumstances the current amplitude is distributed along the conductor in loops with intervening nodes as illustrated by the full line curves of (7) to (15), Fig. 3 of the drawings.

Again, the radiation from each ventral segment of current amplitude in such a relatively long linear oscillator throws off a separate train of waves which pursues its own individual course different from that radiated from any other ventral segment of current amplitude in the oscillator. This is illustrated by Figs. 16 and 17. The arrows indicate the direction of motion of the different trains of radiation from the several ventral segment of current amplitude.

It is to be noted that in Fig. 17, where $l=\lambda$, there is no radiation in the equatorial plane of the oscillator *ab*, while in Fig. 16, where

$$l=\frac{3}{2}\lambda,$$

the radiation in the equatorial plane of the oscillator *ab* is due solely to the central ventral segment of current amplitude.

Ordinarily the radiation, other than that in the equatorial plane, is worse than useless as it is often bent back to earth by the Heaviside layer and causes interference with the direct rays as well as interfering with the directive characteristics of directive receivers and radio compasses.

From all this we see that, other things being equal, the maximum possible useful power of radiation per unit of length of a linear oscillator, without capacity areas and tuned by a coil at its centre to the period of the waves, is attained when $l=\frac{1}{2}\lambda$ (or more exactly $l=0.476\lambda$), under which circumstances the tuning inductance is zero and the current amplitude distribution is that illustrated in Fig. 3, part (3).

The component of this current amplitude which is constant throughout the length of the conductor is

$$\frac{2}{\pi}$$

times the maximum amplitude i, so that the foregoing expression in watts becomes

$$160 l i^2/\lambda^2 = 76.2 i^2/\lambda$$

watts.

For a given maximum current amplitude i and wave length λ, any increase or decrease of the length l of the oscillator from

$$l=\frac{\lambda}{2}$$

(approximate) diminishes the power radiated per unit length of the oscillator from the central part of the oscillator (which is all the radiation that is commonly useful in practice). When the length of the oscillator is $l=\lambda$ (or more exactly 0.976λ), the power radiated from the central part of the oscillator per unit of length of the oscillator is zero. This is case (7) of Fig. 3 and the case of Fig. 17.

When

$$l=\frac{3}{2}\lambda$$

(or more exactly 1.476λ) the power radiated from the central part of the oscillator per unit of length of the oscillator is again a maximum, which however is slightly smaller than one third that reached when

$$l=\frac{1}{2}\lambda.$$

This power radiated from the central part of the oscillator per unit of length of the oscillator reaches subsidiary maxima for

$$l=\frac{p}{2}\lambda.$$

(approximately), when p is any odd integer and reaches zero minimum for

$$l=\frac{q}{2}\lambda$$

when q is any even integer.

The fluctuations of the radiation from the central part of the oscillator per unit of length of the oscillator, and for given i and λ, as l is increased from zero to 4λ is illustrated in Fig. 18.

In view of the foregoing condition in respect of the radiative power of linear oscillators, I have undertaken the task to devise means whereby the radiative power per unit of length of linear oscillators for given maximum current amplitude and wave length may be made to increase continuously with increase of the length of the oscillator, even when the length of such oscillator exceeds the critical value

$$l=\frac{\lambda}{2}$$

(more exactly 0.476λ).

If this radiative power is to be made proportional to the length of the oscillator as illustrated in the right line (**1**) of Fig. 19, it is clearly necessary to cause the effective current amplitude, for points in space outside the oscillator system, to be constant throughout the length of the oscillator.

It is not possible to make the total current amplitude in this oscillator constant throughout the oscillator for this would involve infinite phase speed. So I employ a compound oscillator in which the oscillations of the individual parts or component oscillators consist of nodes and loops, but in which, so far as the field of force external to the compound or resultant oscillator is concerned, the effective current amplitude in the compound oscillator will be constant throughout its length.

The curve (**2**) of Fig. 19 represents the power radiated per unit length of conductor from the central portion of an ordinary linear oscillator, and is the same as the curve of Fig. 18 but to a smaller scale of ordinates and a longer scale of abscissas. It is given to illustrate the gain possible to be effected through the use of the compound oscillator.

The waxing and waning described heretofore of the radiation in the equatorial plane of the linear oscillator of Fig. 3 when its length is increased may be identified with the development of standing waves, the length of each such standing wave being approximately a half wave length in free space. When these standing waves have a node at the center point of the oscillator there will be no radiation in its equatorial plane, but when they have a loop at that point the intensity of the radiation is a maximum. At a considerable distance from the oscillator represented by part (**1**) of Fig. 3, assume a certain plane surface of definite area lying transverse to the equatorial plane, and transverse to the direction of propagation in that plane. Let the power or the rate of flow of energy across this area be unity. Next let the length of the oscillator be increased so that the radiation is a maximum, that is, so that the length of the oscillator is a half wave length or three halves times a wave length, or any odd number of half wave lengths. Then it can readily be shown that the power or energy flow through that same area will be 6.8 units.

The effective length of a linear oscillator for short wave lengths, that is, its length for the purpose of comparison with the wave length in free space, is very nearly the same as the physical length; the two lengths are connected by the equation $l'=l+\lambda/41.5$, where l' is the effective length, l is the physical length and λ is the wave length.

For intensity of radiation it is evident that the oscillator of the third part of Fig. 3 is no less advantageous than the longer oscillators in the parts of the figure to the right. But if we could have an oscillator of the same length as the oscillator in the extreme right-hand part of this figure, and have the same electromotive forces at its ends (as at **25'**) with the electromotive force distribution as shown by the dotted line in Fig. 5, and with the current wave shape shown in Fig. 5, then we would get far greater intensity of radiation, indeed, the intensity would be sixteen times greater than for the third and eleventh parts of Fig. 3, or somewhat more than **108** when the intensity for the first part of Fig. 3 is taken as the unit. Further, if we were to put capacity areas at the ends of this oscillator, as shown in Fig. 6, and have the same extreme electromotive forces at the ends (as at **25''**), then we might have a current of nearly the same magnitude all along the length of the oscillator, as shown by the full line curve **51** in Fig. 6, and in this case, if the maximum amplitude of the current were the same as in Fig. 5, the intensity of radiation would be about 26 times that of the third and eleventh parts of Fig. 3, or about 170 times the intensity in the first part of Fig. 3.

The oscillator of Fig. 1 is constructed and designed to be operated so that it will attain the advantages mentioned for Fig. 6. In other words, Fig. 1 discloses an oscillator whose total effective current amplitude will not be broken up into a succession of loops of successively opposite sense, each a half wave length long, as in the right-hand part of Fig. 3, for example, but will at any moment be of at least approximately the same constant strength throughout the entire length of the oscillator, even though this oscillator is several times the length of a wave length in free space.

The oscillator of Fig. 1 is built up of equal linear oscillators end to end staggered along two parallel axes, as already described in connection with that figure. Thus, when executing free oscillations the two lines of oscillators have the opportunity to form two sets of loops of potential and current amplitude which neutralize the effects of each other in the medium directly surrounding the oscillator, leaving only a component of current whose amplitude is substantially constant throughout the length of the composite oscillator as a whole. This creates an external field of radiation due to the resultant overall potential amplitude, so that there is a substantially constant cylindrical distribution of electric force around the axis of the oscillator in its intermediate portion.

In Fig. 7 I have shown one component oscillator of the system of Fig. 1, assuming in this case that each component has a length equal to the wave length in free space. The continuous line curve represents the current wave shape in this simple component oscillator. In the complete composite oscillator I want a wave shape such as represented by the dotted line **26**. But in the complete composite oscillator there are two rows of component oscillators, so I will assume that only half the desired current represented by the line **26** is to be attributed to the oscillator shown in Fig. 7. This gives the line **27**. This being one component of the current represented by the full line curve **28**, the other component is readily seen to be represented by the dotted line curve **29**.

As indicated by the dotted line in Fig. 6, the electromotive force is expected to grade uniformly from one end to the other of the complete composite oscillator. The actual electromotive force wave shape in a single component oscillator will be as shown by the full line curve **30** in Fig. 8, and its components are readily seen to be given by **31** and **32**.

The component oscillators of Fig. 1 may have other lengths than a wave length in free space, as was assumed in connection with Figs. 7 and 8. Figs. 9 and 10 are corresponding diagrams for the case in which each component oscillator has a length equal to two wave lengths in free space.

Whereas Fig. 7 deals with a single component oscillator, Fig. 11 shows a plurality of such oscillators in a short section of length of the complete oscillator of Fig. 1. For the sake of clearness, the oscillators have been thrown out of alignment, as indicated by the horizontal dotted lines each with an arrow head showing the direction of displacement. With the explanation that has been given heretofore, the significance of Fig. 11 will be apparent at once.

Similarly, Fig. 12 shows the electromotive forces for several associated oscillators as compared with Fig. 8, which is for a single component oscillator alone.

In Fig. 11 the total current in the complete composite oscillator is represented in two parts, half in the line **33** and half in lines **34** and **39**, and in Fig. 12 the electromotive force is represented by lines of equal slope as at **42** and **43**.

Referring to Fig. 11, consider that part of the complete oscillator lying between the points a_2 and b_1. It will be seen that the alternating components represented by the dotted curves **37** and **38** tend to neutralize each other for points outside the immediate vicinity of the two conductors within this stretch, and the same is true for the alternating components of the current amplitudes of the corresponding parts of all juxtaposed component oscillators. But the straight line components **33** and **39** add to give a straight line resultant corresponding to the straight line **51** of Fig. 6. Also, in Fig. 12 we see that the components represented by the curves **40** and **41** neutralize and the components represented by **42** and **43** coincide to give us the overall distribution of electromotive force.

The two simple oscillators **21** and **22** of Fig. 1 are represented by the like reference numerals in Fig. 4. Here the dotted lines represent lines of current flow. Within each unit oscillator **21** or **22** the current flow is conductive, as for example at **20**. But in the air gap between the members **21** and **22** the current is a "displacement current", as represented at **19** in Fig. 4. Thus, although the conduction current in any one oscillator unit such as **21** or **22** is an oscillatory current entirely within that unit, the combined conduction currents and displacement currents of the complete oscillator as a whole give a uniform current along the length of the complete oscillator as a whole, though of course this current varies cyclically in time.

Instead of lapping the simple oscillators past each other in the manner indicated in Fig. 1, they may be built as shown in Fig. 13, where the lower part of each simple oscillator is a cylinder **44** closed above and open below, and the upper part is an axial rod **45** extending into the open cylindrical part of the next consecutive oscillator above.

Instead of separating the oscillators end to end by air gaps, they may be effectively separated by interposed impedances, such as the coils **46** in Fig. 14. In this figure the unit oscillators are the parts extending from coil to coil, as for example from **46** to **47**.

There is no particular need to have the linear oscillators lie in two parallel rows, as in Figs. 1 and 14. In Fig. 13 they lie along a single row, and the arrangement of Fig. 1 may be looked upon as diagrammatic and equivalent to the arrangement shown in Fig. 15. The more essential feature is that in a linear sequence of linear oscillators each extending lengthwise along the general direction of the sequence as a whole, each oscillator laps a substantial distance, preferably half-way, past the two adjacent oscillators in the sequence.

The elementary theory of the steady state of the forced current and potential oscillations in a compound linear conductor of the type that has been disclosed in Figs. 1, 13, 14 and 15, may be made to rest on the following assumptions, for the sake of simplicity. It may be assumed that the dissipative resistance of each component oscillator is concentrated at the middle point of its length, that the component oscillators are all equal, that the oscillations are maintained by equal impressed electromotive forces at the middle point of each oscillator, and that the radiation resistance of the complete compound oscillator may be assigned in equal portions to the various component oscillators and form part of the dissipative resistance that is assumed to be lumped at the middle points of the component oscillators.

On the foregoing assumptions which are obviously valid for the sake of simplifying the mathematics, the mathematical theory of the distribution of currents and electromotive forces can be worked out and the results afford a check on the theory and may be relied upon to some extent for guidance in constructing and operating the system such as shown in Fig. 1.

The complete compound oscillator acts in one aspect like a balanced metallic circuit, and in another aspect like a single conductor. In the first aspect of a balanced metallic circuit, the current and potential amplitudes in this circuit are indicated by the dotted curves such as **37** and **38** in Fig. 11 and **40** and **41** in Fig. 12. In the other aspect of a single conductor, the current amplitude is indicated by adding the ordinates of the dotted lines **33** and **39** in Fig. 11; and the potential amplitude is given by a line having double the steepness of the lines **42** and **43** in Fig. 12.

The quantity of energy that can be radiated at a certain short wave length from a single oscillator alone is small. Though the quantity of energy might be increased by increasing the size of the oscillator and making the wave length longer, this may not be what is desired. When it is desired to make the oscillator larger and thereby increase the radiated energy but keep a short wave length, then my system as illustrated diagrammatically in Fig. 1 may be employed. This acts like a long oscillator in respect to quantity of energy radiated but keeps the short wave length established in connection with each component oscillator.

What is claimed is:

1. In combination, a series of equal linear oscillators arranged lengthwise and consecutively along a common line, each oscillator being tuned to the same comparatively short wave length, each oscillator lapping half-way past both consecutively adjacent oscilators in series, capacity areas connected to the end oscillators of the series, respective energy transmitting circuits connected with the oscillators, and phase adjusters in said circuits to keep said oscillators in the same phase.

2. A radiator for electromagnetic waves consisting of a series of linear oscillators each lapping substantially half way on the consecutively adjacent oscillators of the series, each oscillator having a winding at its middle point, an inductively related energy transmitting winding at each such place, respective circuits comprising these last mentioned windings, a central device to which all these circuits are connected, and phase adjusting means in these respective circuits.

3. A radiator for electromagnetic waves consisting of a series of linear oscillators each lapping substantially half way on the consecutively adjacent oscillators of the series, the end oscillators of the series have capacity areas, each oscillator having a winding at its middle point, an inductively related energy transmitting winding at each such place, respective circuits comprising these last mentioned windings, a central device to which all these circuits are connected, and phase adjusting means in these respective circuits.

4. A radiator for electromagnetic waves consisting of a series of consecutively overlapping oscillators, each oscillator having a coil at its middle point and an inductively related coil adapted for energy transmission, these oscillators lying in staggered relation in two rows side by side, and impedances between the consecutively adjacent ends of the oscillators in each row to separate them electrically.

JOHN STONE STONE.